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Browse Basin High Resolution Study

North West Shelf, Australia

Interpretation Report

J.E. Blevin, H.I.M Struckmeyer, C. Boreham, D.L. Cathro, J. Sayers, and J. M. Totterdell

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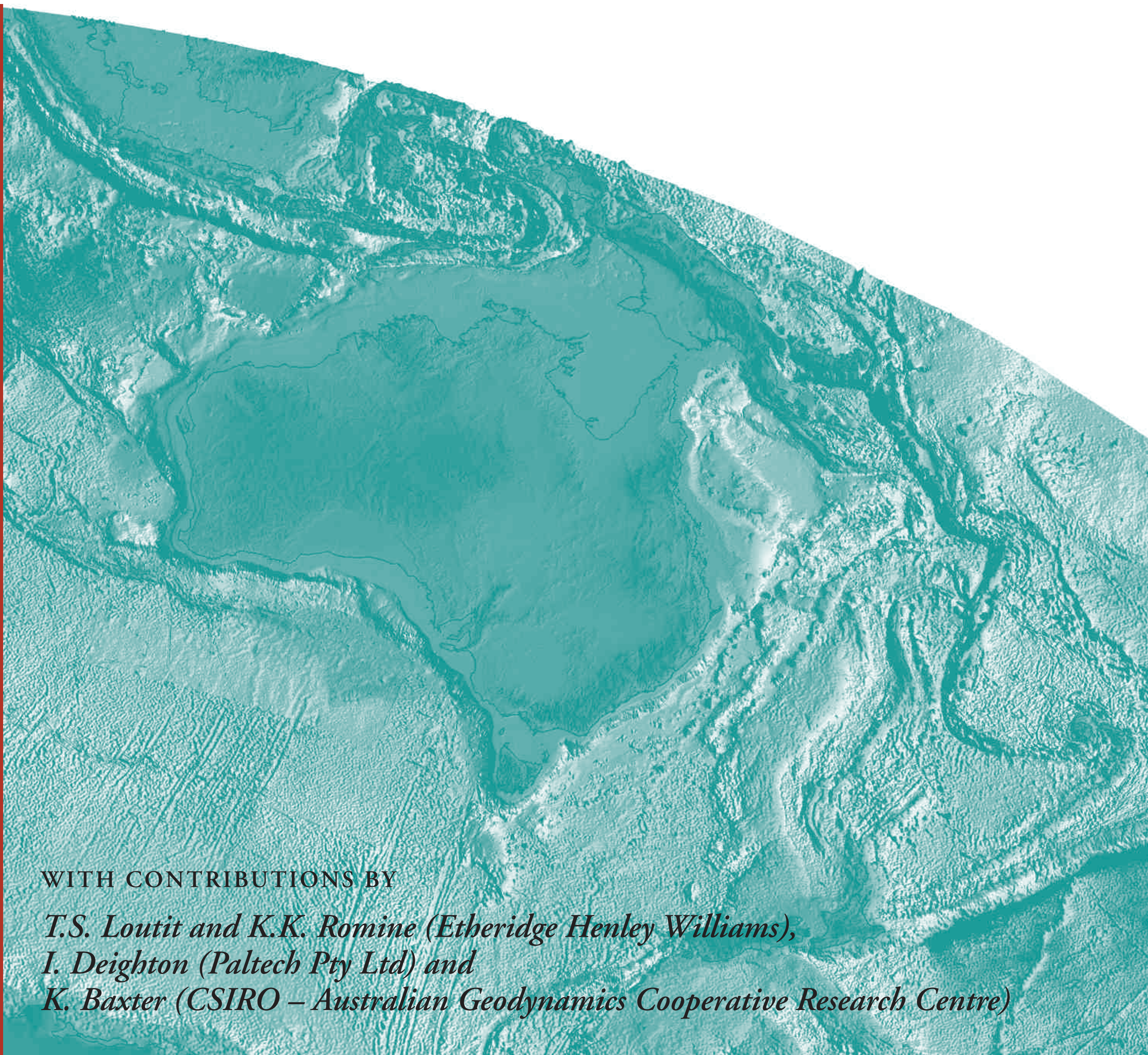

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BROWSE BASIN HIGH RESOLUTION STUDY

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INTERPRETATION REPORT

AGSO RECORD 1997/38

by

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1. Executive Summary

The Browse Basin High Resolution Study was undertaken as a joint project between the Australian Geological Survey Organisation (AGSO) and Nopec International Pty Ltd in early 1997. The study is underpinned by a recently acquired, 5,265 km grid of regional, high-resolution seismic reflection data (1996 Browse Basin High Resolution Survey, AGSO Survey BBHR/175), the integration of sequence stratigraphic analysis of the seismic data and of 21 wells, structural mapping, geochemical analyses, and geohistory modelling of potential source rocks.

The study aims to provide a regional structural and stratigraphic model for the evolution of the Browse Basin, with particular emphasis on the development of petroleum systems in the prospective Mesozoic and Cainozoic sections. It is hoped that this regional framework and assessment of petroleum systems will assist exploration through a better understanding of the basin's prospectivity.

The key results and recommendations of the BBHR Study relating to aspects of basin evolution and prospectivity are:

Basin Formation and Structural Development

- a Palaeozoic compartmentalisation of the Browse Basin into two distinct, structurally-controlled depocentres, the Caswell Sub-basin (northern Browse Basin) and the Barcoo Sub-basin (southern Browse Basin) (terminology based on Symonds *et al.*, 1994);
- the definition of six tectonically-controlled basin phases;
- recognition of the critical role of Late Triassic inversion in trap development;
- recognition of thermal subsidence-controlled deposition of Early to Middle Jurassic source rocks in the Barcoo Sub-basin;
- definition of the timing and nature of reactivation events and their effects on trap formation and/or preservation;
- a recommendation of further work to identify the effects of late stage reactivation events (Late Cretaceous and Miocene) on trap integrity, fluid migration, and geothermal history;
- a recommendation of further work to understand the role of basement lineaments on the deep basin structure.

Stratigraphic Evolution

- a sequence-based, tectonostratigraphic framework for the basin utilising a consistent and updated biostratigraphic database;
- the definition and regional mapping of 22 sequence boundaries relating to basin phases (megasequences) and eustatically-controlled cycles of deposition (supersequences);
- 16 isopach and structure contour maps of critical sequence boundaries and stratigraphic intervals that relate to aspects of trap development, reservoir and source distribution;
- a sequence stratigraphic framework to predict the distribution of Early Cretaceous source rocks, particularly in the central Caswell and Barcoo Sub-basins;
- the recognition of depositional environments, processes and controls that have influenced the distribution of potential reservoir and seal facies;

- the recognition of magmatic activity (dykes) in the Late Cretaceous (Turonian or older), approximately 70 Ma years after continental breakup in the Callovian;
- the compilation of basic and interpretative data to fully utilise the BBHR seismic grid in a regional assessment of the Browse Basin.

Prospectivity and Petroleum Systems

- identification of at least 20 organic-rich rocks of Permian to Late Cretaceous age;
- the definition of an effective Early Cretaceous source rock and petroleum system based on oil-source and biomarker correlations;
- plots of kerogen types, present-day and corrected initial source rock typing for eight sequence groups;
- modelling of kerogen transformation, extract yields, free hydrocarbon saturation, and depths to the "top of the oil window" for selected Browse Basin wells;
- geohistory modelling to define the timing of generation of specific source intervals;
- an analysis of past drilling, hydrocarbon habitat, and timing of trap development;
- the definition of four petroleum systems and play families in the Browse Basin;
- an overview of the 1/1997 Release Areas in the central and northern Browse Basin;
- a recommendation for more targeted sampling of potential source intervals (particularly the Late Jurassic interval) to properly assess the source potential.

2. Introduction

The Browse Basin lies in the southern Timor Sea region of Australia's North West Shelf (Figure 1). Covering an area of approximately 140,000 km^2, the basin is a northwest-trending, Palaeozoic to Tertiary depocentre that contains in excess of 20 km of sedimentary section. The Browse Basin is a proven hydrocarbon province, with major (undeveloped) gas and condensate fields discovered in the outer basin at Scott Reef 1 and Brecknock 1 during 1971 and 1979, respectively (Figure 2). More recently, exploration interest in the area has surged in response to oil and gas discoveries at Gwydion 1 (1995) and Cornea 1/1A/1B (1997) on the basin's inboard margin. Speculation following the Cornea discovery has included reserve estimates ranging from 617 to 2665 million bbls of oil (Financial Review, 30 May 1997), making this possibly the largest Australian oil discovery outside Bass Strait (Financial Review, op. cit). The trend of heightened exploration interest is expected to continue following the gazettal in April 1997 of offshore acreage by the Commonwealth and the Governments of Western Australia and the Northern Territory (Territories of Ashmore and Cartier).

In mid-1996, the Australian Geological Survey Organisation (AGSO) began a regional study of the Browse Basin. The study was based primarily on AGSO's existing dataset of approximately 8,000+ km of deep (16 s TWT) seismic data (AGSO Surveys 119, 128 and 130) and ties to 27 exploration wells (Figure 3, Plate 1). The interpretation of the deep seismic grid enabled the definition of the primary (Palaeozoic) faults which controlled basin initiation, as well as subsequent reactivation events throughout the Mesozoic and Cainozoic. While the dataset provided many insights into basin evolution, the data quality and line spacing was inadequate to undertake a sequence stratigraphic study of the prospective Mesozoic and Cainozoic sections.

To remedy this situation, the Browse Basin High Resolution (BBHR) seismic grid was acquired as part of AGSO's Continental Margins Program during June–July 1996 (Figure 4). The BBHR dataset is a regional, high quality, seismic grid (5.5 s TWT) that infilled (and in some instances overshot) the existing deep seismic grid. A total of 5,264.9 line km of data was acquired over 29 days. The grid provided further ties to "new generation" exploration wells in the southern part of the basin such as Arquebus 1/ST1, Sheherazade 1 and Trochus 1/ST1, as well as Lacepede 1 and Perindi 1 (jump tie) in the northern Canning and Roebuck basins.

The interpretation of the BBHR survey was undertaken by AGSO's Browse Basin Project Team as part of a cooperative agreement between AGSO and Nopec International Pty. Ltd. External consultants (Etheridge Henley Williams; Paltech Pty Ltd; and, CSIRO—Australian Geodynamics Cooperative Research Centre) were contracted to assist with specific tasks related to the BBHR study. It is envisaged that AGSO will produce an additional report on the geological findings of the initial Browse Basin regional study based on the deep seismic grid in late 1997 (Blevin, *et al.*, in prep.). This study will include topics such as geodynamic basin modelling, OBS refraction modelling of the crust and mantle, a detailed geochemistry study, and analysis of the older stratigraphic successions not covered by the BBHR study.

2.1 Scope and Aims of Study

The BBHR Study aims to provide a regional geological model for the structural and stratigraphic evolution of the Browse Basin, with particular emphasis on the formation of petroleum systems in the prospective Mesozoic section. The BBHR seismic grid provides direct ties to 19 exploration wells and forms the basis of this study (Table 1). An additional eleven exploration wells tying to the deep seismic grids were included in the analysis to increase the accuracy of stratigraphic correlations.

The approach used in this study follows the basic principles of basin analysis (Loutit, 1996; Romine and Durrant, 1996) (Figure 5). Sequence stratigraphy was the primary tool used for stratigraphic analysis, and provided a framework to understand and predict the fundamental elements of petroleum systems in the Browse Basin (source, reservoir, seal configuration, as well as maturation, migration and entrapment of hydrocarbons). This framework will hopefully assist exploration through the evaluation and integration of geological data and an improved understanding of the prospectivity of the region.

2.2 Exploration History

Exploration of the Browse Basin commenced in 1963 with an aeromagnetic survey contracted by Woodside (Lakes Entrance) Oil Company. Over the ensuing 34 years, 26 exploration permits have been active and 39 wells drilled. Details of these permits, their operators and completed work programs are summarised in Appendix A1. A chronological summary of drilling is presented in Appendix A2, while a summary of seismic acquisition (listed by permit) is given in Appendix A3. The exploration activities of Woodside Petroleum in the Browse Basin from 1963 to 1988 has been summarised by Willis (1988).

At present (30 June 1997), there are nine exploration permits current in the basin (Figure 4, Table 2). Exploration Permit WA-33-P (Parts 1 and 2) covering the Scott Reef and Brecknock fields is currently in the final stages of the renewal process.

Exploration Activity—1963 to 1968

In 1963, Permit 213H was awarded to the North West Shelf Joint Venture following the definition of a sedimentary basin in the southern Timor Sea region from aeromagnetic data. The permit covered an area of 164,000 km^2 extending from the Browse Basin, southward to the Dampier Sub-basin (Figure 6a). The Joint Venture embarked on a long term program of reconnaissance seismic acquisition from 1964 to 1968. The program predominantly used a dynamite source, with only minimal acquisition of semi-detailed grids using an Aquapulse® system. Regional gravity, magnetic and seismic (sparker) surveys acquired by BMR (Whitworth, 1969) supplemented the industry data. Ashmore Reef 1 was drilled in 1967 in the northern area of the basin with BOCAL as operator. The well confirmed the presence of Mesozoic sedimentary rocks (Late Triassic), although no hydrocarbons were encountered.

Exploration Activity—1969 to 1975

In 1969, the northern part of Permit 213H covering the Browse Basin was subdivided into four new permits as a result of legislative changes to the Petroleum Act (Figure 6b). Permit 232H, located north of 213H, was also converted to a new permit as a result of the change in legislation. The permits were operated as a joint venture between BOCAL, Woodside and Shell. By the end of the first term of these permits, over 20,000 km of seismic data had been acquired over seven surveys, and nine wells had been drilled (Lynher 1, Leveque 1, Lombardina 1, Scott-Reef 1, Yampi 1, Londonderry 1, Rob Roy 1, Prudhoe 1, and Heywood 1) (Appendix A2). The wells tested a range of structural and structural/stratigraphic plays and targeted primarily Jurassic, Triassic and shallow Permian reservoirs. Sealed reservoirs were tested in only two wells, Lynher 1 and Scott Reef 1, a gas discovery. Yampi 1, Heywood 1 and Lombardina 1 recorded high gas readings and fluorescence during drilling. Traces of residual oil were detected in cores through Early to Middle Jurassic sediments at Yampi 1. By the end of 1975, over 60% of the permitted areas had been relinquished.

Exploration Activity—1976 to 1980

BOCAL, Woodside and Shell retained permits WA-32-P, WA-33-P, WA-34-P, WA-35-P and WA-37-P following partial relinquishment of blocks at the time of renewal (Figure 7a). From 1976 to 1979, over 6,500 km of seismic data were acquired on four surveys in Browse Basin permits. A further eight wells were drilled, including a step-out well at Scott Reef 2/2A (Appendix A2). All wells tested structural trap styles such as drape, faulted or domal anticlines, with only two wells proving valid sealed reservoirs: Brecknock 1 (gas discovery) and Mt. Ashmore 1/1A,B. Brewster 1A was interpreted (post-drill) as a gas discovery reservoired within a draped anticlinal structure. High gas readings were recorded at Buffon 1 and 32m^3 of oil flowed from Albian sands in Caswell 1. Advances in deep water drilling technology allowed for the drilling of Barcoo 1 in 720 m water depth.

Acreage relinquished by the BOCAL Joint Venture was re-gazetted and later awarded as permits WA-68-P (Oxaco International) and WA-104-P (Oberon Oil) (Figure 7b). A modest exploration program resulted in the acquisition of 443 km and 2090 km of seismic data in permits WA-68-P and WA-104-P, respectively (Appendix A3). Adele Island 1 was drilled in WA-104-P, before the permits were either relinquished or expired.

Exploration Activity—1981 to 1985

Following a second term renewal, Woodside retained permits WA-32-P (R2) to WA-35-P (R2), and WA-37-P (R2) (Figure 8). Approximately 5,000 km of seismic data was acquired over these permits during six surveys. The areas relinquished by Woodside at renewal were re-gazetted and awarded as permits WA-177-P (Weaver Oil and Gas), WA-180-P (Seahawk Oil), WA-187-P (Esso), WA-188-P (Esso) and WA-197-P (Seahawk Oil). Work programs in these permits were generally limited to seismic acquisition and interpretation. Oberon Oil drilled Adele Island 1 in 1982 as a basement drape play.

Three wells were drilled by Woodside over this period (North Scott Reef 1, Echuca Shoals 1, and Caswell 2). North Scott Reef 1 and Echuca Shoals 1 were hydrocarbon discoveries, with gas reservoired in sands draping an anticline and fault block, respectively. Caswell 2 targeted a Jurassic interval that proved to be dry, but intersected minor oil in thin Campanian sands. The recovery of oil at Caswell 2 offered encouragement for further exploration of stratigraphic plays in the deeper mid-basin area.

Exploration Activity—1986 to 1990

Expired permit WA-68-P (Oxoco) in the northeastern Browse Basin was re-gazetted in 1985, and subsequently awarded to Marathon as permit WA-200-P (Figure 9a). Marathon acquired 1502 km of 2D seismic data, then later relinquished the permit in 1988. Seahawk Oil acquired a further 121 km of seismic data in permit WA-197-P. Santos Ltd. took over as operator of WA-197-P, and drilled Browse Island 1 in 1986 (EP-302). The well was drilled to 405.5 m as a stratigraphic hole, and was designed to determine the velocity pull-up effect of a surface reef on Browse Island and its effect on a deeper, seismically defined structure beneath the island.

In 1988, exploration permit WA-206-P was awarded to a joint venture consisting of Ampolex Exploration Ltd (Operator), Bridge Oil Ltd., TCPL Resources, and Command Petroleum. Ampolex acquired approximately 720 km of seismic data in the permit during 1988 to 1989. In 1991, Amoco Australia Petroleum Company farmed into WA-206-P and drilled Arquebus 1/ST1. Minor shows of light oil and gas were recorded during drilling, although pressure data and post-drill analysis of well logs indicated a 51 to 105 m gross column of oil and gas (Haston and Farrelly, 1993). A number of factors during drilling, such as overbalanced drill mud, resulted in flushing of formation fluids and associated formation damage (Haston and Farrelly, op. cit.). In 1993, Amoco drilled Sheherazade 1 to evaluate a Late Jurassic objective within a Miocene reactivation anticline along the eastern margin of the basin. There were no significant hydrocarbon shows recorded and the well was plugged and abandoned.

Exploration permit WA-207-P was awarded to Bridge Oil, Ampolex, TCPL Resources, and Command Petroleum in 1988. Bridge acquired 1276 km of seismic data across the permit during 1988. In 1990–91, Shell Development (Australia) Pty. Ltd. farmed into the permit and drilled Trochus 1/ST1. The well was situated downdip of Lynher 1, along a Miocene reactivation anticline known as the "Lynher–Lombardina Trend". The well encountered only minor hydrocarbon shows.

Exploration focus shifted to permits in the northernmost Browse Basin within the Territory of the Ashmore and Cartier Islands (Figure 9a). AC/P3 was awarded to BHP Petroleum (BHPP) in 1985. BHPP acquired approximately 5000 km of seismic data and drilled a total of four wells from 1987 to 1989 (Asterias 1, Gryphaea 1, Kalyptea 1/ST1, and Discorbis 1). The wells tested a Triassic fault block (Gryphaea 1) and Early Jurassic to Late Cretaceous stratigraphic intervals in faulted anticlinal structures (Asterias 1, Kalyptea 1/ST1, and Discorbis 1). The wells recorded minor hydrocarbon shows (oil and gas) and were subsequently plugged and abandoned.

In AC/P1, Elf Aquitaine acquired 2543 km of regional and detailed seismic data and reprocessed 710 km of vintage data. Delta 1 was drilled in 1988 in the southern part of AC/P1 to test a Late Cretaceous anticlinal structure. Delta 1 recorded minor gas shows before being plugged and abandoned as a dry hole. In WA-35-P, Shell Development (Australia) Pty. Ltd. drilled Buccaneer 1 (1990) on a northeast trending horst block downdip of the Prudhoe Terrace. The well targeted Callovian to Early Cretaceous reservoirs, and was plugged and abandoned after recording fluorescence in Late Jurassic and Triassic rocks.

Exploration Activity—1991 to 1995

In January 1991, the Commonwealth and the Government of Western Australia gazetted a single area in the central Browse Basin (W91-1) (Figure 9b). A further five areas were released in the second gazettal round in November, 1991. These areas were subsequently awarded as WA-238-P (W91-1) and WA-240-P to Ampolex (W91-14), WA-241-P to Shell (W91-15), WA-239-P to BHPP (W91-16), and W-242-P to Woodside (W91-17). Area W91-13, located east of Scott Reef, did not receive any bids. In the northern Browse Basin, Mobil Exploration and Producing Australia Pty. Ltd. took over as operator of AC/P3 and drilled Productus 1 (1991) and Copernicus 1 (1993). The wells tested Permian/Triassic fault blocks on the outer margin of the Prudhoe Terrace.

Ampol Exploration Ltd acquired 3761 km of seismic data across permit WA-212-P (Appendix A3), before drilling Walkley 1 in 1993. Walkley 1 tested Barremian and Campanian stratigraphic plays in the central Browse Basin. The well did not record significant hydrocarbon shows and was later plugged and abandoned. In 1992, Ampol acquired a further 1134 km of seismic data in permit WA-238-P. In 1993, Ampol shot the Sarah Marine Seismic Survey (1383.7 km) across permits WA-212-P, WA-238-P and WA-240-P, before relinquishing permit WA-212-P in 1995.

In WA-239-P, BHPP shot three seismic surveys totalling 1171 km during 1993-94, and subsequently drilled Gwydion 1 in 1995. The well discovered three gas bearing zones and one oil and gas bearing zone of Barremian to Albian age (Spry and Ward, 1997). After testing, Gwydion 1 was plugged and abandoned as an uneconomic oil and gas discovery. Although not viable, the discovery was significant in that it proved the eastern margin of the Browse Basin is favourably situated to receive charge from mature source rocks within the central basinal area (Spry and Ward, op. cit.). Following the discovery at Gwydion 1, World Geoscience acquired a 2000 km grid of aeromagnetic data over WA-249-P for BHPP.

In WA-241-P, Shell acquired 2975 km of seismic data in 1992 and 1995. In the southern Browse Basin, Woodside acquired 3550 km of 2D seismic data in permit WA-242-P. No wells were drilled in either permit from 1993 to 1995.

Exploration Activity—1996 to 1997

In June 1996, the Commonwealth and the Governments of Western Australia and the Northern Territory (Territories of Ashmore/Cartier Islands) gazetted nine areas in the northeastern Browse Basin and southern Vulcan Sub-basin (1/1996 Release Areas). Areas W96-1 to W96-6 covered the inboard margin of the basin, including the Yampi Shelf and southern Londonderry High. The release of areas followed the discovery of oil and gas at Gwydion 1 in 1995, and provided the opportunity to pursue updip, stratigraphic plays over shallow basement. The inboard margin was previously considered to be non-prospective until Gwydion 1 confirmed adequate seal facies and the viability of long range migration of hydrocarbons from the central basin. Cornea 1 was drilled in WA-241-P (adjacent to the boundary of W96-4) by Shell Development (Australia) Pty Ltd as a tight hole during the 1/1996 bidding round. After the close of applications in late January 1997 and subsequent assessment of bids, new permit offers were extended to a consortium led by Shell Development (Australia) Pty Ltd for Areas W96-4 (permit WA-266-P) and W96-5 (permit WA-265-P). The guaranteed work program for permit WA-266-P includes 1050 km^2 of 3D seismic acquisition and 38 exploration wells. Although the size of the Cornea field has yet to be determined, the unusually high number of wells in Shell's guaranteed work program would strongly suggest that the accumulation extends into WA-266-P. Areas AC96-4, AC96-5, and AC96-6 were awarded in early April 1997 as permits AC/P21 (Hardy Petroleum), AC/P22 (Cartier Oil) and AC/P23 (Nippon Oil Exploration), respectively. No bids were received for Areas 96-1, W96-2, W96-3 and W96-6, and these areas now revert to open acreage.

In 1996, Shell acquired an additional 5000 km grid of seismic data over existing permit WA-241-P, while Woodside shot a further 2119 km of data as part of the Rosella Marine Seismic Survey covering WA-242-P. In mid-1997, Shell followed up the discovery at Cornea 1/1A/1B with a step-out well at Cornea 2/DW1. Ampolex (Mobil) relinquished permits WA-238-P and WA-240-P in the central Browse Basin.

On 14 April 1997, the Commonwealth and Governments of Western Australia and the Northern Territory (Territories of Ashmore/Cartier Islands) gazetted nine areas in the central and outer Browse Basin. Applications for this bidding round must be lodged by 4:00pm, Thursday, 26 March 1998 to the relevant State or Territory Department. More information on the guidelines for applicants can be obtained from the publication *Release of Offshore Petroleum Areas Australia 1/1996*, available from the Department of Primary Industries and Energy (Canberra) or the relevant State/Territory Departments. The present configuration of permits and release areas in the Browse Basin is shown in Figure 4 and Plate 1. An overview of the 1/1997 release areas is presented in Section 5.6.

2.3 BBHR Data Acquisition

The BBHR grid was acquired over a 29 day period from 24 June to 22 July 1996 using AGSO's R/V *Rig Seismic*. The survey consisted of 13 west/northwest trending dip lines and four northeast trending strike lines (Figure 4). A further two north/northwest trending lines were acquired in the central part of the basin. Acquisition of the 5,264.944 line km of data utilised the latest high-resolution seismic technology, including bubble-free GI guns that has proven successful in previous surveys in the Carnarvon Basin (Survey 136/CTT), Yampi Shelf (Survey 165/YST), and Vulcan Sub-basin (Survey 165/VTT). Acquisition parameters are outlined below.

- **19.66 litre GI gun array (1800 psi)**
- **3000 m streamer**
- **12.5 m hydrophone group interval (240 groups)**
- **18.75 m shot interval**
- **80-fold**
- **2 msec (4-180Hz) sample interval**
- **5.5 second record length**

The BBHR grid ties to AGSO's Survey 165/YST and provides further ties to wells on the Yampi Shelf such as Gwydion 1, Londonderry 1 and Cornea 2. The seismic line over Cornea 2 (165/YST-07) was acquired in June 1995, prior to the drilling of the well in early 1997. In the southern Browse Basin, the BBHR survey tied "new generation" wells such as Trochus 1/ST1, Arquebus 1/ST1 and Sheherazade 1 which retested the Miocene anticlinal structures drilled by Lombardina 1 and Lynher 1.

Data quality of the BBHR seismic is generally high, although a minor problem with multiples occurs within the Turonian to Aptian shale package. This problem is caused by a lack of a velocity gradient within the shale, thus making it difficult to distinguish primary events from multiples within the section. Geologically, the shale package has an internal geometry consisting of low angle progrades and apparent downlap in the outer basin. This geometry is overprinted by the multiples which pass through the section at a similar angle. As basement shallows towards the western outer margin of the basin, the multiples cross-cut the basement and inhibit confident correlation of the Valanginian to late Albian sedimentary section (e.g., BBHR Lines 175/07 and 175/08, Plates 73 and 74). This problem has been recognised in previous surveys shot in the Browse Basin and is attributed to geological factors unique to this basin.

In the northern part of the basin (BBHR Lines 175/11 and 175/12), late stage reactivation of deep-seated faults (and the possible presence of salt within the section) has resulted in the release and flow of fluids through the sedimentary section. Intense faulting, in combination with the effect of cementation resulting from fluid flow, is noted by poor data quality zones where resolution below 2.0 s TWT is impaired (Figure 10). An example of seismic data that has been compromised by fluid movement/cementation is shown in Figure 11. Further details on acquisition parameters, line lengths and available displays are presented in Appendix B.

2.4 Products

The contents of this report are supplied to the client in both hardcopy (Vol. 1—Text and Figures; Appendices 1 to 5—Plates) and digital formats (CD). The *Browse Basin Timescale, Biozonation and Stratigraphy Chart* (Plate 2) is the only item not supplied in a digital format. Compressed graphics files are supplied on CD-ROM as plot files in PDF format. A "readme" file is included on the CD-ROM, along with a utility to decompress files. A film overlay showing Palaeozoic faults, well and permit locations is included for reference use on Time Structure Contour and Isopach Maps (Plates 8 to 24). The faults shown on this overlay are in draft form. A copy of the geohistories modelled using Winbury® is also supplied in a digital (read only) format and allows for an interactive assessment of these models. Seismic data purchased in conjunction with this report are supplied by Nopec International Pty. Ltd.

3. Regional Geology

3.1 Regional Setting

The Browse Basin was defined by Challinor (1970), Halse and Hayes (1971) and Crostella (1975) as a northeast trending Permian to Recent basin located offshore from the Kimberley Block in Western Australia. It is one of several northeast–southwest trending sedimentary basins (Figure 12) which formed during initiation of the Westralian Superbasin in the Late Palaeozoic (Yeates *et al.*, 1987). These basins lie outboard of the older, northwest–southeast trending Palaeozoic Canning Basin and Petrel Sub-basin (Figure 1). The Browse Basin is bounded to the south and east by the Proterozoic Kimberley Block and Kimberley Basin, and extends northwestwards to oceanic crust of the Argo Abyssal Plain. It is contiguous with the Roebuck Basin in the southwest and the Vulcan Sub-basin and Ashmore Platform in the northeast (Hocking *et al.*, 1994). The northern boundary is poorly defined, but the basin may extend to the Timor Trough.

3.2 Structural Elements

The structural elements of the Browse Basin illustrated in Figure 13 are based on the terminology introduced by Willis (1988), Elliot (1990), O'Brien *et al.* (1993), Hocking *et al.* (1994) and Symonds *et al.* (1994), with modifications from this study. Hocking *et al.* (1994) divided the Browse Basin into four major sub-basins, the Caswell, Barcoo, Scott and Seringapatam sub-basins. The southeastern basin boundary is defined by a series of shallow basement elements, the Prudhoe Terrace, and the Yampi and Leveque shelves.

Kimberley Basin

The Kimberley Basin and underlying Kimberley Block lie beneath a large part of the Browse Basin (Symonds *et al.*, 1994) and are generally regarded as 'basement' to the Browse Basin. The Kimberley Basin is composed of 5 to 8 km of Proterozoic, mildly deformed metasediments (mostly uniform sandstone and siltstone), tholeiitic basalts and dolerite sills, underlain by Archaean rocks of the Kimberley Block (e.g. Griffin and Grey, 1990; AGSO North West Shelf Study Group, 1994). The Kimberley Basin formed as a result of northeast-directed extension at approximately 1,800 Ma with associated west–northwest and northeast trending fault sets (Etheridge and Wall, 1994), which approximately follow the trends of the King Leopold and Halls Creek Mobile zones (Figure 1). These fracture systems cross the entire Kimberley Block and are likely to continue offshore. O'Brien *et al.* (1996) suggested that the architecture of the Palaeozoic to Mesozoic rift systems throughout the northern North West Shelf was controlled by these 'basement hard links'.

Yampi Shelf, Leveque Shelf, and Prudhoe Terrace

The southeastern flank of the Browse Basin is defined by an area of shallow, gently basinward–dipping basement, which is typically highly eroded with a distinct, rugose palaeotopographic relief, and is onlapped by Permian to Mesozoic sediments. This area has been defined as the Yampi Shelf in the central and northern parts of the basin, and as the Leveque Shelf in the southern part. Hocking *et al.* (1994) defined the boundary between the Yampi and Leveque shelves as an offshore extension of a Kimberley Block lineament along the Prince Regent River, however we propose that the Leveque Shelf is an offshore continuation of the King Leopold Mobile Zone and that the northern margin of the mobile zone defines the boundary between the Yampi and Leveque shelves. The basinward extent of the Yampi and Leveque shelves is usually noted on previous tectonic elements maps as a steep, basinward–dipping normal fault (e.g. Maung *et al.*, 1994) or a basin margin fault system (Spry and Ward, 1997). Although the edge of the shelves is characterised by faulting in places, these faults are of different ages and they are not necessarily linked. In this study, we define the boundary of the Leveque and Yampi shelves with the Browse Basin sub-basins as the 'hingepoint' from more or less flat lying basement to gently basinward–dipping basement. Basinward of this hingepoint the shelves step down to the Prudhoe Terrace, a fault-bounded, intermediate depth terrace.

Caswell and Barcoo Sub-basins

The Caswell and Barcoo sub-basins are the major depocentres of the Browse Basin. In the Caswell Sub-basin, Palaeozoic to Cainozoic sediments reach up to 20 km in thickness, whereas maximum thickness in the Barcoo Sub-basin may not exceed 15 km. This is mostly due to a thinner Palaeozoic succession in the Barcoo Sub-basin. The Caswell Sub-basin is significantly wider (200 km) than the Barcoo Sub-basin (100 km) (Figure 13). It is separated from the Barcoo Sub-basin by a major north to north–northeast trending structural zone, the Brecknock—Scott Reef Trend and its southern continuation (Figure 13).

Scott and Seringapatam Sub-basins

The Scott and Seringapatam sub-basins are deepwater basins (approximately 1500 to 3000 m) to the west and northwest of the main Browse Basin depocentres. The Scott Sub-basin is mostly underlain by the Scott Plateau, a subsided marginal plateau where up to 1 km of Late Cretaceous to Cainozoic rocks overlie Palaeozoic and older basement (Stagg, 1978). Very little is known about the Seringapatam Sub-basin and the basin boundary shown by Hocking *et al.* (1994) appears arbitrary.

3.3 Basin Development

The Browse Basin has been described variously as a Mesozoic passive margin rift basin (e.g. Willis, 1988; Haston and Farrelly, 1993), a Palaeozoic sag basin overlain by a Mesozoic extensional basin (Spry and Ward, 1997), and a Late Carboniferous to Early Permian intracratonic basin (e.g. Bradshaw *et al.*, 1988). Totterdell (1990) and Etheridge and O'Brien (1994) suggested that formation of the Browse Basin was part of a much wider, large scale extensional event which initiated basin formation along the entire North West Shelf in the Late Carboniferous to Early Permian. Symonds *et al.* (1994) postulated that extension in the Browse Basin occurred in two phases; a Late Devonian to Early Carboniferous northeast–southwest extension, similar to that in the Fitzroy Trough; and, a Late Carboniferous to Early Permian northwest–southeast extension. Due to a lack of evidence for large scale normal faults to accommodate the extension, Symonds *et al.* (1994) proposed that extension in the Late Palaeozoic was accommodated by large scale, upper crustal detachment and lower crustal and upper mantle pure shear extension (Symonds *et al.*, 1994).

Palaeozoic Extension

Structural and megasequence mapping in the Browse Basin using AGSO's deep seismic data (Figure 3) is currently being undertaken as part of AGSO's Regional Browse Basin Project (see Section 2).

The deep seismic data collected during AGSO Survey 130 has provided the first direct evidence for ?Carboniferous to Permian, large scale, southeast-dipping normal faults (Struckmeyer *et al*., 1997). Although recognition of basement offsets is sometimes ambiguous due to poor seismic resolution at depth, or the presence of volcanics in the younger section, offsets of up to 10 km can be observed on several lines. The example shown in Figure 14 shows that the basement reflection that dips to the north forms the top of the hanging wall block of a large scale normal fault with an approximate offset of 3 s TWT (8 to 10 km). This fault forms a half-graben of approximately 160 km length. This geometry is evident on a number of deep seismic lines, with the Palaeozoic succession clearly thickening to the west into major normal faults. Thus, the Palaeozoic basement of the Kimberley Basin/Block ramps into large displacement, landward-dipping extensional faults producing a characteristic half-graben basin geometry for the Browse Basin.

In Figure 15, Palaeozoic faults mapped for the Browse Basin, are overlain on a satellite gravity image (GEOSAT) (Sandwell and Smith, 1995, 1997). The faults have a predominant northeast–southwest trend and dip landwards to the southeast. Their orientation suggests a northwesterly extension direction. It is evident that the major Palaeozoic faults compartmentalise the Browse Basin into its two major sub-basins, with the Caswell Sub-basin having the thickest sediment fill. The Brecknock Fault has a north–south trend and offsets the Caswell Sub-basin from the narrower Barcoo Sub-basin. The nature of the boundary with the Vulcan Sub-basin is still unclear but it is likely that another accommodation zone offsets the Vulcan Sub-basin to the northwest.

Several northwesterly-dipping, low displacement faults define the Prudhoe Terrace (Figure 15). The Carboniferous to Permian succession does not show a rift-fill relationship to these faults—they are underlain by an older rift succession which may be of Devonian or older age, similar to the early rift fill in the Canning Basin (Kennard *et al*., 1994) and Petrel Sub-basin (Colwell and Kennard, 1996). Thus, most of the relatively “small-scale” faults which down-fault the Yampi Shelf ramp are likely to represent an older basin-phase that occurred prior to the main basin-forming events in the Carboniferous to Permian. It is likely that the bulk of the Carboniferous to Permian rift succession is equivalent to the Tanmurra, Point Spring and Kuriyippi supersequences of the Petrel Sub-basin (Colwell and Kennard, 1996) and the Anderson Formation and Grant Group of the Canning Basin (Kennard *et al*., 1994).

Permo-Triassic Thermal Subsidence Phase and Triassic Inversion

The Late Carboniferous to Permian rifting event led to breakup and separation of the Sibumasu Terrane (Metcalfe, 1990) as part of the Cimmerian continent (Sengor, 1987) from northwest Australia, and the formation of a new ocean basin (Neo-Tethys). In the Browse Basin, this event was followed by widespread deposition of Permo-Triassic thermal subsidence phase sediments.

The Permo-Triassic post-rift depositional phase was terminated by a major tectonic event throughout the North West Shelf. This event produced a regional unconformity near the top of the Triassic section and formed important features such as the Rankin Platform fault system and the Vulcan Sub-basin depocentre. The ‘Late Triassic event’ has traditionally been regarded as the onset of rifting on the North West Shelf creating accommodation for the Middle to Late Jurassic successions, and ultimately resulted in breakup in the Argo Abyssal Plain in the Callovian/Oxfordian (e.g. Hocking, 1988; Veevers, 1988). The event has also been correlated with the Fitzroy Movement of the Canning Basin (e.g. Barber, 1988; Stagg and Colwell, 1994; Symonds *et al*., 1994) and has been described as a predominantly transpressional event which resulted in both compressional and extensional structures (O’Brien *et al*., 1993; Etheridge and O’Brien, 1994; Labutis, 1994).

The Browse Basin high resolution and deep-seismic data have provided key evidence for defining the nature and timing of Late Triassic/ Early Jurassic events on the North West Shelf; a Late Triassic to earliest Jurassic (Norian—?Hettangian) compressional event predated an Early Jurassic (Sinemurian) extensional event (Struckmeyer *et al.*, 1997). In the Late Triassic, inversion of the Palaeozoic half-grabens resulted in the formation of large scale anticlinal and synclinal features within their hanging walls. Figure 14 clearly shows that the Caswell Fault experienced significant reactivation, and later erosion of the associated anticline. A further example of this event is presented in Figure 16, which images a tight syncline between two anticlines in the Caswell Sub-basin. The syn- to post-inversion fill clearly onlaps the anticlinal structures and is of Late Triassic to earliest Jurassic age. A map of structures associated with the inversion event is given in Figure 17 and shows the predominant northeast–southwest trend of the event. Thus, structures such as the Scott Reef and Brecknock anticlinal trends are inversion structures related to reactivation of Carboniferous to Early Permian normal faults. Inversion structures of similar age have been described for other areas of the North West Shelf, e.g. the Timor Sea (O'Brien, 1993; Colwell and Kennard, 1996; O'Brien *et al.*, 1996). Large-scale, inverted extensional structures similar to those in the Browse Basin have been described from the North Sea (e.g. Thomas and Coward, 1995), and the Fundy Basin (Withjack et al., 1995) and Jeanne D'Arc Basin (Sinclair, 1995) in Canada where they are associated with hydrocarbon accumulations.

Early Jurassic Extension

Faulting of the eroded inversion anticline at Brewster 1A (Figure 14) reflects the next major structural event, extension in the Early Jurassic. Figure 16 shows that the Early Jurassic structural event is a separate event from the Triassic inversion event—two distinct erosional unconformities are associated with two different styles of structuring. Compared with the large scale faulting associated with the Late Palaeozoic extension, Early Jurassic extension was accommodated by numerous smaller scale normal faults, which caused the collapse of many of the Triassic anticlines. The faults frequently die out within the Early Triassic section. In other places, they propagate through the Triassic section as a result of reactivation of Palaeozoic faults. A map of Jurassic structures (Plate 8) indicates that the faults typically trend northeast—southwest and that faulting was concentrated in the northeastern part of the Caswell Sub-basin. Figure 18 shows a typical example of a Jurassic growth fault from the northern part of the basin. The synrift section reaches up to 1.5 km thickness in the central Caswell Sub-basin and contains significant amounts of volcanics.

Late Jurassic to Cainozoic Thermal Subsidence Phase

Rifting terminated in the Late Jurassic with the onset of seafloor spreading in the Argo Abyssal Plain and the separation of 'Argoland' from northwestern Australia (Veevers *et al.*, 1991). This event was accompanied by significant volcanic activity and is associated with considerable erosion of the rift sequence on high blocks (e.g. Figure 14). Some structuring associated with this event is evident on the seismic data, mostly as reactivation of older structures. Following the Callovian breakup, deposition commenced due to thermal subsidence amplified by sediment loading. Accommodation was controlled by changes in sea level and sediment supply rather than large scale structural events. Reactivation of faults occurred in the latest Jurassic to Early Cretaceous, when seafloor spreading ceased in the Argo Abyssal Plain. Minor growth can be observed on faults in the northern part of the basin, while minor reactivation of older faults continued throughout the Late Cretaceous, particularly in the Turonian.

Miocene Reactivation and ?Salt Movement

The most recent stage of structuring in the Browse Basin occurred in the Middle to Late Miocene as a result of the collision of the Australian Plate with the Eurasian Plate. In the Barcoo Sub-basin, collision resulted in the formation of distinct northeast—southwest trending anticlines along the basinward margin of the Leveque Shelf. The example in Figure 19 shows that the structuring occurred in the Middle to Late Miocene with distinct onlap at the Late Miocene sequence boundary. In the southern Barcoo Sub-basin, contractional deformation appears to have continued to the present-day, where the anticline at Lynher 1 and Trochus 1/ST1 is truncated at the seafloor. The anticlines in the Barcoo Sub-basin formed through inversion on Palaeozoic faults at the edge of the Leveque Shelf. In the Caswell Sub-basin, Miocene structuring was confined to small scale extensional faults that are not necessarily linked to older structures. However, in the northern Caswell Sub-basin, the intensity of structuring during the Miocene was stronger with considerable fault offsets. The structuring is similar to that observed for the Vulcan Sub-basin, where the Late Miocene structuring event has led to a decrease in trap integrity (O'Brien and Woods, 1995).

Another important feature of this basin phase is the presence of probable salt withdrawal structures in the northernmost Caswell Sub-basin. Figure 20 shows an example of a possible salt structure, which suggests that salt movement occurred during the late Middle Miocene. The structure is similar in appearance to the Paqualin and Swan structures in the Vulcan Sub-basin (Smith and Sutherland, 1991), and is characterised by a diffuse seismic zone below 3 s TWT. The possible presence of salt in the northern Caswell Sub-basin is also indicated by anomalously high formation water salinities in Discorbis 1 (Bone, 1989) and Rob Roy 1 (BOCAL, 1972), and it implies the probable presence of an old Palaeozoic succession (?Silurian) beneath this part of the basin.

3.4 Summary

The Browse Basin has experienced a multiple stage deformation history. Six major basin phases can be distinguished: A Late Carboniferous to Early Permian extensional phase, a Late Permian to Triassic thermal subsidence phase, a Late Triassic to Early Jurassic inversion phase, an Early to Middle Jurassic extensional phase, a Late Jurassic to Cainozoic thermal subsidence phase, and a Middle to Late Miocene inversion phase. Each of these phases is likely to contain smaller scale structural events. Figure 21 summarises the major basin phases in relation to time, sea level changes and modelled tectonic subsidence. The basin was initiated as a series of extensional half-grabens in the Late Carboniferous to Early Permian. Large scale normal faults compartmentalised the basin into its distinct Palaeozoic sub-basins. The relicts of an earlier extensional phase during the Late Devonian to Early Carboniferous are most likely restricted to the present-day inboard parts of the basin. Breakup in the early Permian was followed by a thermal subsidence phase during the Late Permian to Late Triassic. Late Triassic inversion of Palaeozoic half-grabens resulted in the formation of large scale anticlines and synclines which dominated the intra-basin geometry until the Late Jurassic. A second, minor extensional phase in the Early Jurassic resulted in widespread smaller-scale faulting and the collapse of the anticlines. Break-up in the Callovian was followed by an extended phase of thermal subsidence with only minor fault reactivation during the Cretaceous. Inversion on Palaeozoic and Mesozoic faults occurred in the late Middle Miocene as a result of Australia's collision with Timor.

4. Sequence Stratigraphy

4.1 Time Scales and Biostratigraphy

The *AGSO Phanerozoic Timescale and Biozonation Chart* was used as the time scale for this study. The Mesozoic portion of the biozonation scheme is based on Helby *et al*. (1987), with modifications to age boundaries provided by subsequent radiometric analyses. The basic framework of the AGSO chart has been expanded to present the following data compiled during this study, including: *Hydrocarbon Shows, Sequence Names, Seismic Horizons, Tectonic Events, Basin Phases, and Conventional Nomenclature of the Vulcan Sub-basin* for correlative purposes (Plate 2). The Browse Basin Timescale, Biozonation and Stratigraphy Chart is intended as a comprehensive, visual summary of basin evolution as defined by the BBHR and Browse Regional Studies. Plate 2 is not supplied in a digital format with this report.

The BBHR grid provides direct ties to 19 wells, with a further four wells lying slightly off-line (Figure 22). Helby (1996) reviewed nine of these wells as part of a recent multi-client report covering the Timor Sea—Yampi Shelf gazettals (1/1996 Release). A further eight wells were reviewed by Helby (1997) in support of the BBHR study. Data for wells reviewed by Helby is available for purchase with this report at a discounted rate of $250 per well (Text Appendix C).

Biostratigraphic data for Delta 1 was compiled from the (open-file) well completion report (Elf Aquitaine, 1988), as this well was not reviewed for the study. Biostratigraphic data for Lacepede 1 was compiled from the well completion report (BOC, 1970) and a post-drill review done by Esso Australia Ltd. (Helby, 1981). A biostratigraphic evaluation of 13 wells by Rexilius (1994a,1994b) was purchased through Exploration Data Services and is included in this report. An examination of selected Permian and Triassic sequences was undertaken by C.B. Foster and R. Nicoll of AGSO.

4.2 Nomenclature, Methods and Sequences Mapped

At present, there is no formally recognised stratigraphic nomenclature scheme (formation-based or sequence stratigraphy) used in the Browse Basin. Previous reports have defined stratigraphic packages using an upper bounding surface identified in wells (usually an unconformity) and the correlative seismic horizon (e.g., “the Intra-Aptian Disconformity—Seismic Horizon F” of Maung, *et al*., 1994). In more recent publications (Yampi Shelf Tie Study Group, 1996; Spry and Ward, 1997), formation-based nomenclature of the Vulcan and Petrel sub-basins (Bonaparte Basin) has been adopted to define age equivalent units.

The BBHR study utilised sequence stratigraphic concepts and models to interpret well and seismic sections (Vail, 1987; Posamentier and Vail, 1988; Posamentier *et al*., 1988; Van Wagoner *et al*., 1990; Weimer and Posamentier, 1993). Depositional sequences were interpreted at a range of scales for the purpose of understanding the stratigraphic evolution of the basin. Particular emphasis was placed on intervals of significance to petroleum exploration. Composite logs for 20 wells (Plates 25 to 44) have been generated in Geolog® and are annotated with age, sequence boundaries/seismic horizons, biostratigraphy, and hydrocarbon shows.

A total of 22 sequences (BB1 to BB22) ranging in age from Devonian to Miocene/Pliocene have been identified from well and seismic data in the Browse Basin (Figure 23). Where possible, definition and mapping of the older sequences (Late Permian and older) was undertaken on the BBHR grid, although these horizons often cannot be correlated confidently on seismic data basinward of the Prudhoe Terrace. Permian and older rocks are not discussed in detail in this report.

Twenty seismic horizons defining the boundaries of sequences BB5 to BB22 were correlated throughout the BBHR grid. A summary of these sequences and horizons is presented in Table 3. Sequence boundaries were defined through the integration of seismic, wireline logs, and biostratigraphic data, and were mapped using the ***base of the sequence***. Sequence boundaries were tied to seismic data using synthetic seismograms generated from LogM®. A description of the methods used to generate the synthetics (Plates 45 to 64) is presented in Text Appendix D. A total of eight time structure maps and eight time isopach maps (1:750,000) (Plates 9 to 24) have been produced using Petroseis®, a commercial gridding and contouring software package, to demonstrate the structure and distribution of the selected sequences. A film overlay showing the permit and gazettal boundaries and Palaeozoic faults is included for use with these maps. The maps are also included as figures in this report (Contour Intervals: Time Structure Maps = 100 ms; Time Isopach Maps = 20 ms). A summary of the methods used to construct these maps is presented in Text Appendix E. A key to well symbols used on the figures and logs is shown as Text Appendix Figure I1.

4.3 Basin Phases, Accommodation, and Depositional Cycles—An Overview

Six basin phases have been identified in the Browse Basin (Section 3, Figure 21). Extension during the mid-Carboniferous to early Permian (Extension 1) was followed by a period of thermal subsidence lasting through the early Late Triassic (Subsidence 1). Movement on faults and post-rift thermal decay were the primary forces driving accommodation during this period. Approximately 15 to 20 km of sediment was deposited during the Palaeozoic to Late Triassic syn-rift and early post-rift subsidence phases. The formation and configuration of the Palaeozoic faults resulted in compartmentalisation of the depocentre into the Caswell Sub-basin (in the northern Browse Basin) and the Barcoo Sub-basin (in the southern Browse Basin) (Section 3) (Figure 13). The different subsidence histories of these two sub-basins have resulted in a relative thickening of the Early to Middle Jurassic succession in the Barcoo Sub-basin, and a thinner, overlying wedge of Late Jurassic to Cainozoic sediment (Plate 66). In the Caswell Sub-basin, the Early to Middle Jurassic succession thickens only within restricted synclinal areas, while the Late Jurassic to Cainozoic succession (particularly the Turonian-to-Base Tertiary interval) shows significant thickening northward (towards the southern Vulcan Sub-basin) (Plates 65 and 66).

Inversion of the syn-rift sequence resulted in uplift, erosion and the formation of an anticlinal/synclinal topography during the late Carnian to early Norian (Inversion 1). Accommodation was significantly reduced during this deformational phase, with coeval deposition continuing only within deeper synclinal areas. A time structure contour map on the “Late Triassic Inversion Event” is shown in Figure 24. This report focuses on the evolution of the basin following this inversion phase, and extending to the Early Tertiary.

Accommodation during the Mesozoic and Cainozoic was controlled by the interplay of post-rift subsidence, minor extension, localised inversion and eustasy. As the rate of post-rift subsidence declined through the late Mesozoic, the modulating effects of global sea level had an increasing influence on “net accommodation” and depositional style. Extensional events during the Early and Middle Jurassic (Extension 2) had only minor influence on the overall post-rift (Palaeozoic) subsidence cycle. Significant growth on faults was generally limited to the Caswell Sub-basin, where the crests of anticlines collapsed and small half-grabens were formed (Plate 5). During the Late Triassic to Middle

Jurassic, fluvio-deltaic deposition dominated on the flanks of the intracratonic rift basin (e.g., Yampi 1 and Lombardina 1), while marine conditions persisted in more basinward areas (e.g., Barcoo 1). Continental breakup and the onset of sea floor spreading in the Argo Abyssal Plain during the Oxfordian/Callovian is marked by a pronounced unconformity and megasequence boundary (seismic horizon Jcal).

Post-breakup marine flooding of the basin is recorded by most wells which penetrated the Late Jurassic section. During the Late Jurassic to Early Cretaceous, accommodation was controlled by eustatic fluctuations and tectonically-enhanced subsidence. In general, the thickness and biostratigraphic control across this interval is inadequate to enable a precise subdivision and mapping of individual sequences. By the close of the Jurassic, much of the relict topography within the rift basin had been either eroded or filled by sediment. The depositional substrate began to resemble a ramp margin, rather than a series of inter-linked, fault-bounded depocentres. A low angle, progradational geometry characterises the sequences lying above the Early Cretaceous unconformity.

A lowstand during the earliest Cretaceous (Berriasian) resulted in the deposition of sand-prone deltaic sediment on the inboard shelf margin (e.g., Yampi 1). The delta system prograded north to northwest from King Sound and Collier Bay (Figure 2). Fine-grained, distal facies were deposited in more basinward environments. A global rise in sea level from the Valanginian to Turonian, in combination with sustained post-rift subsidence, resulted in an extended period of maximum flooding in the Browse Basin. Early Cretaceous lowstand fans and wedges of transgressive sediment are preserved along the palaeo-shelf slope, and present viable reservoir targets in the present-day mid-basin region. The Valanginian to Turonian period is characterised by condensed sedimentation in the deeper basin and the widespread deposition of organic-rich rocks during periods of peak flooding (e.g., Caswell 2). A thick wedge of aggradational, siliciclastic shale was deposited in the central Browse Basin (Caswell Sub-basin) during the highstands.

A tectonically-enhanced sea level fall in the early Turonian resulted in basinwide emergence and submarine erosion on the deeper, western margin of the basin. Incised valleys formed in the eastern and northern part of the basin as fluvial systems migrated across the shelf from King Sound, Collier Bay and Prince Regent Sound. Sea level fluctuations from the Campanian to late Maastrichtian resulted in repeated incision of the inner shelf, while lowstand, deltaic-to-shallow marine sand and fan sequences were deposited in the central and northern basinal areas. A global fall in sea level in the latest Cretaceous/early Tertiary resulted in the deposition of fluvial-to-shallow shelf facies on a low-relief, ramp margin. Fluvio-deltaic sedimentation continued until the mid-Eocene. A eustatic fall in the mid-Oligocene resulted in basinwide emergence and incision of the shelf. From the early Miocene onward, deposition was dominated by prograding sequences of bioclastic carbonates and calcareous shales. Sea level fluctuations during the Miocene to Pliocene resulted in periods of lowstand shelf margin outbuilding and highstand periods of inboard progradation and reef growth.

Additional factors have influenced large-scale depositional patterns in the Browse Basin, including: 1) the presence of a long-lived, mature sediment source in the adjacent Kimberley Basin; 2) structural lineaments which dissect the Kimberley Block and focus sediment outfall points (e.g., King Sound and Collier Bay); 3) the King Leopold Mobile Zone (KLMZ), the structural boundary between the Kimberley Basin/Block and the Canning Basin; 4) a re-orientation of the drainage divide in the Late Jurassic which directed sand-prone fluvial sediments away from the Barcoo Sub-basin; 5) the predominant northwest to north–northwest progradational direction of Early to Late Cretaceous fluvio-deltaic and fan systems in the Caswell Sub-basin; and, 6) minor reactivation events beginning in the Late Cretaceous and Tertiary which resulted in subtle flexuring in the outer basin and uplift along the inboard basin margin.

Until the early Eocene, the Kimberley Block/Basin was the principal source of abundant sand during periods of lower sea level. Palaeo-fluvial systems (possibly analogues of the modern river systems) flowed from numerous outfall points along the dissected Kimberley Basin/Block, ensuring deposition of potential reservoir facies along the inboard shelf and adjacent terraces. The present-day offshore extension of the KLMZ (e.g., the Leveque Shelf) appears to have acted as a drainage divide, with fluvial systems directed north and south of this boundary.

4.4 Sequence Interpretation

The detail of sequence interpretation that is possible is clearly related to the data available. Few wells have penetrated complete sections of Permian to Late Triassic rocks, while Early Jurassic to Late Cretaceous sequences are well constrained. Tertiary sequences often display prominent, well developed sequence packaging on the seismic data, such as lowstand shelfal outbuilding, highstand progradation and transgressive, backstepping units. Unfortunately, the Tertiary is very thick in the basin and contains numerous unconformities which cause problems during drilling and with sample recovery. Wells are frequently drilled without sample recovery until the predicted base Tertiary boundary is intersected. The following results of the sequence interpretation reflect these constraining factors.

Extension (1), Thermal Subsidence (1) and Inversion (1) Basin Phases

Pre-Inversion Succession—Permo-Carboniferous (BB1 to BB3) (Base to P)

The AGSO deep seismic data clearly shows that the prospective Mesozoic succession in the Browse Basin is underlain by thick Palaeozoic syn-rift and early post-rift sediments (Section 3) (Symonds *et al.*, 1994). These rocks have not been penetrated by exploration wells in the deeper basinal areas, thus the age of the oldest rock sequence remains speculative. A re-examination of cuttings and core from Rob Roy 1 yielded large, re-worked bean-shaped cysts, that have been tentatively dated as Late Ordovician to mid-Silurian in age (C.B. Foster, AGSO, pers. comm.). These findings (although preliminary) provide the first evidence of Early Palaeozoic rocks in the offshore Browse Basin.

Permian to Early Carboniferous rocks have been intersected in five wells on the Yampi Shelf–Prudhoe Terrace margin of the Caswell Sub-basin (Yampi 1, Rob Roy 1, Prudhoe 1, Echuca Shoals 1, and Productus 1), and to the south at Lacepede 1 (Roebuck Basin) and Perindi 1 (Canning Basin). Permian rocks have not been intersected in the Barcoo Sub-basin or on the adjacent Leveque Shelf. While biostratigraphic data covering the succession of Permian and older rocks is patchy, three unconformities covering the following intervals are evident: 1) at the Visean/Namurian boundary (*G. maculosa* spore/pollen zone) (Perindi 1) (seismic horizon Cnam); 2) Early Permian (Sakmarian, lower APP2.1) (Perindi 1); and, 3) late Early Permian (lower APP3.1 and upper APP3.2) (Yampi 1, Echuca Shoals 1, Prudhoe 1, and Productus 1). The Early Permian unconformity (Sakmarian) correlates to the unconformity between Upper Grant Group and the Poole Sandstone in the northern Canning Basin. The late Early Permian unconformity (APP3) is evident on seismic data at the top of the syn-rift sequence at Yampi 1 (seismic horizon Pearly), and provides a reasonable age constraint for the end of the Extension (1) basin phase (Figures 14, 21 and Plate 2).

The Carboniferous succession is generally fluvio-deltaic in nature, while the Early Permian is marine (primarily limestones and shales). The Late Permian succession (overlying the Stage 4 unconformity) is indicative of a transgressive cycle (transgressive sandstones overlain by limestone). This sequence is the chronostratigraphic equivalent of the Hyland Bay Formation in the Bonaparte Basin.

Significance to Exploration

The present-day and initial source rock typing and kerogen types for sequences BB2 and BB3 are shown in Figures 72a and 76a, respectively. Significant oil shows were recorded throughout the Carboniferous section at Perindi 1 (Canning Basin), however these rocks are too deeply buried to present viable targets in the deep basinal areas of the Browse Basin. The Permian succession (Hyland Bay Formation equivalent) was identified as a primary or secondary drilling target at Yampi 1, Productus 1, Echuca Shoals 1, and Prudhoe 1. Both Prudhoe 1 and Echuca Shoals 1 recorded significant gas shows within Late Permian transgressive sands overlying the unconformity. While the Tern gas and condensate field (Petrel Sub-basin) is reservoired in the Hyland Bay Formation, the viability of this interval as a primary target has yet to be confirmed in the Browse Basin.

Pre-Inversion Succession—Early to Middle Triassic (BB4) (P to Trmid)

The base of the Triassic is a prominent unconformity on seismic and well data (seismic horizon P). The oldest Triassic rocks recovered in the Browse Basin were intersected at Echuca Shoals 1 and Gryphaea 1, and range from Scythian to Anisian in age (*L. pellucidus*, *K. saeptatus* and *T. playfordii* spore/pollen zones). At Echuca Shoals 1, this sequence consists of a light grey to olive black claystone with interbeds of siltstones, volcaniclastics and weathered igneous rocks. Gryphaea 1 also intersected an interbedded, medium grey claystone and siltstone, which was underlain by a friable sandstone with thin interbeds of claystone. Gryphaea 1 reached total depth in a recrystallised limestone containing coral fragments and pyrite nodules. The dark grey claystone sequence is interpreted as the chronostratigrpahic equivalent of the Locker Shale which was deposited across the North West Shelf during an Early Triassic marine transgression. The sands intersected at Gryphaea 1 are probably transgressive facies (?shoreline sands) deposited during the early flooding. In the Beagle Sub-basin to the south, these basal sands often contain reworked Permian fauna (Blevin *et al.*, 1993).

Overlying the deeper water Locker Shale equivalent, is a shallow marine sequence consisting of basal limestones that grade upward to interbedded siltstones and shales (*S. quadrifidus* zone). This sequence represents the most commonly intersected Triassic facies within the Browse Basin (Lynher 1, Brecknock 1, North Scott Reef 1, Buccaneer 1, Discorbis 1, and Copernicus 1). The limestone facies is interpreted to be the chronostratigraphic equivalent of the Cossigny Member described in the Beagle Sub-basin (Blevin, *et al.*, 1993). The Cossigny Member was deposited as a regional paralic to marine facies during a minor transgression in the mid-Anisian to early Ladinian. Palaeotopography appears to have influenced facies distribution, with carbonates deposited at Brecknock 1 and Discorbis 1, and shale deposited in more basinal settings (Copernicus 1).

A prominent unconformity extending from the upper *S. quadrifidus* to Lower *S. speciosus* spore/pollen zones (mid- Carnian to early Norian) is present in most wells intersecting Triassic rocks (e.g., Brecknock 1). Yampi 1 was the only well to intersect beds containing Lower *S. speciosus* pollen. The top of this zone correlates to a regional unconformity on seismic data and the onset of inversion across the basin (Figure 14). At Yampi 1, this boundary marks the base of a barren “red bed” sequence. The upper boundary of the Early to Middle Triassic Megasequence is interpreted to lie at the boundary between the Upper and Lower *S. speciosus* spore/pollen zones.

Significance to Exploration

The basal transgressive sands of the Locker Shale are expected to be best developed on the shallow margins of the basin as onlapping shoreface facies. The limited data available does not support a regional prediction of the quality or distribution of these facies as a reservoir target. These sands could be viable as secondary targets within fault blocks for wells that target an overlying draped, stratigraphic/structural play. A total of 37 samples have been analysed for TOC over the Locker Shale equivalent facies penetrated at Echuca Shoals 1. All samples yielded TOC values of less than 1 percent. This pattern is typical for the Locker Shale across the North West Shelf, as the best quality source rocks are predicted to lie in more basinward environments, while the wells which intersect the unit are generally positioned on the margins of the basin.

Poor reservoir is predicted within the overlying limestones and siltstones of *S. quadrifidus* age (Ladinian to early Carnian) (Cossigny Member/Mungaroo Formation equivalents). The source quality of this interval is largely unknown as only a few reconnaissance samples have been analysed for geochemical parameters (<1 to 4% TOC). The present day and initial source rock typing and kerogen types for sequences BB4 and BB5 are shown in Figures 72b and 76b, respectively.

Syn- and Post-Inversion Megasequence—Late Triassic to Early Jurassic (BB5) (Trmid to Jbase)

The onset of inversion in the Late Triassic (Norian) is marked by the formation of a northeast trending anticlinal/synclinal topography across the basin. The timing of the onset of inversion can be controlled with some confidence through wells such as Yampi 1 and North Scott Reef 1. The deposition of “red beds” occurred during the inversion and early post-inversion phases (Trmid) (e.g., Yampi 1 at 3461 to 3587 m). The red beds are typically barren of microfauna and thus age control is constrained by the sediment lying above and below. The red beds in the Browse Basin are the chrono- and tectonostratigraphic equivalents of the Malita Formation in the Petrel Sub-basin (Colwell and Kennard, 1996), where inversion structures have also been documented (O’Brien *et al.*, 1993). A time structure map on the Late Triassic Inversion Event (Trmid) is shown in Figure 24.

A late Norian transgressive sequence overlies the Trmid horizon in wells in the outer Browse Basin such as Barcoo 1 and North Scott Reef 1. Inundation of the basin resulted in the deposition of onlapping, shallow marine limestones, shelfal sands and siltstones. Well-sorted sands of equivalent age were intersected at Lynher 1. Latest Triassic (Rhaetian) highstand shales preserved at Barcoo 1 (Figure 27) thicken toward the east in the central Barcoo Sub-basin, and are expected to contain viable seal and source facies.

Significance to Exploration

The Late Triassic inversion event was instrumental in defining the essential elements of potential Triassic to Late Jurassic petroleum systems. Inversion created the anticlines which are associated with most structures that have been drilled outboard of the Prudhoe Terrace (Brecknock 1, Brewster 1 and Bassett 1A). Structuring also influenced the migration of potential hydrocarbons towards these traps. Overlying reservoir intervals developed as a result of erosion and onlap of the structures in the latest Triassic to Early Jurassic. Seals across the anticlines are expected to range from intra-formational (e.g., Rhaetian highstand sequence at Barcoo 1), to marine and prodelta shales of the overlying Early to Middle Jurassic megasequence. The source potential of this sequence is expected to be favourable only within areas in the central and outer Barcoo Sub-basin.

Early to Middle Jurassic Megasequence, Pliensbachian to Intra-Callovian (BB6 to BB7) (Jbase to Jcal)

Top Age	Base of *W. digitata* dinocyst zone
Base Age	Intra- *C. torosa* spore/pollen zone
Formation Equivalent	Plover Formation
Dominant Lithology	Fluvial and deltaic-to-shallow marine siliciclastics (eastern basin) and distal marine shales in basinal areas (western basin)
Stacking Pattern	Regressive
Stratal Geometry	Divergent (synrift) to progradational
Sequence boundaries	Intra-Callovian Unconformity (Seismic Horizon Jcal)
and seismic horizons	Early Jurassic intra-rift Unconformity (Seismic Horizon Jearly) Near-base Jurassic (Seismic Horizon Jbase)

Criteria and Age

The near-base Jurassic megasequence boundary (Jbase) is a regional unconformity that marks the onset of an extensional regime in the Browse Basin (Figure 21). The unconformity lies within the very broad *C. torosa* spore/pollen zone (the zone ranges from approximately 190 to 205 Ma) and is interpreted to be of Sinemurian age. On seismic data, the base Jurassic megasequence boundary forms the base of the syn-rift growth package (Plate 70, BBHR Line 175/04). The top of the megasequence is an angular unconformity of late Callovian age (Jcal) (Figure 25), and correlates to the base of the *W. digitata* DZ. An intra-rift event has been identified within the megasequence (Jearly) and relates to a period of renewed fault movement within geographically restricted areas of the basin. The Jearly sequence boundary falls within the *C. turbatus* spore/pollen zone, and is interpreted to be of Aalenian age. There are at least three additional sequence boundaries within the Early to Middle Jurassic Megasequence. These boundaries may be related to structurally enhanced eustatic fluctuations.

Tectono-stratigraphy

By the Early Jurassic, the north–south aligned compressional stresses that had affected the northwestern margin of Australia (Etheridge and O'Brien, 1994) began to diminish as a result of plate reorganisation. A relaxation of these stresses was accompanied by, or closely followed, the onset of an extensional phase which affected areas extending south from the Caswell Sub-basin to the Carnarvon Basin. In the Browse Basin, many of the anticlines that had formed during the Late Triassic inversion were collapsed. Extensional faults along the outboard margin of the Prudhoe Terrace and Leveque Shelf also became active during this time. An intra-rift event (Jearly) marks the onset of extensional movement in the Rob Roy (BBHR Line 175/10) (see Figure 53) and Heywood Grabens (see Figure 32). Stratigraphically, the base of the supersequence is picked at the top of the syn- to post-inversion "red bed" sequence (Yampi 1).

During the Early to ?Late Jurassic the Browse Basin was situated on the margin of a major volcanic province. Intrusive (grabbros and tholeiites) and extrusive (basalts) rocks have been intersected at many wells across the basin (North Scott Reef 1, Buffon 1, Yampi 1, Trochus 1), and can be traced as flows or sills over long distances (Figure 26). Buffon 1 drilled several hundred metres of basaltic flows. Seismic data (BBHR Line 175/09) suggest that the Buffon structure itself may be volcanic in origin. Although the well intersections suggest that there are multiple periods of intrusion/extrusion (mainly Triassic and Early to Late Jurassic), seismic evidence has highlighted the possibility of a much younger volcanic event. BBHR Line 175/09, tying the Buffon 1 well, shows a high-amplitude, cross-cutting seismic event east of Buffon 1 (SP3600 to 5400). This event cross-cuts rocks of Aptian to Albian age, and suggests that magmatic activity continued long after breakup (approximately 50 to 60 Ma).

The tectonic origin of the volcanic rocks has not yet been determined, although suggestions of underplating (Symonds, *et al*., 1994) and a failed spreading centre (Veevers, *et al*., 1991) have been proposed. It is expected that the thermal effects of underplating would have had a significant influence on subsidence and maturation along the western margin of the basin. Recent modelling using AGSO's deep seismic lines by Baxter *et al*. (in review) suggest that upper crustal extension in the Early and Middle Jurassic was accompanied by significant thinning of the lower crust. Extensive thinning may have caused a delay in the onset of post-rift subsidence and has resulted in the deposition of a "thick" sag sequence (relative to the amount predicted by upper crustal extension alone) (Baxter *et al*., in review). Aspects of the basement and deep crustal architecture of the Browse Basin will be detailed further in the Browse Basin Regional Study.

Extension culminated with continental breakup and the onset of sea floor spreading in the Argo Abyssal Plain in the late Callovian (approximately 163 Ma). Tectonic activity associated with the Callovian breakup outboard of the Scott Plateau had minimal influence on the inboard areas of the Browse Basin. Volcanic activity continued through the Late Jurassic.

Stratal Geometry and Depositional Setting

Deposition during the Early to Middle Jurassic was dominated by fluvio-deltaic systems which extended across most of the Browse Basin. Wells such as Trochus 1, Yampi 1 and Buffon 1, typically contain stacked sequences of channel sands and/or coarsening-upward prograding deltaic sands, interbedded with finer-grained beds of prodelta to delta plain siltstone and shale. A number of factors preclude a confident spatial correlation of the Early to Middle Jurassic Megasequence: a) the broad time range of spore/pollen zones covering this interval (e.g., 5 to 15 Ma intervals); b) the ephemeral nature of fluvial and paralic environments which dominated this period; c) the density of wells and their tectonic setting within the basin; and, d) the deposition of facies within isolated half grabens.

Barcoo 1 (Figure 27) intersected the most complete section of Late Triassic to Callovian rocks (*A. reducta* to *C. cooksoniae* DZ's) in the Browse Basin. The thickness and nature of these sediments suggests that the outer Barcoo Sub-basin was the locus of subsidence during the Early to Middle Jurassic period. The disparity of Jurassic sediment thickness is a fundamental factor that distinguishes the Barcoo Sub-basin from the Caswell Sub-basin.

The Jbase sequence boundary is well defined in Barcoo 1, and correlates with a distinct erosional surface that truncates the underlying highstand shales of *R. rhaetica* DZ age (approximately 4750 m depth) (horizon Tr on Figure 27). Jbase is overlain by an interbedded sequence of thin sandstones and shales that were deposited in a distal (?turbiditic) to prodelta setting. At least eight significant sequence boundaries occur within the Middle to Early Jurassic Megasequence at Barcoo 1 (at depths of 4620, 4475, 4420, 4280, 4210, and 3956 m) (Figure 27). Most of these surfaces can not be correlated over long distances on the seismic data.

The most significant of these boundaries occur at 4280 m (near the *C. torosa* and *C. turbatus* boundary), 4195 m (intra-lower *C. turbatus*)(seismic horizon Jearly), and 3956 m (intra-upper *C. turbatus* to *D. complex*). Only the Jearly horizon was mapped on the BBHR seismic grid. The lowermost of the three surfaces (near the *C. torosa* and *C. turbatus* DZ boundary) marks the boundary between moderately deep water marine facies lying below, and the shallow marine to fluvio-deltaic facies that lie above (Figure 27). The deep marine facies are interbedded with pillow basalts and volcaniclastics at Arquebus 1, Buffon 1 and Barcoo 1. The Jearly boundary (intra-lower *C. turbatus*) marks the base of a shallowing upward cycle that grades from prodelta shale, prograding topset beds, and interbedded coastal plain facies, to channel sands (Figure 27). Coal beds are common within coastal plain facies at Trochus 1, Lynher 1 and Caswell 2.

The uppermost surface within the Early to Middle Jurassic Megasequence occurs in the upper *C. turbatus* spore/pollen zone. This boundary marks the change from coarsening upward to fining upward cycles, and ranges in age from upper *C. turbatus*/*D. complex* to *C. cooksoniae*. At least two cycles of flooding can be recognised at Barcoo 1, Caswell 2, Brewster 1A, and Buccaneer 1. This interval is thin to absent at wells along the inboard eastern margin such as Trochus 1/ST1, Lynher 1, and Sheherazade 1. The deposition of sand-prone facies in the outer Browse Basin was terminated by the Oxfordian.

The Early to Middle Jurassic was a period of high sediment influx in the Browse Basin. Sand prone facies were deposited throughout the basin, although marine conditions persisted in the outermost Barcoo Sub-basin due to locally high rates of subsidence. Stacked sequences of prograding sands suggest that subsidence on the rift flanks was relatively low and sediment supply far outpaced accommodation. Delta switching was common, with sediment being fed from the north, east and west. Volcaniclastics and basaltic flows were common across the basin. The stacking of facies over three gross intervals was probably tectonically controlled, and has had a significant influence on source rock deposition and the development of reservoir/seal pairs.

Play Element Distribution—Reservoir

A schematic representation of the distribution and testing of reservoirs across the Caswell Sub-basin is shown in Figure 28. Along the Brecknock—Scott Reef trend, the Late Triassic to Early Jurassic interval (Jbase to Jearly) (mainly the *C. torosa* DZ) has retained good reservoir propeties which may be due an early hydrocarbon charge and/or a minimal depth of burial. On this outer basin trend, Middle and Late Jurassic rocks (Jearly to Jcal; Jcal to Kbase) are thin or absent due to non-deposition and/or truncation.

In the central basin, wells such as Brewster 1A (Figure 28) have penetrated only 1.6 m of pre-Callovian sand that had porosities exeeding 10% (mainly *C. turbatus* DZ age and younger). While Brewster 1A highlighted the risk associated with pre-breakup reservoir degradation, the well did not penetrate the deeper Early Jurassic reservoir interval (*C. torosa* DZ) that hosts the Brecknock and Scott Reef accumulations. This interval (Jbase to Jearly) comprises syn-rift facies that were deposited following the onset of extension in the Early Jurassic. These sands (although presently deeply buried) could reservoir an early hydrocarbon charge from Late Triassic and older source rocks (Figure 28), although the preservation potential of any accumulation would present an additional risk.

The deposition of sand prone facies in the outermost Barcoo and Caswell sub-basins was terminated in the late Bathonian to early Callovian, possibly due to tectonic movement and a re-orientation of the drainage divide. The top of the *D. complex* DZ marks the top of potential reservoir facies in these deeper areas. Aspects of pre-Callovian reservoir development are discussed further in Section 5.4.

Play Element Distribution—Source

The present day and initial source rock typing and kerogen type for sequences BB6 to BB7 are shown in Figures 72c and 76c, respectively. Early Jurassic marine facies in the Barcoo Sub-basin are predicted to have the greatest source potential of the megasequence. Barcoo 1 was the only well to intersect a significant thickness of this unit (Jbase/Tr to Jearly) (Figure 27). Two reconnaissance samples taken from third/fourth order sequences boundaries (4475 and 4530 m) yielded TOC values in excess of 2% (analysis undertaken by AGSO's Geochemical Laboratory). Further samples are not available to determine the true source potential of this interval (e.g., only 4 samples over a 400+ m thick shale interval), although the distal marine setting is predicted to be favourable for source rock deposition.

In other wells, coaly intervals within coastal plain facies (lower *C. turbatus*) may have significant source potential locally (Arquebus 1, Lynher 1 and Caswell 2). Only one sample from this interval has been analysed at Caswell 2 (1% TOC), while 14 samples from Lynher 1 contained from 1 to 15% TOC. Prodelta shales (*C. turbatus* to *C. cooksonaie*) also present a viable source rock. The shales are interbedded with fluvio-deltaic sands and vary significantly in thickness (<1 to 25 m thick). Once again, samples targeted at the intervals of maximum flooding are lacking and make it difficult to assess the true potential of the prodelta shale facies. Cumulatively, the source potential of these facies is likely to be high, but this remains untested.

Play Element Distribution—Seal

The interbedding of prodelta and coastal plain facies within this predominantly fluvio-deltaic sequence has created a number of reservoir and (intra-formational) seal pairs. The sealing potential of these facies has been proven at Brecknock 1 and North Scott Reef 1. In particular, the potential for fining-upward cycles within the *D. complex* to *C. cooksonaie* zones (Barcoo 1 and Brecknock 1) may form a regional seal over relatively shallow targets that subcrop the Callovian breakup unconformity.

Thermal Subsidence (2) Basin Phase

Late Jurassic Supersequence, Callovian/Oxfordian to Tithonian (BB8) (Jcal to Jbase)

Top Age	Top of Lower *P. iehiense* dinocyst zone
Base Age	Base of *W. digitata* dinocyst zone
Formation Equivalents	Lower Vulcan Formation Montara Formation
Dominant Lithology	Lowstand fans and prograding deltaic sand and siltstone, transgressive shoreline sands, prograding distal highstand shales
Stacking Pattern	Transgressive
Stratal Geometry	Mostly prograding sets although sequence geometry is often below seismic resolution; syn-rift developed in Heywood Graben
Sequence boundaries and seismic horizons	Near-base Cretaceous **(Seismic Horizon Kbase)** Intra-Callovian Unconformity **(Seismic Horizon Jcal)**

Criteria and Age

The Late Jurassic supersequence is an amalgamation of several transgressive–regressive sequences which post-date the Callovian/Oxfordian breakup event, and pre-date the overlying Berriasian lowstand fan systems. The base of the supersequence (seismic horizon Jcal) (Figure 23) is a prominent unconformity on both seismic and well data, and is defined as the base of the *W. digitata* dinocyst zone (DZ) (163 Ma). The oldest sediments overlying the unconformity are transgressive/deltaic sands of Late Callovian age (*R. aemula* DZ). Maximum flooding events are recorded in the late Oxfordian (intra-*W. clathrata* DZ), Kimmeridgian (*D. swanense* DZ) and Tithonian (*D. jurassicum* DZ). These events form stacked third-order floodings, within an overall second-order transgressive cycle. The top of the highstand shale package deposited during the Tithonian flooding event (*D. jurassicum* DZ) shows significant erosion (Yampi 1; Figure 29). The top of the Late Jurassic Supersequence is defined by the base of the subsequent Berriasian lowstand sands and occurs at the boundary between the Upper and Lower *P. iehiense* DZ.

Tectono-stratigraphy

Continental breakup and seafloor spreading in the Argo Abyssal Plain during the Oxfordian/Callovian was followed by a period of post-rift subsidence and relative tectonic quiescence in the Browse Basin. Post-breakup tectonism was largely confined to continued movement on extensional faults along the outboard margin of the Yampi Shelf and Prudhoe Terrace in the northern Browse Basin. To the north in the Vulcan Sub-basin, post-breakup extensional faults continued to be active throughout the Late Jurassic, with discrete extensional events evident from well and seismic data during the Early and Late Oxfordian, mid-Kimmeridgian and mid-Tithonian (Pattillo and Nicholls, 1990; Woods, 1992, 1994; Vulcan Tertiary Tie Study Group, 1996). The thick succession of Late Jurassic marine sediment in the Vulcan Sub-basin, along with expanded biostratigraphic zonations and more wells, allows for the regional mapping of significant surfaces associated with the extensional events.

By contrast, the Late Jurassic Supersequence in the Browse Basin is predominantly fluvio-deltaic and relatively thin across most of the central and western Browse Basin (generally less than 100 m; 40 to 60 msec) (Figure 30). This style of deposition in the Browse Basin may suggest a delay in onset of rapid post-rift thermal subsidence. The megasequence thickens across the Leveque Platform and Prudhoe Terrace (100 to 350 m thick), indicating a sediment source to the east (Kimberley Basin and King Leopold Mobile Belt). The separation point of two local sediment "thicks" (Figure 30; near Yampi 1 and the Leveque Shelf) lies outboard of the King Leopold Mobile Zone (Figure 1) and suggests some structural influence on the deposition of the sediment lobes. Biostratigraphic data indicate that the bulk of the southern lobe is Late Callovian to mid-Oxfordian age, while the northern lobe overlying the Prudhoe Terrace ranges from mid-Oxfordian to late Tithonian in age. The age profile suggests a shift or abandonment of the Leveque Shelf delta system in the Oxfordian.

The Late Jurassic Supersequence reaches a maximum thickness in excess of 1000+ m within the Heywood Graben, a geographically restricted, fault-bounded, depocentre near Heywood 1 (Figure 30). Significant thickening also occurs on the outer end of Line 175/10 (north of Buffon 1) (Plate 76), although correlation across the shelf margin is difficult. The basinal setting of this thick may have provided favourable conditions for the deposition of source rocks.

Stratal Geometry and Depositional Setting

It is difficult to determine the stratal geometry of the Late Jurassic Supersequence due to its relatively thin nature across much of the basin. On the southern Prudhoe Terrace, which is located proximal to a sediment source, the supersequence appears to prograde in a north–northwesterly direction. Updip of Yampi 1, a low-angle, oblique progradational geometry is observed (Plate 85), with truncation (?toplap) of the upper surface apparent (Figure 31). AGSO deep seismic line 130/06 crosses the central part of the Heywood Graben, where a distinct syn-rift geometry has resulted from growth during the Jurassic to Valanginian against an extensional fault (Figure 32).

At most wells, the bulk of the (preserved) supersequence consists of stacked sequences of progradational, fluvio-deltaic sand, shale and siltstone. The succession is distinctly aggradational at Heywood 1 (Figure 33) (and to a lesser extent, Asterias 1), and reflects the onset of rapid subsidence in the Heywood Graben during the late Kimmeridgian to Tithonian (*D. swanense* to *D. jurassicum* DZ). There are multiple unconformities within this interval which are particularly evident at wells such as Sheherazade 1 and Buccaneer 1 (Plates 49 and 61).

Thick sequences of early post-breakup (*R. aemula* DZ) deltaic sands and siltstones are only preserved at Trochus 1 and Buccaneer 1, located downdip and adjacent to the Leveque and Yampi shelves, respectively. A thin, prodelta facies of equivalent age is present at Yampi 1 (Plate 64). The Oxfordian (*D. spectabilis* DZ) is characterised by prograding, deltaic facies which are present across much of the basin. Sediment feeding the lowstand deltas originated primarily from fluvial systems that dissected the Kimberley Basin/Block and flowed across the Yampi Shelf. However, a well log correlation between Conway 1, Asterias 1 and Buccaneer 1, indicates a significant sediment source in the southern Vulcan Sub-basin/Londonderry High area during the Oxfordian and Tithonian.

Flooding events in the mid-Oxfordian (*W. clathrata* DZ) and Kimmeridgian (*D. swanense* DZ) may be reflected by thin condensed intervals (Buccaneer 1). Maximum flooding of the basin occurred during the Tithonian, as is evident from the presence of (*D. jurassicum* DZ) highstand shales at 90% of the wells penetrating the Late Jurassic succession. This highstand extended into the northern Canning and Roebuck basins, as shown for example by Lacepede 1 and Perindi 1 (Plates 56 and 57).

Play Element Distribution—Reservoir

Reservoir grade fluvial-deltaic sands are most common within rocks of *R. aemula* and *W. spectabilis* DZ age (Trochus 1 and Sheherazade 1). Heywood 1 penetrated 300+ m of sands ranging from *W. spectabilis* to *D. swanense* age (Figure 33), although porosity decreases rapidly with depth due to cementation. The juxtaposition of Late Jurassic synrift facies against Permian to Carboniferous rocks (Figure 32) may provide conduits for cross-fault and intra-strata migration of hydrocarbons from the Heywood Graben to reservoirs on the adjacent shelf. Migration across the shelf may contribute to gas chimneys observed on the Yampi Shelf (Figure 69).

Potential reservoirs of Tithonian age (*D. jurassicum* DZ) are present in interbedded deltaic sands, although their regional distribution is likely to be limited to inboard of the Prudhoe Terrace. The depositional model proposed for the Late Jurassic Supersequence predicts the presence of a number of valid reservoir/seal pairs in the mid-basin area, particularly within the upper *R. aemula* and *D. swanense* DZ (e.g., Buccaneer 1), although mapping at that scale was not undertaken during this study.

Play Element Distribution—Source

The present day and initial source rock typing and kerogen types of sequence BB8 are shown in Figures 72d and 76d, respectively. A review of the available geochemical data suggests that the true source potential of the Late Jurassic has not been adequately assessed, as many of the samples that were analysed were not selected from the interval of peak transgression (Section 5). In addition, most of the wells that penetrated Late Jurassic were situated on structural highs or on the inboard basin margin. The thickest interval of marine shale recovered lies within the *D. jurassicum* DZ (Heywood 1, Figure 33). As the Late Jurassic is the most effective source interval globally, the potential of this megasequence should not be underestimated. Analysis of hydrocarbons from Gwydion 1 suggests a contribution from the Late Jurassic Upper Vulcan Formation (Ward and Spry, 1997).

The potential distribution of Late Jurassic (?marine) rocks in the Seringapatam and outermost Caswell sub-basins may provide a source to charge anticlinal traps along the Buffon Fault from the west. This scenario could high-grade the prospectivity of the deeper water gazettal areas in the west. The sparseness of recent data beyond Line 175/10 prohibits a thorough assessment of this play.

Play Element Distribution—Seal

Early post-breakup flooding of the basin could provide adequate seal facies over Callovian fluvial sands in the deeper basinal areas. In addition, prodelta facies, such as those penetrated at Caswell 2, Brewster 1A and Yampi 1, could provide excellent intra-formational seals. Buccaneer 1 recorded numerous shows within the *W. spectabilis* and *D. jurassicum* succession of interbedded fluvio/deltaic to prodelta facies (Plate 49). Buccaneer 1 appears to have been ideally situated (structurally) on the Prudhoe Terrace to accumulate both sands and prodelta shales that were shed from the Yampi Shelf during periods of fluctuating sea level.

Base Cretaceous to Intra-Aptian Supersequence, Berriasian to mid-Aptian (BB9 to BB11) (Kbase to Kapt)

Top Age	Intra-*O. operculata* dinocyst zone
Base Age	Upper *P. iehiense* dinocyst zone
Formation Equivalents	Echuca Shoals Formation (transgressive sand and highstand shale Upper Vulcan Formation (lowstand fan and deltaic facies)
Dominant Lithology	Lowstand slope fans and deltaic sands, transgressive quartzose sand and greensand, prograding highstand shale
Stacking Pattern	Transgressive
Stratal Geometry	Aggradational and apparent progradational
Sequence boundaries and seismic horizons	Intra-Aptian Unconformity **(Seismic Horizon Kapt)** Barremian Unconformity **(Seismic Horizon Kbar)** Intra-Valanginian Unconformity **(Seismic Horizon Kval)** Base Cretaceous Unconformity **(Seismic Horizon Kbase)**

Criteria and age

The Base Cretaceous Supersequence boundary is defined as a major erosional surface at the top of the Late Jurassic highstand facies, and is marked by a distinct basinward shift in facies associated with a major second order eustatic fall (Yampi 1, Figure 29). The unconformity generally lies at the boundary between the Upper and Lower *P. iehiense* dinocyst zones (DZ), except in the deeper basin where it may be conformable. The upper boundary of the supersequence (Kapt) is an angular, regional unconformity on both seismic and well data. The Kapt unconformity is associated with a second-order eustatic fall and lies within *O. operculata* DZ. The upper boundary (Kapt) truncates the underlying Barremian and Valanginian highstand shales in updip areas of the Yampi and Leveque shelves. Two additional sequence boundaries were recognised within the supersequence: Kval (intra-Valanginian unconformity) and Kbar (Barremian unconformity) (Figure 23). These surfaces occur at the lowermost *S. areolata*/*E. torynum* and base *M. australis* DZ, respectively. These surfaces are third-order sequence boundaries within the second-order, transgressive–regressive cycle (Early Cretaceous Megasequence).

Tectono-stratigraphy

Outboard of the Scott Plateau, sea floor spreading continued in the Argo Aybssal Plain, while rifting persisted in the Carnarvon Basin to the south. Extensional faults along the outboard margin of the Prudhoe Terrace were active until the mid-Valanginian, although the rate of growth decreased from the Late Jurassic onward. The intra-Valanginian sequence boundary (Kval) coincides with the breakup of Australia and Greater India, and the onset of sea floor spreading in the Gascoyne Abyssal Plain. The onset of spreading was accompanied by a second-order transgression which marked the beginning of an extended period of high sea level along the North West Shelf. The Barremian sequence boundary (Kbar) coincides with the M5/M4 ridge jump and spreading re-adjustment (Romine and Durrant, 1996). The upper boundary of the Early Cretaceous Supersequence (Kapt) is associated with a second-order fall in sea level, probably related to plate reorganisation.

Stratal Geometry and Depositional Setting

The Early Cretaceous Supersequence consists of an upward gradation of distinct lowstand (Upper Vulcan Formation), transgressive and highstand depositional packages (Echuca Shoals Formation) (Figure 23). The Base Cretaceous depositional surface resembled a westward dipping, ramp margin that hinged along the outboard edge of the Leveque Shelf and Prudhoe Terrace (Figure 34). Palaeo-highs consisting of Triassic inversion anticlines along the Brecknock–Scott Reef–Buffon trend formed the western margin of the basin. The palaeo-shelf deepened significantly in a saddle between Buffon 1 and Mt. Ashmore 1/1A. The truncated, eastern edge of the Kbase horizon north of Gwydion 1 is shown on Figure 34.

The second-order lowstand system is defined by the Kbase (lower boundary) and the Kval (upper boundary) surfaces (Figure 35). Facies within the lowstand system include slope fans (Brewster 1A), prograding fluvio-deltaic facies (Yampi 1 and Echuca Shoals 1), and shoreline-to-shallow marine shelfal facies (Echuca Shoals 1 and Asterias 1) (Plate 3). A time isopach map of this interval indicates that the lowstand package thickens to the west and north in the Caswell Sub-basin, outboard of the Yampi Shelf and Prudhoe Terrace (Figure 35). South of BBHR Line 175/03, thickening of this interval occurs inboard over the Leveque Shelf. The spatial and temporal distribution of facies suggest that sand-prone deltaic progradation during the Lower *P. iehiense* and Upper *C. delicata* DZ comprises the bulk of the sedimentary package.

The top of the *C. delicata* delta is itself a significant stratigraphic boundary (third-order sequence boundary) that marks the end of a major progradational cycle and the deposition of high quality reservoir facies (Yampi 1 and Echuca Shoals 1; Figures 29 and 45). Significant gas shows were recorded at both wells over these intervals. A third-order transgression over the *C. delicata* delta was followed by progradation during the uppermost *C. delicata* to *B. reticulatum* DZ's (Echuca Shoals 1). Shales deposited over the delta during the floodback appear to provide a reliable seal facies for the reservoir. BBHR Line 175/07 (SP10600 to 13600) demonstrates the stratigraphic relationship of these facies, as well as the updip truncation of the delta by the Kval unconformity. In a more basinward setting, Brewster 1A and Caswell 2 penetrated marine shale and possible slope fans of equivalent age (*K. wisemaniae* to *C. delicata* DZ) (Plate 3). At Brewster 1A, the presence of 161.2 m of hydrocarbon-bearing sand (Woodside, 1981) has demonstrated the viability of the Berriasian lowstand system play within the deeper basin. A possible slope fan of similar age (Lower *C. delicata* DZ) was also penetrated at Echuca Shoals 1 (Figure 45 and Plate 3).

On seismic data, the lowstand delta system is characterised by a shingled progradational geometry (Figure 36). The delta system prograded to the north–northwest from the King Sound and Collier Bay area (Figure 2). Possible toplap and truncation of the progrades by the Kval horizon is evident on BBHR Line 175/14 near Yampi 1 (Figure 36).

A tectonically enhanced sea level fall in the mid-Valanginian (Kval) was followed by a second order sea level rise and the onset of a period of extended high sea level in the Browse Basin. A time structure contour map on the Kval horizon shows a palaeoslope that hinges outboard of the Leveque Shelf and Prudhoe Terrace (Figure 37). The continued prominence of inversion structures on the western margin (e.g., the Barcoo structure and the Brecknock–Scott Reef trend) is also evident. The Kval surface is truncated along the eastern margin by the Kapt (Intra-Aptian), Ktur (Turonian) or Tbase (Base Tertiary) unconformities (Figure 37). A time isopach map of the Kval to Kbar sequence shows that this interval is generally thin in the Barcoo Sub-basin, and thickens marginally north of BBHR Line 175/04 (Figure 38). Although not well defined, this depositional hinge appears to be on-trend with an offshore extension of the King Leopold Belt/Kimberley Block boundary. The local thinning and thickening observed in the northernmost Caswell Sub-basin is mainly due to the infilling of topographic lows and downlap of the sedimentary package.

Transgressive onlap onto the Kval horizon is generally only observed on seismic lines across the Prudhoe Terrace and the outer Yampi and Adele shelves (Figure 39). A well–well correlation (flattened on the Kval horizon) would suggest that the selected wells have not penetrated sand-prone, backstepping transgressive facies (Plate 3). The absence of these facies (and their prominence in the younger Kbar sequence) may reflect a rapid rate of sea level rise and/or low sediment supply. Maximum flooding appears to have occurred early within this sequence (approximately *E. torynum* to *S. areolata* DZ), thus the Kval horizon is often mapped within the basin as a prominent downlap surface. A review of potential source rocks has demonstrated that the most significant Early Cretaceous source interval was deposited between 134 and 123 Ma (Section 5). The sequence stratigraphic framework for the Browse Basin indicates that this interval was associated with condensed sedimentation in basinward environments during periods of peak flooding. The overlying highstand package of shale and siltstone prograded from the eastern and southeastern margins towards the west-northwest.

The stratal geometry and seismic character of the Early Cretaceous Supersequence is shown in Figure 40. Examples of truncation (below Kbase and Kval), onlap (onto Kval and Kbar) and highstand progradation (primarily above Kbar on this line) are evident on the seismic data (BBHR 175/19). Figure 41 summarises the sequence stratigraphic framework that has been defined for this interval. Significant reservoir facies are predicted below the Kval Unconformity, and as lowstand and transgressive facies overlying the Kbar sequence boundary. Source rock deposition is associated with MFS's (maximum flooding surfaces) above the Kval, Kbar and Kapt boundaries.

A tectonically enhanced sea level fall in the Barremian resulted in significant erosion of the underlying Valanginian highstand shale package (e.g., Yampi 1 and Echuca Shoals 1) (Plate 3). A time structure contour map of the Kbar horizon shows that a hinged shelf margin developed outboard of the Leveque Shelf and Prudhoe Terrace (Figure 42). This configuration is similar to previous periods, although the progressive onlap and flooding of the western margin anticlinal trend is apparent at Kbar time. A time isopach map of the Kbar to Kapt interval indicates an outbuilding of this sequence northward from the previous Kval shelf edge (Figures 43 and 38). A significant thickening also occurs south of Brecknock 1. BBHR Line 175/16 shows that the thickening is due to a combination of increased sedimentation and differential erosion (mounding) at Kapt time (Plate 82).

The Kbar unconformity appears to have been of relatively short duration (e.g., approximately 1 to 4 Ma), as evident from biostratigraphic data where the lower *M. australis* and *M. testudinaria* DZ's lie above and below the unconformity, respectively (Plate 2). Progressive onlap of transgressive packages (*M. australis* DZ) onto the Kbar horizon can be observed on seismic data east of the outer Prudhoe Terrace. An example of seismic onlap onto Kbar is shown in Figure 44a. Figure 44b shows the same segment of seismic data flattened on the Kapt horizon. In this display, both the truncation of the sequence above Kval by Kbar, and the transgressive onlap on Kbar are clearly evident. The transgressive parasequence penetrated at Yampi 1 suggests that these facies are predominantly fine-grained in nature (Figure 29). The facies at Yampi 1 fall within the Upper *M. australis* DZ and probably represent the later part of the transgressive cycle. Facies of Lower *M. australis* DZ penetrated elsewhere in the basin (Buccaneer 1 and Heywood 1) have a higher sand content and may present valid reservoir targets (Plate 3).

A lowstand slope fan of lower *M. australis* age was penetrated at Asterias 1. Figure 46 shows BBHR Line 175/11 over Asterias 1 (flattened on Kbar) and the marginal downlap of the fan onto Kbar (also note the significant erosion which is evident on the Kbase and Kval horizons in this display). A composite log of Asterias 1 demonstrates the sand-prone nature of the fan sequence (Figure 47). A well–well correlation of the Barremian transgressive and lowstand facies suggests that sand prone facies are best developed along the Prudhoe Terrace and Yampi Shelf (Plate 3). These facies comprise quartzose sands and greensands that are proven reservoir intervals at Londonderry 1 and Gwydion 1 (Spry and Ward, 1997).

Maximum flooding occurred early within the Barremian transgressive–regressive cycle (similar to the Valanginian cycle), with the deposition of significant sand facies terminated by the mid-Barremian across most of the basin. Downdip, condensed sedimentation occurred in the deeper basinal areas and resulted in intervals of high TOC at the MFS (downlap surface). Figure 48 shows the stratigraphic framework proposed for the deposition of source rocks in the Early Cretaceous Supersequence. Intervals of high TOC are predicted during the Valanginian, Barremian, and in the overlying Aptian to Turonian Supersequence. Highstand shales prograded to the west–northwest and downlapped on the Barremian MFS (Figure 40). The progradational geometry of the shale is commonly more shingled than sigmoidal in nature, suggesting that accommodation caused by the combination of post-rift subsidence and high sea level marginally outstripped the rate of sediment supply. This scenario may explain the lack of well developed sand facies in the topset facies of the progrades. Significant sand deposition may have been restricted to the inboard shallow shelf margin, while the outer basin continued to subside and was dominated by fine grained sedimentation.

Play Element Distribution—Reservoir

Times of significant sand influx into the basin occurred during a prolonged lowstand in the Berriasian, and during shorter, tectonically enhanced sea level falls in the mid-Valanginian and Barremian. The principal Berriasian reservoirs are predicted to be topset facies within a shingled, northward prograding package (Figure 36), and lowstand slope fans in more basinward settings. These intervals have been proven as reservoirs at Brewster 1A (?stacked lowstand fans) and Echuca Shoals 1 (lowstand slope fan and delta facies) (Plate 3). A subsequent floodback across the *C. delicata* delta provided a valuable reservoir/seal pair (particularly given the high quality nature of the sand facies). Downcutting by the Kval unconformity may have eroded all or part of the seal facies in some areas.

In the overlying Valanginian and Barremian package, onlapping transgressive facies can provide viable (possibly structurally enhanced) stratigraphic targets across the Yampi Shelf and Prudhoe Terrace. These facies consist of quartzose sands and greensands which have overall reservoir properties ranging from fair to good. In particular, the *M. australis* DZ sands provide significant opportunities for updip pinchout plays. A risk associated with reservoir quality is predicted for transgressive plays in basinal areas outboard of the Prudhoe Terrace. The Barremian lowstand fan penetrated at Asterias 1 (Lower *M. australis* DZ) has clearly demonstrated that good reservoir quality sands can be expected within the deeper basin (e.g., 19 to 29% porosity) (BHPP, 1987). A similar play has been identified on BBHR Line 175/19 (Figure 56). Understanding sand distribution in the Early Cretaceous Supersequence is also critical to providing drainage and carrier beds for hydrocarbons generated by Valanginian and Barremian source rocks. Further work is required to determine if sand distribution was controlled by pre-existing structures and/or lineaments.

Play Element Distribution—Source

The stratigraphic framework of the Valanginian to Aptian is characterised by rapid flooding, followed by prolonged periods of highstand. These conditions are favourable for the deposition of organic-rich rocks during times of peak flooding and condensed sedimentation. A plot of TOC, S2 and HI data for all wells in the Browse Basin shows peaks associated with the Kval and Kbar flooding events (Figure 115). The present day and initial source rock typing for sequences BB9 and BB10 is shown in Figures 72e and 72f, respectively. The kerogen types for these sequences are shown in Figures 76e and 76f.

Figure 48 shows the stratigraphic framework predicted for the deposition of source rocks over this period. The TOC richness at MFS's is demonstrated at Caswell 2 (Figure 48). Geochemical work aimed at characterising the composition, organic richness, maturity and oil-source correlation of Early Cretaceous source rocks was undertaken as part of the BBHR study. The results of this work are presented in Section 5.2.

Figure 50 shows the distribution of potential source rocks and reservoirs within the Early Cretaceous Supersequence. The supersequence is thickest along the axis of the Caswell Sub-basin, and to the north and east of Barcoo 1 in the Barcoo Sub-basin. Geohistory modelling (Section 5.3) has shown that this interval entered the oil window during the latest Cretaceous in the mid-basinal area. Hydrocarbons are expected to migrate primarily updip towards the eastern basin margin, although pathways also exist to high relief structures on the western margin north of Buffon 1. In addition, migration updip into the southern Vulcan Sub-basin is also predicted. Late stage reactivation faults along the Prudhoe Terrace and Leveque Shelf are expected to provide conduits to higher reservoirs. The truncation of the sealing facies at the Kapt horizon is also shown (Figure 50).

Play Element Distribution—Seal

Highstand shales of mid-Valanginian to Barremian, and mid-Barremian to Aptian provide a thick, regional seal across much of the basin. Seal quality and thickness decreases in the outermost basin where the Early Cretaceous sequence thins due to distal downlap. Stratigraphic traps within the Valanginian and Barremian sequences are likely to be encased by both potential source rocks and seal facies. Highstand shales of the overlying Intra-Aptian to Turonian Supersequence also provide a thick and reliable seal facies across much of the basin.

Early to Late Cretaceous Supersequence, mid-Aptian to early Turonian (BB12A to BB12C) (Kapt to Ktur)

Top Age	KCCM 33, Lower *S. striatoconus* dinocyst zone
Base Age	Intra-*O. operculata* dinocyst zone
Formation Equivalents	Woolaston Formation Lower and Upper Jamieson Formation
Dominant Lithology	Lowstand fan sands, greensands, radiolarite and shales
Stacking Pattern	Transgressive
Stratal Geometry	Aggradation and apparent progradation
Sequence boundaries and Seismic Horizons	Turonian Unconformity **(Seismic Horizon Ktur)** Intra-Albian Disconformity **(Seismic Horizon Kalb2*)** Intra-Albian Disconformity **(Seismic Horizon Kalb1*)** Intra-Aptian Unconformity **(Seismic Horizon Kapt)**

** not mapped regionally on BBHR seismic grid.*

Criteria and age

The Intra-Aptian Supersequence boundary (Kapt) is an unconformity at the top of the highstand shales of the Echuca Shoals Formation (sequence BB11) (Figure 23). This boundary is a distinct downcutting surface on seismic data and correlates to approximately the mid-*O. operculata* DZ (Plate 2). Figure 51 is a time structure map on the base of the supersequence. Along the updip, northern and eastern margins of the basin, the Kapt unconformity downcuts to the BB9 sequence boundary (Upper Vulcan Formation), eliminating the flooding and highstand packages of Barremian to Valanginian age. The top of the supersequence is defined by the Turonian sequence boundary (calcareous nannofossil zone KCCM 33, Lower *S. striatoconus* DZ) at the erosional top of highstand shales of the Jamieson Formation (Figure 23). The sequence comprises strata of mid-Aptian to Cenomanian age. A major downlap surface (DLS/MFS) associated with the Aptian “radiolarite” has also been recognised (although not mapped) on seismic data.

Two additional sequence boundaries were recognised within the Intra-Aptian to Turonian Supersequence: Kalb2 (intra-*P. ludbrookiae* DZ) and Kalb1 (mid-*M. tetracantha* DZ). In the Barcoo Sub-basin, the Kalb1 sequence boundary is a prominent angular unconformity on seismic data. This surface may be associated with a third order fall in sea level. A slight downward flexing of the outer margin may have tectonically enhanced the signature of this event. At Barcoo 1, the Kalb1 and Kalb2 sequence boundaries are both clearly evident on well logs (Figure 52).

The most significant boundary in the Caswell Sub-basin appears to be the upper Albian surface, Kalb2. This boundary is a prominent angular unconformity on the Yampi Shelf (Figure 53) and can be recognised on well logs at Rob Roy 1 (Plate 40), where distinctive transgressive packages overlie the surface. Downdip at Echuca Shoals 1 (Plate 45), the Kalb2 and Kalb1 boundaries are almost (lithologically) indistinguishable on well logs. The Kalb2 surface also appears to separate a significant change in gross stratal geometry, from low angle (apparent) progrades below the unconformity to the steeper angle progrades above the surface. These surfaces were not mapped regionally as they lose seismic definition outboard of the Prudhoe Terrace and also occur within the seismic interval where multiples impair the quality of seismic data.

Tectono-stratigraphy

As the rate of post-rift tectonic subsidence began to decline in the mid-to-Late Cretaceous, changes in sea level had an increasing influence on net accommodation. Accommodation over this period was largely controlled by a first/second order rise in global sea level, in combination with minor reactivation events attributed to intra-plate stresses. A major ridge jump occurred in the Aptian as India rotated away from Australia/Antarctica, causing minor transtensional reactivation of faults. The effects of reactivation in the Browse Basin are subtle (possibly the downward flexing of the margin as suggested by Kalb1 and Kalb2), and were often overprinted by subsequent stronger tectonic movements (particularly associated with the Miocene collision). Deposition of the supersequence coincided with the opening of the Indian Ocean (Veevers *et al.*, 1991) and the subsequent development of oceanic circulation. In the Northern Carnarvon Basin, this opening resulted in a change in depositional style to carbonate-rich marls and calcilutites (Romine and Durrant, 1996). In addition, the presence of Albian contourites is indicative of strong submarine erosional currents associated with open oceanic circulation (Romine and Durrant, op. cit.). On the southern margin, Australia separated from Antarctica in the Cenomanian (approximately 96 +/- 5 Ma; Veevers, *et al.*, 1991).

Stratal Geometry and Depositional Setting

The Aptian to Turonian Supersequence was deposited during a period when “net accommodation” was controlled primarily by eustasy. The first/second order rise in global sea level which began in the mid-Valanginian was punctuated by a second-order fall during the mid-Aptian (the base of the supersequence). From the mid-Aptian, sea level continued to rise towards a global peak in the Cenomanian/Turonian (Plate 2). Lowstand deposits associated with the mid-Aptian second order fall are generally thin (?beyond seismic resolution) and appear to be more common in the Caswell Sub-basin. Backstepping, transgressive packages are present on the inboard ends of lines 175/05 to 175/10 across the Yampi Shelf and Prudhoe Terrace. The supersequence is characterised by an overall geometry of low-angle progrades on both strike (northeast-trending) and dip (northwest-trending) lines. The direction of progradation is interpreted to be northwest-to-north/northwest. The overall low-angle of the progrades suggests that basin accommodation kept pace with sediment supply. The apparent difference in stratal geometries that was noted above and below the Kalb2 sequence boundary may signify an increase in sediment supply (or source) or a slight decrease in the rate of subsidence. Despite the change in stratal geometry, there is no significant change in lithology across the Kalb2 boundary, particular at wells in more basinward areas (e.g., Caswell 2).

The time isopach map of the Kapt to Ktur supersequence (Figure 54) clearly shows the two distinct depocentres of the Barcoo and Caswell sub-basins. As observed in older sequences, the separation of the sub-basins occurred along the projected strike (or thrusted edge) of the King Leopold Mobile Belt. The mid-Aptian to Turonian sequence thins and onlaps onto the eastern margin of the basin (Yampi Shelf and Prudhoe Terrace) and the “Yampi Nose”, while the thinning onto the outboard Buffon–Scott Reef–Brecknock trend is due to distal downlap. The sequence is truncated by the Turonian Supersequence Boundary south of BBHR Line 175/08 (mainly across the Leveque Shelf) (Figure 54).

The depositional thick in the Caswell Sub-basin has a distinct north–south alignment and underlies Brewster 1A and Basset 1A (Figure 54). The Bassett structure was formed by late stage inversion of the pre-Turonian succession (primarily the mid-Aptian to Turonian Supersequence) (Figure 55). It is clear that Bassett 1A is drilled on a complex structure that has experienced at least three episodes of normal faulting and tectonically enhanced subsidence and two episodes of inversion. Palaeozoic faults have been interpreted to underlie the Bassett and Brewster structures (Figure 15). The degradation of data quality below the Turonian Supersequence Boundary (Ktur) may reflect the presence of salt and/or cementation associated with fluid movement.

Thin transgressive sands that overlie the Kapt boundary grade rapidly upward to greensands with moderate porosities (Walkley 1, Plate 43). The greensands are overlain by what is frequently referred to in well completion reports as a “radiolarite” (*D. davidii* DZ). However, an abundance of siliceous fauna is rarely observed, with the sediment consisting mainly of glauconite, sand, silt and minor amounts of radiolarite. The interval has a characteristic high amplitude character on seismic data (Figure 56) and a low-gamma signature on logs (Figure 57), and is the chronostratigraphic equivalent of the Windalia Radiolarite described in the Carnarvon Basin (Romine and Durrant, 1996). The top of the radiolarite coincides with a prominent downlap/maximum flooding surface on seismic data (Figure 56). The “radiolarite” has been observed at wells in the central basin, such as Walkley 1, Caswell 1 and 2, Yampi 1 and 2, Brewster 1A, Arquebus 1 and Kalyptea 1. The interval is usually a calcareous clay to marly limestone in wells situated on structural highs in the western basin (Brecknock 1 and Discorbis 1).

Overlying the radiolarite/limestone facies is a very thick succession of highstand siltstone and shale (700+ m at Buccaneer 1). Possible distal turbidite facies (?ramp slope fan) are observed on well logs in more basinal settings (e.g., Barcoo 1). The shales were deposited on a low relief ramp margin and have a distinctive low angle progradational geometry. Similarly to the older megasequences, the apparent progradational direction is northwest to north–northwest. This progradation is reflected in the age profile of wells that penetrated progressively younger sequences to the north.

Play Element Distribution—Reservoir

Times of significant sand influx into the basin were limited to periods of lowstand and transgression that occurred early within the transgressive–regressive cycle. The principal reservoir facies are predicted to be lowstand slope fans, distal turbidites and transgressive, shoreface/shelf sands. Lowstand fans and turbidites are likely to be high risk due to the uncertainty of reservoir quality. Onlapping packages of transgressive facies and greensands can be observed across the Yampi Shelf and Prudhoe Terrace on the inboard ends of BBHR lines 175/05 to 175/10 (Plates 71 and 76). These facies have been intersected at Londonderry 1 and Gwydion 1, where overall reservoir properties range from fair to good (Ward and Spry, 1977).

A hydrocarbon-bearing sandstone (3606 to 3611 m) was penetrated at Caswell 1 near the Kalb1 boundary (*M. tetracantha*/*C. denticulata* DZ boundary). Pressure data indicate that the sands were “thin over-pressured streaks not in vertical communication” (Woodside, 1978b). Caswell 2 also penetrated these sands (above Zone KCCM-45), although no hydrocarbon shows were detected (Woodside, 1983).

Play Element Distribution—Source

The stratigraphic framework of the Aptian to Turonian Supersequence is similar to the underlying Valanginian to Aptian succession, in that the supersequence is characterised by rapid flooding and a prolonged period of highstand. The conditions during peak flooding and condensed sedimentation in a basinward setting are favourable for the deposition of organic-rich rocks. At Caswell 2, a depth plot of TOC against the gamma ray curve shows a peak in organic richness during the initial transgressive phase. However, a plot of all Browse Basin wells versus TOC (Figure 63) shows a decrease in organic richness during this period. One explanation for the difference between predicted and observed TOC may be that the interval of peak transgression has not been adequately sampled. Samples within the overlying highstand shale package are likely to have been diluted by high sedimentation rates. The sequence is generally regarded as immature, except within the central Caswell Sub-basin where the shale reaches marginal maturity. The present day and initial source rock typing for sequences BB11 and BB12 are shown in Figure 72g, while the kerogen types are shown in Figure 76g.

Play Element Distribution—Seal

The Aptian to Turonian Supersequence forms a regional seal across the basin, except in outboard areas where the sequence thins due to distal downlap. The highstand shale is in excess of 700 m thick in the central Caswell Sub-basin. Thin, isolated stringers of lowstand sand, deposited during third-order fluctuations, are likely to be encased within both seal and potential source rock facies. The oil shows recorded in Albian sands at Caswell 1 (Woodside, 1978b) were attributed to this configuration.

Late Cretaceous Supersequence, early Turonian to early Tertiary (BB13 to BB15) (Ktur to Tbase)

Top Age	Base C13 and *M. druggii*
Base Age	KCCM Zone 33, Lower *S. striatoconus* zonation
Formation Equivalents	Gibson, Fenelon and Puffin Formations
Dominant Lithology	Primarily siliciclastics with basal interval of calcilutite
Stacking Pattern	Regressive
Stratal Geometry	Transgressive carbonates, incised valleys, fluvio-deltaic and prograding siliciclastics
Sequence boundaries and Seismic Horizons	Near-base Tertiary Unconformity **(Seismic Horizon Tbase)** Intra-Maastrichtian Unconformity **(Seismic Horizon Kmaas)** Early Campanian Unconformity **(Seismic Horizon Kecamp)** Turonian Unconformity **(Seismic Horizon Ktur)**

Criteria and age

The base of the supersequence is defined by a major erosional surface within the Turonian calcareous nannofossil zone KCCM 33, coincident with a tectonically-enhanced sea level fall (Plate 2; Figure 21). A time structure contour map of this boundary is shown in Figure 58. In the southern Browse Basin across the Leveque Shelf, this sequence boundary, Ktur, truncates several older Cretaceous sequences; to the north the truncation is mainly limited to the Upper Albian to Cenomanian. A number of erosional surfaces/sequence boundaries occur within this supersequence, however, only the most regionally significant have been interpreted in this study. The Early Campanian Unconformity (Kecamp; KCCM Zone 20/21) marks the introduction of fluvio-deltaic sandstones in updip areas of the basin (Yampi 1), and probable fans downdip (note that Kecamp is equivalent to the Early Campanian Sequence Boundary/Top Toolonga Calcilutite horizon in the Carnarvon Basin, Romine and Durrant, 1996). The Intra-Maastrichtian Unconformity, Kmaas (KCCM Zone 8/9), marks the base of a period of extensive fan deposition, particularly in the northern Browse Basin. An additional sequence boundary associated with Late Campanian fan deposition (KCCM Zone 14) has been interpreted only in wells. The top of the supersequence is defined by an erosional unconformity referred to as Near Base Tertiary (Tbase; base of foraminiferal zone C13).

Tectono-stratigraphy

Break-up on the southern and eastern Australian margins occurred during the Turonian to Campanian as Antarctica began to drift away from the Australian continent. In the Browse Basin, this event is marked by a period of minor fault reactivation, probably induced by intraplate stress associated with this event.

A second-order transgression that had commenced in the Early Albian culminated in maximum global sea level in the early Turonian (Figure 21), coeval with the final fragmentation of Gondwanaland as Australia separated from Antarctica. A major fall in eustasy, probably tectonically-enhanced, immediately followed the peak transgression, resulting in widespread Turonian erosion on the North West Shelf and formation of the Turonian Supersequence Boundary in the Browse Basin. The deposition of this supersequence records the transition from a transgressive to regressive stacking pattern for the sequences deposited within the basin.

The Turonian sequence boundary also marks a period of submarine erosion in the Browse Basin, similar to that documented in the Northern Carnarvon Basin and probably due to an increase in the strength of the oceanic circulation and the development of sea floor scouring contour currents (Romine and Durrant, 1996). These oceanic circulation changes are most likely related to the continued widening and development of the Indian Ocean as Greater India moved away from the Australian continent.

Stratal Geometry and Depositional Setting

The Turonian to Early Campanian sequence is characterised initially by the deposition of dominantly fine-grained pelagic sediments, primarily calcareous claystone, calcareous shale, marl, and in the deeper basin, calcilutite. The terrigenous component increases to the top of the sequence as the strata aggrade and prograde basinward, with siltstone and a small amount of glauconitic sandstone probably deposited as turbidites. Sea level in the Browse Basin was still relatively high and the shoreline some distance inland, trapping coarser terrigenous material updip. Isopach thicknesses indicate that the Ktur to Kecamp sequence was probably sourced mainly from a fluvial system entering the basin from the Collier Bay area (Figures 59 and 60).

An Early Campanian sea level fall marked the end of high sea level and dominantly fine-grained sedimentation, and the beginning of a phase of regression. The Early Campanian sequence boundary (Kecamp) formed during this fall in sea level, and the basinward shift in the shoreline resulted in fluvio-deltaic sand deposition at Yampi 1. At Kalyptea 1A, turbidite sands interbedded with calcareous claystones and shales were deposited basinward of the Kecamp shelf margin (Figures 59 and 60; Plate 4). Fan deposition is likely to have occurred along the margin in other parts of the basin, but has not been drilled as yet. A seismic example of a fan and levee-channel complex (Figure 65) at the base of the Kecamp–Kmaas sequence is illustrated in Figure 66.

A major pulse of sand deposition occurred during the Late Campanian ("SB" pick on composite logs and cross-section, Plate 4), associated with a major sea level fall and lowstand fan deposition in the Caswell Sub-basin (Caswell 2 and Walkley 1 in the south, Kalyptea 1A in the north; Figures 61 and 62). Lowstand and highstand fluvio-deltaic deposition followed fan deposition, as this sequence prograded into the Browse Basin proper (Figures 61 and 62; Plate 4).

During the Maastrichtian, a major fall in sea level produced the Intra-Maastrichtian Unconformity. Fans were again deposited basinward of the shelf margin, but have only been sampled by well penetrations in the northern part of the Caswell Sub-basin (Bassett 1A and Kalyptea 1A). During deposition of the earlier Ktur–Kecamp and Kecamp–Kmaas sequences, progradation was generally westward to northwestward. The margin formed by the Kecamp–Kmaas sequence is actually a ‘nose’ in the middle of the Caswell Sub-basin (Figures 61 and 62). As a result, subsequent deltaic progradation during deposition of the Kmaas–Tbase sequence was to the north of the ‘nose’ filling in the northern part of the Caswell Sub-basin (Figures 63 and 64).

Facies distribution and direction of progradation suggest that there is a boundary separating the Barcoo and Caswell sub-basins that coincides with the offshore extension of the King Leopold Mobile Zone (Figure 1). This zone is a prominent structural feature onshore forming the King Leopold Ranges. Drainage patterns onshore indicate that the King Leopold Ranges acted as a drainage divide, with fluvial systems to the north flowing into the Browse Basin via Collier Bay, Prince Regent Sound and other northern estuaries. On the southern side of the Ranges, the drainage flows into King Sound and out onto the Leveque Shelf in the southern Browse Basin. Facies distribution patterns for the Turonian and younger sequences indicate that the Barcoo Sub-basin is not sand-prone like the Caswell Sub-basin to the north. This distribution pattern may indicate that the fluvial systems entering the basin at that time followed a similar pattern to that of the present, and that the Kimberley Block on the northern side of the King Leopold ranges was a sandier provenance area than the southern side.

Thick Maastrichtian sands in the southernmost Vulcan Sub-basin wells (Maret 1, Tahbilk 1) are coeval with the Kmaas–Tbase sequence in the northern Caswell Sub-basin. The northernmost fluvial systems on the Kimberley Block are the most likely sediment input points into the Vulcan Sub-basin. The transition zone from the northern Browse Basin to the southern Vulcan Sub-basin for this interval probably contains interfingering and overlapping lowstand fans and lowstand delta facies from both areas.

Play Element Distribution—Reservoir

Sand-prone reservoir facies are best developed in the Late Campanian and Maastrichtian. The environment of sand deposition ranges from fluvio-deltaic to basinal fans. Lowstand fans rank as the best potential reservoir because of the higher probability for seal deposition in a basinal position. Where sampled, fan sands are fine-to-medium grained and interbedded with basinal claystones and shales. Porosities are high (e.g. 15–26% in Kalyptea 1A). The time isopach maps (Figures 59, 61 and 63) provide an indication of the position of shelf margins and the likely areas for deposition of fans for the sequences interpreted within this supersequence. In fact, however, there are many additional higher-order sequences within the interpreted sequences, and many opportunities for fan deposition associated with individual sequence boundaries.

The thick, fluvio-deltaic sandstones in the youngest sequence, Kmaas to Tbase, also have good reservoir characteristics. Medium to coarse grain size and intergranular porosities from 19 to 32% in Asterias 1 are recorded for this interval. These sandstones probably were deposited within a lowstand delta, and may be sealed in limited areas by the overlying downlap of subsequent transgressive and highstand deposition.

Play Element Distribution—Source

During the Turonian, maximum global sea levels resulted in the development of epiric seas worldwide. This was a globally significant period for the deposition of source rocks, but has been generally overlooked on the North West Shelf where it is regarded as immature. High TOC’s occur in some wells in the Browse Basin in this interval (Figure 115), indicating that there is the potential for

Turonian source rocks within the Browse Basin. The present day and initial source rock typing for sequences BB13 to BB15 are shown is Figure 72h, while the kerogen types are shown in Figure 76h.

Play Element Distribution—Seal

Lowstand fan targets are the most attractive because they are often deposited on the slope of in the basin and, hence, are more likely to be encased in seal and/or source facies (Figure 65). The potential for widespread seal deposition updip decreases with decreasing age within the Ktur–Tbase supersequence, as very sandy, reservoir-prone fluvio-deltaic systems prograded out into the Browse Basin. Locally, sealing shales were deposited downdip as discrete and thin beds within stacked fan complexes (e.g., Kalyptea 1A). Thicker, prodelta shales, such as those in the Maastrichtian at Kalyptea 1A, have more than local sealing potential. In general, however, more regionally distributed sealing shales occur in the southern half of the Caswell Sub-basin and in the Barcoo Sub-basin (e.g., Caswell 1).

Tertiary Supersequences—An Overview

At total of seven sequence boundaries of latest Cretaceous/Early Paleocene (Tbase) to Late Miocene (Tlmio) age were mapped on the BBHR seismic data (Table 3). Several other significant boundaries were recognised on the seismic data, although mapping of these horizons fell beyond the scope of this study. Of the 19 wells that tie the BBHR grid, less than half contain any biostratigraphic information from Paleocene or younger sequences. Where present, these picks are usually sparse and often of low confidence. In addition, the often sandy nature of the Miocene and older succession has significantly reduced the preservation potential of this data.

To the south, a recent sequence stratigraphic study of the Cretaceous and Tertiary successions (Romine and Durrant, 1996) has highlighted several significant eustatic and/or tectonically-enhanced sequence boundaries in the Carnarvon Basin. Correlation of the Tertiary sequence boundaries with the data available from the Browse Basin has allowed some confidence to placed in the Tertiary mapping of horizons. However, unlike the Carnarvon Basin, the Browse Basin has undergone significant tectonic activity beginning in the Middle Miocene, in response to the collision of the Australia and Timor plates (Basin Phase—Inversion 2). This event has overprinted the strongly eustatically-controlled accommodation history that has been observed in the Carnarvon Basin (Romine and Durrant, op. cit.).

Aspects of the Tertiary succession are summarised below:

- **Early Tertiary to Oligocene Supersequence (Tbase to Tolig):** The base of the supersequence (Tbase) (Figure 67) is difficult to recognise in the northern and eastern basin as it falls within a homogeneous succession of well-sorted, unconsolidated quartzose sand; two significant boundaries are recognised with the supersequence (Tpal and Teoc) (Table 3); facies are mostly fluvial, shoreline, to delta plain sandstones and siltstones; interbedded coals are most common within Tpal to Teoc package; probably significant reservoir potential in the eastern and northern basin, although no seal is present until at least the Early Miocene.
- **Oligocene to Middle Miocene (Tolig to Tmmio):** base of the supersequence correlates with a major lowstand period across the North West Shelf; significant shelfal outbuilding occurred from the mid-Oligocene to Late Miocene (Figure 68); thin, homogeneous sands in the eastern basin with good reservoir potential, particularly on the Yampi Shelf (Figure 69); the upper boundary of the supersequence is marked by a tectonically-controlled unconformity associated with the collision between Australia and Timor.

- **Middle Miocene to Late Miocene (Tmmio to Tlmio):** base of supersequence correlates with a major flooding of the Browse Basin and the shift from clastic-dominated sedimentation in the eastern basin, to widespread deposition of carbonate and reefal facies (Figure 68); onlap of reactivation anticlines along the outboard margin of the Leveque Platform.

4.5 Summary

A sequence-based stratigraphic framework for the Browse Basin has been defined utilising a consistent and updated biostratigraphic database (Figures 21 and 23). This framework includes the definition and mapping of 22 sequence boundaries relating to basin phases (megasequences) and eustatically-controlled cycles of deposition (supersequences). The detail of each sequence interpretation reflects the quantity and quality of data available, with pre-Triassic and Tertiary succcessions commonly having only sparse stratigraphic and biostratigrahic control.

Several factors that have influenced the sequence stratigraphic evolution of the basin include:

- a Palaeozoic compartmentalisation of the basin into two distrinct, structurally-controlled depocentres (the Barcoo and Caswell Sub-basins);
- the difference subsidence histories and reactivation styles of each sub-basin have influenced the depositon of thick Triassic to Middle Jurassic rocks in the Barcoo Sub-basin, and thick Aptian and younger rocks in the Caswell Sub-basin;
- tectonically-controlled deposition of Late Triassic to Callovian sediments in inversion synclines and extensional grabens;
- erosion of much of the relict rift and inversion topography by the Callovian to Late Jurassic meant that the depositional substrate began to resemble a ramp margin, rather than a series of inter-linked depocentres; sequences above this boundary are characterised by a regressive, progradational geometry;
- the decline of post-rift subsidence in the Mesozoic meant that variations in sea level had an increasing influence on “net accommodation”;
- a first-order eustatic sea level rise that commenced in the Valanginian marked the onset of a period of high sea level that peaked during the Early Turonian;
- during Early Cretaceous highstands, organic-rich rocks were deposited in condensed sections throughout much of the basin;
- the direction of progradation during eustatically-controlled periods of progradation in the Late Jurassic to Late Cretaceous varied from northwest to north-northwest;
- the Kimberley Block/Basin has served as the principal provenance of mature sand for deposition in lowstand and transgressive systems; these facies are the principal reservoirs within Berriasian to Turonian age rocks;

The importance of the sequences to the development of play elements (reservoir, source and seal) is summarised in Section 5.4.

5. Petroleum Systems

5.1 Investigative Strategy

An investigation of the petroleum systems (Magoon and Dow, 1991) operating in the Browse Basin was undertaken by the BBHR Project Team. The study involved a systematic assessment of potential source rocks, maturation modelling, and mapping of potential intervals in order to define each petroleum system. A review of play elements associated with the most effective petroleum systems was also undertaken.

The study sought to characterise potential source rocks (based on richness, quality and maturation), and to correlate these parameters with recovered liquid hydrocarbons to identify potential and effective source intervals. Maturation modelling of these intervals was undertaken using Winbury® software. The distribution and sequence stratigraphic framework of the source rocks were determined (and predicted) from the mapping program. The distribution of potential reservoirs and seals were also assessed from the stratigraphic framework. The results of this investigation are presented as a series of petroleum systems and associated play families.

5.2 Source Rock Characterisation

The hydrocarbon and source rock evaluation given here summarises AGSO's present understanding of the geochemical factors which control Browse Basin petroleum occurrence. Detailed data sets and interpretations will be available in a separate, regional geochemical investigation on completion of AGSO's Browse Basin Regional Project due to finish in December, 1997. (Browse Basin Project Team, in prep.) (Section 2). The aims of the present work are to describe the methods used in, and initial results, of our characterisation (richness, quality and maturity) of the organic-rich rocks (ORR) within the Browse Basin succession. In addition, an oil-source correlation involving biomarkers and isotopes has enabled us to identify the contribution of some specific ORR's to samples of migrated petroleum (oil-stains) in the basin and to predict a correlation with reservoired hydrocarbons.

One important task in effective source prediction is to place the ORR in the sequence stratigraphic framework determined by this study (Section 4, Figure 23). We have chosen to analyse and interpret source rock character within eight age intervals based on the most significant sequence boundaries within the Browse Basin succession.

Database

The primary source of geochemical data available for the interpretation was AGSO's ORGCHEM database. This consists of information collected from well completion reports (WCR's), other external sources such as published papers, and internally generated data, all of which has been compiled in digital format. For the Browse Basin project, the currency of ORGCHEM is considered to be January 1997 for WCR data. Only Rock Eval/TOC, rock extract and vitrinite reflectance data has been evaluated in reaching our conclusions with respect to source rock character.

Source Richness, Quality and Maturation

The 29 wells in the Browse Basin geochemical database contain a total of 1968 records (Table 4), of which 1688, 898 and 320 records have TOC, Rock Eval and vitrinite reflectance data, respectively. These include 177 new Rock Eval and TOC analyses undertaken by AGSO's Isotope and Organic Geochemistry Laboratory. These new analyses, commissioned as part of AGSO's Browse Basin Regional Project, were undertaken on samples selected following an assessment of existing ORGCHEM data. The sampling strategy was aimed at complementing existing data to achieve a representative dataset across the entire stratigraphic succession, and at targeting those intervals (shales and marls) identified as maximum flooding events using sequence stratigraphic principles.

Figures 70 (A) and 71 (A) show present-day TOC and S2 values, respectively, plotted against age (Ma). Only "whole" sediment samples were used to generate the plots as opposed to "hand-picked" (118 records) rock types which are referred to as "lithology-corrected" in the discussion below. Using the interpretation guidelines outlined in Table 5, the source richness and quality plots (Figures 72a to 72h) for the 8 age intervals from Permian to Cretaceous are 'disappointing'. A first pass evaluation would classify the majority of samples showing only poor to fair oil potential. Although HI values indicate that oil-prone sediments do occur, especially in Late Jurassic and Early Cretaceous sediments, their organic content is generally below 2% TOC. At these low TOC levels, the generated oil would mostly remain within the source rock. Exceptions are Early and Late Jurassic coals and related carbonaceous shales which have good to excellent source rock potential but are only found in thin, and spatially limited, beds.

The presence of significant petroleum accumulations in the study area demonstrates that mature source rocks do exist. Hence, we start from the position that the present-day data reflect only the residual source rock potential. To arrive at a realistic estimate of overall potential we need to project backwards in order to define the 'initial' source rock potential of each unit. Thus, a simple method has been devised to correct for the influence of past oil and gas generation using data from those samples which are currently within the mature 'oil window'.

As a first step in this process, we needed to establish the approximate boundaries of the oil generation window within each of the wells in our data set. Figures 73a to 73d show depth profiles for four commonly used geochemical maturity parameters. Each parameter is consistent with a depth threshold of approximately 1500 m, above which the sediments are immature, although, on a well by well basis, the depth to the top of the oil window varies due to local burial and thermal histories. Furthermore, the burial and maturation history models used to predict the timing of oil generation can be validated using this independent field geochemical data set. Figure 74 shows the depth, on a well-by-well basis, to the onset of oil generation based on a combination of PI, Tmax and vitrinite reflectance (Ro) maturity parameters (Table 6). In some cases the vitrinite reflectance-depth profile shows no increase in Ro after the onset of generation and this characteristic is attributed to the vitrinite reflectance 'suppression' found in the Browse Basin as well as other basins of the NW Shelf (Wilkins, in press).

For samples with depths below this local onset threshold, an arbitrary value of HI (100 mg hydrocarbons/gTOC was added to the present-day source potential to approximate the initial source potential of mature sediments. This HI 'correction' is based on the average HI of oil-prone immature sediments of 200–250 mg hydrocarbons/gTOC and assuming that 40–50% of the initial source potential has been transformed into oil and gas (Boreham *et al.*, in press) during passage through the 'oil window' (Table 5). More accurately, S2 (initial) = S2 (present-day) + TOC (present-day) for samples from the mature zone. For immature sediments S2 (initial) = S2 (present-day).

A further correction was made for the lithological content of the whole sediment sample. For this, it was assumed that sandstone and calcilutite lithologies make a negligible contribution to organic content and source quality; the low S2 and TOC contents for rocks rich in these lithologies supports this assumption. Although many of the sediments had lithological descriptions taken from WCR's, a large component of the available data had no information on lithology percentages. Accordingly, and in order to remain fully consistent, lithological percentages were estimated from wire-line logs given the end-member gamma-ray response for mudrock and non-source lithologies.

Figures 70 (B) and 71 (B) show the interpreted or 'initial' source rock parameters which have been adjusted for maturity and lithology. The impact of these corrections on the bulk geochemistry on an individual well basis is illustrated in Figure 75a to 75d for a mature rock succession. Extending this approach, the high-graded or 'hand-picked' samples that we could identify in our data set are considered to have already been corrected for lithology and have been included in the interpretations on this basis.

Inspection of the 'initial' source parameters for Early Cretaceous sediments reveals a consistent increase in source rock quality when compared with present-day data (Figures 70 (A) and 71 (A), and the majority of samples in this age interval show good petroleum potential. Good, but subordinate petroleum potential also exists for Late Jurassic sediments. Figures 72a to 72h show the 'initial' bulk geochemical characteristics compared to present-day characteristics on a well-by-well basis over the eight age intervals. Significant, although irregular improvements in source richness and quality can be identified. Figures 76a to 76h summarise the geochemical data by grading the gas and oil potential from Permian to Cretaceous ORR's. This analysis demonstrates that various degrees of gas and oil potential exist throughout the full extent of the Permian to Cretaceous section. To further delineate which of the potential source rocks are the effective sources for known petroleum occurrences, some oil–oil and oil–source rock correlations were undertaken.

Oil–source correlation

The available liquid and sedimentary bitumen samples used for the correlation study, although limited, are shown in Table 7. The only 'open file' liquid petroleum sample available to AGSO was a condensate from North Scott Reef 1 (AGSO#922). Oil 'stains' were obtained from Lombardina 1 and Caswell 1 based on their high S1>1 and PI>0.5. As the next step, we interrogated ORGCHEM using the criteria of S2>2 and this resulted in a short-list of immature and mature samples in the better range for source potential. We also sought to include samples covering the full age range from Permian to Late Cretaceous and our final selection met all these criteria.

In the process of this final sample selection, it was found that there was an unexpectedly poor correlation between the Rock Eval and TOC parameters derived from mostly WCR data, and those derived from our own analysis of re-sampled intervals (Figure 77). The reason for this discrepancy is unclear although one explanation is that there has been incomplete notification of those rocks selected as 'whole' as opposed to 'hand-picked' samples. This would then account for the overall higher Rock Eval and TOC parameters as they appear in the well completion reports. Our inability to reproduce basic geochemical parameters when undertaking re-sampling programs is of particular concern for the validity of regional organic geochemical evaluations which are based solely on published data.

Our detailed geochemical analysis on the samples listed in Table 7 includes gas chromatography (GC) and gas chromatography-mass spectrometry (GC-MS) of saturated hydrocarbons. We also conducted stable carbon isotope analyses ($d^{13}C$) on the bulk saturated and aromatic hydrocarbon fractions. These data allowed us to derive geochemical correlation parameters based on of the OilMod™

parameter set used in the AGSO–GeoMark (1996) regional oil correlation study 'The Oils of Western Australia' and will enable a future correlation with that database. However, for the present purposes, we utilised a small sub-set of these parameters, specifically those which comprise source/depositional environment-specific biomarkers (Table 8). This was to minimise correlation difficulties stemming from the very wide maturation range in our sample suite which includes a condensate (highly mature), oil-stains (mature) and source rock bitumens of all maturities. Although the correlation parameters may appear limited in number, we consider it appropriate for the present purpose. Indeed, a simple parameter such as the C_{27}/C_{29} sterane ratio is sufficient to roughly distinguish the majority of the Carnarvon Basin oils from the Browse Basin liquid samples that we have analysed (Boreham and Summons, unpublished). The Browse Basin samples have a higher C_{27}/C_{29} sterane ratio consistent with an increased input of marine organic matter in effective source rocks.

Multivariate statistics employing hierarchical cluster analysis (HCA) using 12 biomarker parameters generated the dendrogram displayed in Figure 78. The condensate and oil-stains cluster into two distinct groups or 'families'. North Scott Reef 1 was the sole member of one family while the four oil-stains are geochemically distinct and can be assigned to a second family. It is our opinion that these two families are a real reflection of the basin's petroleum having its origins in two slightly different source rock facies. Indeed, the 'oil-stain' family correlates well with the source rock extract at 134 Ma from Discorbis 1 and is interpreted to be a representative of effective source rocks of Early Cretaceous age (134–123 Ma), bounded by the Valanginian and Barremian unconformities, that show the best source rock character (Figures 71 [B] and 72 [B]). Although the North Scott Reef 1 condensate shows some affinity with the Kalyptea sediment extract at 118 Ma (Figure 78) we consider the low correlation coefficient between the two precludes any definite conclusion. As a consequence, additional potential source rocks from Jurassic and Triassic sections in the western Browse Basin have been sampled and are currently being analysed.

Summary

The geochemical characterisation of ORR's in the Browse Basin shows that potential source rocks exist throughout the Permian to Cretaceous succession. Mature source rocks have been identified over much of the region. After correction for maturation and rock lithology, consistently good 'initial' source potential can be identified in Early Cretaceous (141–123 Ma) fine-grained sediments from several wells. Furthermore, some Late Jurassic and Early to Middle Jurassic rocks also show oil potential, although this is at a reduced level. ORR's of other ages show some oil potential but their restriction to thin intervals limits their capacity to be effective source rocks.

A minimum depth threshold has been established at 1500m, below which mature source rocks are capable of contributing to migrating hydrocarbons in the region. Along with the recent discoveries of significant reservoired petroleum (Gwydion 1 and Cornea 1), prevalent oil-staining throughout the stratigraphic column provides definitive evidence for the existence of at least one effective source rock in the basin.

A strong correlation between several oil-stains (migrated petroleum) and one particular source rock interval indicates that Browse Basin sediments are capable of generating petroleum. Early Cretaceous sediments, and more particularly those within the 134–123 Ma age interval, have a biomarker signature that clearly aligns them with the Caswell 1 and Lombardina 1 'stains'. This provides firm and direct evidence for an effective Early Cretaceous petroleum system within the Western Australian offshore basins. Additional evidence comes from the possible involvement of Cretaceous source rocks in the likely source interval (Callovian to Barremian) for the Bayu/Undan gas-condensate discovery in the Timor Gap (Brooks *et al*., 1996). Identification of an effective Early Cretaceous source interval also confirms earlier predictions of the general occurrence of such an ORR on the NW Shelf (Loutit *et al*., 1996).

Another oil family exists locally within the western Browse Basin, represented by the North Scott Reef condensate. This sample differs both geochemically and geographically from the oil-stains and cannot be presently correlated with any known source rocks. Further analyses aimed at filling this gap are underway.

5.3 Maturation Modelling

Geohistory modelling for 14 wells was carried out by Paltech Ltd Pty using WinBury® software. The wells were chosen to be representative of various basin localities: two wells from the central Caswell Sub-basin (Caswell 2, Brewster 1), four wells from the southeastern Caswell Sub-basin (Yampi 1, Echuca Shoals 1, Heywood 1, Rob Roy 1), two wells from the northern Caswell Sub-basin (Discorbis 1, Kalyptea 1), two wells from the outer Caswell Sub-basin (Buffon 1, North Scott Reef 1), two wells from the Barcoo Sub-basin (Barcoo 1, Lombardina 1), and two wells from the inboard shelf areas (Leveque 1, Londonderry 1). Time/depth data were compiled using the sequence stratigraphic scheme used for this study. Source rock modelling is based on geochemical data from AGSO's ORGCHEM database, modified using "initial" source richness as outlined in the previous section. More detailed subsidence and maturation modelling, including "synthetic wells" modelled from seismic sections, is expected to be available at a later date on completion of AGSO's Regional Browse Basin Project (Section 2). Figures 79 to 102 show examples of models generated by WinBury® software. The full data set for the above listed wells is included in the CD-ROM accompanying this study.

Maturation levels

As discussed in the previous section, geochemical parameters predict that sediments in the Browse Basin are mature below a depth of approximately 1500 m. Geohistory modelling indicates that, in the wells modelled, the top of the oil window (TOW) lies between depths of 1800 to 3800 m (Figure 79). Comparison of depth to TOW for individual wells interpreted from geochemical parameters (Figure 74) with that derived from geohistory modelling indicates that there is reasonably good correlation between the two approaches. It is possible that maturation modelling based on vitrinite reflectance data slightly underestimates true maturity levels due to suppression of vitrinite reflectance in some instances, however, for this study, maturity was already modelled towards the higher end of observed maturity data (see examples in Figures 80 and 81) to account for this assumption. The wet gas and dry gas maturity zones are reached in some of the modelled wells, at depths between 3000 and 5000m.

Source Maturity and Timing of Generation

Hydrocarbon generation was modelled for three source intervals, the Late Jurassic (BB8), Berriasian (BB9) and Valanginian to Hauterivian (BB10) intervals. Figures 82 to 84 show modelled maturity zones for the three source intervals indicating that source rocks of this age have reached oil maturity only in wells from the deeper Caswell Sub-basin. At Brewster 1 and Caswell 2, in particular, all three source intervals have passed through the oil window and are presently in the wet gas maturity zone. These two wells lie close to Early Cretaceous depocentres (Plates 19 and 20) and can be regarded as representative models for generation from these source rocks. The maturity of the three source intervals in the remaining wells ranges from immature to mature for oil generation. Comparison of Figures 82 to 84 with a plot of burial depth versus time for the top BB 10 horizon (Figure 85) indicates that the timing of generation from the three modelled source intervals is closely related to Cretaceous burial rates, with earlier generation from intervals experiencing greater burial during the Cretaceous.

Examples of modelled geohistory, modelled rates of hydrocarbon generation and modelled volumes of hydrocarbon generation for five wells from the Browse Basin are presented in Figures 86 to 100. Late Jurassic to Early Cretaceous source rocks in the central Caswell Sub-basin reached the oil window in the Late Cretaceous and commenced generating liquid hydrocarbons at moderate rates during this time. An increase in the rate of generation is observed for the Eocene, but higher rates of generation from Early Cretaceous source rocks did not occur until the Miocene (Figures 87 and 90). The models also indicate that oil may not have been expelled from the source rock until the Miocene to Pliocene. However, it is likely that expulsion occurred somewhat earlier in the deepest depocentres of the basin.

The example for the southeastern Caswell Sub-basin (Yampi 1; Figures 92 to 94) indicates that significant generation from source units BB 8 and BB 9 did not occur until the Miocene and that generation from BB 10 has been negligible. According to the models, no oil has been expelled at this location. In contrast, at Kalyptea 1 in the northern Caswell Sub-basin (Figures 95 to 97), significant amounts of oil are modelled to have been generated and expelled from BB 9 and BB 10 during the Pliocene. Maturation modelling for the Barcoo Sub-basin suggests that only small amounts of liquid hydrocarbons have been generated from Late Jurassic to Early Cretaceous source rocks (Figures 98 to 100).

Hydrocarbon generation and expulsion from potential Permian to Early Jurassic source rocks were not modelled in detail for this study, but a number of modelled wells intersecting significant thicknesses of these older successions indicate that they reached the oil window during the Cretaceous to Early Cainozoic (Figures 101 and 102). However, these wells were drilled on Permo-Triassic structural highs suggesting that generation from these source rocks commenced considerably earlier in the deeper depocentres of the basin, with timing dependant on structural setting.

5.4 Hydrocarbon Habitat and Play Concepts

The locations of hydrocarbon accumulations in the Browse Basin are highlighted in Figure 2, with details of significant shows and accumulations summarised in Appendices H and I, respectively. Structural and combination structural / stratigraphic traps targeting Permian, Triassic, Early-to-Middle Jurassic (pre-breakup), and Late Jurassic (post-breakup) reservoirs are traditional plays in the Browse Basin. The structural traps are primarily pre-Callovian rotated fault blocks located within an anticlinal trend (e.g., North Scott Reef 1, Brewster 1A, and Brecknock 1), or Triassic to Permian fault blocks along the Prudhoe Terrace / Yampi Shelf (e.g., Echuca Shoals 1, Prudhoe 1 and Buccaneer 1). Many of these structures also have secondary targets within the overlying draped sequences of Middle Jurassic to Aptian age (e.g., structural / stratigraphic traps such as at Echuca Shoals 1).

Post-Callovian inversion structures such as those tested at Bassett 1A (Late Cretaceous anticline) and Lombardina 1 (Miocene anticline) also have significant potential for hydrocarbon trapping. Stratigraphic plays in the mid-basin area, such as those tested at Caswell 1, 2 (Campanian fan) and Walkley 1 (Campanian and Barremian fans), have proven elusive due to risks associated with reservoir quality, hydrocarbon charge and updip seal. On the Yampi Shelf, the recent oil and gas discoveries at Gwydion 1 (1995) and Cornea 1 / 1A / 1B (1996–97) targeted Early Cretaceous reservoirs that draped relict basement topographic features. Maung *et al.* (1994) have reviewed the play types and prospectivity of the Browse Basin.

Prior to Gwydion 1 and Cornea 1/1A/1B, the pre-Callovian anticlinal play (e.g., North Scott Reef 1 and Brecknock 1) had proven to be the most successful for the entrapment and accumulation of hydrocarbons. The recent discoveries on the Yampi Shelf have not only confirmed the potential for significant oil generation, but the viability of long-range migration pathways from the central Browse Basin. While the inboard eastern margin has the potential for the updip entrapment of hydrocarbons, there is also a significant risk associated with gas flushing and seal development.

The gross distribution of known hydrocarbon accumulations in the Browse Basin appears to mirror the broader trends seen in the Carnarvon Basin, specifically an outer basin, gas and condensate trend reservoired in Early Jurassic and Triassic rocks, and an inner basin, oil-prone trend reservoired in Late Jurassic and Early Cretaceous rocks. Unlike the Carnarvon Basin, the Browse Basin also hosts significant gas accumulations within the central basinal area (Brewster 1A) and along the Prudhoe Terrace (Echuca Shoals 1).

Oil-source correlations undertaken by this study have identified two oil families: an Early Cretaceous oil-prone family (which has a relatively good correlation to source rocks) and a possible Triassic to Early Jurassic gas and condensate family (although the low correlation coefficent makes this association inconclusive). The source of gas and condensate for the Carnarvon Basin's Rankin Trend is also likely to be Triassic to Early Jurassic rocks, while the inner basin oil-prone source rocks are presumed to be Late Jurassic age (e.g., Lewis Trough). The Early Cretaceous Muderong Shale of the Carnarvon Basin is the chronostratigraphic equivalent of the Valanginian to Barremian source interval identified in the Browse Basin (Section 5.2). The Muderong Shale displays good to marginal source potential in the Carnarvon Basin, but is regarded as non-generative due to immaturity from lack of deep burial (Romine and Durrant, 1966). A secondary gas charge was likely from Early to Late Jurassic rocks underlying the central Carnarvon Basin.

Gas accumulations in the central Browse Basin (Brewster 1A and Echuca Shoals 1) are likely to have been sourced from the Permian, Triassic and Early Jurassic succession (e.g., a similar source to the Scott Reef and Brecknock accumulations), rather than a late gas charge from younger rocks (e.g., the Valanginian to Barremian source interval). At present, gas samples have not been analysed by AGSO to determine geochemical properties and/or the potential age of the hydrocarbons. The generative potential for Permian and older source rocks is poorly understood in the Browse Basin, although seismic correlation indicates there is in excess of 20 km of Permo-Carboniferous and older sediment in the central basin area.

In general, the migration of generated hydrocarbons in both the Browse and Carnarvon basins appears grossly similar; a westerly migration to the outer basin from older source rocks into structural traps (anticlines/fault blocks associated with ?reactivated Palaeozoic extensional faults); and, an easterly migration of hydrocarbons generated from younger, oil-prone source rocks into stratigraphic and structural/stratigraphic traps. In the Carnarvon Basin, the Lewis Trough provided a structurally-controlled depocentre for the accumulation of anoxic Late Jurassic source rocks. There is no analogue (particularly in terms of scale) of the Lewis Trough in the Browse Basin, and the deposition of thick Late Jurassic sediment is geographically restricted to the Heywood Graben (Plate 17).

Source Rocks and Migration

To the north of the Browse Basin, Late Jurassic extension in the Vulcan Sub-basin resulted in the development of deep, elongate grabens where thick successions of restricted marine sediments were deposited. The thickness and age of these potential source intervals (primarily Late Jurassic), along with the difference in post-Callovian structural development of the Browse Basin and Vulcan Sub-basin, has meant that the elements of any Jurassic and younger petroleum system are essentially different in the two basins.

The Heywood Graben is similar (in terms of structural configuration, although not in size) to the Skua Syncline and Swan Graben of the Vulcan Sub-basin. The pre-Callovian structure on BBHR Lines 175/11 to 13 is grossly similar to structures observed on AGSO's Vulcan Tertiary Tie (VTT) Line 163/06 (Plate 1) across the Londonderry High to Ashmore Platform (see Figure 5 of Baxter *et al.*, 1997). VTT Line 163/27, a strike line oriented northeast/southwest (Plate 1) along the Montara Terrace/Skua Syncline, shows that the Early Permian rises gradually northward from the northern Browse Basin into the southern Vulcan Sub-basin. Ties to Delta 1 on VTT Line 163/27 indicate there is progressive onlap northward of the Callovian to Turonian succession as basement shallows. The data suggests that the Early Permian boundary between the Vulcan Sub-basin and the Browse Basin lies just north of Talbot 1. The southerly dip of the pre-Tertiary age section may provide migration pathways out of the depocentres in the northern Browse Basin and into the southern Vulcan Sub-basin.

The available geochemical data for the Browse Basin would suggest that the true source potential of Late Jurassic rocks has not been adequately tested due to the selective nature of samples (see Section 5.5). Many of these samples are from wells situated on structural highs within the basin and on the shallow shelf margin (Yampi Shelf). Despite the nature of the dataset, it is unlikely that Late Jurassic rocks will be the primary source interval in the basin because of its limited thickness and overall facies distribution (Figure 30). Facies analysis of well logs indicates that Oxfordian to mid-Tithonian age rocks (*R. aemula* to *O. montgomeryi* DZ) were deposited primarily in fluvio-deltaic to prodelta settings (Section 4). A period of maximum flooding of the basin occurred during the late Tithonian (*D. jurassicum* DZ), and is likely to be the most favourable environment for the widespread deposition of source rocks. Further work on the *D. jurassicum* DZ interval is required in mid-basin wells such as Yampi 2, Caswell 2 and Brewster 1A to properly assess source potential. In addition, further work is also required to map possible Late Jurassic source rocks north of Buffon 1, as suggested by the outboard portions of the BBHR grid north of Buffon 1, and to their ability to source traps from west into the Scott Reef—Brecknock trend.

The primary oil-prone source rocks (of significant thickness) in the Browse Basin are interpreted to be of Early Cretaceous age (see Section 5.2). Sequence interpretation suggests that "pods" of organic-rich rocks were deposited during stages of incremental flooding of the basin (within an overall transgressive cycle) during the Valanginian to Barremian. These rocks entered the oil window during the Late Cretaceous to Early Tertiary in the mid-basin and during the Late Tertiary (Neogene) in inboard areas of the basin. Preliminary modelling suggests that the Aptian to Tertiary overburden in the central Caswell Sub-basin has been instrumental in driving maturation of Early Cretaceous source rocks. The extent of a mature source is predicted to correspond with isopachs of maps of these Late Cretaceous successions as shown in Figures 54, 60, 62, and 64. By the onset of generation (probably post-Turonian to Tertiary), the westerly flexing of the outer shelf had commenced. Hydrocarbons generated from Early Cretaceous source rocks are expected to have migrated over long distances from the central basin updip to the shelfal areas (Yampi and Leveque shelves).

This process is dependent on the presence of adequate carrier beds to facilitate migration towards the eastern shelf margin. The Berriasian deltaic sands lying below the proposed source rocks may facilitate movement in areas with a relatively steep slope. Sand distribution within and immediately above the Valanginian to early Barremian source intervals is likely to be limited to slope fans and backstepping wedges deposited during relatively "short term" (e.g., third or fourth order) lowstand and transgressive events (Section 4.4). These facies can also act as potential reservoirs in the central and eastern basin area. The potential for hydrocarbon trapping within the transgressive and lowstand facies is likely to be high given the nature and thickness of the overlying highstand shales (particularly detached lowstand fan plays). Backstepping wedges of transgressive sand/greensand could be effectively sealed by downdipping shale facies of the subsequent (younger) transgressive wedge (Figures 41 and 49). It is envisaged that the nature of Valanginian to Aptian transgression (episodic versus continuous) would have determined the thickness and geometry of transgressive sand bodies.

An understanding of the distribution of the Valanginian to Barremian lowstand/transgressive sequences (as carrier beds) is critical for estimating the potential size of a drainage area. Figures 37 and 42 are Time Structure Contour Maps on the Valanginian (Kval) and Barremian (Kbar) unconformities, respectively. The proposed area of potential lowstand and transgressive deposits, as well as migration direction, is shown in Figure 50. In the deeper basinal areas, drilling records often indicate an overpressuring in the Valanginian to Aptian shale interval (e.g., Brewster 1A) (Willis, 1988). Overpressuring would suggest that rapid and prolonged deposition of shales has not allowed for complete dewatering of interlayers within the clay structure. An excess of water trapped within the system may have resulted in overpressuring and an increased geothermal gradient over the shale interval (e.g., Caswell 1) (Willis, 1988). In addition, overpressuring may influence the movement of hydrocarbons and thus may complicate the pattern of primarily eastward migration.

Although the geochemical analyses indicate a significant potential for oil generation in Early Cretaceous rocks, volumetric calculations based on net effective thickness were not undertaken as part of this study. The AGSO Browse Basin Project Team has proposed to undertake targeted sampling to further constrain the potential of the Late Jurassic and Early Cretaceous source rocks, and to examine possible implications for the prospectivity of areas such as the Malita Graben/southern Petrel Sub-basin where the Early Cretaceous succession thickens significantly. Recently published material on geochemical analyses of Gwydion 1 do not conclusively identify a source rock (Spry and Ward, 1977), although migration route mapping suggests the accumulation is more likely to be sourced by the Late Jurassic to earliest Cretaceous Upper and Lower Vulcan Formations (Swan Group) (Spry and Ward, op. cit). However, a contribution from the Early Cretaceous Echuca Shoals Formation can not be precluded (Spry and Ward, op. cit.).

The potential for similar carrier beds, reservoirs, and seal characteristics within rocks of the Aptian to Turonian transgressive–regressive cycle (Section 4.4) is favourable. The potential for hydrocarbon generation from the highstand shale succession is considered to be low due to immaturity where sampled. Further maturation modelling using synthetic wells in the deeper mid-basin (particularly in the northern Caswell Sub-basin where this interval is overlain by thick Campanian to Maastrichtian sediments) is required before the maturity and generative potential of these rocks can be properly assessed.

Trap Development

Late Triassic inversion and Early Jurassic extension are the events which are most critical to trap development in the central Browse Basin. The anticlines which had formed during the Triassic inversion were collapsed during a period of subsequent relaxation and extension. These events created complex, northeasterly-trending zones of faulted anticlines and synclines which characterise the basin today (e.g., “the Inner Basin Arch” and “Central Basin Arch” of Maung, *et al*., 1994). Hydrocarbons that had generated and were trapped deep within the Palaeozoic half-grabens (prior to inversion) were probably lost during the Triassic and Jurassic deformational events.

Later reactivation of the Palaeozoic faults during the Late Cretaceous and Miocene created additional anticlinal structures, such as those observed at Bassett 1A and along the Lynher–Lombardina trend. These structures have a high potential to trap hydrocarbons due to the relatively “young” age of potential source rocks in the Caswell Sub-basin (e.g., Valanginian to Barremian) and the late onset of generation (e.g., Late Cretaceous to late Tertiary). The risk of continued fault movement (and trap breeching) into the Late Tertiary increases towards the Vulcan Sub-basin. The BBHR seismic data clearly show that many faults near the southern Ashmore Platform extend through to the seafloor (BBHR Lines 175/11 to 13).

In the eastern Browse Basin, the Yampi Shelf was a Palaeozoic “flexural ramp” that dipped westward towards the Palaeozoic faults in the outer basin (Section 3). The Yampi Shelf margin has subsequently been faulted (perhaps due to over-steepening of the ramp) during the (?) Early Jurassic to Valanginian. This movement created a number of potential structural plays on the Yampi Shelf and along the outboard edge the Prudhoe Terrace, such as rotated fault blocks (e.g., Echuca Shoals 1 and Prudhoe 1), buttresses (e.g., Buccaneer 1) and narrow anticlinal structures that rollover into the main fault. These structures are favourably situated to trap hydrocarbons migrating updip from the central basinal area. Continued movement during the Valanginian to Aptian on the steep faults that bound the outer Prudhoe Terrace may have provided conduits for hydrocarbons to migrate into stratigraphically higher reservoirs. Understanding the juxtaposition of reservoirs and seal across these faults, as well as the potential for a fault seal, is critical in assessing the potential for hydrocarbons to move towards the Yampi Shelf. Echuca Shoals 1 tested a Permo-Triassic fault block that is situated some distance basinward of the main fault. In this setting, post-Callovian movement has enhanced the closure of younger stratigraphic reservoirs over the structure (BBHR Line 175/10).

Further updip on the Yampi Shelf, the basement surface is characterised by a relict, rugose topography that has been attributed to glacial erosion during the Early Permian (Yampi Shelf Study Group, 1996). While it is envisaged that glaciation may have initiated this topography, subsequent fluvial erosion during the Triassic and Early Jurassic has probably enhanced the prominance and relief of these features. In addition, the intrinsic composition and fabric of Proterozoic basement may contribute to the development of these structures. Many of the these structures may also be fault controlled (or enhanced), such as the basement high that can be observed on BBHR Line 175/04 (SP10300). Stratigraphic traps associated with the rugose topography and basement fault blocks may have formed through onlap, differential compaction, or late stage fault movement.

Timing of Generation, Reservoirs and Seals

In the western Browse Basin, the Scott Reef and Brecknock hydrocarbon accumulations are reservoired in Early Jurassic to Triassic rocks within faulted, anticlinal structures. Hydrocarbons generated from older source rocks, such as Early Jurassic, Late Triassic, and possibly Permian age, are most likely to have charged these pre-breakup reservoirs. Maturation modelling has shown that the youngest of these successions, the Early Jurassic sequence at Caswell 2 (BB7) (Figure 89), entered the oil window during the Late Campanian. By this time, a number of potential seals were in place over the Early Jurassic to Triassic reservoirs, including intra-formational, pre-breakup shales (Toarcian to Bathonian, *C. torosa* to *D. complex* DZ) and post-breakup shales deposited during the Kimmeridgian flooding event (*D. swanense* DZ). Younger seals, such as the Valanginian to Turonian highstand shale, which is generally regarded as a reliable regional seal in the central and eastern basin, thin to the west with the downlap edge often located to the east of the Scott Reef—Brecknock Trend.

In the deeper, central Browse Basin, traditional Triassic to Middle Jurassic (pre-breakup) reservoirs are considered to be higher risk due to the effects of porosity occlusion caused by deep burial (overburden) and diagenesis. Diagenetic effects such as cementation and quartz overgrowth can strongly occlude primary porosities that ranged initially from fair-to-excellent. However, given that only two wells tested this interval in the central basin (e.g., Brewster 1A and Caswell 2), it is difficult to model or predict reservoir quality on a regional scale based on the depositional facies. The preservation of primary porosity in the deep basin may largely be dependent on either an early hydrocarbon charge into the available reservoir (and preservation of this accumulation), or minimising the depth of burial/post-depositional loading.

Figure 28 is a schematic representation of the distribution and testing of reservoirs across the Caswell Sub-basin. Along the Scott Reef—Brecknock trend, the Late Triassic to Early Jurassic interval (Jbase to Jearly) has retained good reservoir properties due to a possible early charge and a minimal depth of burial, while the Middle and Late Jurassic intervals (Jearly to Jcal; Jcal to Kbase) are thin or absent due to non-deposition and/or truncation.

In the central basin (e.g., "Brewster 1A" on Figure 28), Early to Middle Jurassic strata (Jbase to Jearly, Jearly to Jcal) (*C. torosa*, *C. turbatus* and *C. cooksoniae* DZ's) thicken considerably towards the central Caswell Sub-basin. Brewster 1A targeted pre- and post-breakup reservoirs within a tilted Jurassic horst block and an overlying, low-relief sediment drape (Figure 28). The well encountered two gas-bearing zones: an upper zone of Berriasian sand (*C. delicata* DZ, lying above seismic horizon Kbase) with 161.2 m net sand, and a lower zone of Middle Jurassic sand (*C. turbatus* DZ and younger) with only 1.6 m of sand exceeding 10% porosity. While Brewster 1A highlighted the risk associated with pre-breakup reservoir degradation, the well did not penetrate the deeper Early Jurassic reservoir interval (*C. torosa* DZ) as encountered at Brecknock 1. This interval, Jbase to Jearly (BB7), comprises syn-rift facies deposited following the onset of extension in the Early Jurassic. These sands (although presently deeply buried) could reservoir an early hydrocarbon charge from Late Triassic and older source rocks (Figure 28), although the preservation potential of any accumulation would present an additional risk.

While overburden may be a significant factor in reservoir degradation, additional influences are poorly understood due to a lack of wells penetrating these rocks. The western basin anticlinal trend (Barcoo—Scott Reef—Brecknock—Buffon) has undergone moderate to deep burial, but at a much later stage than the central basin (e.g., the overburden is generally prograding carbonates of Tertiary and younger age) (Figure 28). In the central basin, the bulk of the overburden consists of Early Cretaceous to early Tertiary strata. The relatively "late" deposition of significant overburden rocks and the westerly flexuring of the outer shelf may have ensured partial preservation of porosity and permeability until migration into the underlying Jurassic to Triassic reservoirs occurred.

Maturation modelling of the Early Cretaceous source interval (Kval to Kbar) has shown that generation occurred during the Late Cretaceous to late Tertiary. By this time, the westerly flexuring of the shelf had commenced and hydrocarbons generated since that time were most likely to favour updip, intra-stratal migration towards the north and east. Some hydrocarbons generated from Early Cretaceous source rocks may have migrated towards the western margin (e.g., the Scott Reef—Brecknock trend) and could have provided a secondary charge to reservoirs, particularly within shallower, post-breakup onlap plays.

Updip, intra-stratal migration of hydrocarbons generated from Early Cretaceous source rocks may have have charged reservoirs on the Yampi Shelf ranging in age from Permian to Tertiary. These reservoirs may include Permian transgressive sands (Hyland Bay equivalent), onlapping Late Jurassic fluvio-deltaics, prograding Berriasian deltaic sands, and lowstand-to-transgressive deposits of Valanginian to Aptian age (Section 4.4). Late stage fault movement may have provided conduits to Campanian, Maastrichtian and Early Tertiary lowstand deposits. Reservoirs at higher stratigraphic intervals may have a higher risk associated with seal potential, while the Permian transgressive sands are high risk due to an uncertain distribution.

The best potential for sealed reservoirs lies within the Early Cretaceous succession. The gas-bearing, Berriasian sands penetrated at Brewster 1A were also tested by Yampi 1, and appear to have retained good initial reservoir properties. These sands were deposited as topset beds within a northward prograding delta complex (Figure 36, between horizons Kbase and Kval). The "*C. delicata* delta" is a significant reservoir interval that can be traced as far north as Echuca Shoals 1 and Prudhoe 1. A late transgression over the delta sands (e.g., Yampi 1 and Echuca Shoals 1) has provided a local (although somewhat thin) seal over the sand facies. Careful mapping of the "*C. delicata* delta" is essential as subsequent downcutting during the Valanginian (Kval unconformity) may have removed the reservoir/seal pair in updip areas.

The potential for reservoir development in Valanginian to Barremian transgressive greensands has been proven on the Yampi Shelf. In a presentation of the drilling results at Gwydion 1, Spry and Ward (1997) discuss the reservoir properties, log character and the seismic anomalies associated with these transgressive greensands. Seals over these intervals are generally intra-formational and younger shales deposited during highstands (Section 4.4). The potential for lowstand and transgressive deposits in more basinward settings (e.g., shows at Caswell 2 in a Barremian lowstand sand) has been presented within a sequence stratigraphic context in Section 4.4.

Trap Integrity and Lineaments

The collision of the Australian and Eurasian plates during the latest Miocene to early Pliocene resulted in significant tectonism in the Timor Sea region. To the north in the Vulcan Sub-basin, flexural extension resulting from the downwarping of the Australian plate and the associated formation of the Timor Trough between 5 to 3 Ma BP, resulted in the dilation of the major Jurassic and older extensional faults which defined the petroleum traps in this area (O'Brien *et al.*, 1996b). Fault reactivation has frequently allowed leakage of trapped hydrocarbons into higher stratigraphic reservoirs, and has resulted in carbonate-cemented sands within early Tertiary sandy intervals (e.g., the early Eocene Grebe Sandstone). These zones appear as high velocity, "pull-up" zones on seismic data and have been termed "Hydrocarbon Related Diagenetic Zone" (HRDZ's) by O'Brien *et al.* (1995, 1996b).

The Miocene/Pliocene collision with Timor resulted in both extensional and compressional reactivation of existing structures in the Browse Basin (Section 3). The extensional effects of reactivation are most apparent in the northern and outermost Browse Basin (e.g., BBHR Line 12), while compressional effects are focused along the western margin of the Leveque Shelf (Section 3) (Figure 19). This extensional reactivation is often associated with a HRDZ or a broad, diffuse zone of poor data quality (Section 2.3). A broad, diffuse zone would suggest that fluids and/or hydrocarbons released during fault movement were not simply directed up the fault plane, but also laterally into porous, sand prone intervals such as the Turonian to Eocene succession in the northern basin (Section 4). In addition, the earlier effects of a possible Turonian inversion (e.g., Bassett 1A), and its interaction with the subsequent Miocene/Pliocene event, are poorly understood. At present, studies of charge history and/or potential residual accumulations based on methods such as GOI™ (Lisk *et al.*, 1997) are lacking in the Browse Basin. As such, no conclusions can be drawn on the effect of the Miocene/Pliocene reactivation on hydrocarbon trap integrity or the genetic association of HRDZ's in the Browse Basin with hydrocarbon leakage, other than to observe that fluid movement has been associated with this event.

It is also possible that Palaeozoic salt is present in the northernmost Browse Basin based on seismic character (Figure 20) and the anomalously high formation water salinities recorded at Discorbis 1 (Bone, 1989) and Rob Roy 1 (BOCAL, 1972). A release of fluids associated with deep salt movement, along with the possible dewatering of the overpressured Aptian to Turonian shale interval, may contribute to the formation of HRDZ's in the Browse Basin. The migration path of a late stage gas charge from Jurassic and younger rocks could also be focused into these areas, and may allow the trapping of gas within stratigraphically younger reservoirs that are the traditional (gas) targets (e.g., usually Early Jurassic and older rocks).

The role of lineaments in the formation of hydrocarbon traps on the North West Shelf has recently gained renewed attention (Elliott, 1994; O'Brien *et al.*, 1996a; Romine, *et al.*, 1997). Previous work on the Yampi Shelf (O'Brien, *et al.*, 1996a) (YST Study Group, 1996) has identified the complexity of the basement fabric and composition that underlies the inboard margin of the Browse Basin. Prominent northwest-trending fractures extending offshore from the Kimberley Block may control rift segmentation and the structural boundary between the Browse Basin and the Vulcan Sub-basin (O'Brien, 1993; O'Brien, *et al.*, 1993; YST Study Group, 1996). The relay of fault displacements across basement fractures may also have implications for hydrocarbon migration and the prospectivity of the Yampi Shelf and Londonderry High (YST Study Group, op. cit).

While it is beyond the scope of the BBHR study to assess the influence of basement lineaments on the structural development of the deeper Browse Basin, several possible relationships can be highlighted:

- an offshore extension of the northwest-trending lineament extending from Prince Regent Sound (Figure 2) approximates a possible relay zone of Palaeozoic faults as shown on the GEOSAT gravity map of the basin (Figure 15);
- an offshore extension of the northwest-trending boundary between the King Leopold Mobile Belt (KLMZ) and the Kimberley Block (Figures 1 and 13) approximates the structural and stratigraphic boundary between the Caswell and Barcoo Sub-basins (Section 3);
- this boundary (?relay zone) can be observed on BBHR Line 175/16 (SP11000 to 16000) near the location of Brecknock 1; and,
- the Cornea oil discovery appears to lie at the intersection of a northwest-trending lineament extending from the Kimberley Block, and a north/south-trending lineament that approximates the eastern edge of Collier Bay (Figure 2).

Further mapping of basements structure and the role of lineaments in basin development will be investigated further during the Browse Basin Regional Study (Blevin, *et al.*, in prep).

Summary

The following points summarise aspects of the hydrocarbon habitat and play elements in the Browse Basin.

Hydrocarbon Habitat

- Outer basin gas and condensate trend in older reservoirs, probably from early generation and hydrocarbon charge;
- Gas (?and possibly condensate) in mid-basin traps, probably generated from pre-Callovian source rocks; high risks associated with reservoir quality and fault reactivation (breeching);
- Inner basin to shelf margin oil-prone trend, probably charged from Late Jurassic and Cretaceous source rocks; significant risks associated with gas flushing and updip seal potential;

Trap Development

- **Late Triassic inversion and Early Jurassic extension:** main plays developed in the central and outer basin;

- **Post-Callovian to mid-Cretaceous:** the effects of fault movement on the Prudhoe Terrace have been important for trap development, and the migration of hydrocarbons onto the Yampi Shelf and into stratigraphically higher reservoirs;
- **Late Cretaceous Inversion:** poorly understood and documented, although locally important in the mid-basinal areas; possibly overprinted by Miocene inversion / extension;
- **Miocene / Pliocene Collision:** anticlinal traps developed outboard of the Leveque Shelf and are well positioned for late hydrocarbon charge; possible trap breeching due to dilation of deeper Palaeozoic faults in the western and northern basinal area (e.g., O'Brien, *et al.*, 1996b); possible salt movement in northern basin.

Source Rocks

- **Late Triassic and Early to Middle Jurassic:** greater source potential in the Barcoo Sub-basin and outermost Caswell Sub-basin; Barcoo 1 is the key well for source assessment;
- **Late Jurassic:** source potential not properly assessed due to location of wells and sampled intervals within the sequence (generally not at MFS's).
- **Early Cretaceous:** probably numerous organic-rich facies deposited as "pods" in the Caswell Sub-basin during period of peak flooding in the Valanginian, Barremian and (possibly) Aptian;
- **Late Cretaceous:** Aptian to Turonian shales probably have good source potential, although immature across most of basin; further maturation modelling of synthetic wells in main Aptian to Maastrichtian depocentres to understand generative potential.

Reservoir Development

- **Permian:** Hyland Bay equivalent transgressive sands; a viable target only on the Prudhoe Terrace, although high risk associated with predicted distribution;
- **Early to Middle Jurassic:** sand deposition widespread until *D. complex* DZ; post-*D. complex* reservoir development only confirmed adjacent to, and west of, the Prudhoe Terrace and Leveque Shelf; limited sand deposition in Barcoo Sub-basin in post-*D. complex* DZ time may be due to re-orientation of drainage patterns;
- **Late Jurassic:** significant outbuilding of deltas during *C. delicata* DZ; sealed locally by pro-delta facies during high-order backstepping event (flooding);
- **Valanginian to Barremian:** Lowstand fan systems associated with second and third order falls in sea level; also important as carrier beds for hydrocarbons generated by Early Cretaceous source rocks; proven reservoirs in transgressive greensand facies on the Yampi Shelf;
- **Aptian:** Lowstand fan systems (do not appear to be widespread), greensand facies in updip locations.
- **Turonian to Maastrichtian:** lowstand fan systems, fluvial and incised valley fill.

5.5 Petroleum Systems and Play Families

Magoon and Dow (1991) defined a petroleum system as a mature source rock and all its generated hydrocarbon accumulations. Bradshaw (1993) and Bradshaw *et al*. (1994) classified the petroleum habitats of Australia into a number of petroleum supersystems and regional systems based on geological criteria such as tectonic and palaeogeographic setting. Hydrocarbon product-based analyses undertaken as part of this study have allowed the definition of three new systems (Table 9; Early Cretaceous Systems W4 to W6) within the broad supersystem framework defined by Bradshaw (1993) and Bradshaw *et al.* (1994).

A survey of organic-rich rocks (ORR)(TOC >2.0%)(Table 5A) in the Browse Basin suggests there may be more than 20 ORR's ranging in age from Permo-Carboniferous to Early Cretaceous (Figure 103). A representative assessment of the source potential of each ORR is often difficult due to the placement of samples within the intervals. Samples are frequently not recovered from the intervals of peak flooding and thus may not be representative of the cumulative potential of relatively thin organic rich units. It is also likely that with fewer than 35 wells within a basinal area covering over 140,000 km^2, many potential systems are yet to be tested.

Of the ORR's that have been penetrated, only around 10% have been adequately sampled to enable representative values for bulk organic properties such as TOC, HI, and S2. The highest quality ORR's are concentrated within the age interval 160 to 100 Ma (late Callovian to late Albian) (Figure 103). Play elements (reservoir, source and seal) associated with the most significant petroleum systems have been grouped into Play Families. An analysis of each system is presented below.

Early Cretaceous Petroleum Systems and Play Families

Petroleum Supersystem:	Westralian W3, W4, W5 and W6 (Table 9)
Criteria:	Four ORR identified suggesting the presence of three new petroleum systems (W4, W5 and W6)
Play Family Attributes:	• Access to large volume of effective ORR's; • Focused, moderate to long distance migration (proven); • Multiple reservoirs (basement to Tertiary); • Minimum reactivation/breaching of trap; and, • Adequate updip Early Cretaceous seals and reservoirs.
Distribution:	• Principally the central to northern Browse Basin

Recent discoveries on the eastern margin of the Browse Basin, adjacent to relatively thick sequences of Valanginian to Turonian shales, suggest that Early Cretaceous ORR's may be a significant source of hydrocarbons on the North West Shelf. Results from geochemical analyses of oil at Gwydion 1 suggest a contribution from the Early Cretaceous Echuca Shoals Formation (Spry and Ward, 1997). To the north in the Timor sea, the Bayu/Undan gas and condensate discovery also appears to be sourced from a Cretaceous source interval (Brooks, *et al.*, 1996; Bradshaw, *et al.*, 1977).

Play families associated with the Early Cretaceous Petroleum Systems are shown by "Play Number" on Figures 104 and 105, and include the following:

- ***Play 1, Eastern Margin Play Family***, onlap pinchout, erosional truncation seal. Permian-Triassic incised valley pinchout, basement (enhanced Carboniferous to Triassic faulting);
- ***Play 2, Western Margin Reactivation Play Family;***
- ***Play 3, Late Cretaceous Fans/Tertiary Reservoirs Play Family;***
- ***Play 4, Early Cretaceous Drapes and Jurassic Onlap Play Family; and,***
- ***Play 5, Central and eastern Browse Basin Reactivation Play Family.***

Play Elements—Source

Early Cretaceous organic rich rocks have been identified in a number of wells in the basin (Sections 4 and 5). The distribution of ORR's is illustrated in Figure 106, with the thickest and richest ORR's predicted to be concentrated in the central and northern Browse Basin. The depositional environment of these intervals is discussed in Sections 4 and 5. Carboniferous to Late Jurassic ORR's may also have contributed to the hydrocarbons reservoired along the eastern margin due to the structural configuration of the basin (e.g., the general westerly thickening of the Palaeozoic basin fill) and the lack of late structural movement (reactivation).

Play Elements—Maturation

Geohistory modelling suggests that the Early Cretaceous shales entered the oil window during the late Tertiary over most of the central and northern Browse Basin (Caswell Sub-basin). The exceptions to this timing are in the areas around Caswell 1 and Brewster 1A, where these intervals entered the oil window during the Late Cretaceous to early Tertiary.

Play Elements—Migration

Hydrocarbons generated from Early Cretaceous ORR's will follow relatively simple intra-stratal migration paths to potential reservoirs and traps on the updip, eastern margin of the basin. A Time Structure Contour Map of the Valanginian Unconformity (Figure 37 and Plate 12) illustrates the relatively simple, westerly dip of the Early Cretaceous horizon. Overpressuring in the central basin caused by the ineffective dewatering of shales, and the presence of adequate carrier beds are expected to influence the pattern and effectiveness of migration. Conduits to higher reservoirs are provided along the outer margin of the Prudhoe Terrace where faulting has continued to the mid-Barremian. The incidence of Late Tertiary faulting increases significantly in the northernmost Browse Basin, and could support migration to younger reservoirs and traps in Late Cretaceous and Tertiary strata (Figures 104 and 105). The updip truncation of the Early Cretaceous succession may also provide a charge for sand-prone lowstand systems of Late Cretaceous and Tertiary age.

Play Elements—Traps

Trap styles are predominantly combination stratigraphic/structural, including onlap pinchouts (enhanced by onlap onto local structural highs) and erosional truncation seal (Figures 104 and 105). Intra-formational stratigraphic traps could be expected within Valanginian to Barremian lowstand and transgressive facies deposited west of the Prudhoe Terrace. These traps are expected to carry a risk associated with reservoir quality (e.g., Walkley 1).

Play Elements—Seal

Potential sealing facies were deposited over most of the basin during the regional, second-order Early Cretaceous transgression (Section 4.4). A number of third-order transgressions superimposed on the longer-term, second-order transgression resulted in deposition of adequate sealing facies on the eastern margin of the basin (e.g., Gwydion 1 and Cornea 1). Intra-formational shales within the Late Cretaceous and Tertiary succession provide seals for Play Families 3 and 4 (e.g., Kalyptea 1A and Asterias 1).

Play Elements—Reservoir

Similarly to the Northern Carnarvon Basin, Barremian age (*M. australis* DZ) sands provide high-quality, regionally significant reservoirs over much of the eastern ramp margin of the Browse Basin (particularly across the Yampi Shelf) (Figures 104 and 105). Due to the prolonged nature of the Early Cretaceous transgression and the restriction of siliciclastics to the inboard margin, reworked glauconitic sands play an important role in providing porosity and permeability on the eastern margin, similar to the reservoirs at the Stag and Wandoo fields of the Carnarvon Basin. Late Campanian basin-floor fans and Tertiary clastics and carbonates could provide reservoirs for Play Families 3 and 4.

Late Jurassic Petroleum Systems and Play Families

Petroleum Supersystem:	Westralian W2 (Table 9)
Criteria:	Six ORR identified mainly in northern Browse Basin
Play Family Attributes:	• Late Jurassic ORR's thicker in the northern Browse Basin; • Migration directions to the east and west (Yampi and northern Leveque shelves; western Barcoo Sub-basin); • Traps are tilted fault blocks and combination stratigraphic/structural traps; • Minimum reactivation/breaching of trap; and, • Adequate seal.
Distribution:	Principally the northern Browse Basin

Play families associated with the Late Jurassic Petroleum Systems are shown by "Play Number" on Figures 107 and 108, and include the following:

- ***Play 1, Tilted Fault Block Play Family;***
- ***Play 2, Fault Reactivation Play Family;***
- ***Play 3, Combination Stratigraphic/Structural Trap Play Family,***
  - ***Onlap pinchouts***
  - ***Drape over tilted fault blocks***
  - ***Erosional truncation seal***
  - ***Relay ramp onlap traps (northern Browse Basin/southern Vulcan Sub-basin)***

Play Elements—Source

To date, Late Jurassic ORR's do not appear to be primary contributors to hydrocarbons found in the Browse Basin. Late Jurassic ORR's are expected to be best developed in the northern part of the Caswell Sub-basin and, in particular, within the geographically restricted Heywood Graben (Figure 109)(e.g., Heywood 1). ORR's may be present in Brewster 1A, Lynher 1A and Trochus 1, and were probably deposited as thin transgressive units onlapping high areas on the eastern margin and/or as distal deltaic facies. These thin, organic-rich strata may indicate that there are thicker and higher-quality ORR's in Late Jurassic successions in the central and northern Browse Basin.

Play Elements—Maturation

Geohistory modelling suggests that Late Jurassic ORR's (BB8) in the Caswell Sub-basin (e.g., Caswell 2 and Brewster 1A) entered the oil window from the Cenomanian to Early Tertiary (Figure 82). Wells modelled on the Prudhoe Terrace (Heywood 1, Echuca Shoals 1 and Yampi 1) indicate that Late Jurassic ORR's entered the oil window from the Campanian to Oligocene. Modelling suggests that the ORR's are presently within the oil to dry gas maturity zones (Figure 82).

Play Elements—Migration

In the Caswell Sub-basin, hydrocarbons generated from Late Jurassic ORR's could have migrated along relatively simple migration pathways to the eastern and western margins of the basin, as well as northward into the Vulcan Sub-basin (Figure 34; Plate 10). Reactivation of older fault systems during the Tertiary also provided conduits for hydrocarbons into younger Cretaceous and Tertiary sequences across the basin. Late Jurassic ORR's could also have generated hydrocarbons that migrated westward to traps associated with Carboniferous to Early Jurassic tilted fault blocks (e.g., the Brecknock and Scott Reef Trends).

Play Elements—Trap

Traps include drapes and tilted fault blocks on the western side of the central and northern margin (Figures 107 and 108). Onlap pinchouts may be present on the eastern margin but as yet have not been tested. Hydrocarbons generated from Late Jurassic ORR's could be trapped in the same traps as defined for the Early Cretaceous systems, particularly on the Yampi Shelf. In addition, tilted fault blocks along the eastern margin provide a range of trap types for hydrocarbons generated from Late Jurassic ORR's.

Play Elements—Seal

The dominant seal is provided by Valanginian to Turonian mudrocks. Distal deltaic facies, such as those penetrated at Brewster 1A and Yampi 1, could provide intra-formational seals. Highstand shales of latest Jurassic age (*D. jurassicum* DZ) are likely to be the most reliable and widespread intra-formational sealing facies.

Play Elements—Reservoir

Late Triassic and Early to Middle Jurassic fluvio-deltaic sequences are expected to be the principal reservoirs in the western basin, while these intervals provide additional reservoirs to the Cretaceous and younger succession in the eastern Browse Basin.

Early to Middle Jurassic Petroleum Systems and Play Families

Petroleum Supersystem:	Westralian W1 (Table 9)
Criteria:	Five ORR identified mainly in the Barcoo Sub-basin
Play Family Attributes:	• Thickest ORR's in three discrete areas; • Migration to Late Triassic anticlines and towards the eastern margin; • Structural / stratigraphic traps over anticlines; • Fluvio-deltaic to nearshore marine reservoirs; and, • Sealed by Early Cretaceous shales.
Distribution:	Principally the southern Browse Basin (Barcoo Sub-basin)

Play families associated with the Early to Middle Jurassic Petroleum Systems are shown by “Play Number” on Figures 107, 108, and 110, and include the following:

- ***Play 1, Tilted Fault Block Play Family;***
- ***Play 2, Fault Reactivation Play Family;***
- ***Play 3, Combination Stratigraphic / Structural Trap Play Family,***
    - ***Onlap pinchouts***
    - ***Drape over tilted fault blocks***
    - ***Erosional truncation seal***
    - ***Relay ramp onlap traps (northern Browse Basin / southern Vulcan Sub-basin)***

Play Elements—Source

Although Early to Middle Jurassic (pre-Callovian) ORR’s have been identified in Rob Roy 1 (Plate 40), Barcoo 1 (Figure 27) and Lynher 1, these intervals are poorly documented elsewhere in the basin. The sparseness of data and the incidence of coals would support a focused re-sampling program to evaluate the potential of this interval. In general, pre-Callovian organic-rich sediments are predicted to be widely distributed, but the thicker accumulations appear to be in three discrete areas: the western and northeastern Barcoo Sub-basin, and the northern Caswell Sub-basin (Figure 109).

Play Elements—Maturation

Burial history analysis of Barcoo 1 (Figure 102) suggests that Early Jurassic ORR’s in the western Barcoo Sub-basin have entered the oil window from the mid-Eocene to Pliocene. The relatively late generation from these rocks could provide a charge for anticlinal traps that formed during the Middle Miocene along the outer margin of the Leveque Shelves. Earlier generation could be expected for ORR’s further east under the thickest Cretaceous and Tertiary cover.

Play Elements—Migration

Post-Eocene migration of hydrocarbons was primarily towards the Late Triassic anticlinal highs and fault blocks in the western basin, and fault traps, late stage anticlines, and onlap plays on the Leveque and Yampi shelves.

Play Elements—Trap

Traps for generated hydrocarbons include drapes over Triassic tilted / eroded fault blocks and anticlines in the southwestern Browse Basin. Onlap pinchouts are also present on the perimeter of these fault blocks and may provide combination stratigraphic / structural traps. Combination structural / stratigraphic traps on the Leveque and Yampi shelves could also have been charged by hydrocarbons generated from Early Jurassic ORR’s.

Play Elements—Seal

The dominant regional seal is provided by Valanginian to Turonian highstand shales. Intra-formational seals are also present within the Early to Middle Jurassic succession, but are poorly documented.

Play Elements—Reservoir

Late Triassic to Early Jurassic fluvio-deltaic sequences provide the main reservoirs for outboard structural and stratigraphic traps (i.e., North Scott Reef 1). Potential reservoirs for onlap plays on the eastern margin range from Early Jurassic to Late Cretaceous age.

Permo-Carboniferous to Late Triassic Petroleum Systems and Play Families

Petroleum Supersystem:	Larapintine 4—Gondwanan Systems 1, 2 (Table 9)
Criteria:	More than five ORR units
Play Family Attributes:	• Discrete source pods in Carboniferous–Permian basin phase; • Relatively “late” timing of generation; • Focused migration to eastern margin or Triassic highs; and, • Preservation of early generated hydrocarbons.
Distribution:	Thickest near Palaeozoic faults across the basin

Play families associated with the Carboniferous to Late Triassic Petroleum Systems are shown by “Play Number” on Figures 111, 112, and 113, and include the following:

- ***Play 1, Carboniferous to Permian Extensional Basin Play Family***
  - ***extensional fault-related plays***
- ***Play 2, Late Triassic Anticline / Syncline Play Family***
  - ***combination structural / stratigraphic traps***
- ***Play 3, Combination Structural / Stratigraphic Trap Play Family,***
  - ***Early Cretaceous onlaps and associated traps***
  - ***Erosional truncation seal (Jurassic to Early Cretaceous seal)***
- ***Play 4, Younger traps associated with “late” stage fault reactivation***

Play Elements—Source

Permo-Carboniferous to Triassic ORR’s are not well documented, but at least five units appear to be organic rich. ORRs are present in Prudhoe 1, Rob Roy 1, Echuca Shoals 1, and Yampi 1, but need to be sampled adequately to fully document their character. Late Triassic ORR’s have not been identified, but may have been deposited in topographic lows surrounding the Late Triassic inversion anticlines. Figure 114 shows the probably distribution of Permo-Triassic ORR’s in the Browse Basin.

Play Elements—Maturation

In general, Carboniferous and Permian ORR’s will be overmature due to the thickness of sediment (up to 18 km) deposited during the Permo-Triassic extension and early post-rift basin phases (Section 2). There could be areas where these ORR’s were not as deeply buried, such as the Prudhoe Terrace (e.g., Yampi 1), and could still be generating liquid hydrocarbons in small volumes. Geohistory modelling for Echuca Shoals 1 indicates that Permo-Triassic ORR’s entered the oil window during the Early Cretaceous (Figure 101). The volume and timing of dry gas generation has not been estimated, but could be a significant factor in flushing liquid hydrocarbons along the eastern margin. The timing of generation could range from Late Permian to present.

Play Elements—Migration

Migration pathways are predominantly vertical on the faulted western margins of the Permo-Carboniferous extensional depocentres, and easterly (updip) along the flexural ramp. Lateral migration could also occur across relay ramps linking the Palaeozoic fault systems.

Play Elements—Trap

All of the trap types identified within the younger petroleum systems and play families in the Browse Basin could have intercepted hydrocarbons generated from Permian to Triassic ORR's. Trap preservation is recognised as a major risk, particularly during periods of extension (Early Jurassic) and inversion (Turonian and Miocene).

Play Elements—Seal

Possible seals are provided by Triassic, Jurassic and Early Cretaceous mudrocks as described above. The presence and preservation of Permo-Triassic seals is a major risk.

Play Elements—Reservoir

Reservoirs described for the younger petroleum systems and play families in the Browse Basin could also contain hydrocarbon contributions from Carboniferous to Triassic ORR's.

5.6 Petroleum Systems—Summary and Recommendations

The following points summarise the results of the petroleum systems investigation.

- Over 20 potential organic-rich rocks (ORR's) have been identified;
- Less than 10% of the ORR's have been adequately sampled;
- Three potential new petroleum systems have been identified in the Early Cretaceous;
- The eastern margin of the central and northern Browse Basin represents a major oil province;
- The northwestern and western areas of the Browse Basin could also contain significant quantities of liquid hydrocarbons generated from Early Cretaceous ORR's;
- A significant portion of liquid hydrocarbons generated from the Early Cretaceous may have migrated to the southeastern edge of the Vulcan Sub-basin (northern Yampi Shelf);
- Hydrocarbons generated from Late Jurassic ORR's in the northern Browse Basin may have migrated to the southern Vulcan Sub-basin;
- Early to Middle Jurassic plays are dominantly in the southwestern Browse Basin (Barcoo Sub-basin and to the southwest). These plays are largely untested;
- Carboniferous to Early Triassic ORR's have contributed to the hydrocarbon accumulations of the Browse Basin;

- The ORR's of the Browse Basin need to be sampled/re-sampled to produce representative values for each unit; and,
- A source rock prediction study of the Browse Basin is warranted to improve play prediction in the region.

The review of petroleum systems and organic rich rocks in the Browse Basin was based on existing data. The results indicate that a more comprehensive source rock prediction study should be undertaken in order to develop a better understanding of the petroleum systems operating in the basin.

As in other basins of the North West Shelf, potential organic-rich rocks are sparsely sampled and it is often not possible to accurately predict the timing and nature of the products generated, based on the available suite of samples. Better designed programs for sampling, along with re-sampling and analysis of specific organic-rich rocks within existing wells are recommended in order to obtain accurate, representative estimates for timing of hydrocarbon generation and products.

5.7 Drilling Review and Overview of 1/1997 Gazettal Areas

The following is an overview of past drilling in the Browse Basin and exploration opportunities that are present within the 1/1997 Gazettals Areas at a play/conceptual level. This overview is based primarily on the BBHR seismic grid, and utilises the stratigraphic and geochemical framework derived from this study. The location of play types referred to on the BBHR grid can be located by using Plate 1 (Browse Basin Location and Shot Point Map).

A review of selected wells in the Browse Basin is presented in Appendix G. The review suggests there is a high level of risk associated with the structural integrity of traps, with 14 of the 33 wells reviewed (approximately 40%) testing structures affected by reactivation faulting (e.g., possible breached trap), low closure, or a lack of structural closure. Stratigraphic plays remain elusive due to risks associated with predicted reservoir quality, updip seal, and access to a hydrocarbon source.

Valid Tests:	Arquebus 1/ST1, Brecknock 1, Brewster 1A, Buccaneer, Buffon 1, Caswell 1 and 2, Copernicus 1, Gwydion 1, Kalyptea 1/ST1, Lacepede 1, North Scott Reef 1, Prudhoe 1, Scott Reef 1 and 2, Cornea 1
Valid Tests Affected by Reactivation Faults:	Lombardina 1, Lynher 1, Sheherazade 1, Trochus 1
Tests with Low Closure:	Asterias 1, Barcoo 1, Echuca Shoals 1, Gryphaea 1, Rob Roy 1
Wells Drilled Outside Closure:	Heywood 1, Productus 1, Walkley 1, Yampi 1 and 2
Undrilled Objective:	Bassett 1A and Caswell 1
Stratigraphic Test:	Leveque 1
Unknown/Uncertain:	Delta 1, Discorbis and Mt Ashmore 1B

The occurrence of hydrocarbon shows at numerous stratigraphic levels may indicate that existing accumulations have been displaced through either tilting of the shelf, hydrodynamic displacement, or post-migration structuring. The direction of tertiary migration in areas close to the shelf margin is predicted to be primarily to the east and northeast. This scenario enhances the viability of updip stratigraphic traps such as unconformity sub-crops, pinchouts, and onlaps onto basement highs. In areas affected by Tertiary faulting (e.g., the northernmost Browse Basin), vertical conduits are provided to higher reservoirs such as Campanian, Maastrichtian and Paleocene sands. High relief structures similar to the Scott Reef Trend still remain to be tested in the western parts of gazettal areas AC97-7 and W97-11.

Area AC97-5

- Five wells drilled
- Relatively thick early Cretaceous source intervals to the south and southwest
- Potential to migrate hydrocarbons derived from Late Jurassic source rocks updip from the northern Caswell Sub-basin
- Maastrichtian to Lower Tertiary fan system present
- *Play Type A:* Maastrichtian to Lower Tertiary stratigraphic traps sourced from Early Cretaceous rocks. Further stratigraphic interpretation is required to prove up this play.
- *Play Type B:* Pre-Jurassic horst/fault traps sourced by Early-to-Middle Jurassic, Late Jurassic and Early Cretaceous rocks (northern and eastern part of gazettal area only) (BBHR Line 175/12, SP6400 to 7000).
- *Play Type C:* Basal Tertiary to Maastrichtian sand objectives sourced from Early Cretaceous in horst blocks that formed during the Late Miocene to Pliocene (BBHR Line 175/12, SP6400 to 7000).
- *Plate Type D:* Early Cretaceous fault/anticline plays with possible cross fault seals required (BBHR Line 175/12, SP6400).

Area AC97-6

- One well drilled.
- Early Cretaceous source depocentre present
- Jurassic/Triassic fault blocks at depths of 4000+ m occur in over 80% of the release area.
- Fault connectivity between Early Cretaceous source rocks and post-Campanian stratigraphic plays is critical (see Bassett 1A Well Summary in Appendix G).
- Risk associated with reservoir quality requires mapping of depositional facies.
- *Play Type A:* Jurassic/Triassic fault blocks (horst/subcrop and rollover into fault) potentially sourced from Late Jurassic and Early Cretaceous rocks (northern part of AC97-6).
- *Play Type B:* Maastrichtian to Lower Tertiary stratigraphic traps (subcrop at both top and intra-sand envelope, pinchout) sourced from Early Cretaceous rocks (central/southeast part of AC97-6). Stratigraphic closure in Play Type B is not necessarily coincident with structural closure, thus additional sequence mapping is required to highlight areas of local closure.

- *Play Type C*: Maastrichtian to Lower Tertiary horst blocks formed during Late Miocene to Pliocene structuring and sourced via faults linking Early Cretaceous and Late Jurassic source rocks to reservoirs (throughout AC97-6).
- *Play Type D*: Jurassic/Triassic sands onlapping and/or draping large Late Triassic inversion anticlines (central and southeast part of AC97-6).

Area AC97-7

- No wells drilled.
- Proximal to Cretaceous (mid-Valanginian to base Barremian) source depocentre (Figure 38).
- Possible Late Jurassic depocentre present to the west.
- *Play Type A:* Late Triassic inversion anticline targeting Middle Triassic sands sourced from adjacent Jurassic to Early Cretaceous depocentres (BBHR Line 175/11, SP1001 to 2000; Line 175/10, SP12200 to 12800).
- *Play Type B:* Jurassic to Early Cretaceous sands onlapping (potentially draping) a Late Triassic inversion anticline. This play is different to Play Type 1 and is untested (BBHR Line 175/10, SP12000 to 13300; Line 175/11, SP1900 to 2300).
- *Play Type C:* Early Cretaceous drape anticlines sourced from Early Cretaceous rocks (BBHR Line 175/11, SP3200 to 4200).

Area W97-11

- No wells drilled.
- Proximal to main Cretaceous (Valanginian to Barremian) and Tertiary depocentres.
- Very deep drilling required across 90% of block for Jurassic targets (>4500 m depth).
- Risk of low porosity for deep targets (<10% porosity at 4200 m).
- Main play associated with deep faulted structures.
- Potential risk of late stage reactivation (deeper traps breached).
- *Play Type A:* Late Triassic inversion anticlines and rotated fault blocks targeting Triassic sands sourced from Jurassic or deeper source (BBHR Line 175/09, SP4700 to 6600; Line 175/10, SP7700 to 10800).
- *Play Type B:* Jurassic sands onlapping (potentially draping) Triassic horst blocks (BBHR Line 175/09, SP4700 to 6600; Line 175/10, SP7700 to 10800).
- *Play Type C:* Early Cretaceous drape anticlines over pre-Triassic basement /fault blocks sourced from Early Cretaceous.

Area W97-12

- Three wells drilled (Caswell 1 and 2, Walkley 1).
- Overlies the margin of the main Early Cretaceous (Valanginian to Barremian) depocentre.

- *Play Type A:* Triassic/Jurassic horst blocks sourced from Jurassic or deeper. There is risk of low porosity in deeper reservoirs (<10% at 3800m in Early Cretaceous).
- *Play Type B:* Campanian to Maastrichtian fan plays still remain a viable target although further work would be needed to upgrade this play in view of sub-economic discoveries at Caswell 1, 2 and Walkley 1. Isopach maps of these intervals (Figures 59m 61 and 63) indicate a thickening to the north–northeast with a potential for high sand content. Stratigraphic closure in Play Type B may not necessarily be coincident with structural closure. More detailed sequence mapping maybe required to highlight local closures.
- *Play Type C:* Basal Tertiary sand objective that had wet gas indications in Walkley 1.

Area W97-13

- Brewster 1A (drape anticline over rotated Triassic/Jurassic fault block); suspended gas discovery (sub-economic) (post-breakup reservoir (Late Jurassic to Berriasian) = possible 161 m gas column; pre-breakup reservoir (Callovian) = possible 1.6 m gas column with low porosity).
- Main Cretaceous and Tertiary depocentres to the west and northwest.
- Potential for Late Jurassic source rocks.
- *Play Type A:* Jurassic anticlines sourced from Jurassic/Triassic, with Early to Late Jurassic sands present in Brewster 1A (BBHR Line 175/18, SP5700 to 6100).
- *Play Type B:* Triassic and pre-Triassic horsts sourced from Triassic or older (BBHR Line 175/18, SP2900 to 6900; Line 175/14, SP8600 to 12200).
- *Play Type C:* Early Cretaceous anticlines (Berriasian sands in Brewster 1A) sourced by Early Cretaceous and/or deeper rocks (BBHR Line 175/18, SP6700 to 6100).
- *Play Type D:* Subcrop Campanian fan below the base Tertiary unconformity sourced by Early Cretaceous and/or deeper source rocks (BBHR Line 175/18, SP3000).
- *Play Type E:* Campanian to Oligocene sand envelope (Brewster 1A play within Campanian to Early Tertiary lowstand systems).

Area W97-14

- No wells drilled.
- Diverse play types.
- Overlies main Cretaceous and Tertiary depocentres.
- Early Cretaceous source depocentre to the west.
- Early to Late Campanian depocentre of potential sand thicks within fan system.
- *Play Type A:* Permian to mid-Triassic subcrop plays sourced by Triassic or older (BBHR Line 175/06, SP5200 to 6000). Seal is a major risk with hydrocarbon possibly migrating through the Jurassic.
- *Play Type B:* Campanian to Lower Tertiary sand envelope sub-crop play (BBHR Line 175/05, SP8200 to 11700; Line 175/06, SP5200 to 6800). It may be difficult to source the sands from the Early Cretaceous due to lack of vertical migration paths.

- *Play Type C:* Late Triassic inversion anticlines and rotated fault blocks sourced by Early Jurassic or older rocks (BBHR Line 175/08, SP6900 to 8200).
- *Play Type D:* Faulted Jurassic against Proterozoic basement.

Area W97-15

- No wells drilled.
- Substantial Jurassic depocentre basinward.
- Late Miocene/early Pliocene reactivation dominant near basement hinges.
- Late Miocene/early Pliocene oil migration phase post-dates trap formation.
- Modelled oil and gas in Arquebus 1 (46m column) discovered southwest of the gazettal area.
- *Play Type A:* Triassic/Jurassic rotated fault blocks sourced from Jurassic.
- *Play Type B:* Possible Valanginian subcrop/onlap plays to the west, although additional seismic data is required to identify a precise location.
- *Play Type C:* Campanian to Lower Tertiary sand envelope subcrop play (BBHR Line 175/04, SP6000 to 9000). It may be difficult to source the reservoir from the Early Cretaceous due to lack of vertical migration paths.

Area W97-16

- No wells drilled.
- Proximal to Early Cretaceous source depocentre.
- Potential for Early to Middle and Late Jurassic source rocks.
- Reservoir risk in post-Valanginian section, as no sand has been intersected.
- *Play Type A:* Triassic/Jurassic horst/anticline plays to the west and south (BBHR Line 175/04).
- *Play Type B:* Valanginian sand subcrop/onlap play.
- *Play Type C:* Faulted Triassic/Jurassic against basement sourced from Jurassic or older.

6. Conclusions

The Browse Basin High Resolution Study was undertaken as a joint project between the Australian Geological Survey Organisation (AGSO) and Nopec International Pty Ltd in early 1997. The study is underpinned by a recently acquired, 5,260 km grid of regional, high-resolution seismic reflection data (1996 Browse Basin High Resolution Survey, AGSO Survey BBHR175), the integration of sequence stratigraphic analysis of the seismic data and of 20 wells, structural mapping, geochemical analyses, and geohistory modelling of potential source rocks. The study aims to provide a regional structural and stratigraphic model for the evolution of the Browse Basin, with particular emphasis on the development of petroleum systems in the prospective Mesozoic and Cainozoic sections. It is hoped that this regional framework and assessment of petroleum systems will assist exploration through a better understanding of the basin's prospectivity.

The Browse Basin is a Palaeozoic to Cainozoic depocentre located in the southern Timor Sea region off Australia's northwestern margin (Figure 1). The basin has traditionally been regarded as an under-explored, gas-prone province, with significant (undeveloped) gas and condensate discoveries at Scott Reef 1, Brecknock 1, North Scott Reef 1, Echuca Shoals 1 and Brewster 1 (Figure 2). In 1995, the discovery of oil and gas at Gwydion 1, on the eastern margin of the basin, prompted a reassessment of the basin's hydrocarbon potential. This discovery not only confirmed the potential for oil generation, but the viability of long-range migration pathways from the central Browse Basin. This knowledge opened up significant opportunities to explore for a range of structural and stratigraphic plays on the basin's inboard margin. The uneconomic discovery at Gwydion 1 (Ward and Spry, 1997), was followed in 1996/7 by an oil discovery at Cornea 1 and 2 in exploration permit WA-241-P (Shell Development Australia). Although the size of the Cornea oil field has yet to be determined, suggestions are that it will be one of Australia's largest offshore oil fields (Financial Review, 30 May 1997).

The gazettal of nine release areas in the Browse Basin in early April 1997, has provided further opportunities for explorationists to test the basin's hydrocarbon potential. Much of the gazettal area lies in the deeper, central Browse Basin, where play elements such as reservoir and trap are considered higher risk. The exploration challenge will be to identify appropriate Cretaceous reservoir/seal and trap configurations that lie along migration pathways out of the central basin, and/or to assess the risk of deeper targets for reservoir quality and trap integrity.

There are several key geological factors that have influenced the structural and stratigraphic development of the basin, and ultimately, the development of petroleum systems.

1) The main basinal area developed initially in the Carboniferous to Early Permian (and possibly earlier, in the Devonian/Carboniferous) as a series of inter-linked half-grabens bounded by landward-dipping, normal faults. This extensional phase compartmentalised the Browse Basin into distinct northern (Caswell Sub-basin) and southern (Barcoo Sub-basin) depocentres (Symonds, *et al.*, 1994; Struckmeyer *et al.*, 1997). Inversion of the rift fill in the Late Triassic created an anticlinal-synclinal topography. The Brecknock, Scott Reef, and North Scott Reef hydrocarbon accumulations are located on the most westerly inversion trend.

2) By the Callovian to Late Jurassic, much of the relict rift and inversion topography in the central basin had been eroded. The depositional substrate began to resemble a ramp margin, with strata above this boundary characterised by regressive, progradational geometries. During successive post-Callovian, transgressive–regressive cycles, the direction of apparent progradation varied from northwest to north–northwest. This style of outbuilding is reflected in the age profile (biostratigraphy) of wells, whereby rocks within an individual supersequence are progressively

younger to the north (within the Caswell Sub-basin). In the Barcoo Sub-basin, the preserved rocks within a supersequence are generally from the older part (or base) of the interval, and are commonly capped by a thin, late highstand deposit.

3) During successive periods of low sea level, the Kimberley Block/Basin has served as the principal provenance of mature sand for deposition in the lowstand and transgressive systems; these facies are the principal reservoirs within Berriasian to Turonian age rocks. Lowstand and transgressive facies are sealed by overlying highstand shales, which have a regional distribution and are often considerably thicker than the reservoir interval.

4) The different subsidence histories of the Caswell and Barcoo sub-basins have resulted in a key stratigraphic distinction between the depocentres. The Barcoo Sub-basin contains a relatively thick succession of Triassic, Early and Middle Jurassic rocks, and a thinner wedge of post-Callovian progradational sediment. In the Caswell Sub-basin, the Triassic to Callovian is relatively thin, while the overlying post-Callovian succession (particularly the Turonian to Tertiary interval) thickens northward towards the southern Vulcan Sub-basin.

5) As post-rift thermal subsidence declined in the Mesozoic, variations in sea level had an increasing influence on "net accommodation". The Early and Middle Jurassic was a period of extensional faulting, and was dominated by fluvio-deltaic sedimentation across most of the basin. Marine conditions persisted only in the outermost basinal areas (Barcoo-1). A re-orientation of the drainage divide in the Late Callovian/Oxfordian served to isolate the southern and western Browse Basin, and to limit the deposition of sand-rich facies to the shelfal areas and the central Caswell Sub-basin. Deposition of significant reservoir intervals in the Barcoo Sub-basin was terminated by the mid-Callovian (*D. complex* dinocyst zone).

6) A first-order eustatic rise in sea level commenced in the Valanginian and peaked during the Early Turonian. During highstands, organic rich rocks were deposited in condensed sections (Loutit, *et al*., 1988) through much of the basin. Stratigraphic intervals associated with times of peak flooding, such as the mid-Valanginian, early Barremian, and mid-Aptian, show a distinct increase in TOC as a result of condensed sedimentation. Unlike the Vulcan Sub-basin, the bulk of the Late Jurassic interval in the Browse Basin is predominantly fluvio-deltaic (where sampled). Potential source rock intervals (i.e., periods of peak flooding) are similar to those in the Vulcan Sub-basin, although the only highstand deposit of significant thickness is of *D. jurassicum* (Tithonian) age. An evaluation of existing geochemical data suggests that the true potential of the Late Jurassic has not been adequately tested over the intervals of peak flooding.

7) An effective Early Cretaceous source rock has been identified through geochemical correlation of oils stains and potential source rocks. The highest quality source interval ranges from approximately 131 to 135 Ma in age (Valanginian, *S. tabulata* to *S. aerolata* dinocyst zones). Similar organic-rich intervals of Barremian age have been documented in wells, although mapping would suggest that the "true" character of this interval has not been adequately tested. The cyclic and cumulative nature of the Valanginian to Turonian transgression would predict that numerous "pods" of organic-rich rocks were deposited during third-order flooding events within an overall second-order transgressive cycle. Lowstand and transgressive facies deposited during the early Valanginian and Barremian may serve as carrier beds (as well as reservoirs and stratigraphic traps) for generated hydrocarbons .

8) Geohistory modelling suggests that these source intervals in the central Browse Basin entered the oil window from the Early Tertiary to Miocene. The modelled expulsion of generated hydrocarbons during the Late Miocene to Pliocene post-dates trap formation across most the basin. In the

northernmost Browse Basin, some extensional reactivation of older faults has occurred up to the present-day in response to the downward flexing of the Australian plate toward Timor. Whilst minor reactivation has provided fault conduits to higher reservoirs (particularly Late Cretaceous and Early Tertiary fan and fluvial systems), continued faulting has compromised trap integrity. Reactivation may also have initiated movement of Palaeozoic salt in the area around Discorbis 1 and Kalyptea 1. This movement has created traditional collapse (withdrawal) structures and broad anticlines, the timing of which roughly coincided with the modelled expulsion from Early Cretaceous source rocks. Seismic evidence suggests that the most extensive movement of fluids, possibly associated with the salt, has occurred in the northernmost part of the basin.

9) An assessment of the few wells that targeted Early Cretaceous lowstand plays would suggest they were positioned too low on the depositional slope to intersect the predicted facies. The Barremian transgressive facies (i.e., *M. australis* sands) may be an important carrier bed lying within the migration fairway of Cretaceous source rocks. This interval has been identified as a viable reservoir target in the eastern part of the basin (i.e., Rob Roy-1 and Yampi-1), but remains untested in a “downslope” position. These Early Cretaceous lowstand and transgressive plays are present across several of the 1997 gazettal areas.

6.1 Recommendations for Further Work

- Investigate the interaction between basement structures and extensions of the onshore lineament systems recognised in the Kimberley Block.
- Further source rock analyses, particularly a sampling program focused on intervals of maximum flooding (CD) within the Late Jurassic and Early Cretaceous, in welsl located within the basin and along the outer Prudhoe Terrace.
- Maturation modelling work using AFTA to supplement VR, biomarker and other maturity parameters.
- Mapping potential source rock intervals west of the Brecknock–Scott Reef Trend and north and west of Buffon 1 to verify the presence of Late Jurassic depocentres and possible source rocks.
- Study possible breached accumulations to determine the timing of hydrocarbon charge.
- Investigate fluid flow associated with possible salt movement and/or clay dewatering in the deeper basin; effects of fluid flow on cementation and hydrocarbon migration; possible salt collapse structures such as Discorbis 1.
- Detailed study of the Late Cretaceous section at key wells such as Bassett 1A, and throughout the Tertiary succession in order to constrain the sequence stratigraphic model and improve play prediction

7. References

This list includes references to well completion reports for all wells in the Browse Basin, as well as additional references that were used during the study, although not specifically referred to in the Intepretation Report.

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TABLE 1.

Exploration wells tied by the Browse Basin High Resolution (BBHR) seismic grid.

Well	Operator	TD (mKB)	Spud Date	Line Ties to BBHR
Arquebus 1, ST1	Amoco	3256.0	21/11/91	173/03, 175/15
Asterias 1	BHPP	4402.0	14/06/87	175/12
Bassett 1, 1A	Woodside	949.0 2706.0	19/06/78	175/11,175/15,175/18
Brecknock 1	Woodside	4300.0	31/07/79	175/08
Buccaneer 1	Shell	3574.0	26/02/90	175/11, 175/14
Buffon 1	Woodside	4787.0	04/01/80	175/09
Delta 1	Elf Aquitaine	2900.0	26/02/88	175/13, 175/15
Discorbis 1	BHPP	4196.0	08/08/89	175/15
Echuca Shoals 1	BOCAL	4224.0	08/11/83	175/10
Heywood 1	Woodside	4572.0	07/04/74	175/14
Kalyptea 1, ST1	BHPP	4170.5, 4575.0	17/11/88	175/12
Lacepede 1	BOCAL	2282.0	01/07/70	175/14
Perindi 1	Esso	1867.0	10/05/83	175/17 (jump tie)
Productus 1	Mobil	2590.0	12/10/91	175/12
Prudhoe 1	BOCAL	3322.0	13/09/74	175/14
Rob Roy 1	BOCAL	2286.0	27/01/72	175/10
Sheherazade 1	Amoco	2544.0	19/04/93	175/02
Trochus 1, ST1	Shell	1122.0, 1622.0	13/03/91	175/01
Walkley 1	Ampolex	3950.0	31/07/93	175/15
Yampi 1	BOCAL	4176.0	03/06/73	175/07, 175/08, 175/14

TABLE 2.

Status of active exploration permits in the Browse Basin (30 June 1997)

Permit No.	Operator	Expiration Date	Comments and Wells Drilled by Operator
WA-33-P (Part 1) WA-33-P (Part 2) EP-36	Woodside Offshore Petroleum Pty Ltd	Suspended with Renewal Pending	Scott Reef 1 Scott Reef 2/2A North Scott Reef 1 Brecknock 1
WA-35-P (R4)	Shell Development (Australia) Pty Ltd	15/12/1997	Fourth Renewal
WA-206-P (R1)	Mobil Exploration & Producing Australia Pty Ltd	9/11/1999	First Renewal
WA-239-P	BHP Petroleum Pty Ltd	23/07/1998	Gwydion 1
WA-241-P	The Shell Company of Australia Limited	18/07/1998	Cornea 1/1A/1B Cornea 2/DW1
WA-242-P	Woodside Offshore Petroleum Pty Ltd	21/07/1998	
WA-266-P (formerly W96-4)	Shell Development (Australia) Pty Ltd	19/05/2003	Guaranteed Work Program 1050 km^2 3D seismic acquisition and 38 exploration wells
WA-265-P (formerly W96-5)	Shell Development (Australia) Pty Ltd	19/05/2003	Guaranteed Work Program 550 km^2 3D seismic acquisition and 8 exploration wells
AC/P23 (formerly AC96/6)	Nippon Oil Exploration Ltd	31/08/2003	Guaranteed Work Program 9000 km 2D seismic 500 km^2 3D seismic 4 exploration wells

TABLE 3.

Summary of seismic horizons and sequences mapped for the BBHR Interpretation Report.

Sequence	Horizon (Base)	Age (Ma) (Base)	Biozonation (Base)	Tectono-stratigraphic Event(s)	Reference Well(s)	Plate No.*
BB 22	Tlmio	7	mid-N17	Late Miocene compression	Lombardina 1	
BB 21	Tmmio	13	N10/11	Middle Miocene regional unconformity	Buffon 1 Yampi 1	
Base of Basin Phase - Inversion 2						
BB 20	Temio	20	mid-N5	Early Miocene regional unconformity (base of carbonate platforms)	Buffon 1	
BB 19	Tolig	28.5	P21/22	Oligocene regional unconformity (start of northern margin collision)	Buffon 1	
BB 18	Teoc	50	T10	Early Eocene regional unconformity	Brecknock 1	
BB 17	Tpal	56	T6	Paleocene regional unconformity	Brecknock 1	
BB 16	Tbase	65.5	base C13 & *M. druggii*	near base Tertiary regional unconformity; K/T boundary is a flooding surface at T1/C13	Brecknock 1	Plate 16
BB 15	Kmaas	70	KCCM 8/9 upper *I. korojonense*	base of Maastrichtian sands (SB between Kecamp & Kmaas [KCCM 14] at base of Caswell fan)	Heywood 1 Echuca Shoals 1	Plate 24
BB 14	Kecamp	79	KCCM 20/21 mid-*x. australis*	base of Campanian sands ("top Toolonga" equivalent)	Yampi 1 Kalyptea 1/ST1	Plate 23
BB 13	Ktur	90	KCCM 33 lower striatoconus	base Turonian unconformity	Caswell 2 Heywood 1	Plates 15 and 22
BB 12C	*Kalb2*	102	KCCM 43, *P. ludbrookiae*	*mid-Albian unconformity*	Brewster 1 Echuca Shoals 1	
BB 12B	*Kalb1*	105	mid *M. tetracantha*	*early Albian unconformity*	Brewster-1 Echuca Shoals 1	
BB 12A	Kapt	112	mid-*O. operculata*	mid-Aptian unconformity	Arquebus 1 Kalyptea 1/ST1	Plates 14 and 21

TABLE 3. (*cont.)*

Sequence	Horizon (Base)	Age (Ma) (Base)	Biozonation (Base)	Tectono-stratigraphic Event(s)	Reference Well(s)	Plate No.*
BB 11	Kbar	123	base *M. australis*	Barremian unconformity	Heywood 1 Kalyptea 1ST1	Plates 13 and 20
BB 10	Kval	134	*S.areolata / E. torynum*	Valanginian unconformity	Heywood 1 Discorbis 1 Yampi 1	Plates 12 and 19
BB 9	Kbase	141	upper / lower *P. iehiense*	Near base Cretaceous; base of Berriasian sands	Yampi 1 and 18	Plates 11
Base of Basin Phase - Thermal Subsidence 2						
BB 8	Jcal	163	base *W. digitata*	Break-up unconformity (sea-floor spreading in Argo Abyssal Plain)	Discorbis 1 Sheherazade 1	Plates 8 and 17
BB 7	Jearly	183	intra-*C. turbatus*	Early Jurassic intra-rift unconformity	Arquebus 1 / ST1 Brecknock 1	
BB 6	Jbase	196	mid-*C. torosa*	Early Jurassic rifting event	Brecknock 1 Lacepede 1	
Base of Basin Phase - Extension 2						
BB 5	Trmid	220	upper / lower *S. speciosus*	Regional inversion	Yampi 1	Plate 9
Base of Basin Phase - Inversion 1						

Horizons listed in italics were recognised as significant sequence boundaries, but were not mapped due to problems in seismic resolution.

See Section 3 and Figure 21 for an explanation of "Basin Phases".

*** Plate No. refers to Time Structure Contour or Time Isopach Maps that are relevant to the sequence / megasequence.**

TABLE 4.

Summary information for Browse Basin wells with geochemical data.

Well	Well Abbreviation*	Top (m)	Bottom (m)	Top (Ma)*	Bottom (Ma)**	No. of Records
Arquebus 1	Aq	915.0	3256.0	57.0	197.6	63
Asterias 1	As	2492.0	4331.5	69.7	141.6	120
Barcoo 1	Bc	2740.0	5060.0	70.0	207.1	54
Bassett 1A	Bs	1945.0	2690.0	63.6	100.1	38
Brewster 1A	Bw	2000.0	4650.0	74.5	178.4	34
Buccaneer 1	Bu	804.0	3474.0	28.0	218.1	37
Buffon 1	Bf	2355.0	4770.0	20.0	204.0	43
Caswell 1	C1	2600.0	4095.0	65.0	125.0	43
Caswell 2	C2	2647.0	4880.0	66.0	180.0	171
Copernicus 1	Cp	1740.0	2750.0	72.6	238.0	20
Discorbis 1	Ds	2784.0	4197.0	68.8	234.0	143
Echuca Shoals 1	ES	1880.0	4360.0	80.7	295.0	138
Gryphaea 1	Gy	2238.0	3948.0	65.0	244.0	62
Heywood 1	Hy	1340.0	4250.0	50.0	150.3	30
Kalyptea 1	Kl	2547.0	4572.0	67.0	139.0	128
Leveque 1	Lq	274.0	877.8	70.0	142.5	24
Lombardina 1	Lm	950.0	2855.0	57.0	198.0	73
Lynher 1	Ly	427.0	2697.4	58.0	235.0	106
Mount Ashmore 1B	MA	1650.0	2660.0	71.5	217.5	19
North Scott Reef 1	NS	2070.0	4760.0	15.0	223.0	62
Productus 1	Pd	1655.0	2587.0	91.4	298.0	26
Prudhoe 1	Ph	735.0	3300.0	12.5	290.5	77
Rob Roy 1	RR	582.0	2209.0	24.1	309.4	65
Scott Reef 1	SR	732.0	4730.5	8.0	207.0	98
Sheherazade 1	Sc	1100.0	2544.0	68.6	190.0	29
Trochus 1	Tr	399.0	1561.0	62.0	193.0	20
Walkley 1	Wa	2512.0	3885.5	65.0	125.0	35
Yampi 1	Y1	600.0	4170.0	10.8	294.5	148
Yampi 2	Y2	2180.0	3274.0	116.8	167.0	62

** Refers to abbreviations used in Figure 103.*

*** Interpreted age using the age-to-depth curve from the STRATDAT biostratigraphic database.*

TABLE 5.

Guidelines for interpreting.

Table 5A.	source rock generative potential;
Table 5B.	type of petroleum generated from immature sediments (Ro<0.6%); and,
Table 5C.	degree of thermal maturation (modified after Peters, 1986; Espitalié J. and Bordenave M.L.,1993).

Table 5A.

Quantity	TOC (%) (mg / HC / g rock)	Rock Eval S2 Wt %	EOM	HC (ppm)
Poor	<0.5	<2.5	<0.05	<200
Fair	0.5–1	2.5–5	0.05–0.1	200–500
Good	1–2	5–10	0.1–0.2	500–800
Very Good	>2	>10	>0.2	>1200

TOC = total organic carbon; S2 = yield of hydrocarbons(HC) released during Rock Eval pyrolysis;
EOM = extractable organic matter; HC = free saturated and aromatic hydrocarbon content of rock.

Table 5B.

Type	Hydrogen Index (mg HC / g TOC)	Rock Eval S2 / S3	Extract Yield (mg HC / g TOC)*	Atomic H / C
Gas	50–200	1–5	<20	0.6–0.9
Gas and Oil	200–300	5–10	20–50	0.9–1.1
Oil	>300	>10	50–200	>1.1

* mature samples

Table 5C.

Maturation Level	Production Index (PI)	Tmax for Type I	Tmax for Type II	Tmax for Type III
immature	<0.15	<445	<435	<440
mature	0.15–0.4	445–455	435–460	440–470
overmature	<0.15	>455	>460	>470

TABLE 6.

Interpreted onset of oil generation for Browse Basin wells.

Well	Depth (m)	Age (Ma)*	Weighting** Ro	Tmax	PI
Arquebus 1	2600	175		xx	xxx
Asterias 1	3500	118	xx	x	xx
Barcoo 1	4000	185	xxx	x	xxx
Bassett 1A	immature to 2700		x	x	xxx
Brewster 1A	2500	99	xxx	x	xx
Buccaneer 1	2700	122	xxx	xx	xx
Buffon 1	3000	50	xx	x	xx
Caswell 1	2800	96	xxx	xx	x
Caswell 2	2600	66		xx	xxx
Copernicus 1	2400	104		x	xx
Discorbis 1	3500	86	xxx	xx	x
Echuca Shoals 1	2700	115		x	xxx
Gryphaea 1	3000	73	xx	x	x
Heywood 1	3000	104	x	xx	xxx
Kalyptea 1	3400	79	xx	xx	x
Leveque 1	immature to 1000		xx	xx	xx
Lombardina 1	1500	102	xx	xx	xx
Lynher 1	2200	200	xx	xx	x
Mount Ashmore 1B	2300	210		x	xx
North Scott Reef 1	3500	56		xx	xx
Productus 1	1800	100	xxx	x	xxx
Prudhoe 1	2000	101	xxx	xx	xxx
Rob Roy 1	1800	302	x	x	xxx
Scott Reef 1	3500	61	xx	xx	xx
Sheherazade 1	2100	125		x	x
Trochus 1	immature to 1500m		xx	xx	xx
Walkley 1	3300	95	xx	xx	xxx
Yampi 1	2600	139	xx	x	x
Yampi 2	2700	142		xx	xx

**Interpreted age using the age-to-depth curve from the STRATDAT biostratigraphic database.*

*** importance placed on data: x=poor, xx=moderate, xxx=high.*

TABLE 7.

Samples used in oil-source biomarker correlation studies.

AGSO No.	Well	Top (m)	Base (m)	Age (Ma)
9290	Kalyptea 1	2649	2655	70.5
9291	Kalyptea 1	3207	3210	77.4
9292	Kalyptea 1	3579	3585	94.0
9293	Kalyptea 1	3618	3621	96.0
9294	Kalyptea 1	3663	3666	98.0
9295	Kalyptea 1	3798	3801	103.0
9198	Echuca Shoals	2410	2415	103.6
9296	Kalyptea 1	3888	3891	104.3
9297	Kalyptea 1	3954	3960	105.9
9357	Barcoo 1	3370	3380	107.2
9376	Caswell 1	3685	3690	108.0
9298	Kalyptea 1	4092	4095	120.0
9429	Yampi 1	2320	2340	120.4
9273	Lombardina 1	2060	2065	121.6
9408	Echuca Shoals	3050	3055	122.6
9377	Caswell 1	4080	4085	124.5
9299	Kalyptea 1	4160.15	4160.15	125.0
9300	Kalyptea 1	4239	4249	127.4
9369	Prudhoe 1	2520	2520	127.9
9214	Prudhoe 1	2555	2560	129.0
9203	Echuca Shoals	3125	3130	130.0
9384	Discorbis 1	3939	3942	130.4
9405	Brewster 1A	3770	3770	132.0
9280	Brewster 1A	3825	3830	132.6
9301	Kalyptea 1	4329	4335	134.8
9363	Lombardina 1	2425	2425	143.4
9364	Lombardina 1	2435	2435	151.0
9365	Lynher 1	1459.99	1463.03	160.1
9375	Yampi 1	3265	3270	170.0
9370	Rob Roy 1	1539.23	1542.28	175.0
9366	Lynher 1	1539.23	1542.28	177.2
9385	Buccaneer 1	3273	3276	180.0
9373	Rob Roy 1	1582	1585	293.5

TABLE 8.

Biomarker parameters used in hierarchical cluster analysis (HCA).

OilMod	Definition	Source / Environment Indicator
C19T/C23T	tricyclic ratio (C19=no. of carbons)	land plant vs marine input
C22T/C21T	tricyclic ratio	bacterial communities
C24Tet/C23T	tetracyclic / tricyclic	bacterial communities in carbonate sediments
C29H/C30H	hopanes (C29=no. of carbons)	carbonate vs siliciclastic
C31H/C30H	hopane ratio	bacterial communities
C35H/C34H	hopane ratio	anoxic marine bacterial input
C29D/C30H	C29D = C29Ts rearranged hopane	bacterial input in clay-rich sediments
C30X/C30H	diahopane / hopane ratio	bacterial input in oxic clay-rich sediments
%C27S	% C27 steranes (C27=no. of carbons)	marine algal input
% C28S	% C28 steranes	marine algal (diatoms) input
% C29S	% C29 steranes	terrestrial plant input
S/H	ratio of SC27-29steranes to /SC27-35hopanes	eucaryote vs procaryote input

TABLE 9.

Summary of Australian Petroleum Systems. Bold italics highlight the new Early Cretaceous petroleum systems proposed in the Browse Basin (modified from Loutit et al., 1996).

Petroleum Supersystem	Age	Palaeogeographic and Tectonic Setting	Sub-systems and Source Units
Larapintine	Cambrian to Late Carboniferous	Palaeotropics; warm, often shallow epicontinental seaways; Alice Springs Orogeny, compressive regime.	L1. Basinal shales and carbonates (Elcho Island Fm.) L2. Shallow marine carbonates and shales (Goldwyer, Nita and Bongabinni Fms.) L3. Basinal shales and carbonates (Gogo, Luluigi, Clanmeyer and Laurel Fms.)
		Cooling with shift to high southerly latitudes; climax of Alice Springs Orogeny.	L4. Marine clastics (Bonaparte, Milligans and Anderson Fms.)
Gondwanan	Late Carboniferous to Permian	Pervasive glacial influence; high palaeolatitudes; major extensional regime.	G1. Terrestrial, carbonaceous shales and coals (Irwin R. and Sue CM, Carynginia Fm.) G2. Post-glacial, transgressive calcareous shales (Treachery Shale)
Westralian	Mesozoic	Temperate to tropical; western margin transition from Tethys to Indian Ocean; Late Triassic compression, minor extension, subsidence and formation of major depocentres.	W1. Paralic shales and coals (Mungaroo Fm.) W2. Marine shales and terrigenous organic matter deposited in restricted depocentres (Dingo, Legendre Fms. and Flamingo Gp.) W3. Marine shales deposited in shallow depocentres during Berriasian subsidence. ***W4. Marine shales deposited during Early Cretaceous sea level rise in Valanginian.*** ***W5. Marine shales deposited during Early Cretaceous sea level rise in Barremian.*** ***W6. Marine shales deposited during Early Cretaceous sea level rise in Albian.***
Austral	Jurassic to Cainozoic	Temperate; southern margin Australia-Antarctica rift; southern Indian Ocean and Tasman Sea extension, subsidence and Miocene compression.	No identified source units in northern Western Australia or Northern Territory.
Capricorn	Cainozoic	Sub-tropical to tropical; extension and subsidence.	No identified source units in northern Western Australia or Northern Territory.
Murta	Mesozoic	Temperate; interior basin sag; Late Cainozoic compression.	No identified source units in northern Western Australia or Northern Territory.

APPENDIX A1

Summary of exploration permits and work programs in the Browse Basin, 1963 to 1997

Permit	Term	Participants/Operator	Grat. Blocks	Seismic	Wells
PE-213-H PE-232-H	1963-1968	NWS Joint Venture		Montebello-Mermaid NWS Aeromag 1963	
WA-32-P	1969-1975	BOCAL, Woodside, Shell		Adele Scott Legendre-Marie Tryal-Evans Trimouille-Dillon Browse Basin Seismic Mermaid-Cartier Kendrew-Cootamundra	Leveque 1 Lynher 1 Lombardina 1 Prudhoe-Hibernia
WA-32-P (R1)	1975-1980	BOCAL, Woodside, Shell	100	Tessa-Troubadour Woodbine-Victoria	Barcoo 1
WA-32-P (R2)	1980-1985	Woodside	50	Dampier-Broome, Proj 81D 2DW, Proj 82D	
WA-33-P	1969-1975	BOCAL, Woodside, Shell		as for WA-32-P Scott Reef Seismic North Reef Seismic	Scott Reef 1
WA-33-P (R1) Parts 1, 2	1975-1980	BOCAL, Woodside, Shell	194	Tessa-Troubadour Hermite-Barton Woodbine-Victoria, Proj 79 E to 79H	Scott Reef 2/2A Brecknock 1
WA-33-P (R2)	1980-1985	Woodside	97	Dampier-Broome, Proj 81D,81E1,81E2, 81E-3 2DW, Proj 82E-1, 82E, 82J Lewis-Brecknock, Proj 83E	N. Scott Reef 1
WA-33-P (R3)	1985 (renewal pending)	Woodside	48		
WA-34-P	1969-1975	BOCAL, Woodside, Shell		as for WA-32-P Browse Island 72M	Yampi 1
WA-34-P (R1)	1975-1980	Woodside	149	Tessa-Troubadour Haycock-Laminaria Hermite-Barton Woodbine-Victoria, Proj 79E, 79F	Caswell 1
WA-34-P (R2)	1980-1985	Woodside	74	Dampier-Broome, Proj 81D, 81F2DW, Proj 82F, 82G Greater Caswell Echuca Shoals-Heywood	Caswell 2
WA-34-P (R3)	1987-1992 (surr 1989)	BHP	37	BW87	

APPENDIX A1. *(cont.)*

WA-35-P	1969-1975	BOCAL, Woodside, Shell		as for WA-32-P Browse Island 72M	Londonderry 1 Rob Roy 1 Prudhoe 1
WA-35-P (R1) Parts 1, 2	1975-1980	BOCAL, Woodside, Shell	123	Tessa-Troubadour Haycock-Laminaria Hermite-Barton Woodbine-Victoria, Proj 79M	Brewster 1A
WA-35-P (R2)	1980-1985	Woodside	62	Dampier-Broome, Proj 81D, 81G, 81J 2DW, Proj 82F, 82G Greater Caswell Echuca Shoals-Heywood	Echuca Shoals 1
WA-35-P (R3)	1987-1992	Shell	31	BW87	Buccaneer 1
WA-37-P	1969-1975	BOCAL, Woodside, Shell		as for WA-32-P	Heywood 1
WA-37-P (R1)	1975-1980	BOCAL, Woodside, Shell	59	Tessa-Troubadour Haycock-Laminaria Buffon 1 Hermite-Barton Woodbine-Victoria, Proj 79M	
WA-37-P (R2)	1980-1985 (surr 1983)	Woodside	30	Dampier-Broome, Proj 81D, 81G, 81J	
WA-68-P	1977-1983 (exp)	Oxoco International	249	Penguin Shoal North Whimbrel	
WA-104-P	1978-1984 (canc 1983)	Oberon Oil	242	Fraser Inlet Churchill Adele Island	Adele Island 1
WA-177-P	1981-1987 (rel 1983)	Weaver Oil & Gas	233		
WA-180-P	1982-1988 (surr 1987)	Seahawk Oil	61	Calliance Reef Fantome	
WA-187-P	982-1988 (surr 1983)	Esso Expl & Prod Australia	32	BE82A	
WA-188-P	1982-1988 (surr1984)	Esso Expl & Prod Australia	71	BE82B	
WA-197-P	1982-1988	Seahawk Oil	31	Calliance Reef Scobell Fantome	Browse Island 1
WA-200-P	1985-1991 (surr 1988)	Marathon Petroleum Australia Ltd.	116	Capella	
WA-206-P	1988-1994	Ampolex	77	Olga Loretta Elizabeth Lynne	Sheherazade 1 Arquebus 1/ST1
WA-206-P (R1)	1995-1999	Mobil			
WA-207-P (rel 1994)	1989-1994	Bridge	72	Lynher Clarion	Trochus 1/ST1

APPENDIX A1. *(cont.)*

WA-212-P	1989-1995 (rel 1995)	Ampolex	105	A89M Enneidra Eliza 1991 MI Sarah	Walkley 1
WA-238-P	1993-1998 (surr 1996)	Ampolex	17	Sascha Sarah	
WA-239-P	1993-1998	BHPP	114	HY1 HY93 HY94 Gwydion Aeromag	Yampi 2 Gwydion 1
WA-240-P	1993-1998 (surr 1996)	Ampolex	116	Sarah Catherine	
WA-241-P	1993-1998	Shell	147	BS92 Browse 1995 Browse 1996	Cornea 1/1A/1B Cornea 2/2DW1
WA-242-P	1993-1998	Woodside	190	Cockatoo Rosella	
WA-265-P	1997-2003	Shell	30		
WA-266-P	1997-2003	Shell	24		
AC/P3	1997-2003	Nippon Oil Exploration Ltd	55		

APPENDIX A2

Chronological summary of wells drilled in the Browse Basin.

Well	Operator and Permit No.	Permit	TD Date	WD (m)	KB (m)	TD (mKB)	Mapped Trap Type	Remarks
Exploration Wells, 1963 to 1968								
Ashmore Reef 1	Burmah Oil Co of Aust Ltd	OP141	23-Mar-68	36.6	12.20	3914.0	Anticline	No structural closure
Exploration Wells, 1969 to 1975								
Leveque 1	Burmah Oil Co of Aust Ltd	WA-32-P	01-Sep-70	77.7	9.45	899.00	Stratigraphic	No structural closure
Lynher 1	Burmah Oil Co of Aust Ltd	WA-32-P	11-Feb-71	57.9	9.45	2725.0	Anticline	Young structure
Scott Reef 1	Burmah Oil Co of Aust Ltd	WA-33-P	26-May-71	49.7	9.45	4730.0	Drape anticline	Discovery
Rob Roy 1	Burmah Oil Co of Aust Ltd	WA-35-P	25-Feb-72	102.0	9.45	2286.0	Stratigraphic	
Yampi 1	Woodside/Burmah Oil NL	WA-34-P	16-Sep-73	91.0	13.0	4176.0	Anticline	No structural closure
Londonderry 1	Woodside/Burmah Oil NL	WA-35-P	06-Oct-73	90.0	13.0	1145.0	Stratigraphic	
Heywood 1	Woodside/Burmah Oil NL	WA-37-P	27-Jun-74	35.0	10.0	4572.0	Anticline	Velocity pull-up
Lombardina 1	Woodside/Burmah Oil NL	WA-32-P	16-Jul-74	145.0	30.0	2855.0	Faulted anticline	Lack of fault seal
Prudhoe 1	Woodside/Burmah Oil NL	WA-35-P	01-Nov-74	175.0	30.0	3322.0	Tilted fault block	No structural closure
Exploration Wells, 1976 to 1980								
Scott Reef 2/2A	Woodside Petroleum Ltd	WA-33-P	24-Apr-77, 09 Aug 77	56.0	8.0	31.0, 4820.0	Drape anticline	Discovery
Caswell 1	Woodside Petroleum Ltd	WA-34-P	02-Jan-78	345.0	8.0	4097.0	Drape anticline	Overpressured, TD'ed early
Bassett 1/1A	Woodside/Burmah Oil NL	NT/P5	05-Jun-78, 23 Jul 78	364.0	8.0	949.0, 2706.0	Faulted anticline	No fault seal
Brecknock 1	Woodside Petroleum Ltd	WA-33-P	13-Nov-79	543.0	11.0	4300.0	Drape anticline	Discovery
Brewster 1/1A	Woodside/Burmah Oil NL	WA-35-P	16-May-80, 08-Dec-80	256.0	8.0	633.0, 4703.0	Drape anticline	Post-drill interpreted hydrocarbon column
Buffon 1	Woodside Petroleum Ltd	WA-37-P	17-Jun-80	533.0	10.0	4787.0	Faulted drape anticline	Objective proved volcanic
Barcoo 1	Woodside Petroleum Ltd	WA-32-P	28-Jun-80	720.0	11.0	5109.0	Anticline	No stuctural closure
Mount Ashmore 1/1A,B	Woodside/Burmah Oil NL	NT/P5	19 Jul 80, 26-Jul-80, 22 Oct 80	623.0	11.0	664.0, 1058.0, 2655.0	Domal anticline	Young structure
Exploration Wells, 1981 to 1985								
North Scott Reef 1	Woodside Petroleum Ltd	WA-33-P	06-May-82	442.0	8.0	4771.0	Drape anticline	Discovery
Adele Island 1	Oberon Oil	WA-104-P	17-Aug-82	0.00	-4.00	789.50	Basement drape	No structure
Caswell 2	Woodside Offshore Petroleum	WA-34-P	28-Oct-83	344.0	17.0	5000.0	Drape anticline	Outside closure
Echuca Shoals 1	Woodside Offshore Petroleum	WA-35-P	24-Feb-84	194.0	17.0	4365.0	Drape over fault block	Discovery

APPENDIX A2 *(cont.)*

Exploration Wells, 1986 to 1990								
Browse Island 1	Santos Ltd	EP 302 (WA-197-P)	26-May-86	0.00	-2.90	405.0	Shallow stratigraphic test	To determine shallow velocities
Asterias 1	BHP Petroleum	AC/P3	07-Sep-87	194.6	17.4	4402.0	Faulted anticline	Lack of cross-fault seal
Gryphaea 1	BHP Petroleum	AC/P3	16-Nov-87	199.6	17.0	3595.0	Fault block	Lack of quality reservoir
Delta 1	Elf Acquitaine	AC/P1	16 Apr 88	205.0	25.0	2875.0	Stratigraphic	
Kalyptea 1/ST1	BHP Petroleum	AC/P3	06-Feb-89	215.3	17.7 4575.0	4170.5,	Anticline	Low porosity reservoir
Discorbis 1	BHP Petroleum	AC/P3	14-Nov-89	202.0	22.0	4196.0	Faulted anticline	Migration timing
Buccaneer 1	Shell Dev (Aust) Pty Ltd	WA-35-P	02-Apr-90	156.1	15.2	3574.0	Fault block	No seal, outside closure
Exploration Wells, 1991 to 1997								
Trochus 1/ST1	Shell Dev (Aust) Pty Ltd	WA-207-P	29-Mar-91	69.0	22.0 1622.0	1122.0,	Faulted anticline	Lack of migration
Arquebus 1/ST1	Amoco Aust Explor	WA-206-P	27-Nov-91	191.7	17.7 3256.0	1492.9,	Faulted anticline	Post-drill interpreted oil column
Productus 1	Mobil Explor and Prod Aust Ptd Ltd	AC/P3	10-Dec-91	142.0	22.0	2590.0	Fault block	
Sheherazade 1	Amoco Aust Explor	WA-206-P	13-May-93	179.0	22.0	2544.0	Faulted anticline	Reactivation structure
Walkley 1	Ampolex (PPL) Pty Ltd	WA-212-P	15-Sep-93	324.0	23.0	3950.0	Stratigraphic	No reservoir
Yampi 2	BHP Petroleum	WA-239-P	27-Jun-94	91.0	25.0	3318.0	Structural/ stratigraphic	Reservoir quality
Gwydion 1	BHP Petroleum (Aust) Pty Ltd	WA-239-P	08-Jun-95	81.50	26.0	876.0	Structural/ stratigraphic	Discovery
Cornea 1/1A	Shell Dev (Aust) Pty Ltd	WA-241-P	07-Jan-97, 14 Jan 97	n/a	n/a	n/a	Structural/ stratigraphic	Discovery
Cornea 1B	Shell Dev (Aust) Pty Ltd	WA-241-P	20-Jan-97	n/a	n/a	n/a	Structural/ stratigraphic	n/a
Cornea 2/2DW 1	Shell Dev (Aust) Pty Ltd	WA-241-P	31-Jan-97, 6 Feb 97	n/a	n/a	n/a	Structural/ stratigraphic	n/a

APPENDIX A3

Summary of seismic surveys in the Browse Basin (listed by exploration permit).

APPENDIX A3. Summary of seismic surveys in the Browse Basin (listed by exploration permit).

Permit	Permit Operator	Total Kms	Contractor	Survey
OP141	Burmah Oil Co of Aust Ltd	91	Western Geophysical	Ashmore Reef Seismic
PE-213-H	Woodside Oil NL	5768	Aero Service	North West Continental Shelf,WA,1963. Magnetic
	Burmah Oil Co of Aust Ltd		Western Geophysical	North West Shelf Seismic
	Burmah Oil Co of Aust Ltd	2760.7	Western Geophysical	Rankin-Troubadour Seismic
	Burmah Oil Co of Aust Ltd	1641.8	Western Geophysical	Scott-Cartier Marine Seismic
	Burmah Oil Co of Aust Ltd	2796	Western Geophysical	Offshore Canning-Seringapatam Seismic
	Burmah Oil Co of Aust Ltd	6998	Western Geophysical	Legendre-Marie Seismic
PE-232-H	Burmah Oil Co of Aust Ltd	6998	Western Geophysical	Legendre-Marie Seismic
WA-32-P	Burmah Oil Co of Aust Ltd	5253.9	Western Geophysical	Adele-Scott Seismic
	Burmah Oil Co of Aust Ltd	7396	Western Geophysical	Tryal-Evans Seismic
	Woodside Oil NL	6539	Western Geophysical	Trimouille-Dillon Seismic
	Burmah Oil Co of Aust Ltd	2356	Geophysical Service Inc	Browse Basin Seismic
	Gulf Research and Dev Co	5975	Gulf Research and Dev Co	Gulfrex Reconn Marine Seismic, Refraction, Gravity & Magnetic
	Barkley Oil Co P/L	4861	Geophysical Service Inc	Mermaid Cartier Marine Seismic
	Barkley Oil Co P/L	8974	Geophysical Service Inc	Kendrew-Cootamundra Marine Seismic
	Barkley Oil Co P/L	5531	Geophysical Service Inc	Tessa-Troubadour Marine Seismic, Gravity & Magnetic
	Woodside Oil NL	177	Geophysical Service Inc	Woodbine-Victoria Project 79G Marine Seismic
	Woodside Oil NL	70	Geophysical Service Inc	Woodbine-Victoria Project 79H Marine Seismic
	Woodside Oil NL	151	GSI	Dampier-Broome Marine Seismic: Project 81D
	Woodside Oil NL	215	Western Geophysical	Project 82D of 2DW (Dampier-Broome Marine Seismic)
WA-33-P	Burmah Oil Co of Aust Ltd	5253.9	Western Geophysical	Adele-Scott Seismic
	Burmah Oil Co of Aust Ltd	7396	Western Geophysical	Tryal-Evans Seismic
	Woodside Oil NL	6539	Western Geophysical	Trimouille-Dillon Seismic
	Burmah Oil Co of Aust Ltd	722	Western Geophysical	Scott Reef Seismic
	Burmah Oil Co of Aust Ltd	2356	Geophysical Service Inc	Browse Basin Seismic
	Burmah Oil Co of Aust Ltd	81.9	Geophysical Service Inc	North Reef Seismic
	Gulf Research and Dev Co	5975	Gulf Research and Dev Co	Gulfrex Reconn Marine Seismic, Refraction, Gravity & Magnetic
	Barkley Oil Co P/L	4861	Western Geophysical	Mermaid Cartier Marine Seismic

APPENDIX A3 *(cont.)*

	Barkley Oil Co P/L	8974	Geophysical Service Inc	Kendrew-Cootamundra Marine Seismic
	Barkley Oil Co P/L	5531	Geophysical Service Inc	Tessa-Troubadour Marine Seismic, Gravity & Magnetic
	Woodside Oil NL	2909	Geophysical Service Inc	Hermite-Barton Marine Seismic, Gravity & Magnetic
	Woodside Oil NL	240	Geophysical Service Inc	Woodbine-Victoria Project 79F Marine Seismic
	Woodside Oil NL	87	Geophysical Service Inc	Woodbine-Victoria Project 79E Marine Seismic
	Woodside Oil NL	177	Geophysical Service Inc	Woodbine-Victoria Project 79G Marine Seismic
	Woodside Oil NL	70	Geophysical Service Inc	Woodbine-Victoria Project 79H Marine Seismic
	Woodside Oil NL	151	GSI	Dampier-Broome Marine Seismic: Project 81D
	Woodside Oil NL	95	GSI	Dampier-Broome Marine Seismic: Project 81E-1
	Woodside Oil NL	606	GSI	Dampier-Broome Marine Seismic: Project 81E-2
	Woodside Oil NL	380.9	GSI	Dampier-Broome Marine Seismic: Project 81E-3
	Woodside Oil NL	319.5	Western Geophysical	Projects 82E-2 & 82J of 2DW Marine Seismic
	Woodside Oil NL	178.2	Western Geophysical	Projects 82E-1 of 2DW Marine Seismic
	Woodside Oil NL	291	Western Geophysical	Lewis-Brecknock Part 3 (Project 83E) Marine Seismic
WA-34-P	Burmah Oil Co of Aust Ltd	5253.9	Western Geophysical	Adele-Scott Seismic
	Burmah Oil Co of Aust Ltd	7396	Western Geophysical	Tryal-Evans Seismic
	Woodside Oil NL	6539	Western Geophysical	Trimouille-Dillon Seismic
	Burmah Oil Co of Aust Ltd	2356	Geophysical Service Inc	Browse Basin Seismic
	Burmah Oil Co of Aust Ltd	147	Western Geophysical	Browse Island 72-M Marine Seismic
	Burmah Oil Co of Aust Ltd	4861	Western Geophysical	Mermaid-Cartier Seismic
	Barkley Oil Co P/L	8974	Geophysical Service Inc	Kendrew-Cootamundra Marine Seismic
	Barkley Oil Co P/L	5531	Geophysical Service Inc	Tessa-Troubadour Marine Seismic, Gravity & Magnetic
	Woodside Oil NL	3316	Geophysical Service Inc	Haycock-Laminaria Marine Seismic, Gravity & Magnetic
	Woodside Oil NL	2909	Geophysical Service Inc	Hermite-Barton Marine Seismic, Gravity & Magnetic
	Woodside Oil NL	240	Geophysical Service Inc	Woodbine-Victoria Project 79F Marine Seismic
	Woodside Oil NL	87	Geophysical Service Inc	Woodbine-Victoria Project 79E Marine Seismic
	Woodside Oil NL	151	GSI	Dampier-Broome Marine Seismic: Project 81D
	Woodside Oil NL	66	GSI	Dampier-Broome Marine Seismic: Project 81F
	Woodside Oil NL	1529	Western Geophysical	Projects 82F & 82G 2DW Marine Seismic
	Woodside Oil NL	300	Western Geophysical	Interpretation of the Greater Caswell Area
	Woodside Oil NL	308	Western Geophysical	Interpretation of the Echuca Shoals-Heywood Area
	BHPP	597	GSI	BW87 34P Marine Survey

APPENDIX A3 *(cont.)*

WA-35-P	Burmah Oil Co of Aust Ltd	5253.9	Western Geophysical	Adele-Scott Seismic
	Burmah Oil Co of Aust Ltd	7396	Western Geophysical	Tryal-Evans Seismic
	Woodside Oil NL	6539	Western Geophysical	Trimouille-Dillon Seismic
	Burmah Oil Co of Aust Ltd	2356	Geophysical Service Inc	Browse Basin Seismic
	Gulf Research and Dev Co	5975	Gulf Research and Dev Co	Gulfrex Reconn Marine Seismic, Refraction, Gravity & Magnetic
	Burmah Oil Co of Aust Ltd	1544	Western Geophysical	Prudhoe-Hibernia Seismic
	Burmah Oil Co of Aust Ltd	147	Western Geophysical	Browse Island 72-M Marine Seismic
	Burmah Oil Co of Aust Ltd	4861	Western Geophysical	Mermaid-Cartier Seismic
	Barkley Oil Co P/L	8974	Geophysical Service Inc	Kendrew-Cootamundra Marine Seismic
	Barkley Oil Co P/L	5531	Geophysical Service Inc	Tessa-Troubadour Marine Seismic, Gravity & Magnetic
	Woodside Oil NL	3316	Geophysical Service Inc	Haycock-Laminaria Marine Seismic, Gravity & Magnetic
	Woodside Oil NL	2909	Geophysical Service Inc	Hermite-Barton Marine Seismic, Gravity & Magnetic
	Woodside Oil NL	119	Geophysical Service Inc	Woodbine-Victoria Project 79M Marine Seismic
	Woodside Oil NL	151	GSI	Dampier-Broome Marine Seismic: Project 81D
	Woodside Oil NL	312	GSI	Dampier-Broome Marine Seismic: Projects 81G and 81J
	Woodside Oil NL	1529	Western Geophysical	Projects 82F & 82G 2DW Marine Seismic
	Woodside Oil NL	300	Western Geophysical	Interpretation of the Greater Caswell Area
	Woodside Oil NL	308	Western Geophysical	Interpretation of the Echuca Shoals-Heywood Area
	BHPP	597	GSI	BW87 34P Marine Survey
WA-37-P	Burmah Oil Co of Aust Ltd	5253.9	Western Geophysical	Adele-Scott Seismic
	Woodside Oil NL	6539	Western Geophysical	Trimouille-Dillon Seismic
	Gulf Research and Dev Co	5975	Gulf Research and Dev Co	Gulfrex Reconn Marine Seismic, Refraction, Gravity & Magnetic
	Burmah Oil Co of Aust Ltd	1544	Western Geophysical	Prudhoe-Hibernia Seismic
	Burmah Oil Co of Aust Ltd	147	Western Geophysical	Browse Island 72-M Marine Seismic
	Burmah Oil Co of Aust Ltd	4861	Western Geophysical	Mermaid-Cartier Seismic
	Barkley Oil Co P/L	8974	Geophysical Service Inc	Kendrew-Cootamundra Marine Seismic
	Barkley Oil Co P/L	5531	Geophysical Service Inc	Tessa-Troubadour Marine Seismic, Gravity & Magnetic
	Woodside Oil NL	3316	Geophysical Service Inc	Haycock-Laminaria Marine Seismic, Gravity & Magnetic
	Woodside Oil NL	2909	Geophysical Service Inc	Hermite-Barton Marine Seismic, Gravity & Magnetic
	Woodside Oil NL	119	Geophysical Service Inc	Woodbine-Victoria Project 79M Marine Seismic
	Woodside Oil NL	151	GSI	Dampier-Broome Marine Seismic: Project 81D
	Woodside Oil NL	312	GSI	Dampier-Broome Marine Seismic: Projects 81G and 81J

APPENDIX A3 *(cont.)*

WA-68-P	Oxoco International	262	Geophysical Service Inc	Penguin Marine Seismic
	Oxoco International	181	Western Geophysical	North Whimbrel
WA-104-P	Oberon Oil	1082	Western Geophysical	Fraser Inlet Marine Seismic
	Brunswick Oil NL	851	Western Geophysical	Churchill 1980 Marine Seismic
	Oberon Oil	157	Western Geophysical	Adele Island Marine Seismic, Gravity & Magnetic
WA-180-P	Seahawk Oil	1015.9	GSI	Calliance Reef Marine Seismic & Seismic Refraction
	Seahawk Oil	601.5	GSI	Fantome Marine Seismic
WA-187-P	Esso Explor and Prod Aust Ltd	2015	GSI	BE82A Marine Seismic
WA-188-P	Esso Explor and Prod Aust Ltd	2114	GSI	BE82B Marine Seismic
WA-197-P	Seahawk Oil	1015.9	GSI	Calliance Reef Marine Seismic & Seismic Refraction
	Seahawk Oil	200.5	GSI	Scobell Marine Seismic
	Seahawk Oil	601.5	GSI	Fantome Marine Seismic
WA-200-P	Marathon Petroleum Aust Ltd	1501.9	Western Geophysical	Capella Marine Seismic
WA-206-P	Ampol Explor Ltd	378.3	Geophysical Service	Olga Marine Seismic
	Ampol Explor Ltd	340.9	Halliburton GSI	1989 Loretta Marine Seismic
	Ampol Explor Ltd	324	Western Geophysical	Elizabeth Marine Seismic
	Ampolex Limited	1165	Western Geophysical	1996 Lynne Marine Seismic
WA-207-P	Bridge Oil Ltd	1276.1	Geophysical Service	Lynher Marine Seismic
	Bridge Oil Ltd	975.6	Digicon	Clarion Marine Seismic
WA-212-P	Ampol Explor Ltd	2563.1	Halliburton GSI	A89M Enneidra Marine Seismic
	Ampol Explor Ltd	531	Digital Explor Ltd	Eliza 1991 Marine Seismic
	Ampol Explor Ltd	667	Digital Explor Ltd	1991 MI Marine Seismic
	Ampol Explor Ltd	1383.7	Digicon	Sarah Marine Seismic
WA-238-P	Ampol Explor Ltd	1134	Western Geophysical	Sascha 1992 Seismic
	Ampol Explor Ltd	1383.7	Digicon	Sarah Marine Seismic
WA-239-P	BHP Petroleum	138	Digicon	HY1 Marine Seismic
	BHP Petroleum	507.2	Western Geophysical	HY93 Marine Seismic & Magnetic
	BHP Petroleum	526	Geco-Prakla	HY94 Marine Seismic
	BHP Petroleum	2000	World Geoscience Corp	Gwydion R & D Aeromagnetic

APPENDIX A3 *(cont.)*

WA-240-P	Ampol Explor Ltd	1383.7	Digicon	Sarah Marine Seismic
	Ampolex	737	Digicon	Catherine Marine Seismic
WA-241-P	Shell Dev (Aust) P/L	1829.5	Halliburton GSI	BS92 Marine Seismic
	Shell Dev (Aust) P/L	1145	Digicon	Browse 1995 Marine Seismic
	Shell Dev (Aust) P/L	5000	PGS Exploration	Browse 1996 Marine Seismic
WA-242-P	Woodside Offshore Petroleum	3550	Digicon	Cockatoo 2D Marine Seismic 1994
	Woodside Offshore Petroelum	2119	Western Geophysical	Rosella Marine Seismic
AC/P3	BHP Petroleum	3549	GSI	HH1 Marine Seismic
	BHP Petroleum	18	GSI	HH2 Marine Seismic
	BHP Petroleum	194	GSI	XH3 Experimental Marine Seismic
	BHP Petroleum	981	Geophysical Service Inc	Delta No. 1 Marine Seismic
	BHP Petroleum	685	GSI	HH4 Marine Seismic
	BHP Petroleum	500	Halliburton GSI	HH6 Marine Seismic
	Mobil Explor and Prod Aust	2280	Digital Explor Ltd	PK90 Marine Seismic
	Mobil Explor Aust	553	Western Geophysical	Galileo Marine Seismic
	Mobil Explor and Prod Aust	6165	Western Geophysical	Copernicus Marine Seismic
NT/P5	Aust Gulf Oil Co	3746	Gulfrex	Gulfrex SI 2SL Reco Marine Seismic, Refraction, Gravity & Magnetic
	Barkley Oil Co P/L	4861	Geophysical Service Inc	Mermaid Cartier Marine Seismic
	Barkley Oil Co P/L	5531	Geophysical Service Inc	Tessa-Troubadour Marine Seismic, Gravity & Magnetic
	Woodside Oil NL	3316	Geophysical Service Inc	Haycock-Laminaria Marine Seismic, Gravity & Magnetic
	Woodside Oil NL	2909	Geophysical Service Inc	Hermite-Barton Marine Seismic, Gravity & Magnetic
	Woodside Oil NL	182	Geophysical Service Inc	Woodbine-Victoria Project 79A Marine Seismic
	Woodside Oil NL	109	Geophysical Service Inc	Woodbine-Victoria Project 79B Marine Seismic
	Woodside Oil NL	56	Geophysical Service Inc	Woodbine-Victoria Project 79C Marine Seismic
	Woodside Oil NL	79	Geophysical Service Inc	Woodbine-Victoria Project 79D Marine Seismic
	Woodside Oil NL	151	GSI	Dampier-Broome Marine Seismic: Project 81D
	Woodside Oil NL	234	GSI	Dampier-Broome Marine Seismic: Project 81K
	Woodside Oil NL	206.3	Western Geophysical	Project 82K of Dampier Broome Marine Seismic (2DW)
Vacant	Western Geophysical	5333.3	Western Geophysical	Bonaparte-Browse 2D 1996 SPA Marine Seismic

APPENDIX B.

A summary of acquisition and processing parameters, line lengths, and available data for the Browse Basin High-Resolution (BBHR) seismic reflection grid (AGSO Survey 175).

ACQUISITION—FIELD PARAMETERS

Survey Vessel		R/V Rig Seismic
Seismic Source		
	Type	4 x 2 Sodera GI Guns
	Volume	1200 cu. in.
	Pressure	1800 psi
	Source Depth	5 m

Recording Parameters

Record Length	5.5 seconds
Sample Interval	2 ms
Low Cut Filter	5 hz 12 db/Oct
High Cut Filter	205.9 hz, >130 db/Oct
Shot Interval	18.75 m

Seismic Cable

Length	3000 m
Near Offset	86.8–95.2 m
Group Interval	12.5 m
No. of Groups	240
Depth	5 m

PROCESSING PARAMETERS

Processing Record Length 5.5 secs
Processing Sample Interval 2 ms
Parameters spatially varied according to water depth

Main Processing Steps:

Minimum Phase Band Pass Filter 6-250 hz
FK Filter on Shots passing depths +/- 1500 m/s
Predictive deconvolution, 2 windows, each with 180/16 ms
Dip Moveout
Velocity Analysis every 1 km
CDP Stack, 60 fold, 12.5 m CDP interval
Predictive Deconvolution, Single window 240/36 ms
Finite Difference Migration
Tau-P Filter
Time Variant Band Pass Filter
Scaling

Zero Phase Product:

Data phase matched after migration using existing seismic and well control to product zero phased digital output.

Available Displays:

Horizontal Scale	Vertical Scale	Display	Version
50,000	20 cm/s	4 sec	Migrated, Dual Polarity
100,000	10 cm/s	5.5 sec	Migrated
200,000	5 cm/s	5.5 sec	Migrated

Digital Data:

Tapes	Format
Navigation	UKOOA
Ray Stack	SEG-Y
Raw Migration	SEG-Y
Final Migration (Min Phase)	SEG-Y
Final Migration (Zero Phase)	SEG-Y
Velocities	ASCII

APPENDIX B. *(cont.)*

BBHR-97 Line Lengths

Line Number	Shot Point Range	Shot Point Interval	Line Length (Kms)
175/01	1001–14521	18.75	253.519
175/02	1001–1924	18.75	242.325
175/03	1001–15819	18.75	277.856
175/04	1001–14461	18.75	252.394
175/05	1001–14026	18.75	244.238
175/06	1001–13248	18.75	229.650
175/07	1001–15152	18.75	265.350
175/08	1001–16304	18.75	286.950
175/09	1001–10135	18.75	171.281
175/10	1001–14778	18.75	258.337
175/11	1001 -12546	18.75	216.488
175/12	1001–11352	18.75	194.100
175/13	1001–8688	18.75	144.150
175/14	1001–32456	18.75	589.800
175/15	1014–30013	18.75	543.750
175/16	1001–27890	18.75	504.188
175/17	1001–16363	18.75	288.056
175/18	1001–10260	18.75	173.625
175/19	1001–7874	18.75	128.887
		Total	**5264.944**

APPENDIX C.

Summary of biostratigraphic data used in the BBHR study and supplied with this report at the special discounted rate of $250.00 per well.

Well Name	Helby, 1996	Helby, 1997
Arquebus 1/ST1		xx
Asterias 1	xx	
Bassett 1/1A	xx	
Brecknock 1		xx
Buccaneer 1	xx	
Buffon 1		xx
Delta 1	n/a	n/a
Discorbis 1	xx	
Echuca Shoals 1	xx	
Heywood 1		xx
Kalyptea 1/ST1	xx	
Lacepede 1	n/a	n/a
Perindi 1	n/a	n/a
Prudhoe 1		xx
Productus 1	xx	
Rob Roy 1	xx	
Sheherazade 1		xx
Trochus 1/ST1		xx
Walkley 1		xx
Yampi 1	xx	

Helby, R., 1996, Multi-client palynology reviews, Timor Sea Release AC95-1 to AC95-3 and W95-1.
Helby, R. 1997, AGSO Browse Basin Project.

APPENDIX D.

METHODS—SYNTHETIC SEISMOGRAMS

Synthetic seismograms are included for all wells in this package (Table 1) (Plates 45–64). The seismograms display the interpreted horizons, edited well logs, checkshot surveys and the synthetic ties derived from applying both a Ricker minimum (35 and 40Hz) and Ricker zero (35 and 40Hz) phase wavelets to the reflection coefficient series for each well. The general method used to construct these synthetic seismograms is discussed below.

Prior to creating synthetic seismograms an idea of the shape of the wavelet was required. A wavelet was extracted from the seismic data at four well locations using the statistical method in Schlumberger IESX®. This method determines an average seismic wavelet from the autocorrelation of seismic traces over a user specified interval and assumes the phase of the wavelet (in this case the data was processed to minimum phase by the processing contractor). Selected results of the wavelet extraction are illustrated in Appendix Figures D1 to D5. Four wells illustrate extracted wavelets that approximate the minimum phase Ricker wavelet at frequencies of 35 and 40 hertz with a following noise train (Appendix Figures D1 and D2). One wavelet was chosen to generate all synthetic ties using the PC based application LogM®. The following steps summarise the methodology:

1. Digital logs were available for all wells, but were of varying quality and depth coverage. Both the sonic and the density tools are affected by borehole rugosity and are therefore of poorer quality where washouts and cave-ins are common. Using the caliper curve as an indicator of borehole rugosity the sonic and density curves were edited. Additional editing around casing points and across gaps was also needed in some wells.

2. Checkshot surveys were available for all wells tying with the high resolution dataset (Survey 175/BBHR) (Table 1). Checkshots were edited where necessary to minimise overcorrection of sonic velocities.

3. After modifying both the logs and the checkshot surveys, synthetic seismograms were produced in LogM®. The synthetics were based on the modified sonic and density logs and calibrated in time with the checkshot surveys. The wavelets used to generate the synthetic seismograms were the 35 and 40 Hertz minimum phase and zero phase Ricker.

4. The synthetics were then compared to the seismic data. Although character matches were possible, in general, the synthetic ties were only fair. The most common problems included:

    - time shifts typically ranging from 10 to 30 ms were required to match the synthetic seismogram with the seismic data; and,

    - phase matching between the seismic data and the synthetics varied with minimum phase synthetic seismograms commonly displaying a poorer match with the seismic data than zero phase synthetic seismograms.

Time shifts may be due, in part, to velocity problems in the seismic associated with the northwestward thickening carbonates in the shallow tertiary section (Willis, 1988). Effects of the carbonates on seismic acquisition and processing are significant and can be seen in the widely differing quality and frequency content of the seismic data below the carbonate overburden. This problem was beyond the scope of the BBHR study and remains unresolved.

The phase matching problem was investigated using a deterministic wavelet extraction method supplied in IESX®. The difference between the statistical and the deterministic method is that the latter makes no assumption about the phase of the wavelet and uses a cross correlation between the reflection coefficient series obtained from the well and seismic traces to extract the wavelet. The statistical method requires the user to make an assumption about the phase of the wavelet to be extracted (in this case minimum phase) (Appendix Figures D1 and D2). The results of deterministic wavelet extraction over the same trace and time ranges in the wells are illustrated in Appendix Figures D4 and D5. The amplitude and phase spectra in Appendix Figures D4 and D5 vary markedly between the wells in the deterministic method, as well as between the amplitude and phase spectra of the statistical method. Wavelets for Kalyptea 1, Echuca Shoals 1, Sheherazade 1 (Appendix Figures D4 and D5) are mixed phase, whereas Delta (Appendix figure D5) is approximately zero phase within the bandwidth of the seismic data. These results may indicate that a different wavelet for each synthetic tie is required to improve the phase and character match, as well as a more comprehensive source extraction review (e.g., use of different design windows). An ideal minimum phase spectra for a 35 and 40 Hz Ricker wavelet is shown in Appendix Figure D3.

APPENDIX E.

METHODS—TIME STRUCTURE CONTOUR AND ISOPACH MAPS

Time structure contour and isopach maps have been prepared for the area of the Browse Basin covered by the Browse Basin High Resolution Survey. The maps were produced using Petroseis® v. 7.56d and are at a scale of 1:750 000. A film overlay is supplied with this report in both hardcopy and digital formats to indicate the locations of Palaeozoic faults, exploration wells, and permit/gazettal boundaries.

Structure contour maps (in two-way-time (ms)) have been produced for seven horizons in the Late Jurassic to Early Tertiary interval (Plates 10–16). These horizons, which all represent major sequence boundaries, are:

- intra-Callovian unconformity (Jcal), base of supersequence BB8
- base Cretaceous unconformity (Kbase), base of supersequence BB9
- base Valanginian unconformity (Kval), base of supersequence BB10
- base Barremian unconformity (Kbar), base of supersequence BB11
- intra-Aptian unconformity (Kapt), base of supersequence BB12A
- base Turonian unconformity (Kbase,) base of supersequence BB13
- near base Tertiary unconformity (Tbase), base of supersequence BB16

Also, a structure contour map has been made for the seismic horizon that marks the Middle Triassic (Ladinian) inversion event (base of supersequence BB5) (Plate 9).

The structure contour maps were produced using a grid cell size of 1500 m and a contour interval of 100 ms. The extent of each map has been constrained, where possible, by the truncation point(s) of the mapped horizon. Substitutions were necessary on the down dip ends of some lines where, due to downlap, some sequences thinned beyond seismic resolution and the underlying horizon was carried. In general, fault throw and growth on faults in the Late Jurassic-base Tertiary interval is relatively minimal, therefore faults were not used in the generation of the structure contours. The maps have not been depth converted.

Isopach maps (in two-way-time) have been produced for eight supersequences between the intra-Callovian and near base Tertiary horizons (Plates 17–24). The intervals mapped are:

- supersequence BB8—intra-Callovian to base Cretaceous (Jcal-Kbase)
- supersequence BB9—base Cretaceous to base Valanginian (Kbase-Kval)
- supersequence BB10—base Valanginian to base Barremian (Kval-Kbar)
- supersequence BB11—base Barremian to intra-Aptian (Kbar-Kapt)
- supersequence BB12—intra-Aptian to base Turonian (Kapt-Ktur)
- supersequence BB13—base Turonian to Early Campanian (Ktur-Kecamp)
- supersequence BB14—Early Campanian to Early Maastrichtian (Kecamp-Kmaas)
- supersequence BB15—Early Maastrichtian to base Tertiary (Kmaas-Tbase)

Each isopach map polygon is constrained by a zero isopach representing the truncation or pinchout edge of the mapped interval. The isopach maps were produced using a grid cell size of 4000 m, which was resampled to 1500 m and clipped to the polygon, and a contour interval of 20 ms. As the seismic horizons mapped represent the bases of the depositional packages, substitutions were necessary on the updip and downdip portions of some lines where the upper bounding horizon of the interval being mapped was truncated.

APPENDIX F.

Time (TWT) and depth (metres) picks for wells tied to the BBHR grid.

Horizon depth and time picks										
	Arquebus 1 / ST1		Asterias 1		Bassett 1 / 1A		Brecknock 1		Buccaneer 1	
Horizon	Depth (mKB)	TWT (ms)	Depth (mKB)	TWT (ms)	Depth (mKB)	TWT (ms)	Depth (mKB)	TWT (ms)	Depth (mKB)	TWT (ms)
Tlmio	505		852		765	835	1150	1067	589	531
Tmmio	648	523	1050		932	934	1575	1450	710	640
Temio	793	629	1180		1025	986	1945	1749	820	740
Tolig			1245		1120	1039	2500	2039		
Teoc	952	748	1565		1475	1272	3310	2375	1015	883
Tpal	980	780	1685		1595	1351	3340	2390	1110	943
Tbase	1003	797	1914		1720	1427	3425	2439	1312	1103
Kmaas	1051	840	2515		2305	1779			1525	1257
SB*			2587	1817	2400	1836			1670	1354
Kecamp	1106	890	2798	1942	2500	1896	3510	2483	1685	1365
Ktur	1300	1039	2930	2015	2670	2025	3573	2512	1880	1503
Kalb2	1589	1301								
Kalb1	1630	1338								
Kapt	1847	1519	3390	2303			3775	2630	2600	2008
Kbar	2118	1723	3500	2362			3802	2646	2665	2047
Kval	2320	1862	3700	2460			3809	2650	2840	2151
Kbase	2424	1925	4000	2596					2970	2214
Jcal	2500	1968					3830	2660	3261	2360
Jearly	2731	2069					3910	2702		
Jbase							3985	2736	3360	2413
Trmid							4040	2762		
P										
Pearly										
Cnam										

APPENDIX F. *(cont.)*

Horizon depth and time picks										
	Buffon 1		Delta 1		Discorbis 1		Echuca Shoals 1		Heywood 1	
Horizon	**Depth (mKB)**	**TWT (ms)**	**Depth (mKB)**	**TWT (ms)**	**Depth (mKB)**	**TWT (ms)**	**Depth (mKB)**	**TWT (ms)**	**Depth (mKB)**	**TWT (ms)**
Tlmio	1070	1080	620	631	1140		678	650	600	477
Tmmio	1556	1527	940	843	1450		723	690	768	608
Temio	2663	2151	1192	1006	1635		780	740	870	694
Tolig	2828	2257	1305	1069	1710		820	777	882	702
Teoc	3273	2443	1765	1327	2000		1040	951	1140	886
Tpal	3320	2469	1830	1360	2020		1113	1004	1210	933
Tbase	3480	2554	2085	1486	2320	1674	1358	1173	1551	1158
Kmaas					3305	2210	1614	1358	1900	1377
SB*						1678	1401	2030	1466	
Kecamp					3415	2268	1775	1467	2165	1557
Ktur	3487	2558			3560	2330	2049	1651	2278	1628
Kalb2										
Kalb1										
Kapt	3776	2780			3855	2522	2379	1902	3093	2187
Kbar					3873	2533	3080	2340	3125	2206
Kval					3970	2598	3285	2450	3290	2292
Kbase					4070	2657	3615	2597	3557	2418
Jcal	4430	3072			4111	2681	3677	2624	2570	
Jearly										
Jbase	4678	3194								
Trmid										
P							4187	2874		
Pearly							4332	2944		
Cnam										

APPENDIX F. *(cont.)*

Horizon depth and time picks

Horizon	Kalyptea 1 / 1ST Depth (mKB)	Kalyptea 1 / 1ST TWT (ms)	Lacepede 1 Depth (mKB)	Lacepede 1 TWT (ms)	Perindi 1 Depth (mKB)	Perindi 1 TWT (ms)	Productus 1 Depth (mKB)	Productus 1 TWT (ms)	Prudhoe 1 Depth (mKB)	Prudhoe 1 TWT (ms)
Tlmio	725	736	202		204	161	520		575	506
Tmmio	980	902	268	251			620		750	663
Temio	1178	1028					700		816	732
Tolig	1290	1100								
Teoc	1738	1361					880	771	990	887
Tpal	1810	1396					939	828	1000	895
Tbase	2150	1559	300	281			1090	917	1210	1064
Kmaas	3015	2010					1430	1153	1448	1240
SB*	3276	2141							1500	1274
Kecamp	3460	2235					1600	1275	1595	1339
Ktur	3579	2285	370	355			1678	1330	1797	1470
Kalb2									2118	1713
Kalb1										
Kapt	4035	2558	541	530			2000	1573	2392	1890
Kbar	4125	2608	702	670					2575	1999
Kval	4345	2732	904	830			2016	1582	2718	2080
Kbase			1219	1050	439	365	2030	1589	2895	2167
Jcal			1276	1090	540	448				
Jearly			1670	1293	825	646				
Jbase			1998	1453	829	649				
Trmid										
P									2955	2198
Pearly							2409	1754		
Cnam					1772	1177				

APPENDIX F. *(cont.)*

Horizon depth and time picks										
	Rob Roy 1		Sheherazade 1		Trochus 1 / 1ST		Walkley 1		Yampi 1	
Horizon	**Depth (mKB)**	**TWT (ms)**	**Depth (mKB)**	**TWT (ms)**	**Depth (mKB)**	**TWT (ms)**	**Depth (mKB)**	**TWT (ms)**	**Depth (mKB)**	**TWT (ms)**
Tlmio	422	419	498		240		763	840	473	450
Tmmio	538	506	760	699			1320	1185	785	708
Temio	567	528	895	779			1556	1323	825	745
Tolig			900	782			1612	1360		
Teoc	709	645	981	827			1935	1537	922	822
Tpal			1013	845			1980	1559		
Tbase	760	697	1072	885	410	356	2480	1848	1013	893
Kmaas	773	711	1112	918	449	390	2791	2027	1060	930
SB*					479	414	3061	2175	1100	960
Kecamp			1212	984	522	451	3144	2220	1147	995
Ktur	795	730	1378	1095	680	549	3281	2288	1550	1289
Kalb2	1025	944	1588	1275						
Kalb1			1650	1326			3440	2399		
Kapt	1188	1078	1870	1492	937	768	3744	2591	1948	1613
Kbar	1370	1220	2097	1658	992	814			2379	1924
Kval	1390	1233	2240	1755	1112	909			2572	2044
Kbase			2301	1793	1175	953			2827	2169
Jcal	1479	1290	2385	1840	1319	1037			3238	2375
Jearly	1570	1351	2444	1873					3390	2454
Jbase									3459	2484
Trmid									3592	2542
P									3915	2681
Pearly									4010	2720
Cnam	2249	1683								

APPENDIX G.

Well summaries and assessments.

Well Summary	
Name:	Arquebus 1/ST1 (sidetrack at 1492m)
Company:	Amoco Austalia Petroleum Company
Permit:	WA-206-A
Coordinates:	15 18 46.98S 121 29 33.76E
Spud and Release Dates:	21/09/91, 2/12/91
TD - (mKB, Age at TD):	3256 in Early Jurassic (*C.torosa* DZ)
RT and WD (m)	17.7, 191.7
Status:	Plugged and abandoned
Shows:	Strong oil indication in Middle Jurassic, strong oil and gas in Upper Jurassic 2461-2509m (Upper Jurassic), trace-1% pale yel/wh to bright pinpoint fluorescence, nil cut fluorescence to v sl dull milky wh bl/st cut fluorescence, nil to v wk pale yel/wh residual cut fluorescence. 2509-2595m, trace-3% bright wh pinpoint and patchy dull bright to moderately bright yel/wh fluorescence, nil to v sl, occ moderately fast yel/wh to wh bloom crush cut fluorescence with dull to moderately bright yel/wh residual fluorescence. Below 2539m trace sl milky wh st cut fluorescence with v sl to moderately fast yel/wh to milky wh bloom crush cut fluorescence with dull to moderately bright yel residual ring, nil to very faint cut residual bright ring. Dead oil in some sandstone aggregates.
RFT/DST/FITs:	58 RFT points were taken with 13 valid pressure tests. Two interpretations possible: gas column with GWC at 2530m with good data points ~2499m rejected or indicate transitional gradient, with wireline logs indicating a GWC at 2545m, the second interpretation suggests a 45m oil column (OWC 2545m) and 6m gas cap. The presence of an intra formational seal must be invoked (tight streak at 2500m) to account for the differing pressure gradients 2495-2500m. Thin Upper Jurassic sand at 2440m may be gas charged, 100% Sw at 2675m. No hydrocarbon recovered, only sniff of gas (gas wetness can be calculated from C ratios in WCR). Mud filtrate recovered. Significant invasion and fm damage is suggested, MW was raised through the Cretaceous Radiolarite, drilled through Jurassic overbalanced, drill rate slow; sheared PHPA mud.
Play Type/objectives:	Target three-way structural closure to the SW of Lombardina 1 in the greater Lombardina structure against the basin bounding fault off the Leveque Shelf. Target sands were Middle and Early Jurassic sandstones. Structure results from Late to Middle Eocene reactivatation and inversion on the basin margin.Maturation modelling indicates that the majority of hydrocarbon generation and migration post-date the trap formation. Two “flat spots” were interpreted on the seismic within the Early Jurassic sandstones. Secondary objectives were the Late Jurassic sandstones.
Post audit comments:	TOC 0.08 to 2.22 over 1710-2725m, with HI 27-215 (over the same interval of highest TOC). Mature. Kerogen types III and IV. Gross hydrocarbon column 2440-2545m, with possible residual column down to 2675m. Late Jurassic sandstone (*D. jurassicum* DZ), main hydrocarbon sandstone (*W. spectabilis* DZ),Callovian unconformity at 2524m (*C. cooksoniae* DZ)
Post audit conclusion:	Successful discovery but reservoir was damaged during drilling (Haston and Farrelly, 1993). Flat spots were correlated to lithological changes, not related to hydrocarbons. STC processed sonic Poissons Ratio support oil/gas column with intra formational seal. Further work required on understand fault relationships in late stage reactivation structures. The Barcoo 1 well with near continuous fluorescence within the Jurassic-Cretaceous interval and hydrocarbons trapped at Arquebus 1 proves the presence of an active petroleum system. Further hydrocarbons are expected to be found along this trend.

Well Summary	
Name:	Asterias 1A (Well was respudded after TGB problems at surface, then sidetracked at 1350 mRT after string stuck in hole.)
Company:	BHP Petroleum
Permit:	AC/P3
Coordinates:	13 09 03.30S 124 07 16.50E
Spud and Release Dates:	14/06/87, 15/9/87
TD - (mKB, Ma Age at TD):	4402 in Tithonian (upper *D.jurassicum* DZ)
RT and WD - (m):	17, 194.4
Status:	Plugged and abandoned
Shows:	Oil show and gas indication Late Jurassic, oil and gas indication in Early Cretaceous, gas indication in Late Cretaceous 3380-3500m, Trace to 10% very dull orange-brown fluorescence, very slow dull white cut to faint white/yellow cut and crush cut, dull white residual ring. 3646-3719m, traces of dull orange/brown fluorescence, very faint slow white to pale yellow cut fluorescence. 4000-4210m (claystone with arenaceous siltstone and sandstone), slow to streaming pale to moderate milky white to green cut, moderate to strong milky crush cut and residual ring. 4210-4402m, (sandstone with siltstone and claystone, becoming predominantly sandstone) occasional to trace dull orange brown fluorescence, faint milky white cut, moderate pale milky white crush cut and residual ring. Petrophysical analysis concentrated on sand I (3413-3499mRT), sand II (3647-3729mRT) and sand III (4291-4400mRT). Sand I: 63m of net, average porosity 19% from 3413-3463m and 25% from 3468-3487m. Sand II: 33m net, average porosity 13%, RFT recovered filtrate and formation water. Sand III: 26m net, average porosity 14% from 4323-4350m and 20% from 4350-4380m. Log analysis indicates residual HC saturations, Sw down to 70%. Geochem extraction on SWC 149 at 4325mRT (claystone) indicates oil saturations.
RFT/DST/RFTs:	An RFT was run in the 8 $^{1}/_{2}$" section, with 30 pretests taken, resulting in 10 valid tests. Samples taken at 3651.1m and 3716m retrieved mud filtrate and formation water, no evidence of hydrocarbons.
Play Type/objectives:	Drilled to test a faulted anticline at the junction of two faults. The primary objective was the Berriasian sands immediately beneath the Valanginian disconformity. Secondary objectives included the Maastrichtian and Tithonian sands.
Post audit comments:	VR data suggest mature for oil generation at TD. However, VR modelling (Waples method) indicates that Asterias enters the oil window at 3100m, and at the gas window at TD. GC/MS data support this modelling. TOC values <1 with only few samples >1 (max 1.9 at 3641mRT). Geochemistry report discusses the moderate source rock nature of the Valanginian and Tithonian sections.
Post audit conclusions:	Post drill analysis indicates that structure at the Hauterivian level (sand I) and Valanginian level (sand II) are low relief and of limited areal extent. Investigation of the seals within the well indicate that the only competent seals are that overlying sand I. A 17m seal overlies this sand with a 15m waste zone immediately above this, in turn overlain by 25m of competent seal. Shows were noted in the waste zone.Factors influencing the failure of the play include, low structural relief, lean localised source rocks and seal competency.

Well Summary	
Name:	Bassett 1A (36.5m east of Bassett 1 due to lost pipe in hole)
Company:	Woodside Petroleum Development Pty Ltd
Permit:	NT-P5 (R1)
Coordinates:	13 18 36.69S 123 25 35.30E
Spud and Release Dates:	19/6/78, 28/7/78
TD - (mKB, Ma Age at TD):	2706 in Albian (*X.asperatus*)
RT and WD - (m):	8, 364
Status:	Plugged and abandoned
Shows:	Gas indications in Early and Late Cretaceous
	No significant hydrocarbon shows, no fluorescence apparent in any sediments.
RFT/DST/FITs:	none
Play Type/objectives:	Primary objective was Maastrichtian/Campanian sands on large faulted anticline. Secondary objective was Early Tertiary sandstones on an east-west elongate anticline.
Post audit comments:	The age of faulting episodes are: Upper Jurassic, Cretaceous, Late Tertiary and recent. No Cenomanian sediments were intersected. Both the Maastrichtian and Lower Tertiary sandstones merge to form a sand envelope. Development of maximum structural closure occurred post Paleocene-Eocene.
Post audit conclusions:	The deeper part of Bassett 1A structure was never tested. Early Cretaceous and potential thin Jurassic/Late Triassic sands onlapping and/or covering a large Mid-Triassic inversion dome still remains as a play. A tortuous migration path from Early Cretaceous and Late Jurassic source rocks through a thick Campanian claystone sequence into Maastrichtian - Early Tertiary reservoirs is interpreted as the main cause for failure of this well.

Well Summary	
Name:	Brecknock 1
Company:	Woodside Petroleum Ltd
Permit:	WA-33-P
Coordinates:	14 26 08.04S 121 40 25.49E
Spud and Release Dates:	31/07/79, 2/12/79
TD - (mKB, Ma Age at TD):	4300 in Ladinian (*S.quadrifidus*)
RT and WD (m):	11, 543
Status:	Plugged and abandoned
Shows:	Proven gas and condensate zone Middle Jurassic, gas indications in Early to Late Cretaceous and Triassic.
Shows:	3983-3986m highest gas readings, hydrocarbons detected during drilling. 3929-3906.5 (63m net pay) with gas saturation of 66% & porosity of 17%. 3918-3933m (9.5m net pay) with gas saturation of 34% & porosity of 15%. Transitional gas zone saturations with free water at 3930m.
RFT/DST/FITs:	30 tests, gas gradients indicated on testing; DST over 3967-3971, condensate 2016 BBLs/day 1590 BBLs/day water with trace of gas
Play Type/objectives:	Jurassic/Triassic horst block with draped overlying sediments. Primary objective was Middle to Early Jurassic sandstones.
Post audit comments:	Crest of Brecknock 1 exposed until Late Neocomian. Cretaceous interval at Brecknock 1 is 384m, 948m at Scott Reef 1. Good sandstone reservoirs of Jurassic/Triassic age have only been encountered in Brecknock 1. Upper reservoir in Upper D.complex DZ and lower reservoir in C. torosa DZ. Seal on upper reservoir is upper D.complex DZ (intraformational) and Kimmeridgian D.swanense DZ regional flooding seal. seal on lower reservoir is probably C. torosa to C. turbatus DZ. Valanginian may have structural closure while Aptian to Turonian has closure due to depositional mounding and/or submarine erosion. Permeabilities of 225-270 md indicated from pressure tests.
Post audit conclusions:	Successful well. Production testing on a gas zone was cancelled due to problems with the Otis Sub Sea test tree.

Well Summary	
Name:	Buccaneer 1
Company:	Shell Development
Permit:	WA-35-P
Coordinates:	13 39 44.65S 123 57 20.70E
Spud and Release Dates:	26/02/90, 12/4/90
TD - (mKB, Ma Age at TD):	3574 in Triassic (Lower *S.speciosus)*
RT and WD - (m):	15.2, 156.1
Status:	Plugged and abandoned.
Shows:	Oil indication Late Triassic - Early Jurassic, oil show and gas indication in Late Jurassic, oil show in Early Cretaceous Swan D(E) (*D. lobispinosum*) 2828-2857m wk cut fluorescence, spot moderately bright bl fluorescence, slow streaming pale wh cut fluorescence Swan C (*D. jurassicum*) 2969-3081m trace yel pinpoint fluorescence, dull yel very slow cut fluorescence, strong crush cut; to spot bright gr/yel fluorescence, weak to very weak yel/wh cut fluorescence occasional fast strong yel cut fluorescence, milky wh/yel fast crush cut, bright gr/yel residual ring. Swan A (*R. aemula* to *W. spectabilis*) 3100-3156m, 3175m, 3243m trace to patchy dull or bright bl fluorescence, occasional wh/yel cut fluorescence to slow streaming pale wh cut fluorescence. Triassic 3539m patchy moderately bright bl fluorescence, fast strong moderately bright yel cut fluorescence.
RFT/DST/FITs:	No RFT or testing.
Play Type/objectives:	Downthrown dip and fault closed structure against the basin margin fault. Fault closure was mapped at three levels; near Base Cretaceous, (top Swan Fm), main unconformity and lower Swan Sandstones onlapping main unconformity. The Petrel Fm sandstones being the primary objective.
Post audit comments:	Mature for light oil and condensate below 2300m, <1.21% TOC, HI 104. Mature for gas generation below 2800m, <3.85% TOC, HI 268. Mature for oil generation below 3400m, <0.44% TOC, HI 84. Residual oils (<30% hydrocarbon sat) extracted from 2882-3175m SWC's indicate generation from a similar source, algal/bacterial deposited in anoxic conditions. Type III kerogens predominate.Hydrocarbon odour from 3175m, 3128m, 3101m, 3081m, 3003m SWC's sandstone Petrophysical evaluation indicated average hydrocarbon saturations in the Swan Fm (2828-3307m) of 7%, and average hydrocarbon saturations of 12% in the Triassic section (3307-3565m). Reservoir quality of the Swan (*D. lobispinosum* to *R. aemula*, Callovian to Berriasian) section average 15% porosity (4-21%), very fine grained-coarse grained and moderately to poorly sorted. Triassic contained moderate reservoir quality sands and carbonates, average 17% porosity (2-24%). Cenomian to Valanginian claystones (Heywood Fm) were top seal for the Swan FM, however the predicted claystones of the Swan C were absent to seal the Jurassic section.
Post audit conclusions:	The well failed due to lack of seal overlying the Jurassic objective and fault reactivation may have caused hydrocarbons to leak. This well clearly shows the presence and passage of hydrocarbons migrating through the reservoir updip towards the shallower shelf areas.

Well Summary	
Name:	Buffon 1
Company:	Woodside Petroleum Development Pty Ltd
Permit:	WA-37-P
Coordinates:	13 23 32.90S 122 11 04.12E
Spud and Release Dates:	4/1/80, 3/8/80
TD - (mKB, Ma Age at TD):	4787 in Early Jurassic (*C. torosa* DZ)
RT and WD - (m):	10.4, 533
Status:	Plugged and abandoned
Show classification:	Oil indication in Early Jurassic, gas and oil indication in Middle Jurassic and Early Cretaceous
Shows:	Highest peaks 4240-4269m 137-288 units in Middle Jurassic. Solvent fluorescence Middle Jurassic 4140-4470, sample fluoresence in Early Miocene 2360.
RFT/DST/FITs:	All RFT/FIT unsuccessful, DST 3739-4246 12 bbls/hr formation fluid with trace gas.
Play Type/objectives:	Horst block, Middle-Late Jurassic and Triassic sandstones primary target sealed by Cretaceous claystones.
Post audit comments:	SWC porosity in Toarcian-Pliensbachian with 5-15% at 4532-4754.4, core porosity of 8.8-14.2% at 4271-4278.
Post audit conclusions:	The volcanics flows within the Jurassic have affected the integrity of the reservoirs.

Well Summary	
Name:	Delta 1
Company:	Elf Aquitaine
Permit:	AC/P1
Coordinates:	12 38 51.60S 123 58 17.71E
Spud and Release Dates:	28/02/88, 16/04/88
TD - (mKB, Ma Age at TD):	2900 in Late Campanian (*S.carnarvonensis*)
RT and WD (m):	25/205
Status:	Plugged and abandoned
Shows:	Gas indication in Late Cretaceous.
	No significant shows.
RFT/DST/FITs:	None
Play Type/objectives:	NE-SW elongate anticline related to mounding of Maastrichtian sandstones over deeper horst block. Primary objective is the Maastrichtian sand envelope. Secondary objectives is top Cretaceous Woodbine sands and intra-Cretaceous Puffin 2 type sands.
Post audit comments:	Puffin 2 sands absent. Good reservoirs in top Cretaceous. All reservoirs are water saturated.
Post audit conclusions:	The WCR reports that hydrocarbon generation and/or migration are possible causes for the well failing due to tortuous migration path from source to reservoir through a thick almost unfaulted Campanian marl.

Well Summary	
Name:	Discorbis 1
Company:	BHP Petroleum
Permit:	AC/P3
Coordinates:	12 52 51.91S 123 48 50.53E
Spud and Release Dates:	8/08/89, 21/11/89
TD - (mKB, Ma Age at TD):	4196 in Middle Triassic (*S.quadrifidus*)
RT and WD - (m):	22, 202.5
Status:	Plugged and abandoned
Shows:	Oil indication in Middle - Late Jurassic, Early - Late Cretaceous. Shows detected in Puffin sands 3395-3425 and Woolaston Fm 3521 - 3543m
RFT/DST/FITs:	no tests
Play Type/objectives:	Fault controlled structure, Puffin Fm/Echuca Shoals Fm (primary), Upper Vulcan sandstones (secondary)
Post audit comments:	top Puffin sands, average porosity 18% Sw 65%; Woolaston sands average porosity 13% Sw 70%. Good source rocks in Echuca Shoals Fm, 3890 - 3975, TOC 1.79%
Post audit conclusions:	Late Miocene - Pliocene re-activation may have breached the structure.

Well Summary	
Name:	Echuca Shoals 1
Company:	Woodside
Permit:	WA-35-P
Location:	13 44 56.20S 123 43 29.51E
Spud and Release Dates:	8/11/83, 29/2/84
TD - (mKB, Ma Age at TD):	4365 in Early Permian (Stage 2)
RT and WD (m):	17, 194
Status:	Plugged and abandoned
Shows:	Gas indications in Permian; oil & gas indications in Middle to Upper Jurassic and Early Cretaceous. Highest gas readings in Aptian 2695-2740, Late Permian 4281-4304. Fluorescence Aptian to mid Triassic 2695-3684. Gas sand 3617-3656.6, 23.7m net, porosity 15% Sw 23%; gas sand 3314-3335.5, 17.5m net, porosity 12% Sw 19/23%.
RFT/DST/FITs:	2 RFT runs, no samples taken. 18 pressure measurements in Tithonian, indicated a GWC at 3356 & 3656.5, untested gas shows through DST.
Play Type/objectives:	Permian - Triassic block with minor Jurassic and Lower Cretaceous drape closures. Neocomian, Tithonian and Middle Jurassic sandstones above horst block.
Post audit comments:	Permian, 10% porosity in SWC at 4235. Tithonian, Albian, 10/15% porosity in SWC at 2720/3408.
Post audit conclusions:	There is only mild closure at reservoir level which may have been reduced during reactivation phases and/or tilt. Hydrodynamic influences may have had an effect on displacing originally emplaced hydrocarbons updip. shows prove up the passage of hydrocarbons through the reservoir.

Well Summary	
Name:	Heywood 1
Company:	Burma Oil Company Australia Pty Ltd
Permit:	WA-37-P
Coordinates:	13 27 40.61S 124 04 04.67E
Spud and Release Dates:	7/04/74, 14/7/74
TD - (mKB, Ma Age at TD):	4672 in Oxfordian (*W.spectabilis* DZ)
RT and WD (m):	10, 35
Status:	Plugged and abandoned
Shows:	Gas and oil indications in Late Jurassic and Early Cretaceous.
RFT/DST/FITs:	FIT 3299 recovered water, FIT 4147.5 recovered drilling mud.
Play Type/objectives:	Permian - Middle Jurassic horst block
Post audit comments:	10% porosity above 4240 in the Jurassic.
Post audit conclusions:	Heywood failed due to lack of closure at all levels. The well TD'ed before reaching its primary objective.

Well Summary	
Name:	Kalyptea 1/ST1, sidetracked at base of well
Company:	BHP Petroleum
Permit:	AC/P3
Coordinates:	13 01 54.53S 123 52 24.81E
Spud and Release Dates:	17/09/88, 26/3/89
TD - (mKB, Ma Age at TD):	4575 in Berriasian (*C.delicata* DZ)
RT and WD (m):	17.7, 215
Status:	Plugged and abandoned
Shows:	Gas show and oil indication in Early Cretaceous.
	Minor to good hydrocarbon shows in all sands, fluorescence 4119.5-4124.5, 4151.7-4217.5, 4312-4341.8, 4371.5-4443, 4508.3-4550.
RFT/DST/FITs:	RFT recovered 65.6 cu ft gas 0.95 liter condensate and formation water 4541 and 4540.4. DST 1 (4390-4443) recovered formation water. DST 2 (4166.5 - 4172 and 4180 - 4184.5) recovered formation water.
Play Type/objectives:	Anticline with 100m closure at base Cretaceous. Primary objectives, Echuca Shoals, Upper Vulcan Fm; secondary objectives, Puffin Formation.
Post audit comments:	Significant source rock penetrated 4200-4295, TOC average 2.16.
Post audit conclusions:	Valid structural test. The well intersected poor quality reservoirs which contained residual hydrocarbons.The reservoirs are interpreted to have been diagenetically altered prior to oil phase migration. There is a chance that stratigraphic closure is not coincident with structural closure, considering the palaeogeographical setting of the sand body, namely submarine fans.

Well Summary	
Name:	Lacepede 1A (loss of drill string in upper hole following loss of returns)
Company:	Burmah Oil Company of Australia Ltd
Permit:	WA-31-P
Coordinates:	17 05 13.40S 121 26 45.92E
Spud and Release Dates:	1/07/70, 19/8/70
TD - (mKB, Ma Age at TD):	2287 in Upper Carboniferous (*D.birkheadensis*)
RT and WD (m):	9, 58.5
Status:	Plugged and abandonned
Shows:	Gas indication in Middle Jurassic.
	No fluorescence, some minor gas in Middle Jurassic
RFT/DST/FITs:	no tests
Play Type/objectives:	Jurassic/Permian
Post audit comments:	Log interpretation indicates 100% water saturation good porosity in Early Cretaceous and Jurassic; core 4 1784-1792 porosity 20, 21, 38%, permeability 52-2080 md
Post audit conclusions:	The well is thought to have adequately tested the Cretaceous, Jurassic and Upper Permian. The well failure can be assigned to Permian rocks being overmature and the well positioned too far from Mesozoic mature source rocks.

Well Summary	
Name:	Perindi 1
Company:	Esso Exploration
Permit:	WA-109-P
Coordinates:	16 49 37.20S 122 15 51.87E
Spud and Release dates:	10/05/83, 12/6/83
TD - (mKB, Ma age at TD):	1867
RT and WD (m):	21, 23
Status:	Plugged and abandoned
Shows:	Oil show and gas indication in Carboniferous-Permian, Late Triassic - Early Jurassic.
	Minor oil shows in Poole, Grant and Laurel Fm. Gas shows in the Pillara Fm. Free oil recovered from vugs in core cut in Nura Nura Limestone.
RFT/DST/FITs:	RFT pressure tests at 1773.2-1782.8 and 1365.5-1781.7 proved up tight reservoirs. DST 1 at 869.9-881.7 in the Nura Nura Limestone and uppermost sand of the Grant Fm produced formation water.
Play Type/objectives:	Domal structure with multiple sands in the Poole, Grant and Anderson Fms as primary objectives. The Devonian Pillara Fm limestones are secondary objectives.
Post audit comments:	The Pillara Fm had excellent porosity, permeability between 1797-1804, Grant Fm porosities range between 18-26%, good porosities in Cretaceous and Jurassic succession.
Post audit conclusions:	The well proved the presence of oil generating source. Lack of significant oil is due to poor source, leaking seal on structure and migration pathway blocked by igneous intrusions.

Well Summary	
Name:	Productus 1
Company:	Mobil Exploration
Permit:	AC/P3
Coordinates:	13 16 38.20S 124 21 45.54E
Spud and Release Dates:	12/10/91, 15/12/91
TD - (mKB, Ma age at TD):	2590 in Early Permian (Stage 3b)
RT and WD (m):	22, 142
Status:	Plugged and abandoned
Shows:	Oil indication in Early Cretaceous. 1938-1941m sandstone, very fine to fine grained, wh fluorescence, wh moderately fast blooming cut, moderately thick residual ring.
RFT/DST/FITs:	No RFT or testing.
Play Type/objectives:	Drilled on a 12km long Permian horst block along the Prudhoe Terrace. Objective was the Permian Highland Bay Formation sands, juxtaposed against down faulted Triassic shales of the Mt Goodwyn and Sahul formations. Pre-drill risks were the presence of reservoir sands and reservoir quality.
Post audit comments:	Palynofacies: 1679m fair oil source, 1697m good oil source, 1920m-1961m fair oil source, 2002m-2010m gas prone, 2017-18m gas source, 2193m-2206m gas prone, 2275m-2323m gas prone, 2423m-2587m gas prone. Palynofacies: 1225m-2010m early mature, 2193m-TD late mature. Type III kerogen for all samples, except type II at 1697m, localised oil source (16% TOC, 574 HI, 413 Tmax, early mature). No significant shows from the thin sands within the claystone dominated Jamieson Fm (late Early Cretaceous). The Permian sequence was dominated by tight carbonates and shales with no reservoir sand development.
Post audit conclusions:	Late Maastrichtian to Early Tertiary sands have no closure, Early Cretaceous and Permian have no reservoir and closure. Plays immediately downdip of this well, including faulted Middle Jurassic against Permian, onlap of Early Cretaceous/Upper Jurassic remain untested and are suitably located to receive hydrocarbons.

Well Summary	
Name:	Prudhoe 1
Company:	Burmah Oil
Permit:	WA-35-P
Coordinates:	13 44 50.53S 123 51 55.53E
Spud and Release Dates:	13/09/74, 12/11/74
TD - (mKB, Ma age at TD):	3322 in Permian (Stage 3a)
RT and WD (m):	30, 175
Status:	Plugged and abandoned
Shows:	Gas indication in Carboniferous - Permian, gas and oil indication in Late Jurassic, Early - Late Cretaceous, gas indications in Tertiary. No significant hydrocarbons, higher methanes at 2853-2854m. Early Cretaceous 2525-2550 had solvent fluorescence, Late Cretaceous 2865-2885 had sample & solvent fluorescence.
RFT/DST/FITs:	No tests
Play Type/objectives:	NE-SW horst with Middle Jurassic as primary objectives.
Post audit comments:	All sands are water saturated. Upper Jurassic had trace to poor visual porosity with cleaner intervals of 13-17% (from logs). The sandstones in the Maastrichtian-Campanian from 1330-1448 had good visual porosity.
Post audit conclusions:	The well failed as the Middle Jurassic objective was not present, but encountered the Upper Jurassic seal unit.

Well Summary	
Name:	Rob Roy 1
Company:	Burma Oil Company of Australia Ltd
Permit:	WA-35-P
Coordinates:	13 58 10.59S 124 12 01.59E
Spud and Release Dates:	21/01/72, 28/2/72
TD - (mKB, Ma age at TD):	2286 in Pre-Carboniferous basement (*S.ybertii*)
RT and WD (m):	9, 49.7
Status:	Plugged and abandoned
Shows:	Dry well.
	No significant shows
RFT/DST/FITs:	No tests.
Play Type/objectives:	Anomalous dip zone (later deemed pre-Jurassic erosional surface).
Post audit comments:	Log analysis revealed 100% water saturation in all sands.core porosities from 9-12%, 3-12.5%, permeabilities less than 0.21 md.
Post audit conclusions:	Well failed due to lack of significant closure or drilling outside closure and the tortuous migration pathway.

Well Summary	
Name:	Sheherazade 1
Company:	Amoco Australia
Permit:	WA-206-P
Coordinates:	15 28 16.03S 121 22 20.61E, YDBC92-16, SP420
Spud and Release Dates:	19/04/93, 18/5/93
TD - (mKB, Ma age at TD):	2544 in Early Jurassic (*C.turbatus* DZ)
RT and WD (m):	22, 179
Status:	Plugged and abandoned,
Shows:	Gas and oil indications in Middle - Late Jurassic
	Dead oil staining on quartz grains at 2370 and 2418m. 2303-2315m nil direct fluorescence and cut to pale bl spotty fluorescence, 2315-2406m <1% fluorescence, weak pale yel/wh residual fluorescence, no residual ring. RFT was run but failed, no backup tool available. Minor trip gas at 2315m, .01%TG. Trip and swab gas noted through seal section. Petrophysical evaluation indicates hydrocarbon sats of <20% throughout the Jurassic sand interval. Porosity ranges 19-22%.
RFT/FIT/DSTs:	no tests.
Play Type/objectives:	Combination trap anticline with updip faulted lateral seal. Primary objective Late Jurassic sands, with Early Jurassic sands as the secondary objective. Good quality Jurassic reservoir sands beneath the Cretaceous/Jurassic unconformity and sealing claystones. Well was follow up to the 1991 Arquebus 1 well drilled to the northeast along trend.
	Casing program was designed to avoid the problems of the relative overpressured seal and possible formation damage over the reservoir interval experienced in Arquebus 1.
Post audit comments:	Cretaceous section; TOC 7-46%, HI 123-395 (SWC's)
	Jurassic section; TOC 14-22%, HI 53-127 (1 SWC and composite cuttings)
	Type III kerogens predominate, with type II ~2250m (Hauterivian section). TOC (source rock potential) is coincident with the Cretaceous MFS. Probable Early Cretaceous and Early Jurassic - Permian sources. Upper Jurassic reservoirs are favourable.
Post audit conclusions:	Most probable cause for failure is the lack of updip lateral seal and/or re-activation Pliocene faults. Late structuring and migration is not a problem since Arquebus 1 reservoired hydrocarbons. The Late Miocene inversion structure that originally trapped the hydrocarbons could have a high probability of leaking. An assessment of the fault block compartmentilisation is critical in addressing further plays. The Barcoo 1 well recorded near continuous fluorescence within the Jurassic-Cretaceous interval and hydrocarbons trapped at Arquebus 1 prove the presence of an active petroleum system. Further hydrocarbons are expected to be found along this trend.

Well Summary	
Name:	Trochus 1
Company:	BHP Petroleum
Permit:	WA-207-P
Coordinates:	15 55 24.67S 121 06 06.03E
Spud and Release Dates:	13/03/91, 3/4/91
TD - (mKB, Ma age at TD):	1622 in Sinumerian (*C.torosa* DZ)
RT and WD (m):	22, 69
Status:	Plugged and abandoned
Shows:	Oil indication in Middle - Late Jurassic.
	Early Cretaceous sandstone 1173-1183m, no fluorescence, fnt milky yel residual ring. Middle- Late Jurassic sandstone at 1218m, 1221m and 1236m v sl fnt, milky crush fluorescence with weak residual ring. Early Jurassic sandstone (1466-1593m) v sl fnt, milky yel crush cut fluorescence with weak residual ring.
	SWC samples at 1561m (#3) and 1502m (#6) were reported as having a hydrocarbon odour in hand specimen from the petrographic report, with 1561m damp due to the presence of hydrocarbon. No shows were reported in SWC descriptions. Organic geochem on these SWC's indicate that SWC #3 is almost certainly drilling contaminants (diesel), while #6 has contaminant and possibly some indigenous hydrocarbon.
RFT/DST/FITs:	5 pretests were taken with RFT tool, a clear water gradient of 1.419psi/m was evident, no samples taken.
Play Type/objectives:	Objective was the Middle to Upper Jurassic sandstones sealed by Early Cretaceous claystones in a 4 way dip closure along the Lynher-Lombardina basin fault trend, off the Leveque Shelf. Well was drilled on a 4 way dip closure updip of the Lynher 1 well which tested a 3 way dip closure against the basin margin fault.
Post audit comments:	Early to Middle Jurassic interval is immature, VR=0.5. Claystones in Jurassic sequence (2 samples) 1.16 & 3.8 TOC, 149 & 459 HI. Early Jurassic sample 1453m type II kerogen, Middle to Late Jurassic sample 1360m type III kerogen. Mid to Late Jurassic sandstone (1210-1317m) is excellent reservoir quality, 92% N/G, 24% porosity. Fine to coarse, dominantly medium grained, well sorted quartzarenites. The Early to Middle Jurassic sandstone (1317m-1466m) were fine grained, well sorted quartzarenites, 38% N/G, 21% porosity. The Early Jurassic sandstone (1466-1622m) were fine to coarse, dominantly medium grained, moderately well sorted quartzarenites, 74% N/G, 24% porosity. Hydrocarbon charge is believed to have post dated Miocene inversion. Petrophysical analysis summarised in WCR, 0% hydrocarbon saturation throughout Jurassic.
Post audit conclusions:	WCR state that the failure of this play is attributable to either lack of mature source rocks within the drainage area, or poor migration and trap timing. It is now interpreted that hydrocarbons leaked up the fault system.
	The Late Miocene to Pliocene inversion anticline is heavily faulted so that originally trapped hydrocarbons could have a high probability of leaking. A thorough understanding of the fault block compartmentilisation is critical in addressing further plays. The Barcoo 1 well with near continuous fluorescence within the Jurassic-Cretaceous interval and hydrocarbons trapped at Arquebus 1 proves the presence of an active petroleum system. Further hydrocarbons are expected to be found along this trend.

Well Summary	
Name:	Walkley 1
Company:	Ampolex Ltd
Permit:	WA-212-P
Coordinates:	14 16 06.63S 122 29 59.89E
Spud and Release Dates:	31/07/93, 27/9/93
TD - (mKB, Ma age at TD):	3950 in Barremian (Upper *M.australis*)
RT and WD (m):	22.25, 324.05
Status:	Plugged and abandoned
Show classification:	Oil indication in Early Cretaceous.
Shows:	3525-3900 m, cut fluorescence of bulk samples. No direct hydrocarbons observed. 2300-2390 m, moderate levels of wet gas in Early Tertiary (max unit 35.9 units of C1-C5). 3290-3950 m low to high gas with abnormally pressured claystones below base Tertiary unconformity (max units 2722 units) Base Tertiary, 2365m sandstone 48ppm C5, 35.9 TG. No shows reported in the Campanian fan. Below 3525m bulk samples no direct fluorescence, slow pale yel-bl wh diffuse bl cut fluorescence with light bl-yel milky yel residual ring in claystone sequence. Peak ditch gas readings below Turonian unconformity (3288m) are associated with overpressuring, increasing pore pressure in claystone dominated sequence. Gas bubble circulated out at 3862m, up to C5 gas.
RFT/DST/FITs:	No tests.
Play Type/objectives:	Two basin floor submarine fans of Campanian and Barremian age, closure provided by depositional mounding. Structural closure only present at levels below the targets (Neocomian and Oxfordian Breakup Unconformity). Campanian fan previously intersected in Caswell 1and 2.
Post audit comments:	Campanian fan objectives had fair to excellent reservoir characteristics, but were water wet. Absence of Barremian basin floor fan. Geothermal gradient of 3.15deg/100m above Turonian unconformity at 3288m, 6.1deg/100m below to TD, average of 3.64deg/100m overall. Campanian fan porosity 2898.5-2990m 10-25% (18 ave), fair to good permeability, log derived.
Post audit conclusions:	Potential reasons for the well failing are as follows: poor access to Jurassic and Cretaceous source rocks via adequate migration pathways, poor seal and lack of structural integrity.

Well Summary	
Name:	Yampi 1
Company:	Burma Oil Company of Australia Pty Ltd
Permit:	WA-34-P
Coordinates:	14 33 26.97S 123 16 38.38E
Spud and Release Dates:	3/06/73, 27/9/73
TD - (mKB, Ma age at TD):	4176, Early Permian (Stage 3a)
RT and WD (m):	13, 91
Status:	Plugged and abandoned
Shows:	Gas and oil indications in Carboniferous, Permian to Middle Jurassic, oil show and gas indication in Late Jurassic, gas and oil indication in Early Cretaceous. Fluorescence in Early to Late Jurassic 2724-2828, 3026-3048, 3048-3074, 3106-3304 (also gas). Traces of residual oil in core 3173-3178.3. Fluorescence in Permian 3923-3930 and 3995-4044. Petrophysical analysis reveals water saturated sands.
RFT/DST/FITs:	3 FIT tests 3175, 3265 and 4065.5 in Jurassic with no recovery.
Play Type/objectives:	Permian/Triassic fault controlled anticline.
Post audit comments:	Sandstones 2570-3587m had trace to poor porosity. Core 3173-3178.3 derived porosity of 4.9-8.1% and permeability of less than 0.1 md. Sands are heavily cemented.
Post audit conclusions:	Yampi 1 failed because of poor reservoir development and lack of structural closure in post Triassic objectives.

APPENDIX H.

A summary of hydrocarbon shows in Browse Basin wells present by sequence. Refer to Figure 23 to cross-reference sequence name and age.

Sequence	Well name	Show	Comments
BB1	Perindi 1	oil show and gas indication	could be BB2
BB2	Echuca Shoals 1	gas indication	could be BB3
	Perindi 1	oil show and gas indication	could be BB1
	Prudhoe 1	gas indication	could be BB3
	Yampi 1	gas and oil indication	could be BB3
BB3	Echuca Shoals 1	gas indication	
	Prudhoe 1	gas indication	could be BB2
	Yampi 1	gas and oil indication	could be BB2
BB4	Brecknock 1	gas indication	
	Copernicus 1	oil indication	
	Gryphaea 1	gas and oil indication	
	Yampi 1	gas and oil indication	
BB5	Brecknock 1	gas indication	
	Buccaneer 1	oil indication	
	Buffon 1	oil indication	
	Lynher 1	gas indication	
	Perindi 1	oil show and gas indication	
	Scott Reef 1	proven gas and condensate zone	DST, recovered condensate and gas
	Yampi 1	gas and oil indication	
BB6	Brecknock 1	gas indication	
	Lynher 1	gas indication	
	Maret 1	gas and condensate show	RFT, recovered condensate and gas
	Scott Reef 2	proven gas zone	FIT, recovered gas
	Yampi 1	gas indication	
BB7	Arquebus 1	strong oil indication	formation damage, no oil flow
	Barcoo 1	gas and oil indication	
	Brecknock 1	proven gas and condensate zone	RFT, condensate and gas recovered
	Brewster 1	gas and oil indication	
	Buffon 1	gas and oil indication	
	Caswell 1	gas and oil indication	
	Discorbis 1	oil indication	
	Echuca Shoals 1	oil and gas indication	
	Lacepede 1	gas indication	
	Lombardina 1	oil and gas indication	
	North Scott Reef 1	proven oil and gas zone	full production runs
	Sheherazade 1	gas and oil indication	
	Trochus 1	oil indication	
	Yampi 1	gas and oil indication	
	Yampi 2	strong oil indication	40 RFT run, tight
BB8	Arquebus 1	strong oil and gas indication	formation damage, no oil flow
	Asterias 1	oil show and gas indication	oil in SWC
	Barcoo 1	gas and oil indication	
	Brewster 1	gas & oil indication	
	Buccaneer 1	oil show and gas indication	oil extracted from SWC
	Caswell 1	gas and oil indication	
	Discorbis 1	oil indication	
	Heywood 1	gas and oil indication	
	Lombardina 1	oil indication	
	Prudhoe 1	gas and oil indication	
	Sheherazade 1	gas and oil indication	
	Trochus 1	oil indication	
	Yampi 1	oil show and gas indication	
	Yampi 2	strong oil indication	40 RFT run, tight

BB9	Asterias 1	gas and oil indication	
	Barcoo 1	gas indication	
	Brecknock 1	gas indication	
	Brewster 1	gas and oil indication	
	Buccaneer 1	oil show	oil extracted from SWC
	Caswell 1	gas and oil indication	
	Discorbis 1	oil indication	
	Echuca Shoals 1	oil and gas indication	
	Heywood 1	gas and oil indication	
	Kalyptea 1 1ST	gas show & oil indication	RFT gas/condensate recovered
	Lombardina 1	oil indication	
	Prudhoe 1	gas and oil indication	
	Tahbilk 1	proven gas and condensate zone	RFT gas/condensate recovered
	Yampi 1	gas and oil indication	
BB10	Asterias 1	gas and oil indication	
	Barcoo 1	gas indication	
	Brewster 1	gas and oil indication	
	Caswell 1	gas and oil indication	
	Copernicus 1	oil indication	
	Discorbis 1	oil indication	
	Echuca Shoals 1	oil and gas indication	
	Gryphaea 1	gas and oil indication	
	Heywood 1	gas and oil indication	
	Kalyptea 1 1ST	oil indication	
	Lombardina 1	gas and oil indication	
	Lynher 1	gas indication	
	Prudhoe 1	gas indication	
	Yampi 1	gas indication	
BB11	Asterias 1	gas indication	
	Barcoo 1	gas indication	
	Brewster 1	gas and oil indication	
	Buffon 1	gas and oil indication	
	Caswell 1	gas and strong oil indication	
	Echuca Shoals 1	oil and gas indication	
	Gwydion 1	proven oil and gas zone	RFT, flow of gas/oil
	Heywood 1	gas indication	
	Kalyptea 1 1ST	oil indication	
	Lombardina 1	gas and oil indication	
	Prudhoe 1	gas and oil indication	
	Walkley 1	oil indication	
	Yampi 1	gas indication	
BB12	Asterias 1	gas and oil indication	
	Bassett 1	gas indication	
	Brecknock 1	gas indication	
	Buffon 1	gas and oil indication	
	Caswell 1	oil show and gas indication	FIT, oil recovered
	Discorbis 1	oil indication	
	Echuca Shoals 1	oil and gas indication	
	Gryphaea 1	gas and oil indication	
	Gwydion 1	gas indication	
	Heywood 1	gas indication	
	Productus 1	oil indication	
	Yampi 1	gas indication	
BB12A	Barcoo 1	gas and oil indication	
	Brewster 1	gas and oil indication	
	Lombardina 1	gas indication	
	Walkley 1	oil indication	
BB12B	Lombardina 1	gas indication	
	Prudhoe 1	gas indication	
BB12C	Brewster 1	gas and oil indication	
	Lombardina 1	gas indication	
	Prudhoe 1	gas indication	
BB13	Asterias 1	gas indication	
	Bassett 1	gas indication	
	Brecknock 1	gas indication	
	Discorbis 1	gas and oil indication	
	Lombardina 1	gas indication	
	Prudhoe 1	gas indication	

BB14	Bassett 1	gas indication	
	Discorbis 1	gas and oil indication	
	Prudhoe 1	gas indication	
	Tahbilk 1	proven gas and condensate zone	RFT gas/condensate recovered
BB15	Brecknock 1	gas indication	
	Caswell 1	oil show and gas indication	RFT oil/gas recovered
	Delta 1	gas indication	
	Discorbis 1	oil indication	
	Gryphaea 1	gas and oil indication	
	Lombardina 1	gas indication	
	Prudhoe 1	gas indication	
BB16	Delta 1	gas indication	
	Prudhoe 1	gas indication	
BB17	Buffon 1	gas indication	
	Prudhoe 1	gas indication	
BB18	Buffon 1	gas indication	
	Delta 1	gas indication	
BB19	Buffon 1	gas indication	
	Prudhoe 1	gas indication	
BB20	Buffon 1	gas and oil indication	
	Prudhoe 1	gas indication	
BB21	Prudhoe 1	gas indication	
BB22	Prudhoe 1	gas indication	

APPENDIX I.

A summary of known hydrocarbon accumulations in the Browse Basin.

Discovery, Year, Operator, and Permit No.	Age of Reservoir(s)	Structure	Column Height (m)	Economic and Development Status	Reserves (million cu feet, million barrels)
Cornea (1996) Shell WA-241-P	Early Cretaceous	drape anticline over basement feature	unknown	economic, under development	estimates range from 617 to 2665
Gwydion (1995) BHPP WA-239-P	Early Cretaceous	drape anticline over basement feature	36.1 m over four zones	uneconomic	unknown
Scott Reef (1971) Woodside WA-33-P, EP36	Early Jurassic to Late Triassic	faulted anticline	620	economic	11 TCF dry gas 158.5 condensate
North Scott Reef (1982) Woodside WA-33-P			81	undeveloped	
Brecknock (1979) Woodside WA-33-P	Early Jurassic	Jurassic/ Triassic horst	unknown	economic, undeveloped	9 TCF gas
Brewster (1980) Woodside WA-35-P	Early Cretaceous and Middle Jurassic	Lower Jurassic horst	2 inferred gas zones	undeveloped	unknown
Caswell 2 (1977) Woodside WA-34-P	Albian and Campanian	?stratigraphic	unknown	sub-economic	unknown
Echuca Shoals (1983) Woodside WA-35-P	Late Jurassic	Permian/ Triassic horst and drape	2 gas and condensate zones	sub-economic	unknown
Arquebus (1991) Amoco WA-206-P	Middle to Late Jurassic	Miocene anticline	estimated 51 to 105 m (light oil and gas)	P&A (post-drill formation evaluation)	unknown
Heywood (1974) Woodside WA-37-P	Late Jurassic	Permian/ Triassic horst	unknown	sub-economic	unknown

The Cornea discovery is the most significant oil discovery to date. Multiple reservoirs were intersected in the Early Cretaceous and, like Gwydion drilled nearby, is believed to be associated with DHI's. Other well information is unavailable due to its recent drilling and confidential status. Cornea 2/2DW1 were drilled as appraisal wells during early 1997. A full field appraisal and plans for the acquisition of 3D seismic data over the area are underway. This assessment probably extends across the Shell's recently awarded (adjacent) permits WA-265-P and WA-266-P.

The Scott Reef discovery, drilled by Woodside Petroleum on the Scott Reef–Brecknock trend, is the most important dry gas discovery to date. The field remains has remained undeveloped for a number of year due to several factors, including economic viability, environmental considerations, and the potential for further deep water drilling. An agreement over issues that have affected the renewal of WA-33-P (Part 1) is likely to be reached soon.

The gas discovery at Brewster 1A was interferred (post-drill) from geophysical logs due to lack of hydrocarbon returns in the RFT's. The well is interpreted to have intersected two gas bearing sands of Berriasian and Middle Jurassic age. The 161.5 m thick Berriasian sands recorded good porosities, although sands in the Middle Jurassic were tight. The Brewster structure presently lies within the recently gazetted release area W97-13 and may attract further interest, although reservoir quality may be considered high risk.

The Caswell discovery has been termed sub-economic due to the thin nature of the sands and the associated difficulty in predicting their distribution. The depth to the reservoir and the stratigraphic isolation of these intervals will be factors in the economic viability of these plays.

The Echuca Shoals and Heywood discoveries are sub-economic, as the lack of hydrocarbon returns in the RFT's and FIT probably indicates low porosity and permeability in the reservoirs.

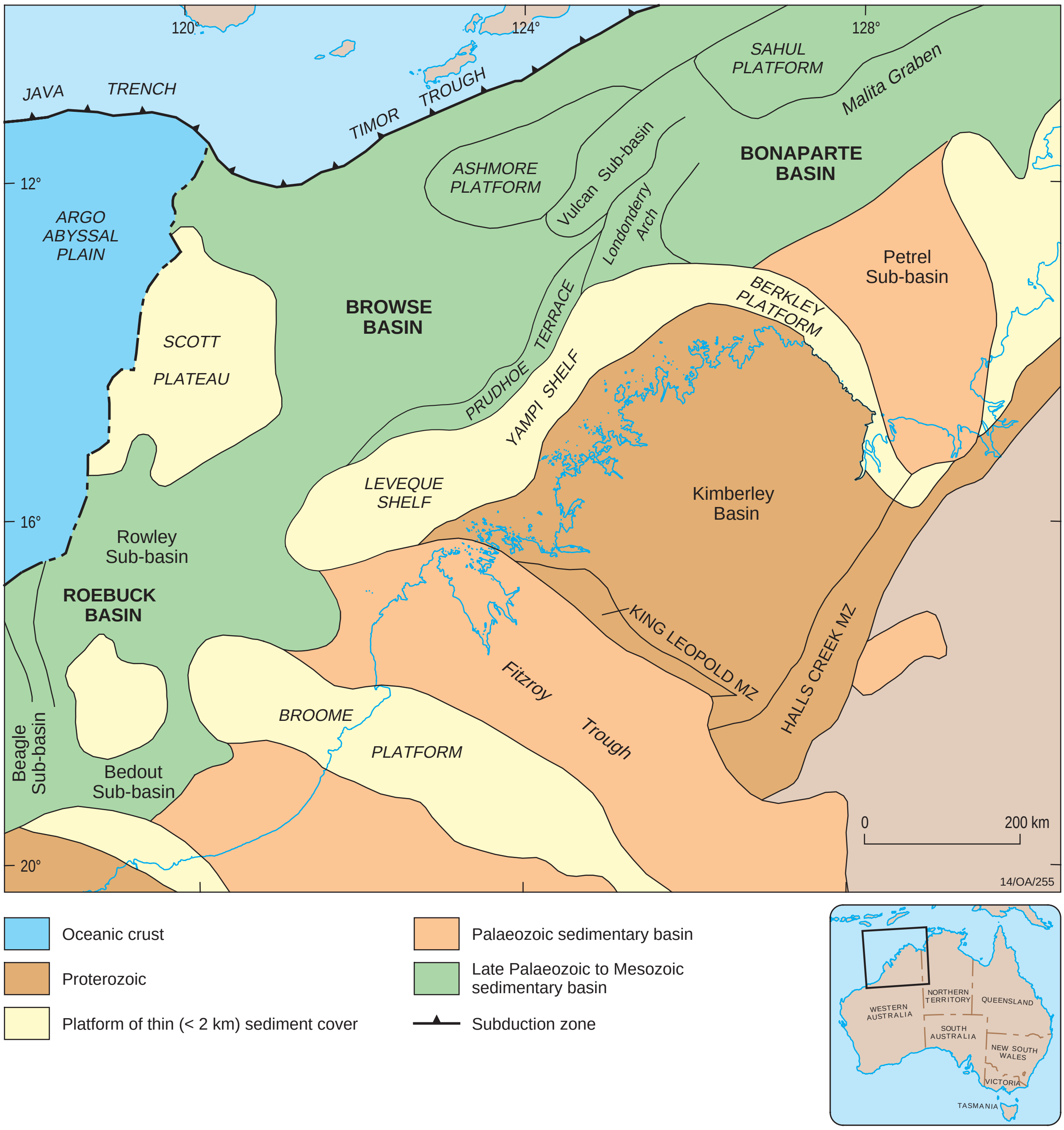

Figure 1 Regional structural elements map (modified after Hocking, *et al.*, 1994, and Symonds *et al.*, 1994).

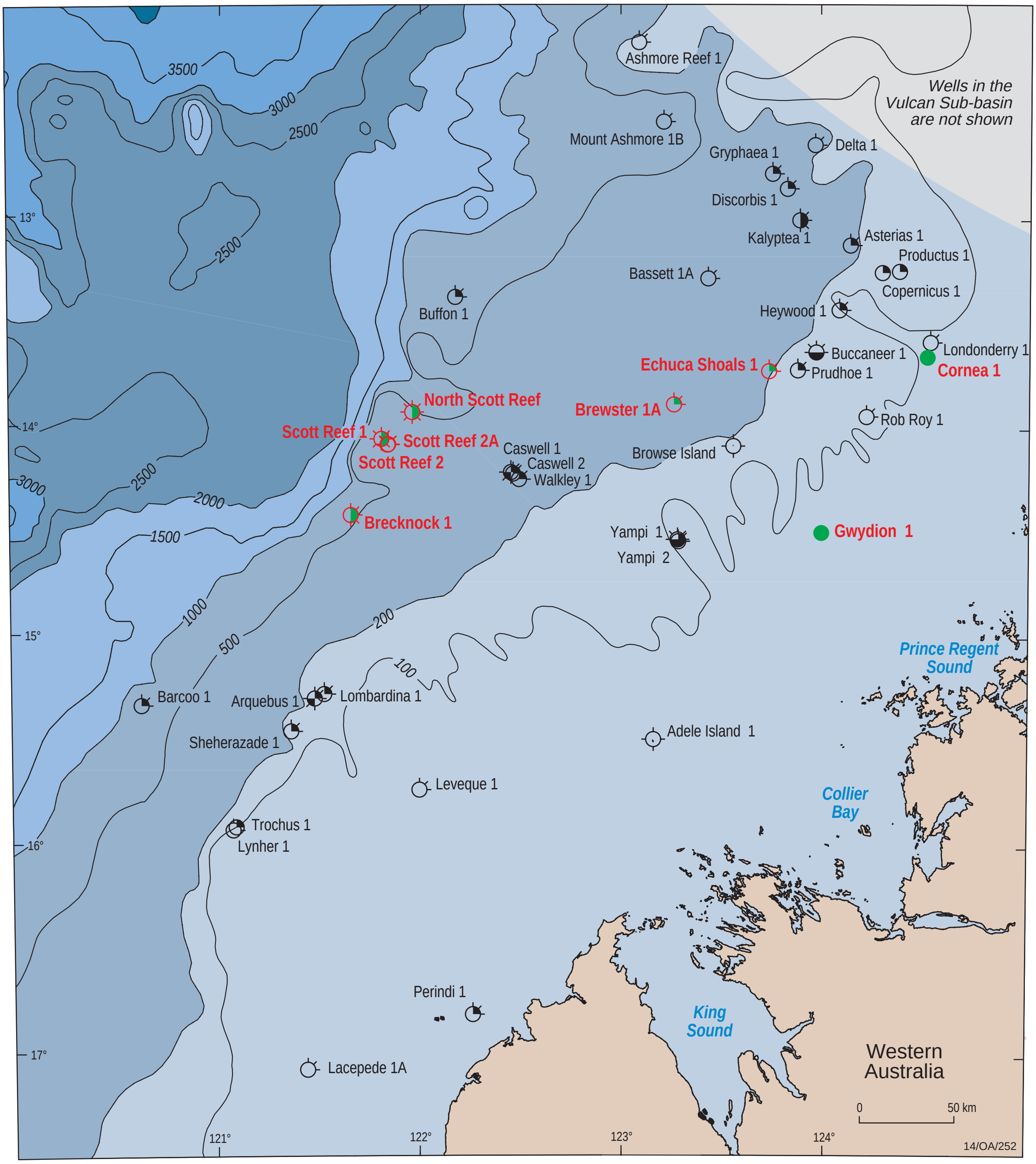

Figure 2 Browse Basin bathymetry and well location map.

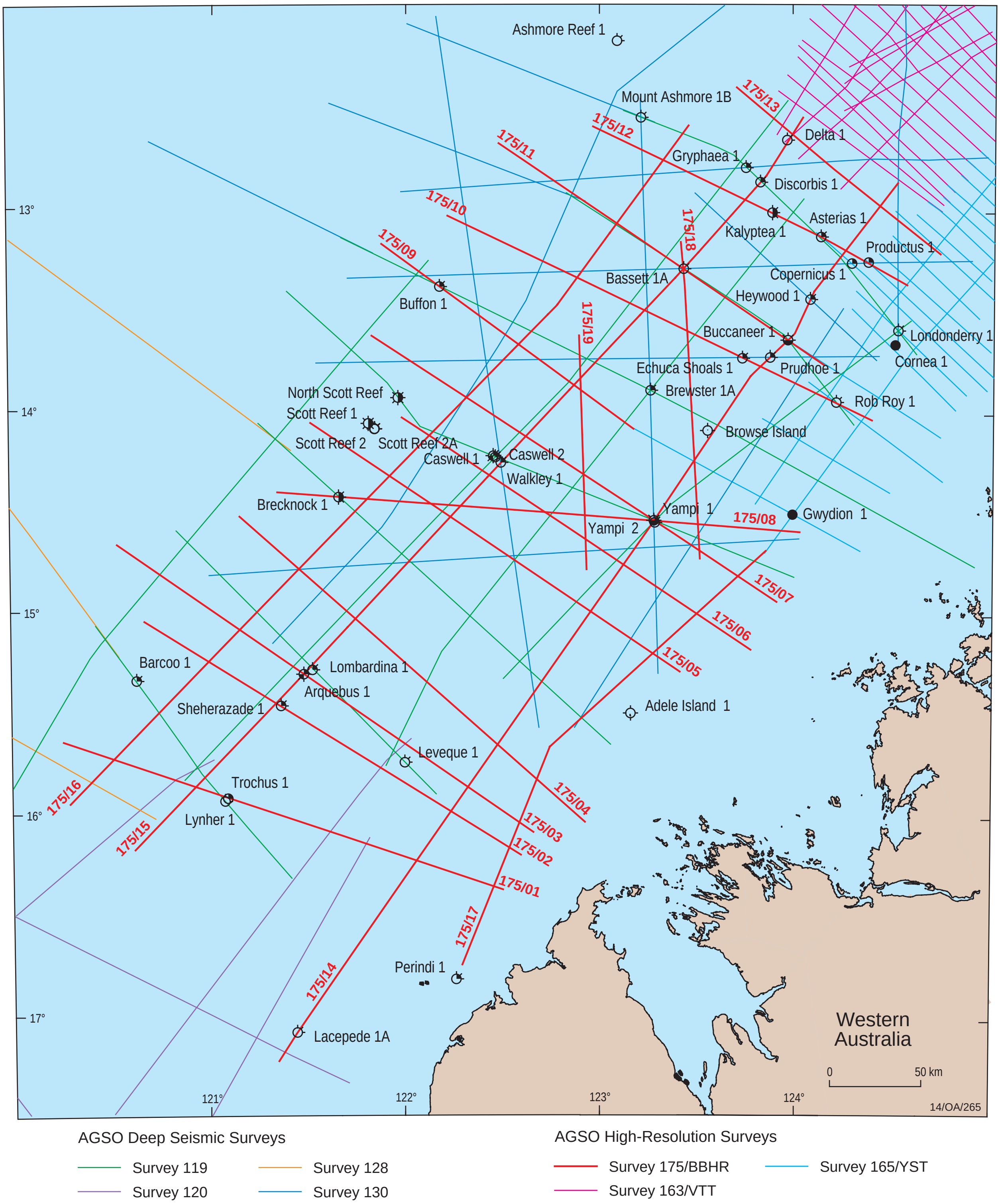

Figure 3 Location map of AGSO seismic surveys in the Browse Basin.

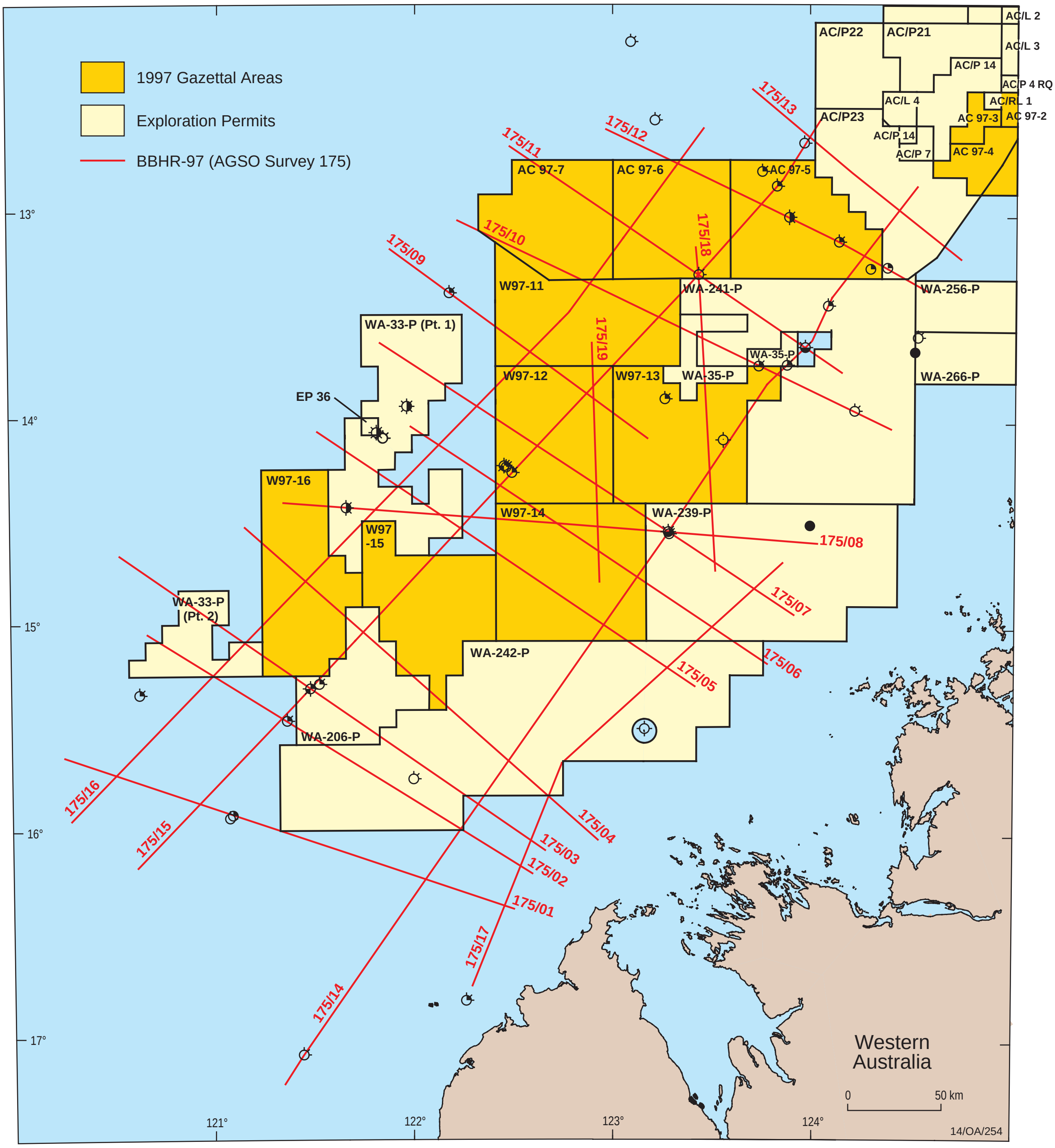

Figure 4 Exploration permits and Browse Basin High-Resolution (BBHR) seismic grid.

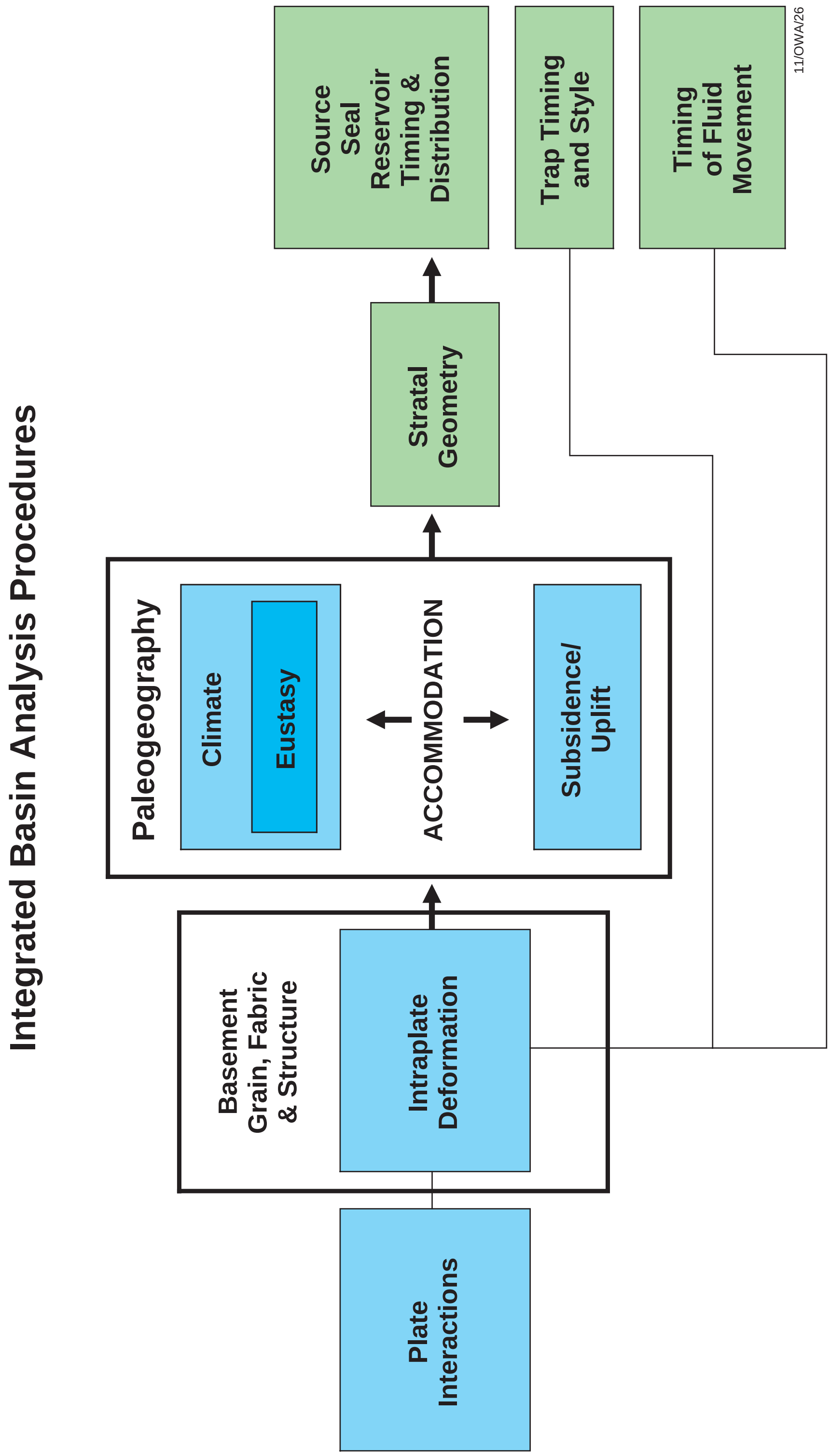

Figure 5 Intergrated basin analysis proceedures (after Loutit,1996).

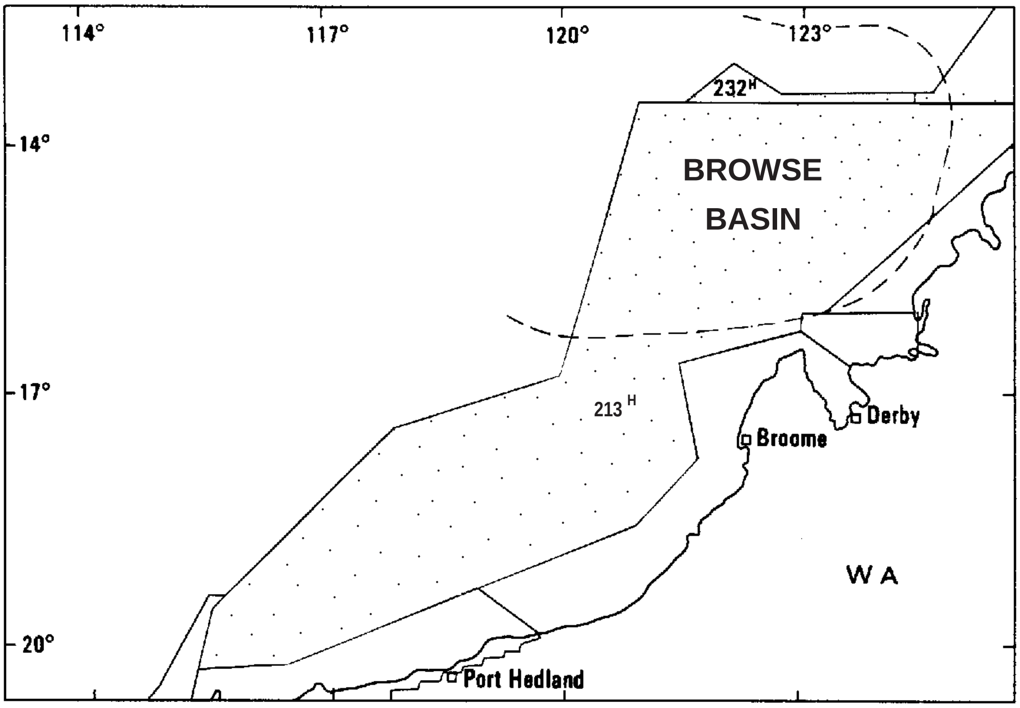

Figure 6a Permit status December 1964 (after Cadman *et al.*, 1991).

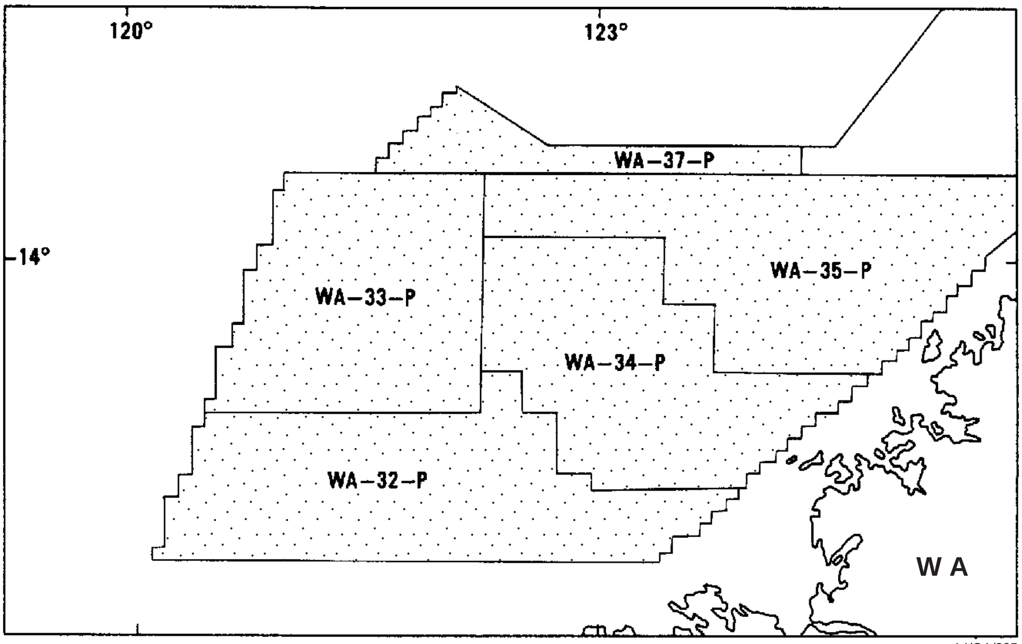

Figure 6b Permit status December 1969 (after Cadman *et al.*, 1991).

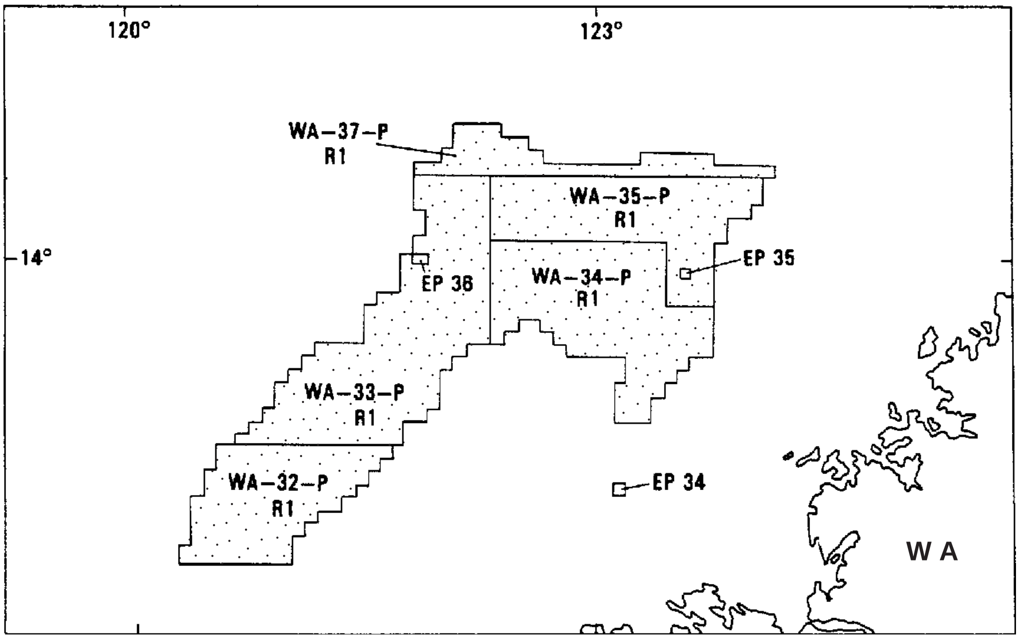

Figure 7a Permit status December 1975 (after Cadman *et al.,* 1991).

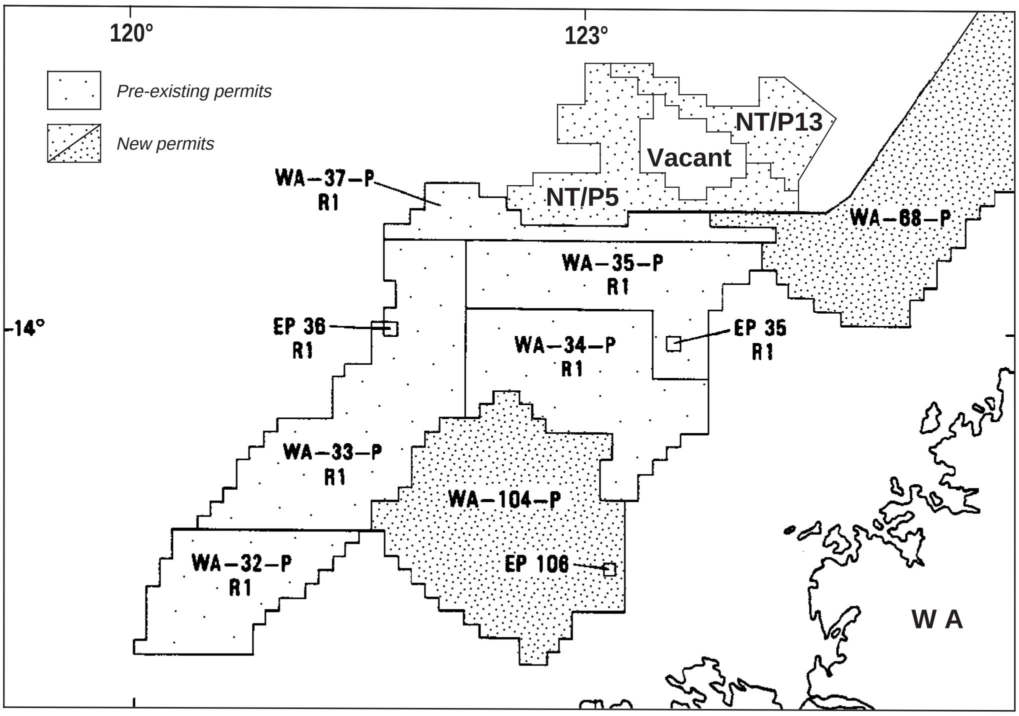

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Figure 7b Permit status January 1979 (after Cadman *et al.*, 1991).

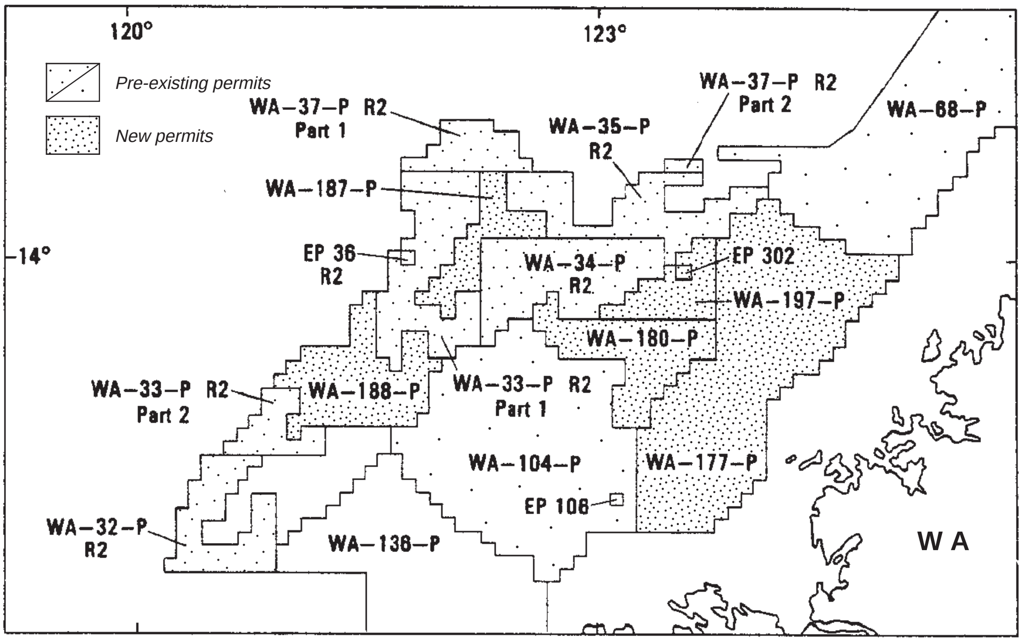


Figure 8 Permit status January 1983 (after Cadman *et al.*, 1991).

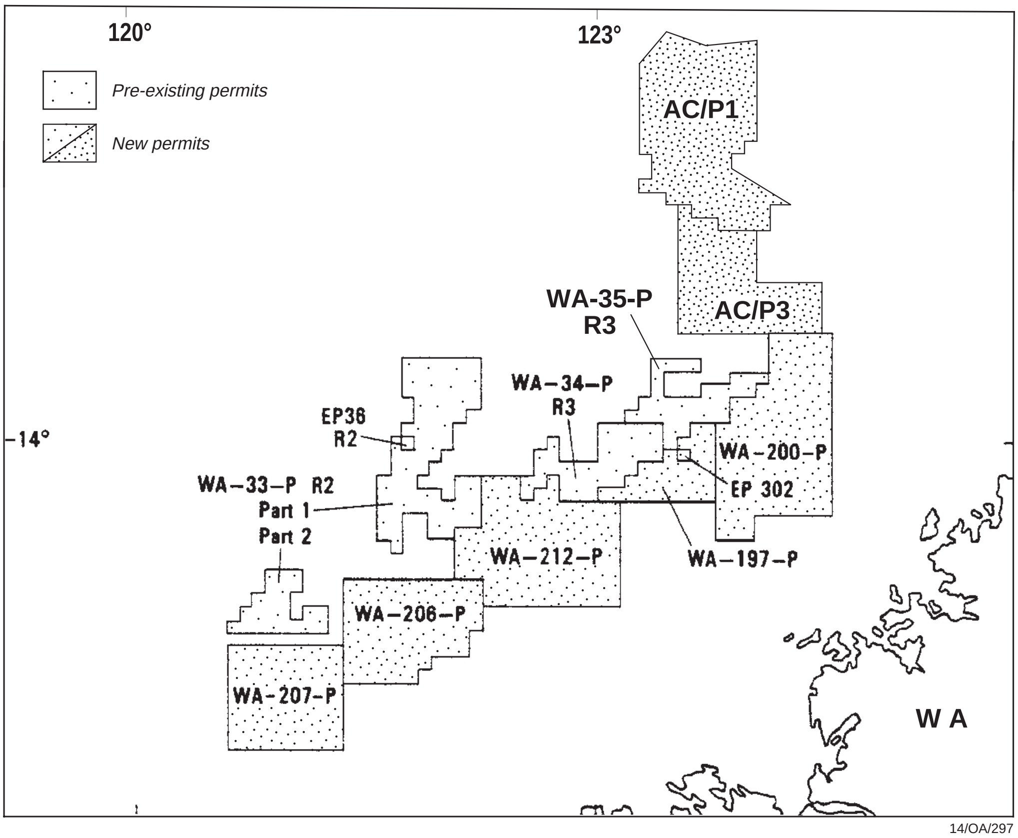
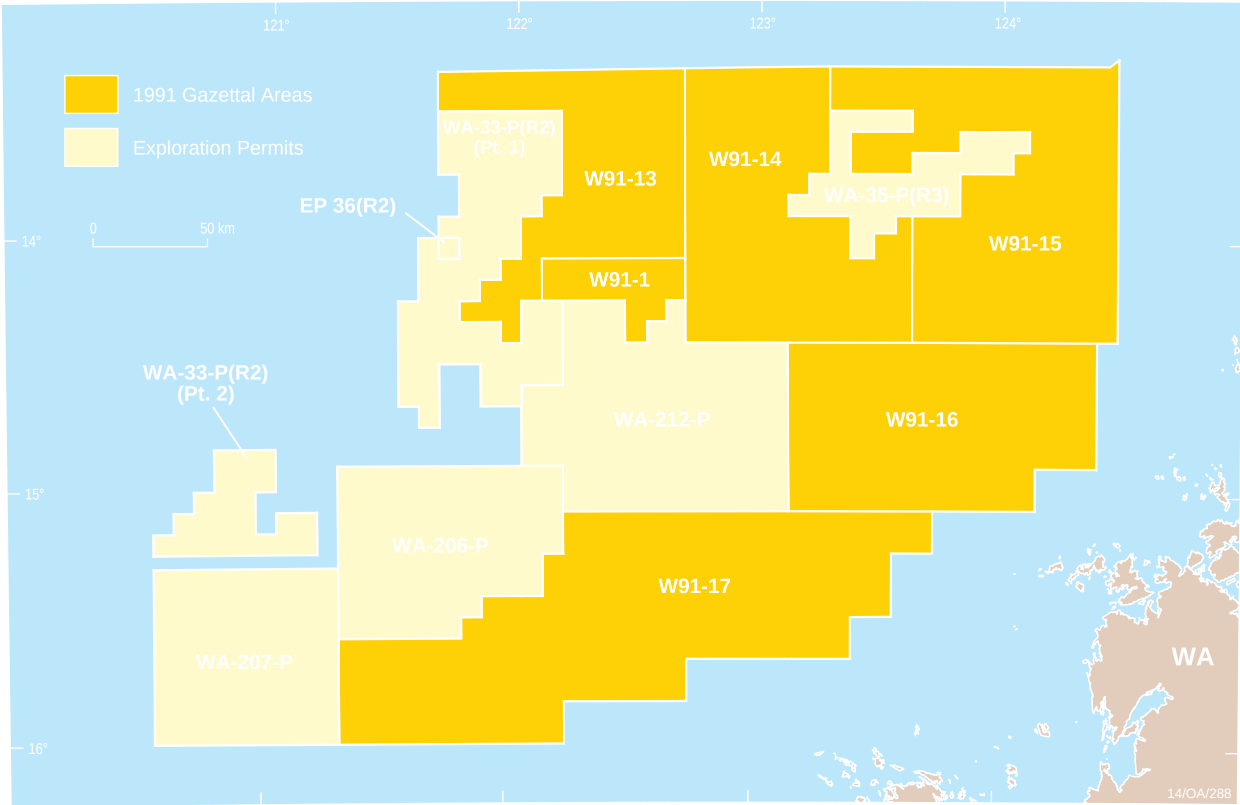
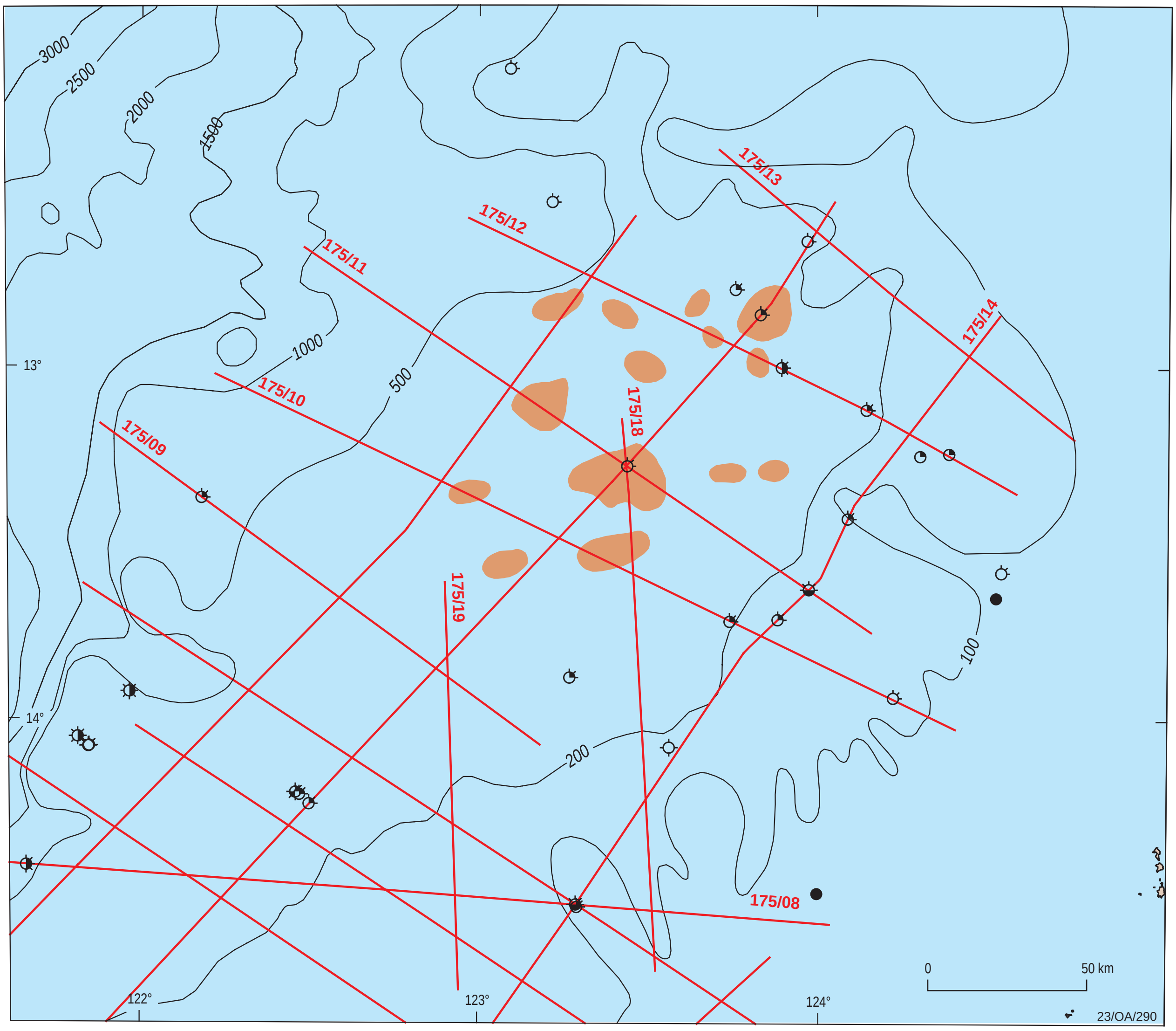


Figure 9a Permit status January 1989 (after Cadman *et al.,*1991)



121°
122°
123°
124°
14°
15°
16°
1991 Gazettal Areas
Exploration Permits
0
50 km
WA-33-P(R2)
(Pt. 1)
W91-13
W91-14
WA-35-P(R3)
W91-15
EP 36(R2)
W91-1
WA-33-P(R2)
(Pt. 2)
WA-212-P
W91-16
WA-206-P
W91-17
WA-207-P
WA
14/OA/288

Figure 9b



BBHR-97 (AGSO Survey 175)

Possible salt deposits

Figure 10 Location map of areas affected by impaired data due to geological factors.

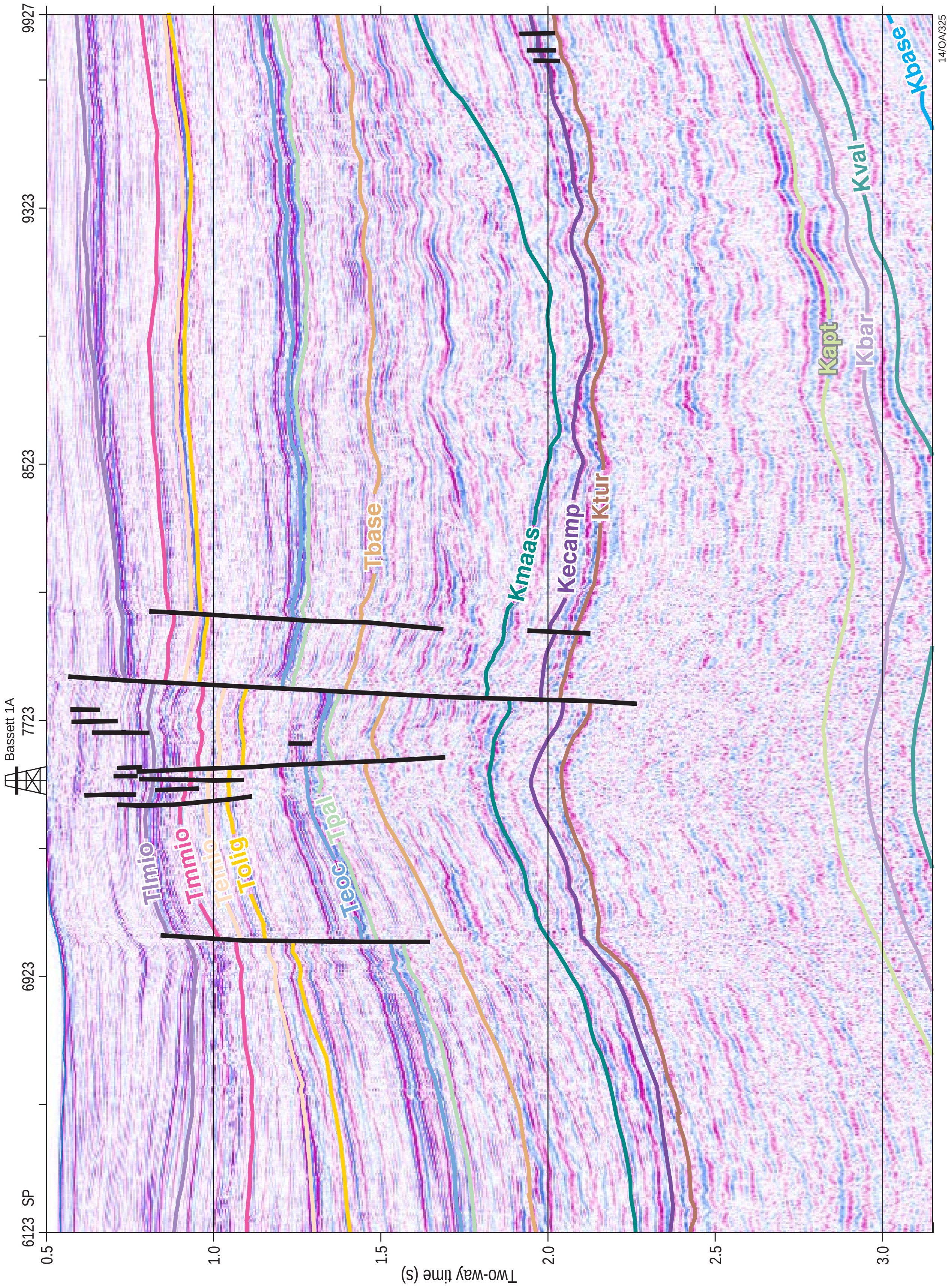


Figure 11 Seismic Line BBHR 175/11 over Bassett 1A showing a zone of impaired data below the Ktur (Turonian Unconformity) horizon. This effect is interpreted to result from geological factors related to fluid movement and cementation.

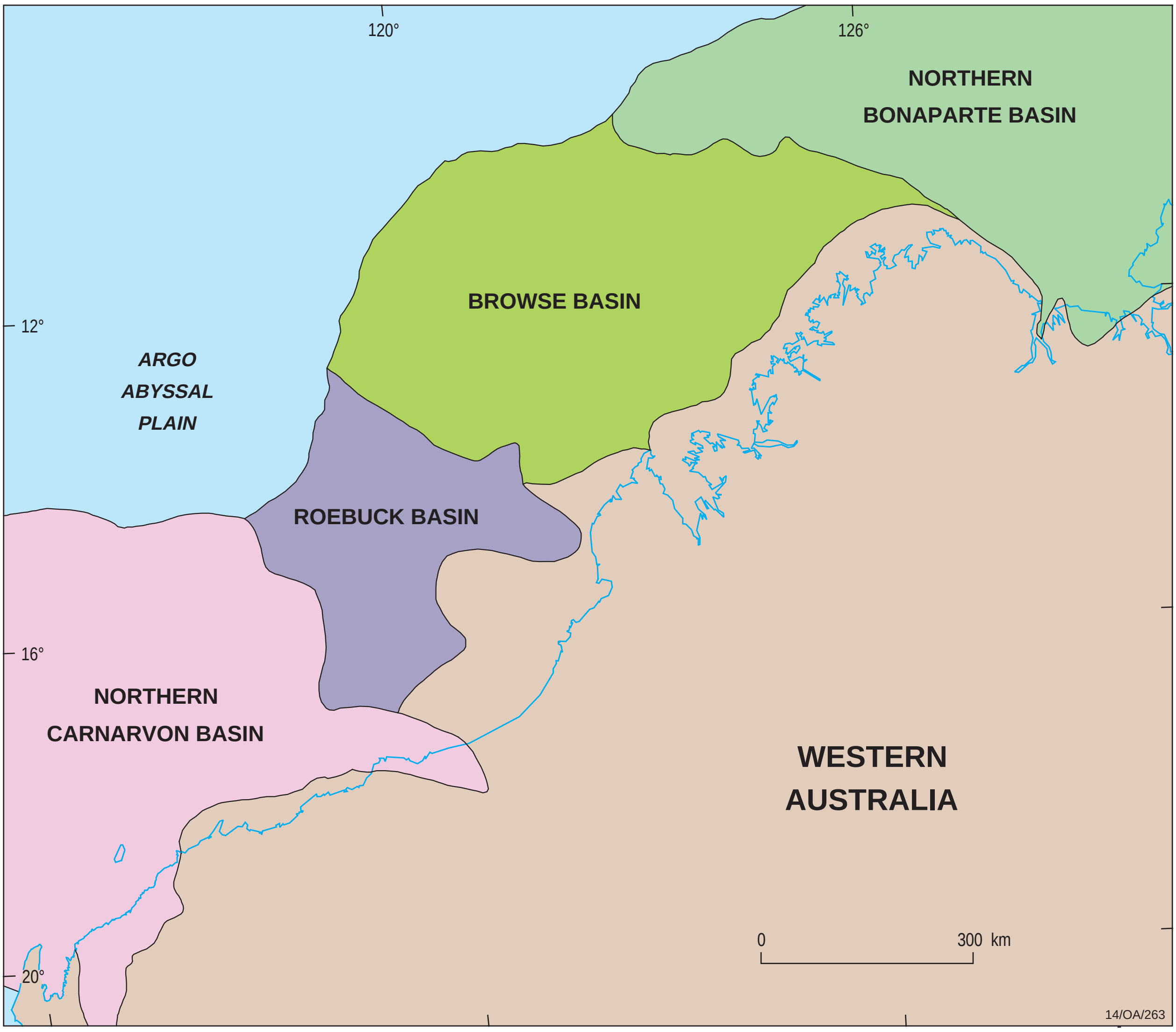


Figure 12 Sedimentary basins of the North West Shelf.

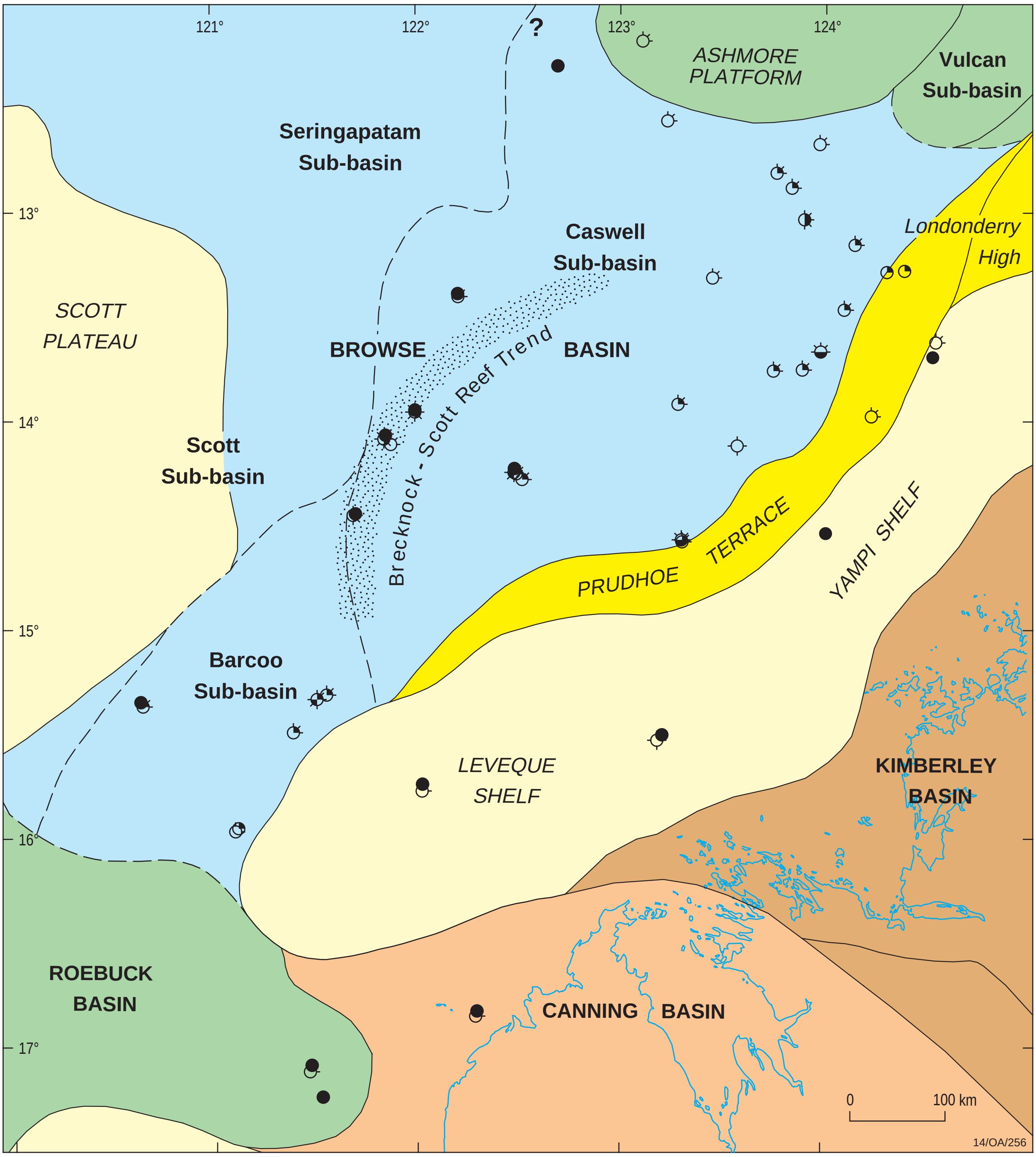


Figure 13 Browse Basin structural elements (modified after Hocking *et al.*,1994, and Symonds *et al.*,1994).

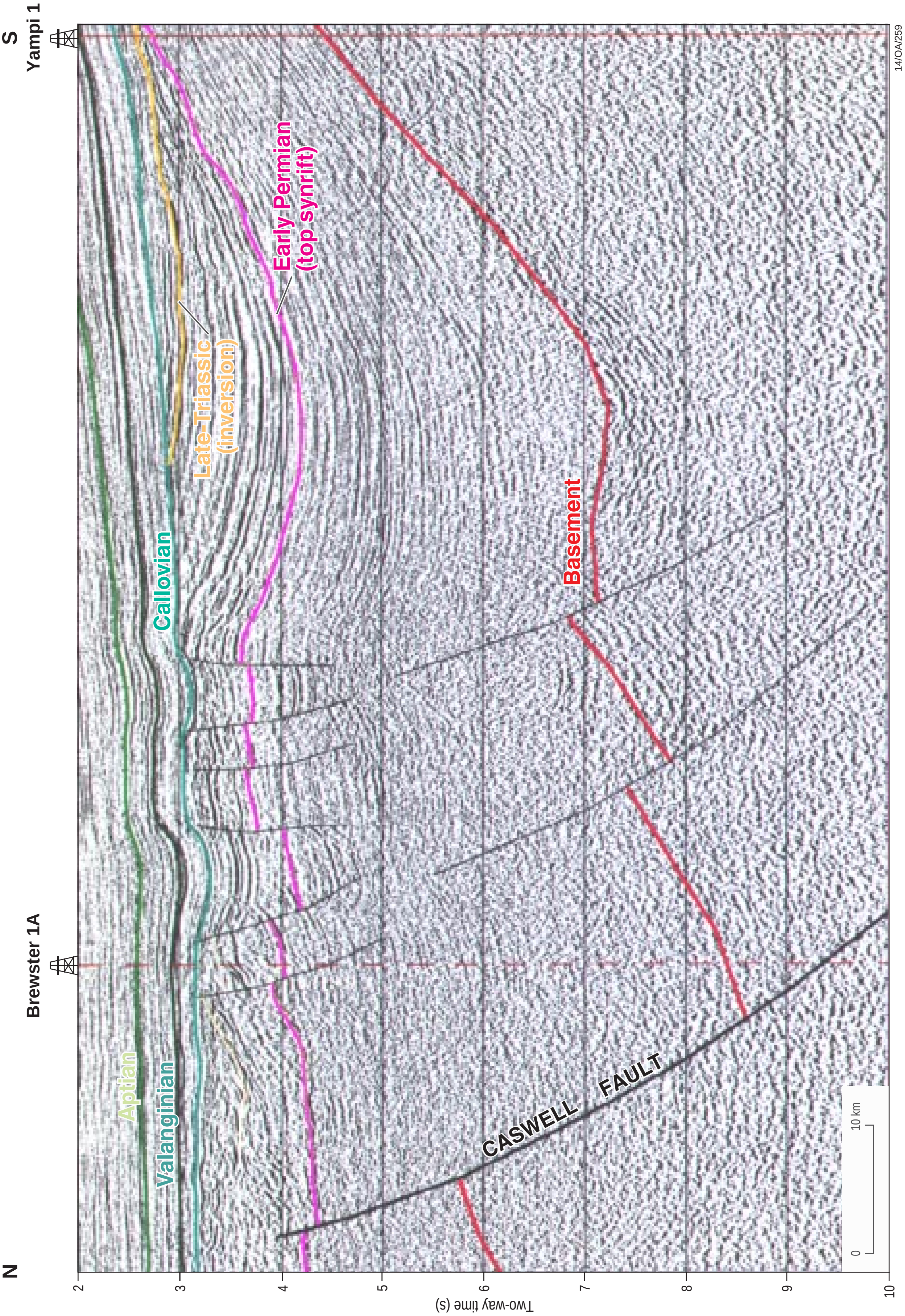


Figure 14 Portion of AGSO deep seismic line 130/13 imaging Palaeozoic halfgraben in the Caswell Sub-basin.

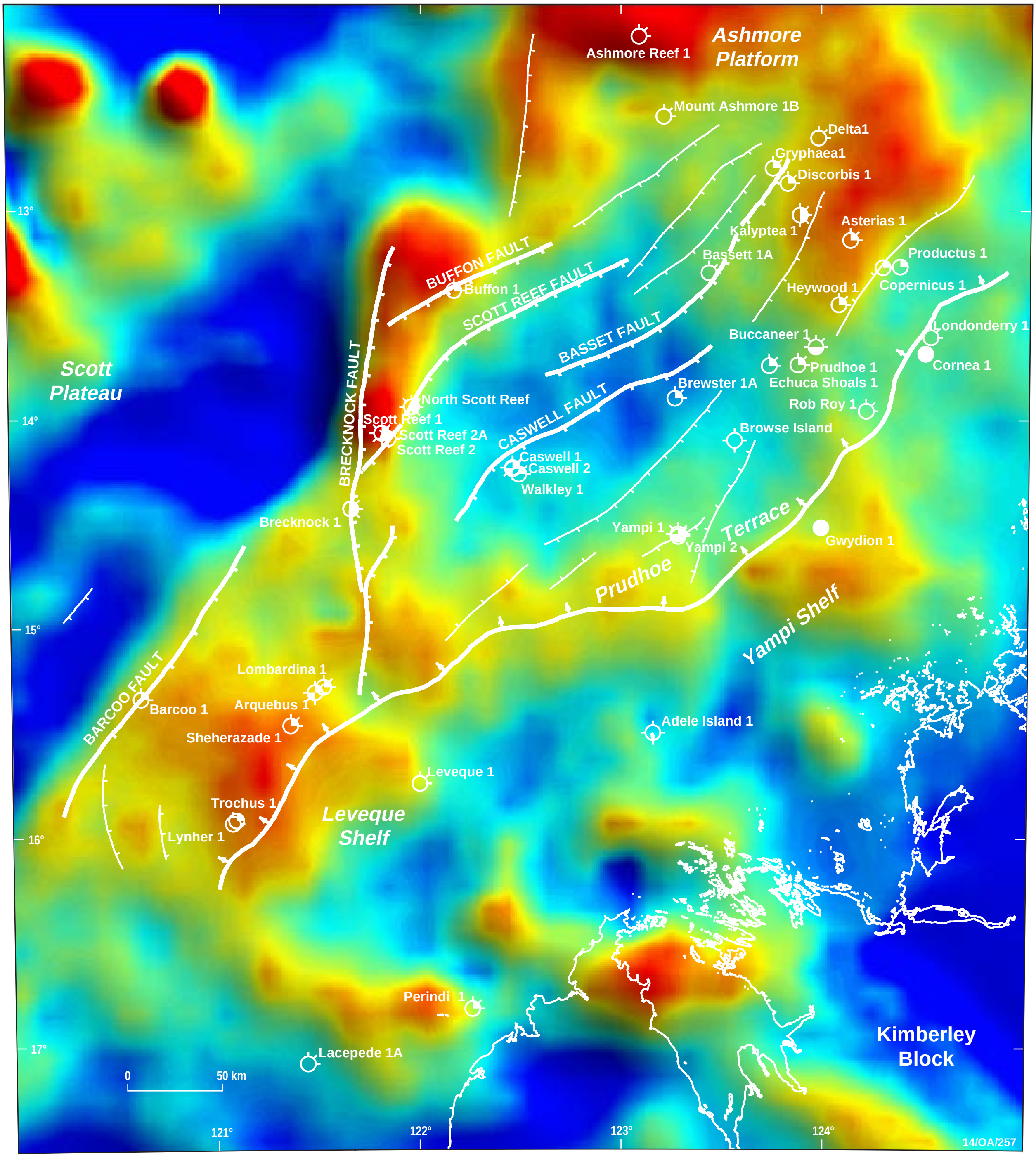


Figure 15 Major Palaeozoic fault zones overlain on satellite gravity image.

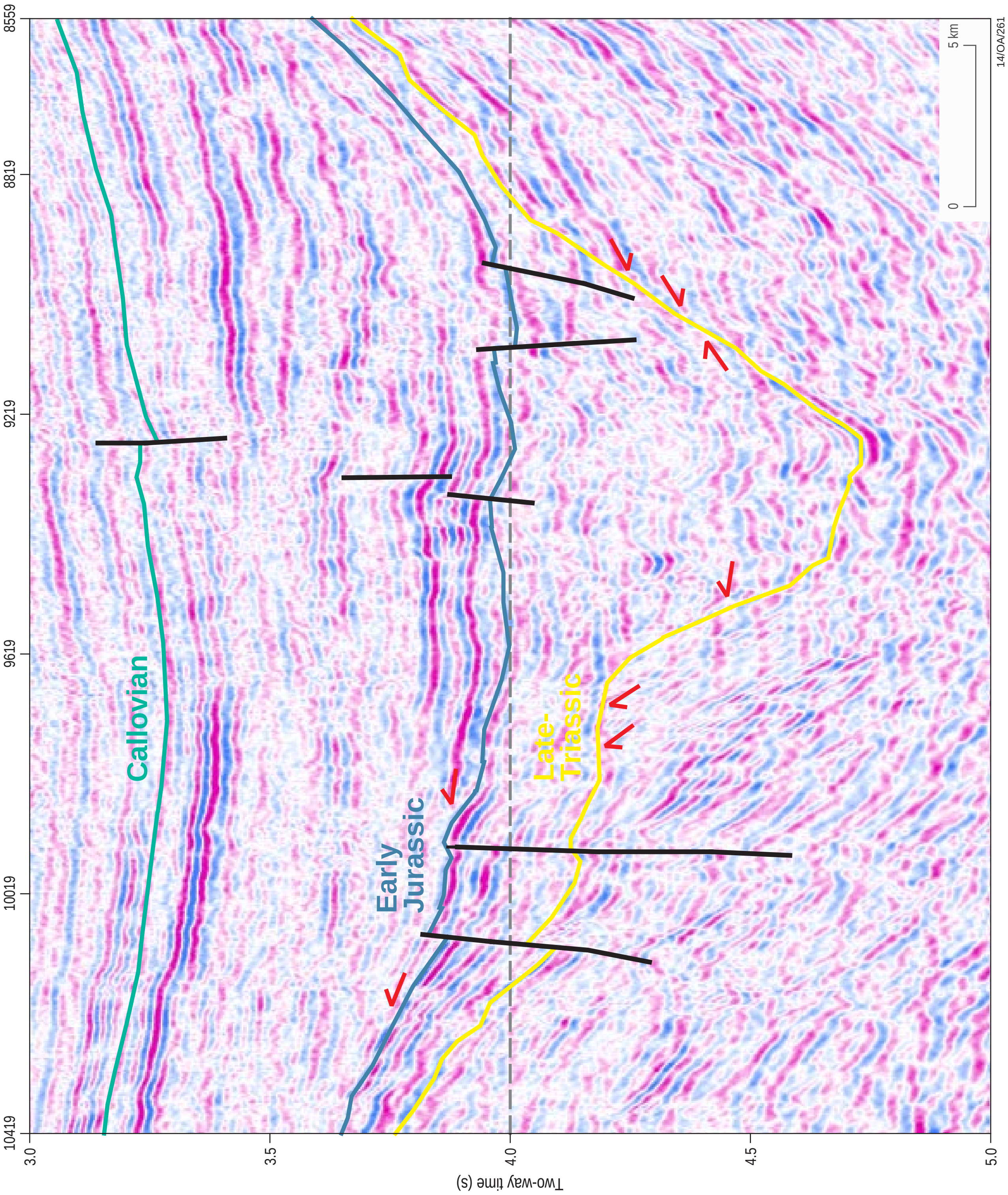


Figure 16 Portion of seismic line 175/08 showing Late Triassic inversion structures in the Caswell Sub-basin.

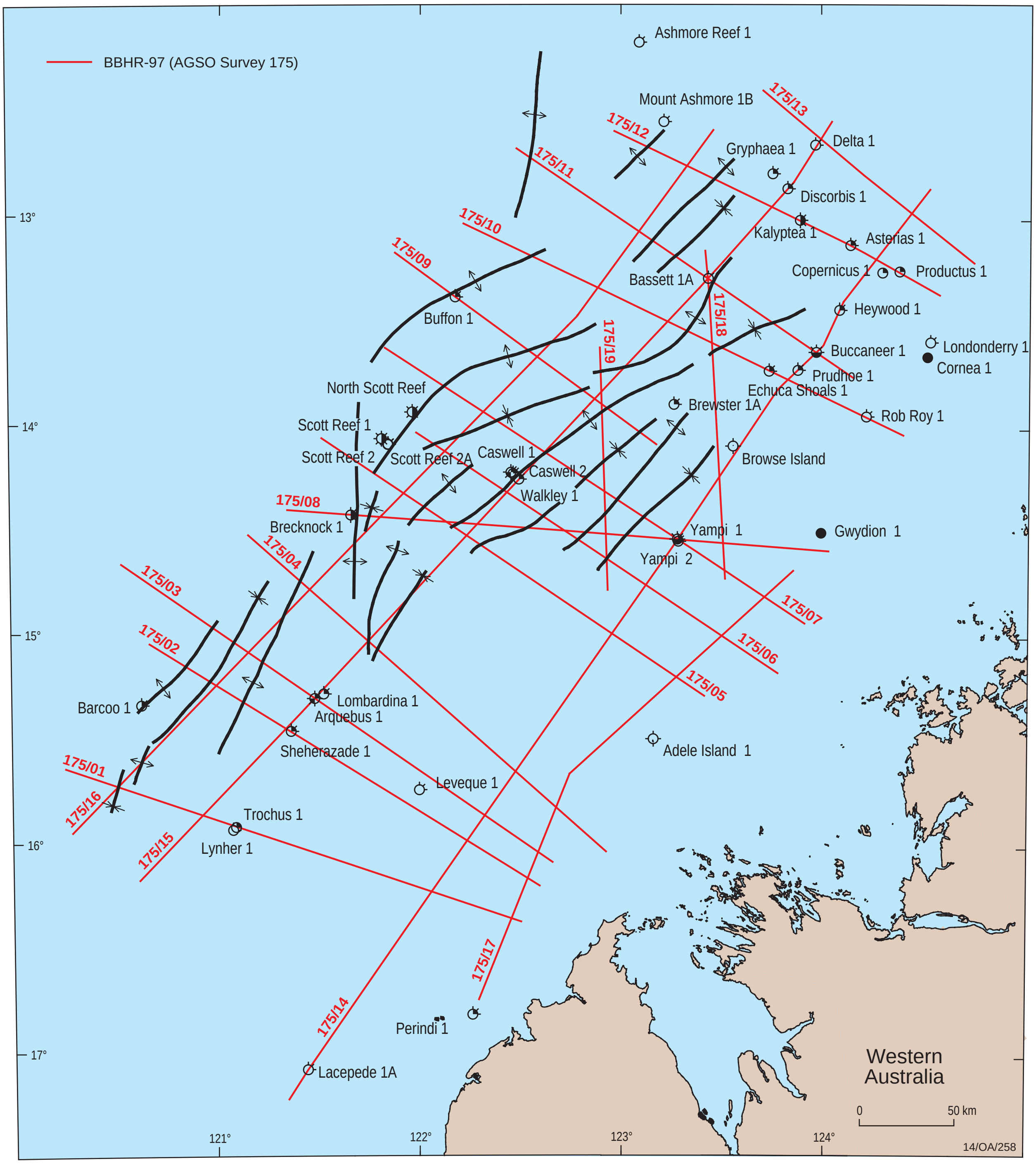


Figure 17 Late Triassic inversion structures in the Browse Basin.

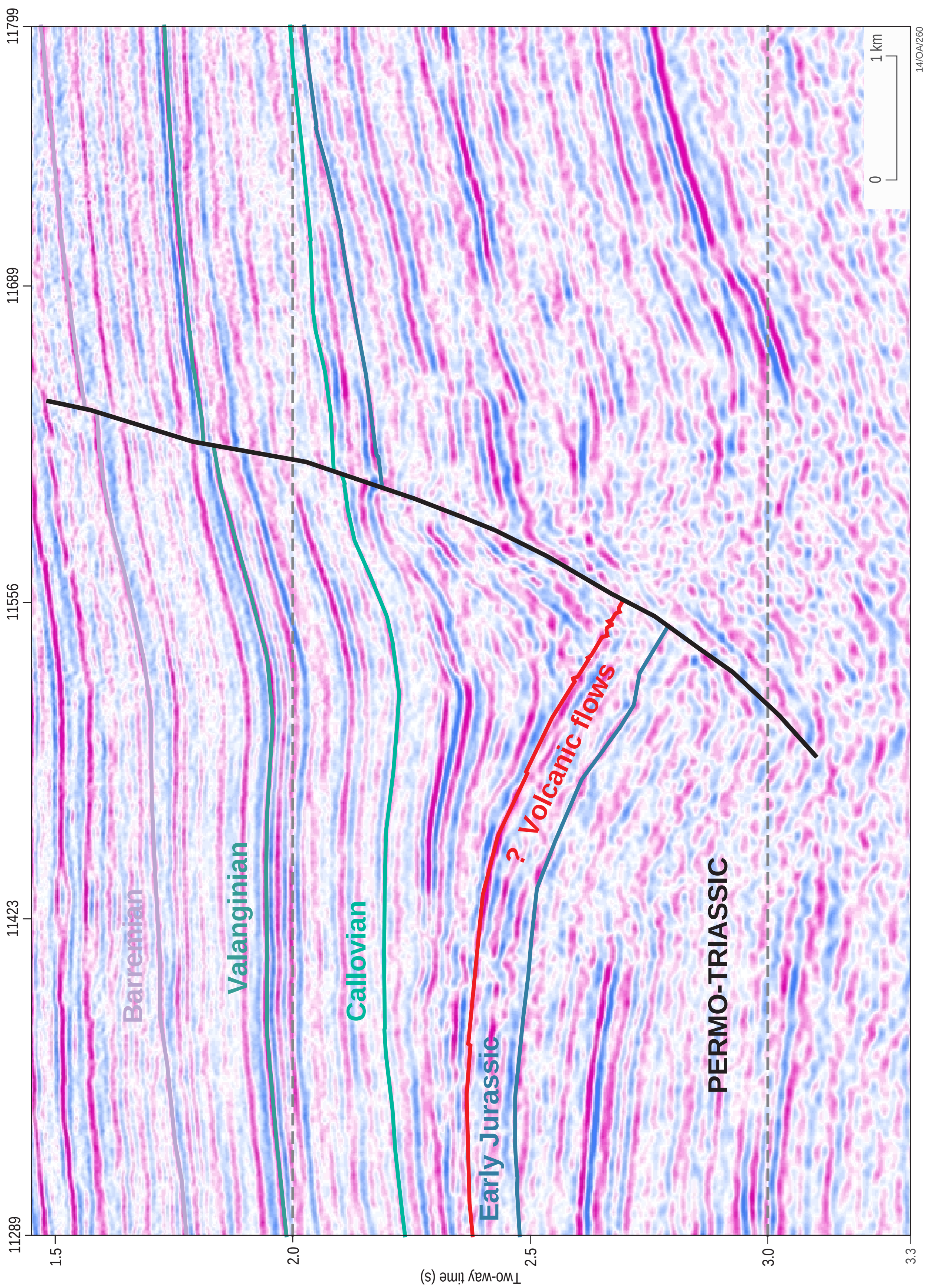


Figure 18 Portion of seismic line 175/07 showing Jurassic growth fault.

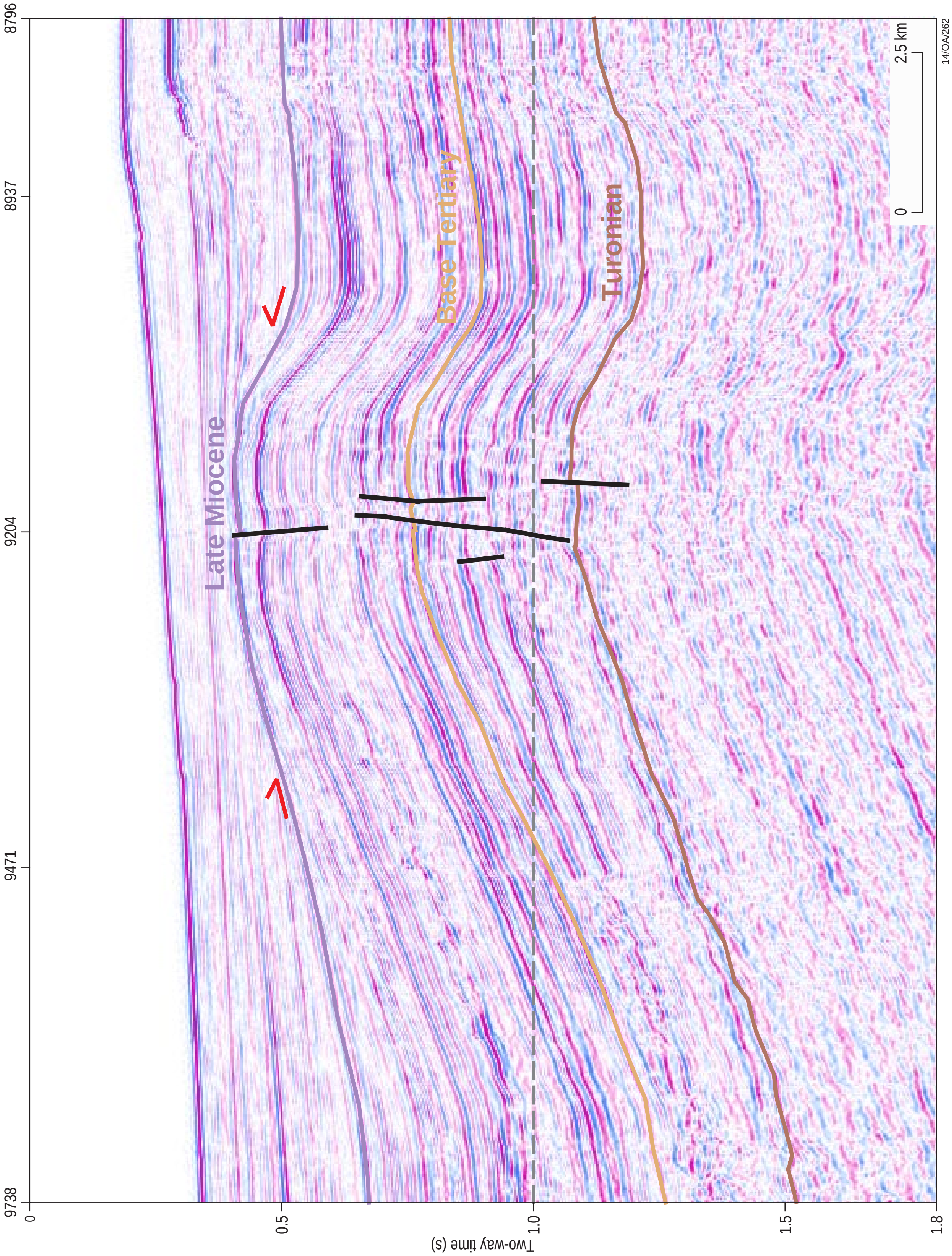


Figure 19 Portion of seismic line 175/03 showing Miocene inversion structure.

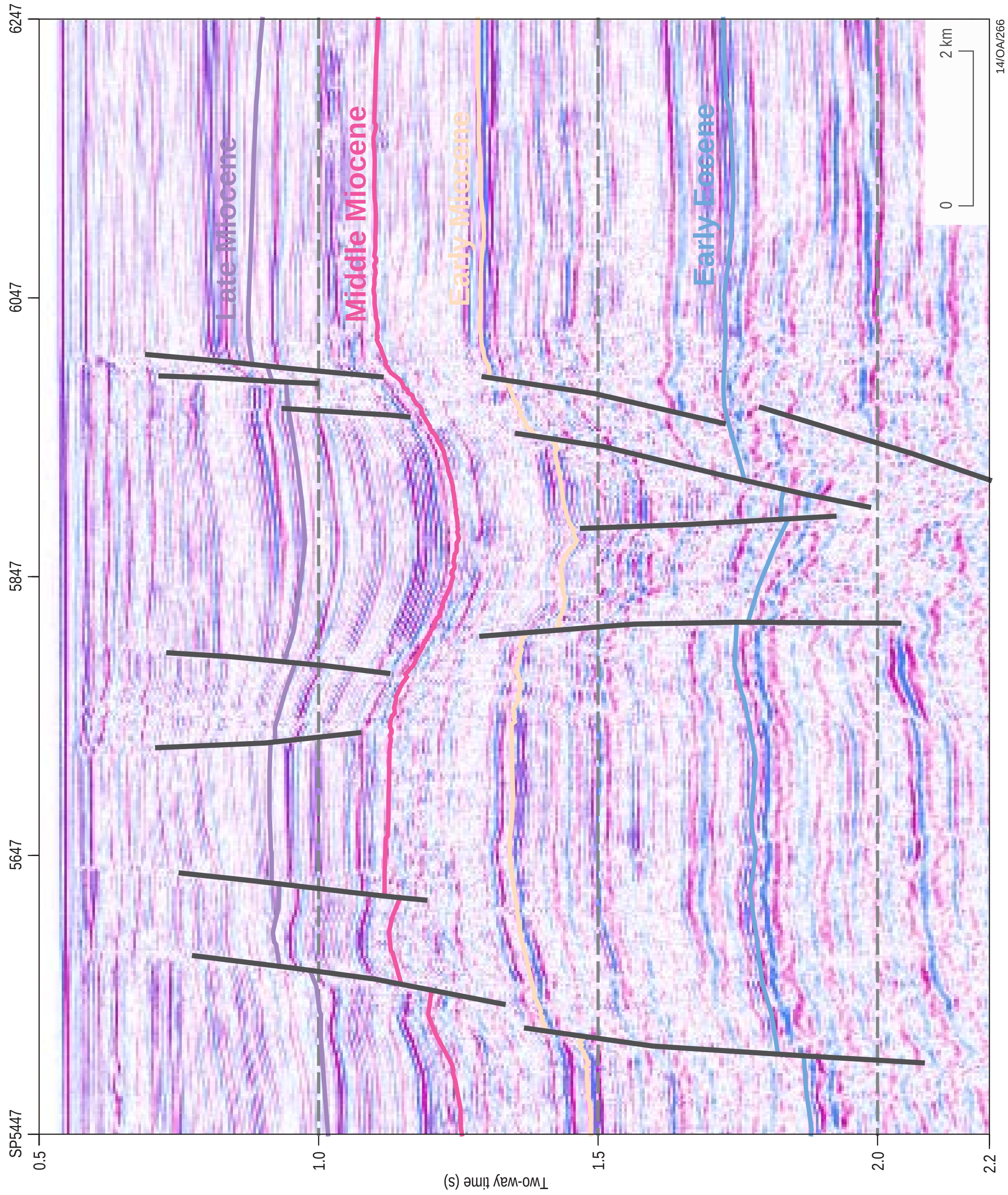


Figure 20 Portion of seismic line 175/11 showing possible salt withdrawal structure.

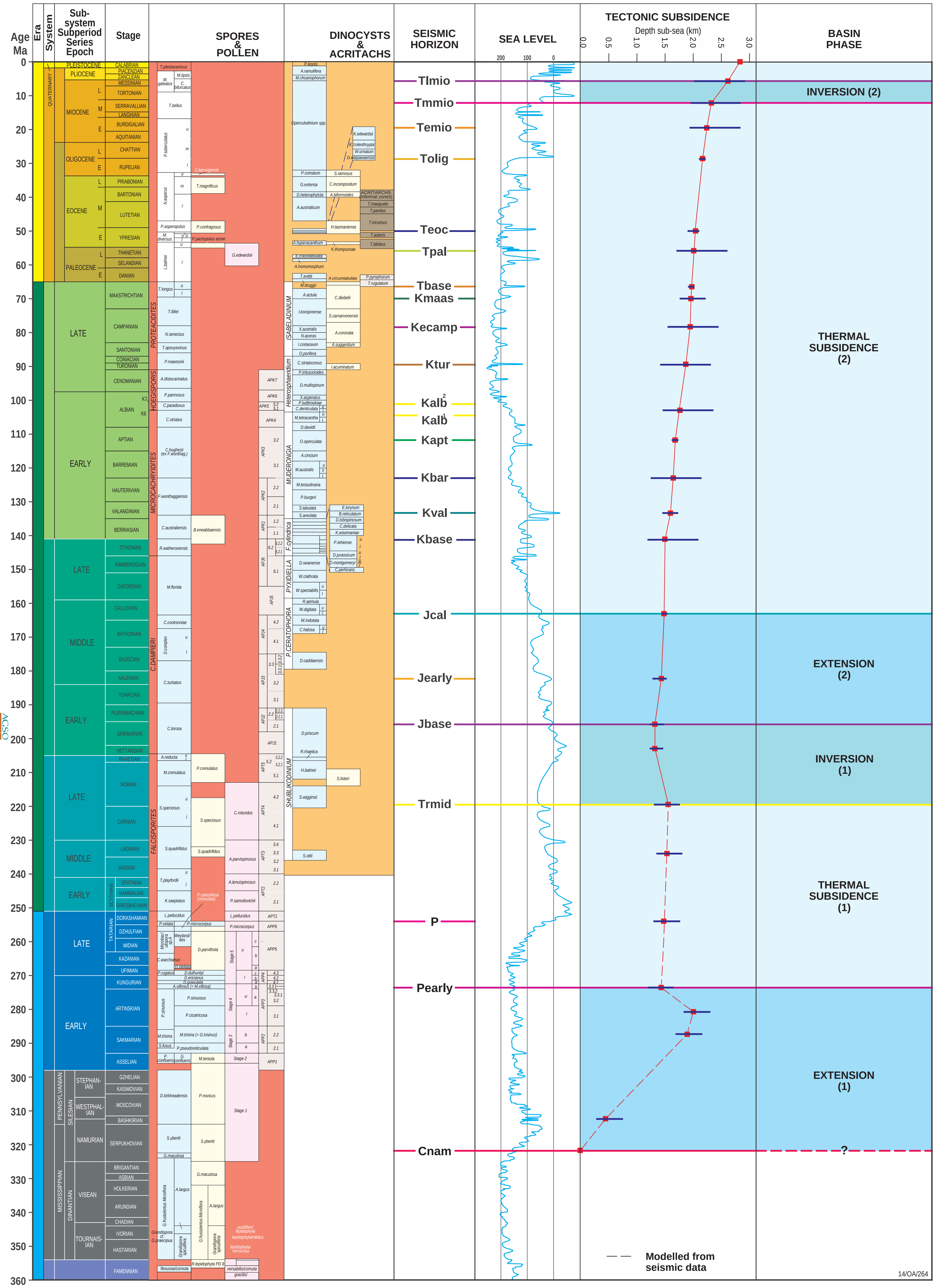


Figure 21 Tectonostratigraphic summary diagram. AGSO timescale (Young & Laurie, 1996); sea level curve (Haq *et al.*, 1988; Greenlee & Lehmann, 1993; Schutter, pers.comm.) modified to AGSO timescale; subsidence curve from Caswell Sub-basin for Mesozoic to Cainozoic.

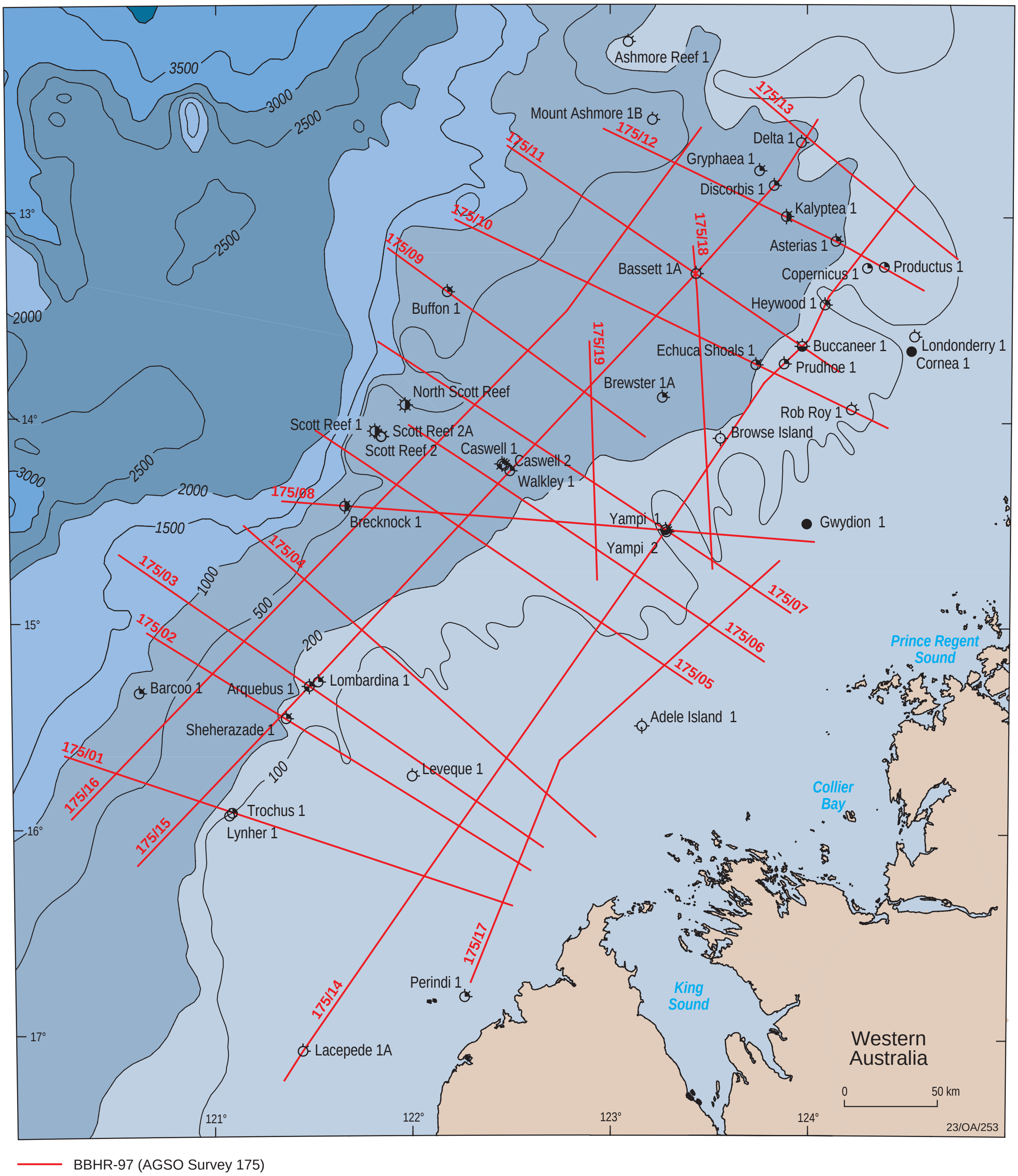


Figure 22 BBHR line and well location map.

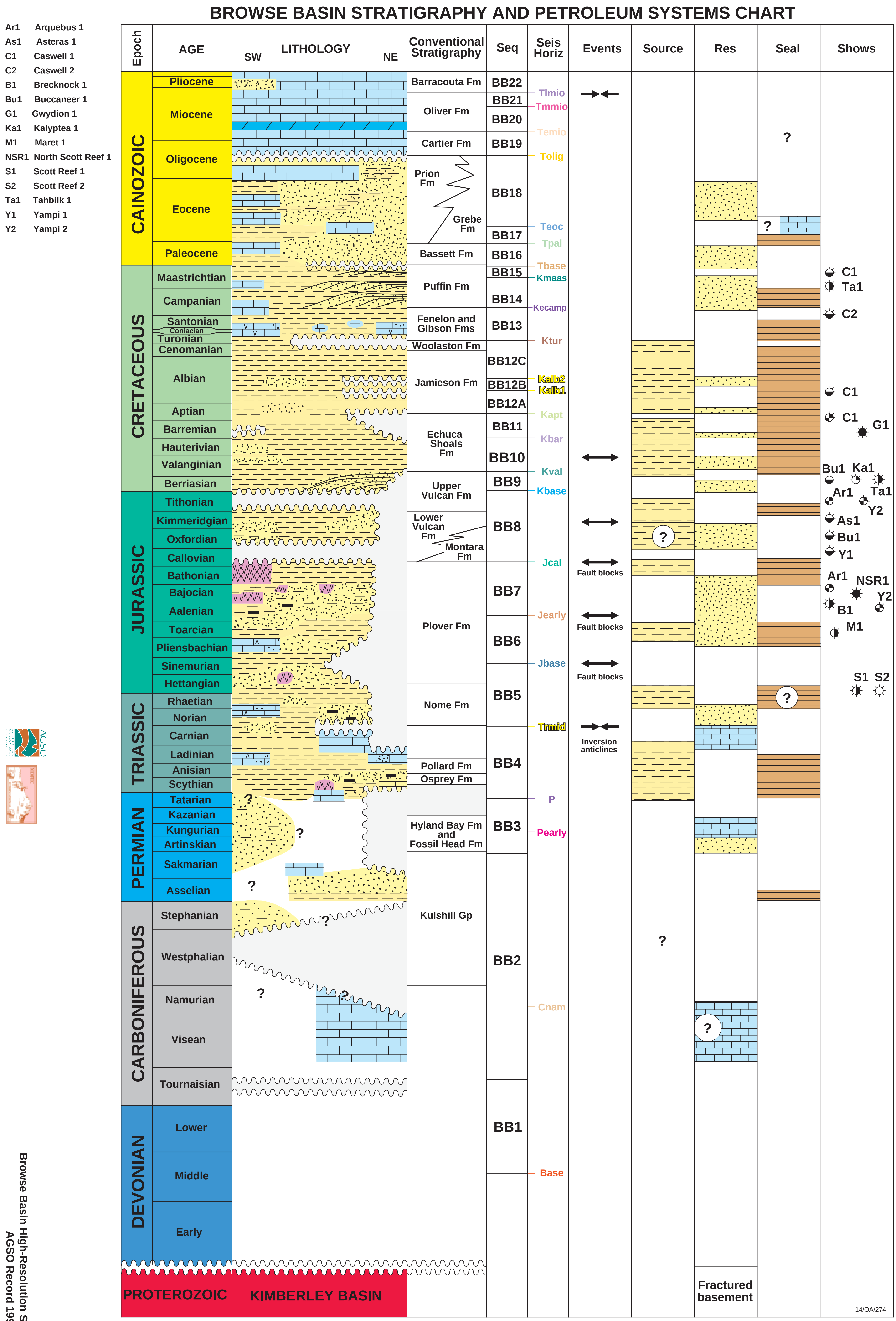


Figure 23 Browse Basin stratigraphy and petroleum systems chart (lithology modified from Symonds *et al.*, 1994), with hydrocarbon shows.

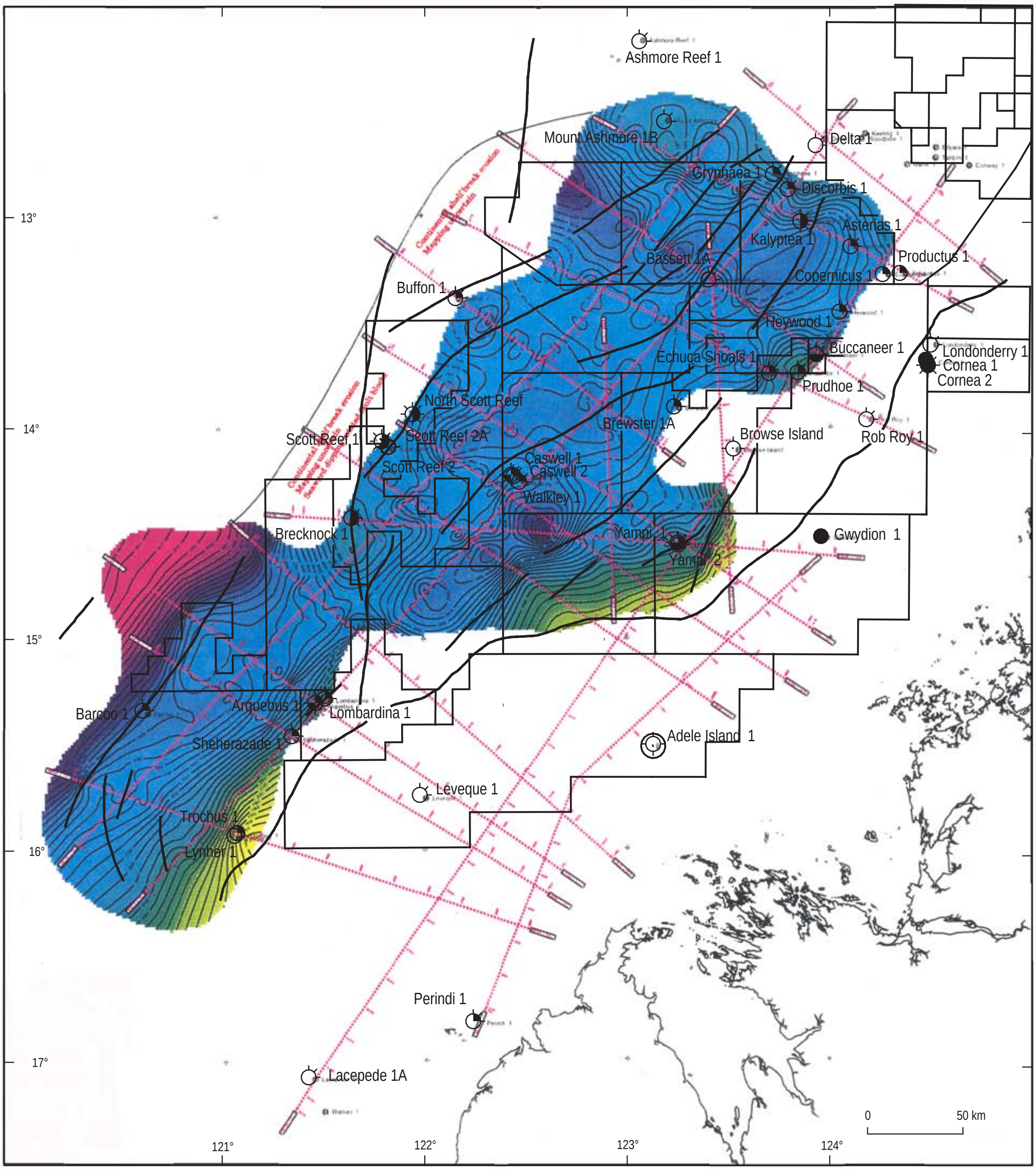


Figure 24 Time structure contour map on Late Triassic Inversion Event (Trmid Unconformity). This map is also included as Plate 9.

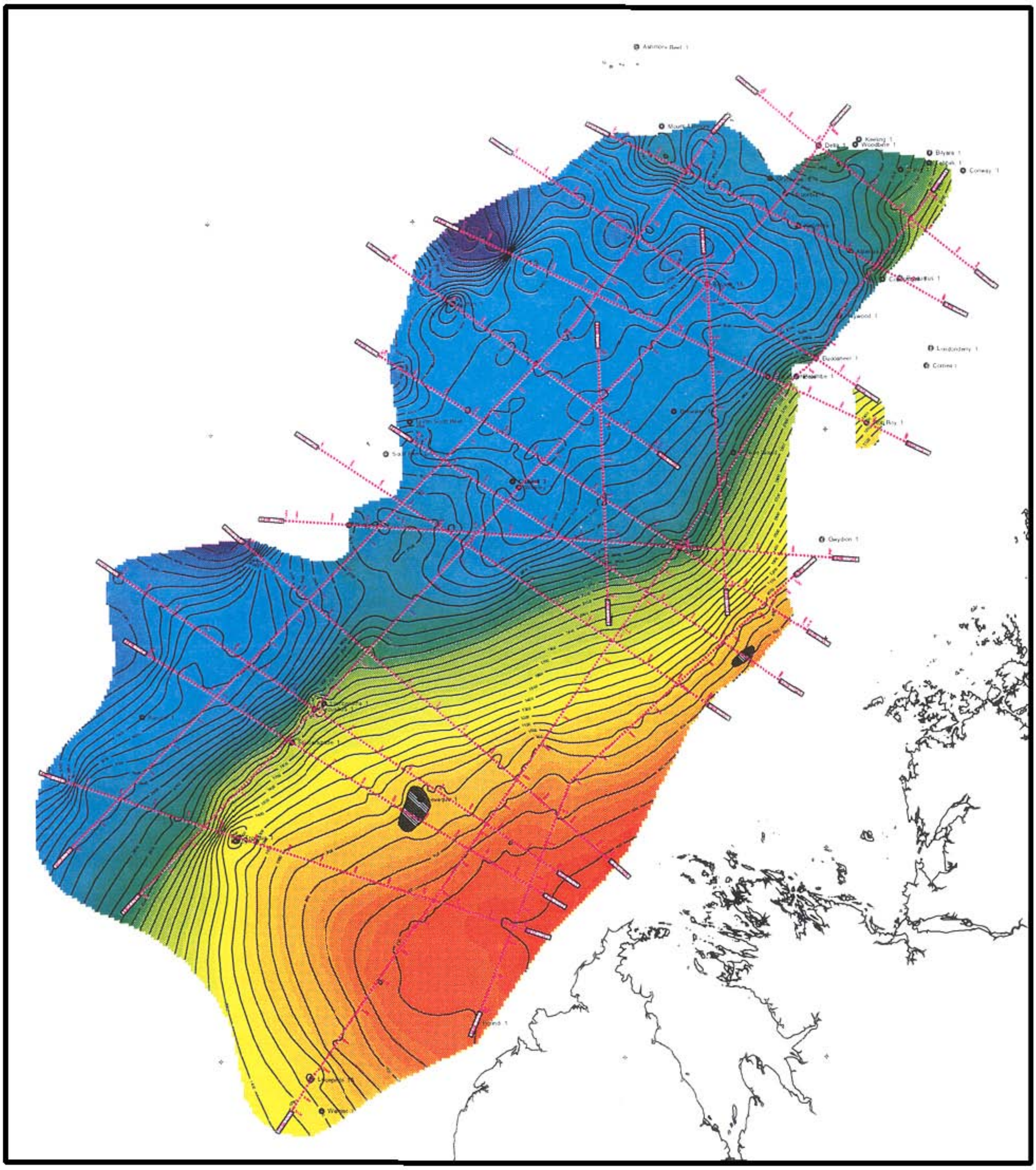


Figure 25 Time structure contour map on Jcal horizon (Intra-Callovian Unconformity). This map is also included as Plate 10.

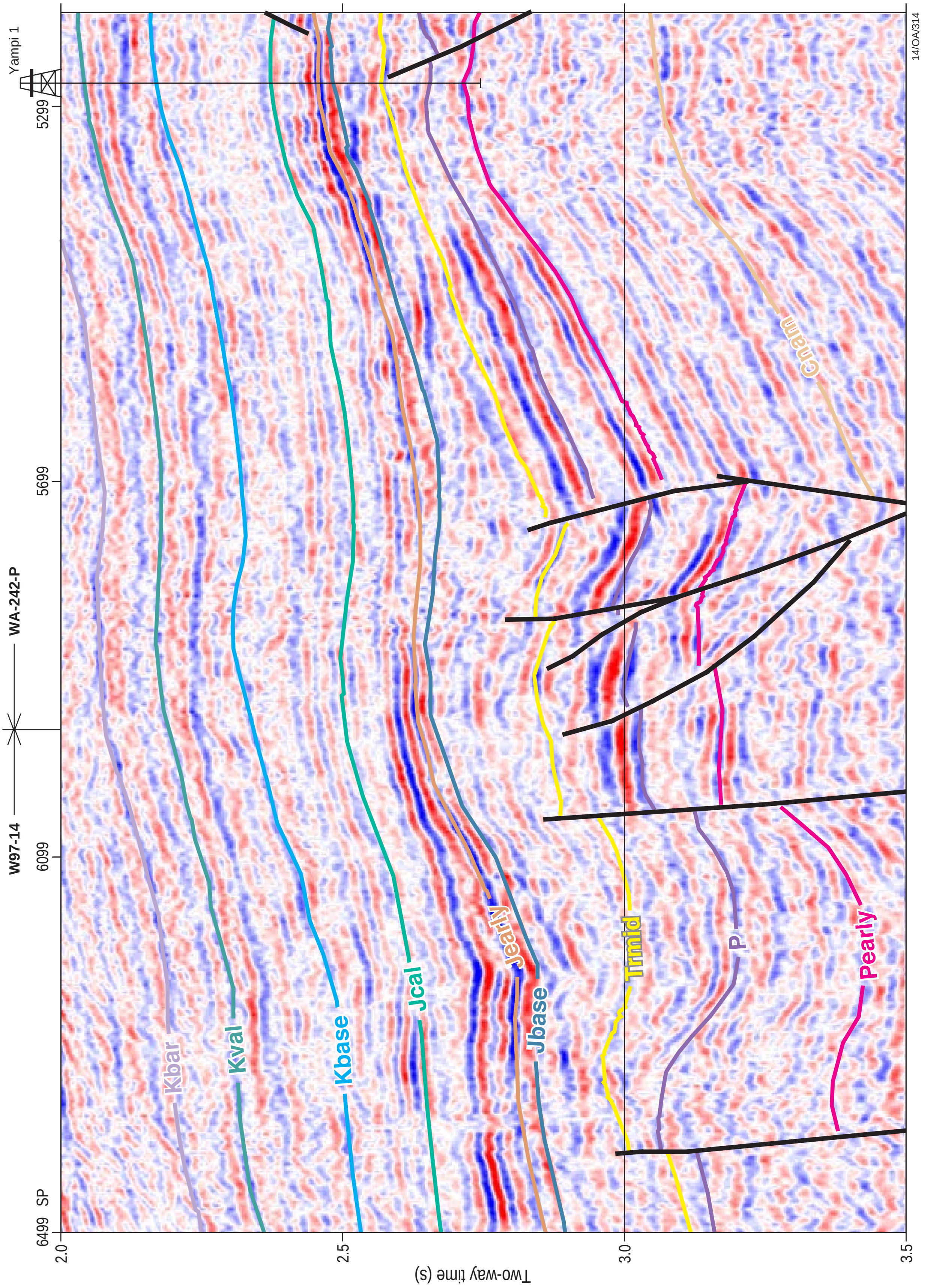
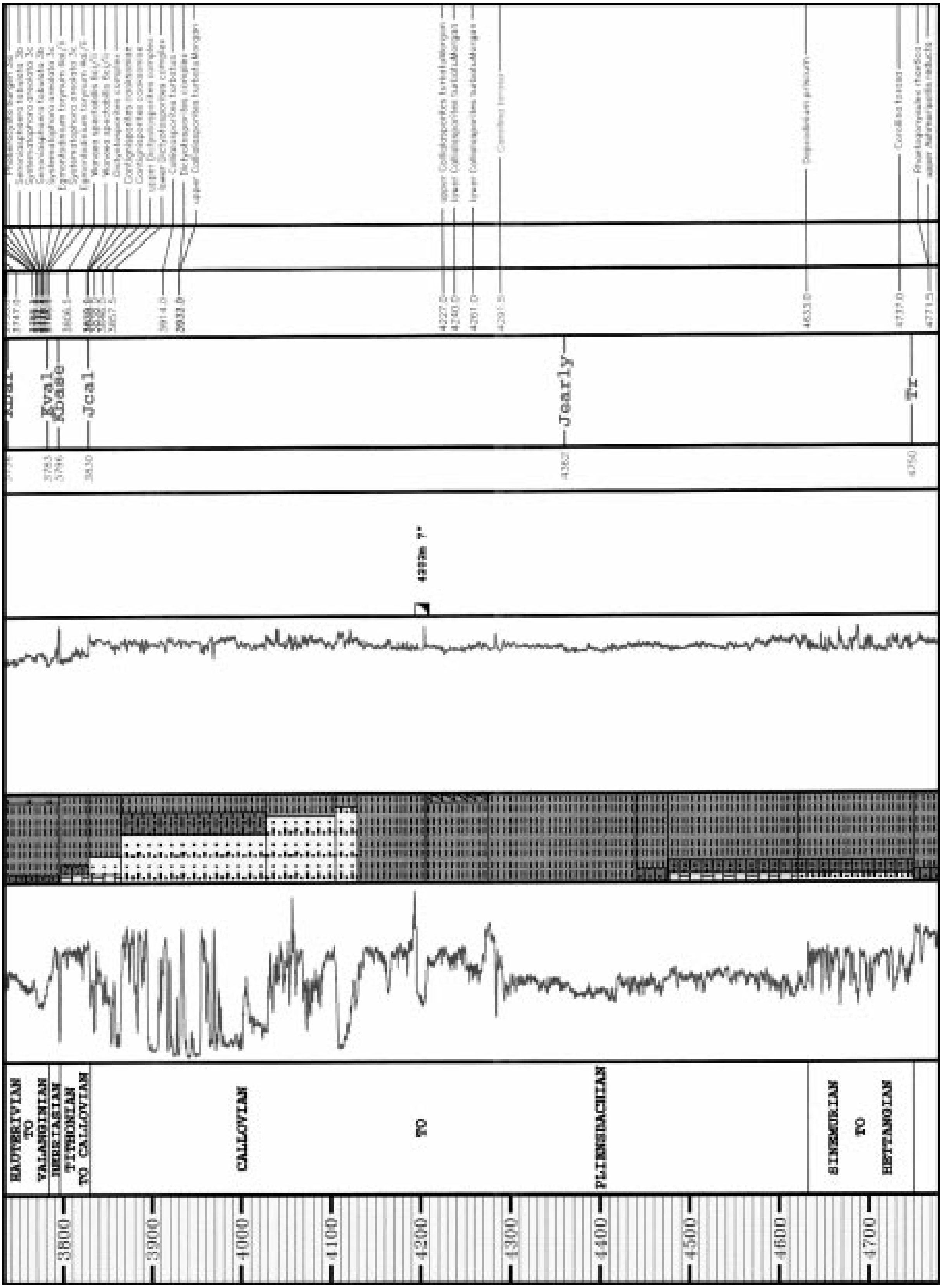


Figure 26 Seismic Line 175/08 downdip pf Yampi 1 (within W97-14) showing Callovian horst block, early Jurassic volcanic rocks, and possible DHI in overlying drape sequence.



14/OA/308

Figure 27 Barcoo 1 composite well log showing the upward gradation of the Early Jurassic to Callovian succession from marine (distal deltaic) to fluvio-deltaic facies. The deposition of significant sand facies in the outer Barcoo Sub-basin was terminated by the late Callovian.

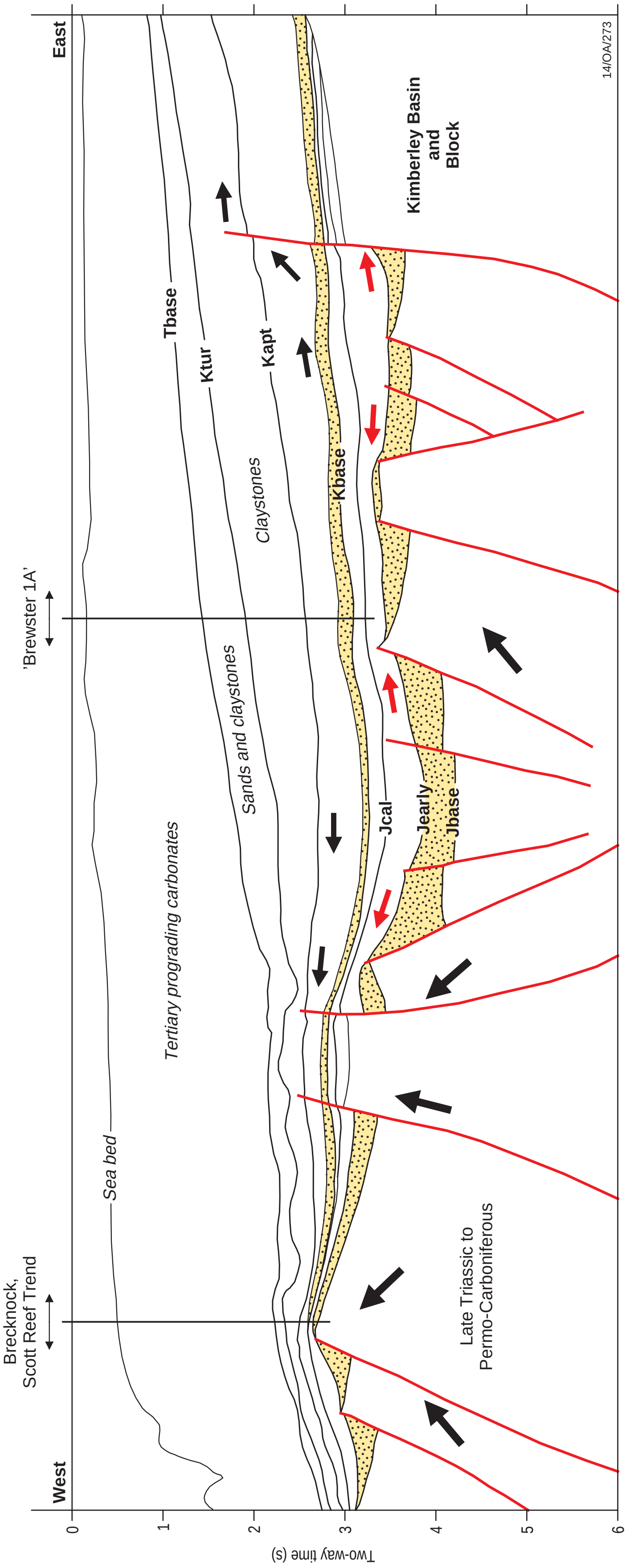
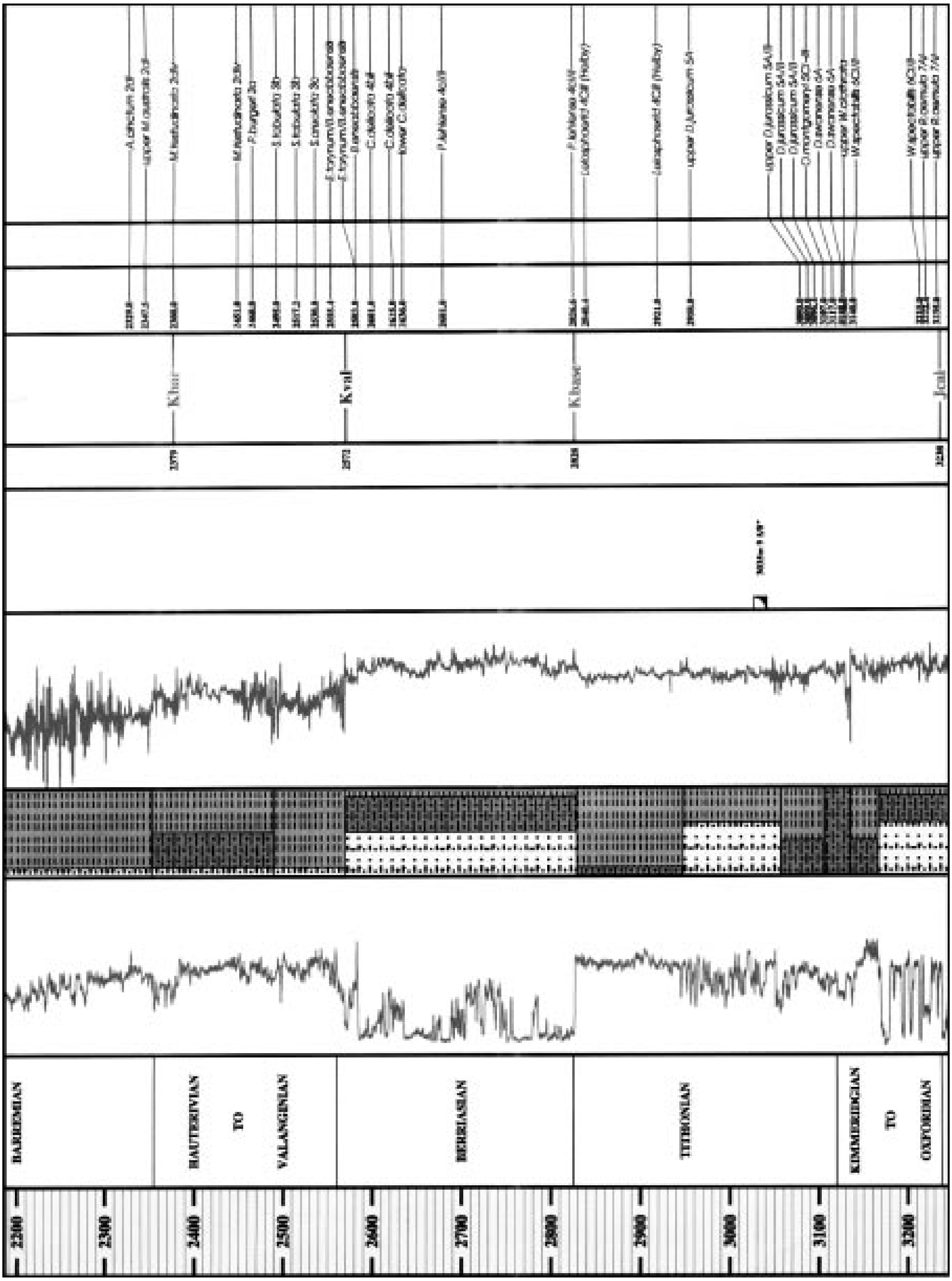


Figure 28 Schematic cross-section showing the distribution and testing of reservoir intervals in Early and Middle Jurassic (C. torosa to C. turbatus DZ) and Berriasian fluvio-deltaic sands. The arrows indicate migration paths from potential source rocks.



14/OA/309

Figure 29 Yampi 1 composite well log showing the truncation of the Late Jurassic highstand shale by the Base Cretaceous Unconformity (Kbase). Also note the sequence boundary developed within the *C. delicata* DZ.

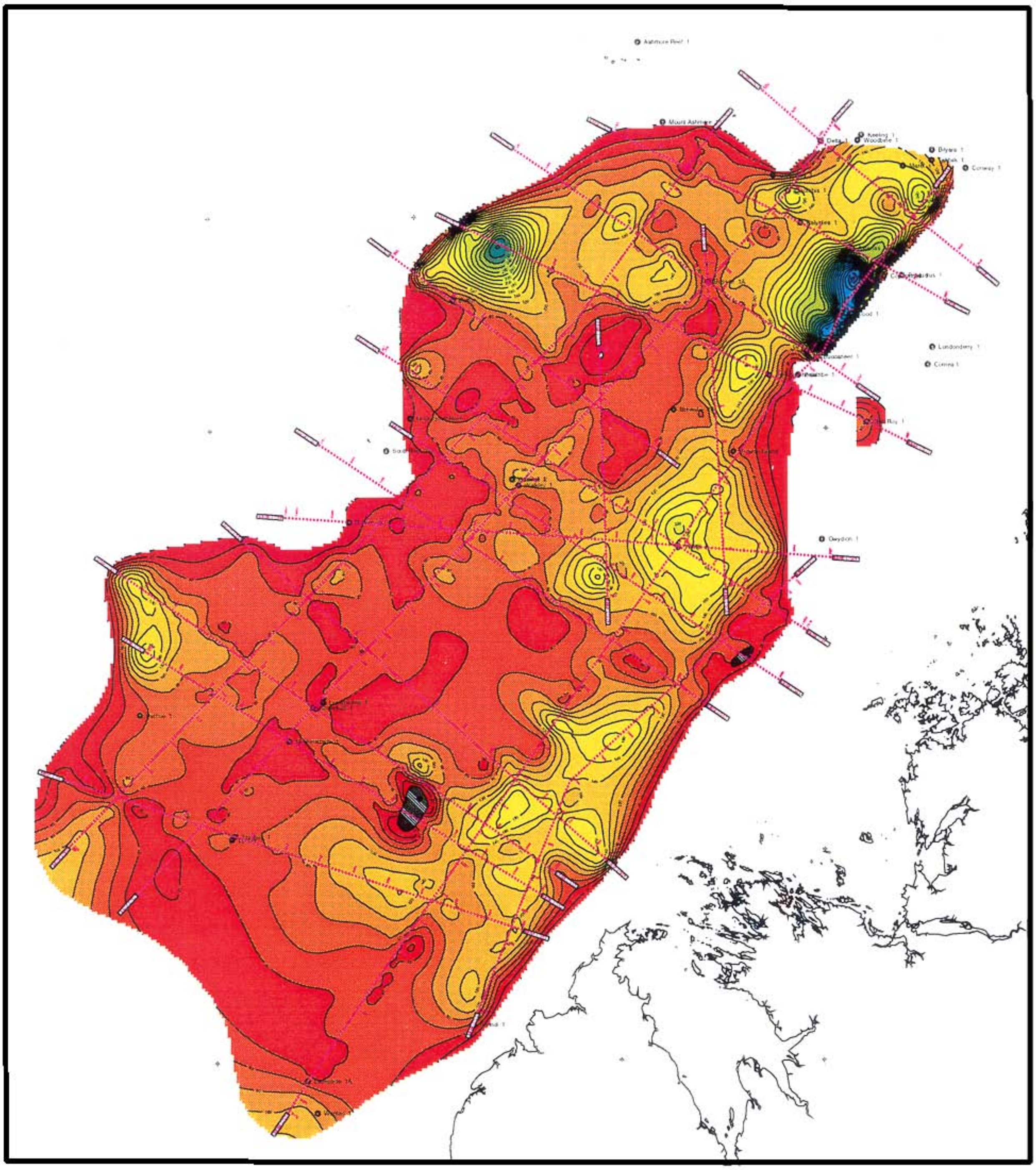


Figure 30 Time isopach map of Jcal to Kbase sequence (Intra-Callovian to Base Cretaceous).
This map is also included as Plate 17.

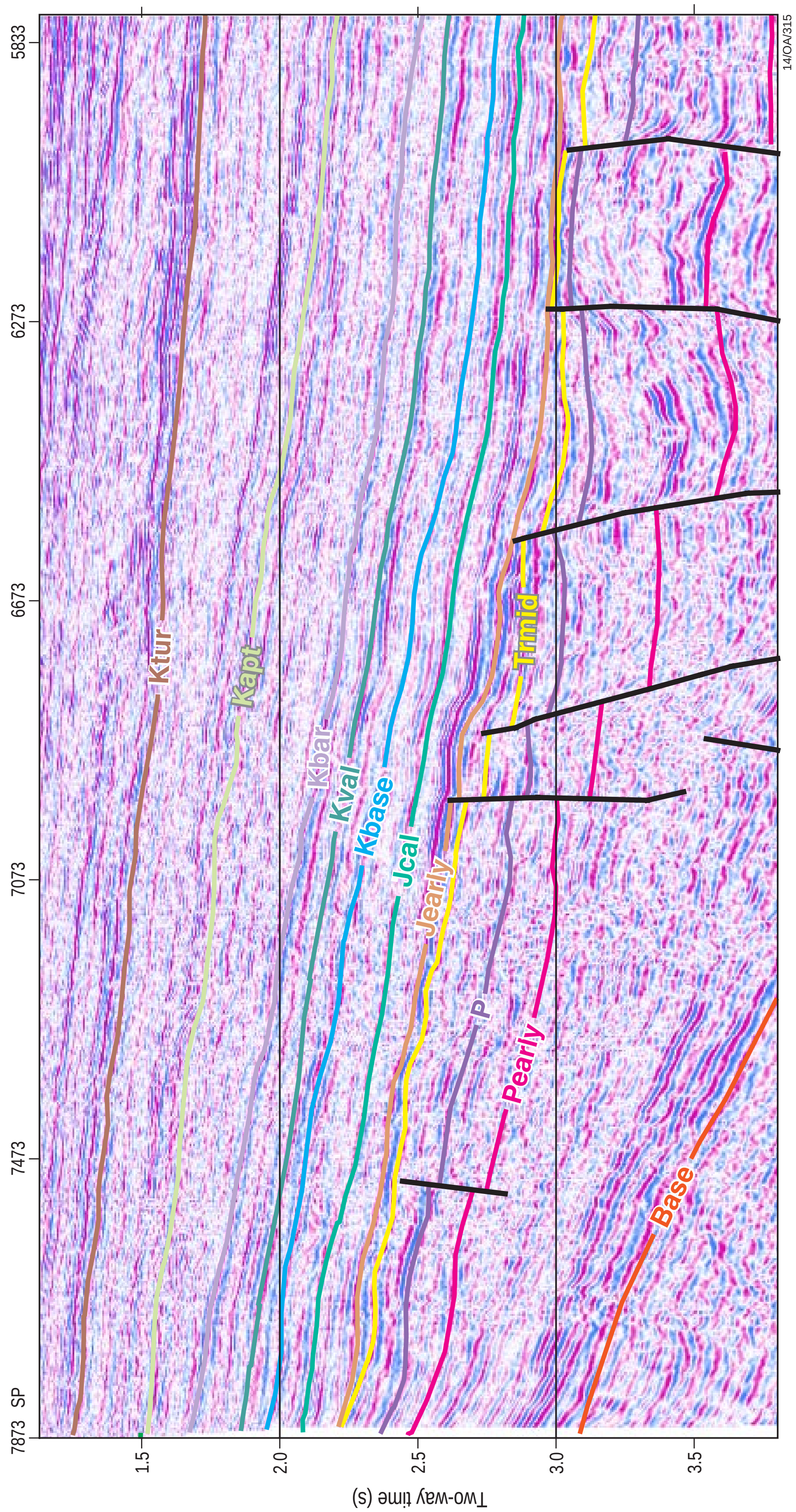


Figure 31 Seismic Line 175/19 showing apparent truncation of the Late Jurassic succession by the Kbase horizon (Base Cretaceous Unconformity).

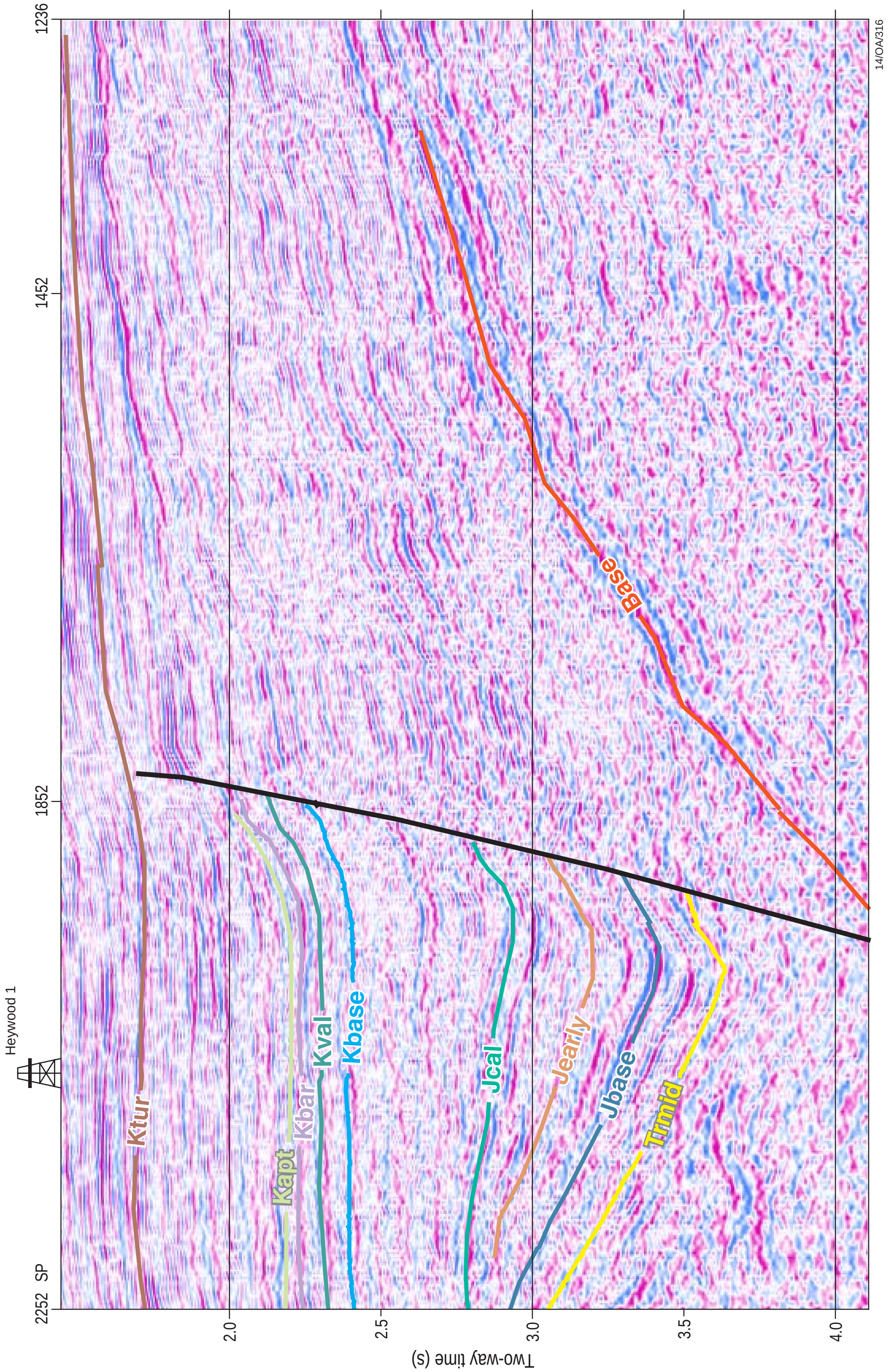
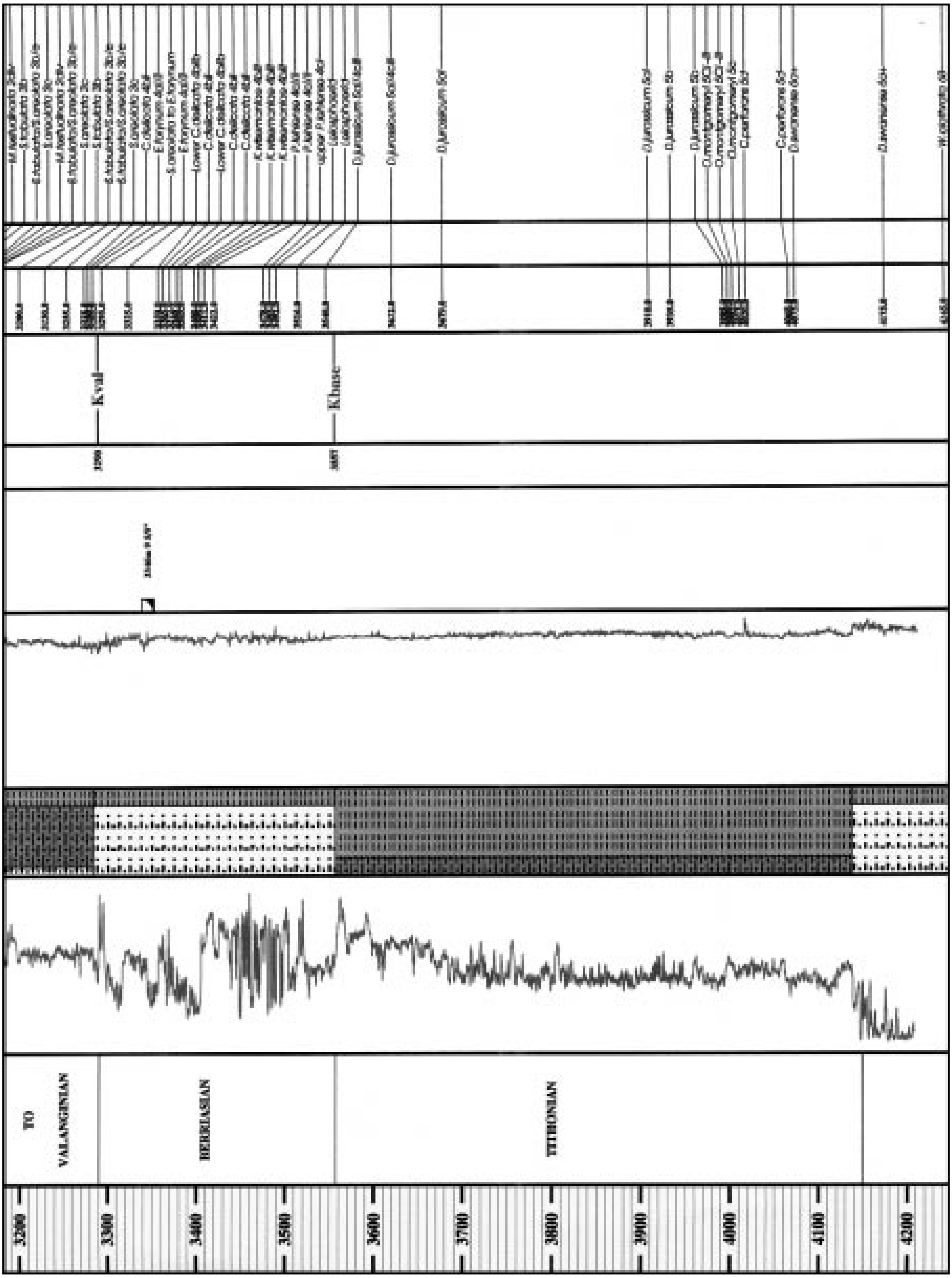


Figure 32 Seismic Line 130/06 showing growth of syn-rift facies of Early to Late Jurassic age in the Heywood Graben. These rocks are juxtaposed to Permian and Carboniferous rocks on the Prudhoe Terrace.



14/OA/307

Figure 33 Heywood 1 composite well log showing the aggradational nature of the Late Jurassic succession.

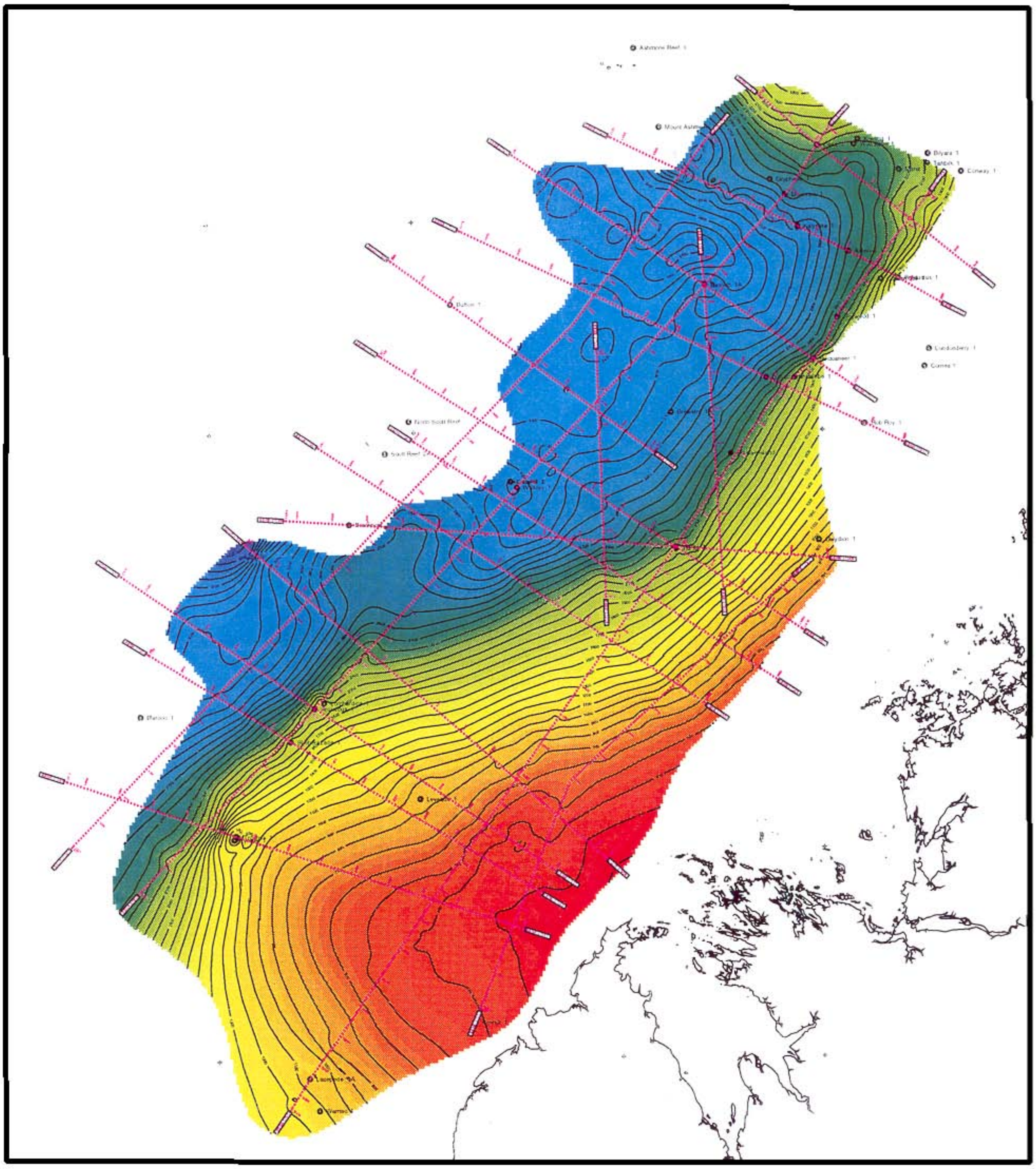


Figure 34 Time structure contour map on Kbase horizon (Base Cretaceous Unconformity). This map is also included as Plate 11.

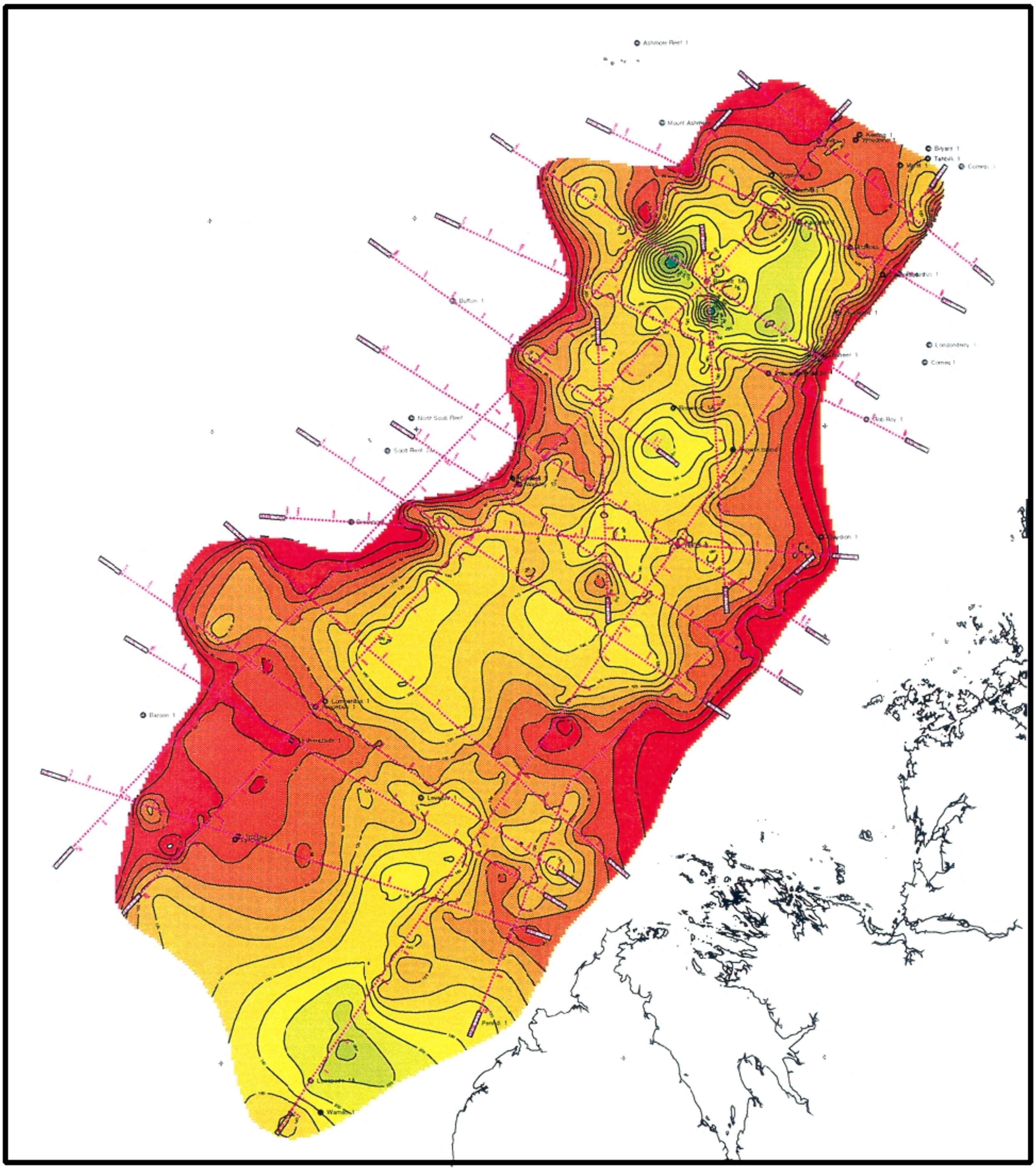


Figure 35 Time isopach map of Kbase to Kval sequence (Base Cretaceous to Intra-Valanginian). This map is also included as Plate 18.

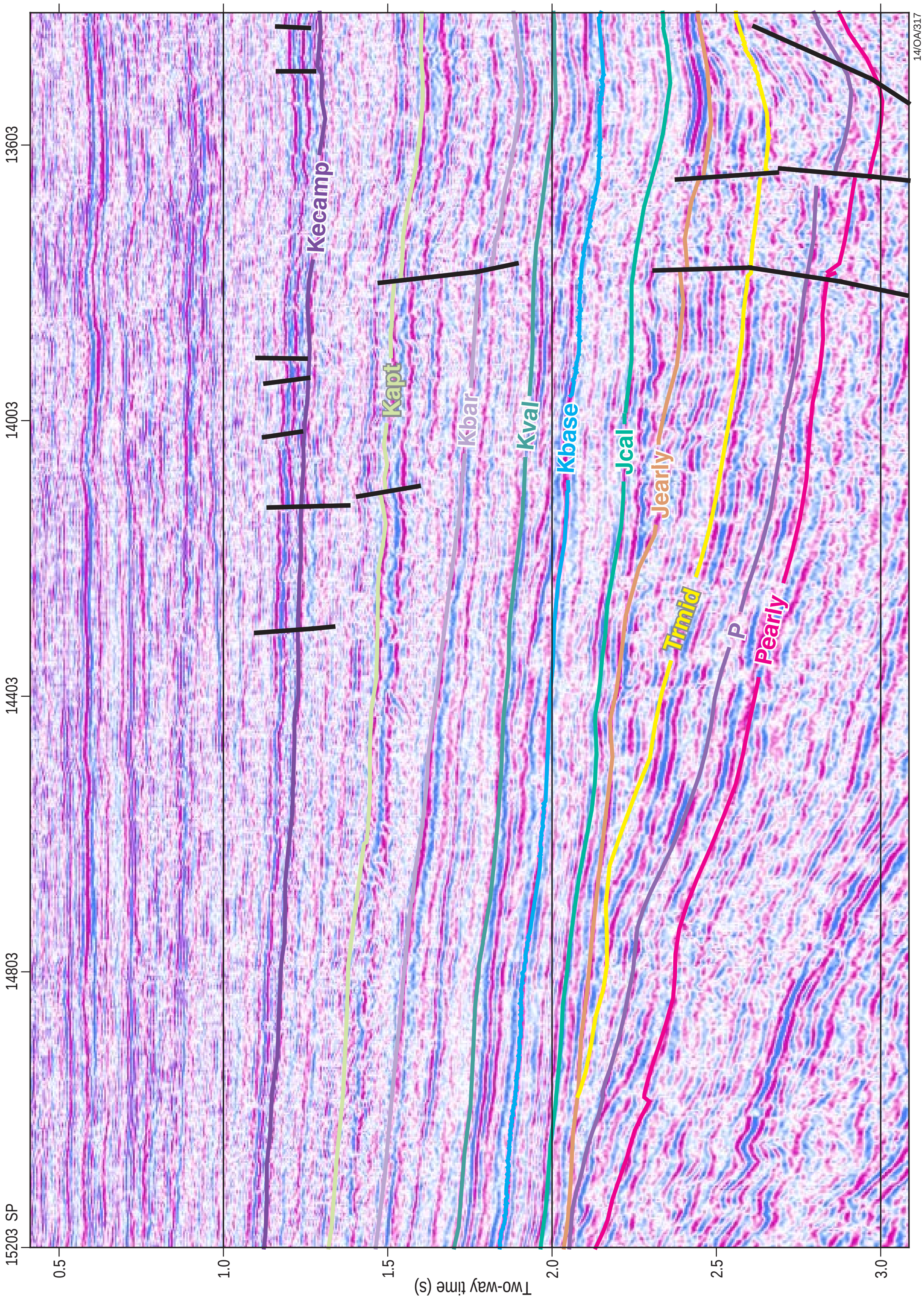


Figure 36 Seismic Line 175/14 (strike line) showing the northward prograding geometry of the Berriasian delta system near Yampi 1 (see Figure 29).

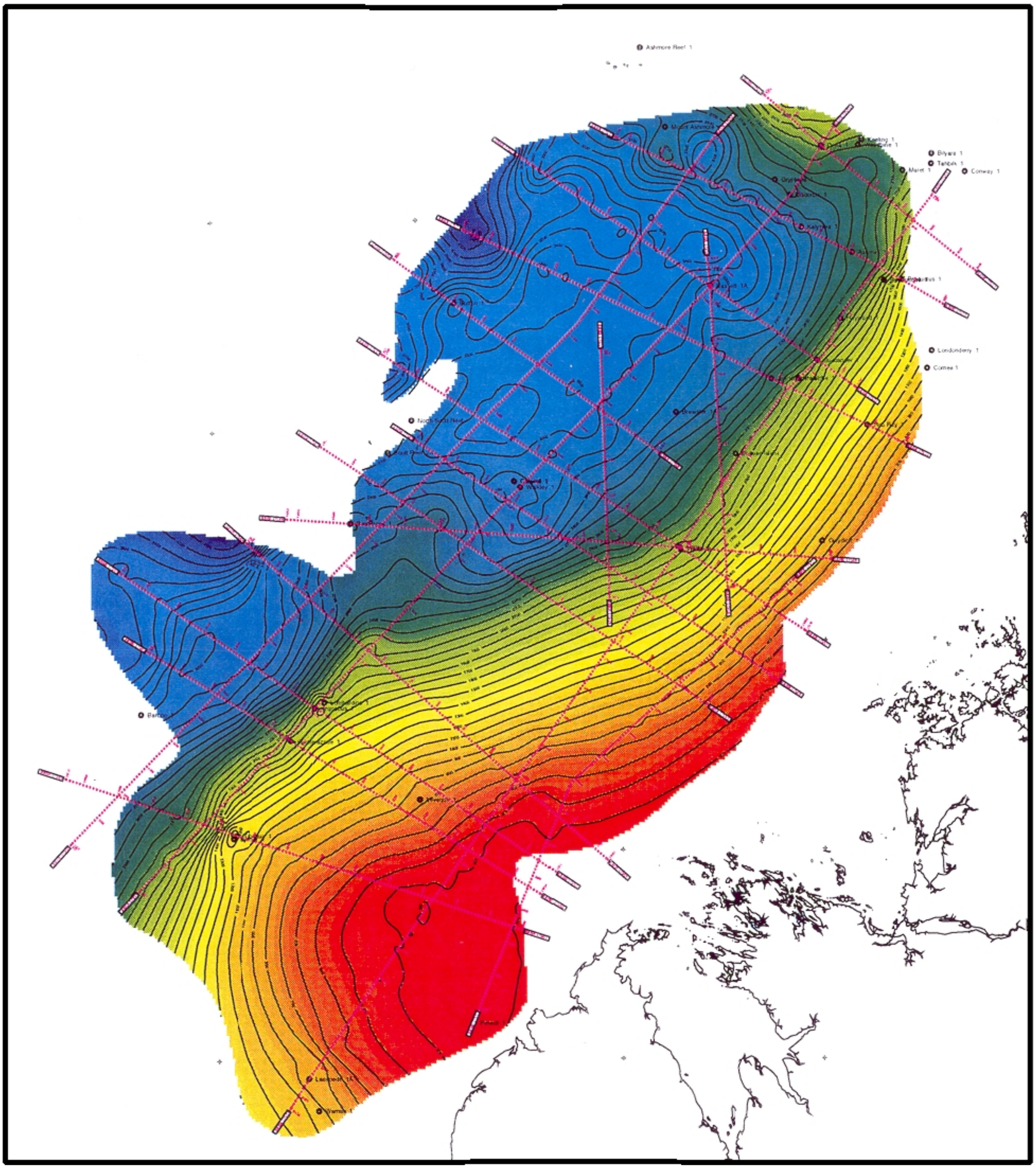


Figure 37 Time structure contour map on Kval horizon (Intra-Valanginian). This map is also included as Plate 12.

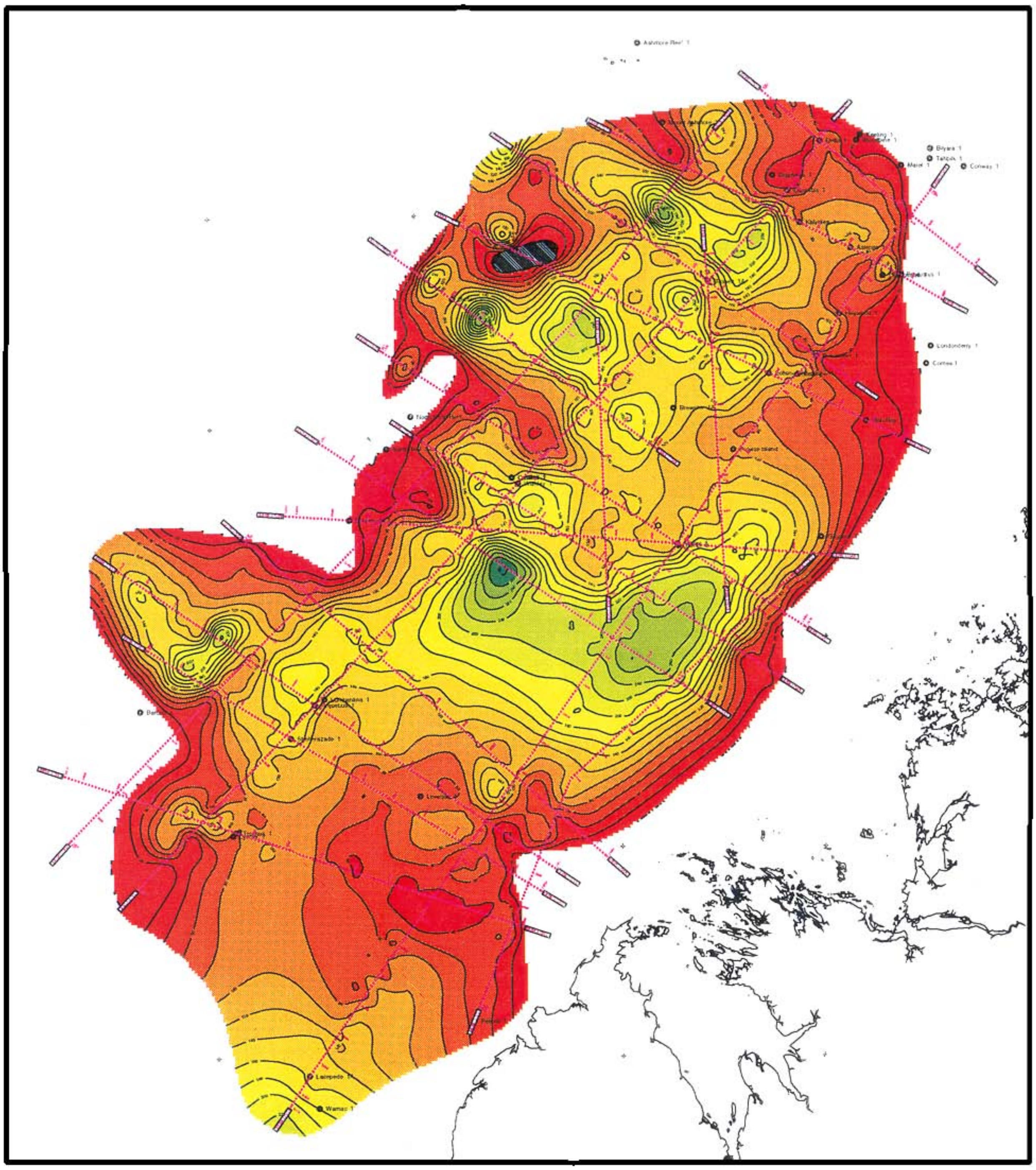


Figure 38 Time isopach map of Kval to Kbar sequence (Intra-Valanginian to Barremian). This map is also included as Plate 19.

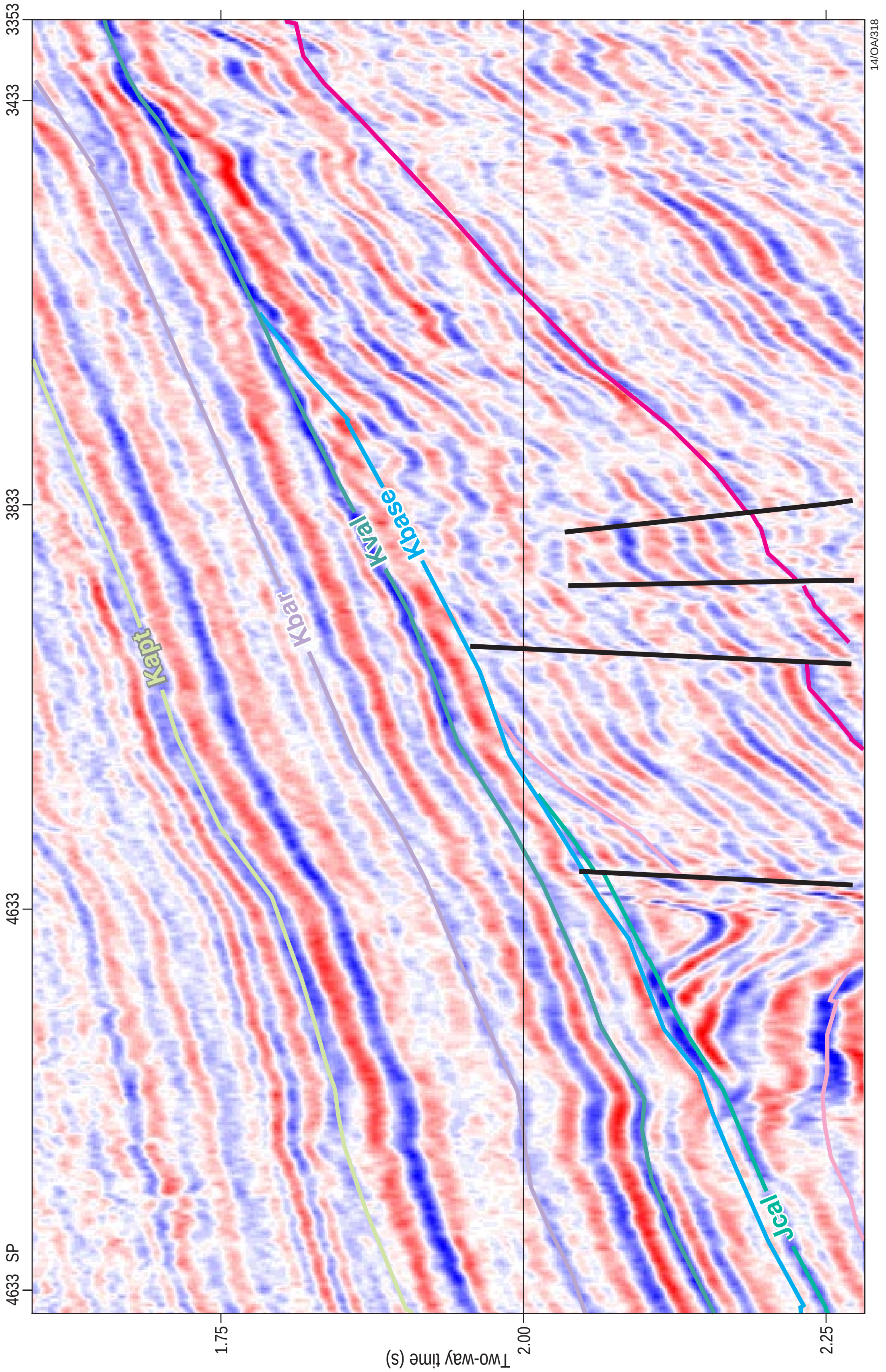


Figure 39 Seismic Line 175/10 across the Prudhoe Terrace showing the onlap of facies onto the Kval horizon and the truncation of sands within the *C. delicata* DZ lying below.

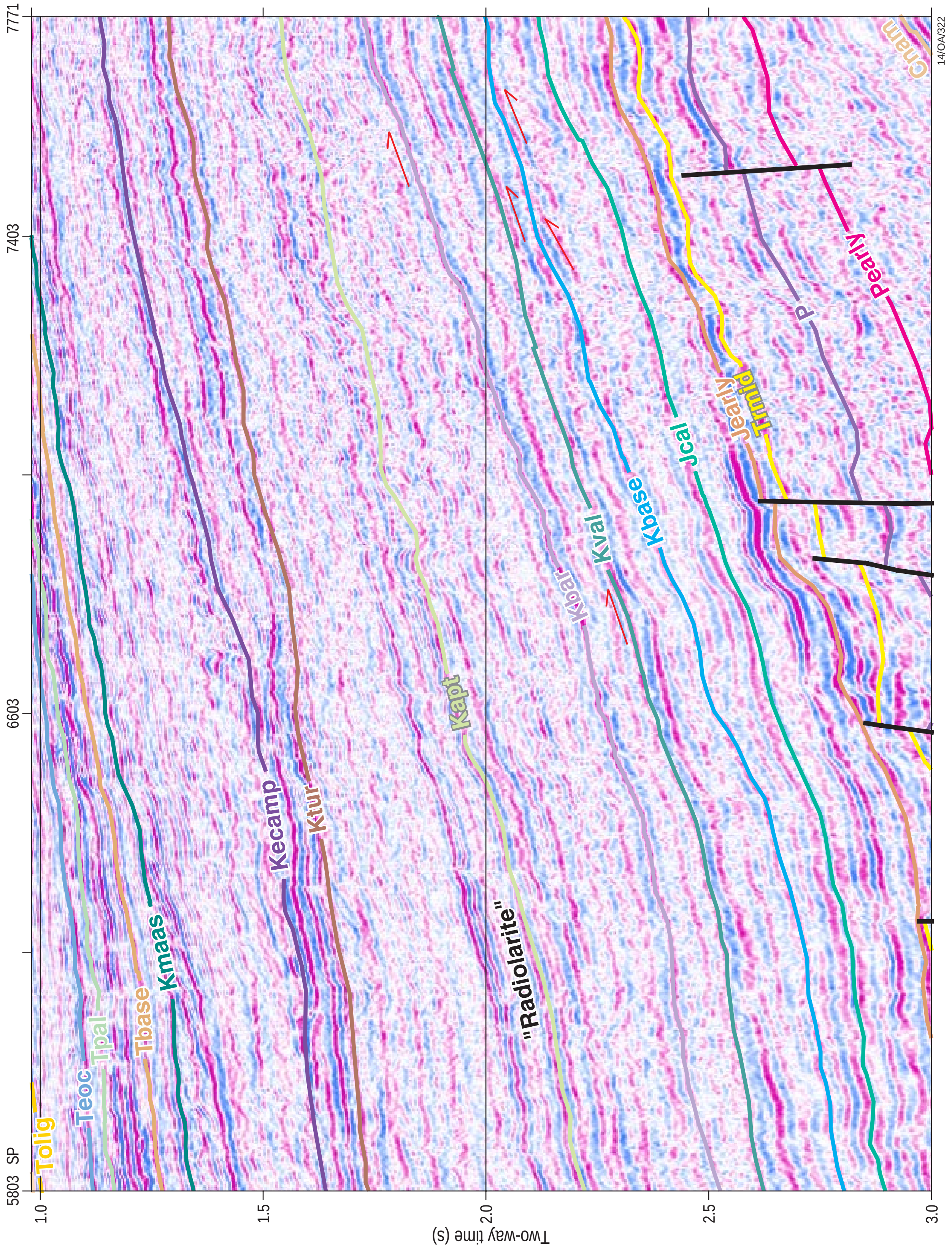


Figure 40 Seismic Line 175/19 showing the stratal geometry and seismic character of the Jurassic to mid-Tertiary succession. Note the truncation by Kbase and Kval horizons, and onlap onto the Kbar horizon. The radiolarite/greensand above the Kapt horizon has a distinct high amplitude seismic character.

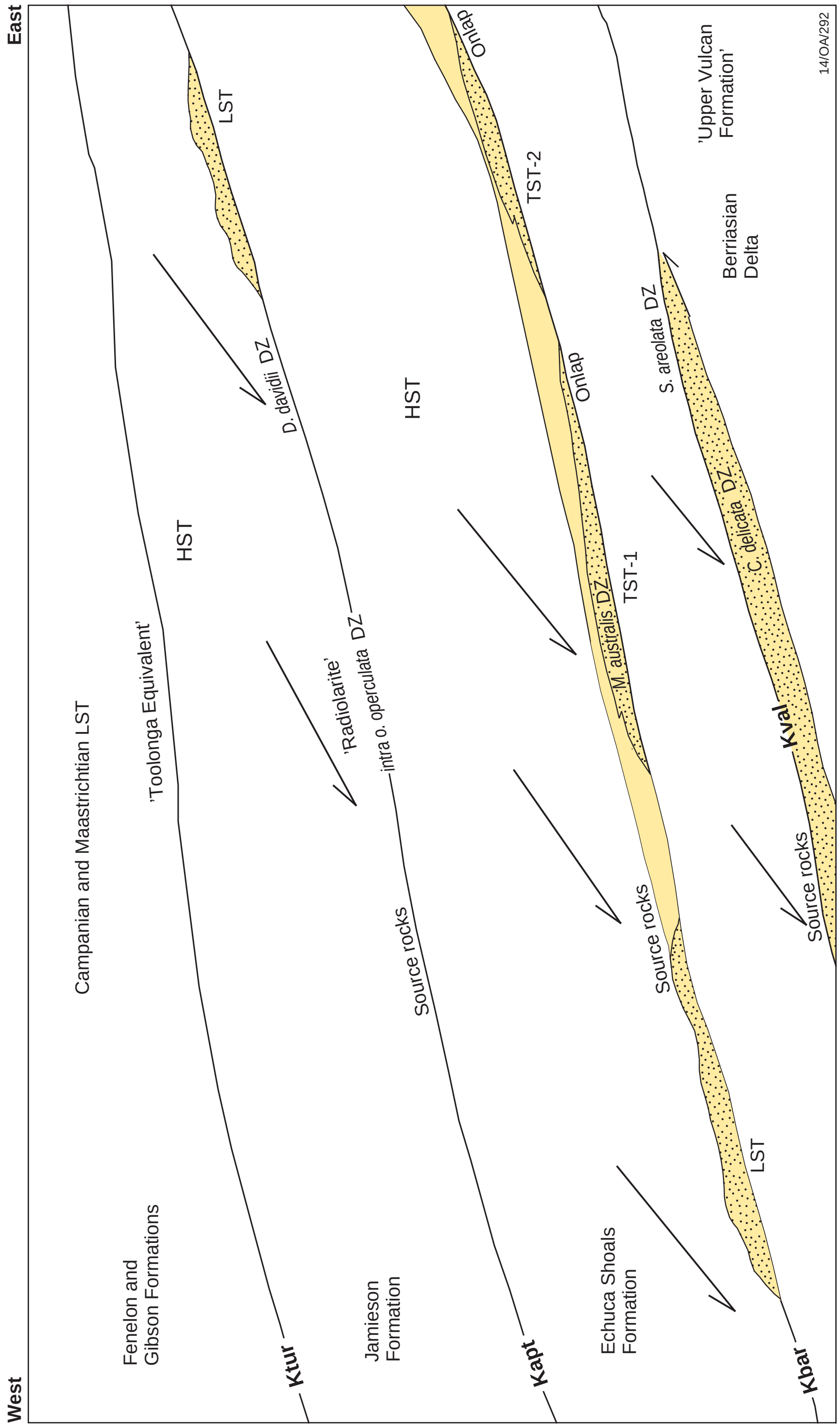


Figure 41 Schematic diagram showing the framework for deposition of potential reservoir and source rock intervals within the Early Cretaceous supersequence (Kbase to Kapt).

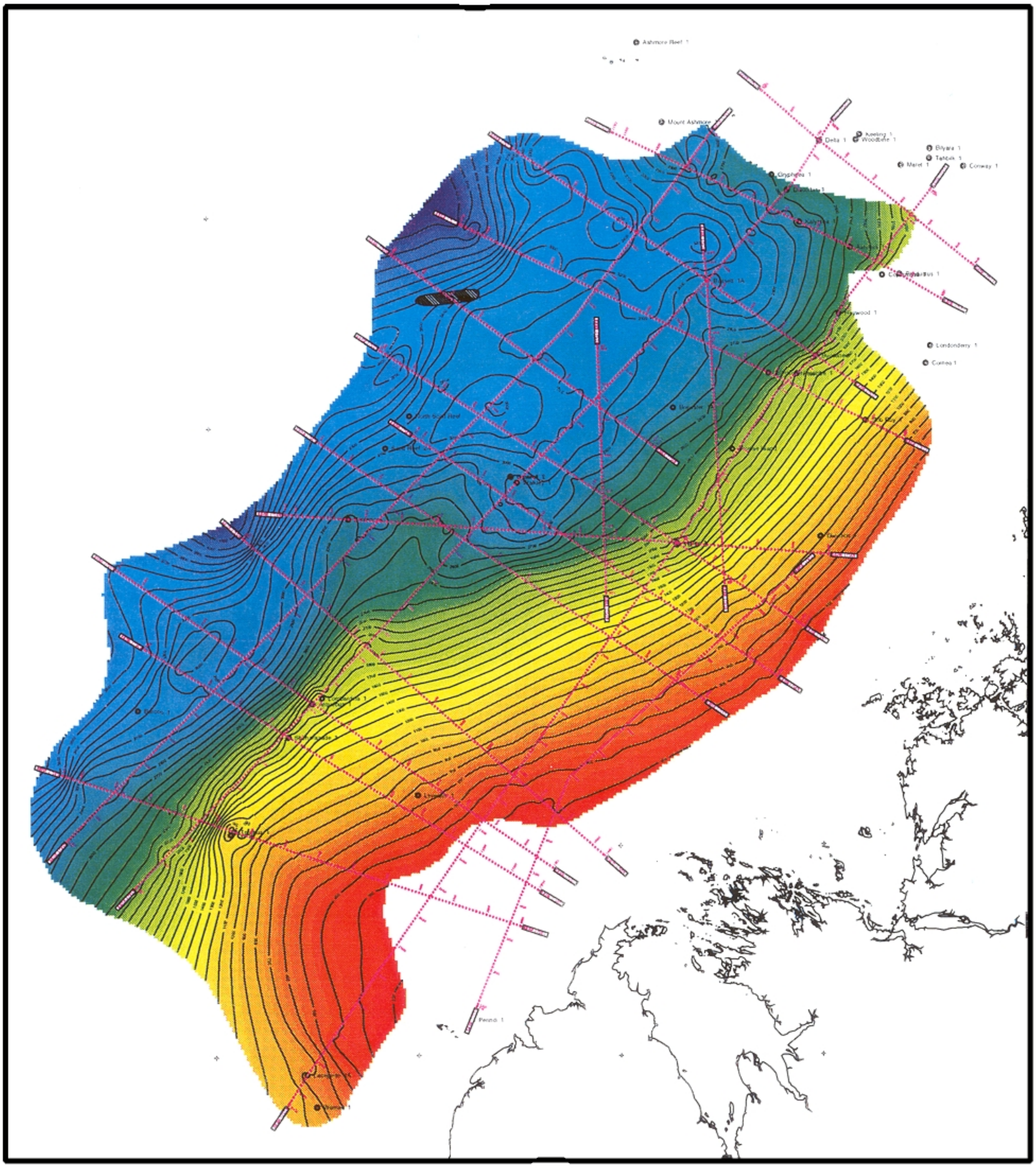


Figure 42 Time structure contour map of Kbar horizon (Barremian Unconformity). This map is also included as Plate 13.

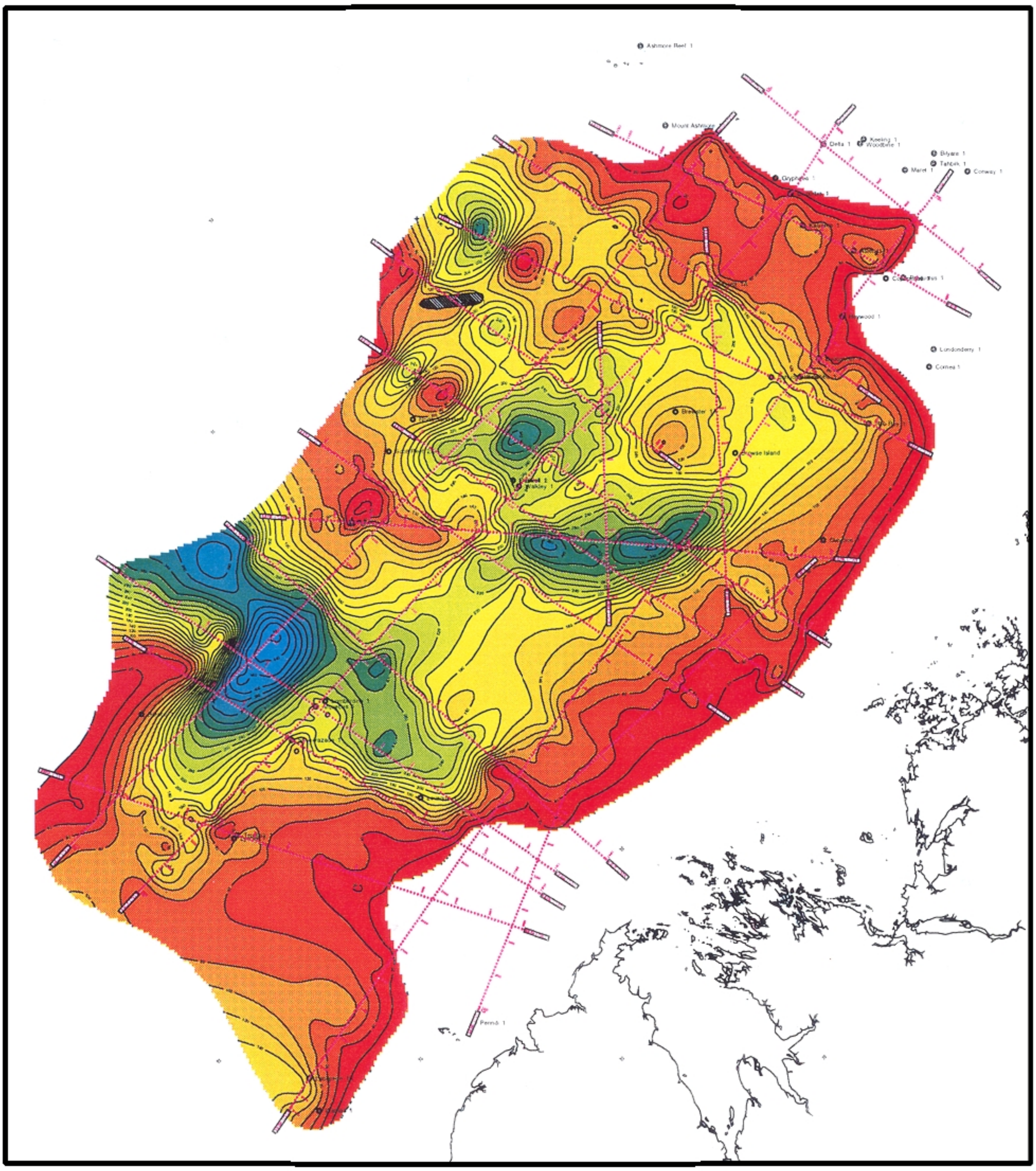


Figure 43 Time isopach map of Kbar to Kapt sequence (Barremian to Intra-Aptian). This map is also included as Plate 20.

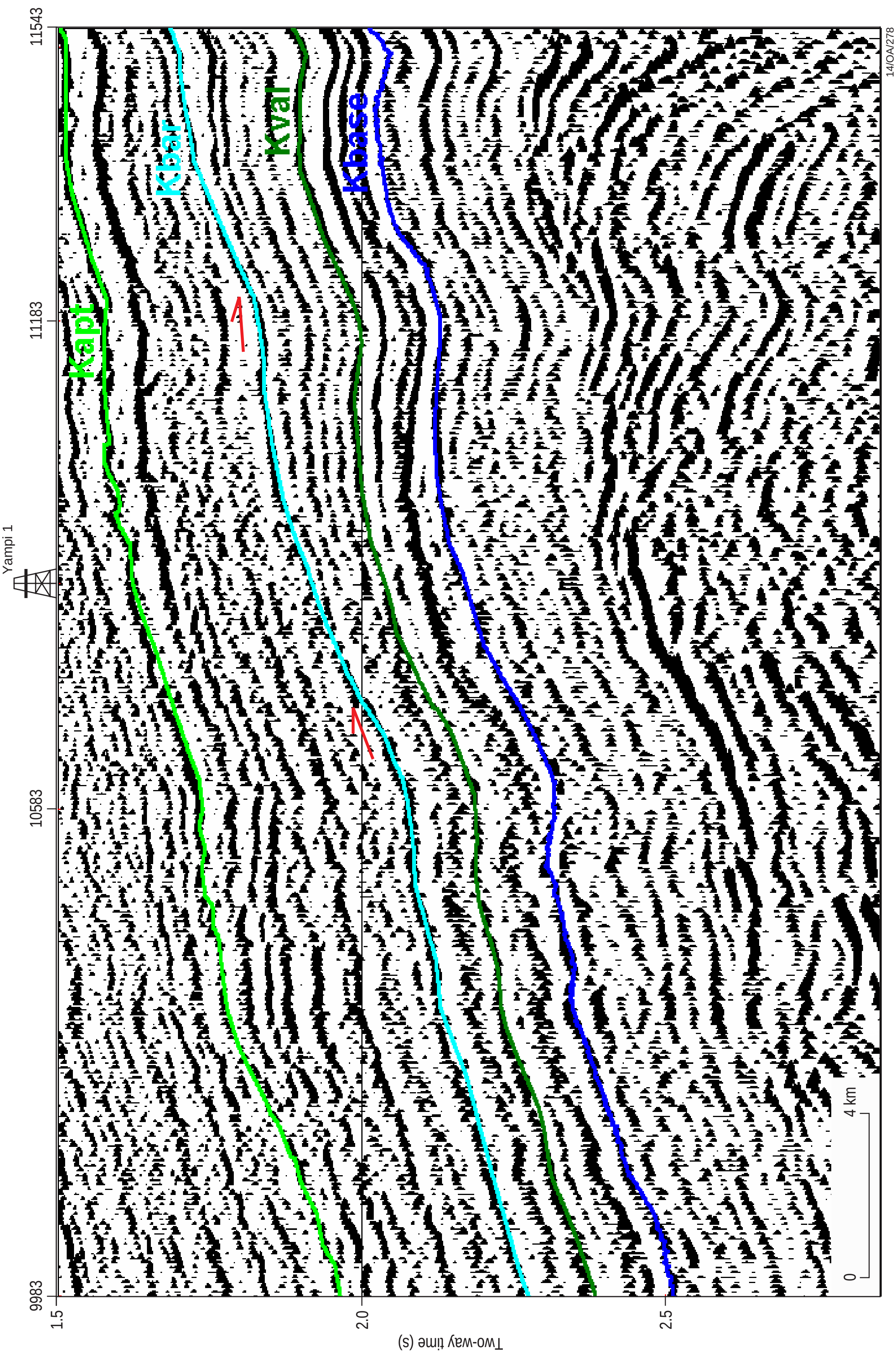


Figure 44a Seismic Line 175/07 showing the onlap of transgressive facies on the Kbar sequence boundary (Barremian Unconformity). This facies was penetrated at Yampi 1 (see Figure 29).

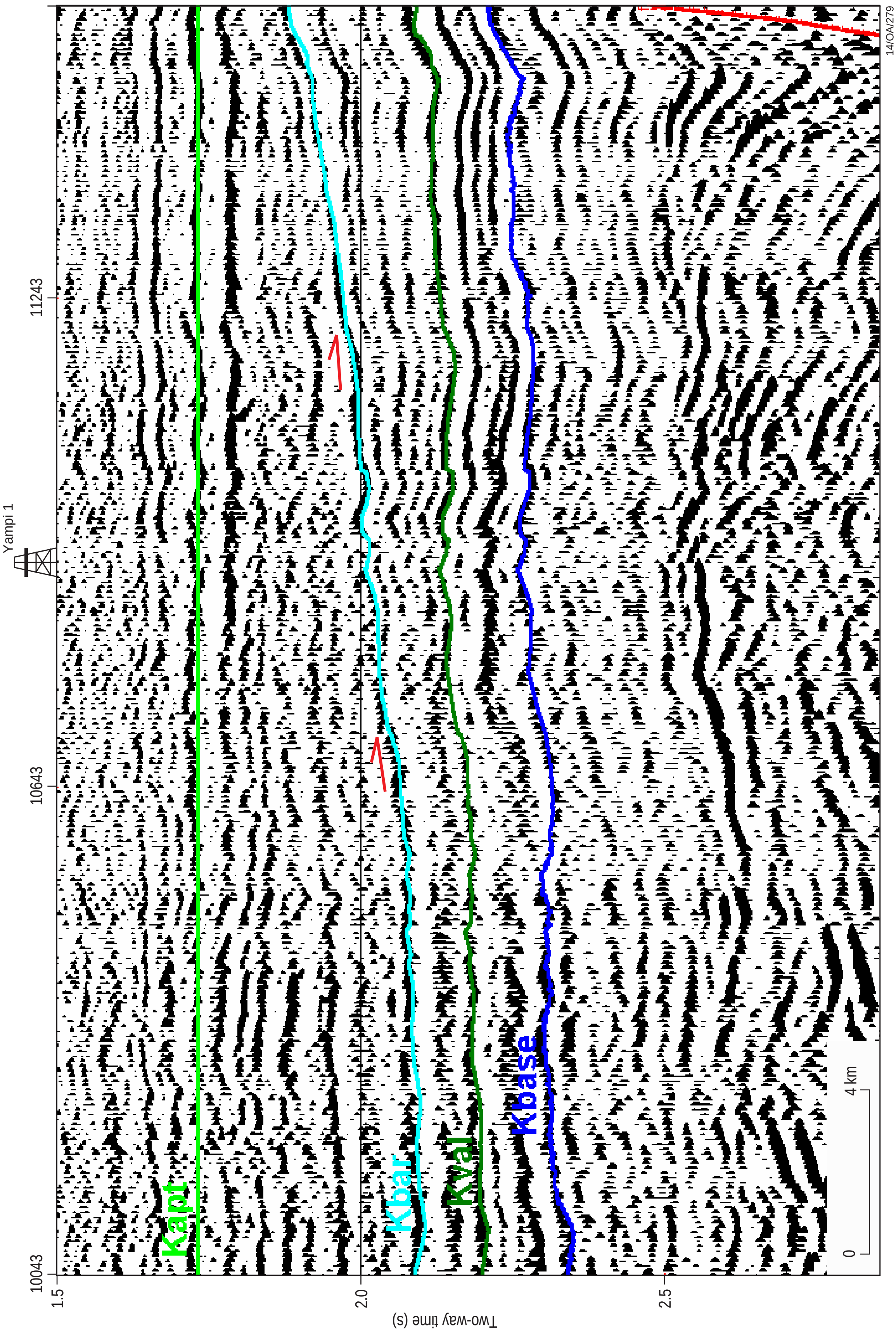
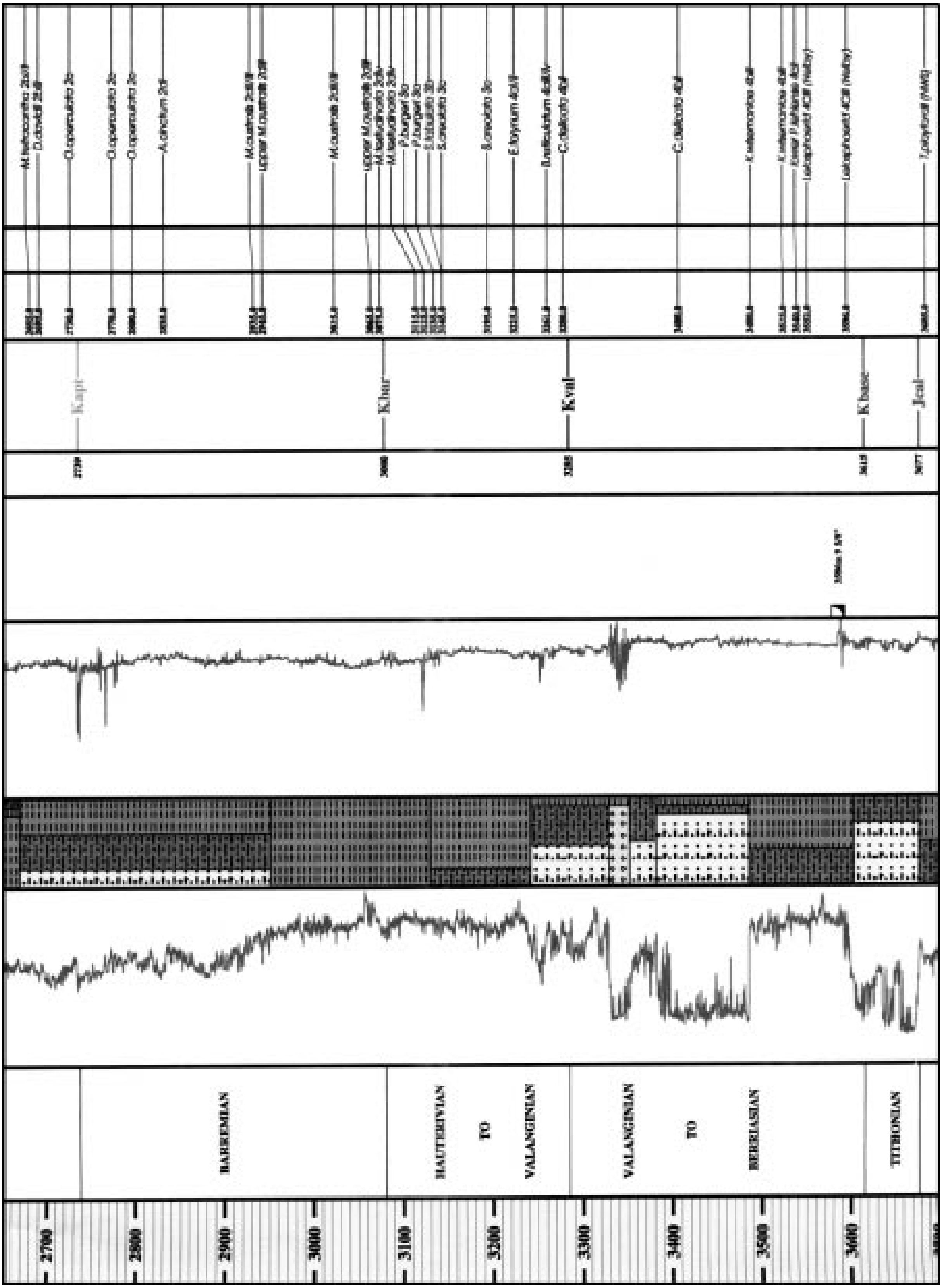


Figure 44b Seismic Line 175/07 flattened on Kapt (Aptian Unconformity) showing truncation of the Valanginian succession by Kbar (Barremian Unconformity).



14/OA/310

Figure 45 Echuca Shoals 1 composite well log showing a succession of backstepping, transgressive facies in the Valanginian (Kval) to Aptian (Kapt) interval. These facies (particularly the *M. australis* DZ) are commonly greensands and have been proven as effective reservoirs on the adjacent Yampi Shelf. Gas shows of 10 to 790 units were recorded at Echuca Shoals 1in transgressive sands above the Aptian Unconformity (Kapt).

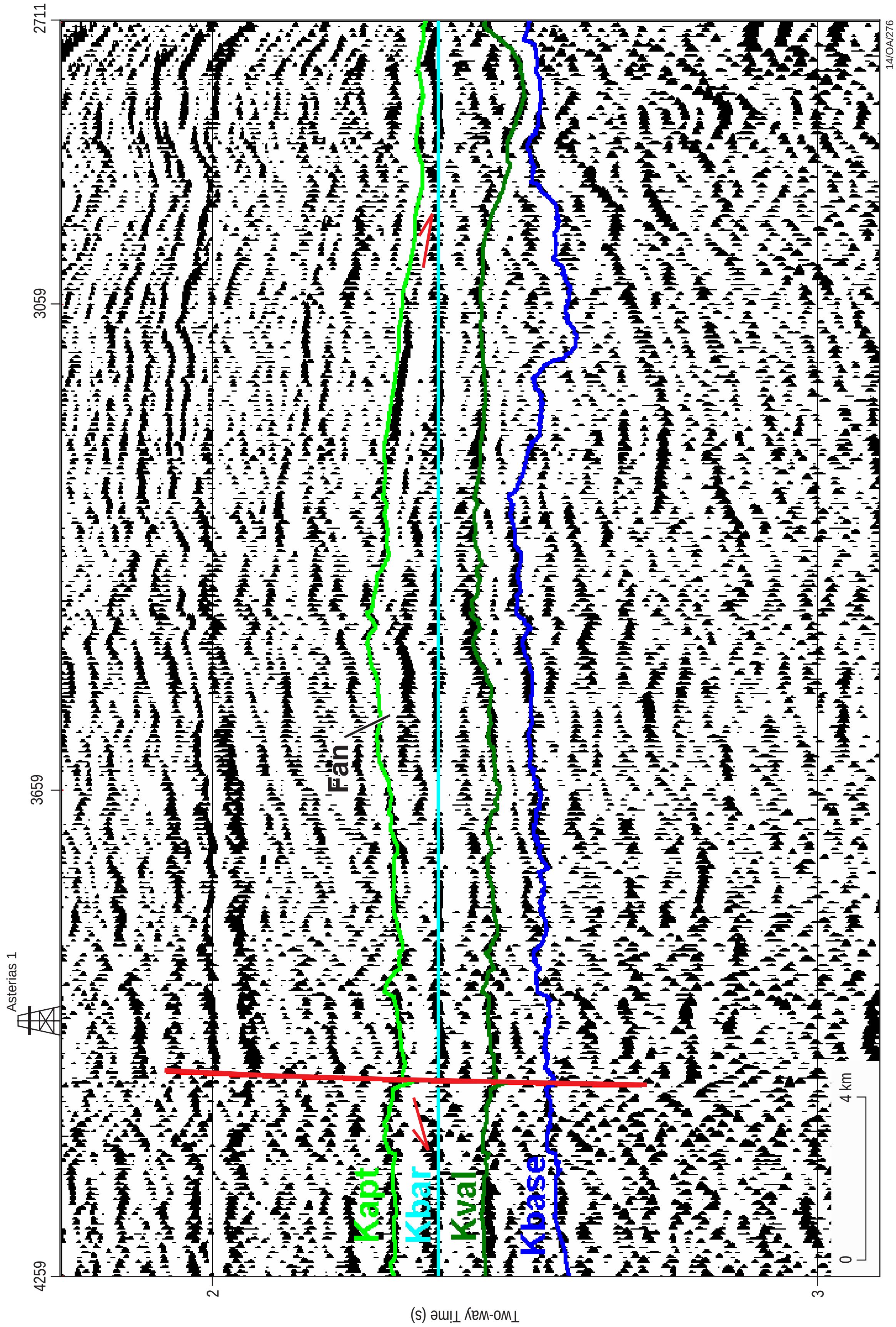
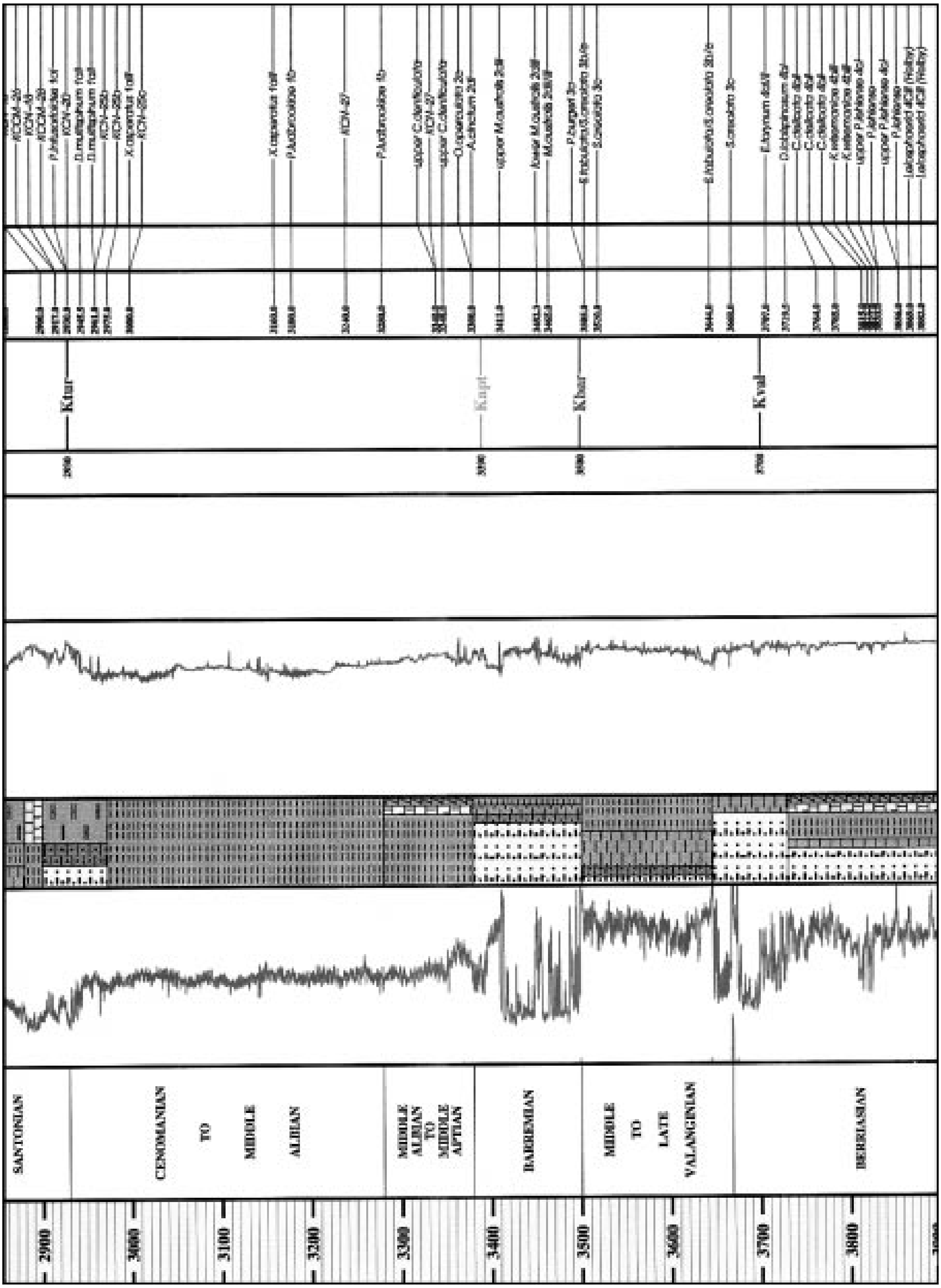


Figure 46 Seismic Line 175/11 flattened on Kbar (Barremian Unconformity) showing the lowstand fan penetrated at Asterias 1 (see Figure 47).



14/OA/311

Figure 47 Asterias 1 composite well log showing a the development of a lowstand fan above the Barremian (Kbar)sequence boundary. Similar fans are predicted to be present along the Barremian palaeo-depositional slope in the northern Browse Basin (see Figure 50).

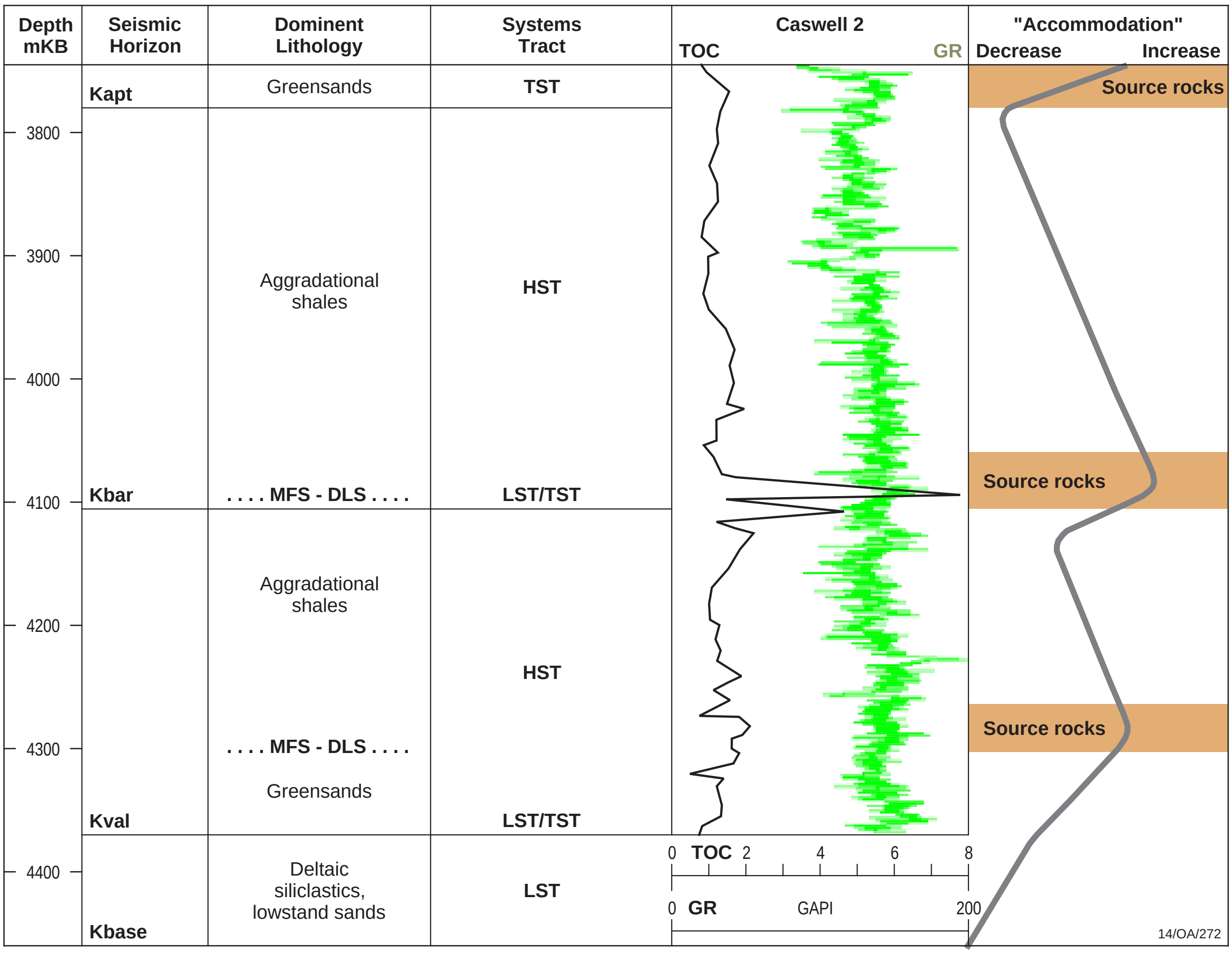


Figure 48 Schematic diagram showing the stratigraphic framework for deposition of source rocks during periods of peak flooding in the Early Cretaceous. Source rocks were deposited as condensed intervals associated with downlap surfaces above the Kval (Valanginian Unconformity), Kbar (Barremian Unconformity), and Kapt (Intra-Aptian Unconformity) sequence boundaries. The profile of TOC values plotted against the Gamma Ray log at Caswell 2 shows peaks during floodings as interpreted from the log.

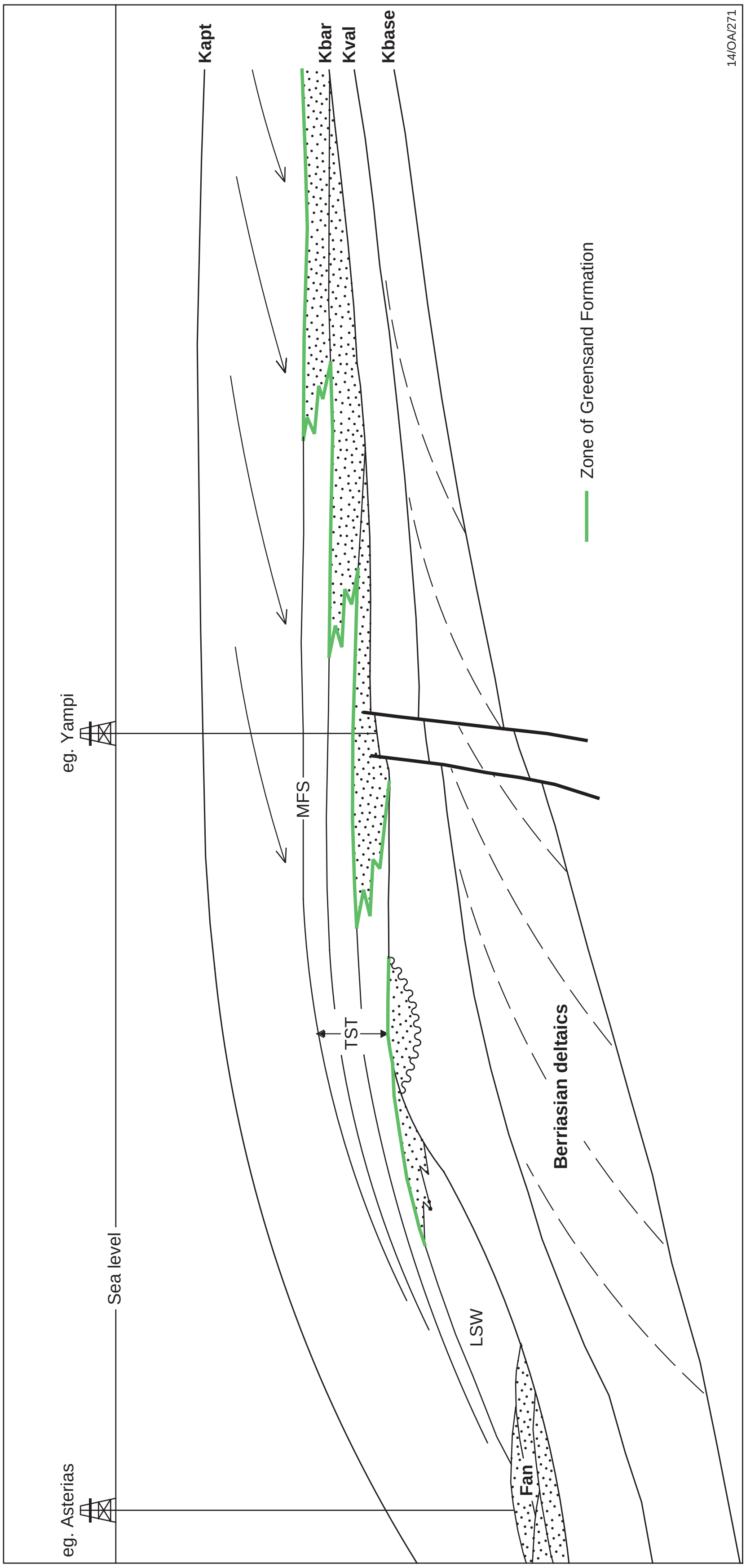


Figure 49 Schematic diagram showing the depositional framework for development of lowstand fans (Asterias 1) and wedges (LSW), and backstepping sequences of transgressive greensands above Kbar (Barremian Unconformity).

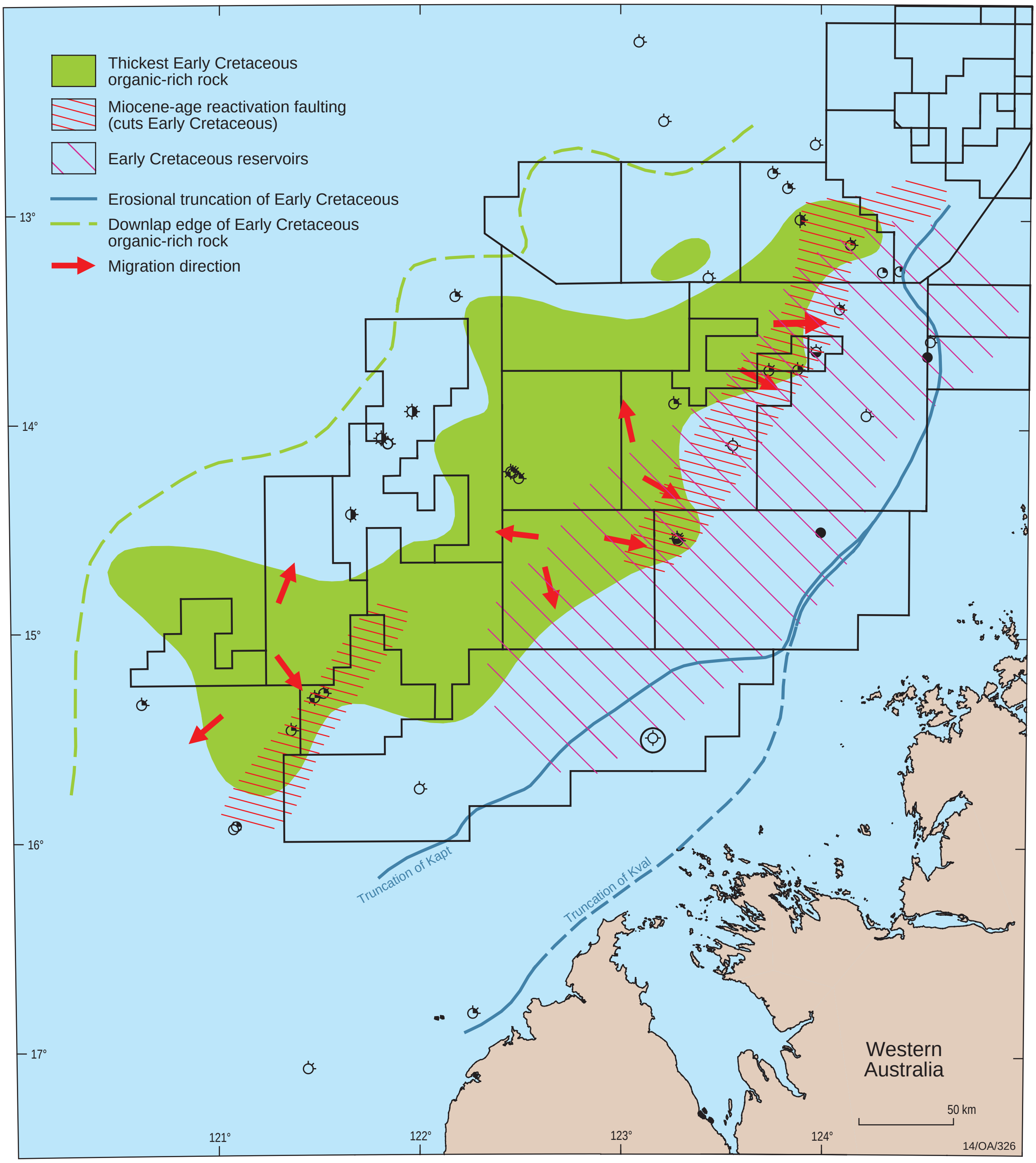


Figure 50 Map showing the distribution of potential source rocks and reservoirs within the Early Cretaceous supersequence. The arrows indicate migration paths for hydrocarbons generated in the basin.

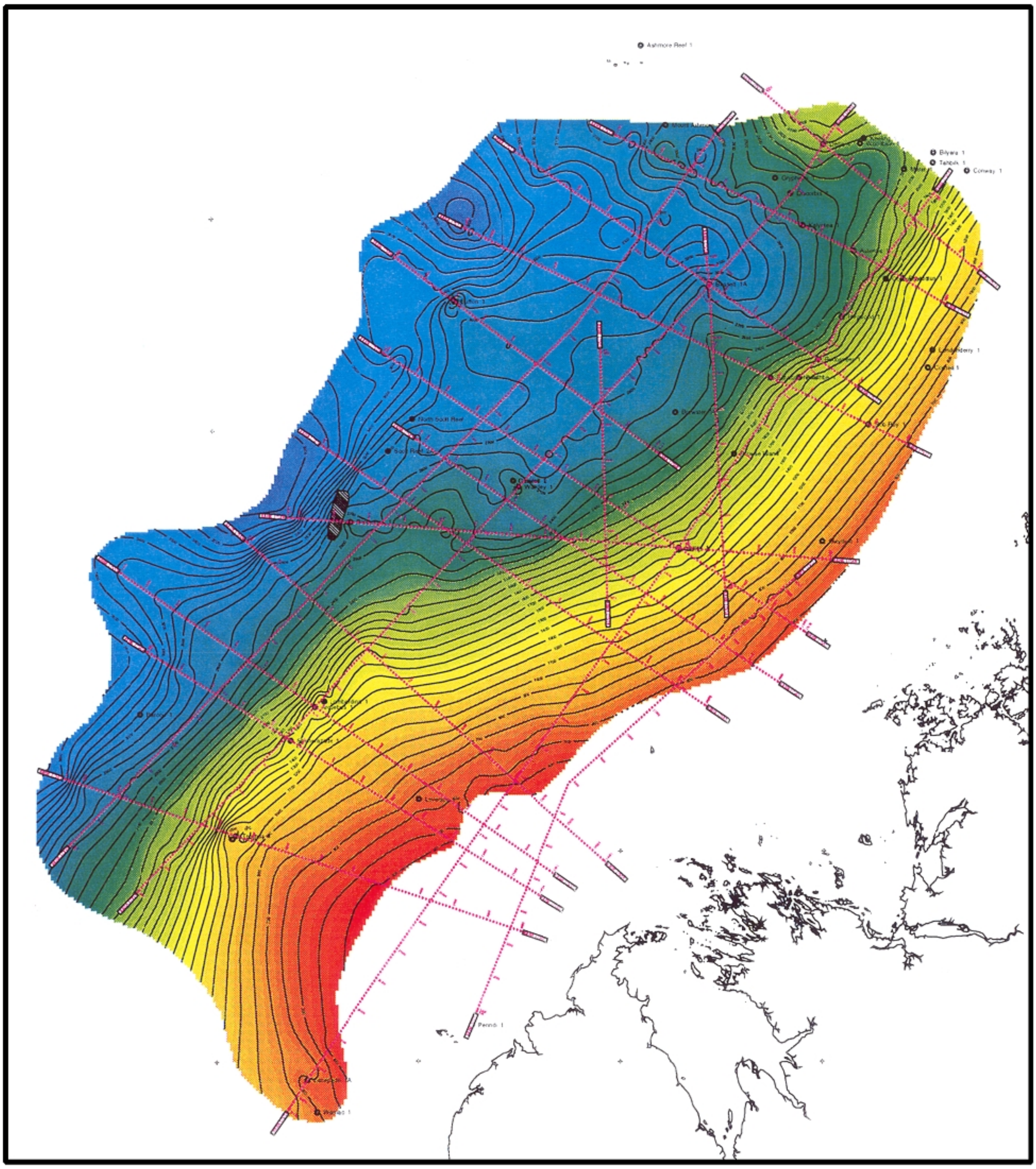
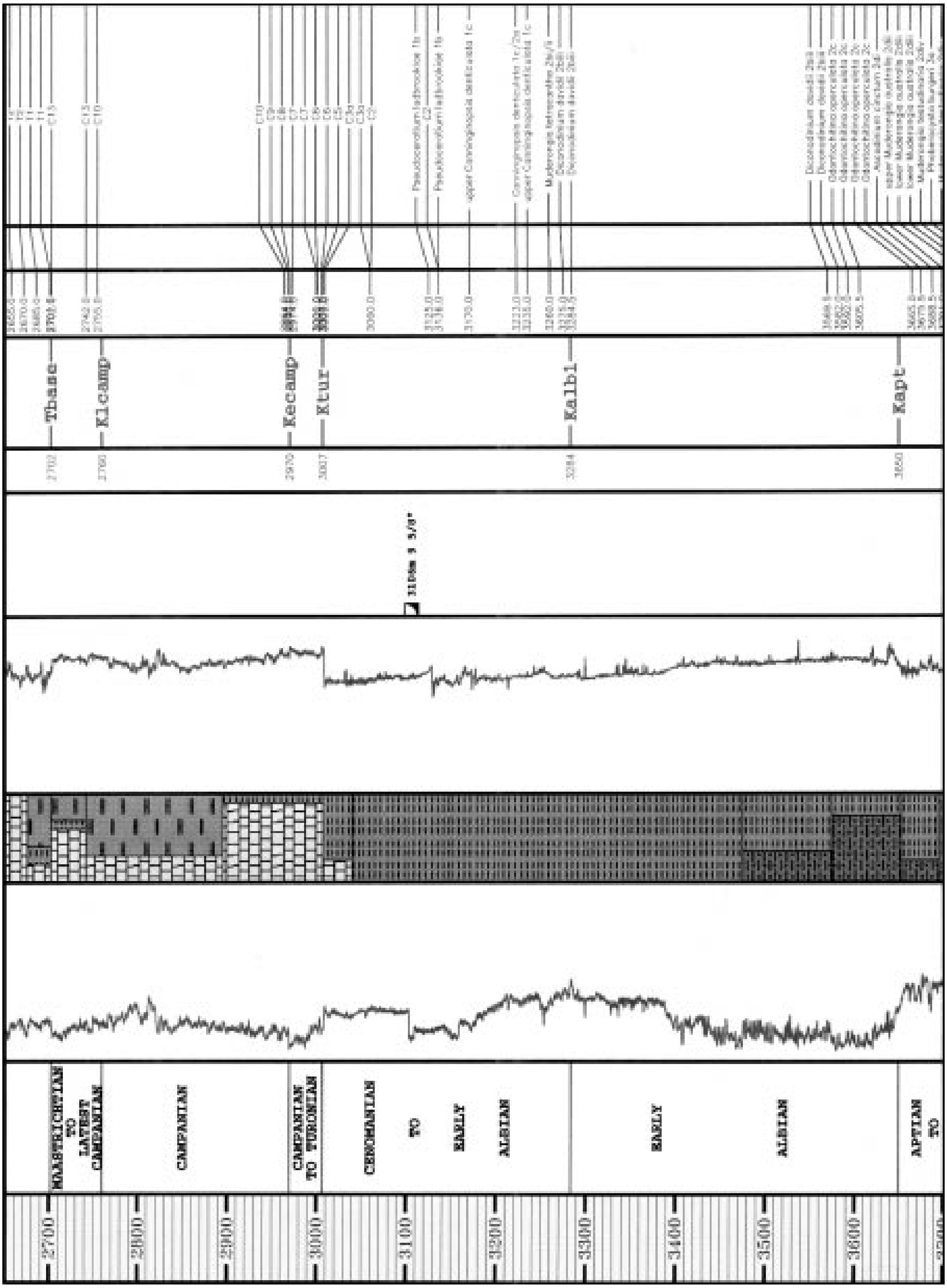


Figure 51 Time structure contour map of Kapt horizon (Intra-Aptian Unconformity).
This map is also included as Plate 14.



14/OA/312

Figure 52 Barcoo 1 composite well log showing the multiple unconformities present within the Aptian (Kapt) to Turonian (Ktur) shale package. These events are difficult to map on seismic data in areas west of the Yampi Shelf and Prudhoe Terrace.

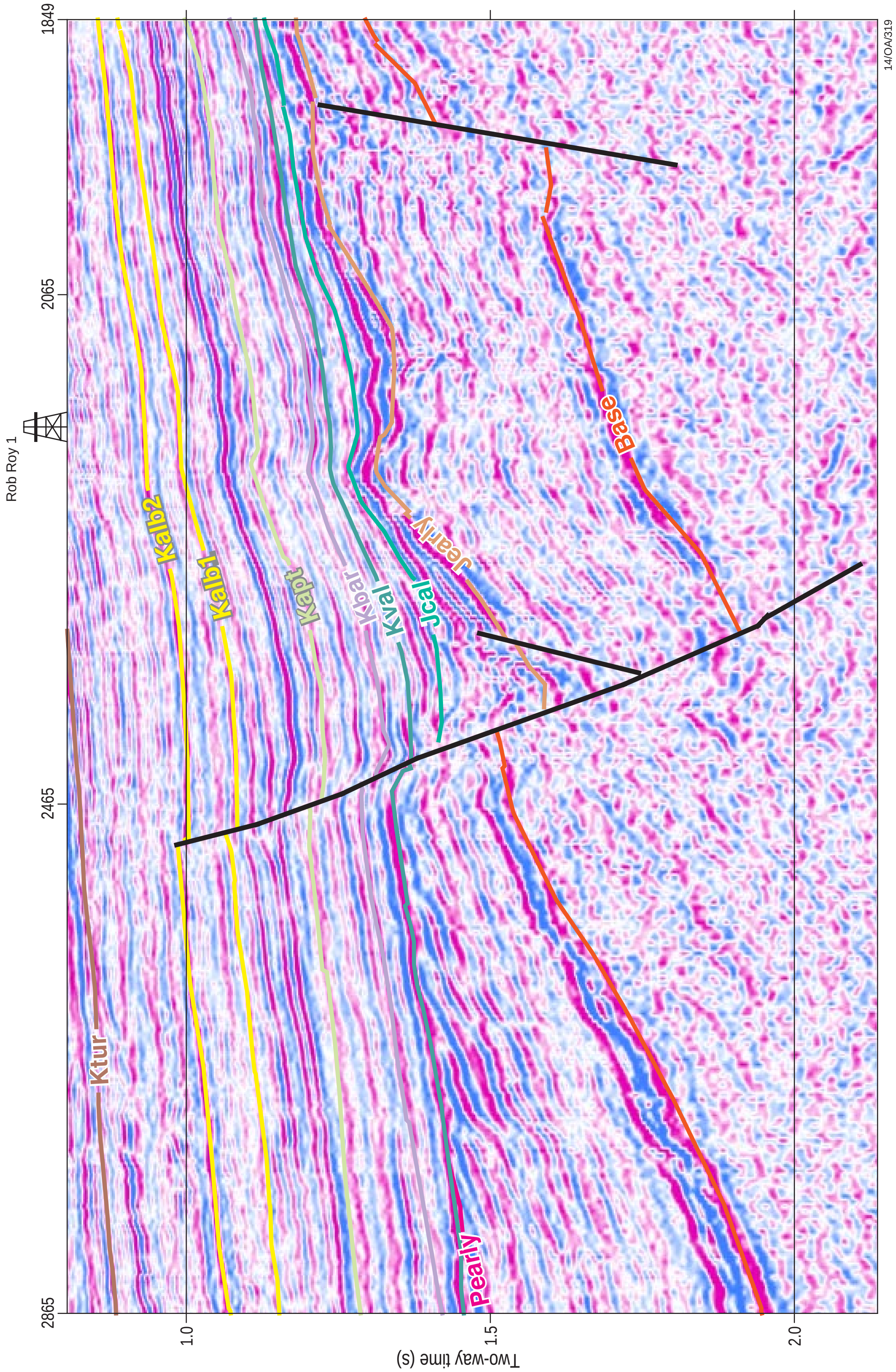


Figure 53 Seismic Line 175/10 across the Rob Roy Graben showing the multiple unconformities present within the Aptian (Kapt) to Turonian (Ktur) succession.

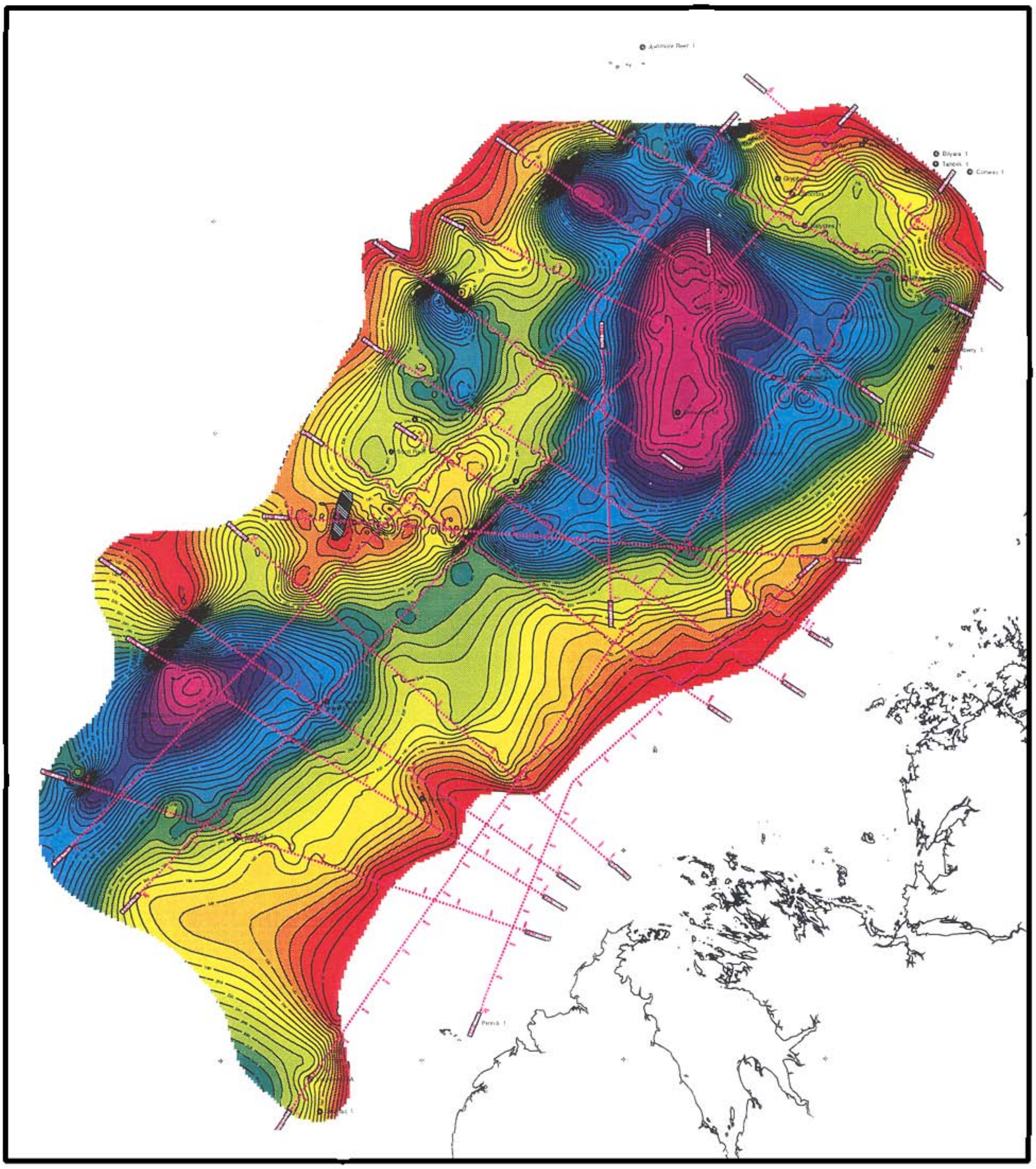


Figure 54 Time isopach map of Kapt to Ktur sequence (Intra-Aptian to Turonian).
This map is also included as Plate 21.

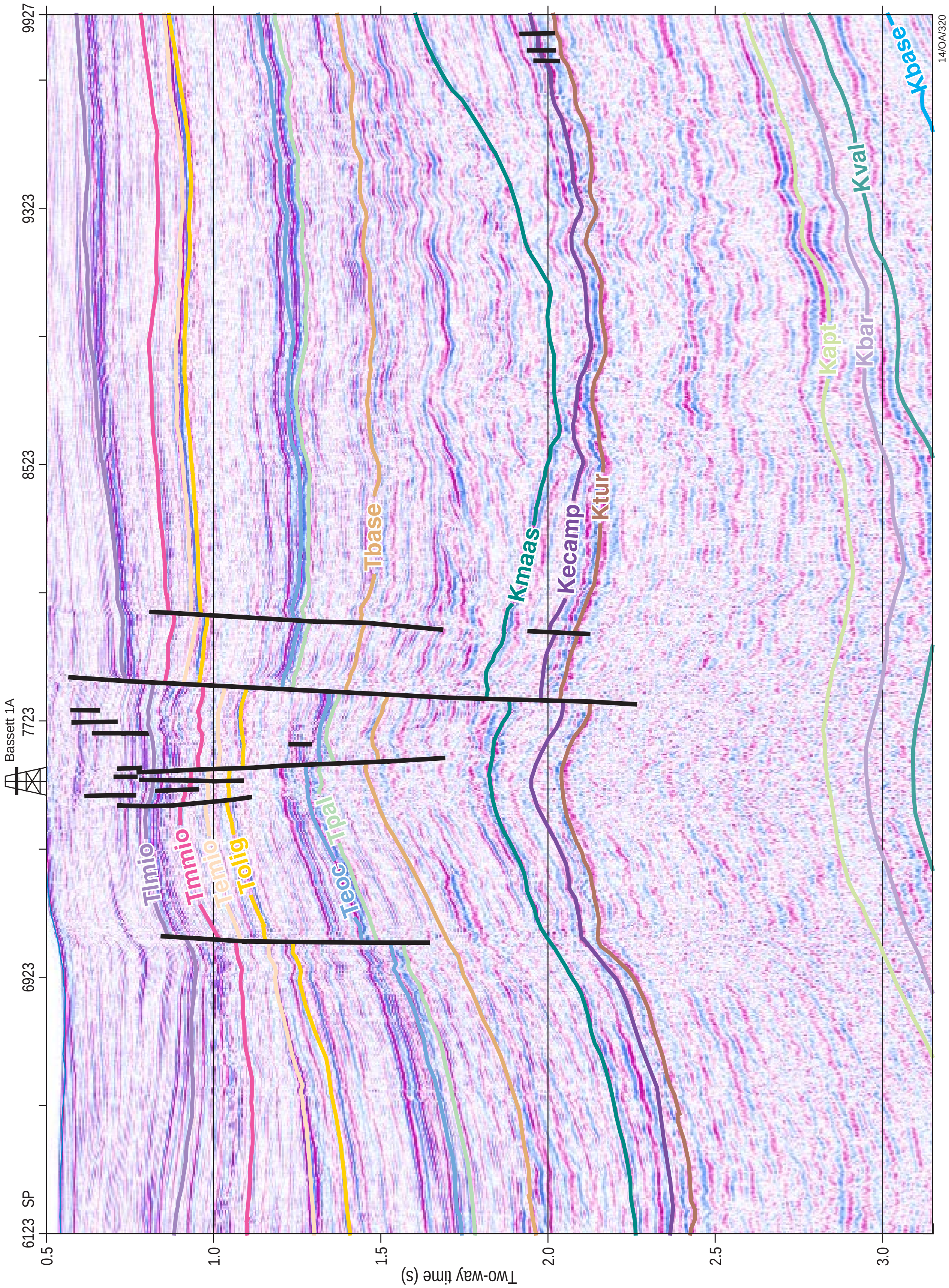


Figure 55 Seismic Line 175/11 over Bassett 1A showing an inversion structure (Kapt to Ktur) that developed during the Early Turonian. Extensional reactivation during the Late Miocene may have been accompanied by movement of salt in the deeper section.

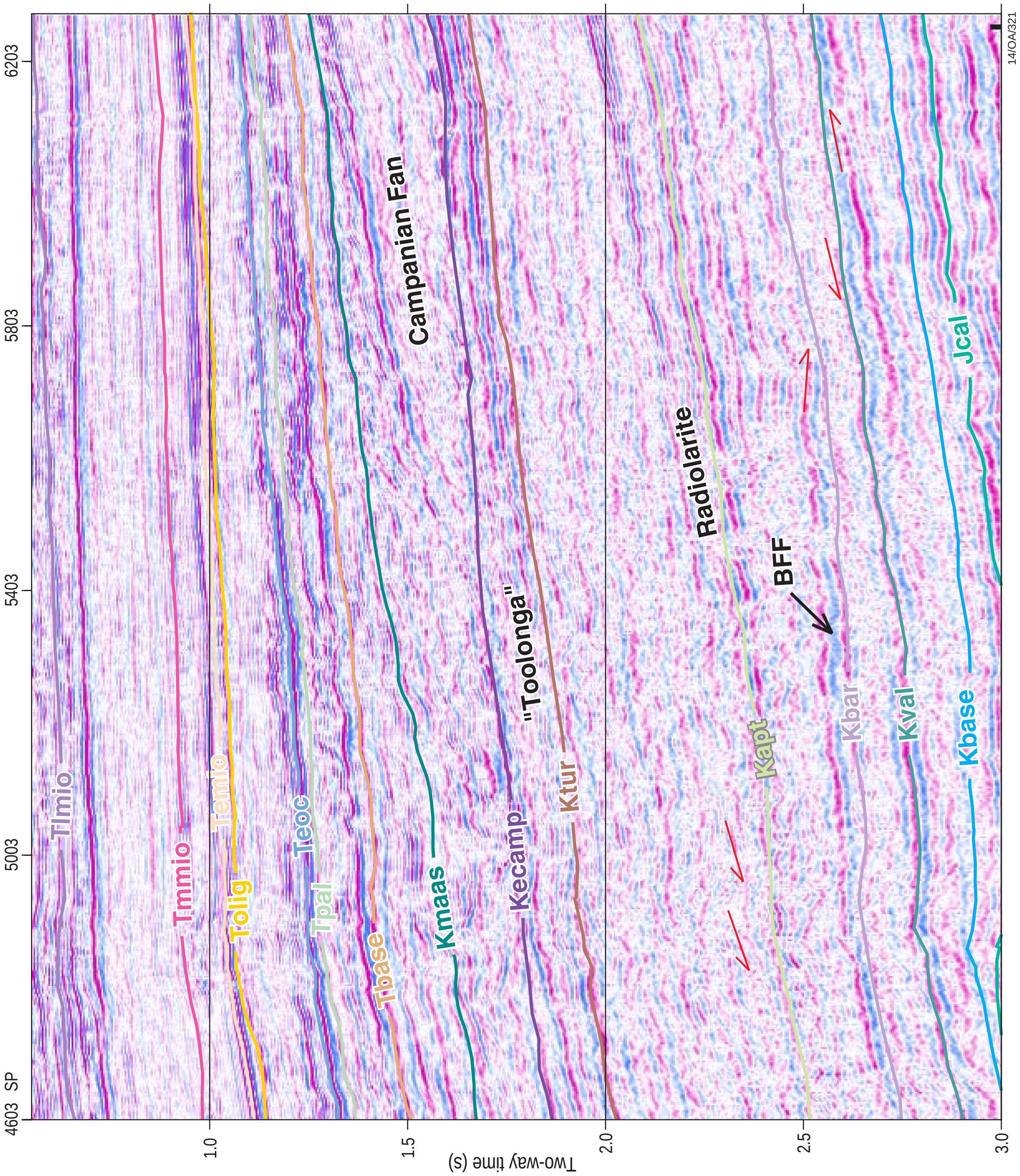
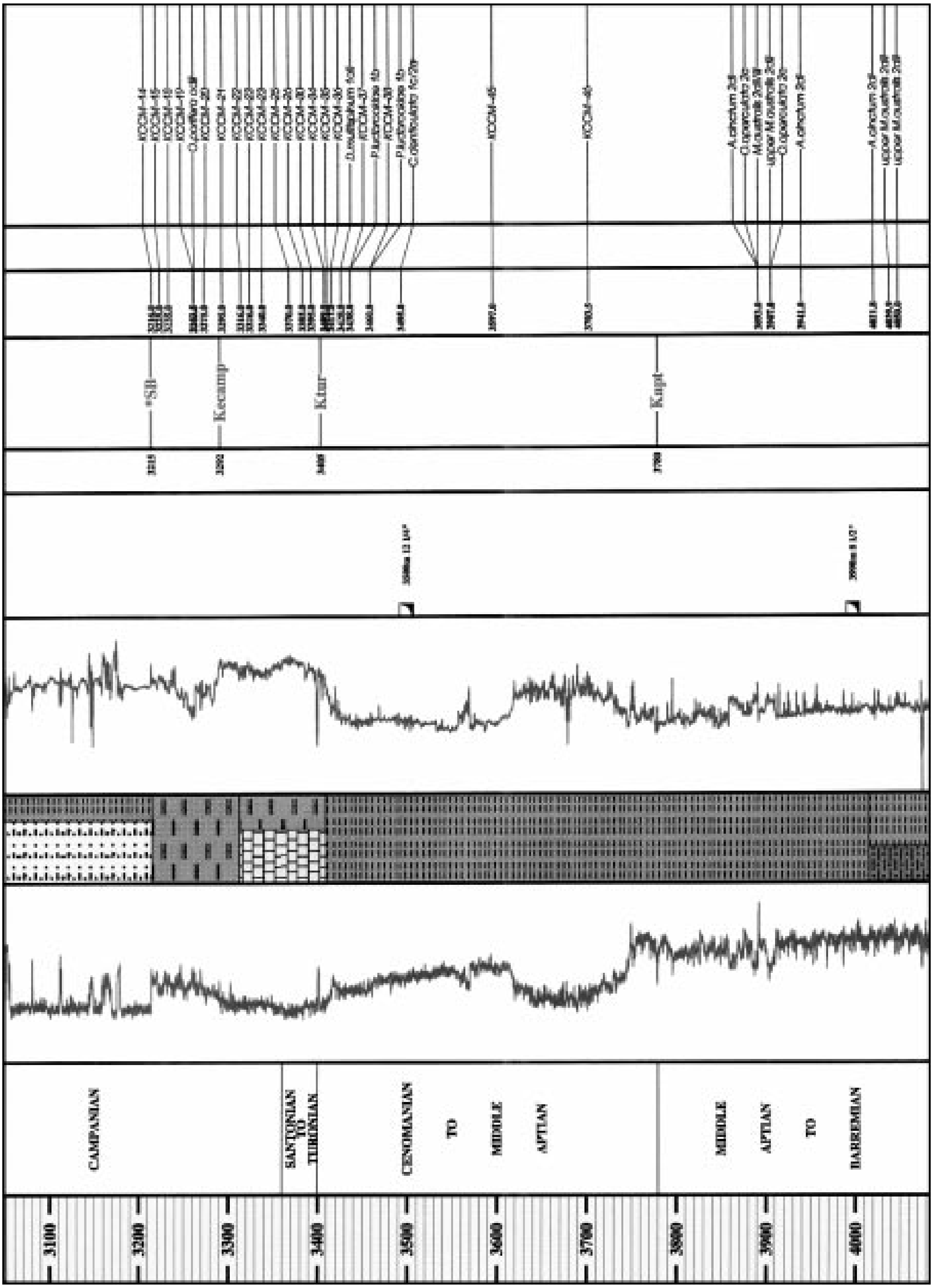


Figure 56 Seismic Line 175/19 showing the stratal geometry and seismic character of the Jurassic to Tertiary succession. Note the basin floor fan developed above the Kbar horizon, and the downlap surface developed over the Aptian "radiolarite" sequence.



14/OA/313

Figure 57 Caswell 2 composite well log showing the characteristic signature of the "radiolarite" and greensand facies above the Aptian Unconformity (Kapt). These facies were deposited in a relatively deep water environment following the flooding of the basin in the mid-Aptian (Intra-*O. operculata* DZ).

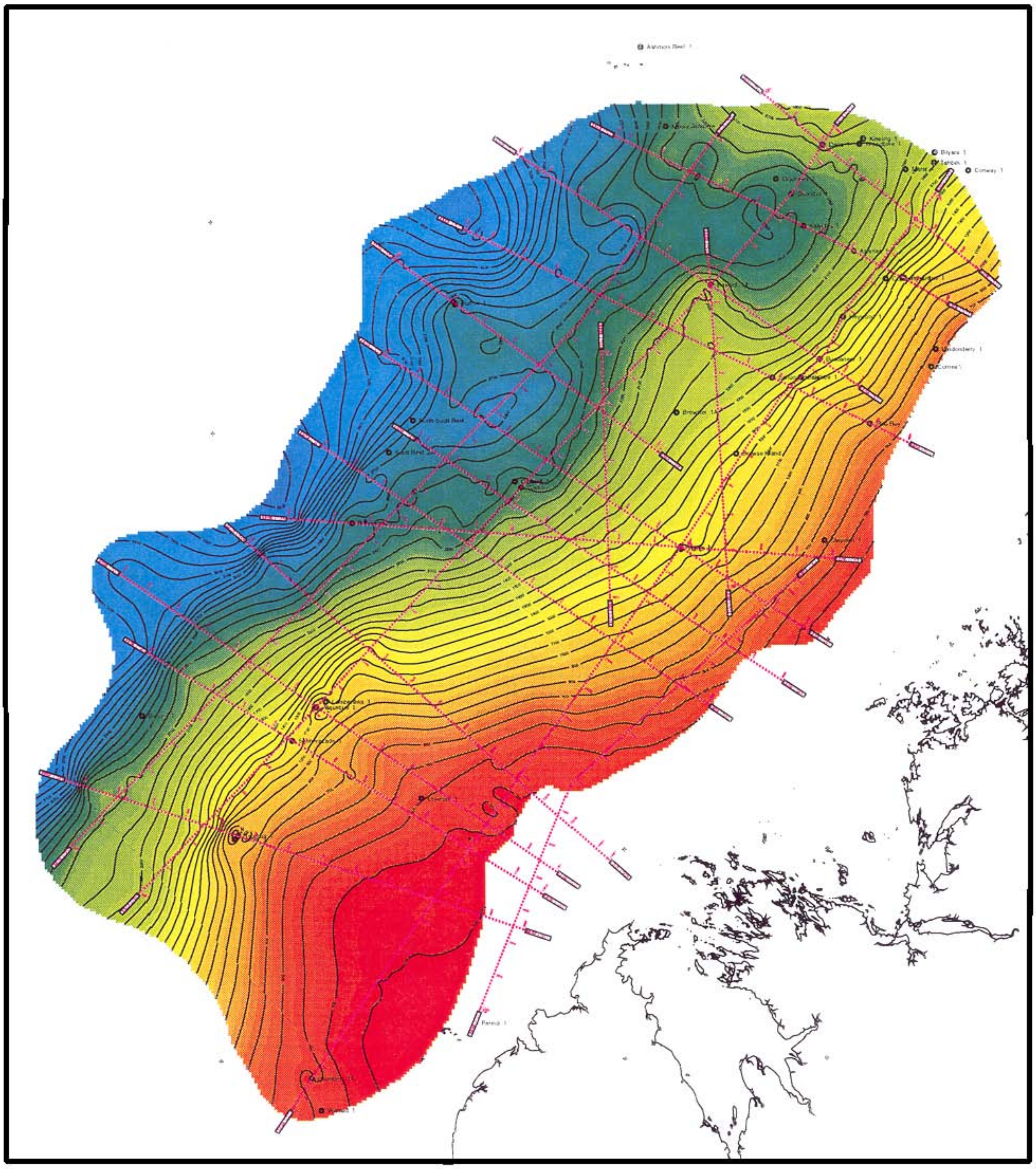


Figure 58 Time structure contour map of Ktur horizon (Turonian Unconformity). This map is also included as Plate 15.

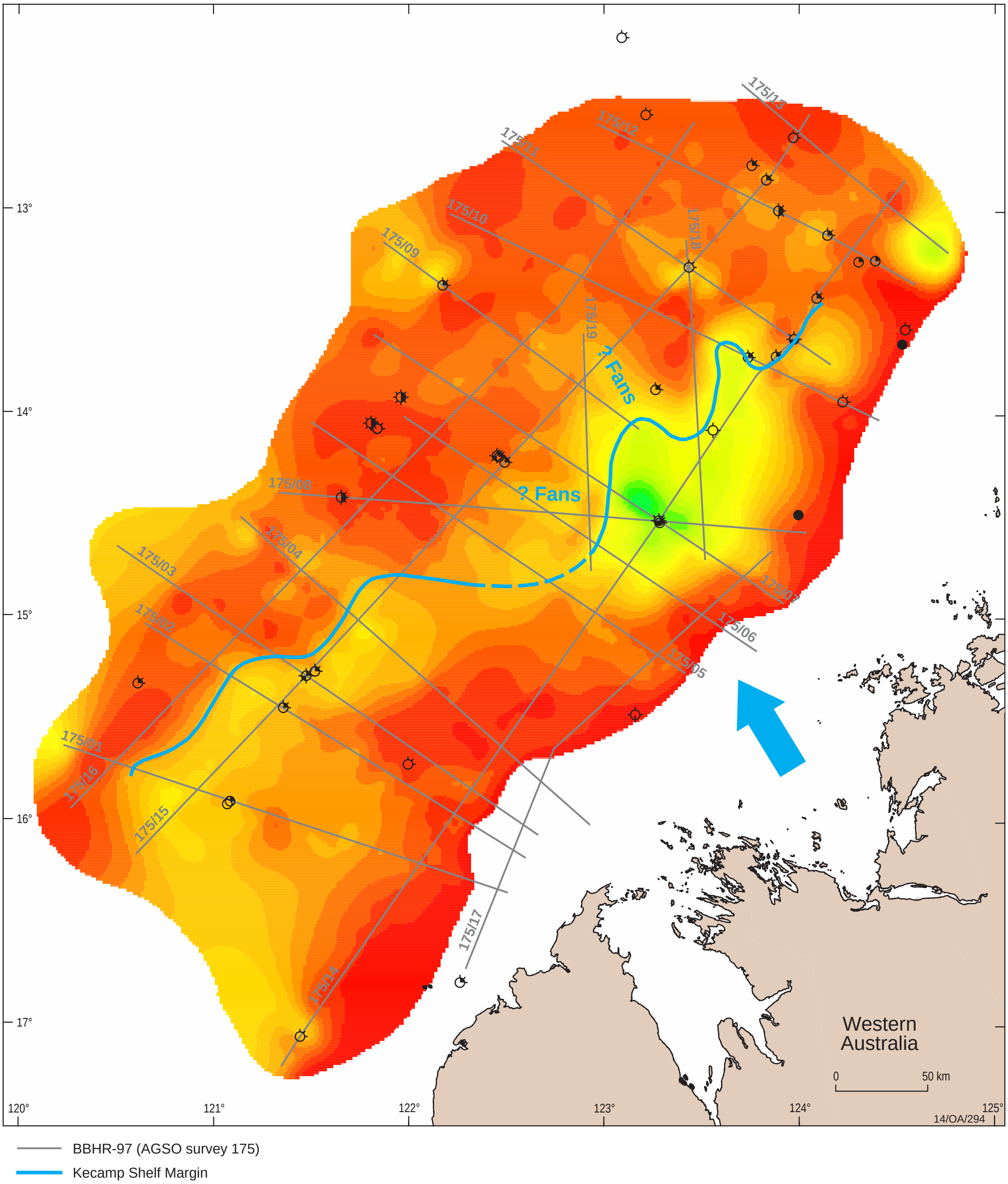


Figure 59 Time isopach map of the Ktur to Kecamp sequence, showing the Kecamp shelf margin defined by seismic onlap, and the location of fan deposition interpreted from seismic facies (see Figure 66). The arrow indicates probable source direction. The time isopach base used for this map is included as Plate 22.

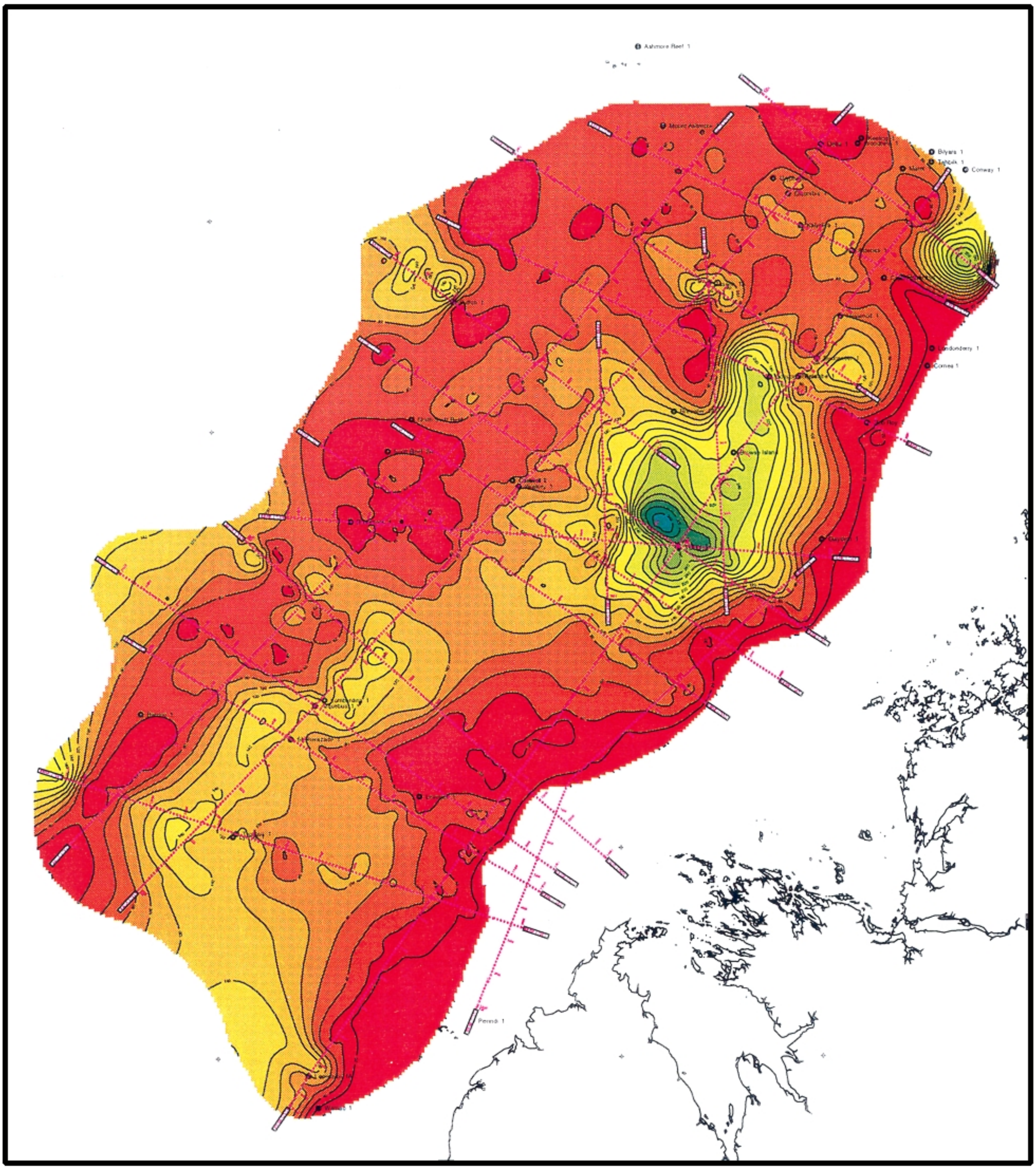


Figure 60 Time isopach map of Ktur to Kecamp sequence (Turonian to Early Campanian). This map is also included as Plate 22.

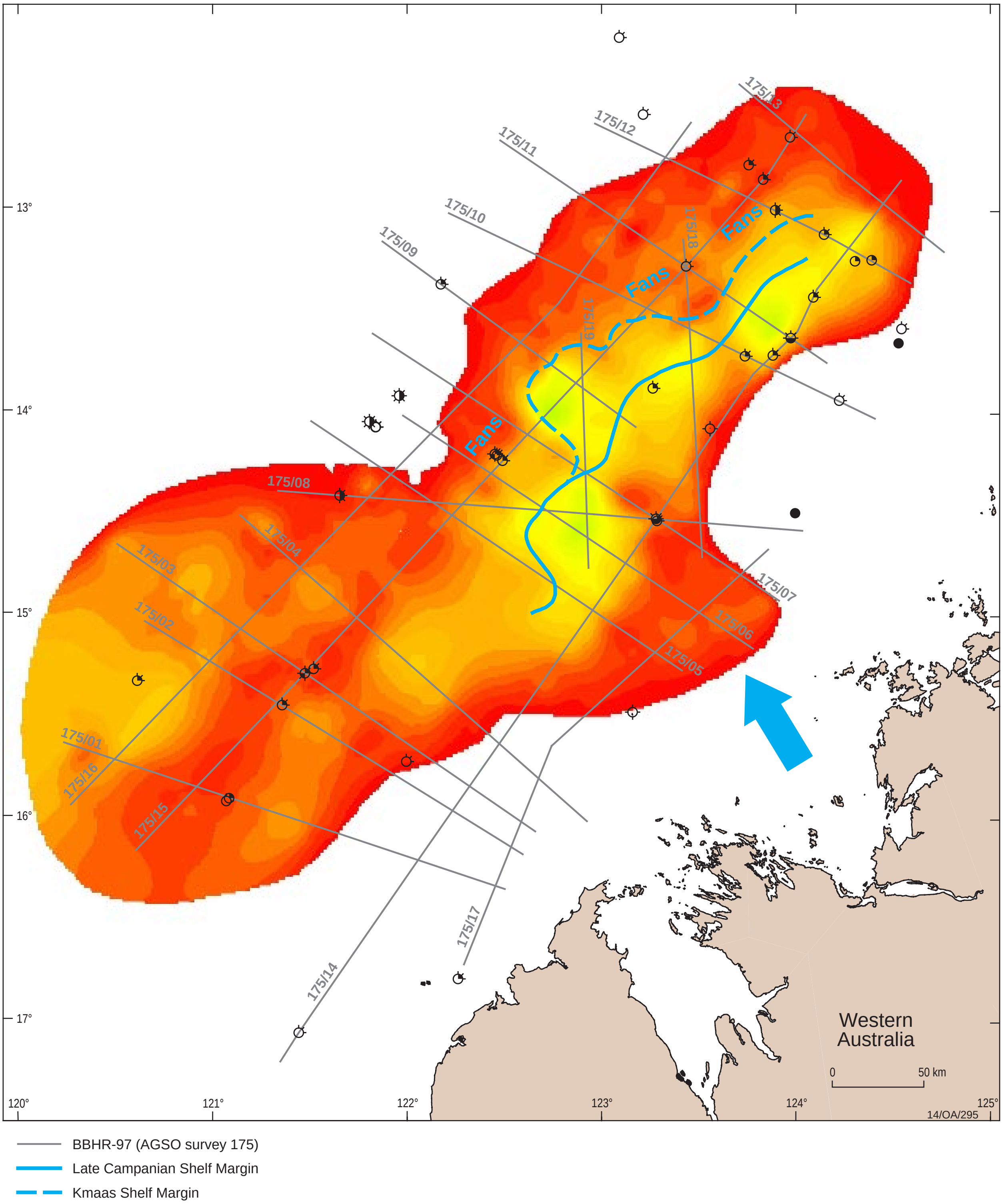


Figure 61 Time isopach map of the Kecamp to Kmaas sequence, showing the late Campanian (SB) and Kmaas shelf margins defined by seismic onlap. The location of lowstand fan facies interpreted in wells is indicated basinward of shelf margin(s). The arrow indicates the probable source direction. The time isopach base used for this map is included as Plate 23.

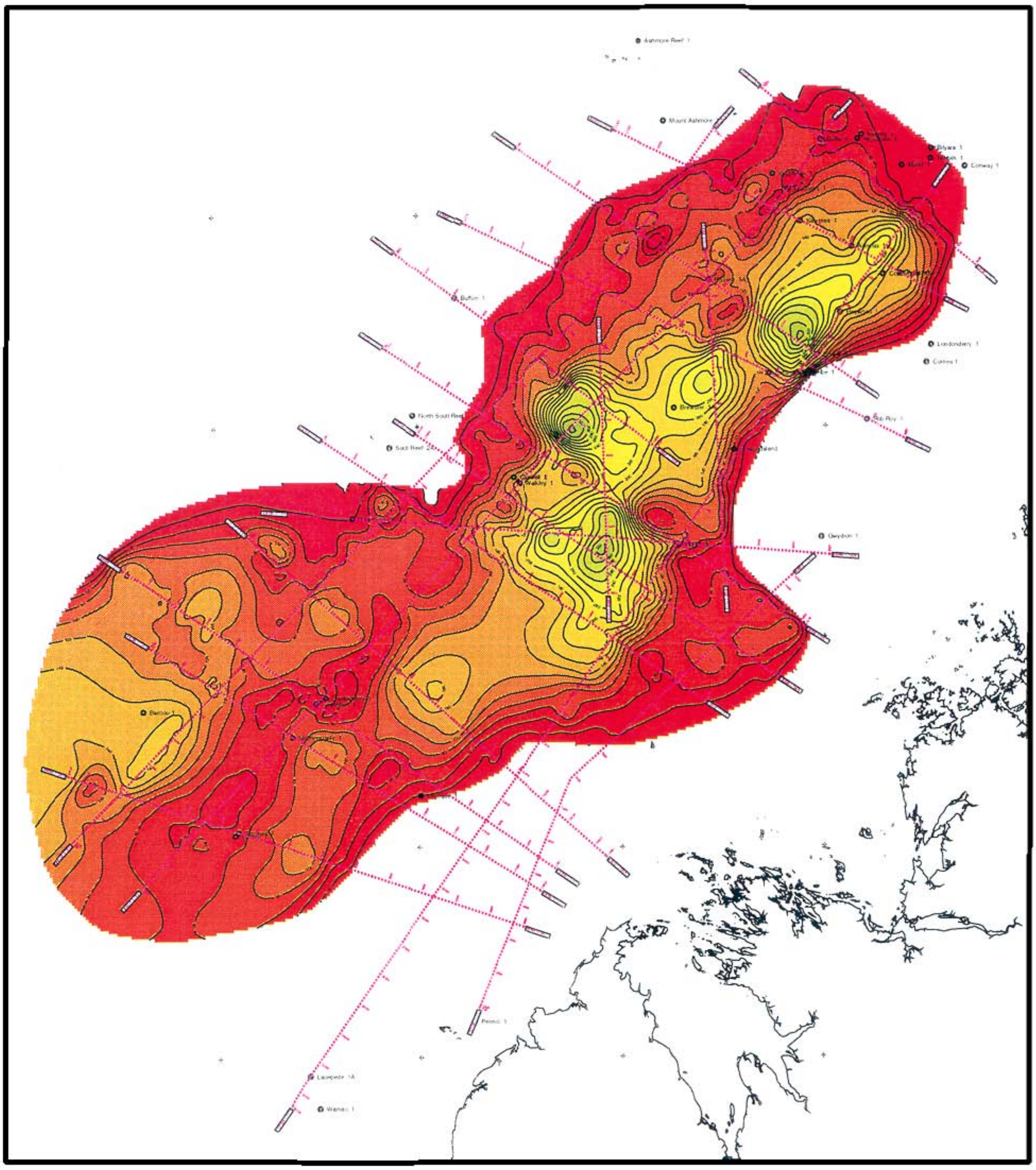


Figure 62 Time isopach map of Kecamp to Kmaas sequence (Early Campanian to Maastrichtian). This map is also included as Plate 23.

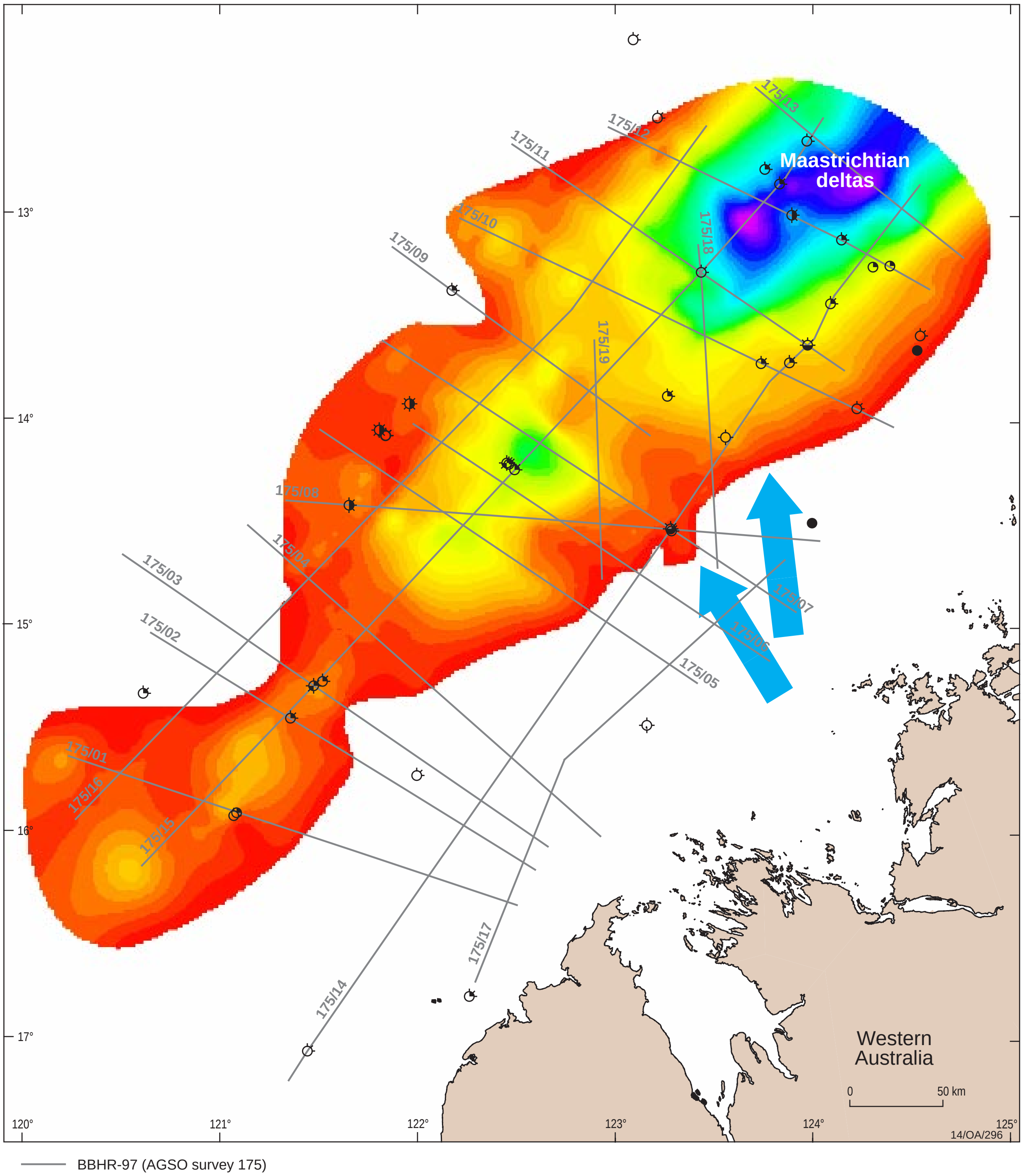


Figure 63 Time isopach map of the Kmaas to Tbase sequence. The arrows indicate the probable source direction. Seismic data indicates the direction of delta progradation is predominantly to the north. The time isopach base used for this map is included as Plate 24.

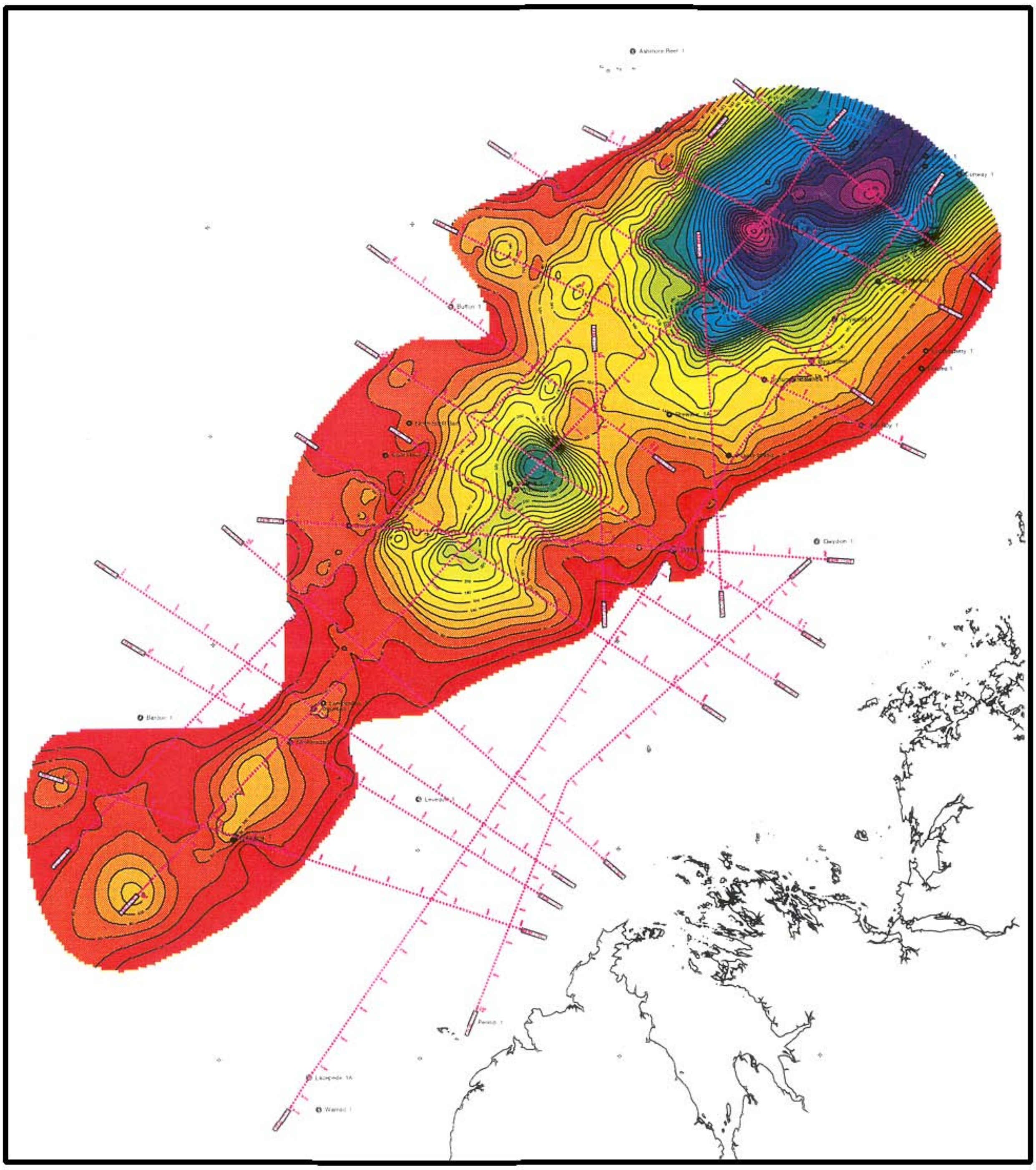


Figure 64 Time isopach map of Kmaas to Tbase sequence (Maastrichtian to Base Tertiary). This map is also included as Plate 24.

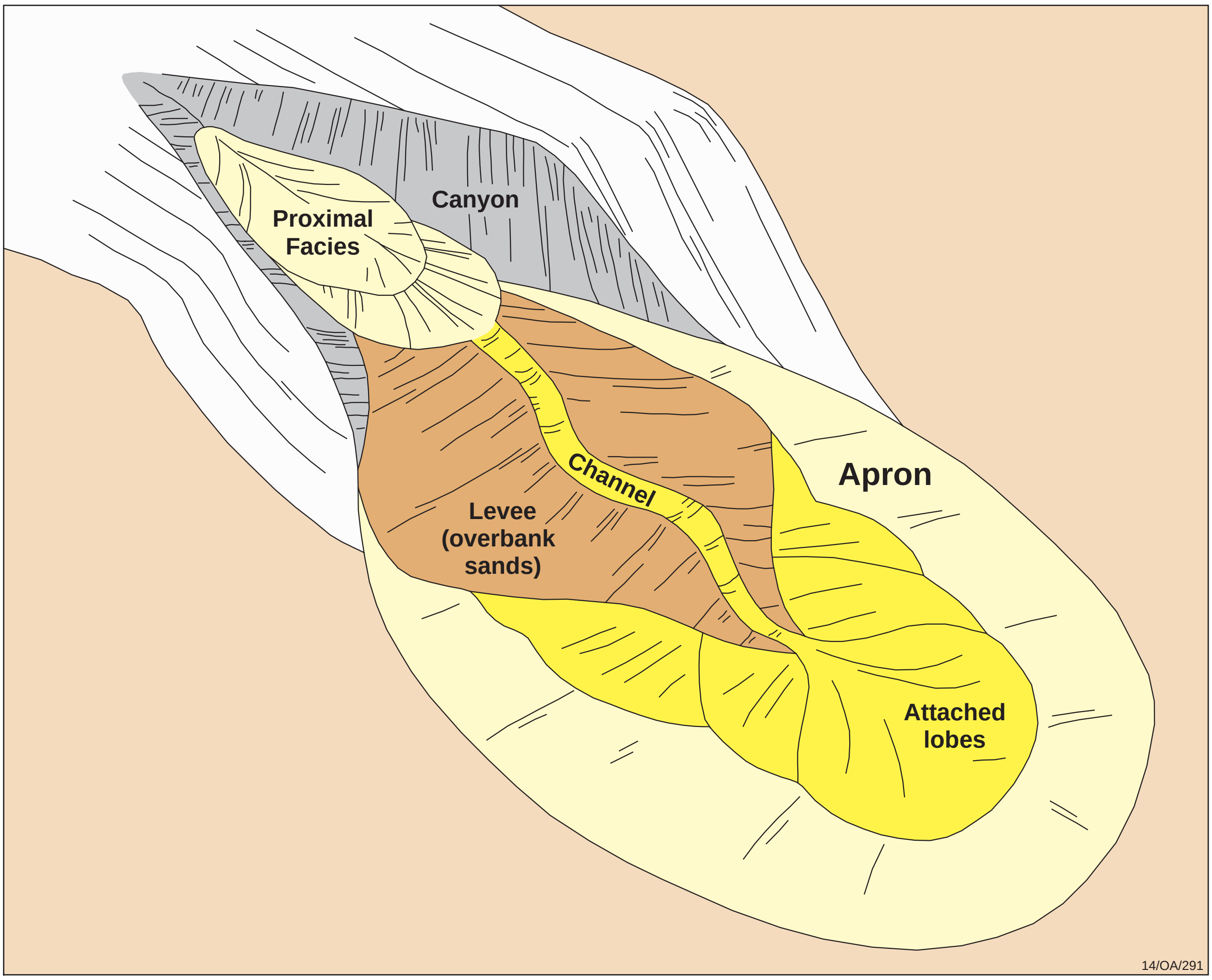


Figure 65 Fan model from Mitchum *et al.* (1993), showing distribution of facies based on seismic observation.

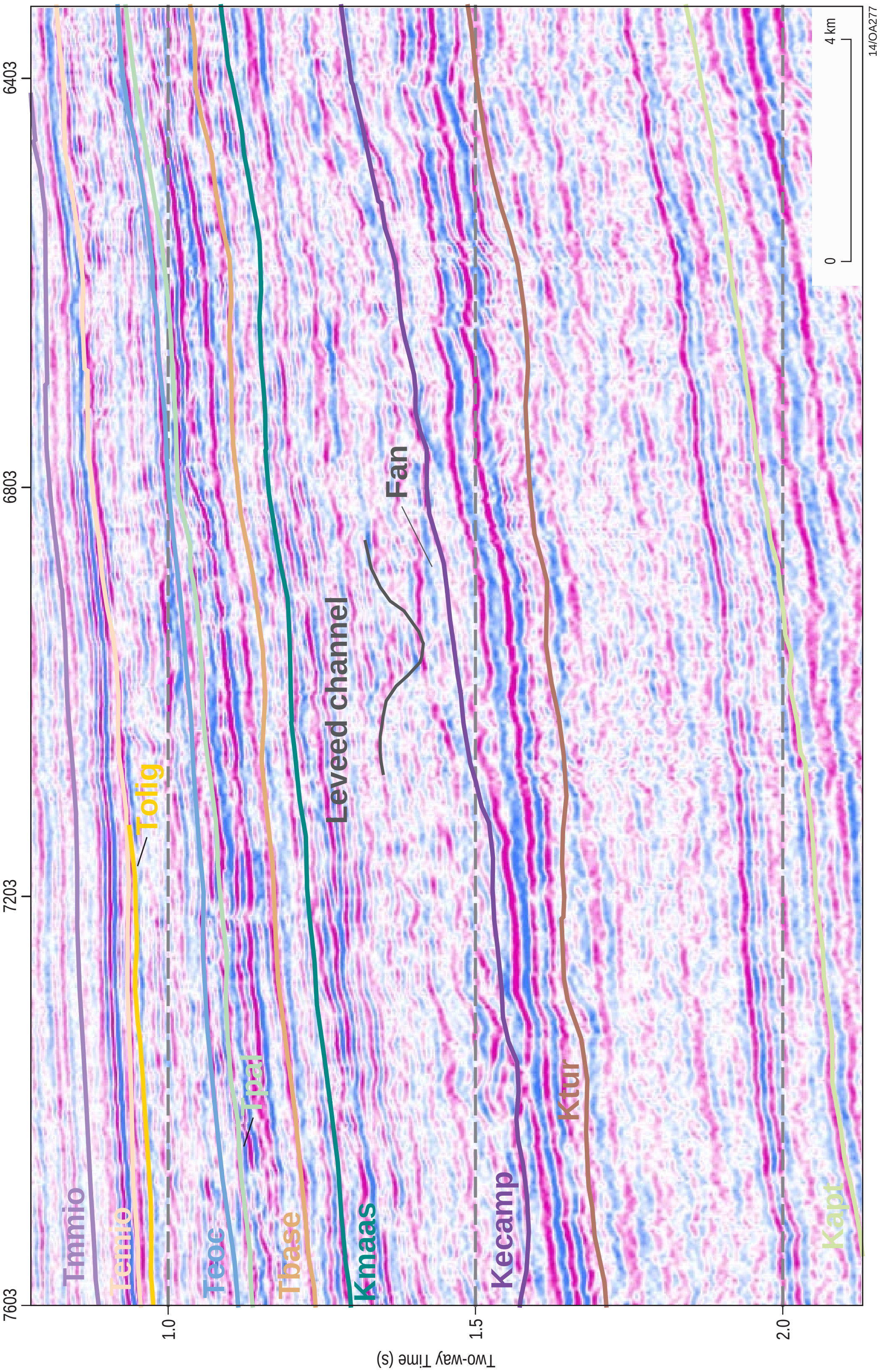


Figure 66 Seismic example from BBHR Line 175/08 showing leveed-channels within a fan complex deposited on the Kecamp sequence boundary.

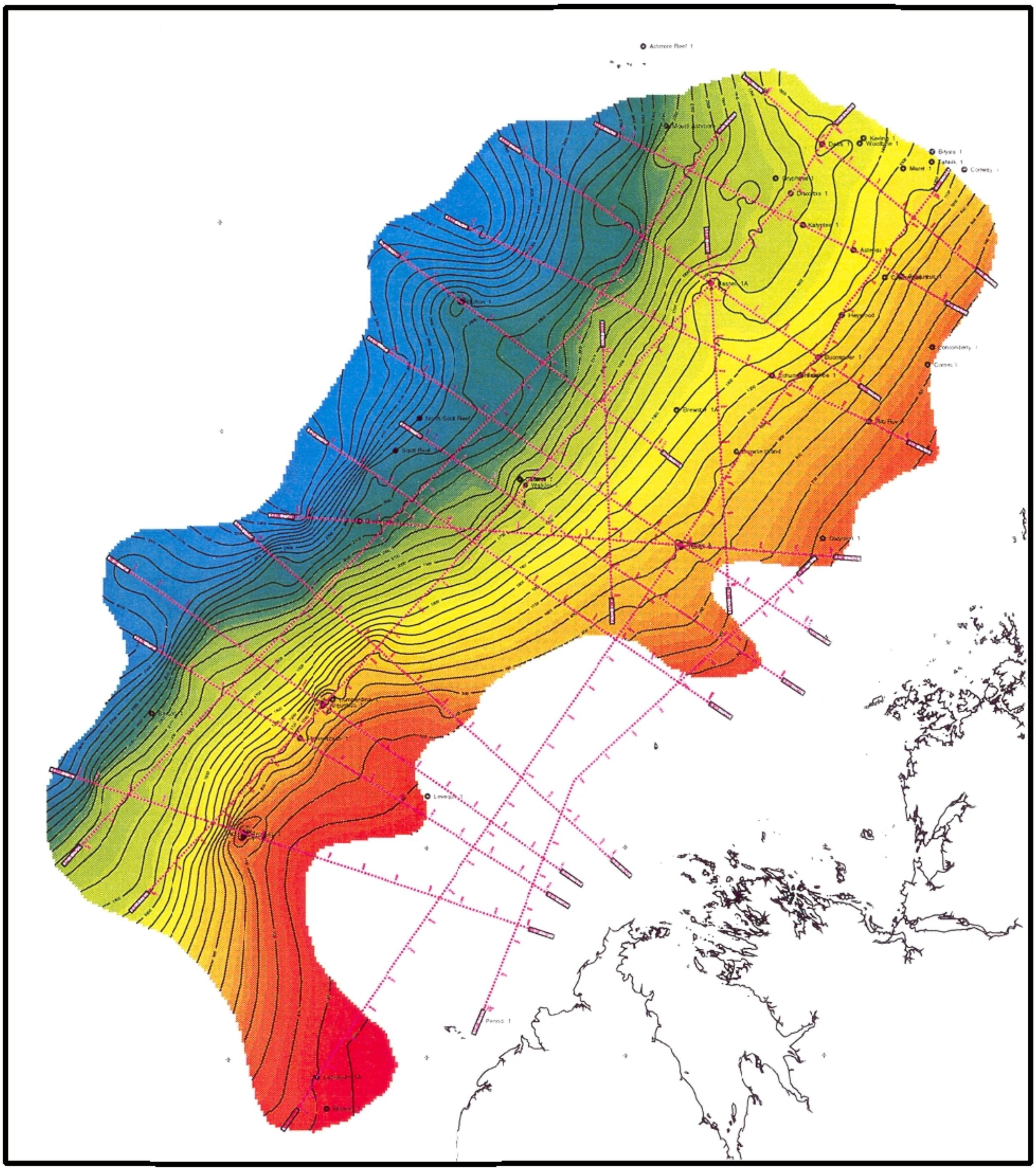


Figure 67 Time structure contour map of the Tbase horizon (Base Tertiary Unconformity).
This map is also included as Plate 16.

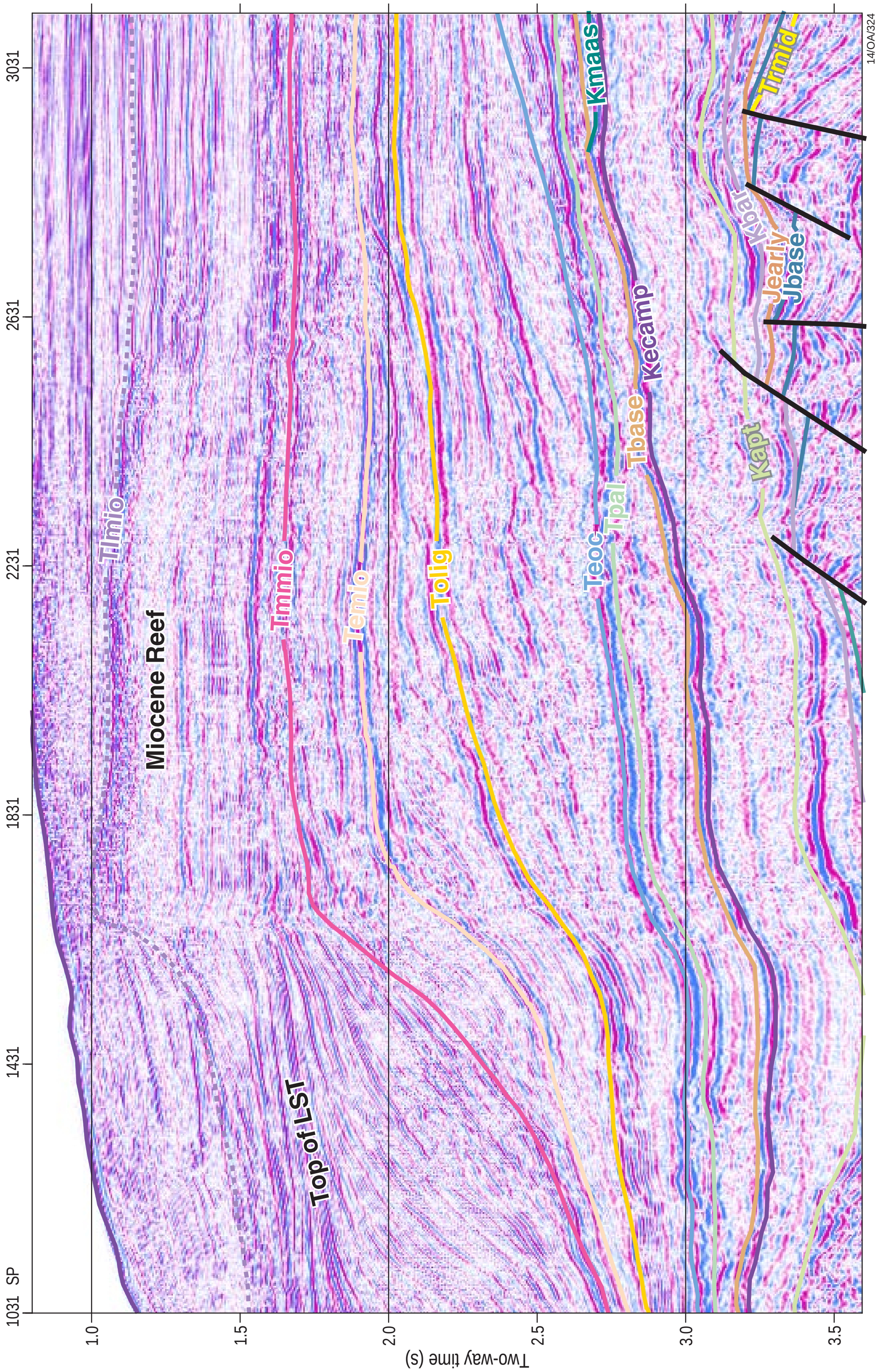


Figure 68 Seismic Line 175/07 showing the regressive stacking of sequences above the Ktur (Turonian Unconformity) and the shelfal outbuilding during successive lowstands in the Tertiary. The top of the Middle Miocene LST is noted. A platform reef developed during the Middle-Late Miocene on trend with the present-day Scott Reef.

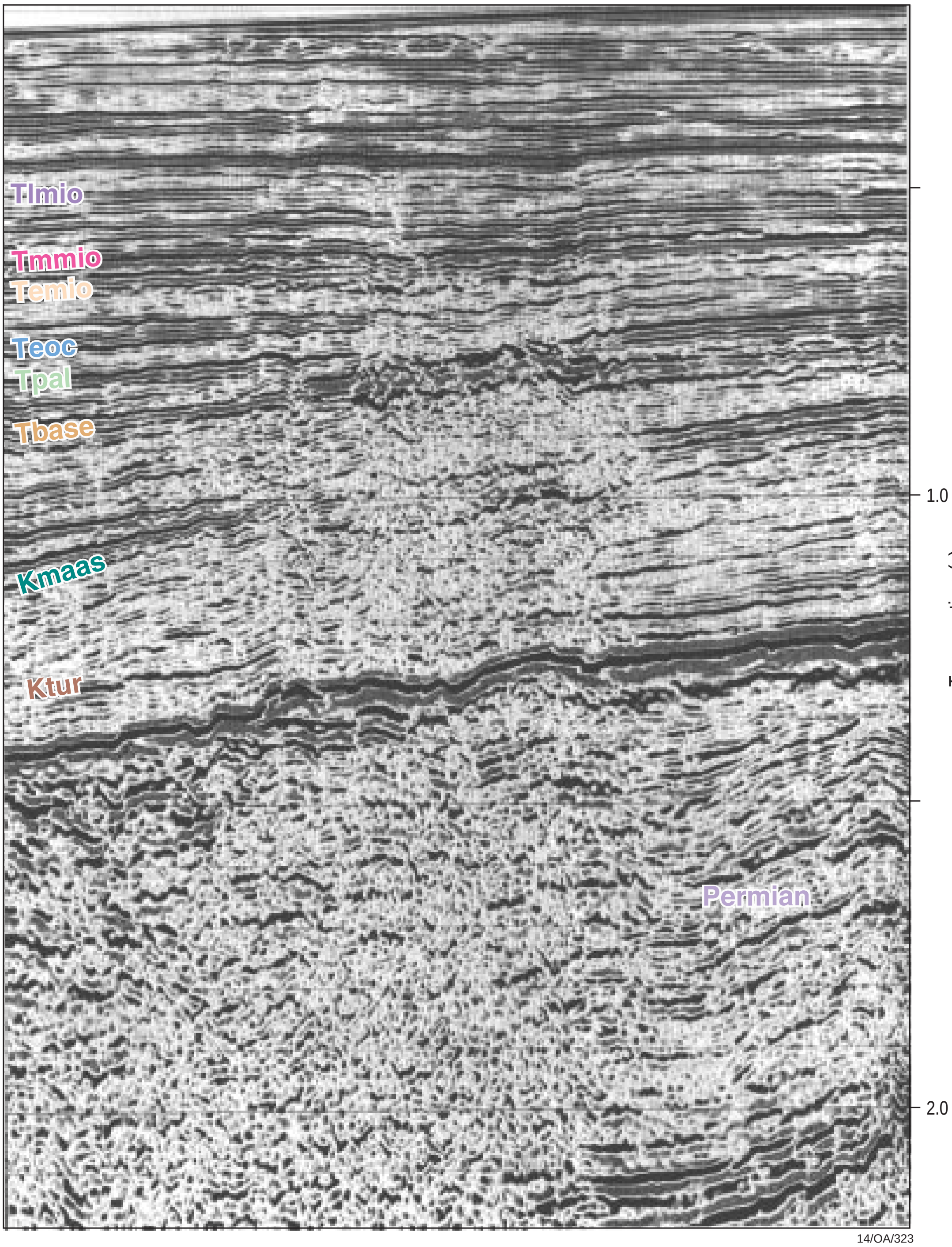


Figure 69 Seismic Line 175/13 in the northern Browse Basin showing a possible gas chimney extending into Eocene rocks. This example is located updip of the faulted margin of the Heywood Graben.

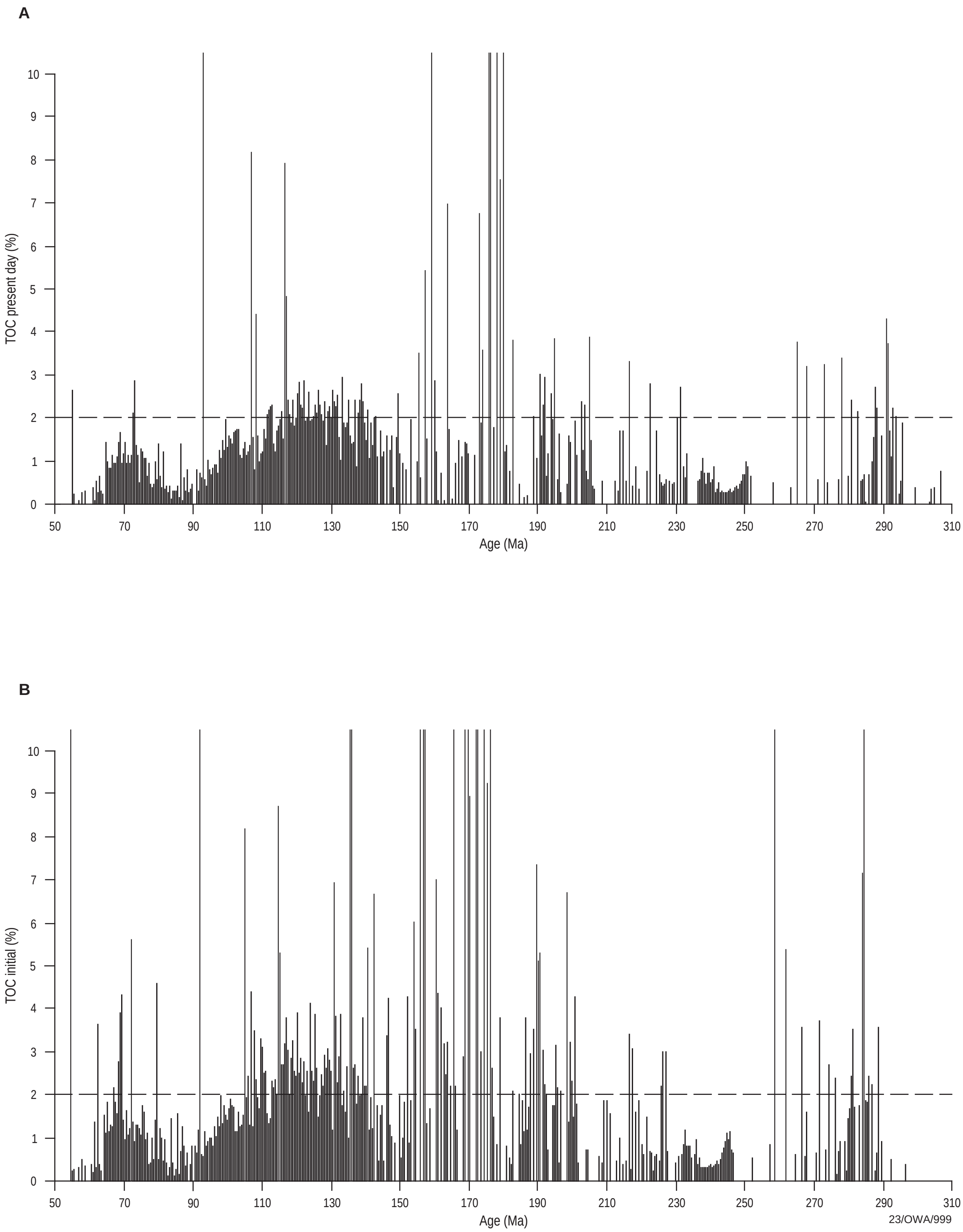


Figure 70 Age profile of (A) present-day TOC and (B) initial TOC values.

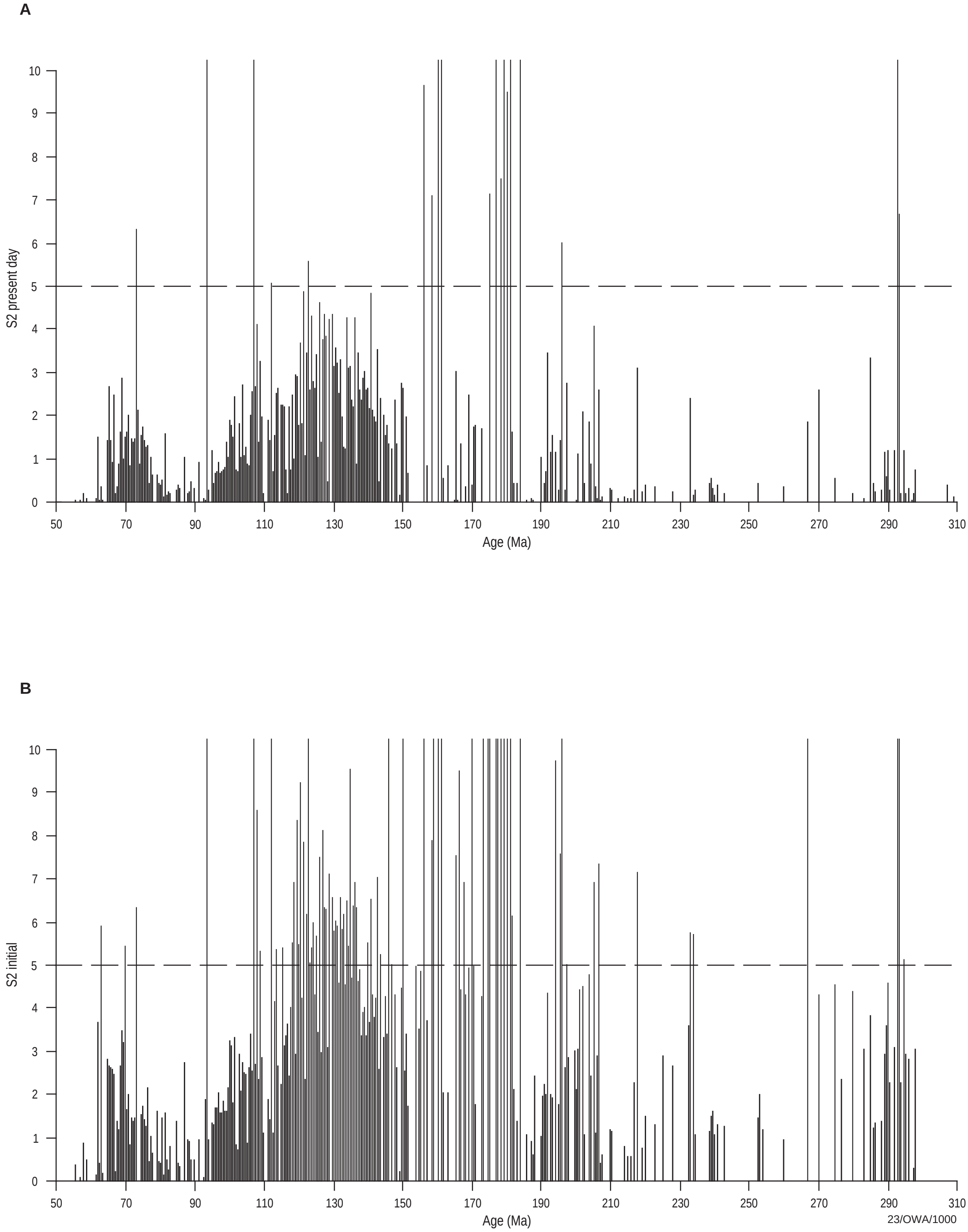


Figure 71 Age profile of (A) present-day S2 and (B) initial S2 values.

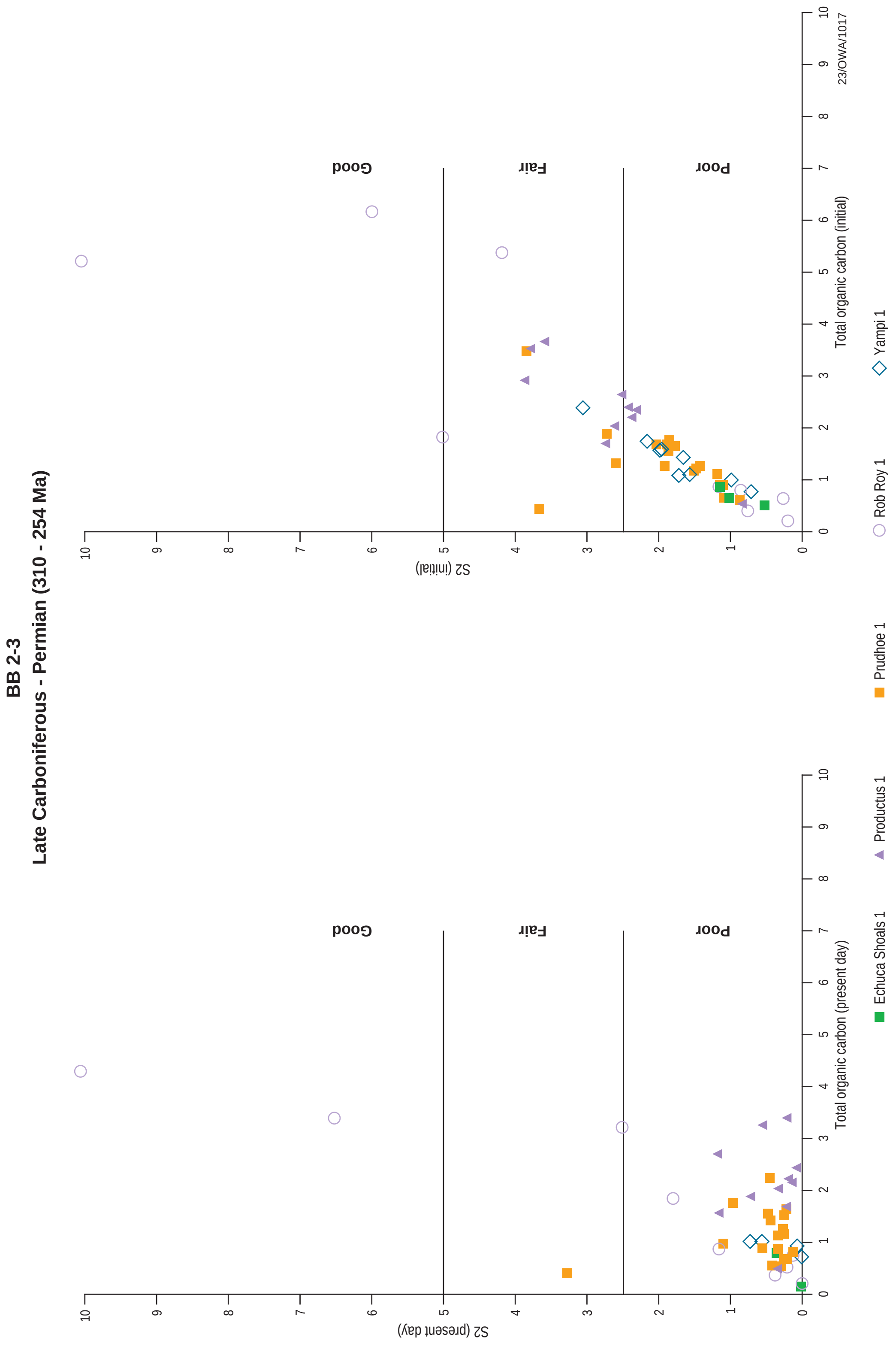


Figure 72a Present-day and initial source rock typing for BB 2-3

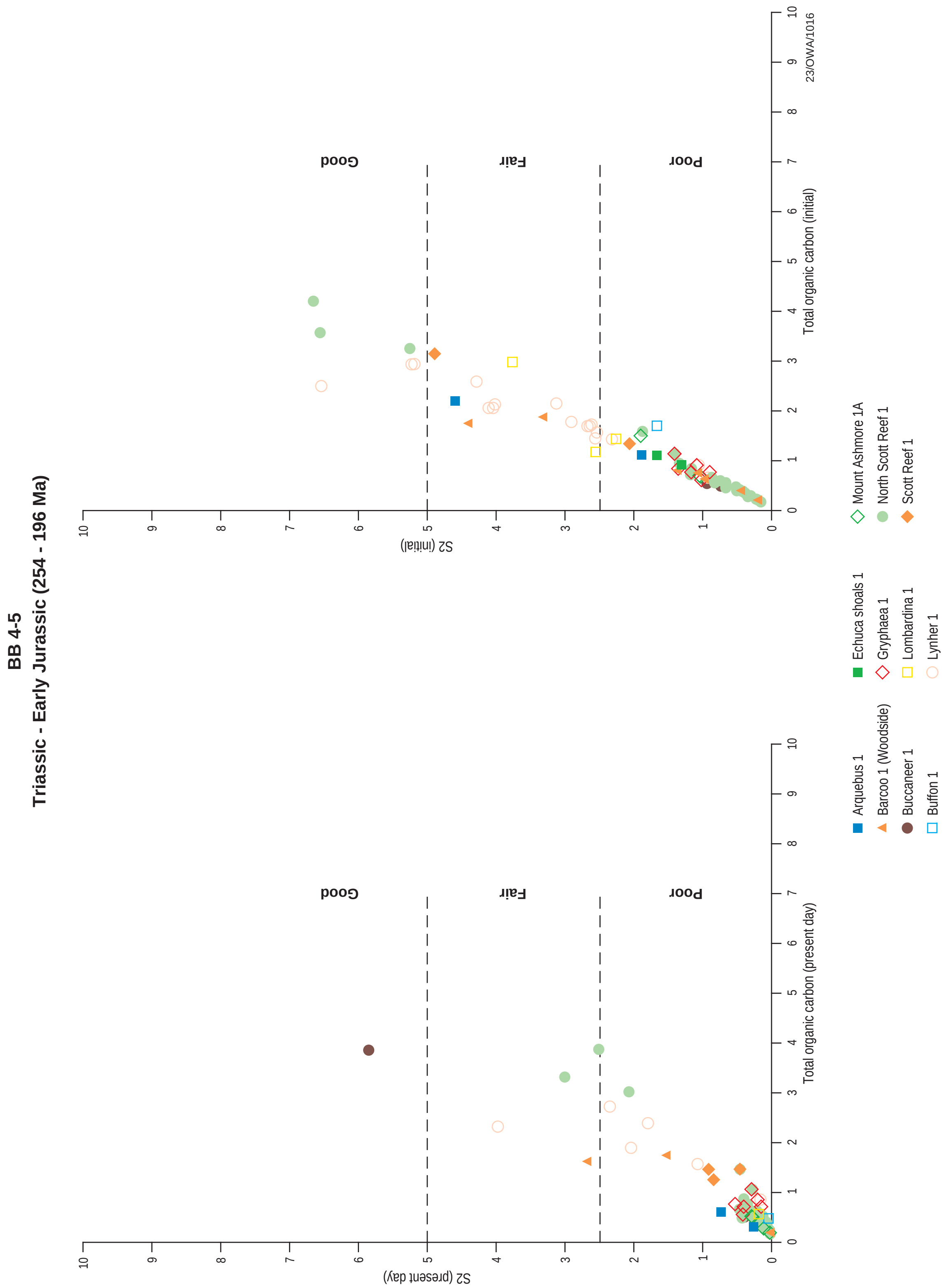


Figure 72b Present-day and initial source rock typing for BB 4-5

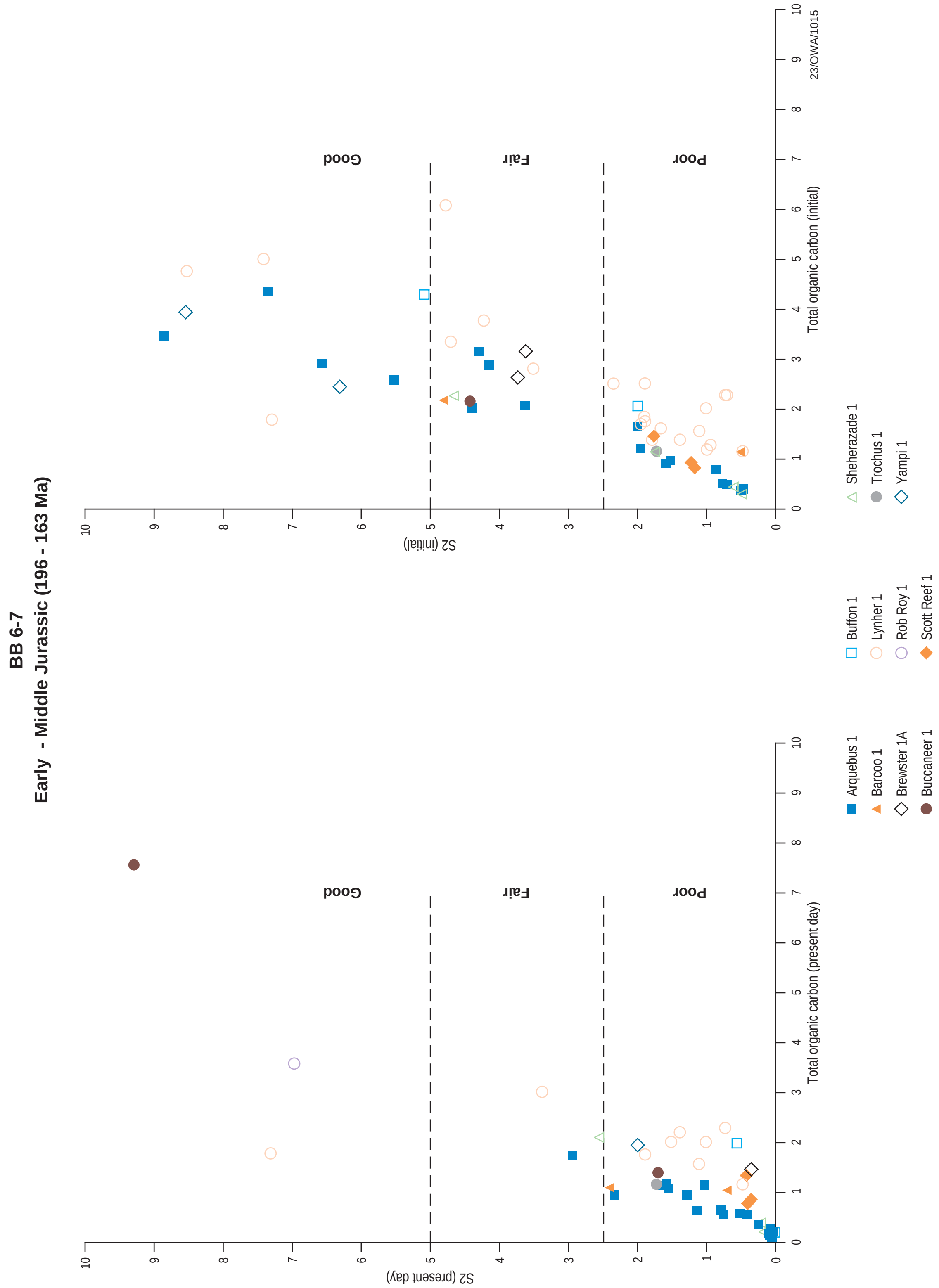


Figure 72c Present-day and initial source rock typing for BB 6-7

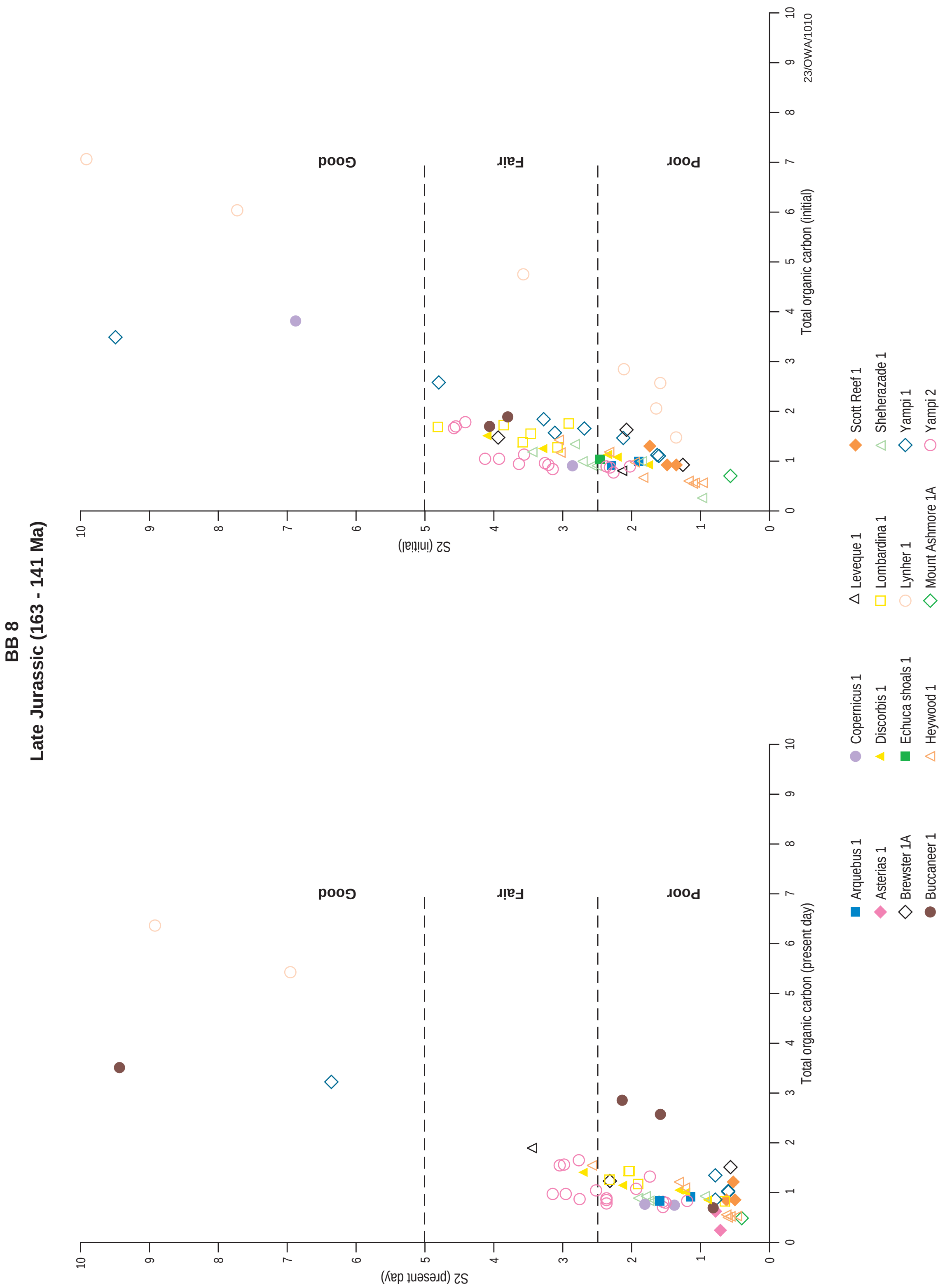


Figure 72d Present-day and initial source rock typing for BB 8

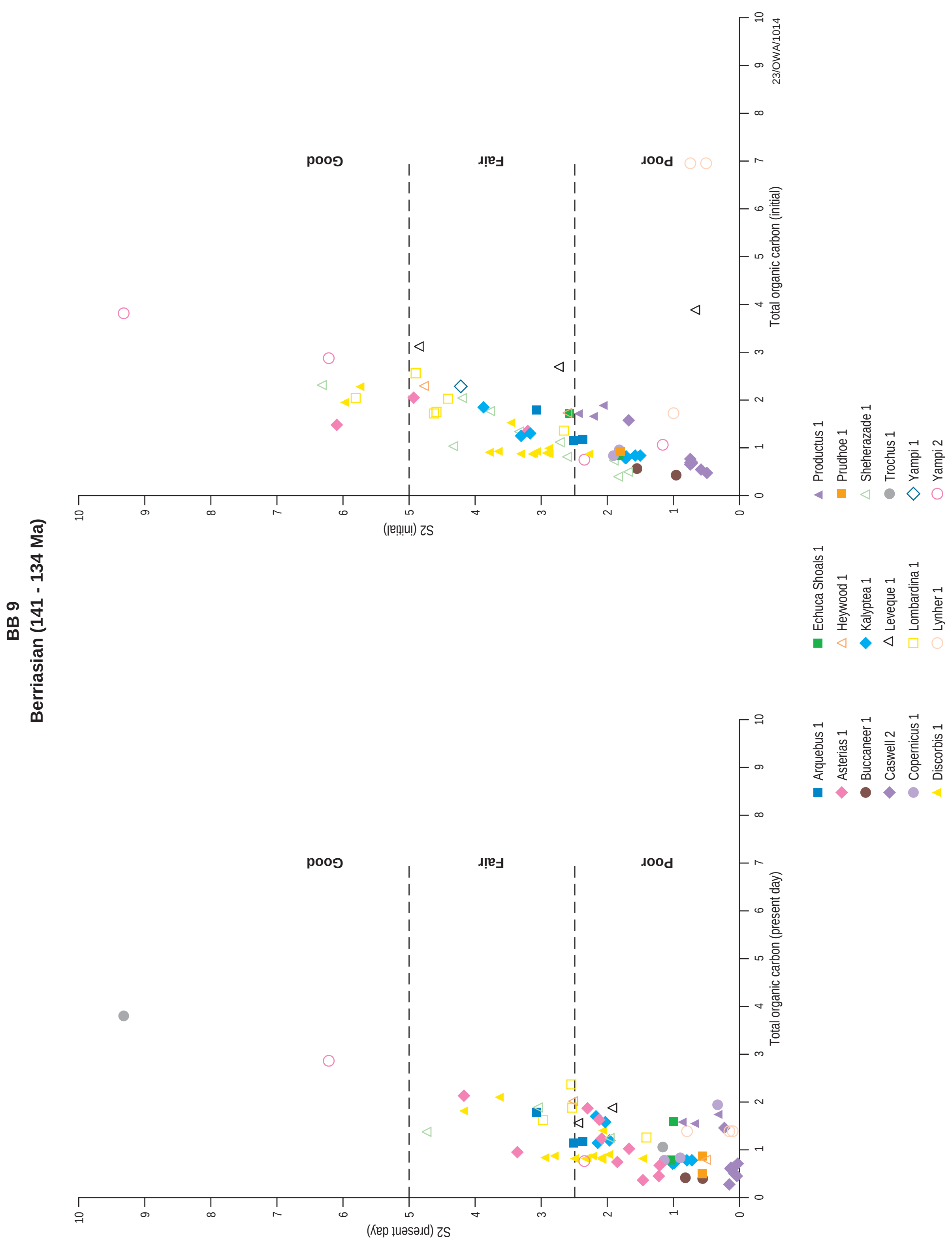


Figure 72e Present-day and initial source rock typing for BB 9

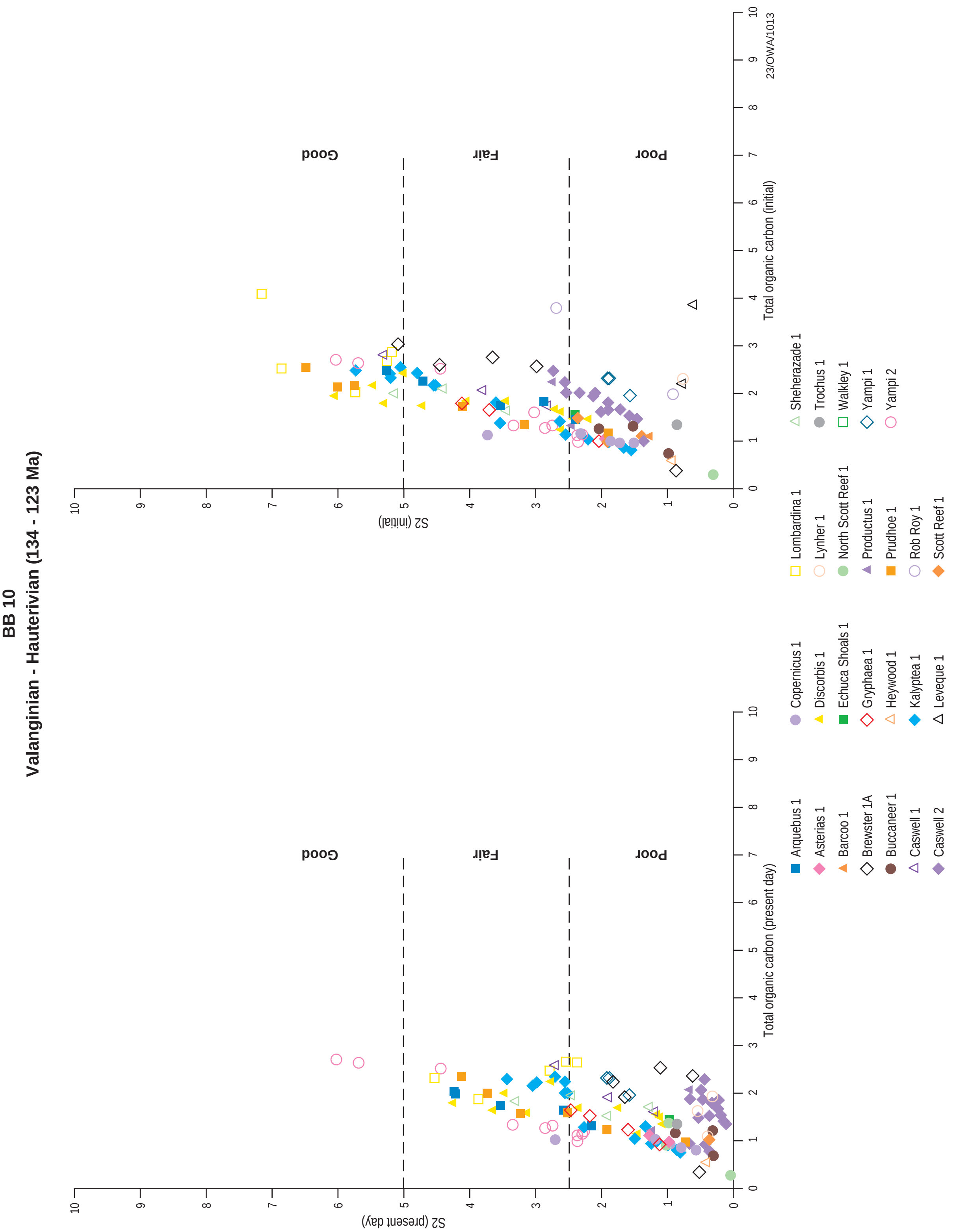


Figure 72f Present-day and initial source rock typing for BB 10

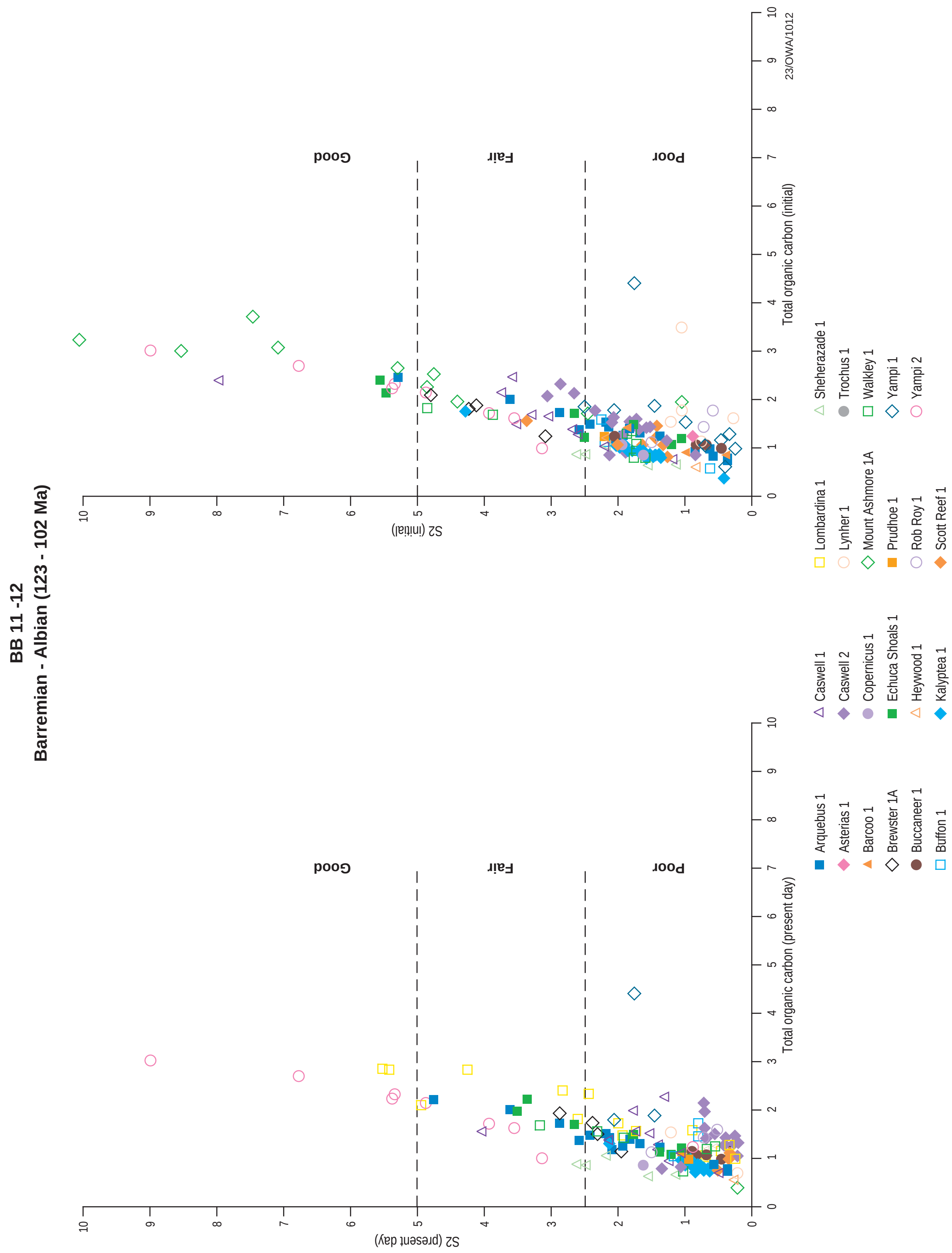


Figure 72g Present-day and initial source rock typing for BB 11-12

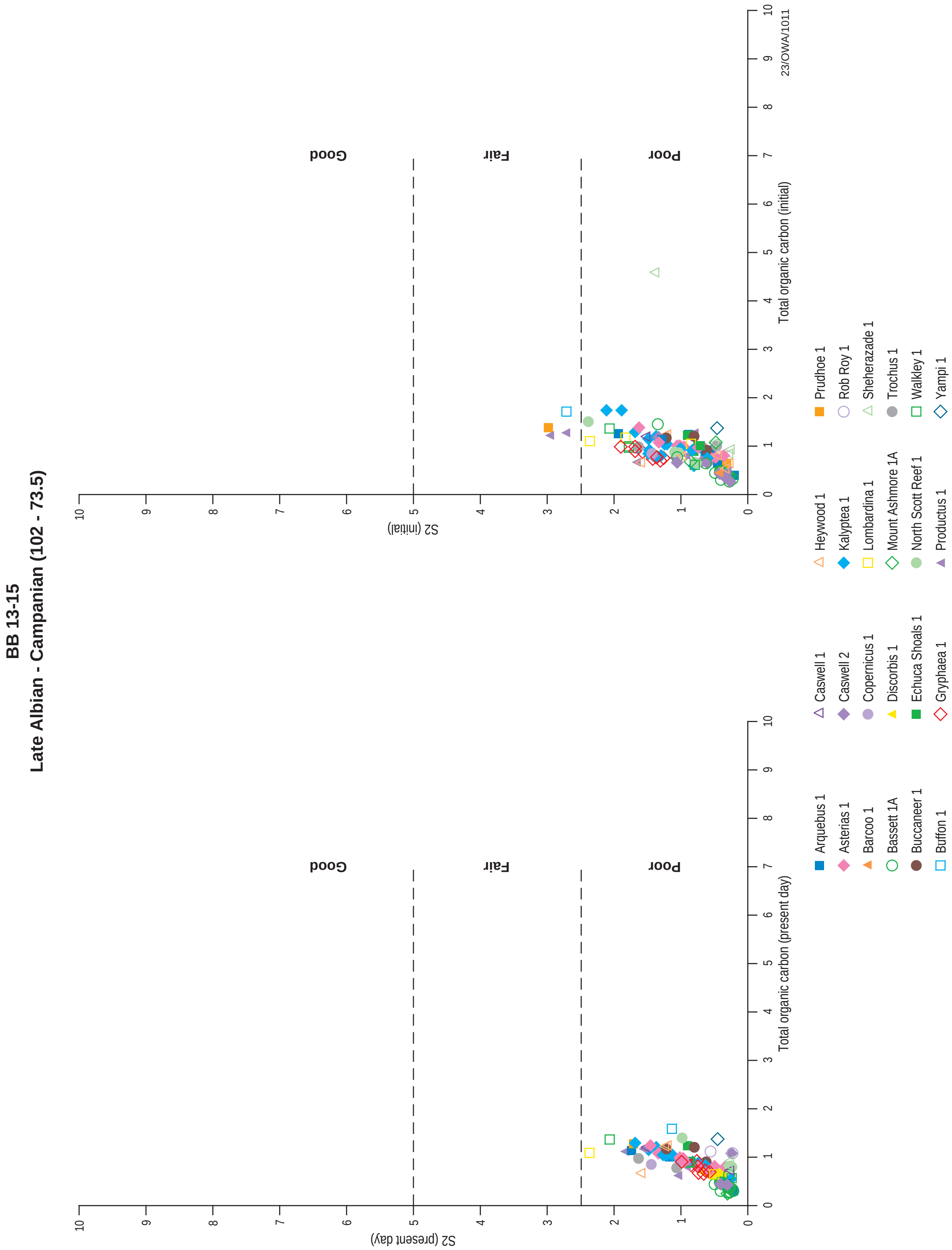


Figure 72h Present-day and initial source rock typing for BB 13-15

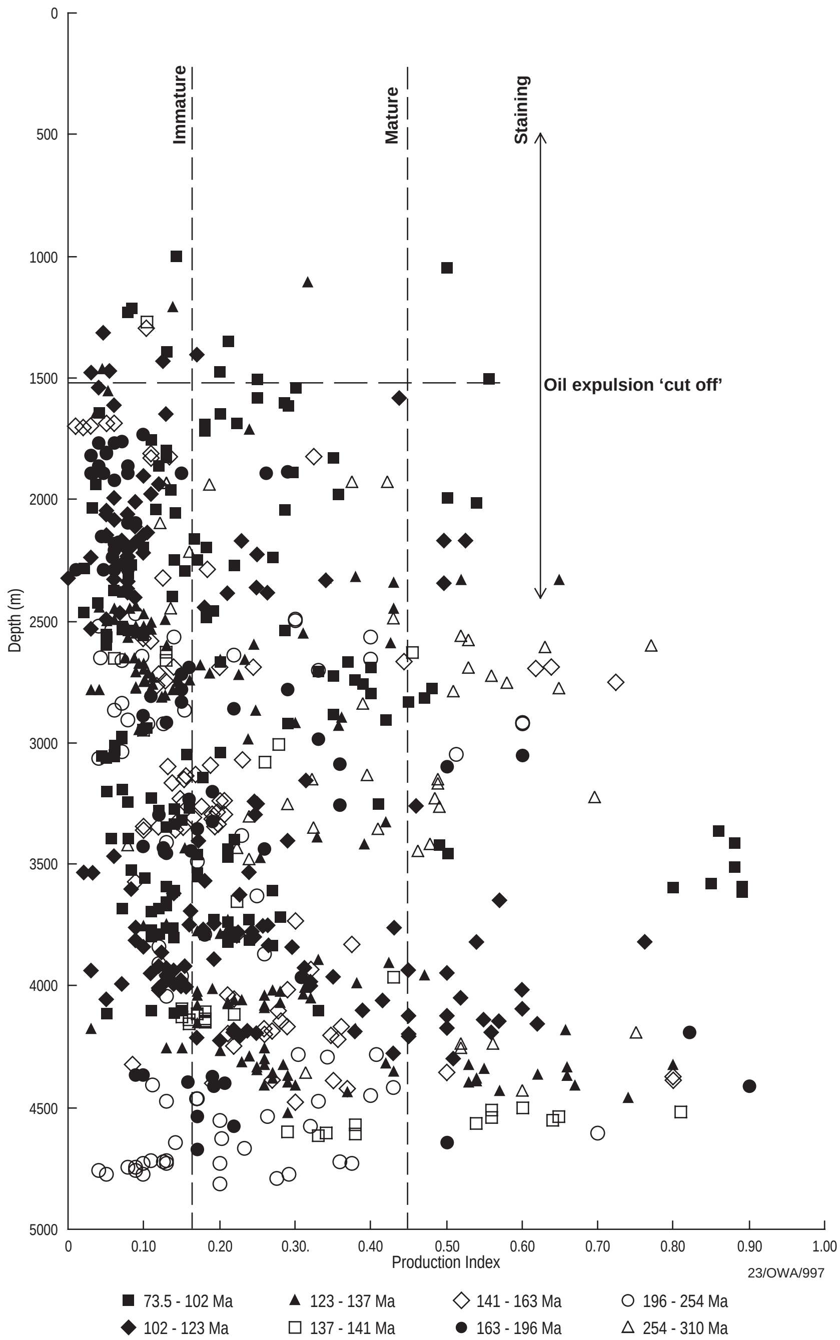
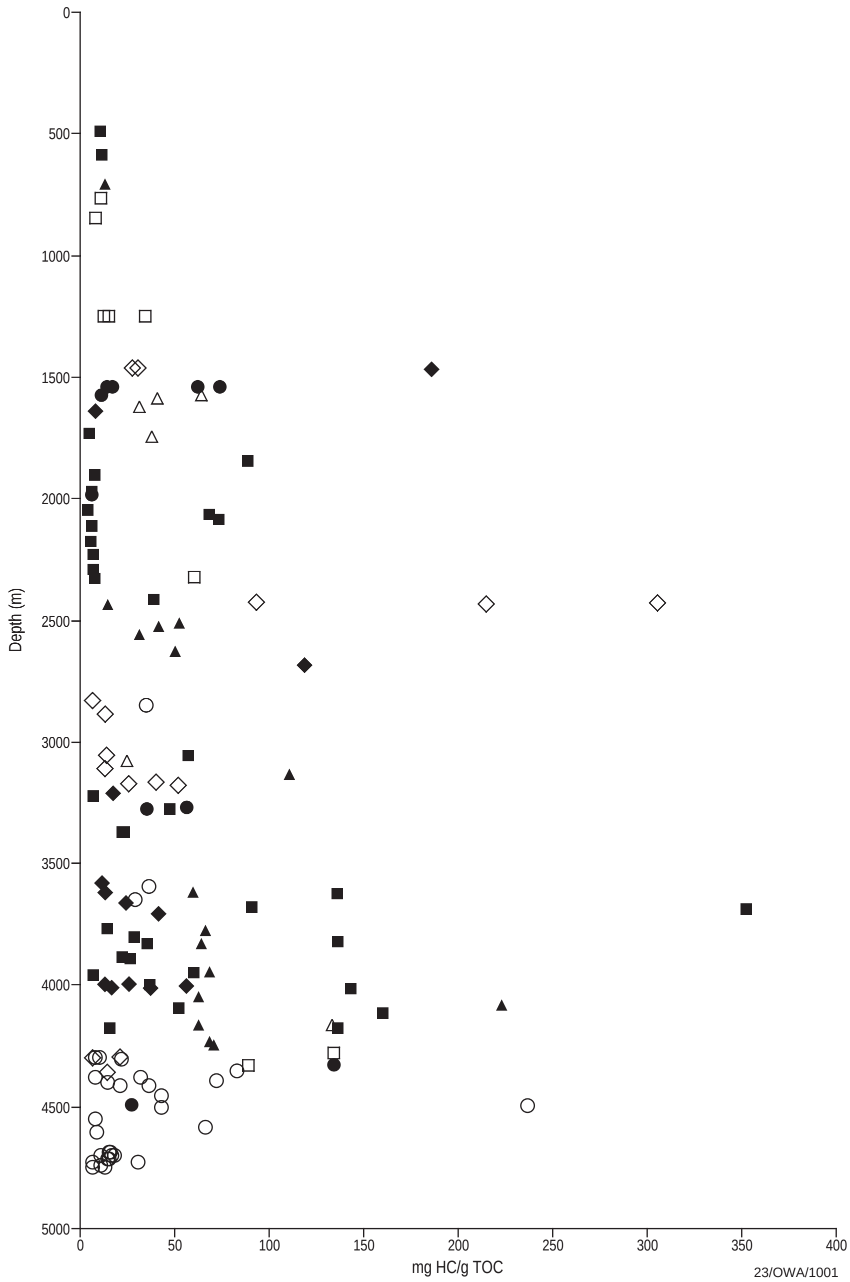


Figure 73a Extent of kerogen transformation in Browse Basin samples.



- ◆ Late Albian - Campanian (102 - 73.5 Ma)
- ■ Barremian - Albian (123 - 102 Ma)
- ▲ Valanginian - Hauterivian (134 - 123 Ma)
- □ Berriasian (141 - 134 Ma)
- ◇ Late Jurassic (163 - 141 Ma)
- ● Early - Middle Jurassic (196 - 163 Ma)
- ○ Triassic - Early Jurassic (254 - 196 Ma)
- △ Late Carboniferous - Permian (310 - 254 Ma)

Figure 73b Extract yields from Browse Basin samples.

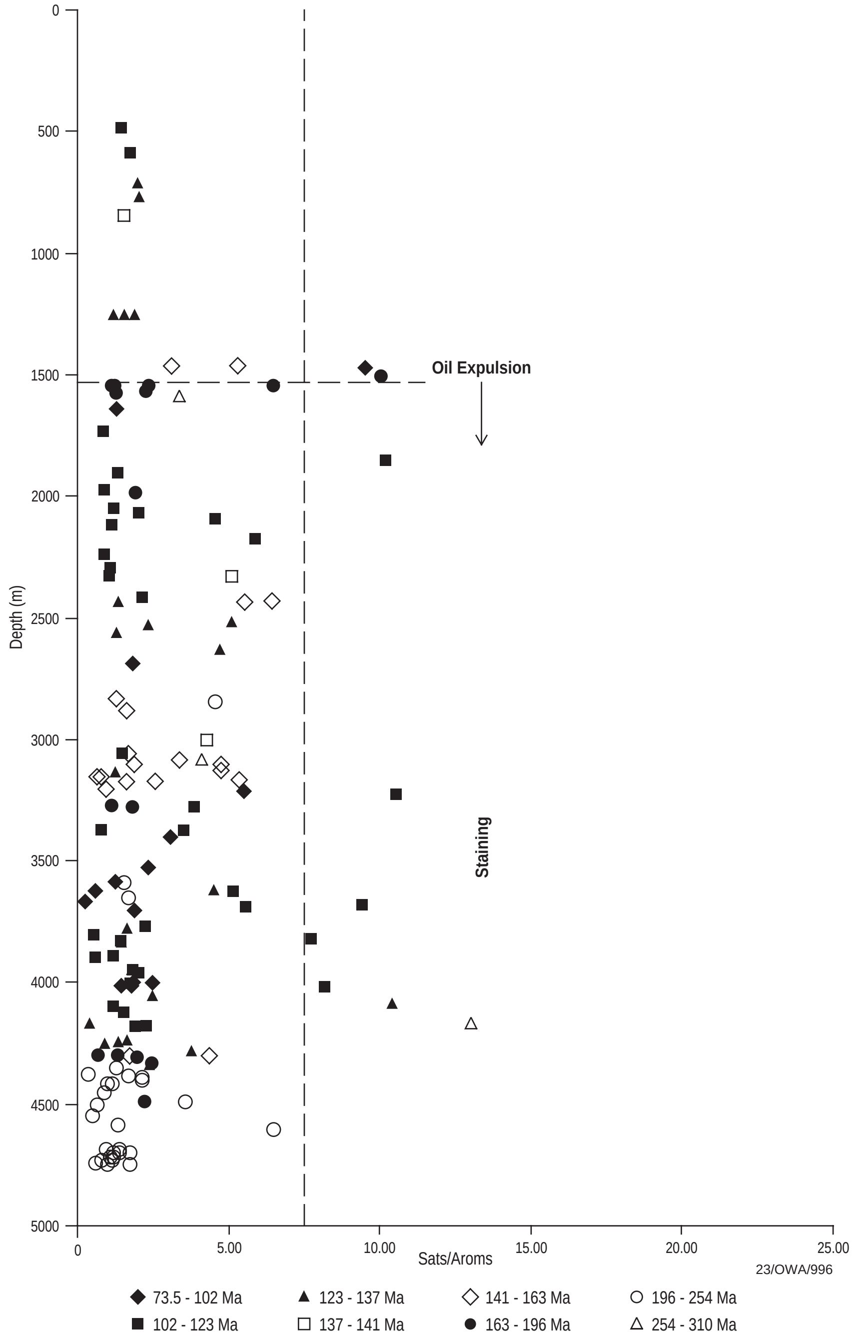


Figure 73c "Oil-like" character of kerogen in Browse Basin samples.

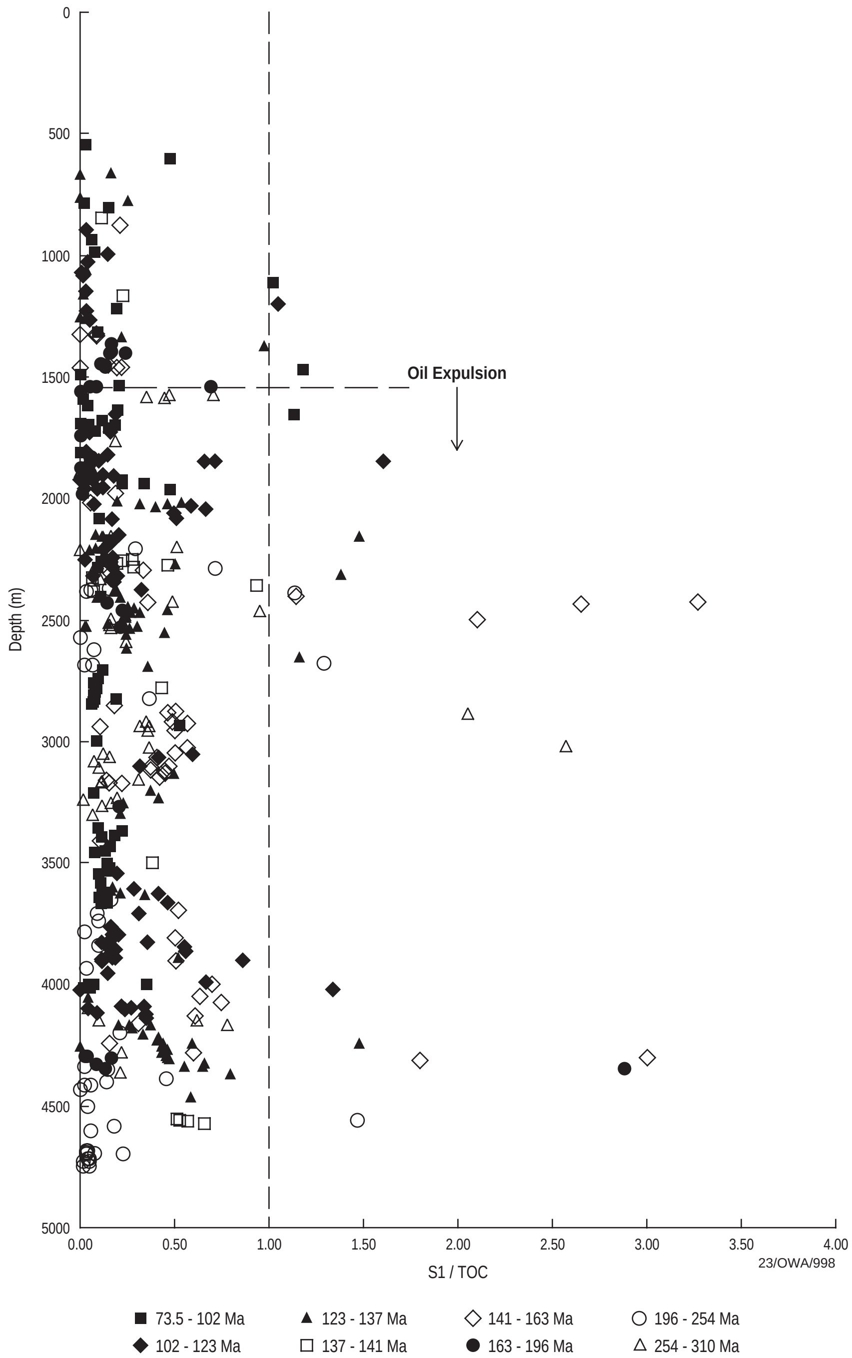


Figure 73d Free hydrocarbon saturation in Browse Basin samples.

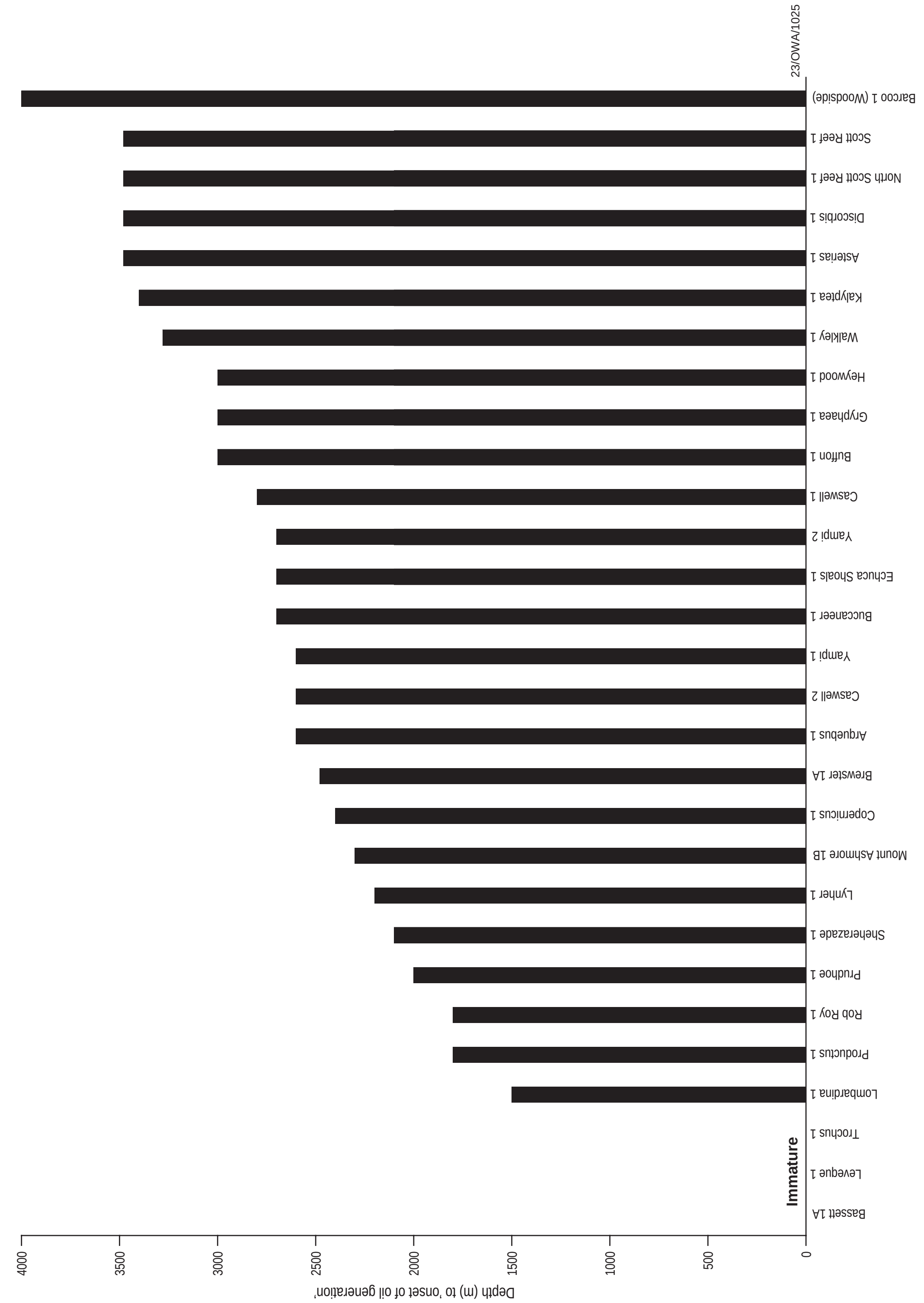


Figure 74 Depth to the top of the oil window for Browse Basin Wells.

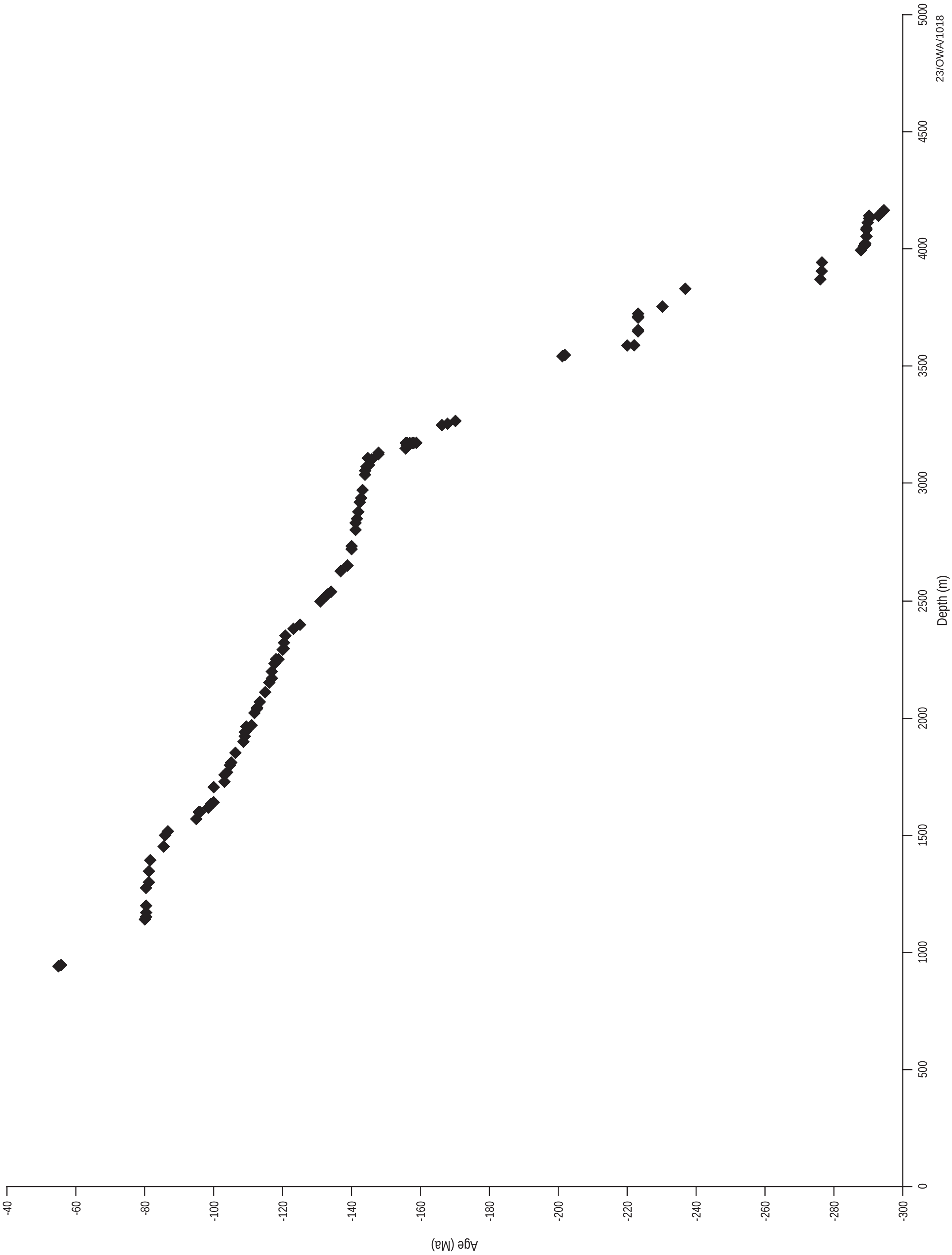


Figure 75a Age-depth plot for Yampi 1.

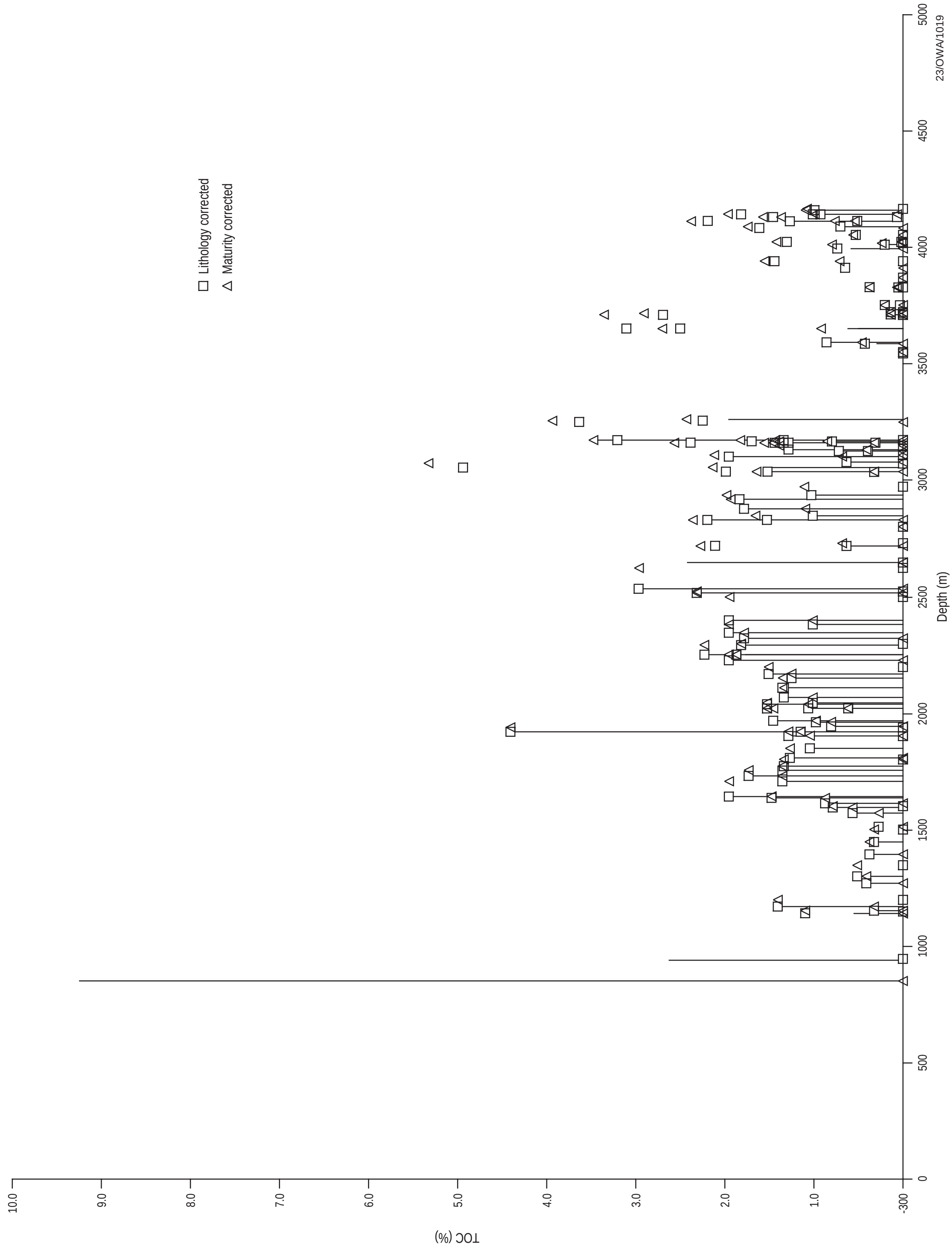


Figure 75b TOC-depth plot for Yampi 1.

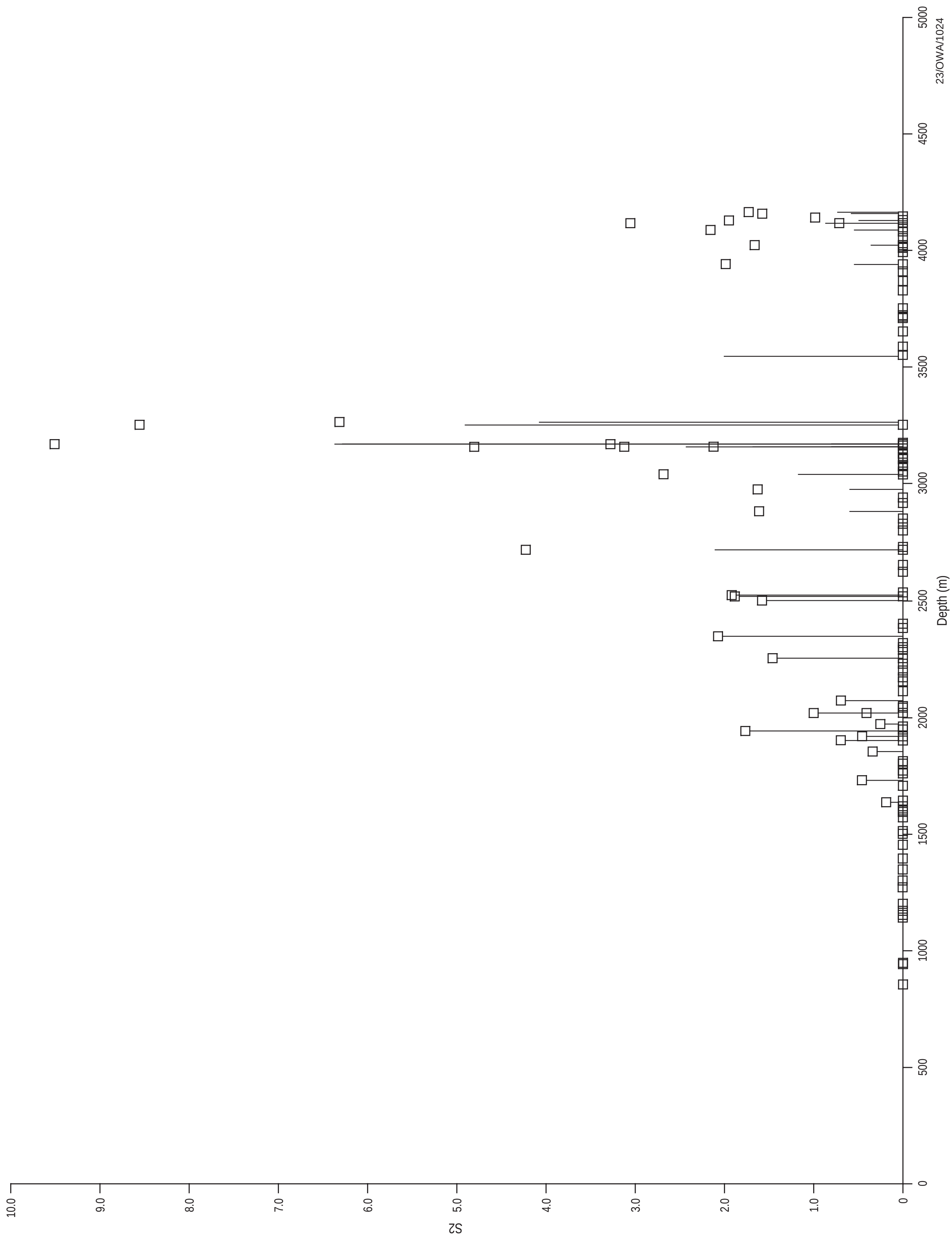


Figure 75c S2-depth plot for Yampi 1.

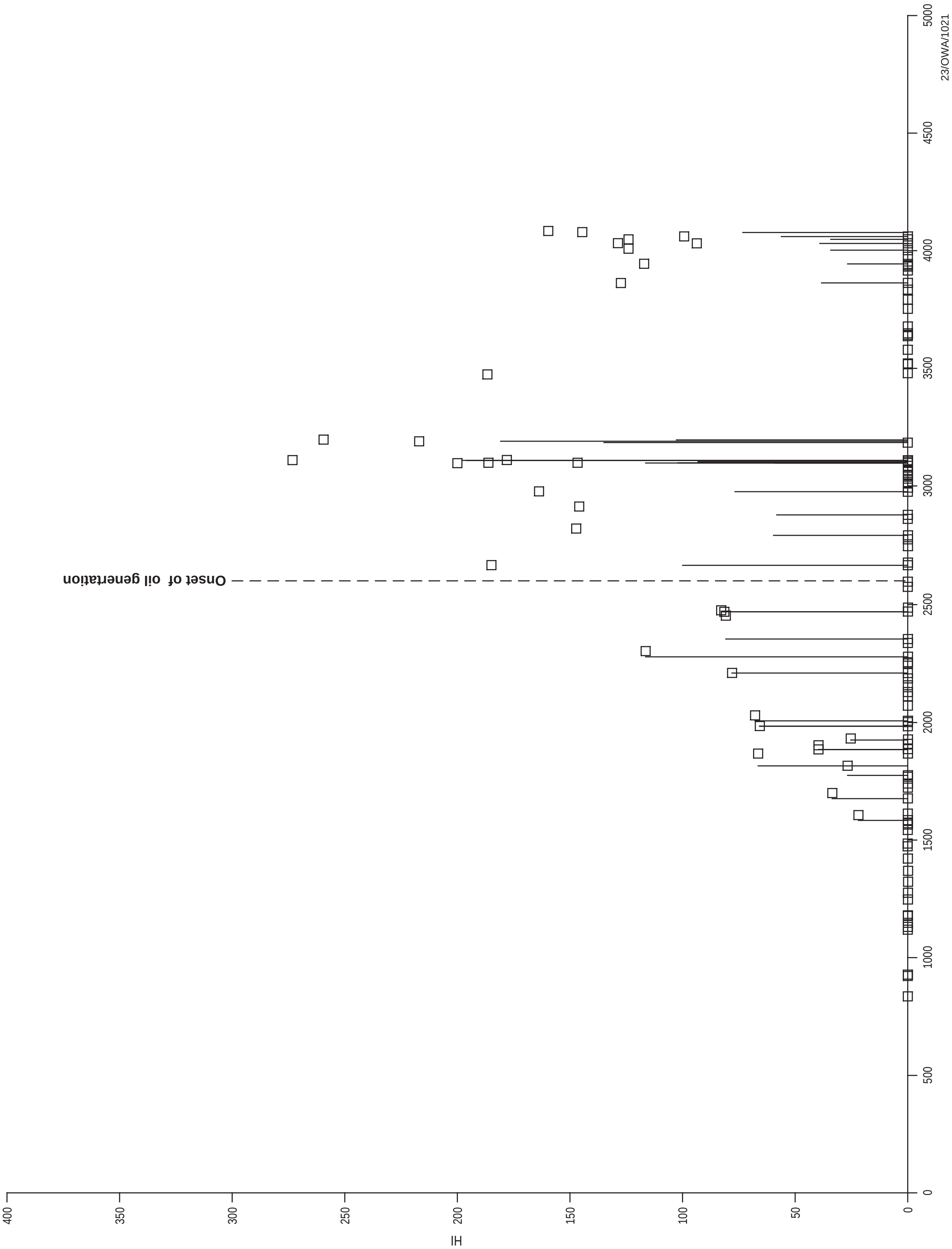


Figure 75d HI-depth plot for Yampi 1.

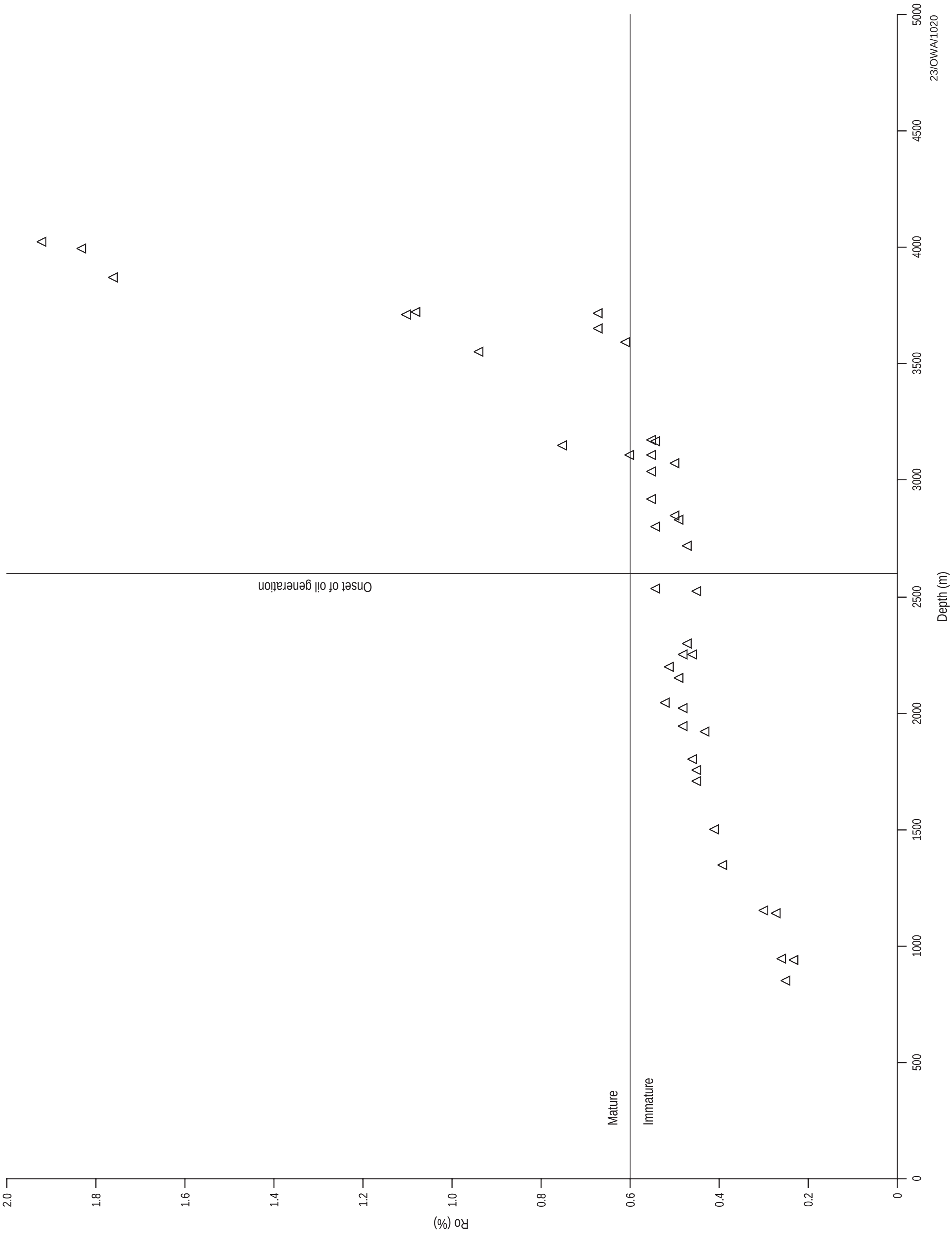


Figure 75e Vitrinite reflectance-depth plot for Yampi 1.

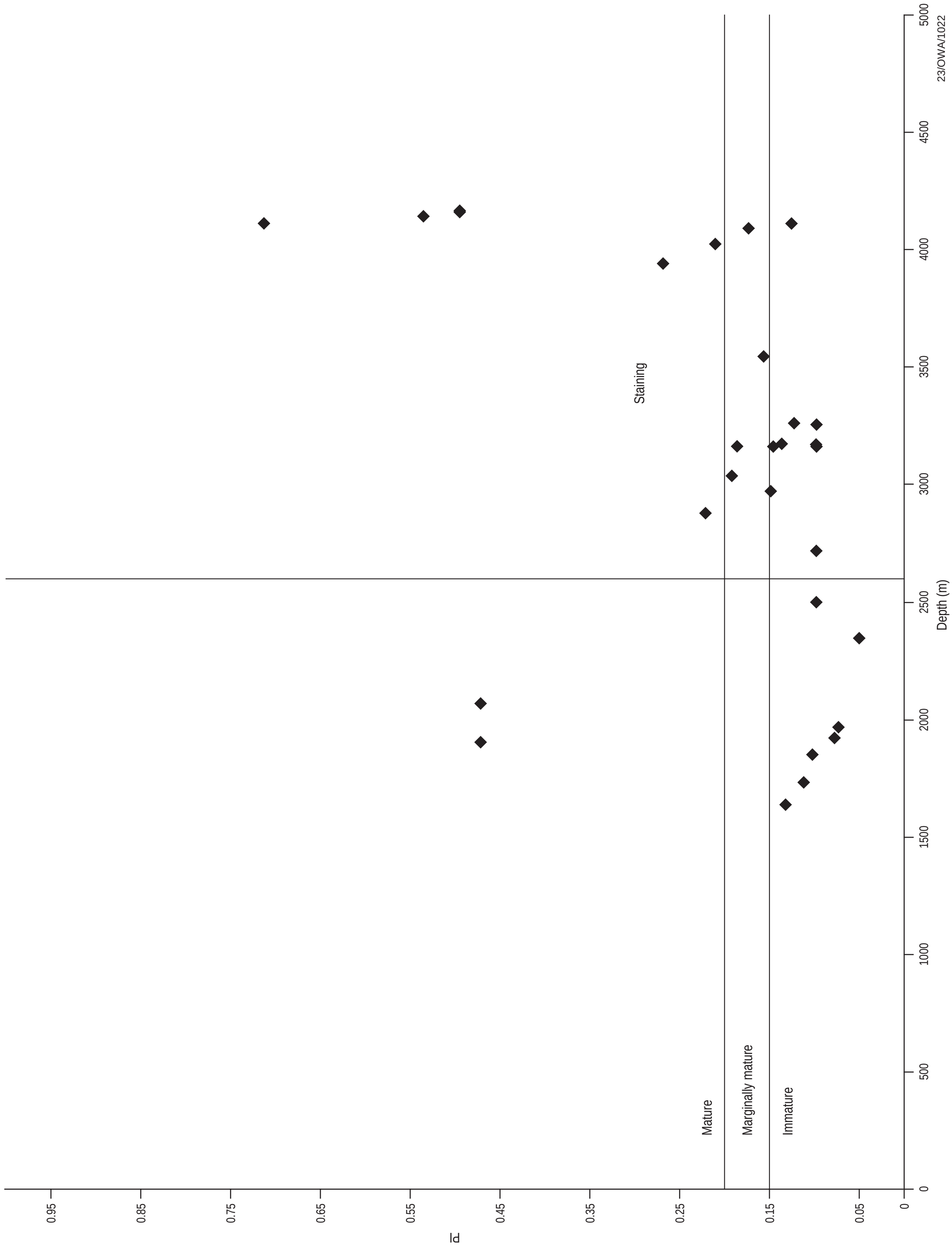


Figure 75f PI-depth plot for Yampi 1.

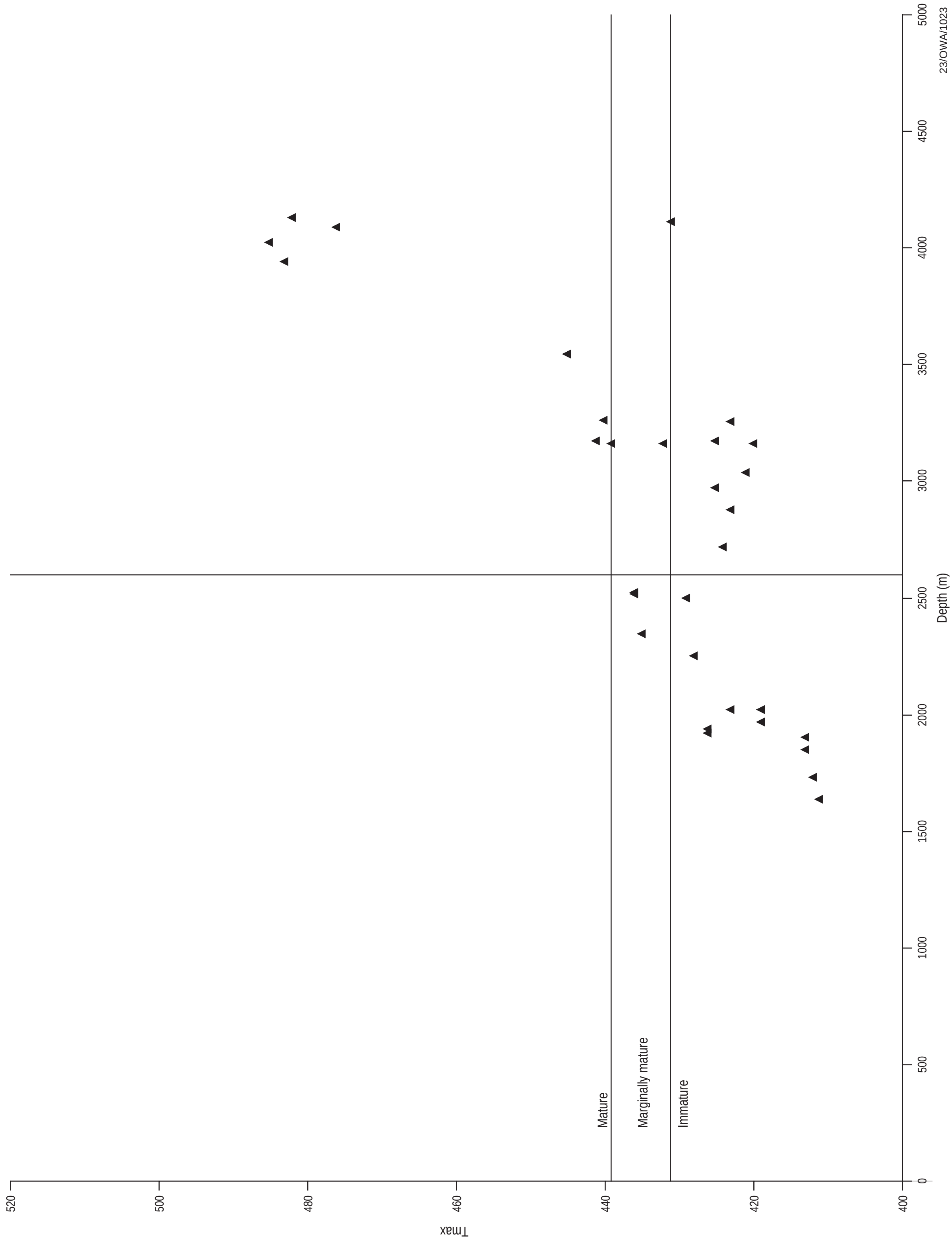


Figure 75g Tmax-depth plot for Yampi 1.

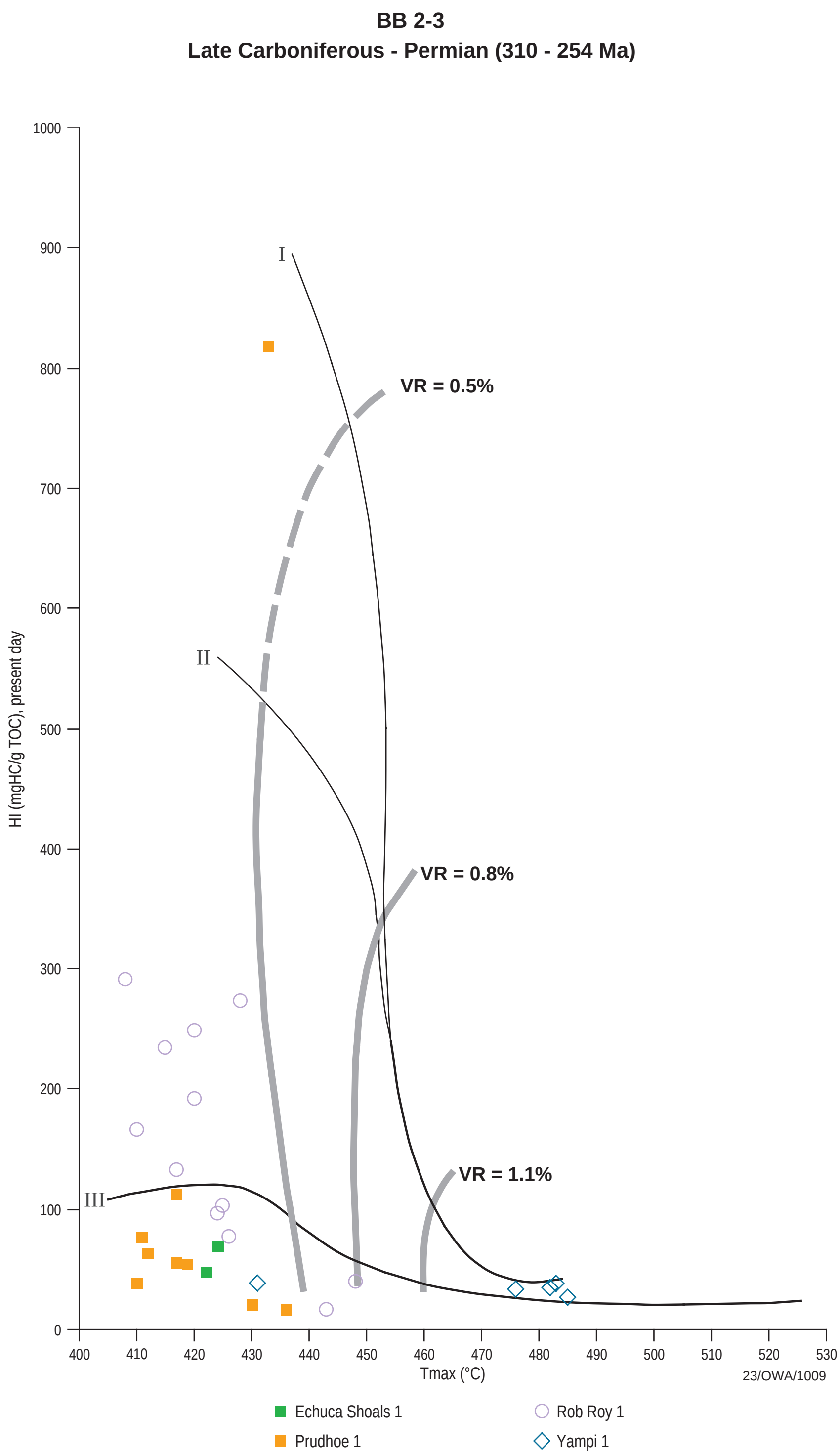


Figure 76a Kerogen types from Rock-Eval data for potential source rocks in BB 2-3.

BB 4-5
Triassic - Early Jurassic (254 - 196 Ma)

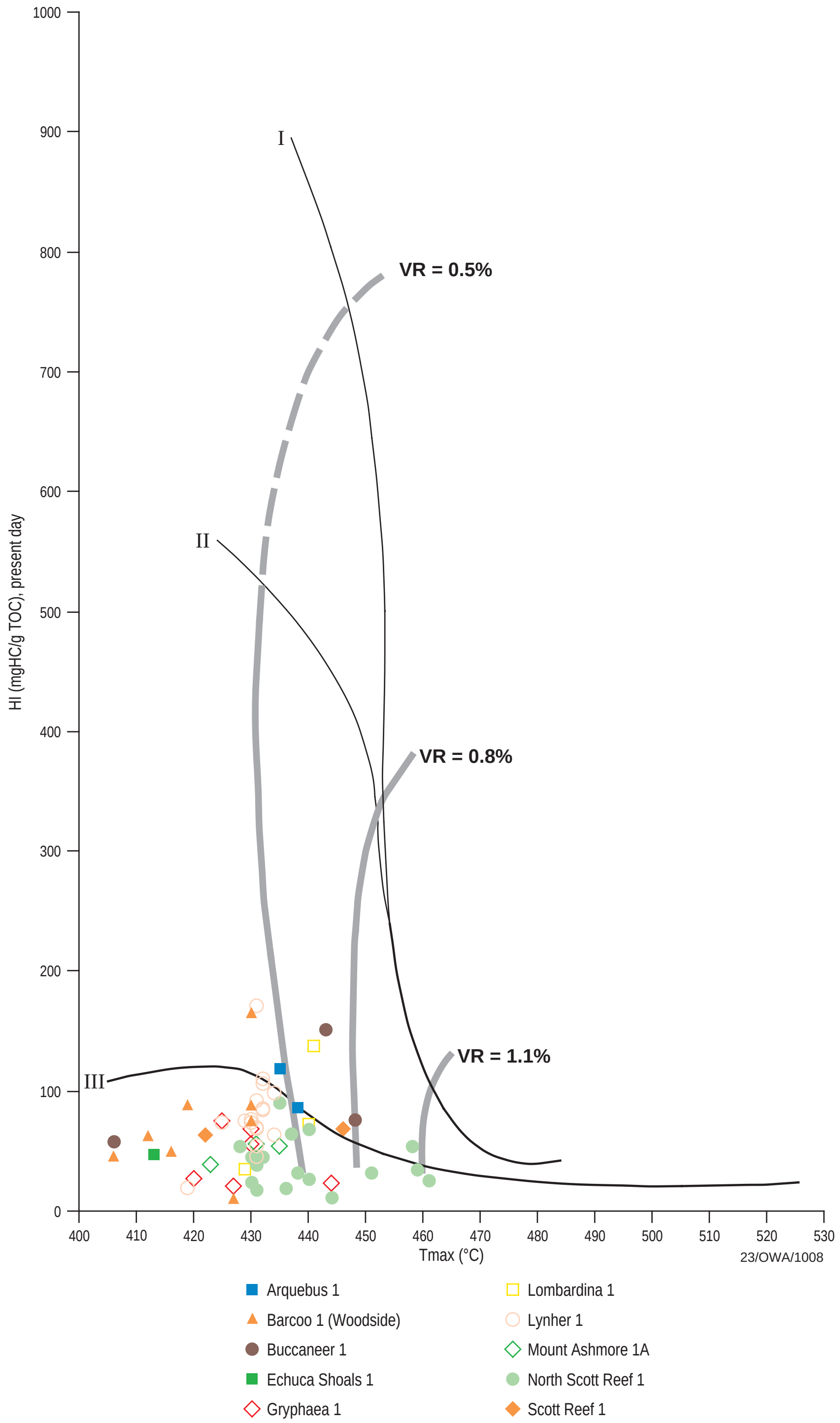


Figure 76b Kerogen types from Rock-Eval data for potential source rocks in BB 4-5.

BB 6-7
Early - Middle Jurassic (196 - 163 Ma)

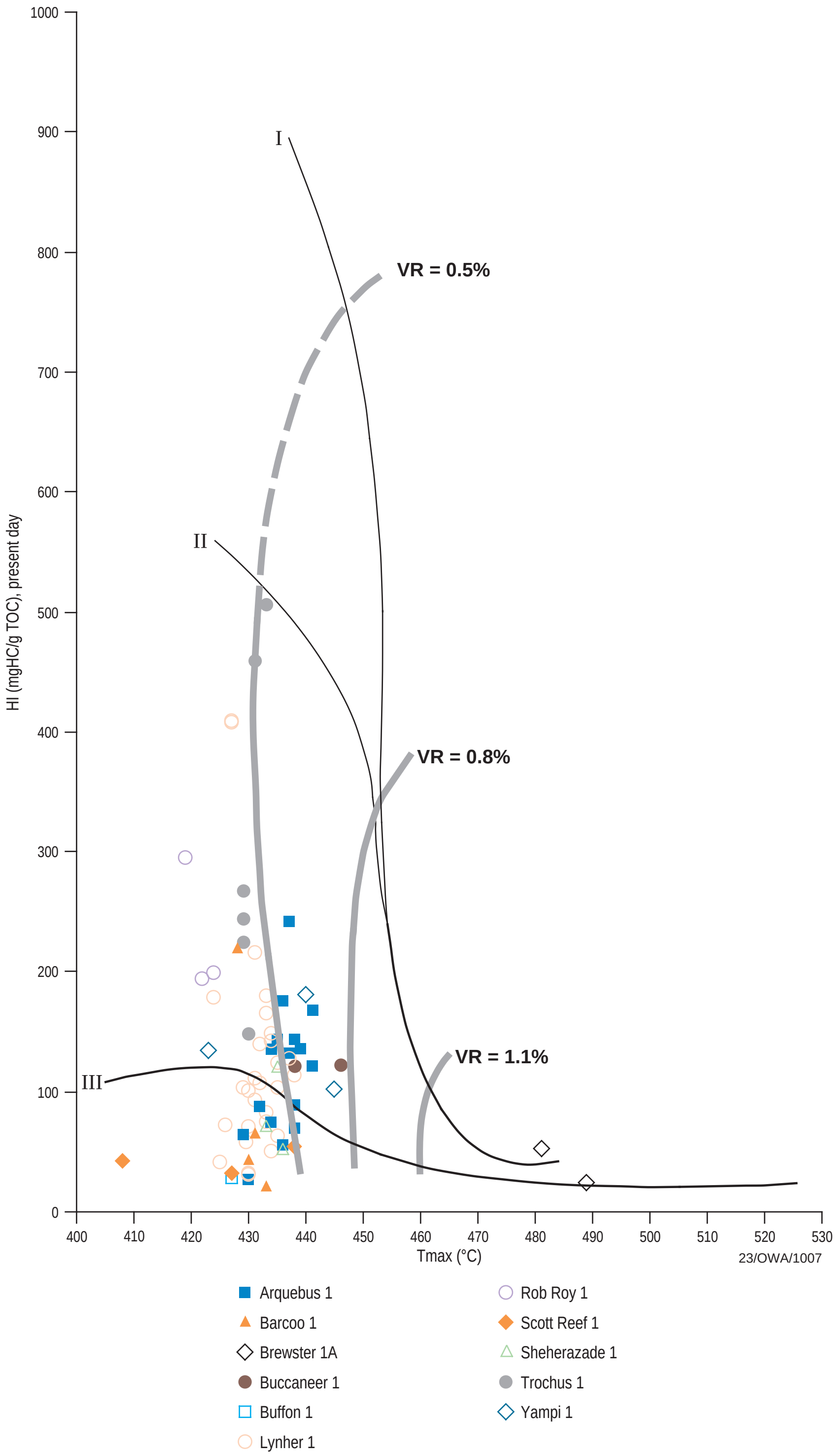


Figure 76c Kerogen types from Rock-Eval data for potential source rocks in BB 6-7.

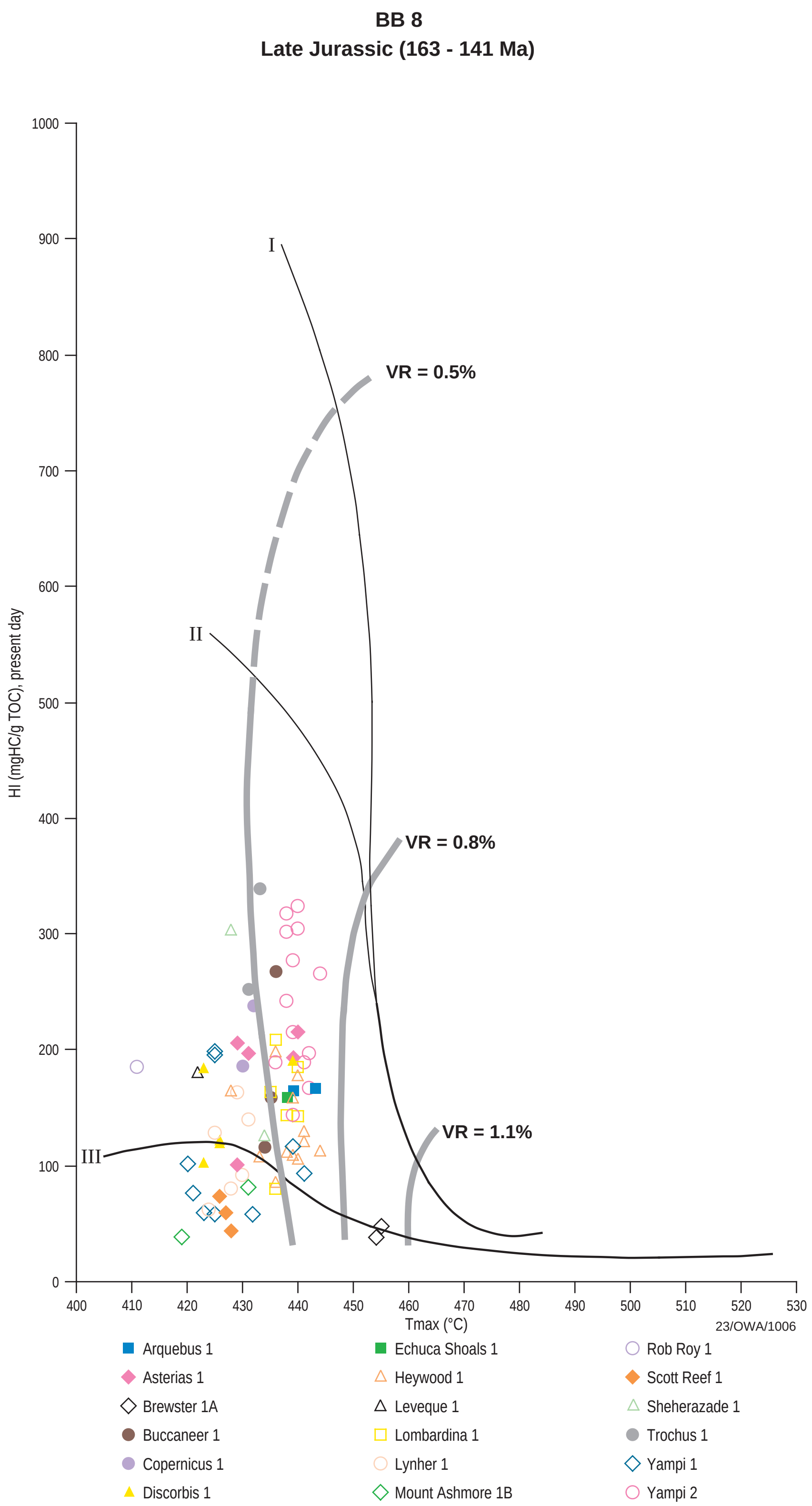


Figure 76d Kerogen types from Rock-Eval data for potential source rocks in BB 8.

BB 9
Berriasian (141 - 134 Ma)

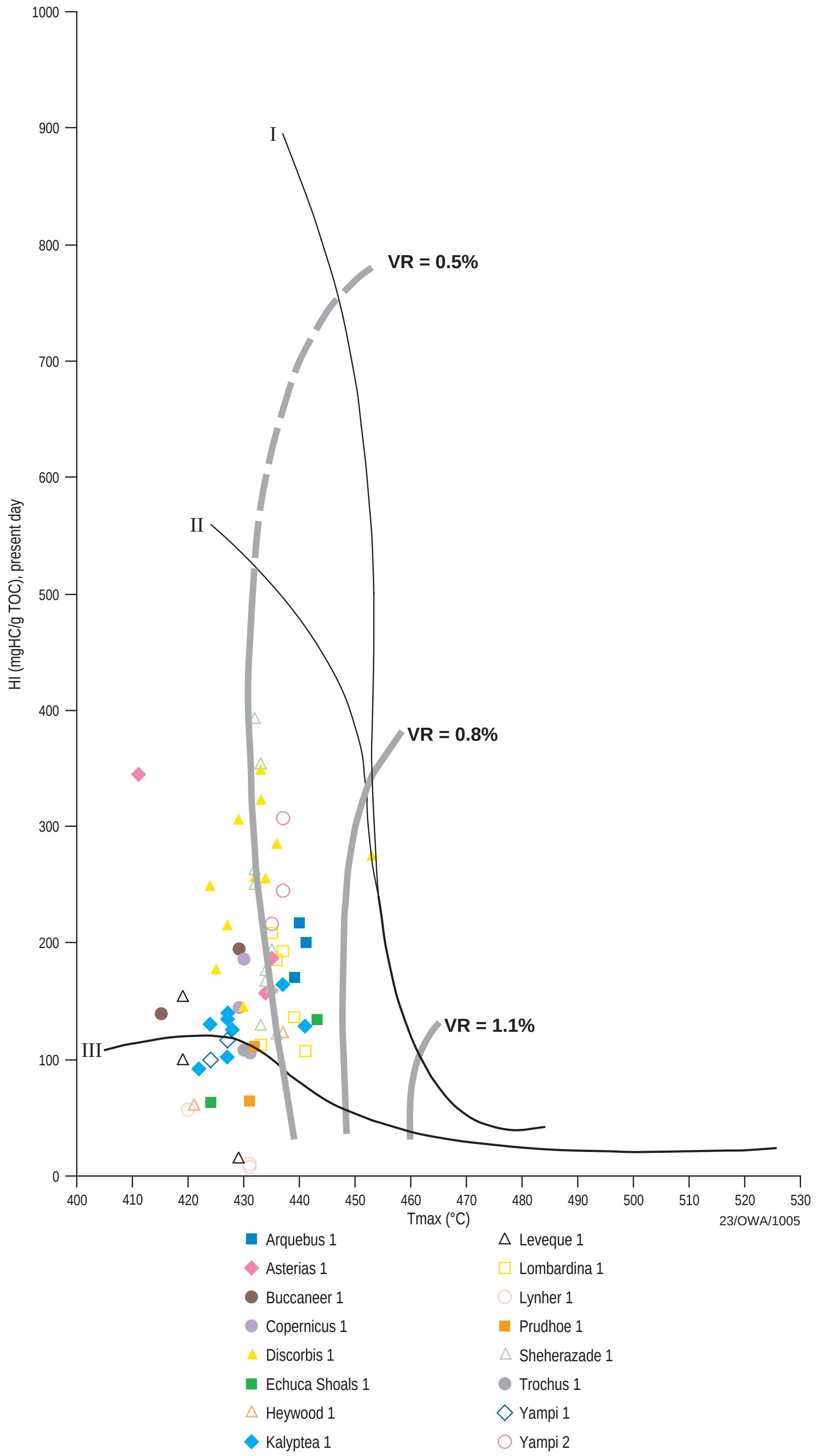


Figure 76e Kerogen types from Rock-Eval data for potential source rocks in BB 9.

BB 10
Valanginian - Hauterivian (134 - 123 Ma)

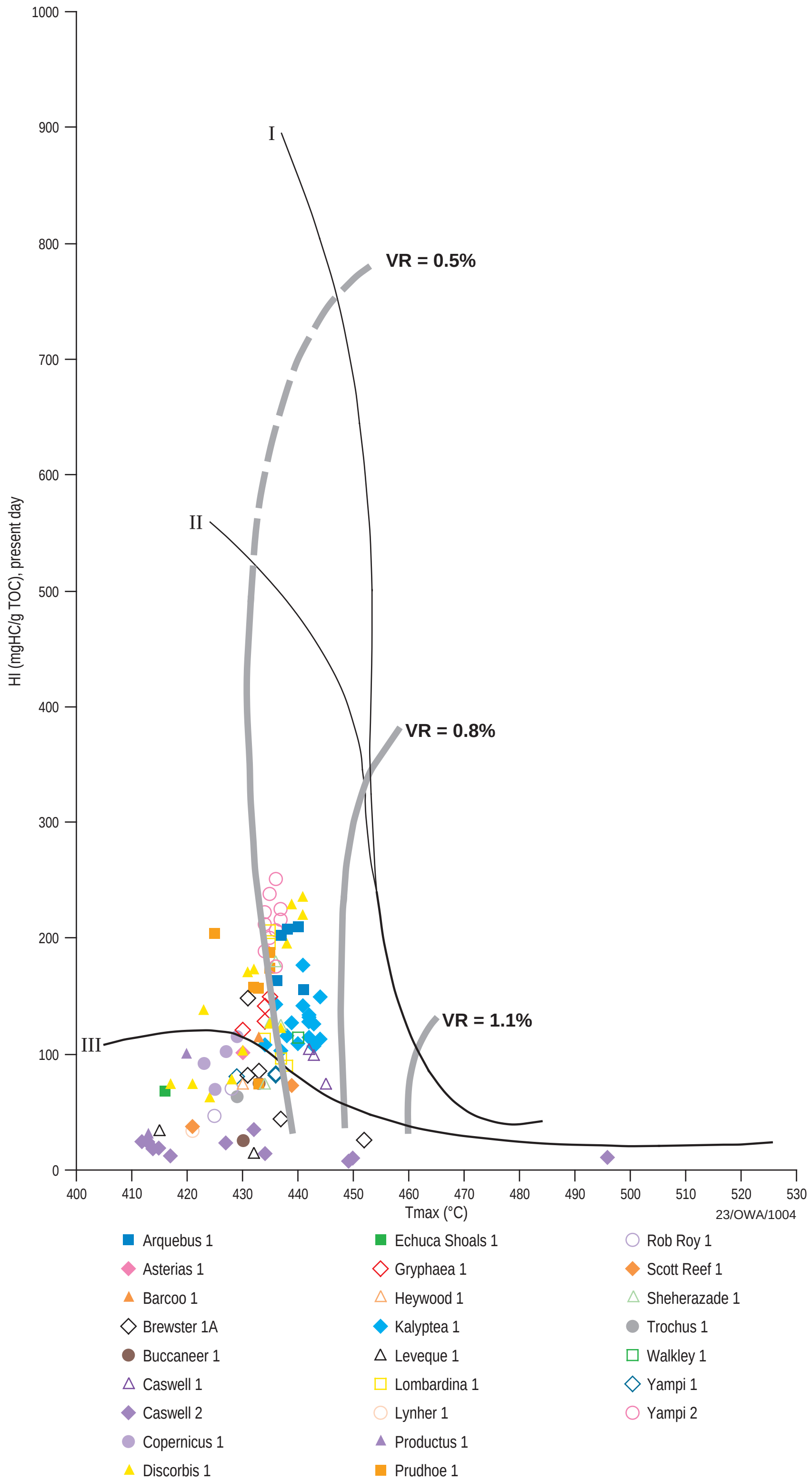


Figure 76f Kerogen types from Rock-Eval data for potential source rocks in BB 10.

BB 11-12
Barremian - Albian (123 - 102 Ma)

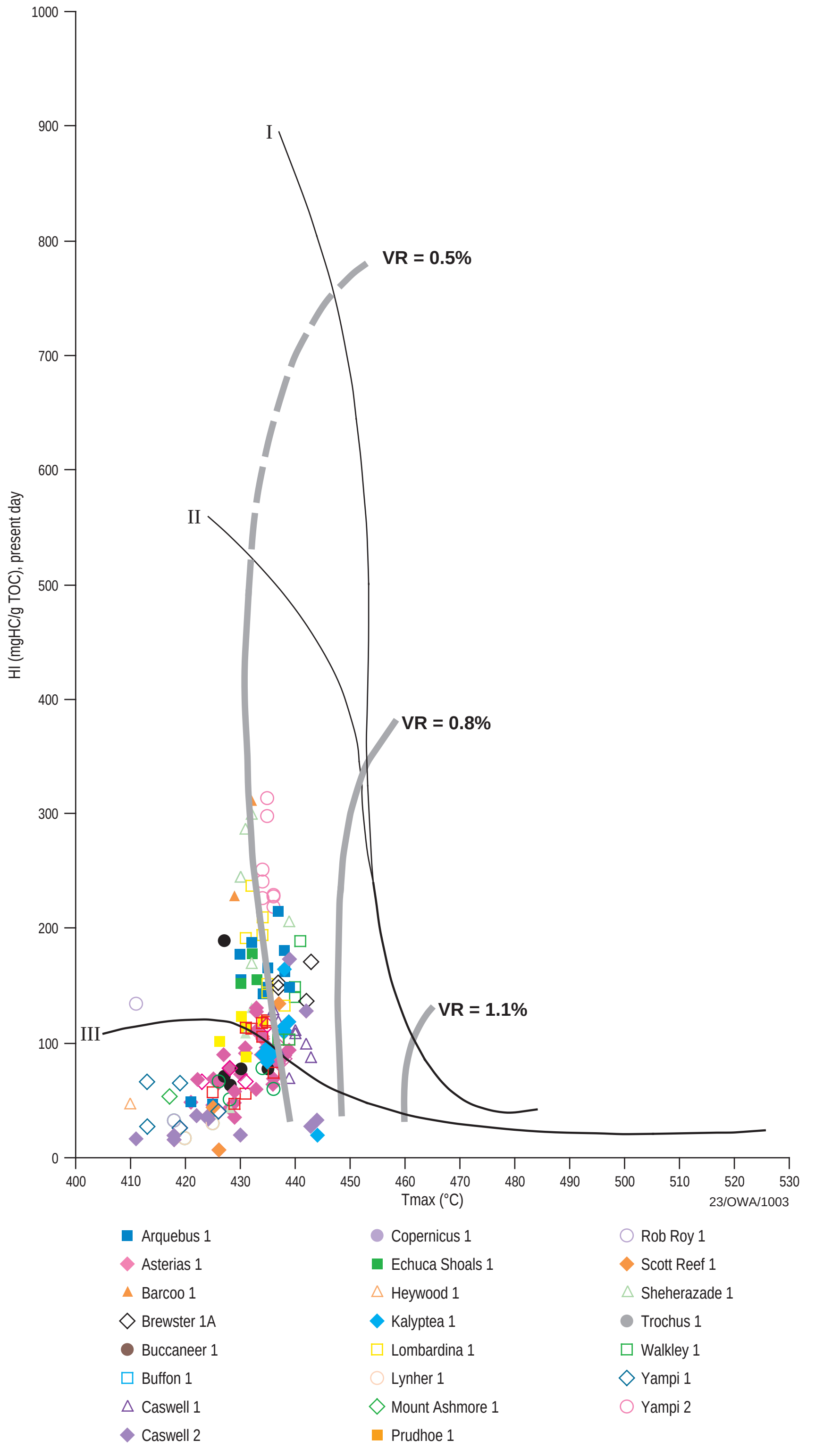


Figure 76g Kerogen types from Rock-Eval data for potential source rocks in BB 11-12.

BB 13-15
Late Albian - Campanian (102 - 73.5 Ma)

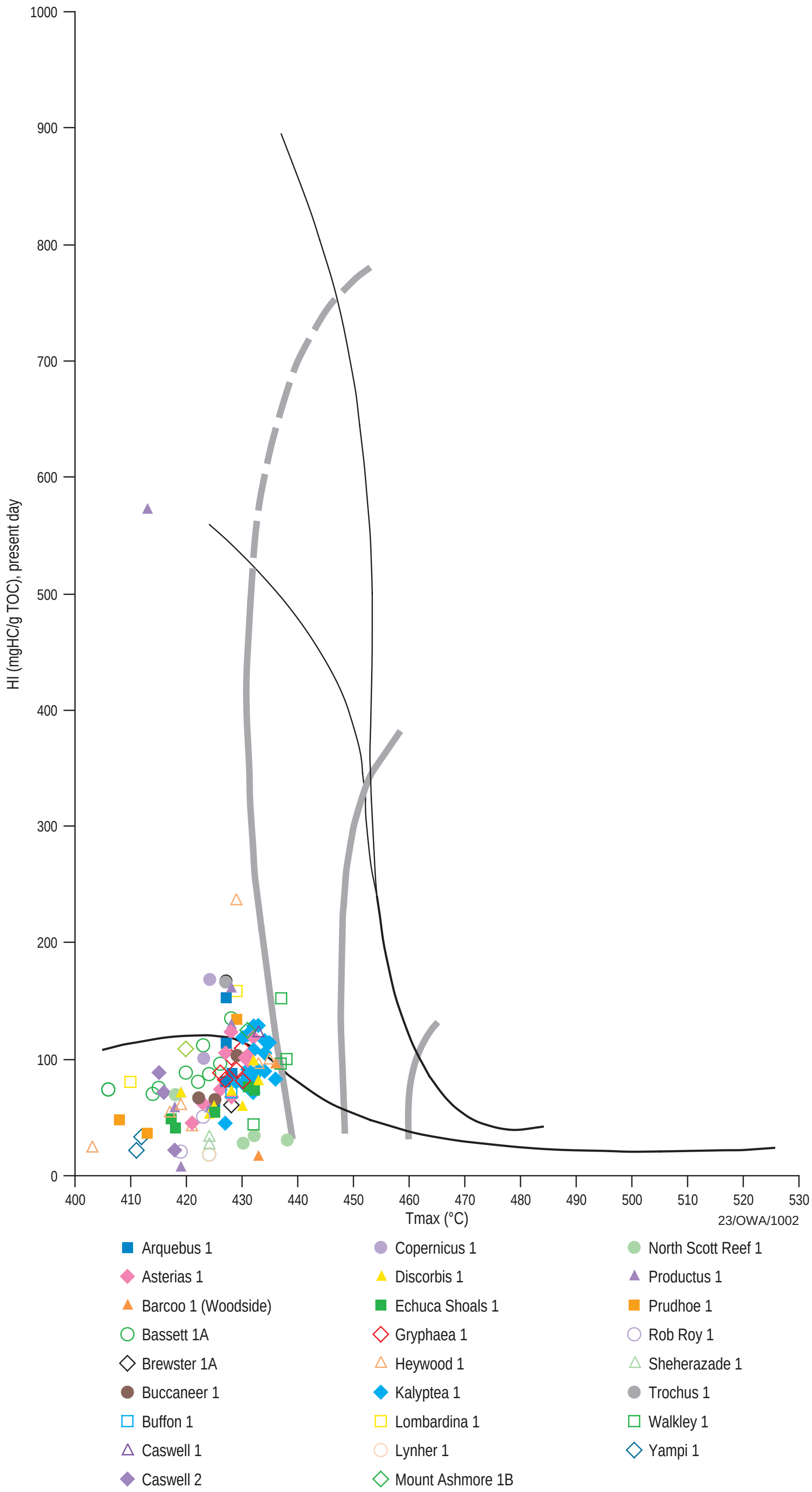
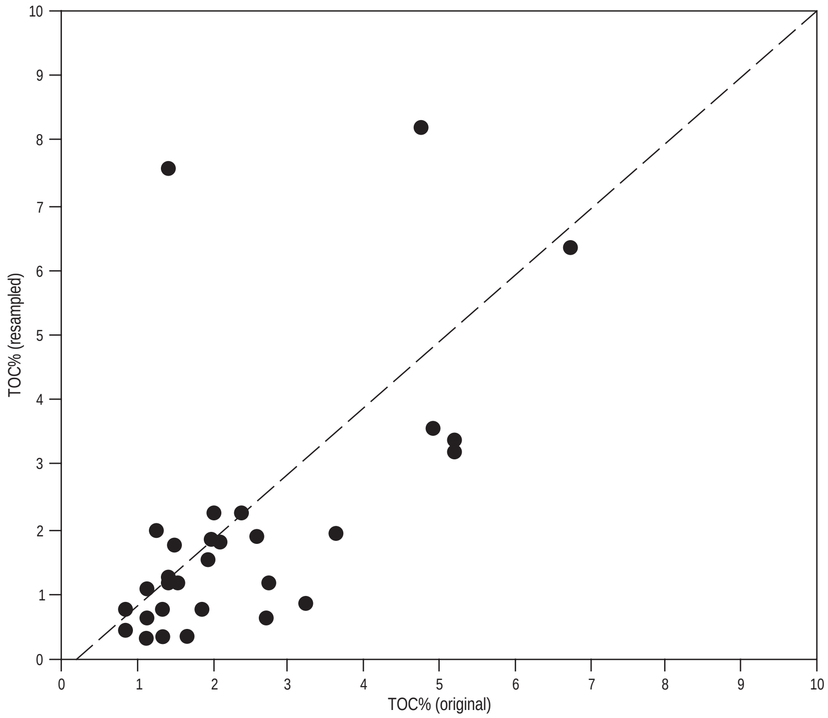


Figure 76h Kerogen types from Rock-Eval data for potential source rocks in BB 13-15.



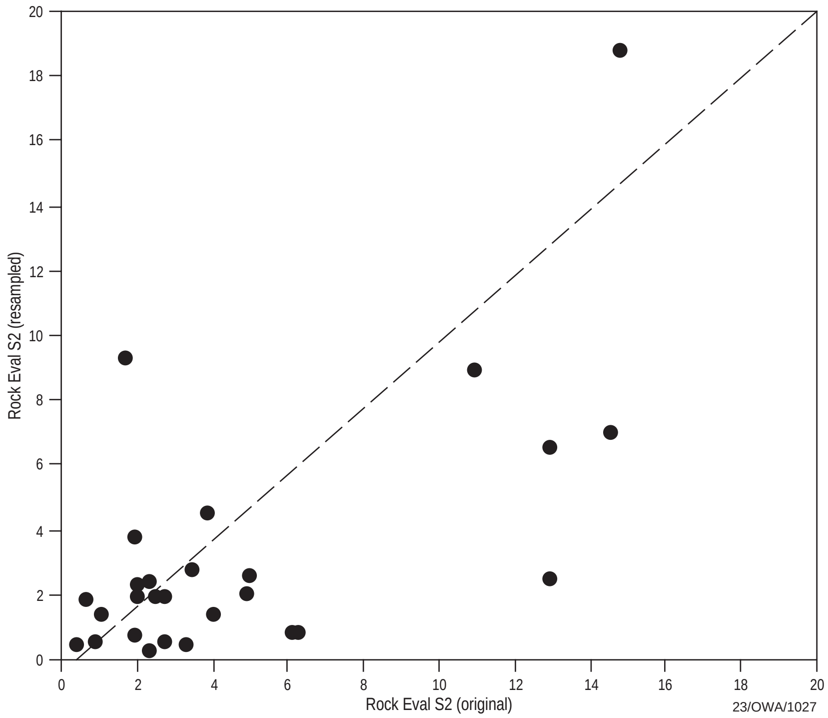


Figure 77 Plot of (A) TOC and (B) S2 for original (well completion report) versus resampled (AGSO) sediments.

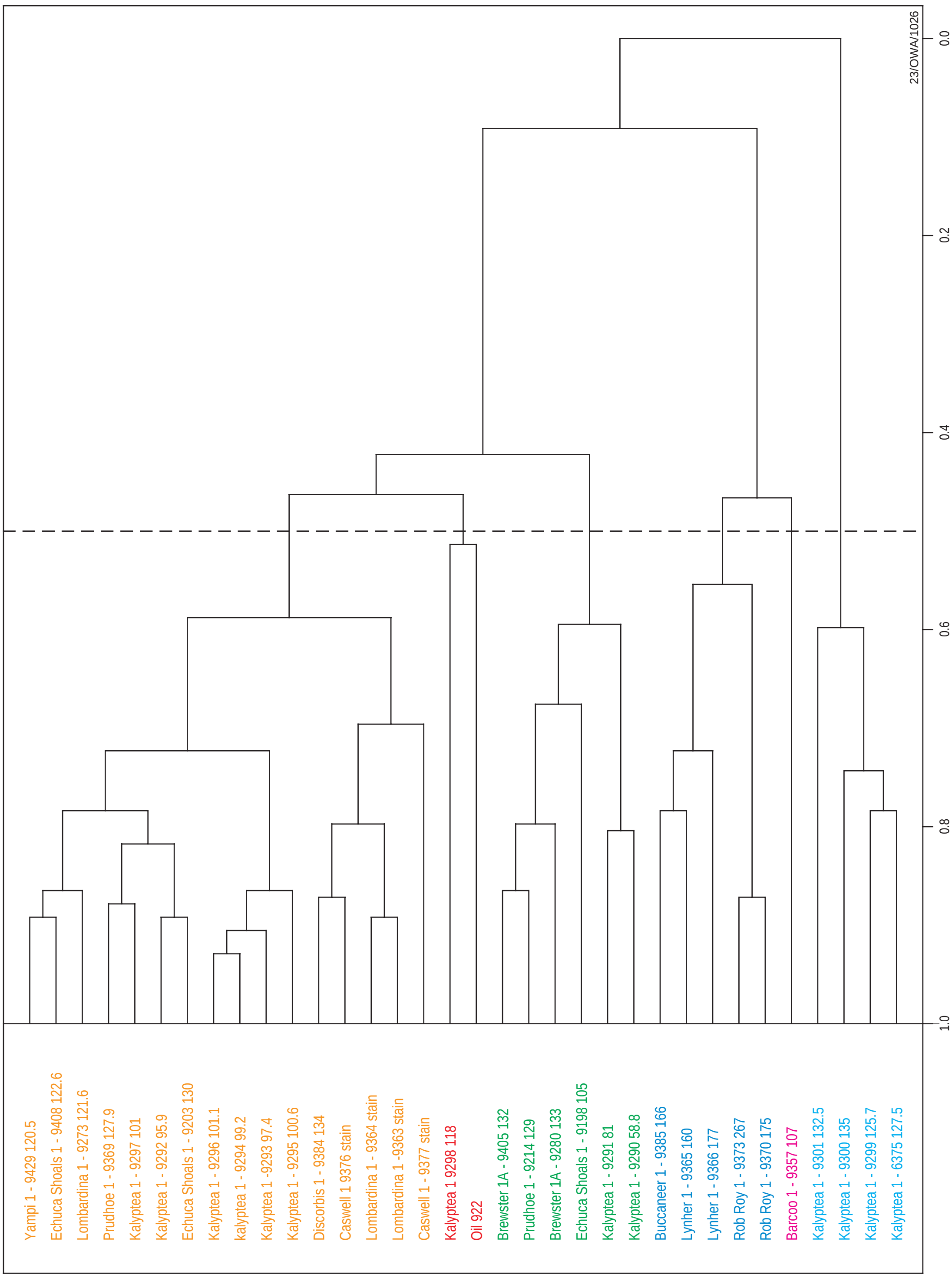


Figure 78 Dendrogram resulting from HCA on biomarker OilMod ™ parameters for the samples in Table 8.

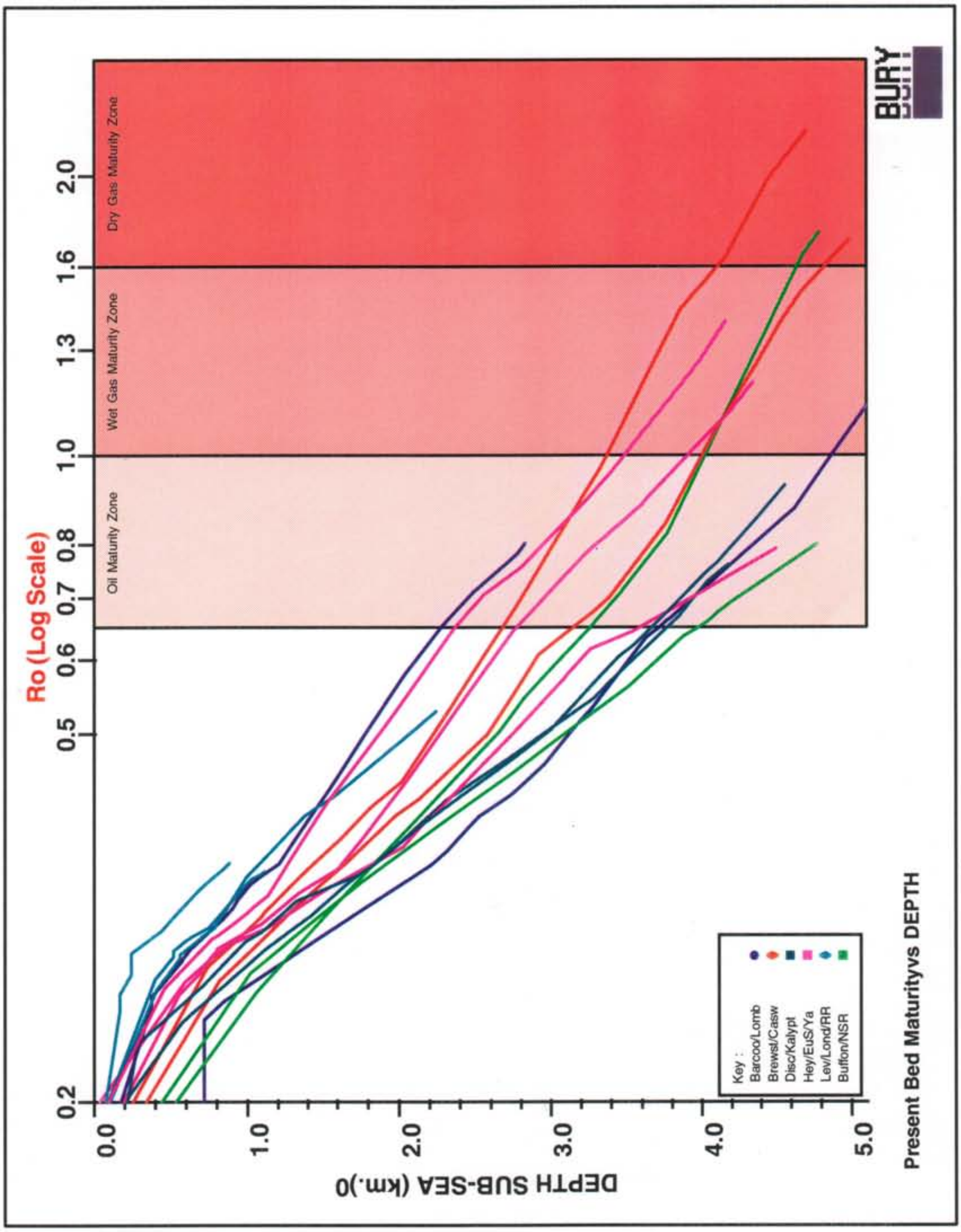


Figure 79 Depth to present-day maturity zones in Browse Basin wells.

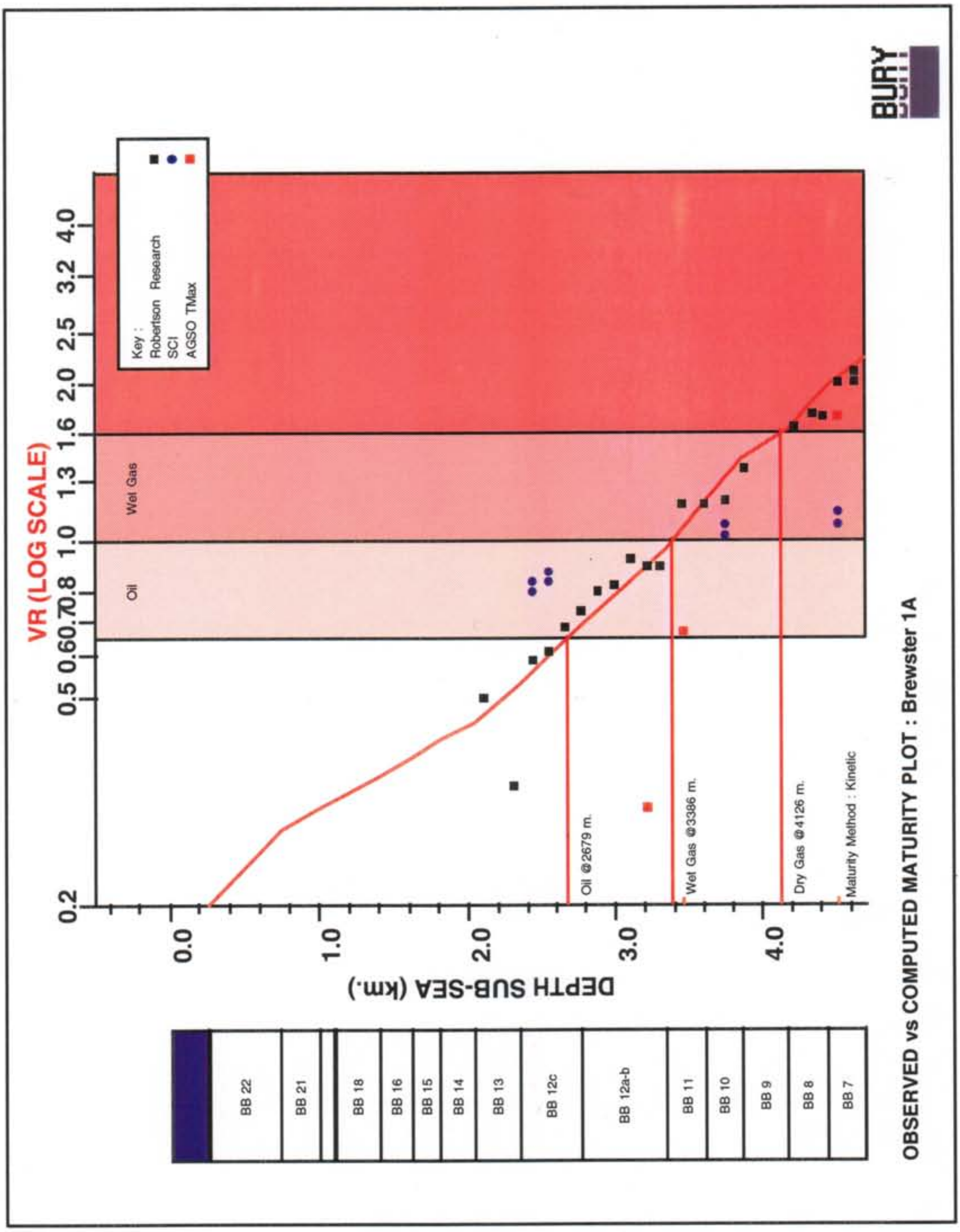


Figure 80 Observed and modelled maturity for Brewster 1A.

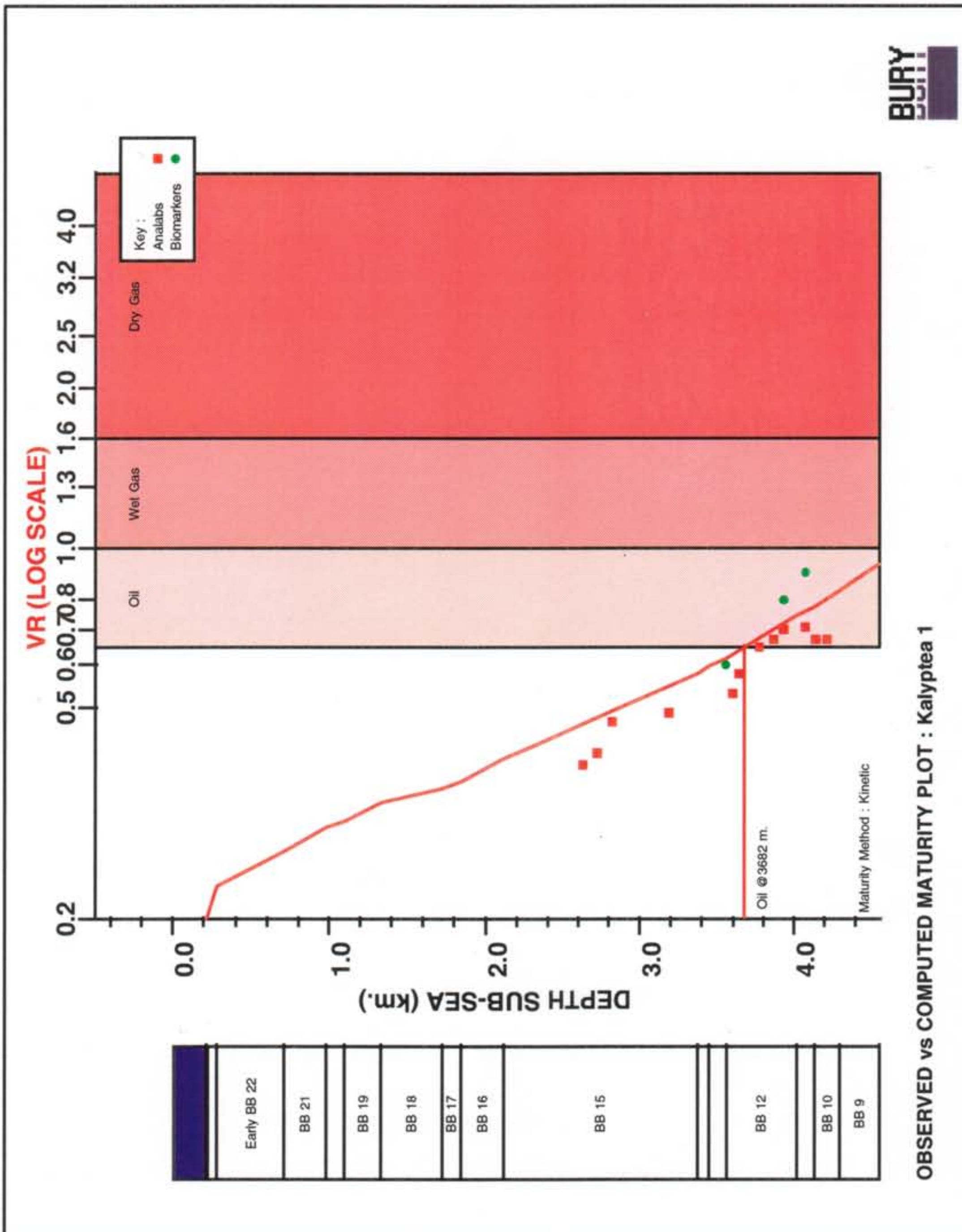


Figure 81 Observed and modelled maturity for Kalyptea 1.

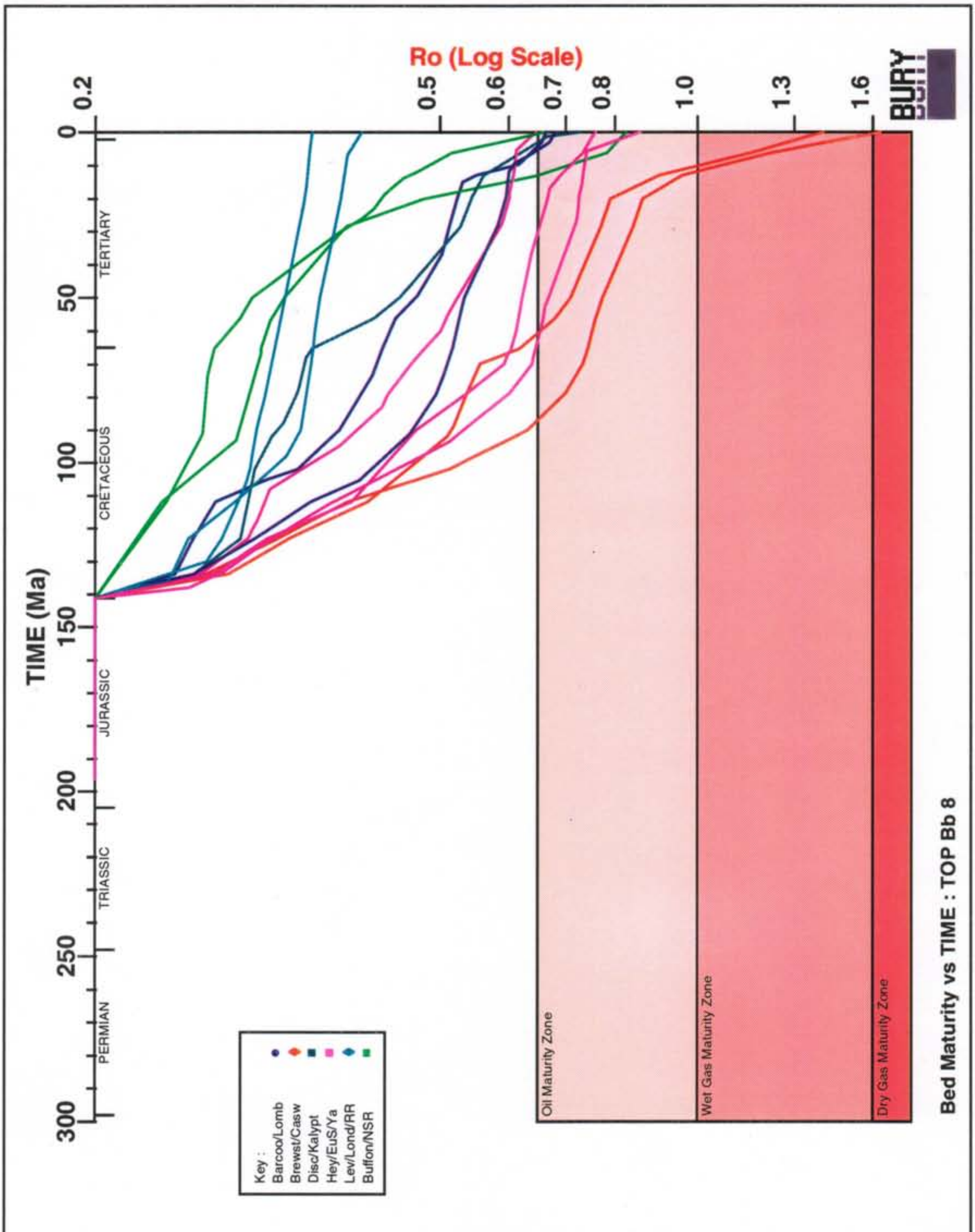


Figure 82 Maturity levels at the top of sequence BB 8 plotted against time.

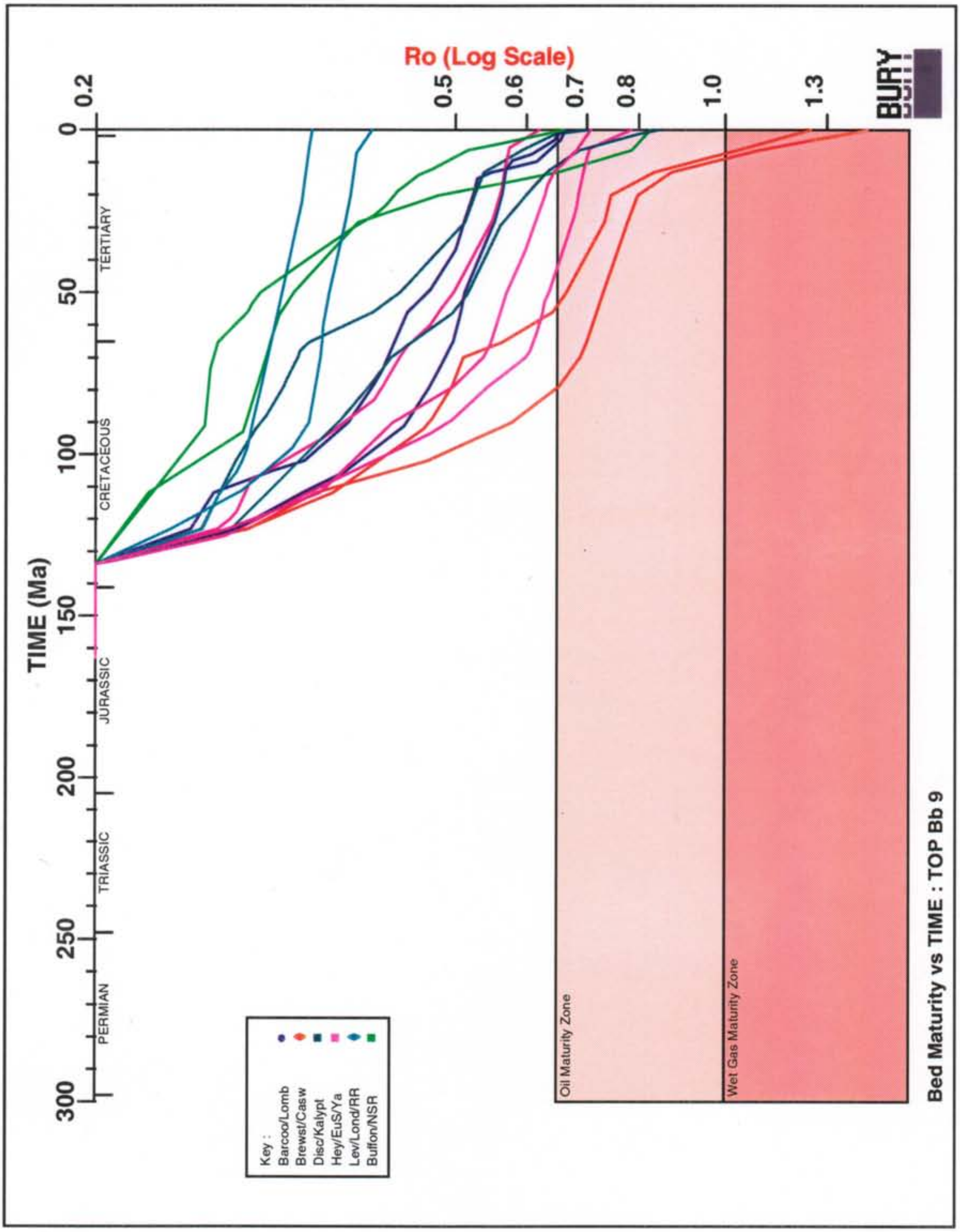


Figure 83 Maturity levels at the top of sequence BB 9 plotted against time.

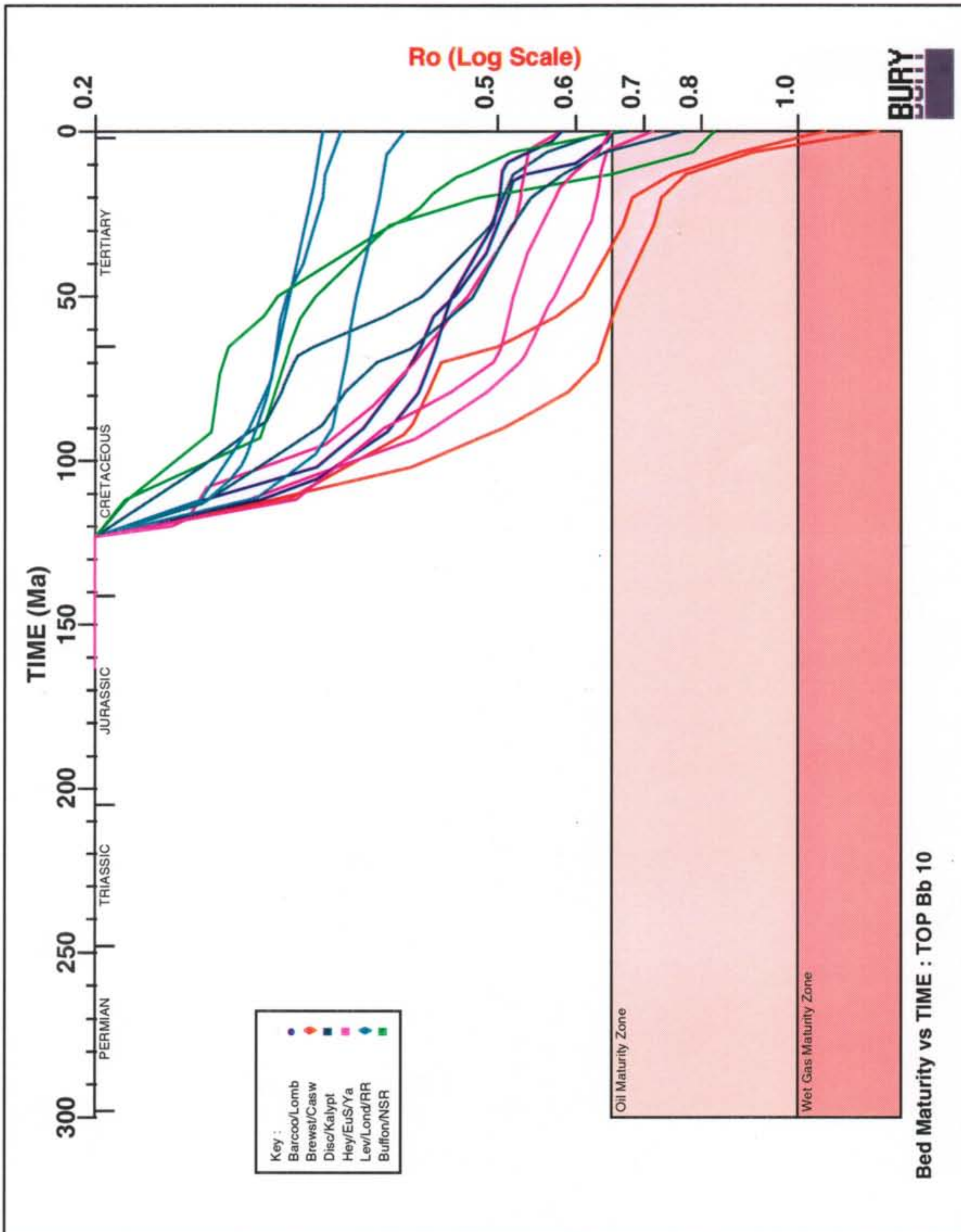


Figure 84 Maturity levels at the top of sequence BB 10 plotted against time.

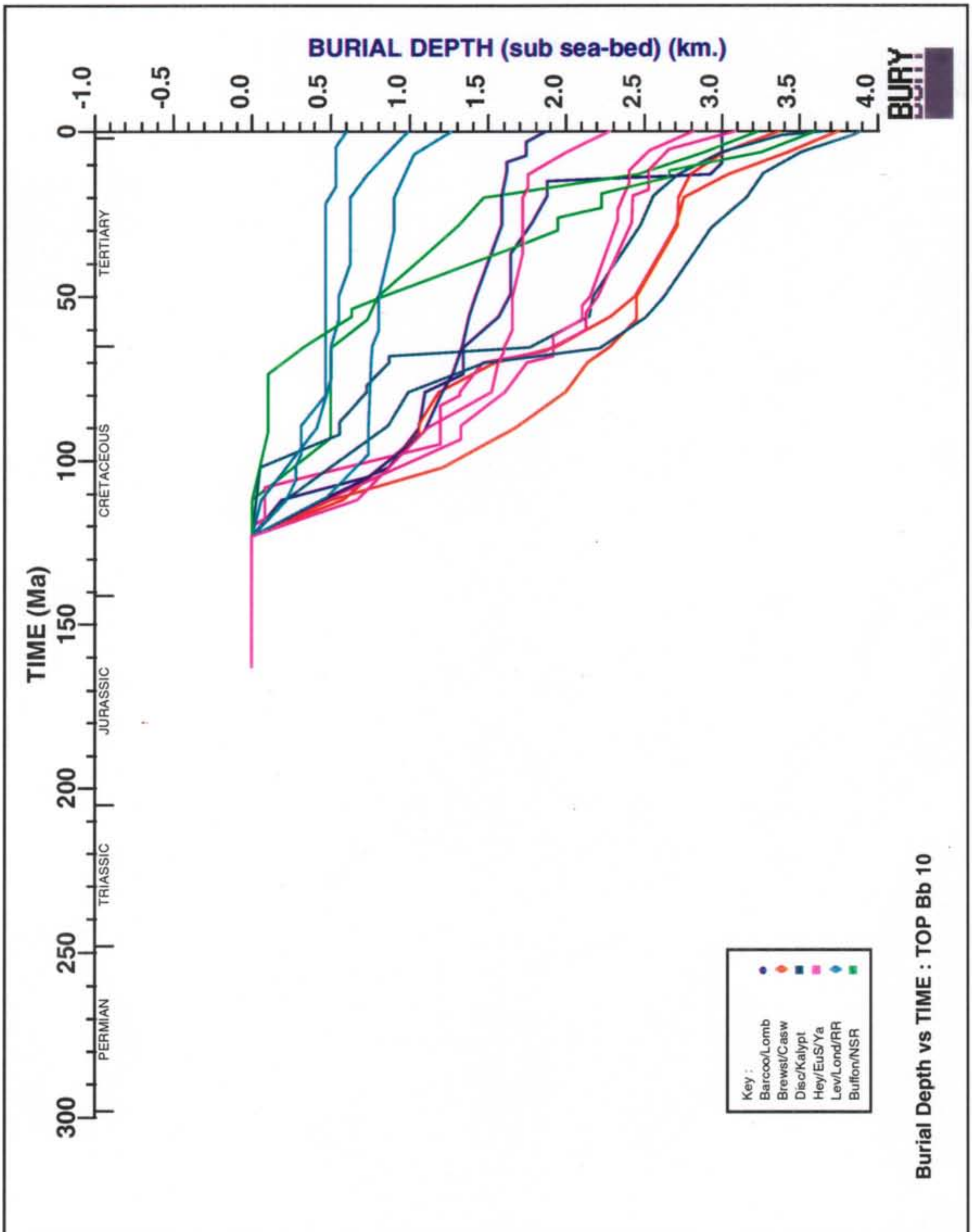


Figure 85 Burial depth of sequence BB 10 plotted against time.

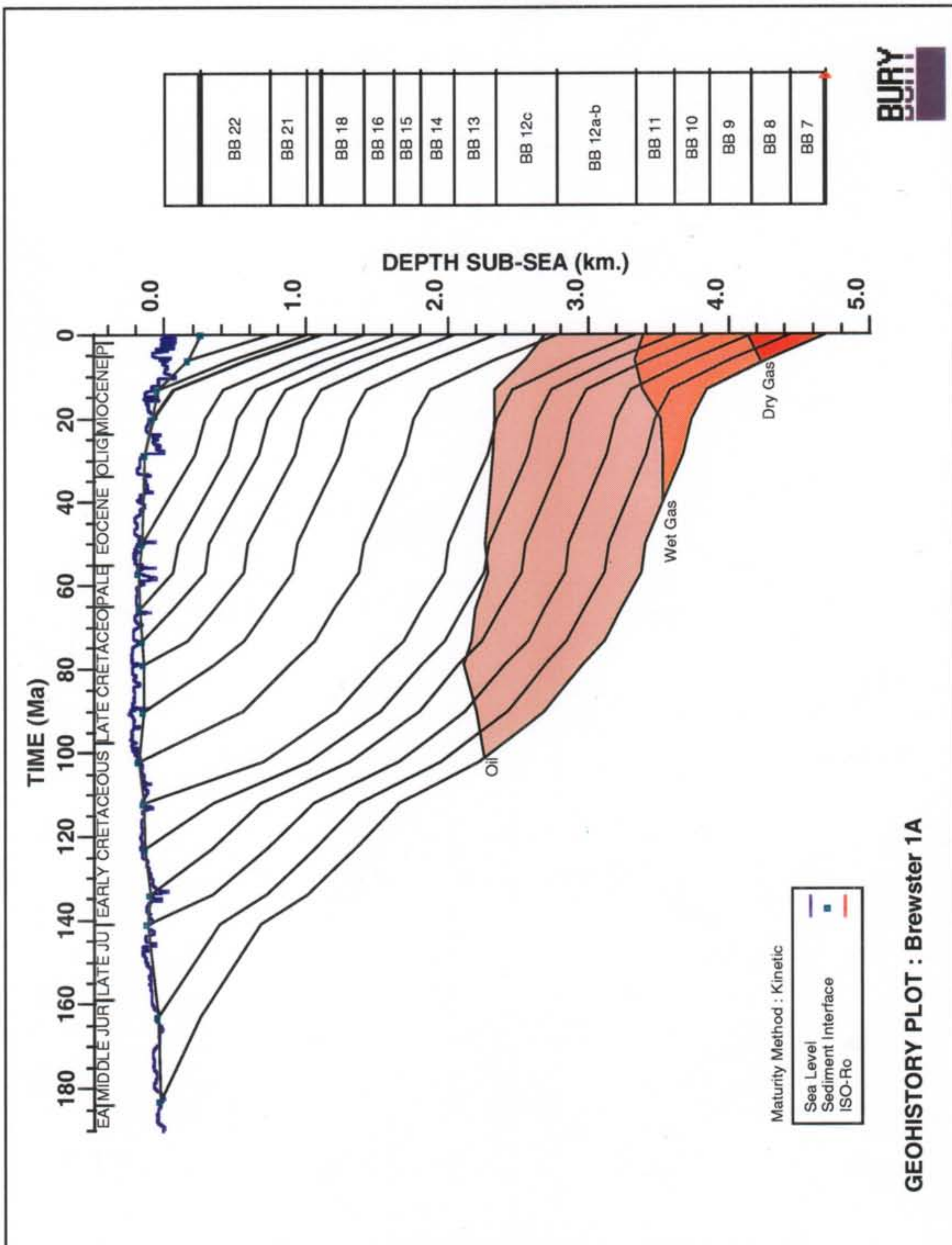


Figure 86 Geohistory for Brewster 1A.

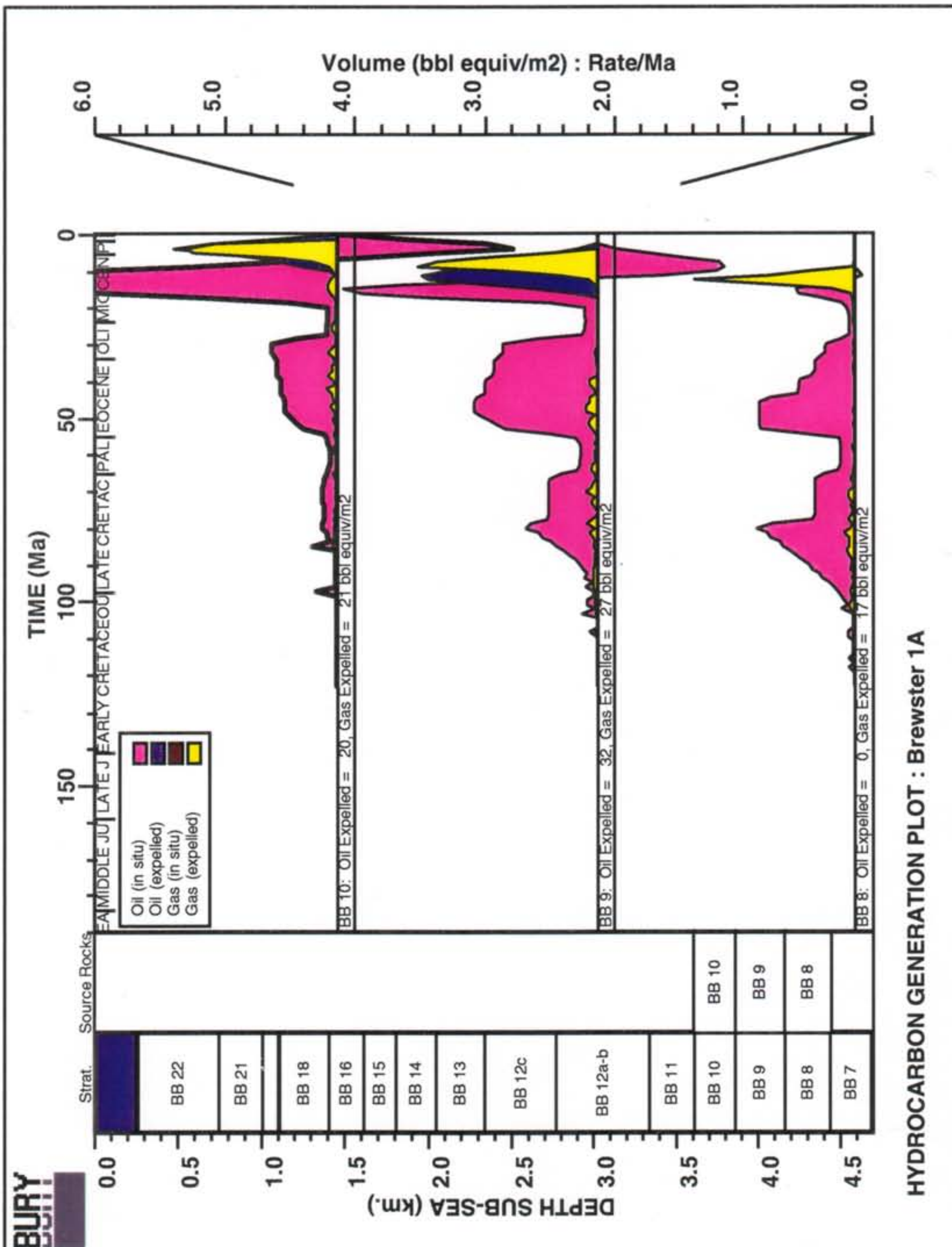


Figure 87 Rates of hydrocarbons generated from Late Jurassic to Early Cretaceous source rocks at Brewster 1A.

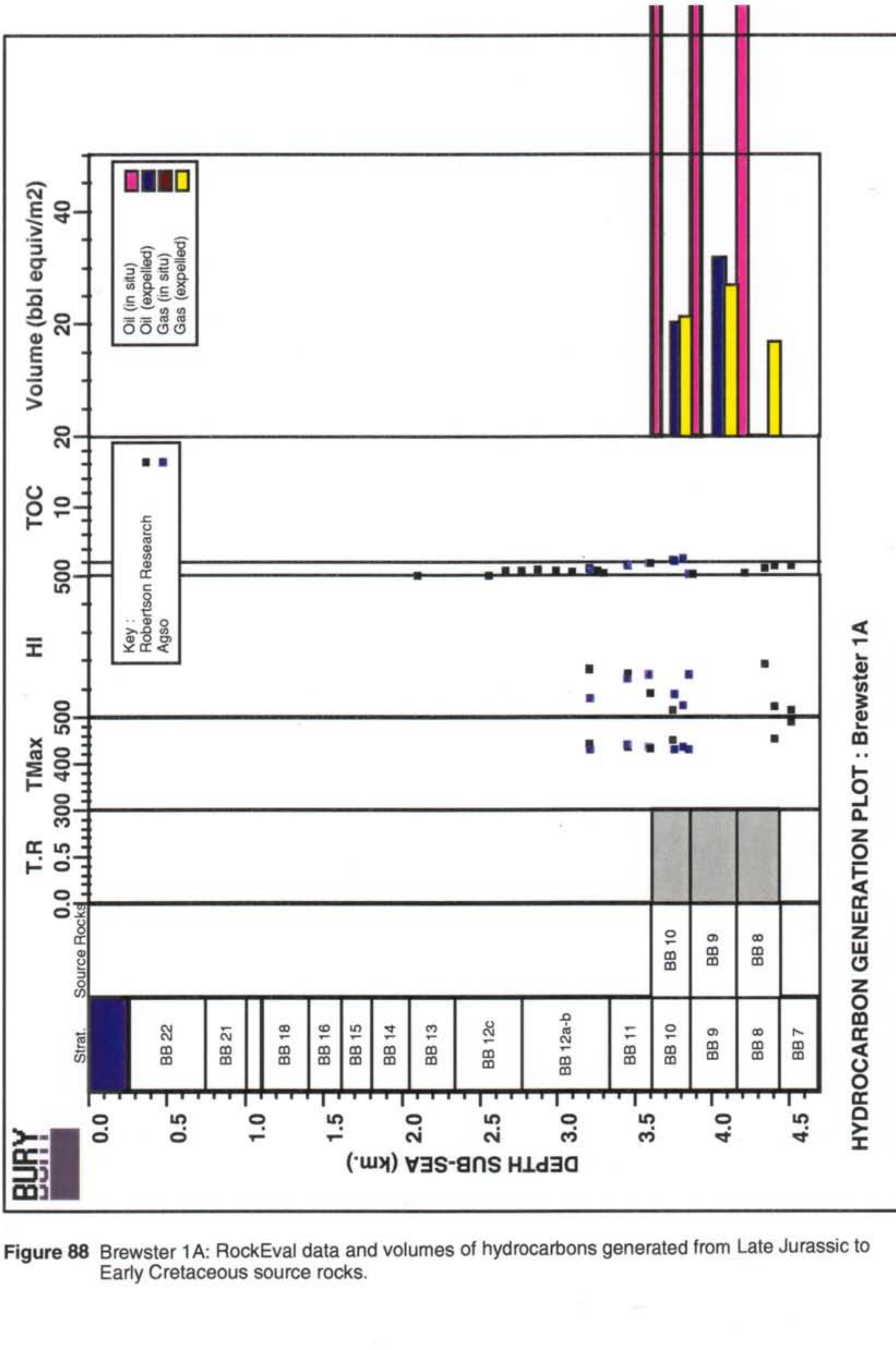


Figure 88 Brewster 1A: RockEval data and volumes of hydrocarbons generated from Late Jurassic to Early Cretaceous source rocks.

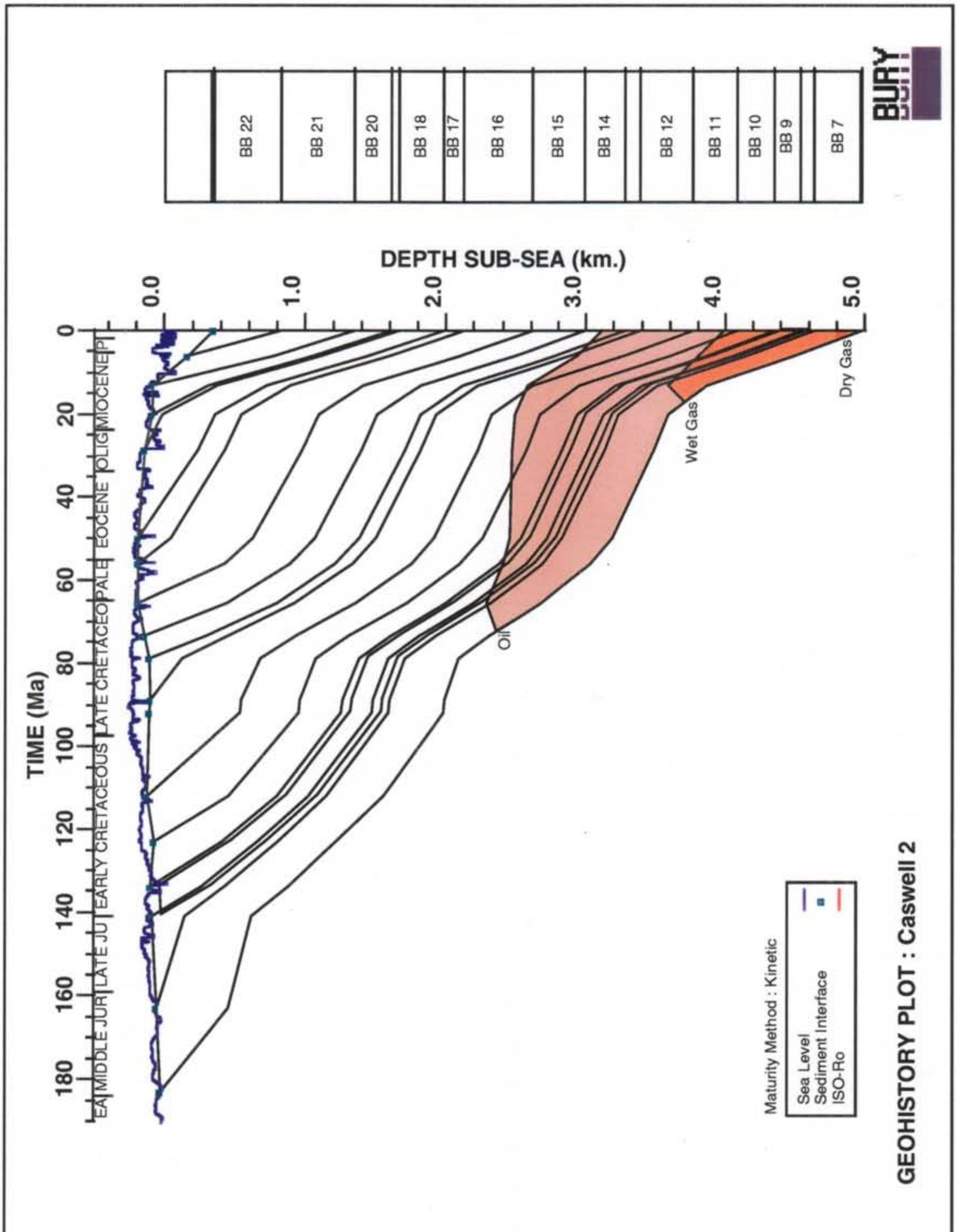


Figure 89 Geohistory for Caswell 2.

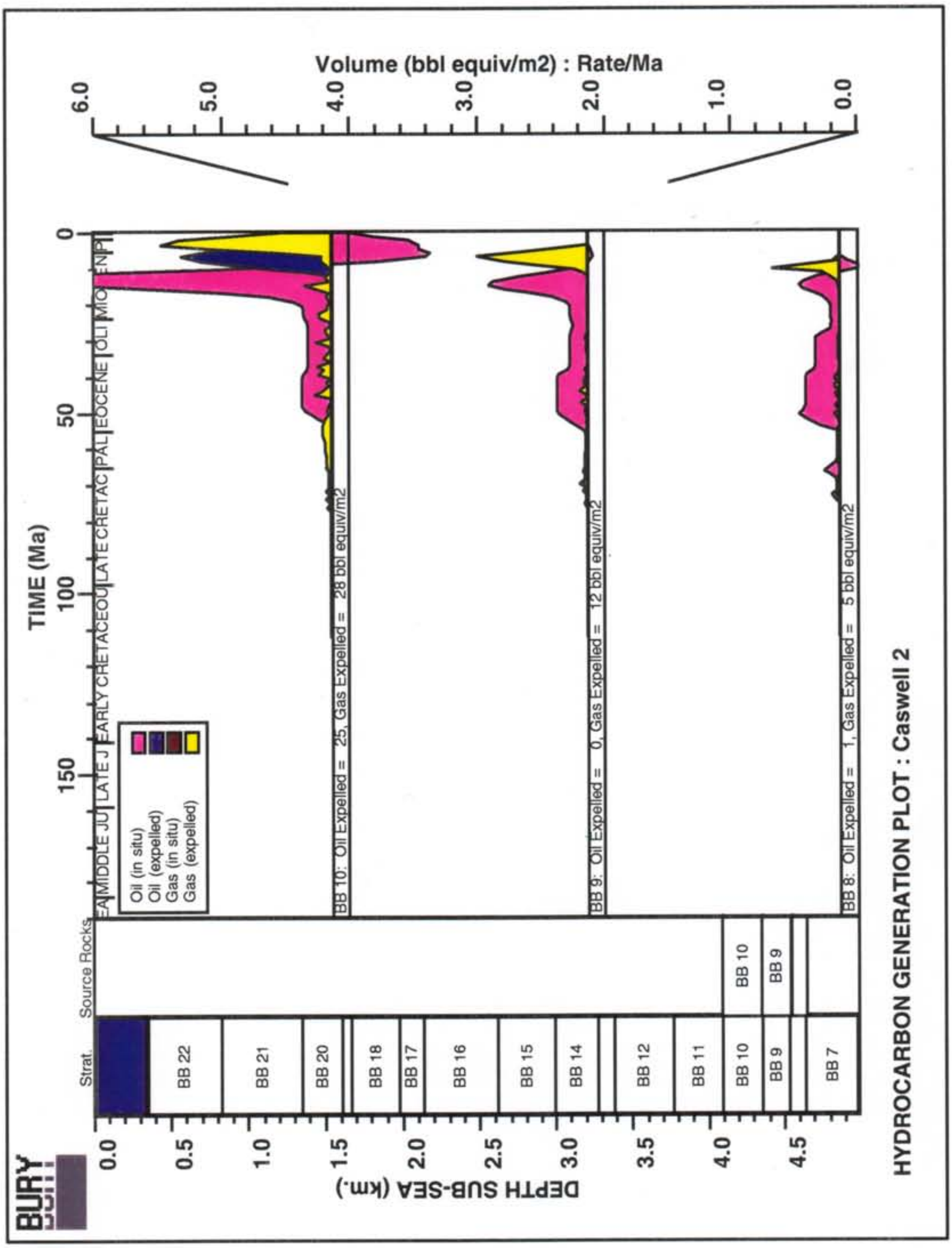


Figure 90 Rates of hydrocarbons generated from Late Jurassic to Early Cretaceous source rocks at Caswell 2.

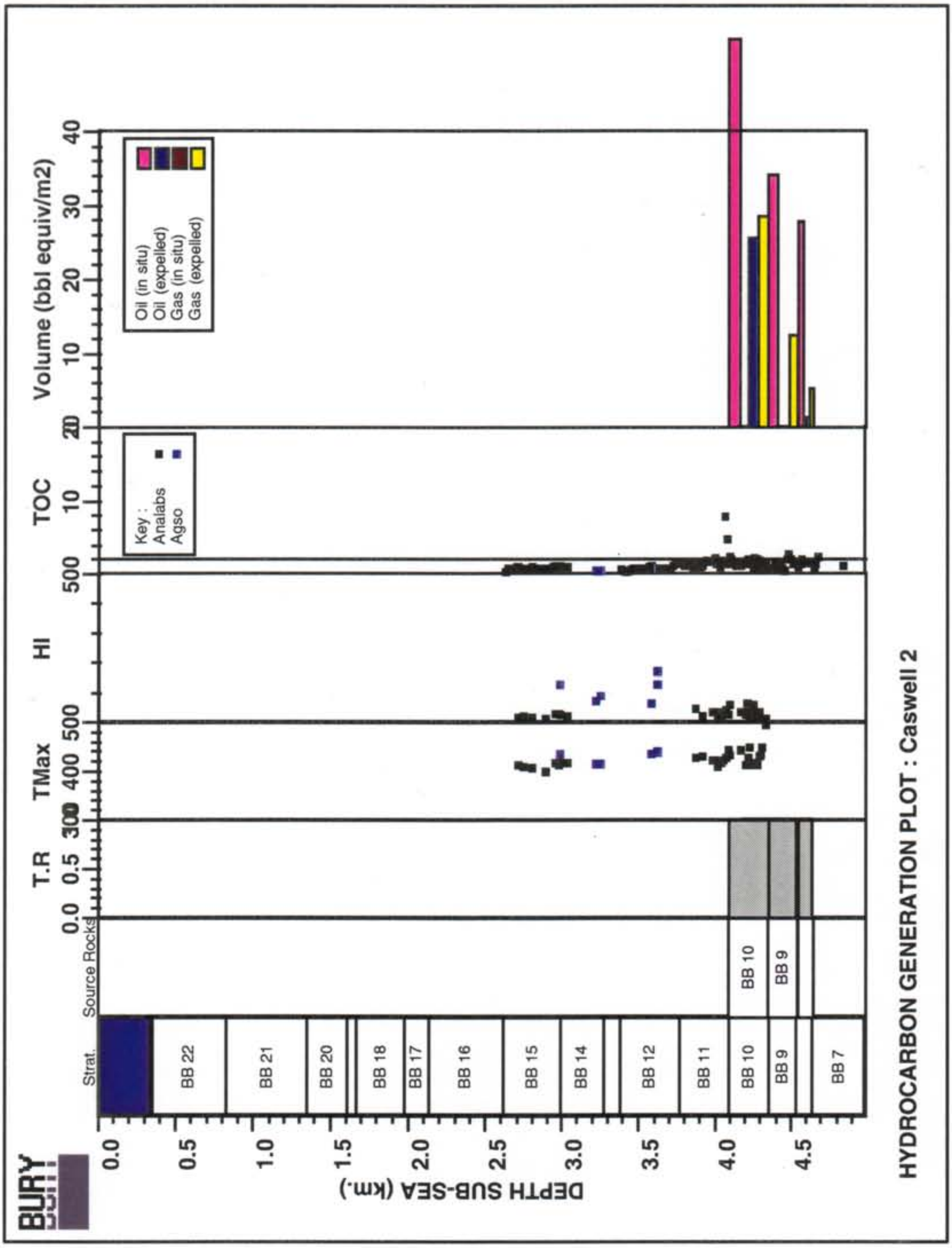


Figure 91 Caswell 2: RockEval data and volumes of hydrocarbons generated from Late Jurassic to Early Cretaceous source rocks.

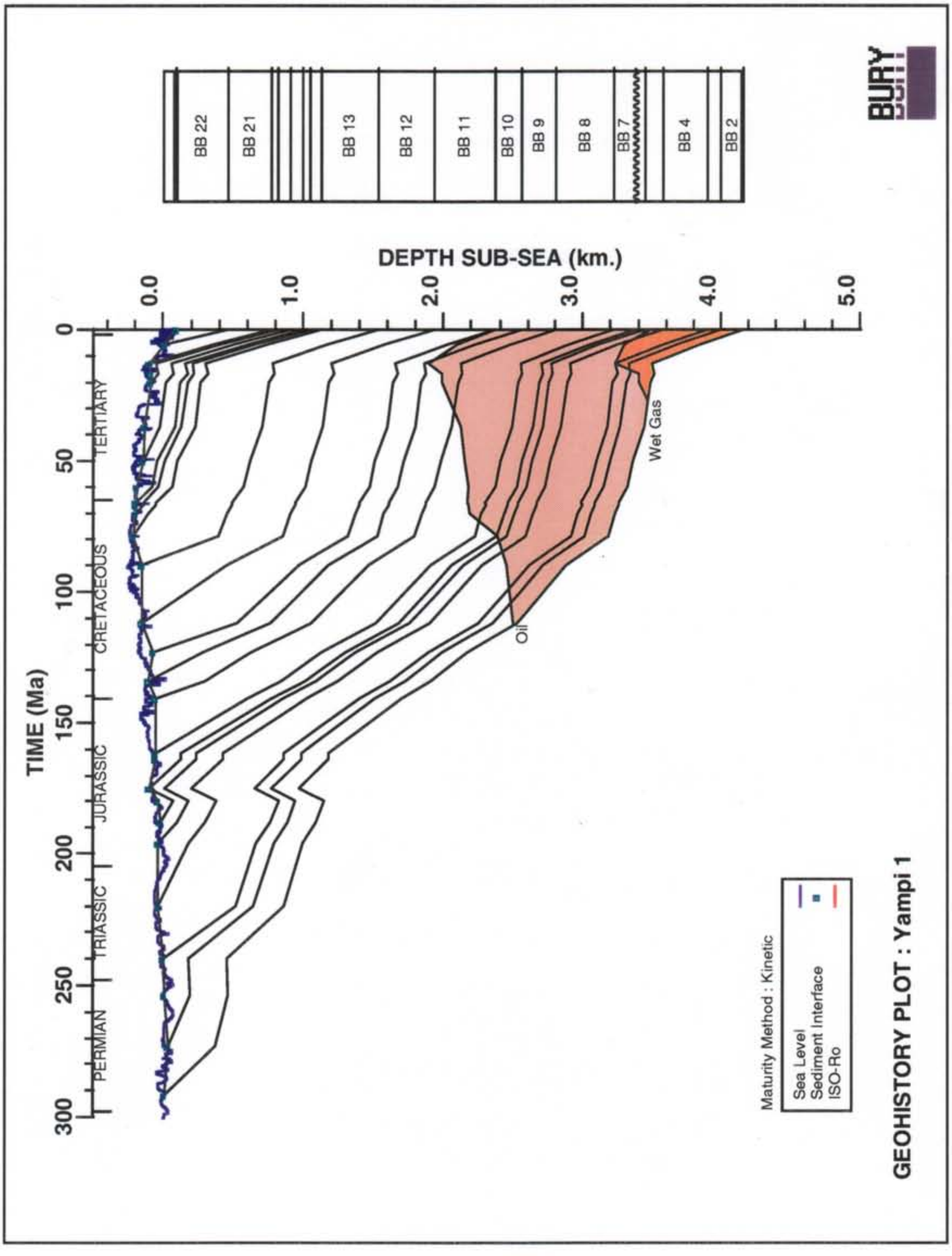


Figure 92 Geohistory for Yampi 1.

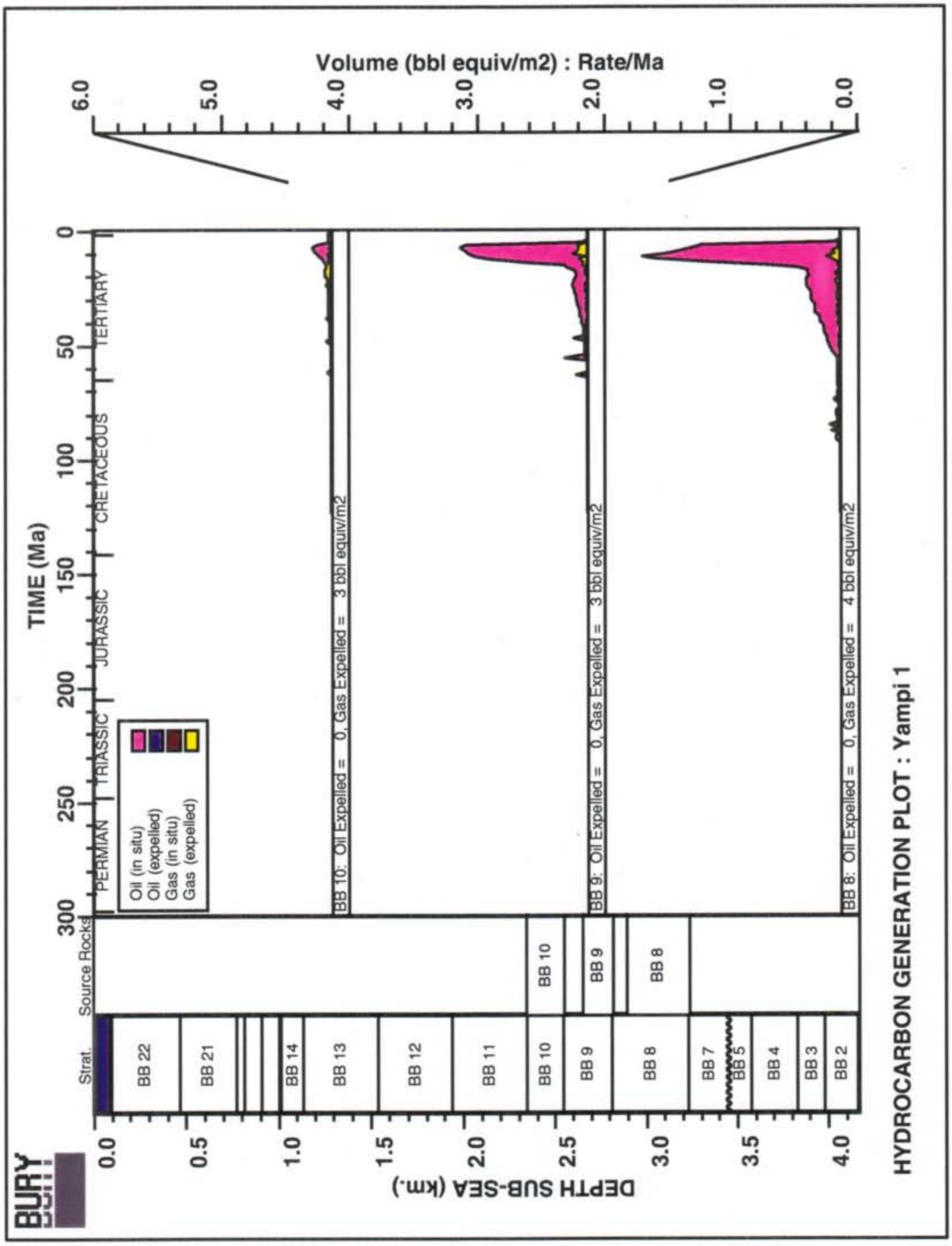


Figure 93 Rates of hydrocarbons generated from Late Jurassic to Early Cretaceous source rocks at Yampi 1.

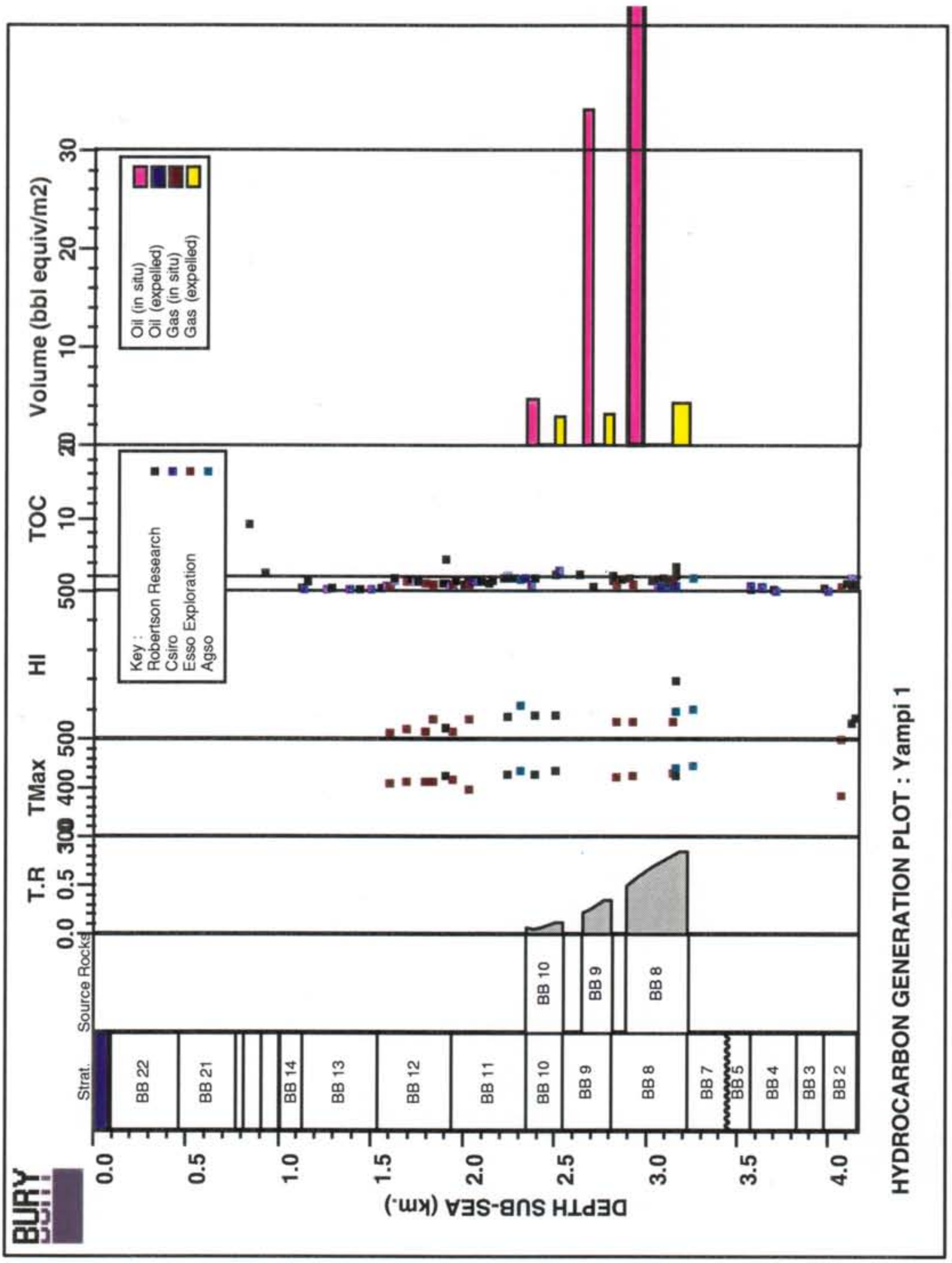


Figure 94 Yampi 1: RockEval data and volumes of hydrcarbons generated from Late Jurassic to Early Cretaceous source rocks.

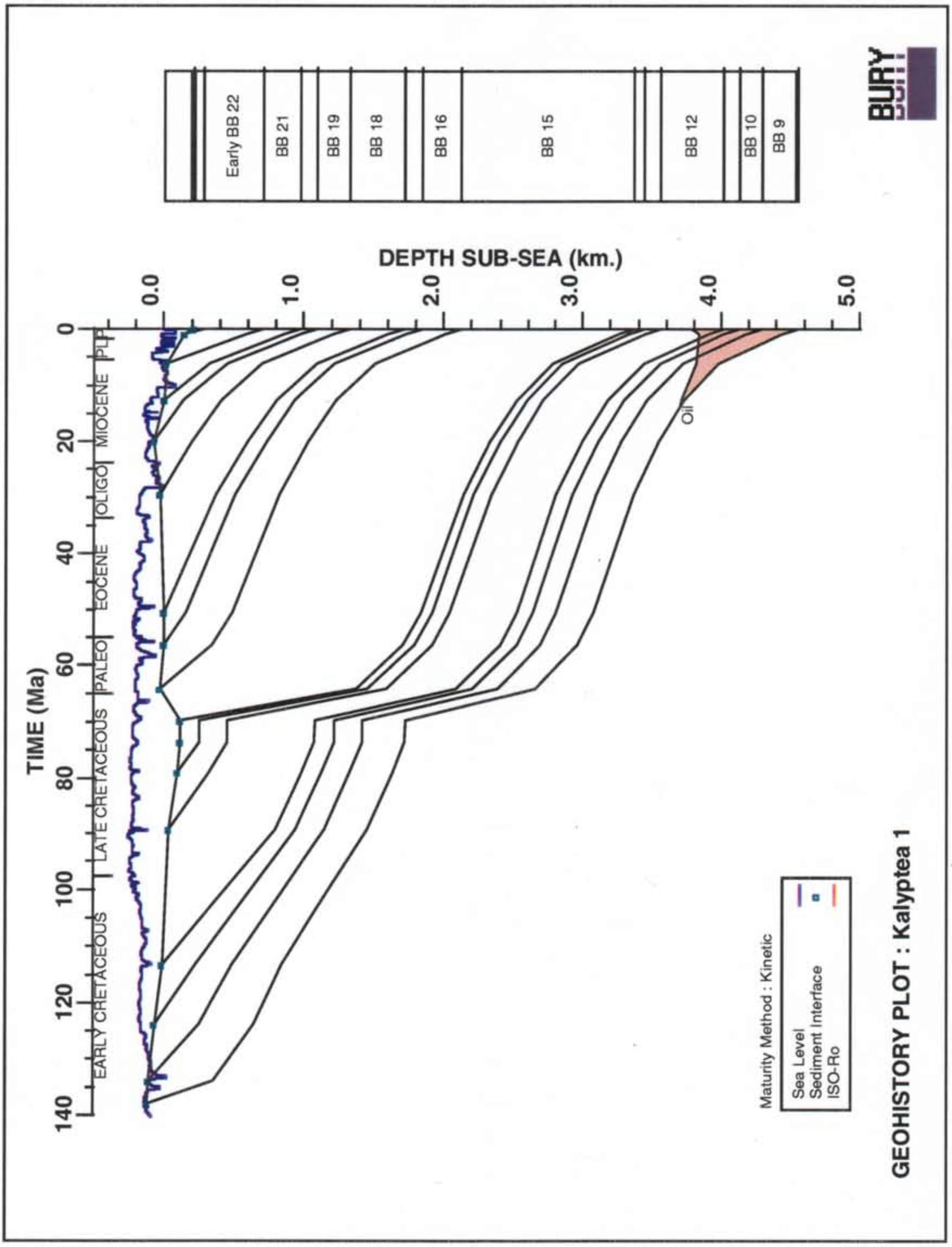


Figure 95 Geohistory for Kalyptea 1.

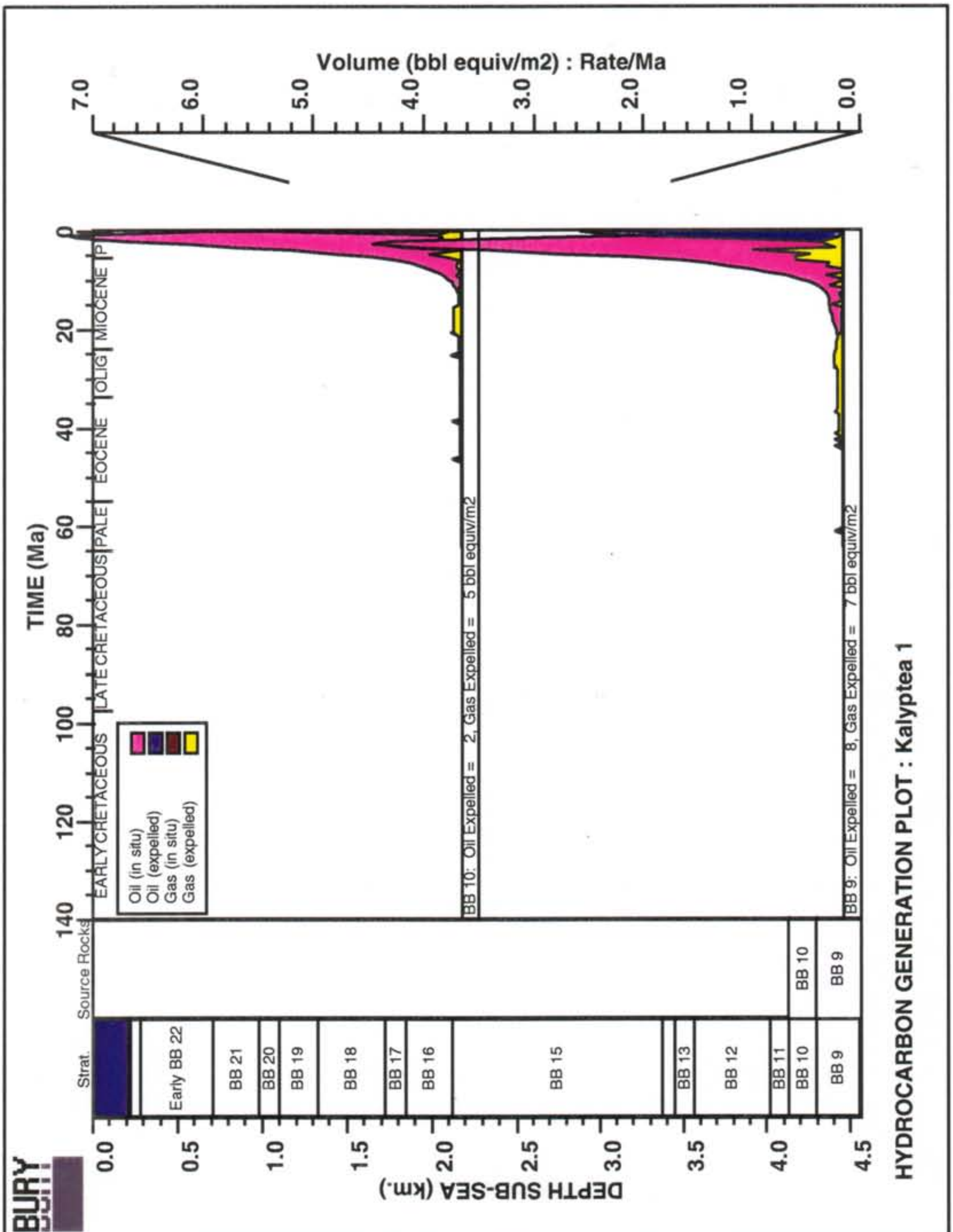


Figure 96 Rates of hydrocarbons generated from Late Jurassic to Early Cretaceous source rocks at Kalyptea 1.

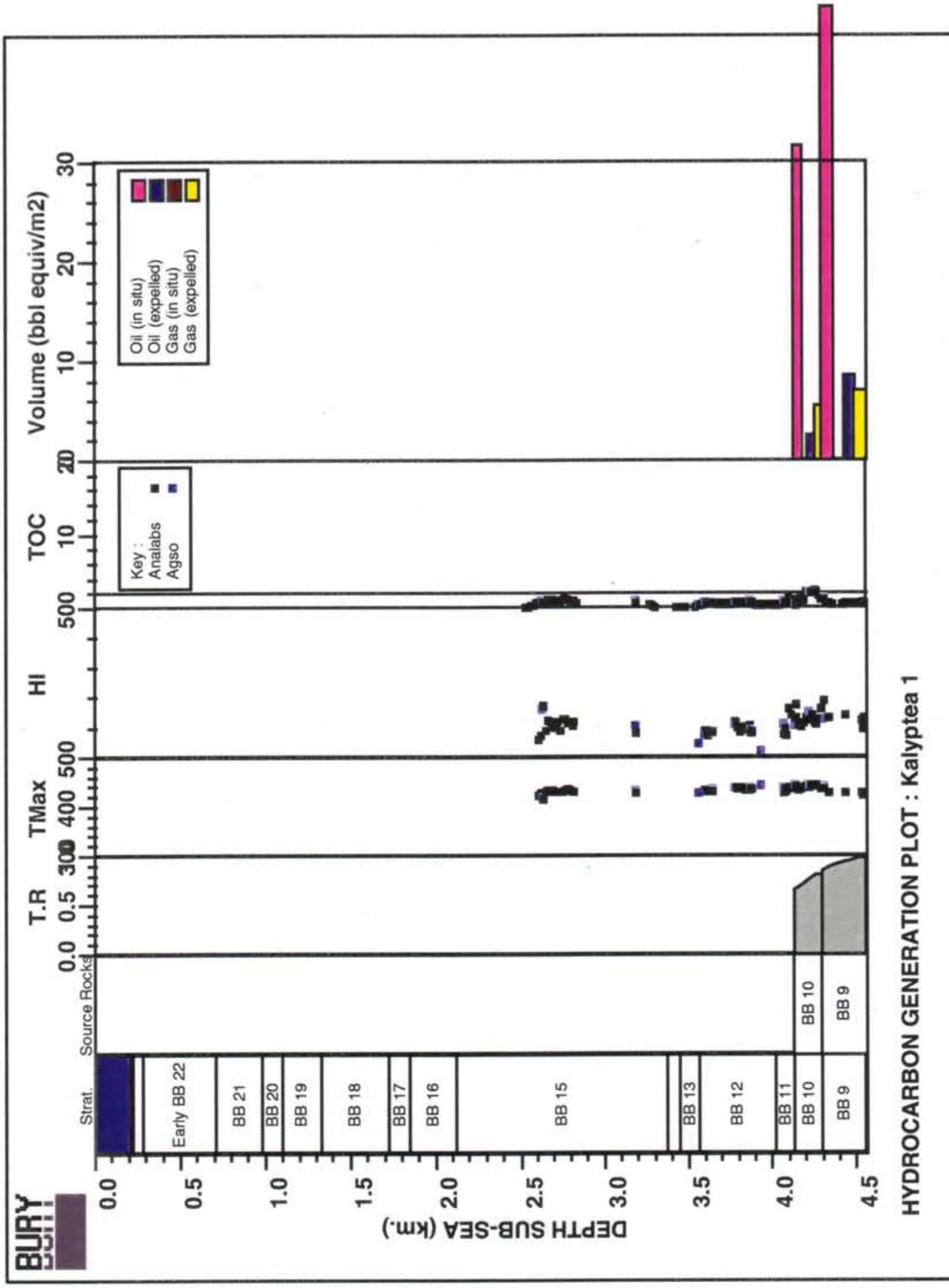


Figure 97 Kalyptea 1: RockEval data and volumes of hydrocarbons generated from Late Jurassic to Early Cretaceous source rocks.

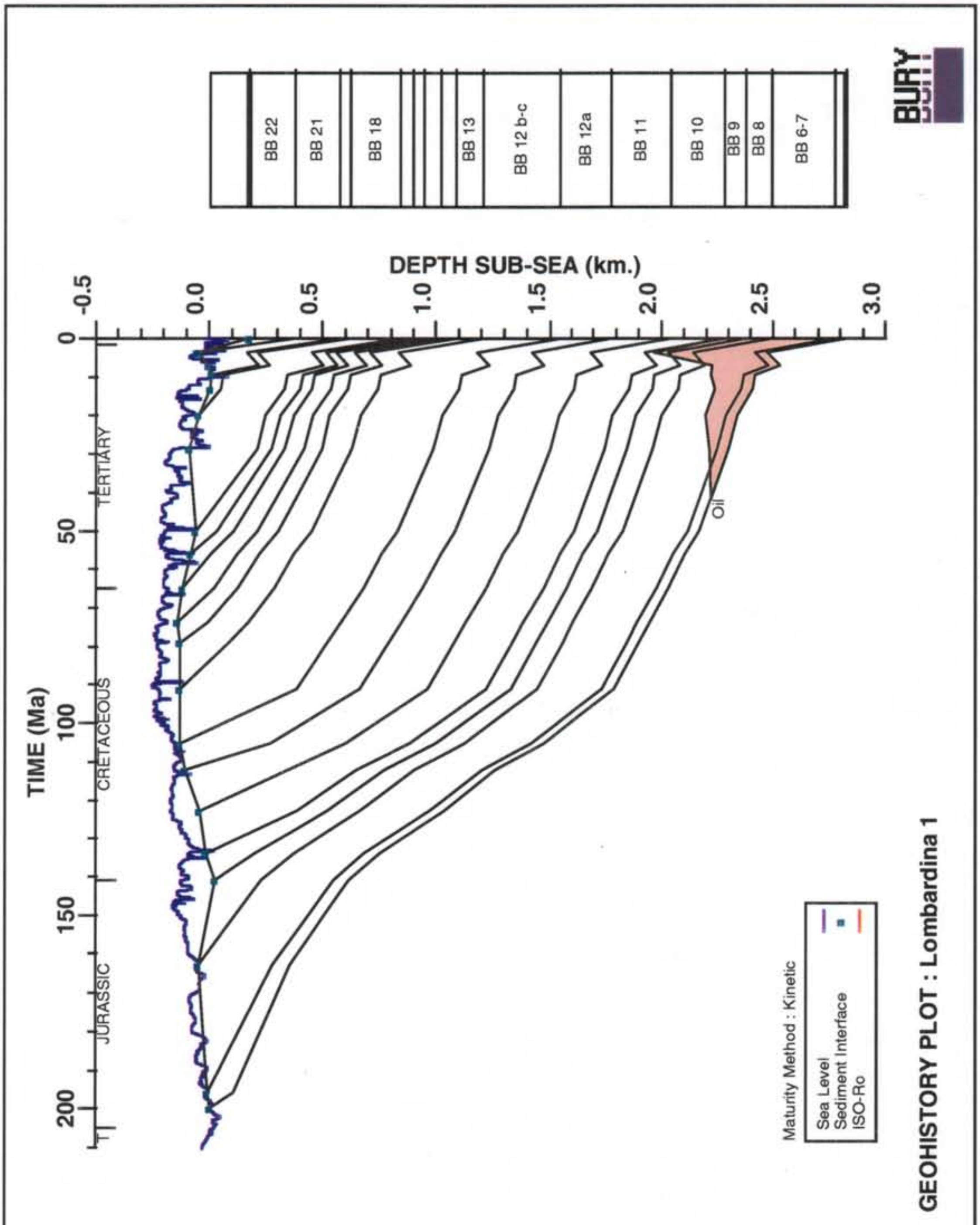


Figure 98 Geohistory for Lombardina 1.

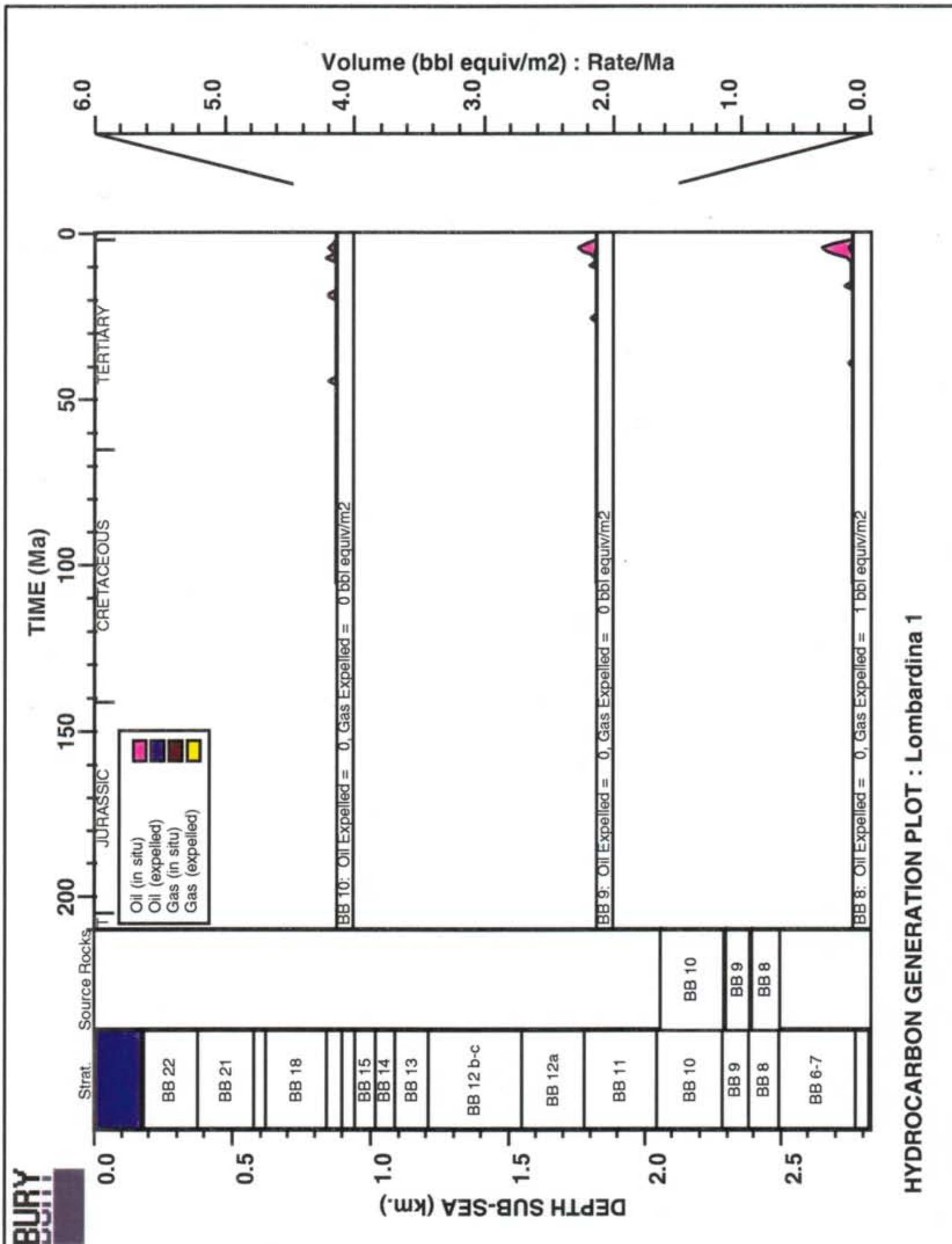


Figure 99 Rates of hydrocarbons generated from Late Jurassic to Early Cretaceous source rocks at Lombardina 1.

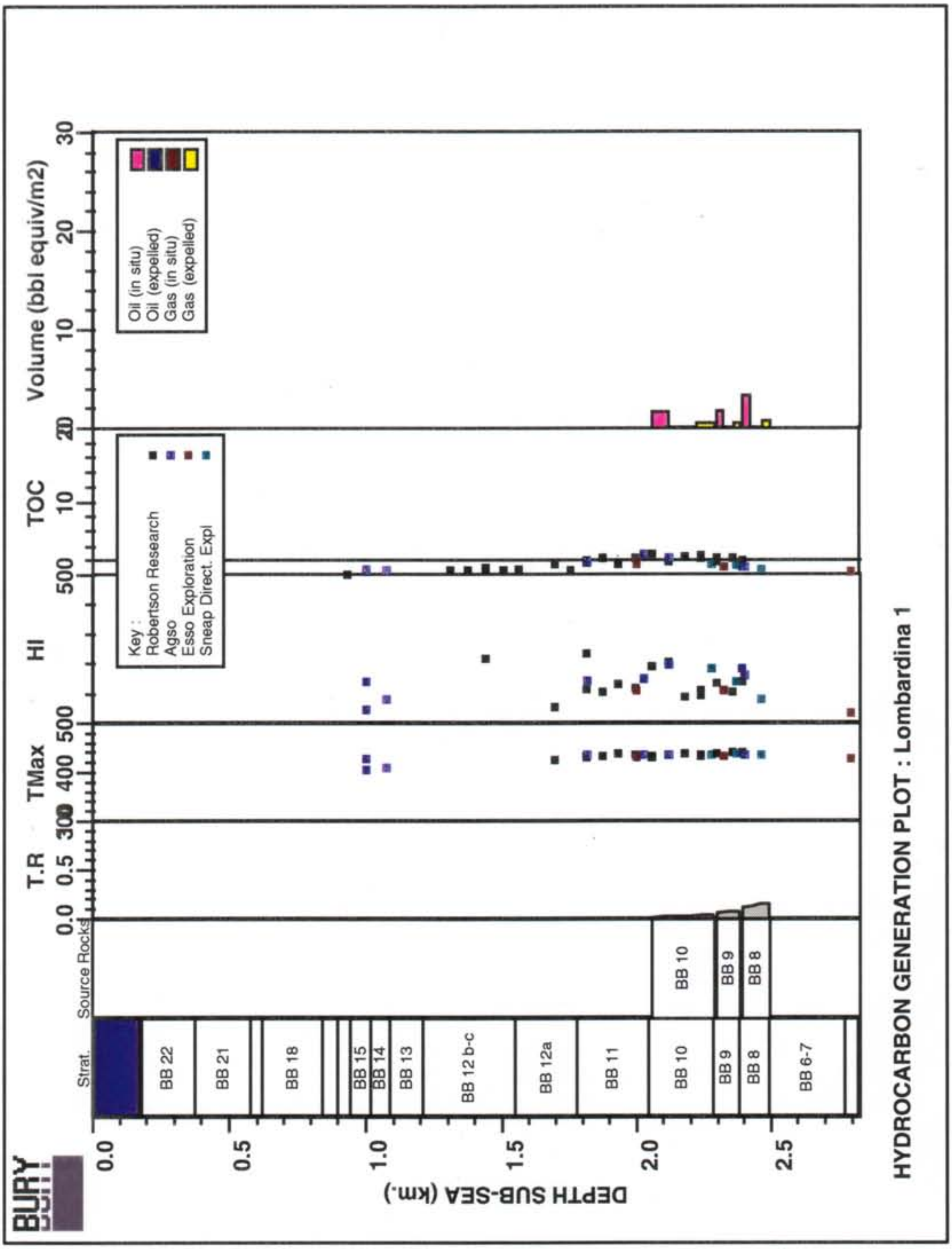


Figure 100 Lombardina 1: RockEval data and volumes of hydrocarbons generated from Late Jurassic to Early Cretaceous source rocks.

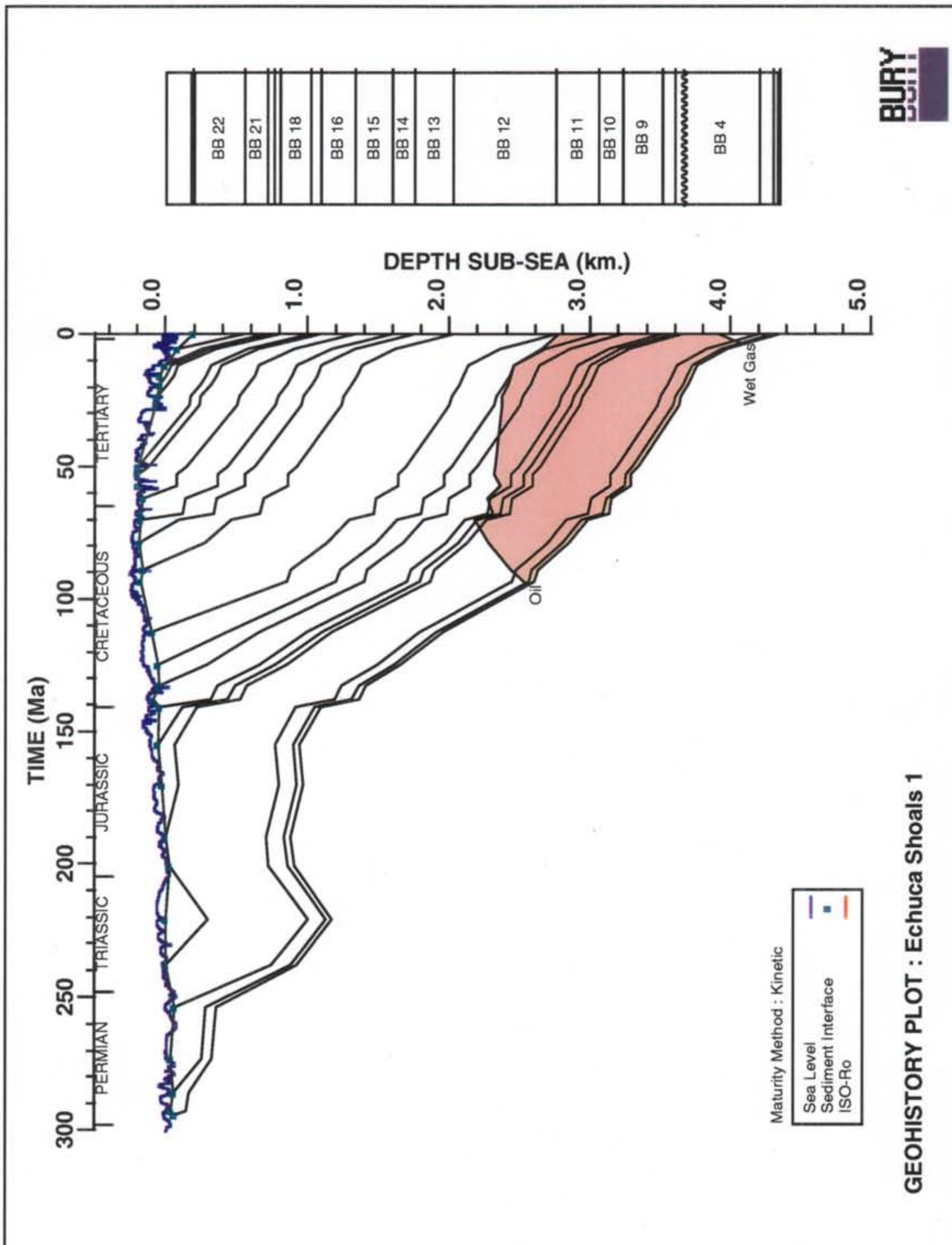


Figure 101 Geohistory for Echuca Shoals 1.

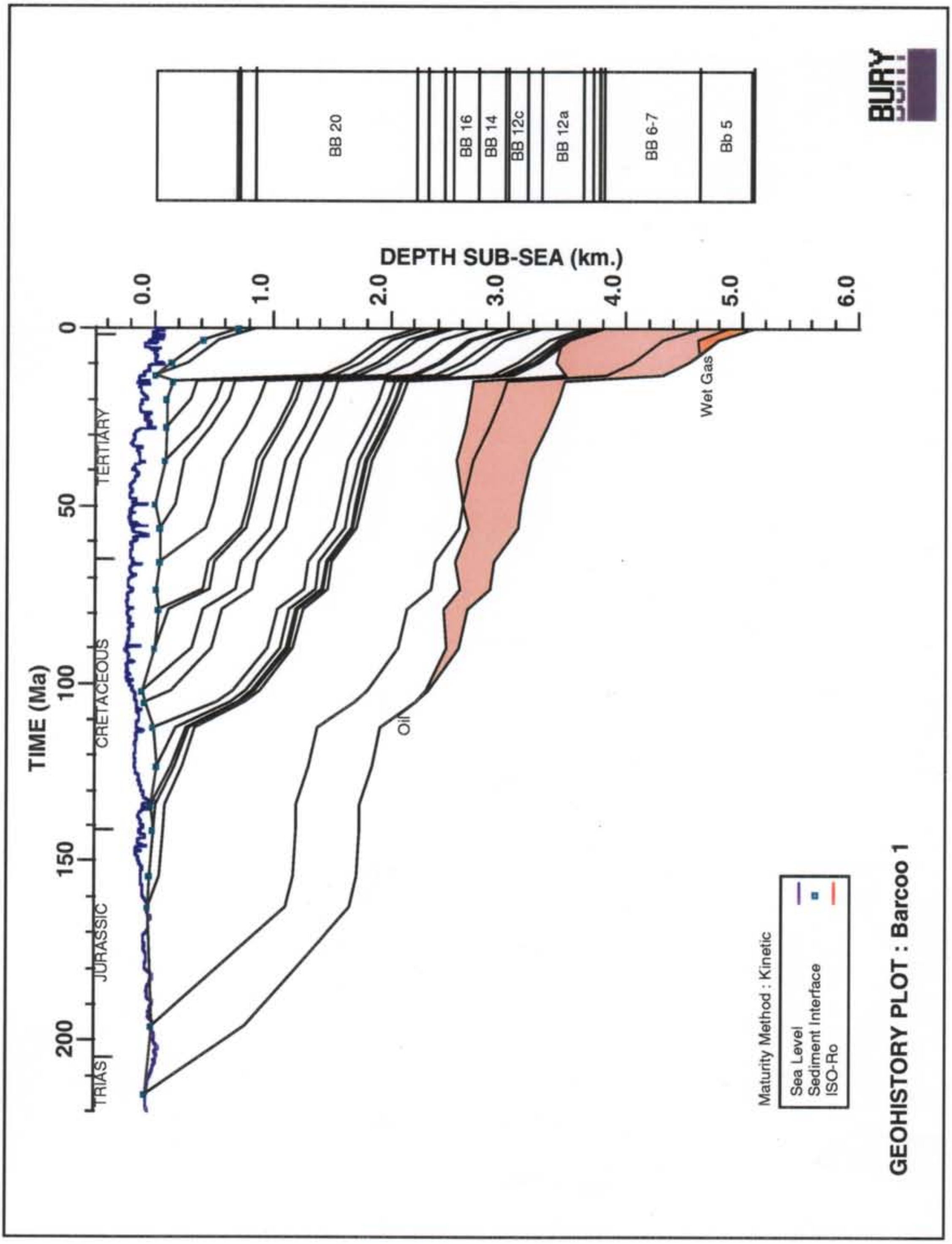


Figure 102 Geohistory for Barcoo 1.

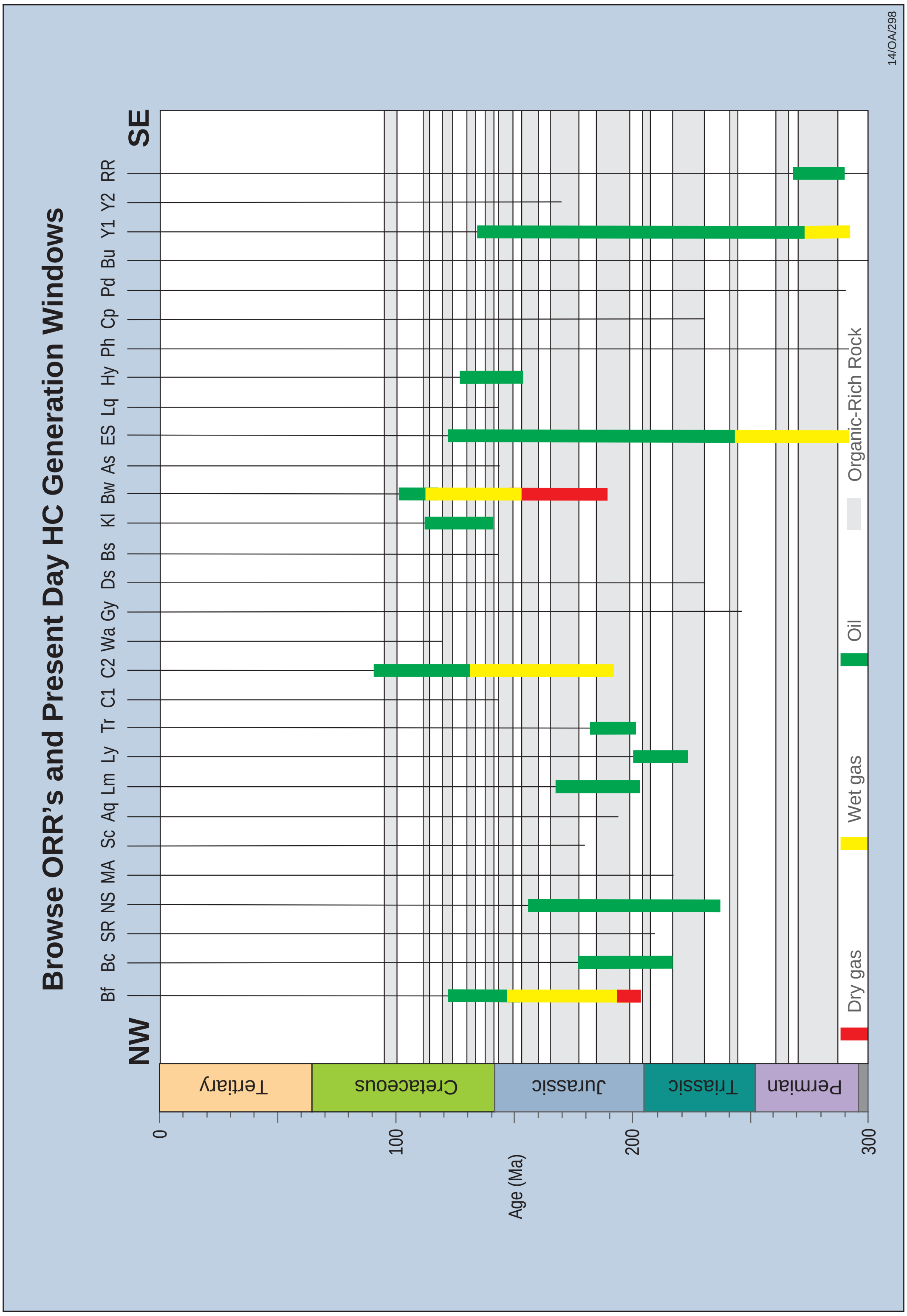


Figure 103 Summary of occurrences of organic-rich rocks in the Browse Basin plotted by well and age (see Table 4 for abbreviations of well names). The present day hydrocarbon generation windows for 13 wells have been analysed using the Winbury burial history program.

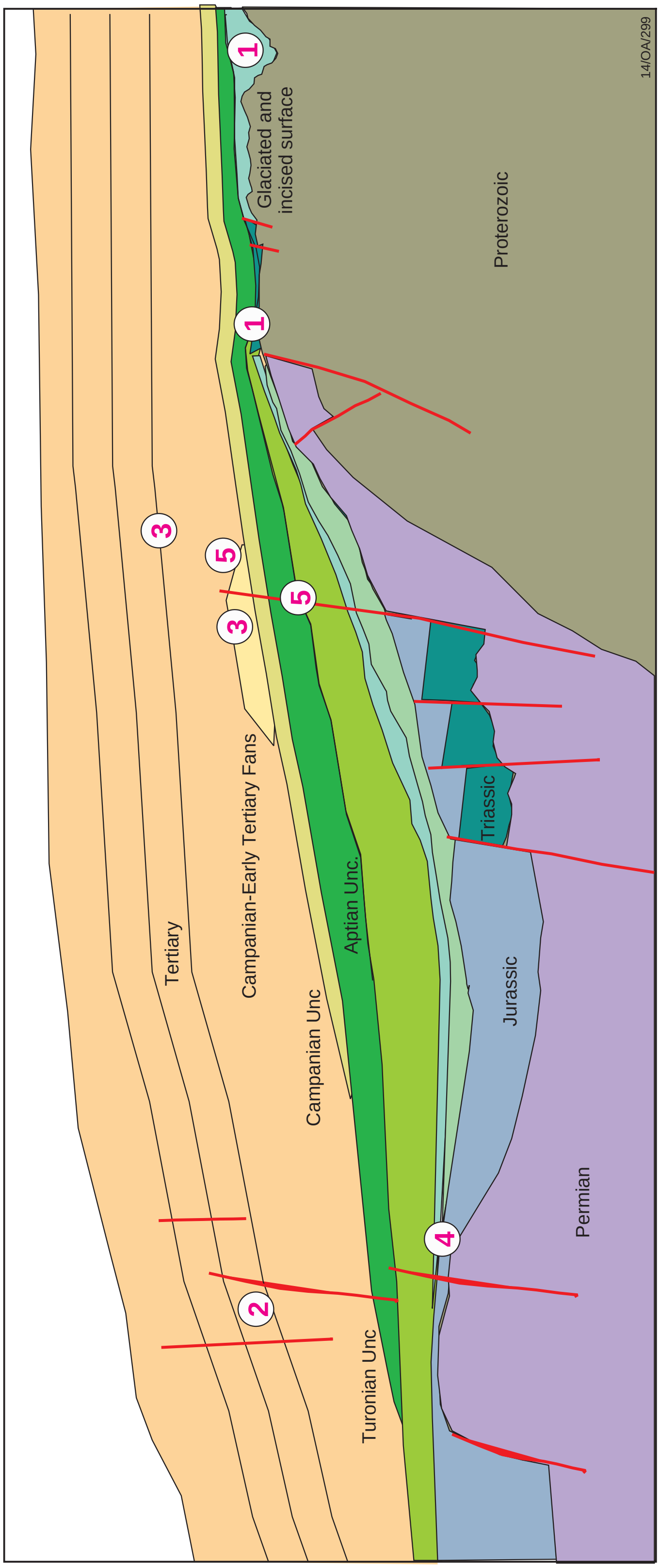


Figure 104 Early Cretaceous Petroleum Systems and Play Families in the northern Browse Basin. Schematic stratal geometry for Lines 175/10 to 175/12 is plotted against seismic time.

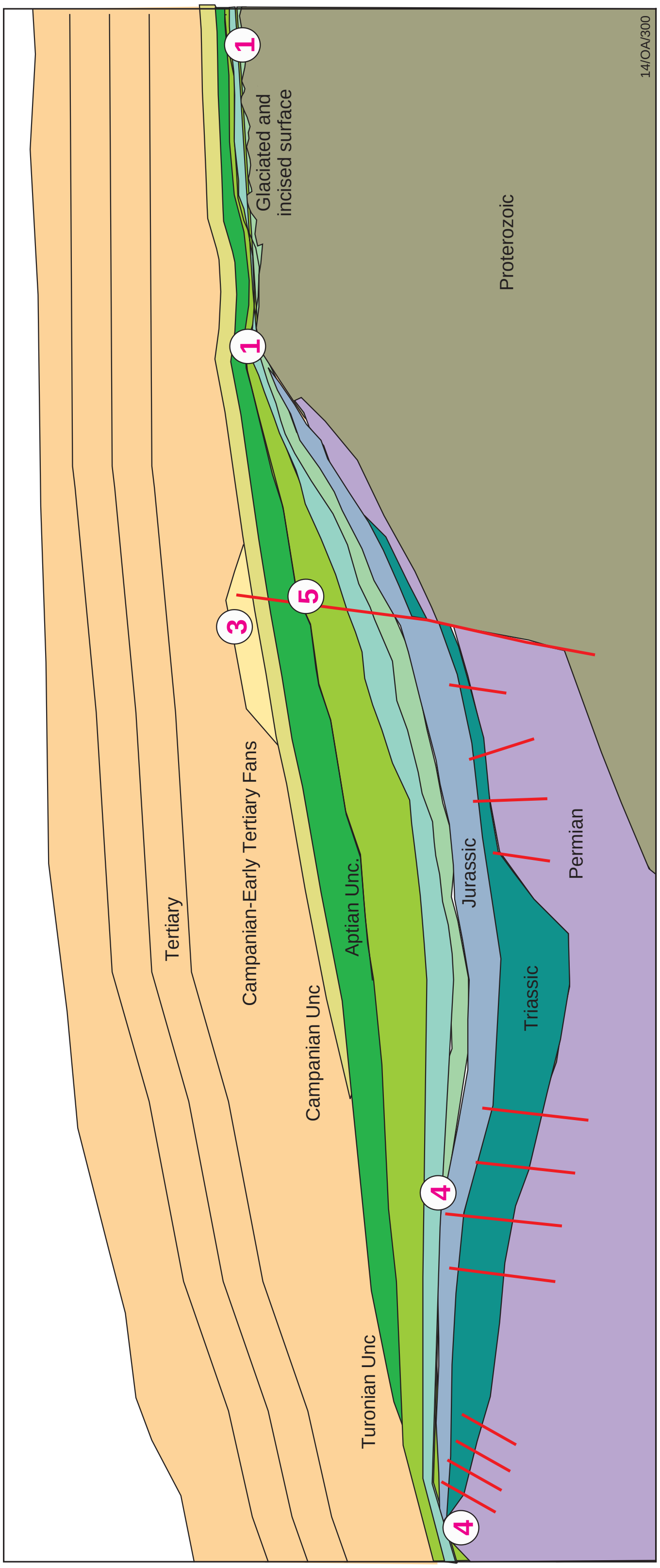


Figure 105 Early Cretaceous Petroleum Systems and Play Families in the central Browse Basin. Schematic stratal geometry for the area near Line 175/08 is plotted against seismic time.

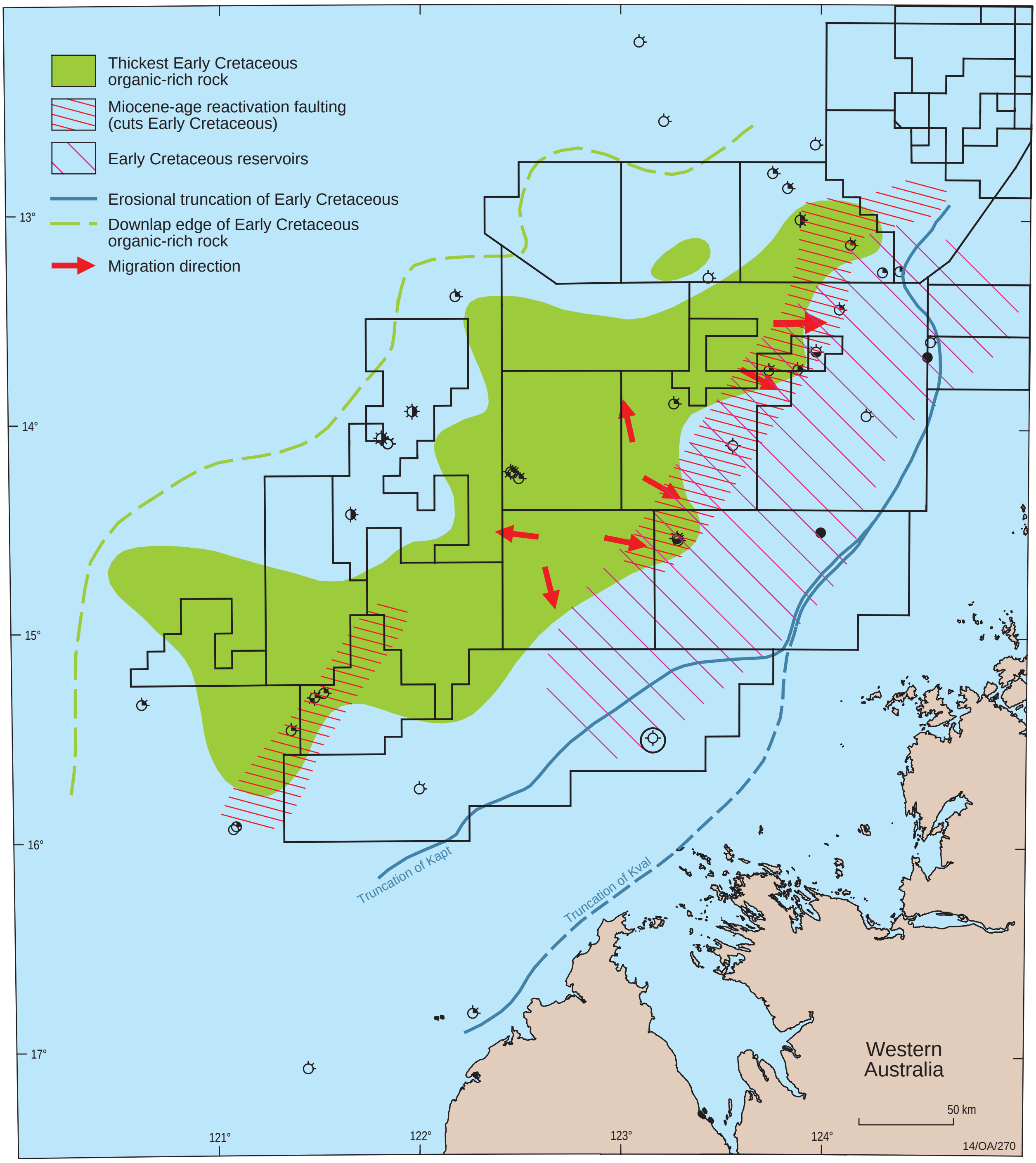


Figure 106 Map of play elements for Early Cretaceous Petroleum Systems and Play Families.

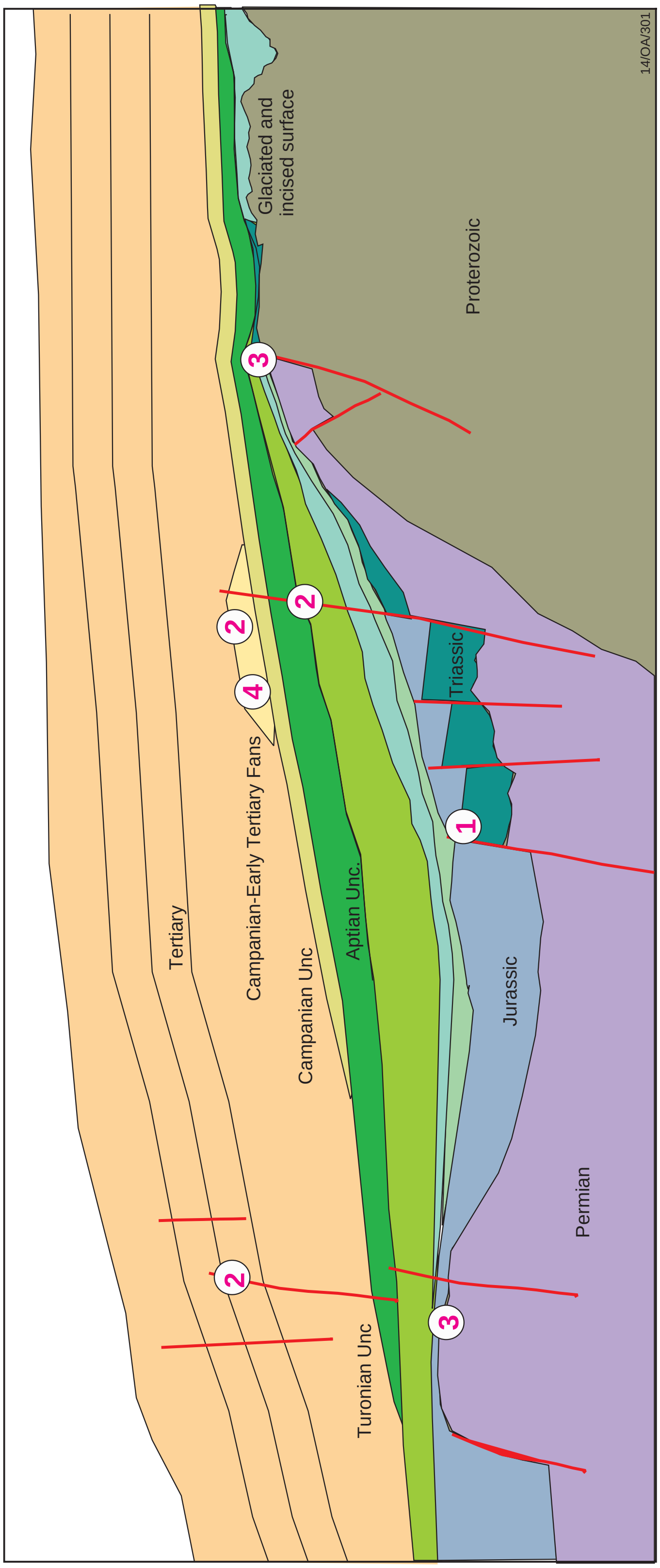


Figure 107 Late Jurassic Petroleum Systems and Play Families in the northern Browse Basin. Schematic stratal geometry for Lines 175/10 to 175/12 is plotted against seismic time.

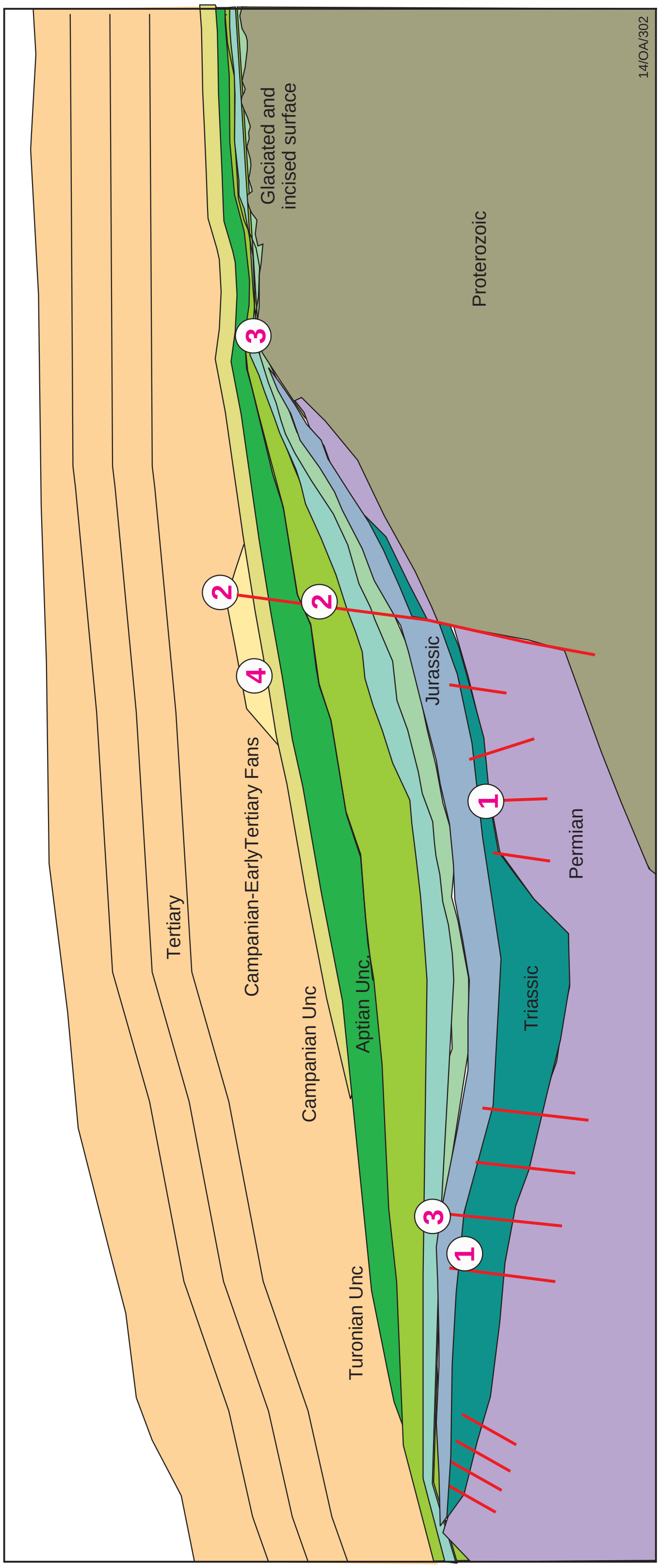


Figure 108 Late Jurassic Petroleum Systems and Play Families in the northern Browse Basin. Schematic stratal geometry for the area near Line 175/08 is plotted against seismic time.

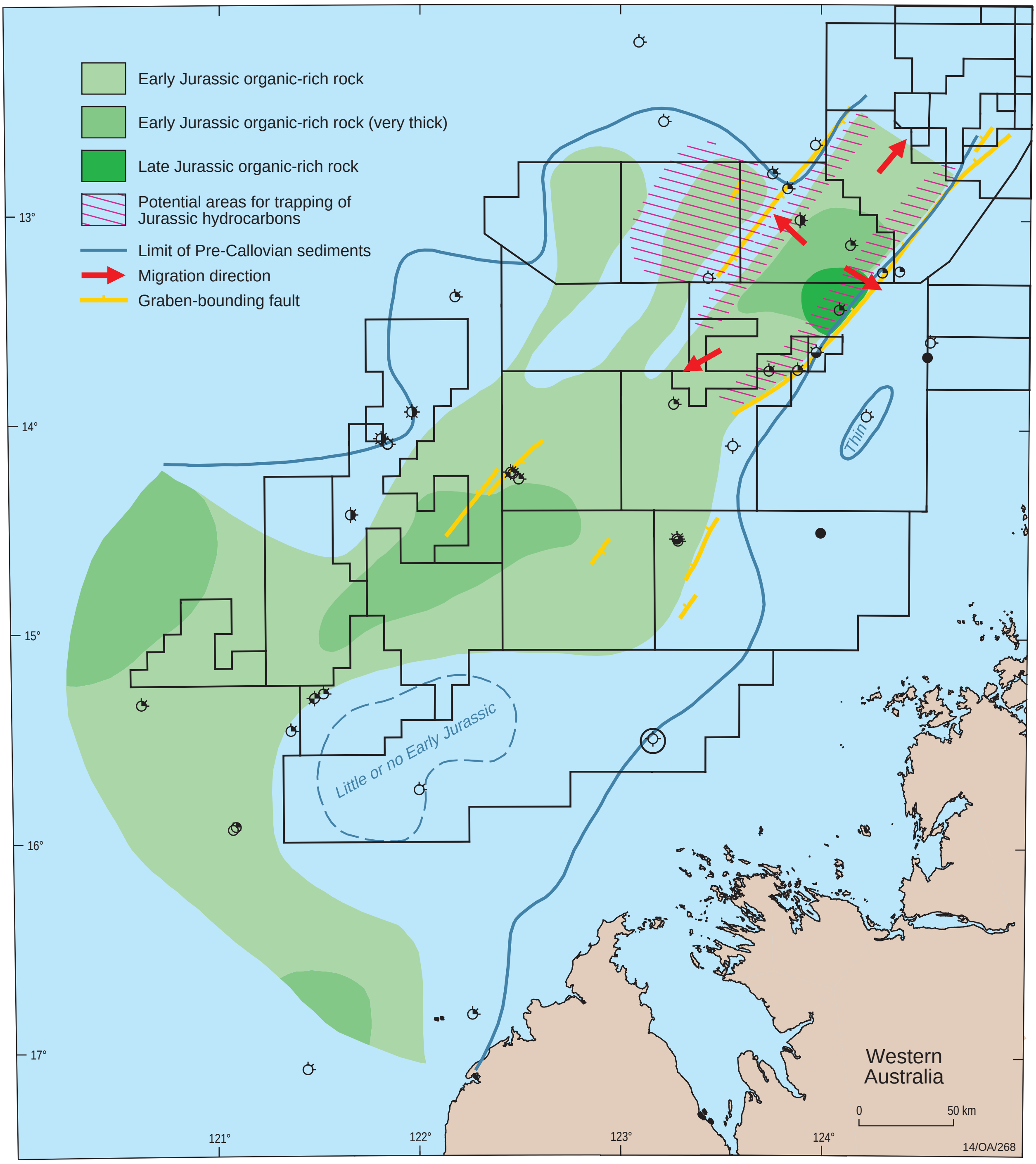


Figure 109 Map of play elements for Jurassic Petroleum Systems and Play Families.

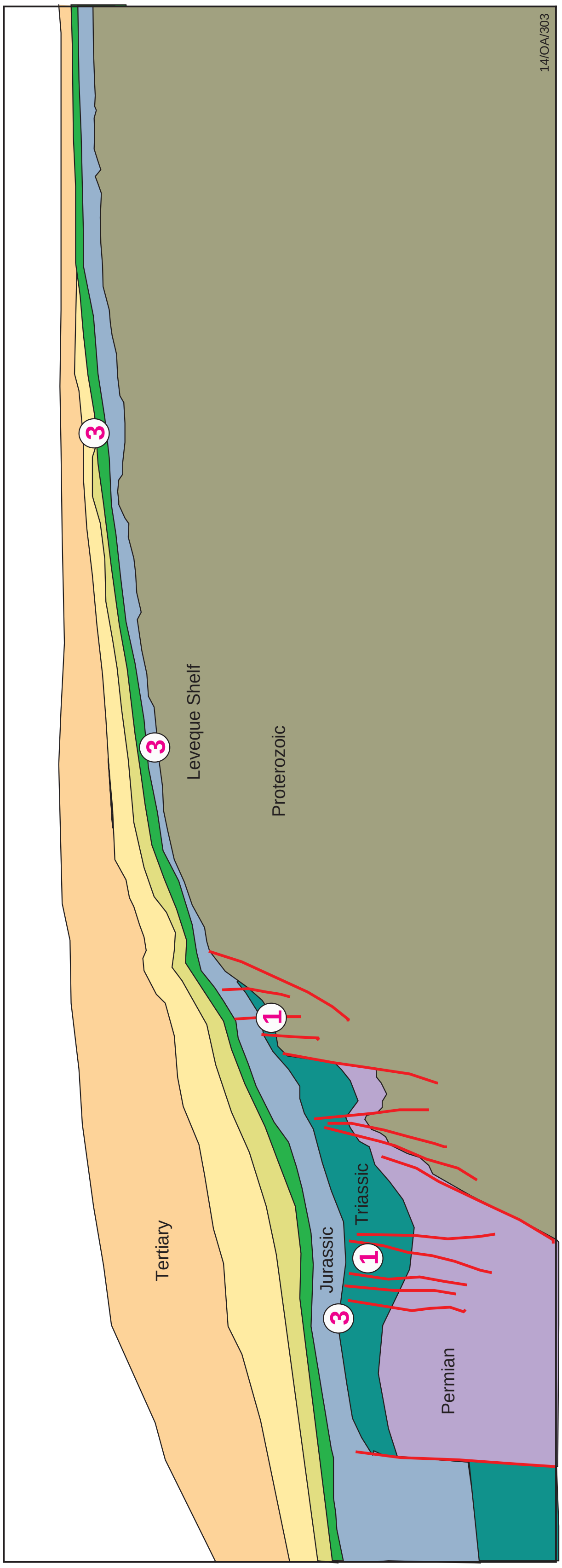


Figure 110 Early to Middle Jurassic Petroleum Systems and Play Families in the Barcoo Sub-basin (southern Browse Basin). Schematic stratal geometry for the area near Line 175/03 is plotted against seismic time.

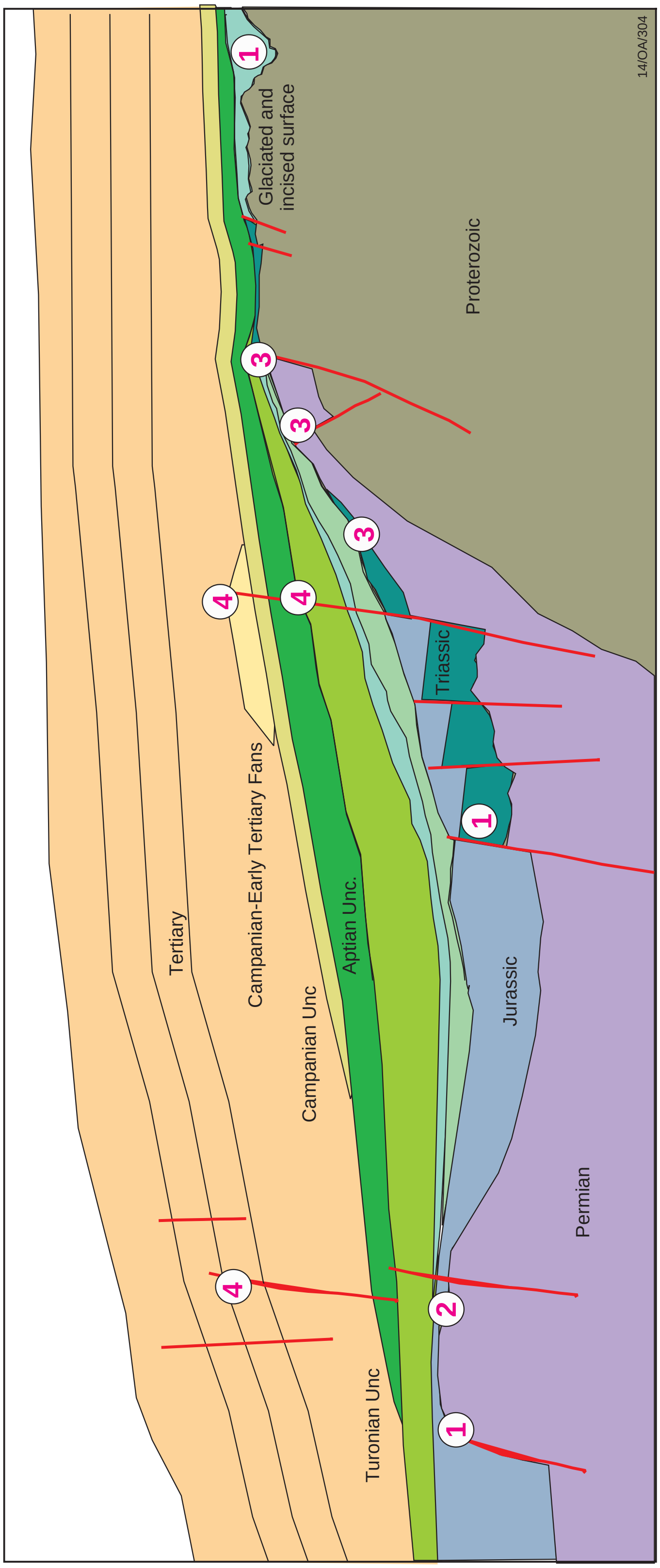


Figure 111 Carboniferous to Late Triassic Petroleum Systems and Play Families in the northern Browse Basin. Schematic stratal geometry for Line 175/10 to 175/12 is plotted against seismic time.

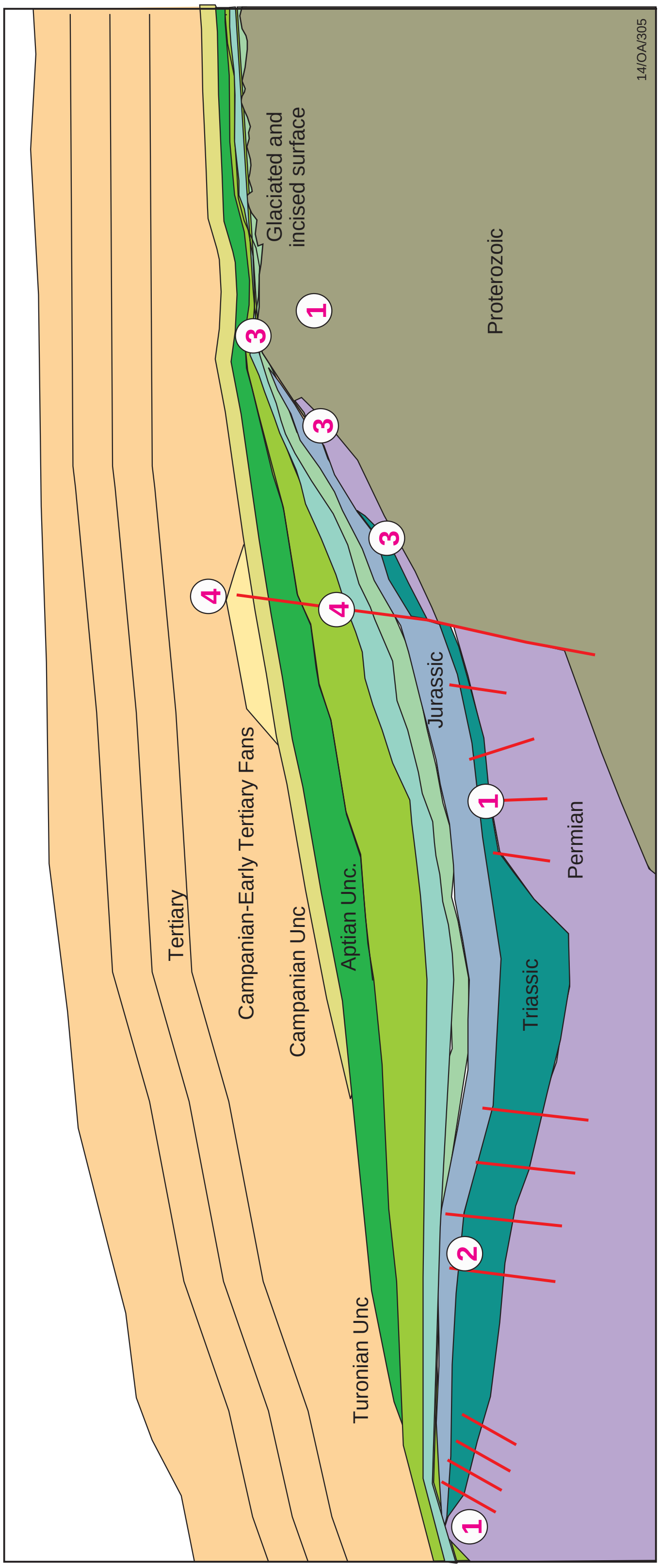


Figure 112 Carboniferous to Late Triassic Petroleum Systems and Play Families in the central Browse Basin. Schematic stratal geometry for the area near Line 175/08 is plotted against seismic time.

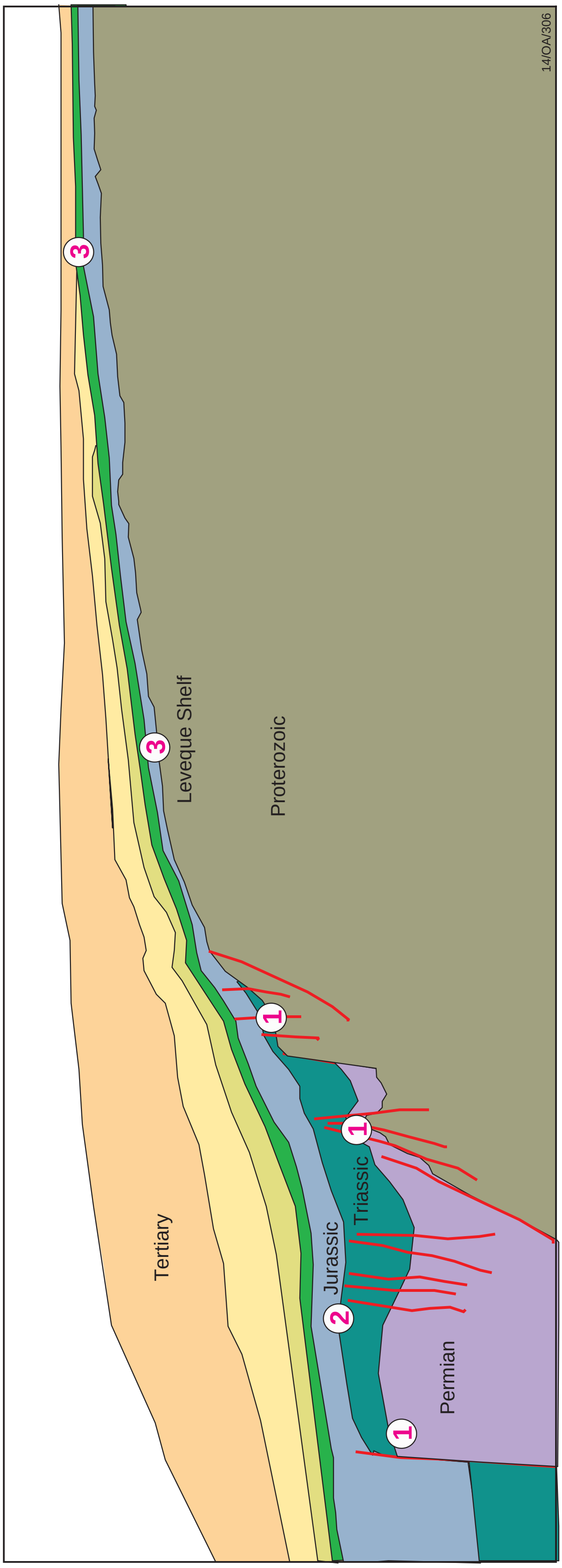


Figure 113 Carboniferous to Late Triassic Petroleum Systems and Play Families in the southern Browse Basin. Schematic stratal geometry for the area near Line 175/03 is plotted against seismic time.

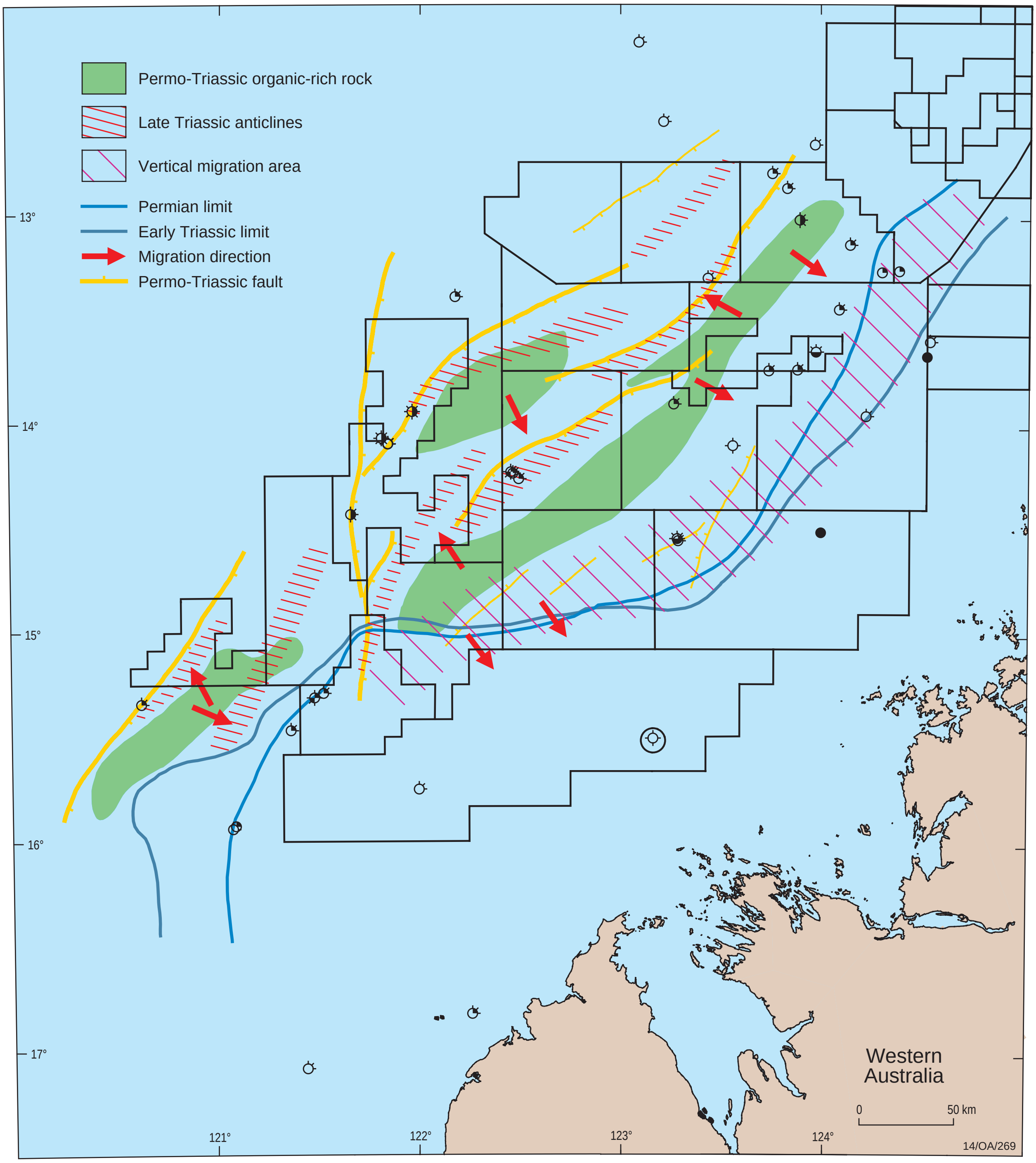


Figure 114 Map of play elements for Carboniferous to Late Triassic Petroleum Systems and Play Families.

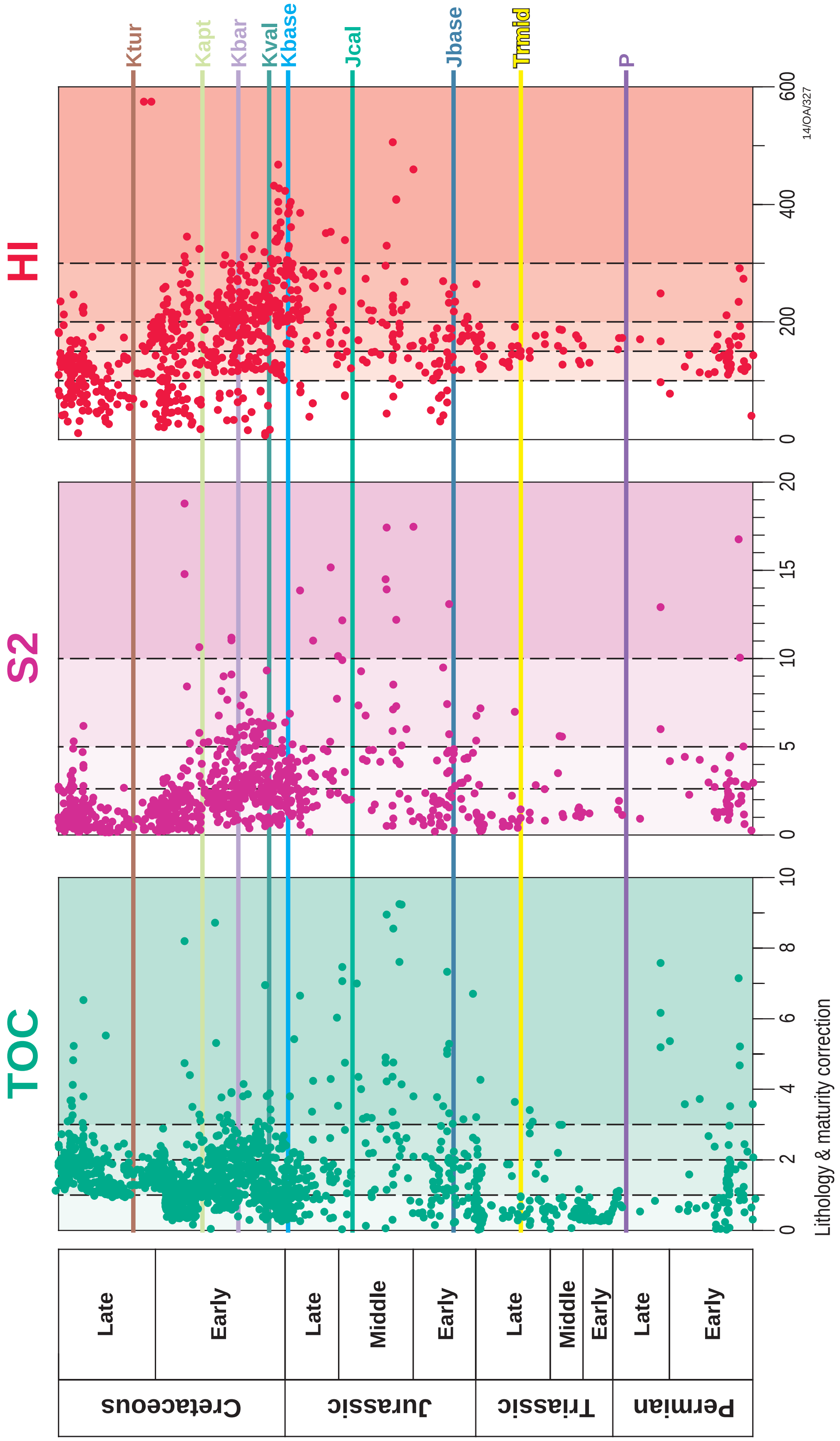
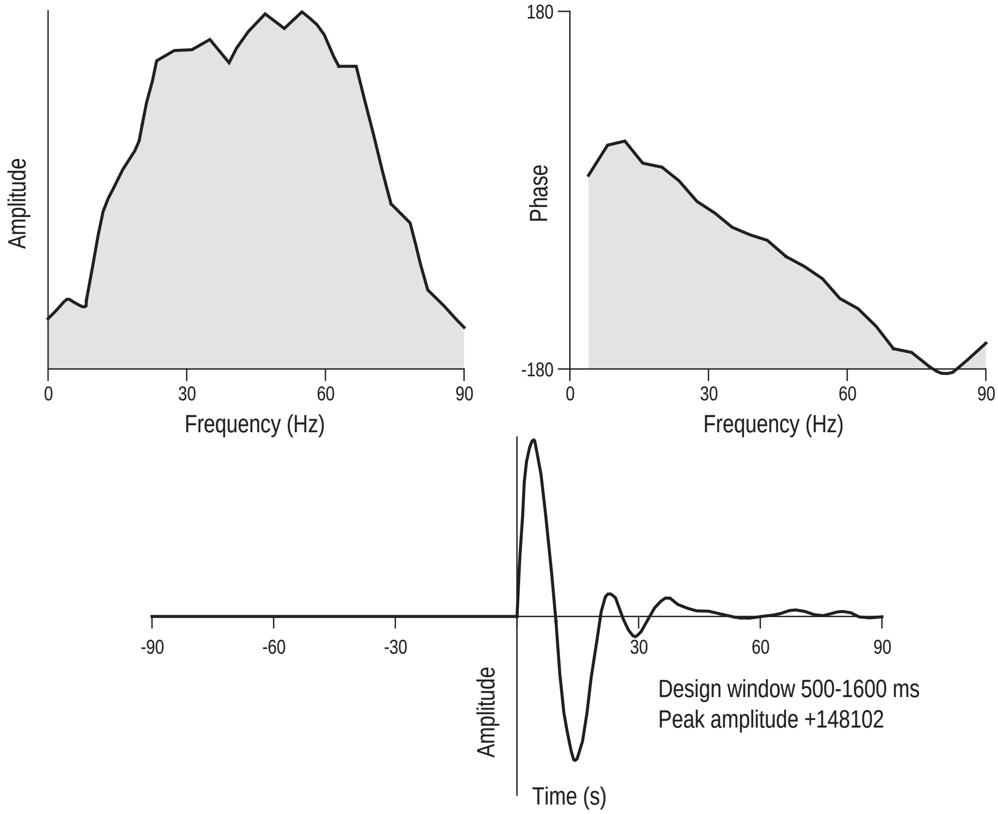
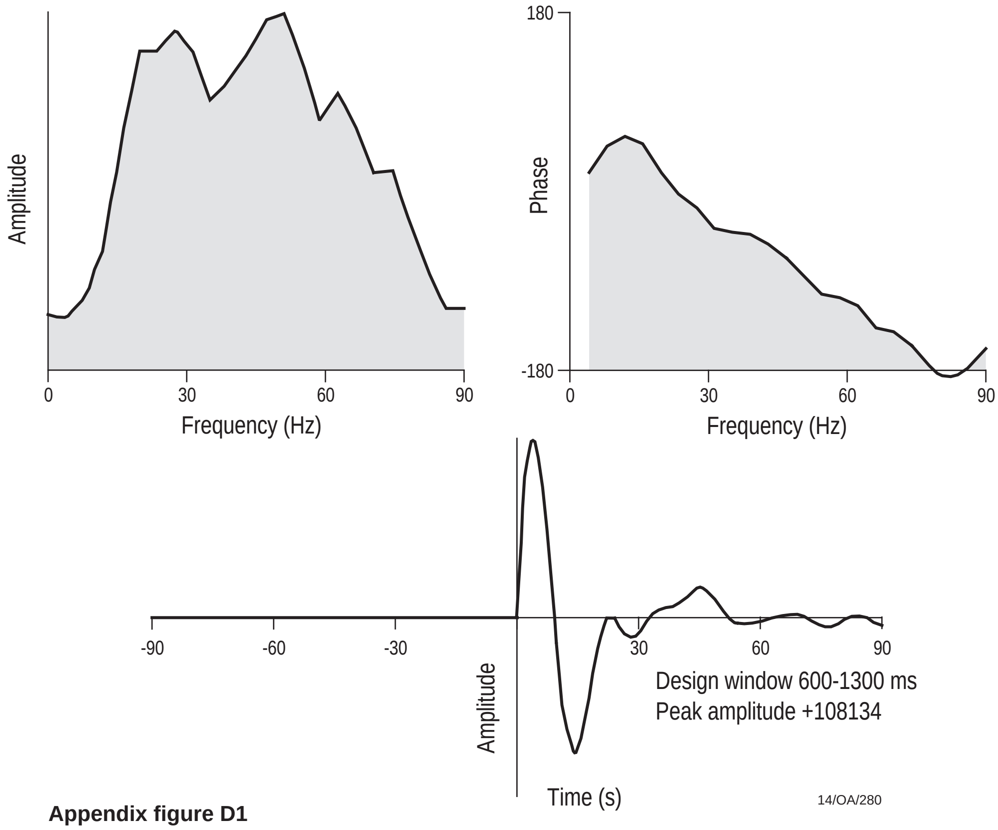


Figure 115 Plot of TOC, S2 and HI against time for all wells in the Browse Basin (lithology and maturity correction).

ECHUCA SHOALS 1

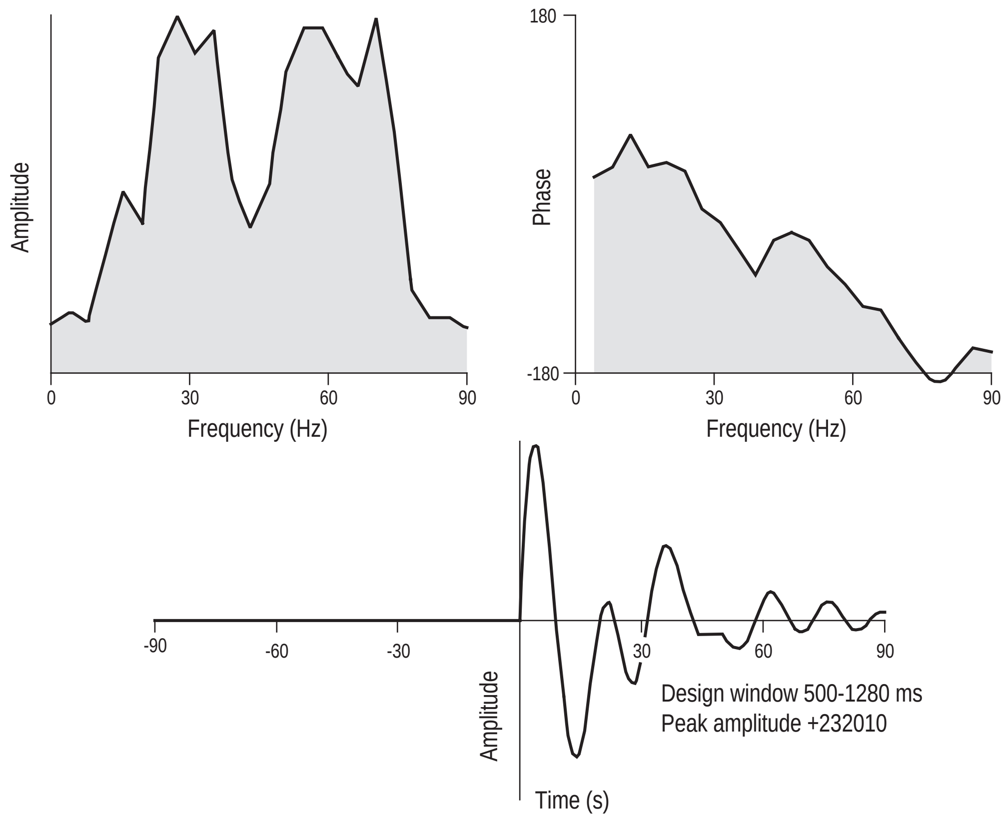


SHEHERAZADE 1

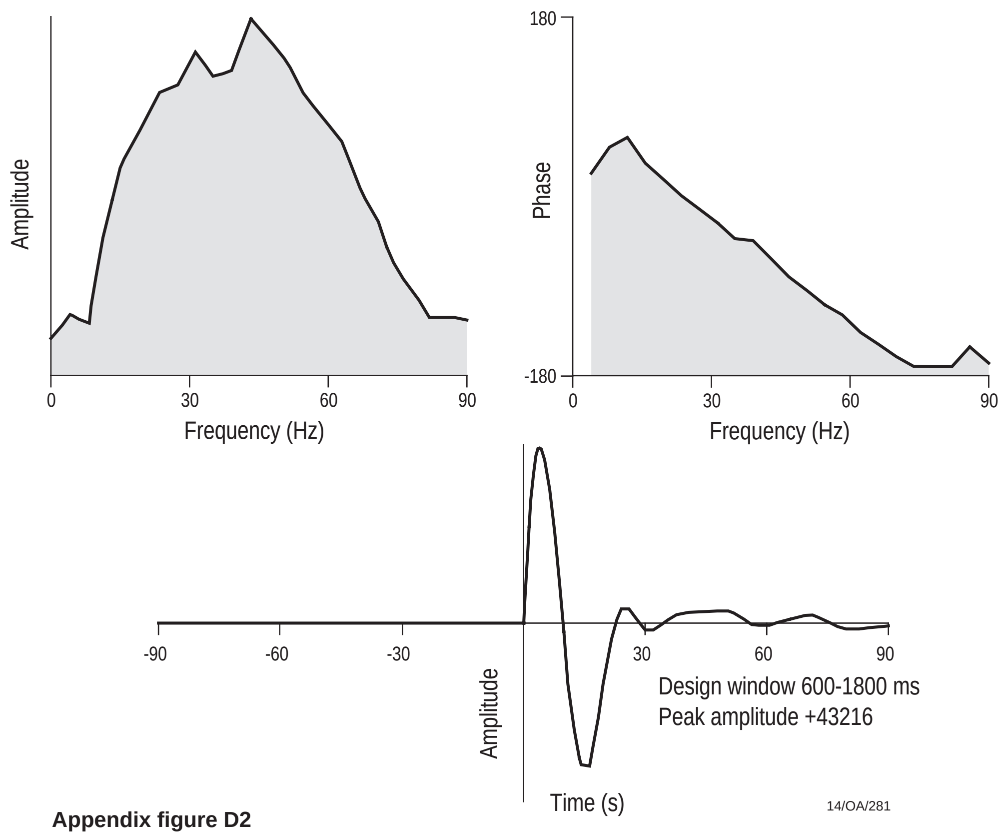


Appendix figure D1

KALYPTEA 1



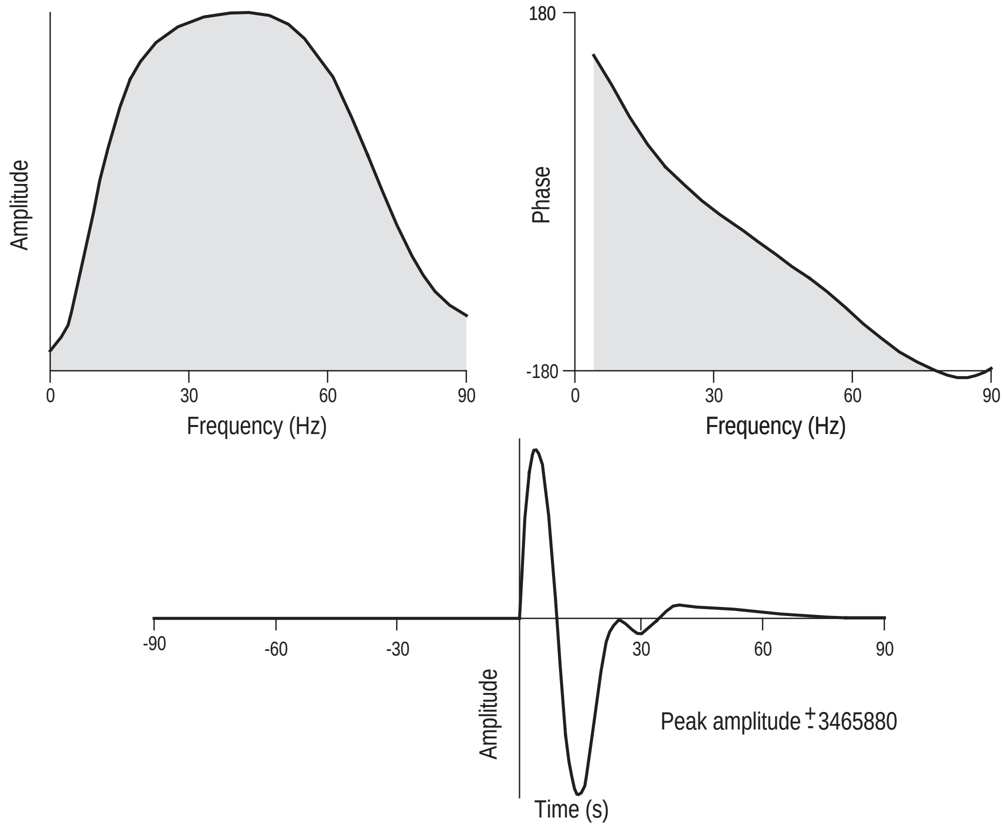
DELTA 1



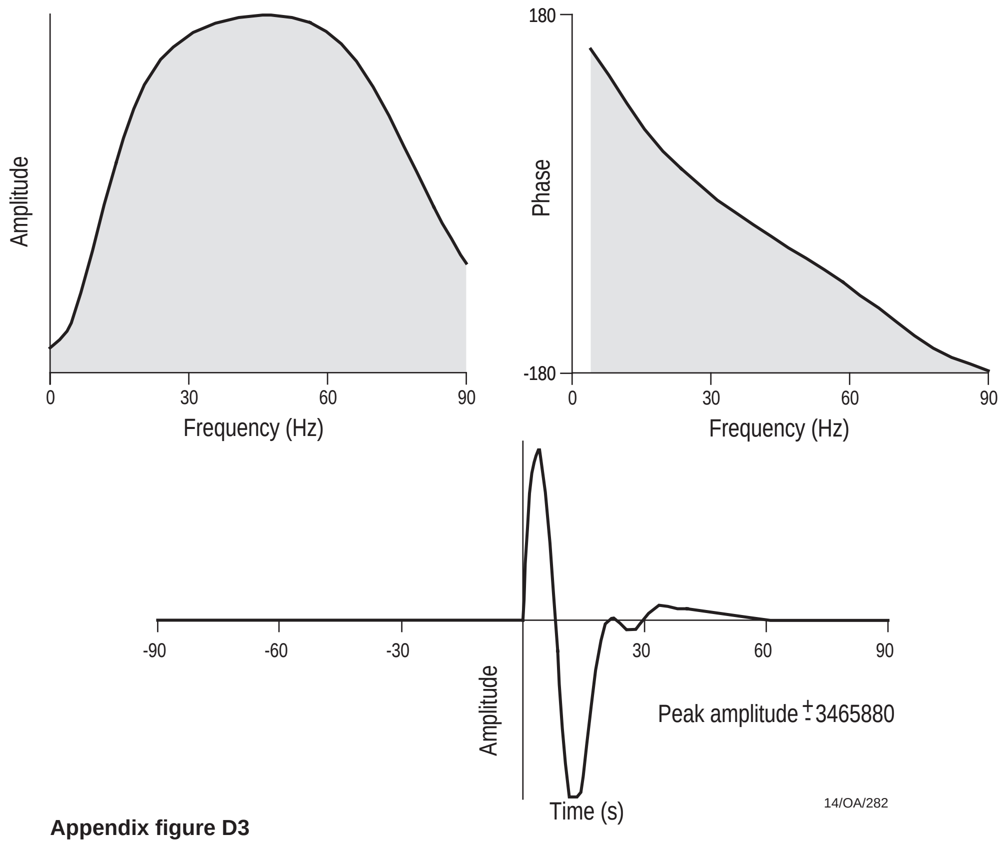
14/OA/281

Appendix figure D2

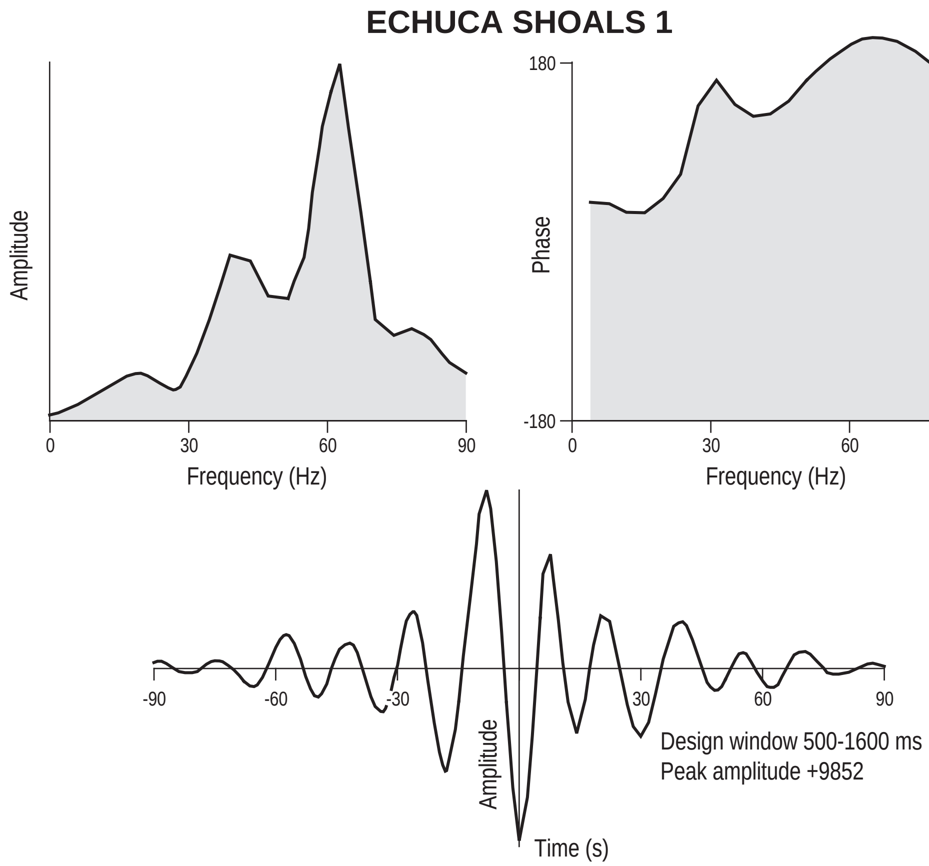
MINIMUM RICKER 35 Hz

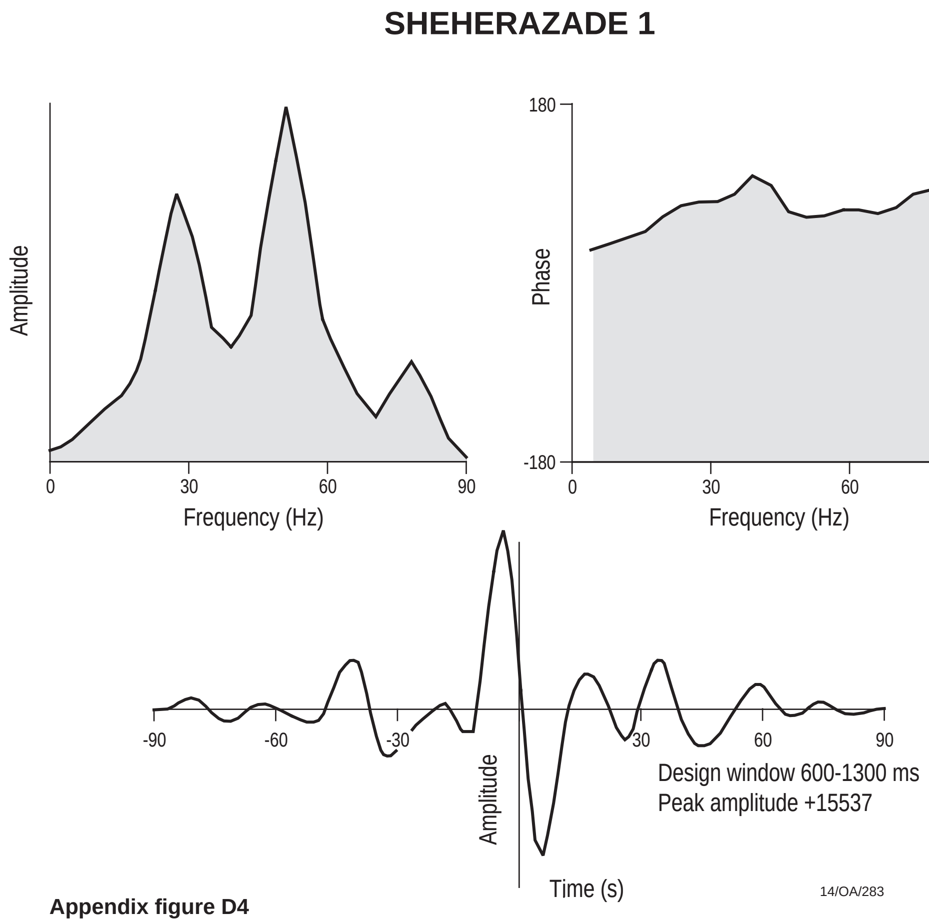


MINIMUM RICKER 40 Hz

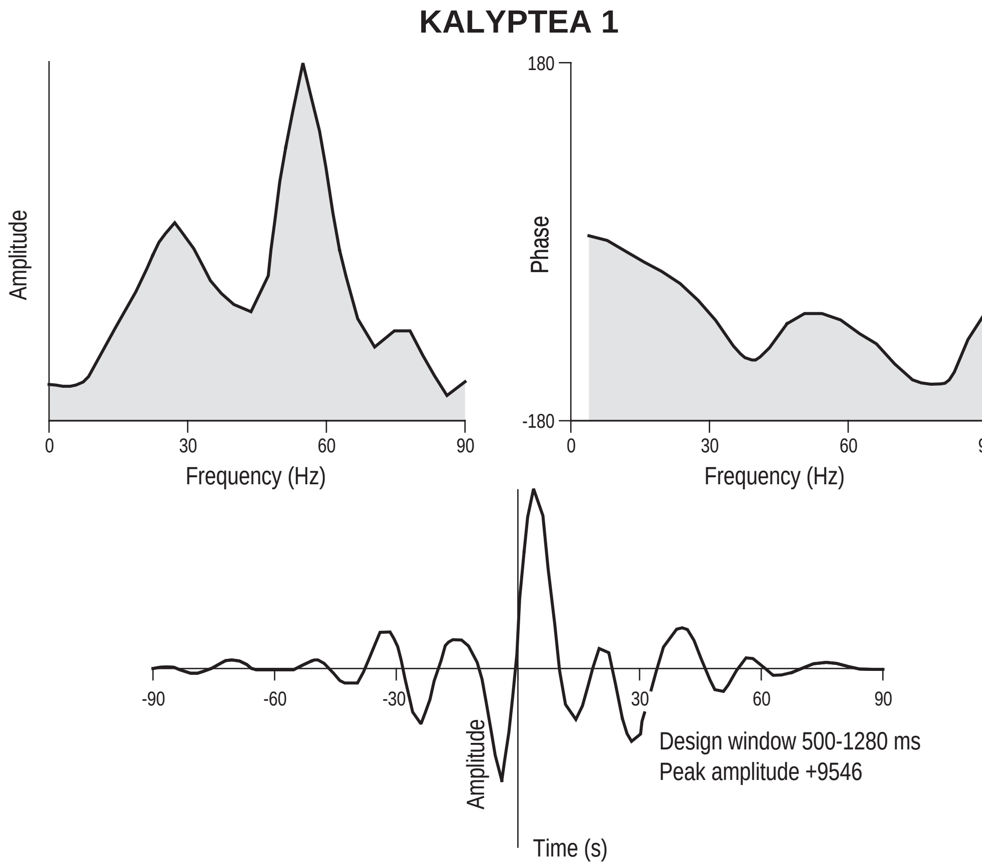


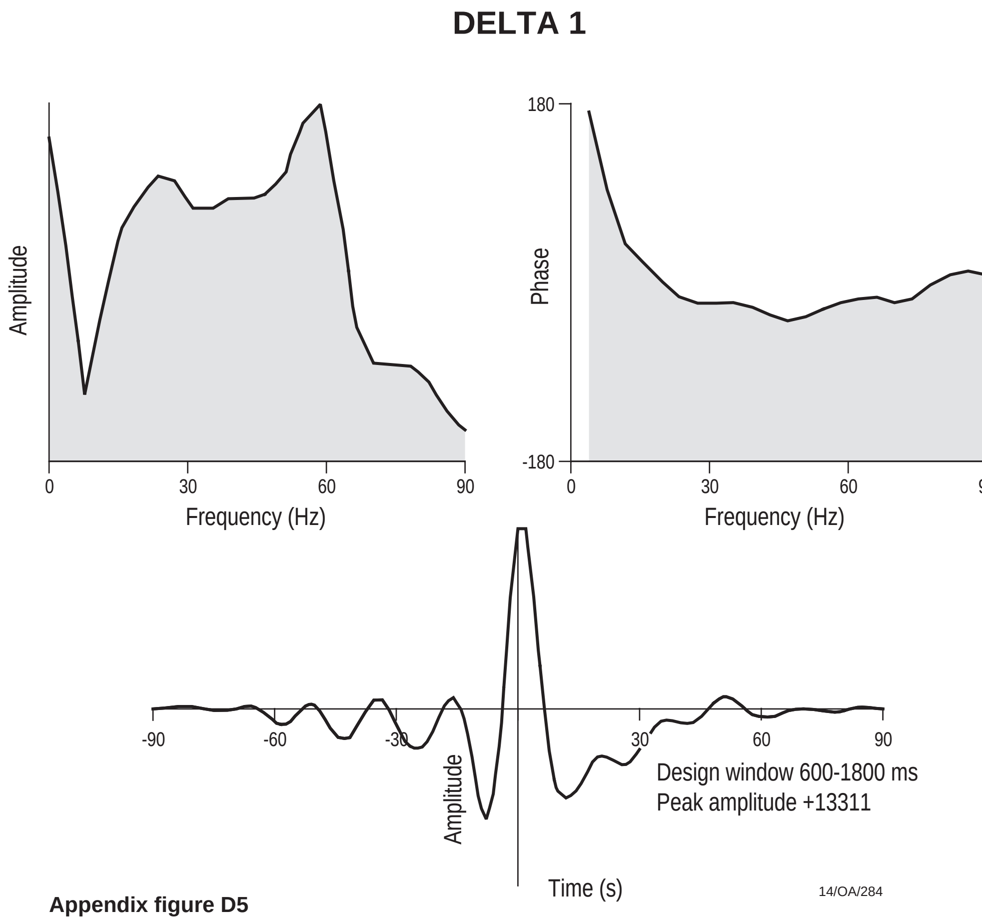
Appendix figure D3



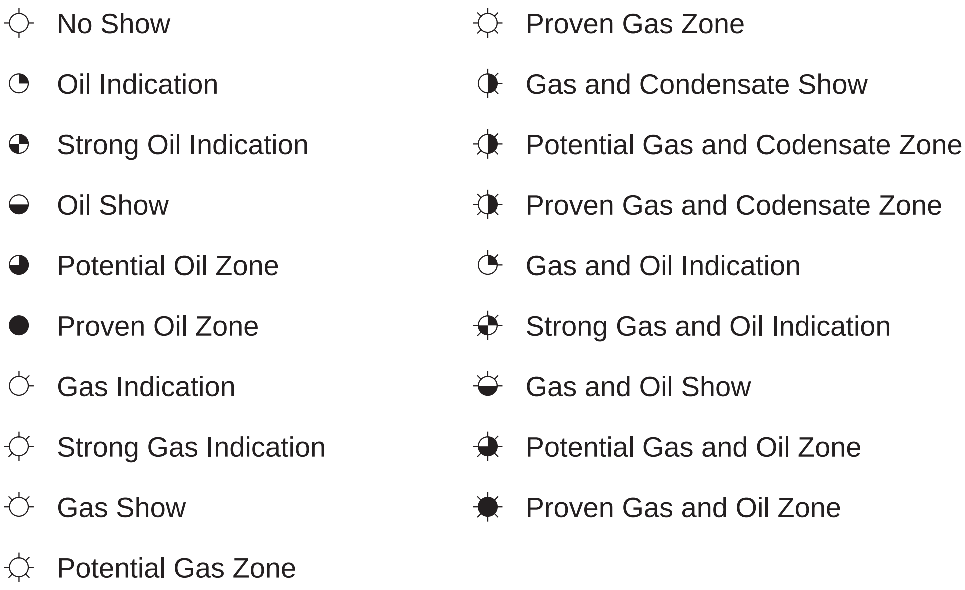


Appendix figure D4





Appendix figure D5



Appendix figure E1 Key to well symbols used in figures and maps.