Australian Government

Department of Industry
Tourism and Resources

2007 RELEASE OF AUSTRALIAN OFFSHORE PETROLEUM EXPLORATION AREAS

AREAS W07-5 TO W07-7
CASWELL SUB-BASIN, BROWSE BASIN, WESTERN AUSTRALIA

SECTIONS

Australian Government

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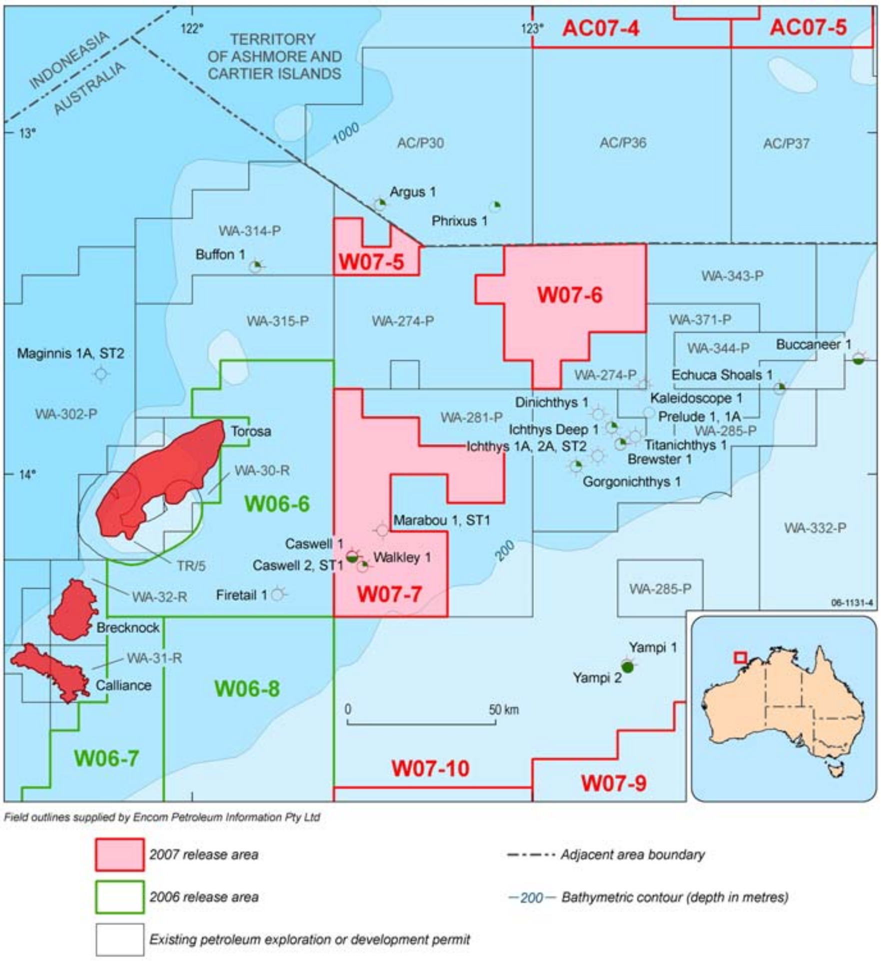
2007 RELEASE OF AUSTRALIAN OFFSHORE PETROLEUM EXPLORATION AREAS

SUMMARY

AREAS W07-5, W07-6 AND W07-7
CASWELL SUB-BASIN, BROWSE BASIN
WESTERN AUSTRALIA

BIDS CLOSE 18th OCTOBER 2007

- Proven major hydrocarbon province, and adjacent to giant gas fields; Scott Reef (Torosa), Brecknock, Brecknock South (Calliance), and Brewster area (Ichthys), where aggressive appraisal drilling programs are underway.
- Early–Middle Jurassic (Plover Formation) and Early Cretaceous (upper Vulcan, Echuca Shoals) source rocks.
- Good quality Early–Middle Jurassic (Plover Formation) reservoir.
- Tilted Permo-Triassic to Jurassic horst blocks with Early Cretaceous seal.
- Water depths between 200 and 500 m.
- Special Notices apply, refer to Guidance Notes.



Field outlines supplied by Encom Petroleum Information Pty Ltd

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2007 RELEASE OF AUSTRALIAN OFFSHORE PETROLEUM EXPLORATION AREAS

LOCATION

AREAS W07-5, W07-6 AND W07-7
CASWELL SUB-BASIN, BROWSE BASIN
WESTERN AUSTRALIA

BIDS CLOSE 18th OCTOBER 2007

Areas W07-5, W07-6 and W07-7 are located in the Caswell Sub-basin of the Browse Basin, 250–300 km off the northwest coast of Western Australia (**Figure 1**). The release areas lie adjacent to current offshore petroleum exploration permits and, are situated between and to the north of, the giant gas accumulations at Scott Reef (Torosa), Brecknock, Brecknock South (Calliance), and Brewster (Ichthys).

Area W07-5 comprises 6 graticular blocks or parts thereof (approximately 375 km^2), and water depths range from 460 m in the south to 590 m in the north.

Area W07-6 comprises 25 graticular blocks (approximately 1695 km^2), and water depths range from 300 m in the southeast to 430 m in the northwest.

Area W07-7 comprises 28 graticular blocks (approximately 2325 km^2), and water depths range from 174 m in the south to 455 m in the north.

GRATICULAR BLOCK LISTINGS AND MAPS

W07-5
Caswell Sub-basin, Browse Basin, Western Australia

Map Sheet SD 51 (Brunswick Bay)

1110	1112 part	1113 part	1182	1183	1184

Assessed to contain 6 blocks (includes 4 full blocks and 2 part blocks)

W07-6
Caswell Sub-basin, Browse, Basin, Western Australia

Map Sheet SD 51 (Brunswick Bay)

1116 part	1117 part	1118 part	1119 part	1120 part	1188
1189	1190	1191	1192	1259	1260
1261	1262	1263	1264	1332	1333
1334	1335	1336	1404	1405	1406
1477					

Assessed to contain 25 blocks (includes 20 full blocks and 5 part blocks)

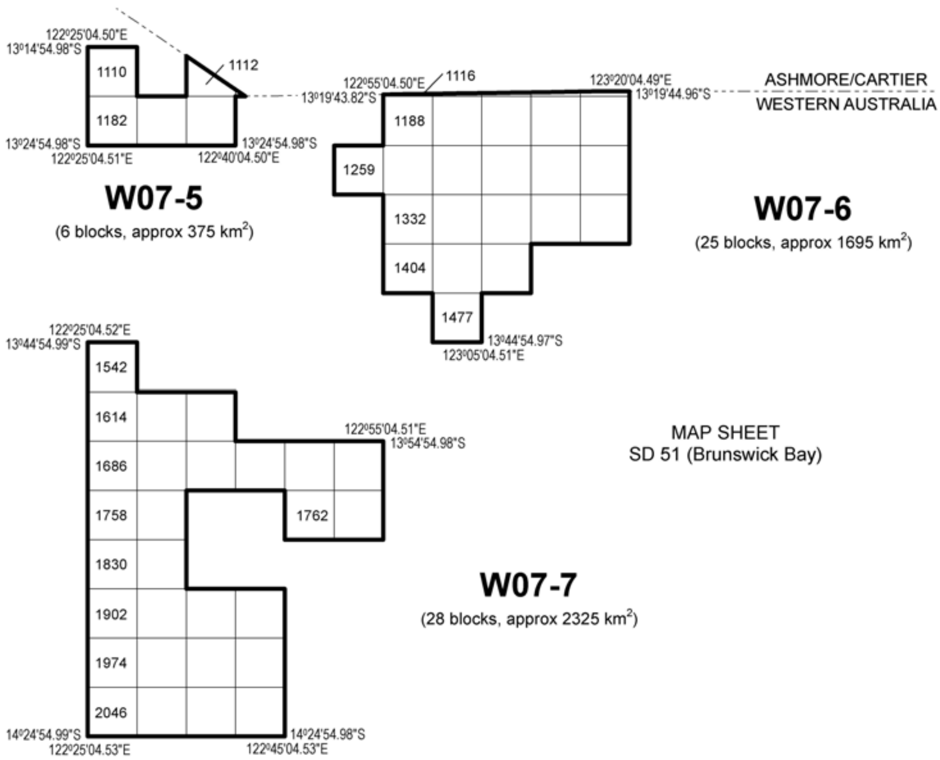
W07-7
Caswell Sub-basin, Browse, Basin, Western Australia

Map Sheet SD 51 (Brunswick Bay)

1542	1614	1615	1616	1686	1687
1688	1689	1690	1691	1758	1759
1762	1763	1830	1831	1902	1903
1904	1905	1974	1975	1976	1977
2046	2047	2048	2049		

Assessed to contain 28 full blocks

2007 Release Areas
Caswell Sub-basin, Browse Basin
Western Australia



Grid coordinates on this map are presented with reference to the Geocentric Datum of Australia (GDA94). Permit areas are based on the same grid, Australian Geodetic Datum (AGD66), that has defined areas since the Petroleum (Submerged Lands) Act was proclaimed in 1967. However, with the adoption of GDA94, the gridlines are no longer referred to in whole multiples of 5 minutes as they were under AGD66.

ASPD 6118-8

BROWSE BASIN GEOLOGY

REGIONAL GEOLOGY

The Browse Basin is a northeast–southwest-trending, Palaeozoic to Cenozoic depocentre situated entirely offshore in the Timor Sea region of Australia's North West Shelf (**Figure 2**). It covers an area of approximately 140,000 km^2 and contains in excess of 15 km of Palaeozoic, Mesozoic and Cenozoic sedimentary section (Struckmeyer et al, 1998). It hosts significant, but as yet undeveloped reserves of gas and condensate. Oil discoveries are focussed on the Yampi Shelf (ie Cornea area and Gwydion), although oil was discovered at Caswell 2 in the central Caswell Sub-basin.

The basin is one of a series of northwest-trending extensional basins that formed part of the Westralian Superbasin underlying the North West Shelf region (Bradshaw et al, 1988; Willis, 1988). Struckmeyer et al (1998) divided the Browse Basin into three major sub-basins; Caswell, Barcoo and Seringapatam. The basin is flanked to the west by the Scott Plateau, and the eastern and southeastern elements of the basin are the Yampi and Leveque shelves (Maung et al, 1994; Struckmeyer et al, 1998). The basin is contiguous with the Rowley Sub-basin of the Roebuck Basin to the southwest, and the Vulcan Sub-basin and Ashmore Platform of the Bonaparte Basin to the northeast (**Figure 2**).

Basin evolution and tectonic development

The Browse Basin has experienced a multi-stage structural history with six major phases of basin development (Struckmeyer et al, 1998):

1. Late Carboniferous to Early Permian extension.
2. Late Permian to Triassic thermal subsidence.
3. Late Triassic to Early Jurassic inversion.
4. Early to Middle Jurassic extension.
5. Late Jurassic to Cenozoic thermal subsidence.
6. Middle to Late Miocene inversion.

Since no formal lithostratigraphy has been established for the basin, formation-equivalent names from the Vulcan Sub-basin (Bonaparte Basin) to the north have been adopted by Blevin et al (1988a) and Struckmeyer et al (1998) and are used in this review (**Figure 3**).

The basin was initiated as a series of intracratonic extensional half graben during the Late Carboniferous to Early Permian (Symonds et al, 1994). Further to the west this extensional event is thought to have led to breakup and separation of Sibumasu from northwest Australia in the Early Permian (Metcalfe, 1990). The upper-crustal faulting resulted in a characteristic half-graben geometry with large-scale normal faults compartmentalising the basin into distinct sub-basins. Structures resulting from the Late Palaeozoic extensional event controlled the location of subsequent reactivation events and the distribution and nature of the sedimentary fill (Struckmeyer et al, 1998).

The Carboniferous section is dominated by fluvio-deltaic sediments, while the Early Permian sediments (mainly limestones and shales) were deposited in a marine environment. The Late Permian section consists of sandstone grading into shale and limestone. The oldest Triassic rocks intersected in the Browse Basin are marine claystones, siltstones and volcaniclastic sediments (eg, Echuca Shoals 1) deposited during a regional Early Triassic marine transgression. Overlying Triassic rocks include fluvial and marginal to shallow-marine sandstones, limestones and shales.

The Permo-Triassic sag phase was terminated by compressional reactivation in the Late Triassic to Early Jurassic, resulting in partial inversion of Palaeozoic half graben and the formation of large-scale anticlinal and synclinal features within the hanging walls. This event is marked by a regional unconformity that is correlated with the Fitzroy Movement in the Canning and Bonaparte basins (Etheridge and O'Brien, 1994). The arcuate Buffon–Scott Reef–Brecknock anticlinal trend (**Figure 2**) developed at this time.

The Early to Middle Jurassic extensional phase resulted in widespread small-scale faulting and the collapse of the Triassic anticlines. Extensional faulting was concentrated in the northeastern part of the Caswell Sub-basin (**Figure 4)** and along the adjacent outer margin of the Prudhoe Terrace (**Figure 2**: Struckmeyer et al, 1998). The Heywood Graben also formed during this period. The Early–Middle Jurassic syn-rift sediments (Plover Formation) comprise sandstones, mudstones and coals deposited in deltaic and coastal-plain settings. Widespread erosion and peneplanation occurred in the Callovian, associated with continental breakup and the initiation of sea-floor spreading in the Argo Abyssal Plain.

From the Late Jurassic to the Cenozoic, accommodation space was controlled by the interplay of thermal subsidence, minor reactivation events and eustasy. Late Jurassic interbedded sandstones and shales onlap and drape the pre-Callovian structures, and provide a thin, regional seal across much of the basin. An overall transgressive cycle began in the Early Cretaceous and peaked in the mid-Turonian, with open marine conditions established throughout the basin by the Aptian (**Figures 4** and **5**). Thick marine claystones deposited during this period (Echuca Shoals and Jamieson/Heywood formations), provide a regional seal and contain potential source rocks, with particularly high total organic carbon (TOC) values recorded at the maximum flooding surfaces of several Early Cretaceous transgressive cycles (**Figure 6**: Blevin et al, 1998b).

The Turonian–Cenozoic section records a major progradational (regressive) cycle in which the shelf edge migrated northwestwards to the outer limits of the Buffon–Scott Reef–Brecknock anticlinal trend. The development of submarine canyons on the Yampi Shelf and deposition of turbidite mounds within the central Caswell Sub-basin occurred during the middle to late Campanian (Benson et al, 2004). Inversion in the Late Miocene occurred as a result of the convergence of the Australia-India and Eurasia plates (Shuster et al, 1998).

HYDROCARBON RESERVES

The Browse Basin is one of Australia's most hydrocarbon-rich basins. It has estimated reserves of 13.6 MMbbls (2.2 GL) of oil, 25.9 TCF (733.0 BCM) of gas, 438.2 MMbbls (69.7 GL) of LPG and 543.4 MMbbls (86.4 GL) of condensate as at January 2005 (Geoscience Australia, 2004). This represents more than half of Australia's total hydrocarbon production. The most significant hydrocarbon fields of the Browse Basin occur in the Caswell Sub-basin;

- Scott Reef (Torosa) 11.5 TCF gas, 121 MMbbls condensate (DOIR, 2005),
- Brecknock 5.3 TCF gas, 109 MMbbls condensate (DOIR, 2005),
- Brecknock South (Calliance) 4.0 TCF gas, 87 MMbbls condensate (DOIR, 2005),
- Brewster area, Ichthys 9.5 TCF gas, 312 MMbbls condensate (INPEX, 2006), and
- Crux 1.3 TCF gas, 48 MMbbls condensate (Nexus investor update, March 2006).

During late 2006–07 several appraisal wells were drilled; Brecknock 3, Torosa 1, 2 and 3, and Prelude 1, 1A. Brecknock 3 reached a total depth (TD) of 3,948 m, to appraise the Early to Middle Jurassic Plover Formation reservoir. It intersected a 48.5 m gross gas column. A second hydrocarbon bearing zone was intersected in the Late Cretaceous overburden with an 8.7 m gross gas column (Woodside investor update, November 2006). Torosa 3 reached TD in November 2006, but details have not been released by the operator (Woodside) at the time of publication, and Torosa 2 is currently drilling (January 2007). Prelude 1 was terminated due to a severed drill string at 1385 m, and a follow-up well, Prelude 1A, is currently being drilled (January 2007).

Browse Basin Initial Reserves

Field	Liquids mmbbls	Gas tcf	Gas mmboe	Date	Source
Argus	6.80	0.60	102.00	Aug-04	DPIFM
Brecknock	109.44	5.30	901.01	Dec-05	DoIR
Calliance	86.80	3.97	674.91	Dec-05	DoIR
Crux	38.9	1.4	238.0	Oct-04	DPIFM
Ichthys	312.0	9.5	1614.9	Dec-05	DoIR
Torosa	121.0	11.5	1955.0	Dec-05	DoIR

* All reserves are P_{50}
* Conversion factor for gas (bcf to mmboe) is 0.17
DoIR - Department of Industry and Resources, Western Australia.
DPIFM - Department of Primary Industry, Fisheries and Mines, Northern Territory.

RELEASE AREA GEOLOGY

Areas W07-5 to W07-7 – Caswell Sub-basin

The Caswell Sub-basin is the northernmost major depocentre of the Browse Basin, containing up to 15 km of Palaeozoic to Cenozoic sediments (Struckmeyer et al, 1998). It is flanked to the east and southeast by the Prudhoe Terrace and Yampi Shelf (**Figure 2**).

The outer margin of the Caswell Sub-basin is marked by an arcuate Triassic structural high (Buffon–Scott Reef–Brecknock anticlinal trend). This outer high passes westward into the deep waters of the Scott Plateau, the inboard (eastern) portion of which is underlain by the Seringapatam Sub-basin.

EXPLORATION HISTORY

Browse Basin Exploration Overview

Five large undeveloped gas fields have been discovered in the Browse Basin; Scott Reef (Torosa), Brecknock, Brecknock South (Calliance), Brewster (Ichthys) and Crux, together with a number of other gas accumulations (Adele, Argus, Arquebus, Caspar, Echuca Shoals and Psepotus). Small oil accumulations have been discovered at Caswell 2 and Cornea 1; oil and gas accumulations were encountered at Gwydion 1, Cornea South 2, Focus 1 and Sparkle 1, and minor oil shows have been found in several other wells.

The first well drilled in the Browse Basin was Leveque 1 (1970), which was a stratigraphic test of the sedimentary succession on the Leveque Shelf. This was followed by the discovery of gas at Scott Reef 1 in 1971. Scott Reef 1 intersected a thick sequence of gas-bearing reservoirs within Early–Middle Jurassic (Plover Formation) sandstones, together with sandy dolostones of Late Triassic–Jurassic age on the southern culmination of a faulted anticline located on the Buffon–Scott Reef–Brecknock anticlinal trend. Gas flows of 278,000–515,000 m^3/day were recorded from drill stem tests (DSTs), and were accompanied by 49–54° API gravity condensate (Willis, 1988). Two appraisal wells (Scott Reef 2A in 1977, and North Scott Reef 1 in 1982) were drilled to further delineate the extent of the field (Bint, 1988). North Scott Reef 1 recorded a maximum gas flow rate of 1,275,000 m^3/day from a DST (Willis, 1988).

In 1979, Brecknock 1 tested a broad anticlinal feature 40 km southwest of Scott Reef. The well penetrated 68.3 m of net gas sand in Early to Middle Jurassic sediments, of similar age to the reservoir section at Scott Reef (Bint, 1988).

Other significant discoveries during the early 1980's include Brewster 1A (1980), Caswell 2 and Echuca Shoals 1 (both 1983). Late Jurassic to Early Cretaceous gas-bearing sands were interpreted in Brewster 1A. Caswell 2 encountered numerous minor oil shows and high gas readings within the Late Jurassic and Early Cretaceous sediments, and it recovered oil from a thin Late Cretaceous (Campanian) sandstone. Echuca Shoals 1 discovered gas in two separate reservoirs of Late Jurassic (Tithonian) to Early Cretaceous (Berriasian) age (Willis, 1988).

Between 1984 and 1994 exploration was focussed largely in the northern Caswell Sub-basin (Gryphaea 1, Asterias 1, Discorbis 1 and Kalyptea 1, ST1), and along the basin margin faults of the Leveque Shelf (Trochus 1, Arquebus 1 and Sheherazade 1) and Prudhoe Terrace (Copernicus 1 and Yampi 2). Many of the wells reported minor hydrocarbon shows from Late Jurassic or Early Cretaceous reservoirs (Maung et al, 1994). Definitive evidence of the oil generative potential of the basin was demonstrated by the Gwydion 1 oil and gas discovery in 1995, and the Cornea 1 oil discovery in 1997, both located on the Yampi Shelf.

Gwydion 1 discovered three gas-bearing zones and one oil/gas-bearing zone in Barremian to Albian shallow marine sandstones draped over a prominent basement high (Spry and Ward, 1997). The Cornea 1, 1B and 2 wells encountered a 25 m gas column overlying an 18 m oil column in the base Albian reservoir sequence (Ingram et al, 2000), and was the first potentially commercial oil discovery in what was previously considered to be a gas-prone basin (Stein et al, 1998). In 1998, Adele 1 discovered gas with oil shows in Middle Jurassic (Plover Formation) sands, and Psepotus 1 and Caspar 1A discovered small gas accumulations within Early Cretaceous sands on the Leveque Shelf and Yampi Shelf, respectively.

Drilling in 2000 resulted in the discovery of several major gas accumulations in the Browse Basin, as well as the extension of previous recognised gas provinces. Brecknock South 1, located on the Scott Reef–Brecknock-trend some 19 km south of Brecknock 1, intersected a 134 m gross gas column in good quality reservoir sandstones of the Middle Jurassic Plover Formation (King, 2001). To the north, on the same structural trend, Argus 1 encountered a gas column in excess of 240 m in Oxfordian sandstones (Keall and Smith, 2004). Significant gas accumulations were encountered in the central Caswell Sub-basin in 2000 with the drilling of Titanichthys 1, Gorgonichthys 1 and Dinichthys 1.

Crux 1 was drilled in 2000 in the northeastern part of the Heywood Graben, and encountered a 280 m gross gas column in the Late Triassic to Early Jurassic Nome Formation (Kaoru et al, 2004).

In 2001–2002, exploration of Early Cretaceous lowstand fans and ponded turbidite oil targets within the Caswell Sub-basin was unsuccessful (Carbine 1, Firetail 1 and Marabou 1). In 2002–2003 Maginnis 1, 1A tested the hydrocarbon potential of the deep-water Seringapatam Sub-basin, but no hydrocarbons were encountered.

Appraisal drilling of the Brewster (Ichthys) field was completed in 2003–04 (Ichthys 1, 1A, Ichthys 2, 2A, ST2 and Ichthys Deep 1). Gas is primarily reservoired within the Brewster Member of the upper Vulcan Formation and within the Plover Formation (Ban and Pitt, 2006). In addition, these authors report that some gas also occurs within Callovian sands, named as the Ichthys Formation, and in the basal Oxfordian sands of the lower Vulcan Formation. Exploration is continuing in this region with Prelude 1, 1A being drilled in December 2006–January 2007.

Evaluation of the gas accumulations along the Scott Reef–Brecknock anticlinal trend is continuing since the drilling of the appraisal wells Torosa 1, 2 and 3, Brecknock 2 and 3, and Calliance 1.

Appraisal drilling of the Crux field is continuing with the drilling of Crux 2 (December 2006–January 2007).

Relevant wells

Areas W07-5 to W07-7 – Caswell Sub-basin

Multiple wells, Caswell 1 (1978), Caswell 2, ST1, ST1 (1983), Walkley 1 (1993) and Marabou 1, ST1 (2001) have been drilled in Area W07-7. A number of wells have been drilled in permits adjacent to areas W07-5 (Argus 1, 2000) and W07-6 (Basset 1, 1A).

Caswell 1 (1978) targeted Jurassic sandstones in a northeast–southwest-trending anticlinal feature, but bottomed in Early Cretaceous claystones at 4,097 m due to drilling difficulties. The well encountered oil and gas shows within Albian sandstones in the depth range 3,606–3,611 m. Four sidewall cores within this section recovered claystones, siltstones and limestones with a sample of oil with an API gravity of 46° being extracted from one of these sidewall cores. Repeat formation tests (RFTs) confirmed over-pressuring in the Early Cretaceous claystones, but provided little information on the occurrence of hydrocarbons.

Caswell 2, ST1, ST1 (1983) was drilled to follow-up the shows encountered in Caswell 1 and to test Late Jurassic and Early–Middle Jurassic sandstones in a drape anticline. The well discovered a thin oil accumulation within Campanian silty sandstones at 3,264.7–3,268.7 m. A RFT fluid sample taken at 3,265.5 m in the first sidetrack recovered 0.8 L of oil with an API gravity of 47° and 21.2 CF gas. No significant hydrocarbons were recorded in the overlying clean Campanian sandstone between 3,009 and 3,221.5 m, but numerous minor oil shows and high gas readings were encountered below 3,680 m in claystones and low-porosity sandstones in the Early Cretaceous and Late–Middle Jurassic section. The well bottomed in Middle Jurassic sediments of the Plover Formation at 5,000 m.

Walkley 1 (1993) targeted two submarine fan sandstones of Campanian (primary objective) and Barremian age within a 4-way dip mounded structural/stratigraphic play. Caswell 1 and 2 were previously drilled on the flank of this structure. Walkley 1 intersected Campanian reservoir sands (Puffin Sandstone, 2,899–3,062 m) that had no significant hydrocarbon shows, and failed to encounter the deeper prognosed Barremian sands. High gas readings were recorded in Aptian radiolarite and peaked within the Barremian claystones (3,732 m to TD at 3,950 m).

Marabou 1, ST1 (2001) was drilled in the central part of the Caswell Sub-basin to test late Campanian ponded turbidites similar to those tested at Caswell°2. Log interpretation suggested a 22 m gas column within a small four-way dip closure (Benson et al, 2004). These authors concluded that the probable occurrence of trapped hydrocarbons at Marabou 1 indicates that the vertical migration from the Early Cretaceous (Echuca Shoals Formation) source rocks is probably effective, but that up-dip seal is lacking at this location (Benson et al, 2004).

Firetail 1 (2002) was drilled immediately to the west of Area W07-7. The well targeted Campanian turbidite sands of the Puffin Sandstone in a four-way dip closure, similar to that tested at Caswell 1 and 2, Walkley 1 and Marabou 1 (Woodside Petroleum, 2002). The well was plugged and abandoned as a dry hole (Benson et al, 2004).

Argus 1 (2000) encountered a gas column in excess of 240 m in Late Jurassic (Oxfordian) sediments, and oil was recovered from the drilling mud and sidewall cores of Paleocene carbonates. The Argus structure consists of a complex east–west-oriented horst that has undergone several phases of faulting, and the source of the gas is interpreted to be deeply buried Triassic and Jurassic sediments. The oil is interpreted to be sourced from Late Jurassic–Early Cretaceous marine shales, and contained in micro-porosity, possibly linked by a network of fractures that developed over the crest of the deeper Argus structure (Keall and Smith, 2004).

Bassett 1, 1A (1978) tested Cretaceous (Maastrichtian–Campanian) sands on a seismically defined faulted anticline in the Central Browse Basin, but only minor amounts of gas were encountered, and it was subsequently plugged and abandoned.

Relevant Wells Listing – Areas W07-5 to W07-7, Caswell Sub-basin

Well	Operator	Year	Total Depth (m)	Hydrocarbons
Bassett 1	Woodside Petroleum	1978	949	No shows
Bassett 1A	Woodside Petroleum	1978	2706	Gas indications
Brecknock 1	Woodside Petroleum Development Pty Ltd	1979	4300	Potential oil zone, oil indications
Brecknock 2	Woodside Energy Ltd	2005	3872	Proven gas zone
Brecknock 3	Woodside Energy Ltd	2006	N/A	Gas indications
Brecknock South 1	Woodside Energy Ltd	2000	4008	Proven gas zone, oil indications
Calliance 1	Woodside Energy Ltd	2005	4178	Proven gas zone
Caswell 1	Woodside Petroleum Development Pty Ltd	1978	4097	Oil recovered, gas indication
Caswell 2	Woodside Offshore Petroleum Pty Ltd	1983	3396	Oil recovered, gas indication
Caswell 2 ST1	Woodside Offshore Petroleum Pty. Ltd.	1983	4900	Oil recovered, gas indication
Caswell 2 ST1 ST1	Woodside Offshore Petroleum Pty. Ltd.	1983	5000	Oil & gas indications
Firetail 1	Woodside Energy Ltd	2002	3355	Gas indications
Gorgonichthys 1	Inpex Browse, Ltd.	2000	4767	Proven gas zone, oil indications
Ichthys 1A	Inpex Browse Ltd	2003	4826	Proven gas zone, oil indications
Ichthys 2A ST2	Inpex Browse Ltd	2003	4752	Potential oil zone, oil indications
Ichthys Deep 1	Inpex Browse Ltd	2003	4956	Potential oil zone, oil indications
Kaleidoscope 1	Coveyork Pty Ltd	2001	4437	Gas indications
Maginnis 1A ST2	BHP Billiton Petroleum Pty. Ltd.	2003	4642.5	No shows
Marabou 1	Santos Ltd	2001	2863	No shows
Marabou 1 ST1	Santos Limited	2001	3729	No shows
Phrixus 1	BHP Petroleum Pty. Ltd.	2001	3874	Oil indication
Toroas 1	Woodside Energy Ltd	2006	N/A	Not available
Toroas 2	Woodside Energy Ltd	2006		Drilling at time of publication
Walkley 1	Ampolex Limited	1993	3950	Oil & gas indications

PETROLEUM POTENTIAL

Source rocks

A comprehensive assessment of the source rock potential of the Browse Basin was undertaken by Boreham et al (1997), and the results summarised by Blevin et al (1998a, b). These studies recognised organic-rich rocks with fair to moderate oil potential at multiple stratigraphic levels within the Permian–Early Cretaceous section, and some local, thin, high-quality coals and pro-delta shales occur within the Early–Middle Jurassic, fluvio-deltaic Plover Formation (**Figure 6).**

Blevin et al (1998b) noted that although many potential source units within this succession have liquids potential (HI values of >200 mg hydrocarbons/gTOC), they contain less than 2 % TOC **(Figure 6**). At these low-to-moderate TOC levels, any generated oil may remain within the source rock (ie, not be expelled from the source rock) and may be subsequently cracked to gas at higher maturities.

Figure 7 shows generalised distribution maps of Late Jurassic (Vulcan Formation) and Early Cretaceous (Echuca Shoals and Jamieson formations) potential source units in the basin. The Late Jurassic section is generally thin throughout the Browse Basin, with major sediment thickening restricted to the Heywood Graben in the northeast, where restricted marine source facies are likely to be best developed. Localised thickening of Late Jurassic sediments also occurs on the Leveque Shelf and Prudhoe Terrace (**Figure 7a**), but here the section is dominated by deltaic facies with poorer quality terrigenous organic matter. Thick sections of Early Cretaceous sediments occur within both the Caswell and Barcoo sub-basins (**Figure 7b, 7c** and **7d)**, and contain mixed marine and terrestrial organic matter with moderate to good source potential. However, available pyrolysis data suggests that these sediments have better liquid potential within the Caswell Sub-basin (HI=150–350 mg hydrocarbons/gTOC) than the Barcoo Sub-basin (HI=100–250 mg hydrocarbons/gTOC; Kennard et al, 2004, table 1).

Potential source facies also occur within the thick succession of Early–Middle Jurassic sediments (Plover Formation) that extend throughout the basin and reaches a maximum penetrated thickness within the Barcoo Sub-basin (920 m in Barcoo 1). This section is dominated by fluvio-deltaic facies, including pro-delta shales and coastal plain shaly coals that have significant source potential (Blevin et al, 1998a). However hydrocarbons generated from this section are likely to be dominated by gas or gas rather than oil.

Reservoirs and seals

Reservoir facies are best developed within the fluvio-deltaic Early–Middle Jurassic Plover Formation, and submarine fans and ponded turbidite mounds of Berriasian, Barremian, Campanian and Maastrichtian age. Late Jurassic (Vulcan Formation) and Early Cretaceous (Echuca Shoals Formation) claystones provide regional seals throughout much of the basin. Potential intraformational shale seals occur within the Early–Middle Jurassic Plover Formation (Blevin et al, 1998a), and Late Cretaceous claystones of the Puffin (or Turnstone) Formation provide potential seals for Campanian–Maastrichtian ponded turbidites and unconfined fans (Benson et al, 2004).

Petroleum systems

Geochemical analysis of oils, oil stains, fluid inclusion oils, condensates, gases and source rocks from the Browse Basin have been undertaken by AGSO and Geotech (2000), Boreham et al (1997, 2001), Blevin et al (1998a, b), Edwards et al (2000, 2004, 2006), Edwards and Zumberge (2005) and Volk et al (2005). **Figure 8** demonstrates that the stable ^{13}C isotopic data of gases and oils can be used to discriminate the different sources of hydrocarbons in this basin. These isotopic datasets, together with molecular analyses, provide evidence that at least three hydrocarbon families/petroleum systems are present in the Caswell Sub-basin (Kennard et al, 2004).

1. An outer sub-basin, relatively dry gas-prone system sourced from mixed terrestrial and marine organic matter (Torosa, Brecknock and Calliance fields: condensate/gas ratios of 10–20 bbls/MMscf). The Argus gas accumulation (CGR <10 bbls/MMscf; Keall and Smith, 2004) probably represents a northern extension of this system (Kennard et al, 2004). Edwards et al (2004) proposed that the Early–Middle Jurassic Plover Formation was the most likely source for these gases, whereas a Permo-Triassic source has been modelled by Belopolsky et al (2006).

2. A central sub-basin, wet gas-prone system, the source(s) of which has yet to be established (Brewster/Ichthys field; condensate/gas ratios of 60 bbls/MMscf). These accumulations could have been charged from either underlying Jurassic (Plover or Vulcan formations) or overlying Early Cretaceous (Echuca Shoals Formation) source rocks, but the lack of an oil leg in these wells tends to suggest that they did not receive a significant charge from the oil-prone Early Cretaceous petroleum system. From the similarity of the $\delta^{13}C$ isotopic data of the gas/condensates recovered from the Brewster-reservoir in the Ichthys field with those of Bayu and Undan in the northern Bonaparte Basin, a Jurassic source is implied, with the possibility of a contribution from Late Jurassic Vulcan Formation source rocks.

3. An inner sub-basin oil (plus gas)-prone petroleum system sourced from predominantly marine algal and bacterial organic matter within the Early Cretaceous sediments of the Echuca Shoals Formation (Cornea and Gwydion fields, Caswell 2 oil accumulation). Blevin et al (1998a) defined this system as the Westralian (W3) Petroleum System. The Cornea and Gwydion oils and gases are biodegraded to differing extents.

In the Heywood Graben, the Crux gas discovery is interpreted to be sourced from mixed terrestrial and marine organic matter contained within Early–Middle Jurassic source rocks (Edwards et al, 2004). However, the gas is drier than the gases from the Ichthys field (Nippon Oil Exploration, 2001; Kaoru et al, 2004). From biomarker data (George et al, 2000), and the $\delta^{13}C$ isotopic evidence presented in **Figure 8**, the samples of gas and condensate recovered from Crux 1 represent another hydrocarbon family within the Browse Basin.

Timing of generation and expulsion

Hydrocarbon expulsion modelling (Kennard et al, 2004) suggests multiple effective source units for gas expulsion in the basin, whereas effective oil-charge is largely restricted to the Heywood Graben in the northeast, the central and southern Caswell Sub-basin, and possibly the rift section in the deep-water Seringapatam Sub-basin.

Significant quantities of oil are modelled to have been expelled from Jurassic sediments (Plover and lower Vulcan formations) in the Heywood Graben during the Cenozoic and Neogene, respectively. These charges are likely to have sourced the thick palaeo-oil columns interpreted at Heywood 1 and Crux 1 on the basis of fluid inclusion analysis (Eadington and Middleton, 2000; Brincat et al, 2004). Lesser quantities of oil are modelled to have been expelled from the Vulcan Formation in the central and southern Caswell Sub-basin. Indeed an investigation of the fluid inclusions in the sandstone reservoirs of the Browse Basin gas accumulations has shown that the hydrocarbon charge consisted of an early oil charge, filling only the crestal parts of the structures before being displaced or absorbed by gas (Brincat, 2006). Only relatively minor gas expulsion, but no oil, is predicted to occur in the Barcoo Sub-basin where source facies are generally leaner (Kennard et al, 2004).

Recent hydrocarbon generation and expulsion studies of Early Cretaceous (Echuca Shoals and Jamieson formations) source rocks using Small Angle Neutron Scattering (SANS) confirms the existence of potential oil and gas-prone source rocks that are sufficiently thermally mature for generation to occur, but which show little or no evidence of expulsion and effective regional charge (Radlinski et al, 2004).

Similarly, fluid inclusion analysis provides no evidence of an effective regional oil charge to Cretaceous reservoirs in the Caswell Sub-basin (Brincat and Kennard, 2004; Brincat et al, 2004). However, as the organic-rich sediments within this succession occur as thin transgressive sheets deposited in response to fluctuating sea level on a gently inclined ramp margin, detailed understanding of the local expulsion-migration history may require higher resolution (systems tract level) sequence stratigraphic models. Effective oil charge from parts of the Echuca Shoals Formation is confirmed by geochemical analysis of the Cornea, Gwydion 1 and Caswell 2 accumulations, and is postulated as the probable source of the inferred gas accumulation at Marabou 1 (Benson et al, 2004).

Play types

The major play types within the basin are Late Triassic faulted anticlines, Jurassic horsts/tilted fault blocks and associated drape anticlines, Early Cretaceous drape of erosional basement highs on the Yampi and Leveque shelves, and Late Cretaceous basin floor fans and ponded turbidite stratigraphic traps (**Figures 4, 5** and **9**). To date, the prominent Late Cenozoic fault-reactivation anticlines along the basinward margin of the Leveque Shelf (eg, Trochus, Lynher, Lombardina and Sheherazade structures) have proved unsuccessful, with the possible exception of the inferred hydrocarbon column at Arquebus 1 (Haston and Farrelly, 1993).

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FIGURES

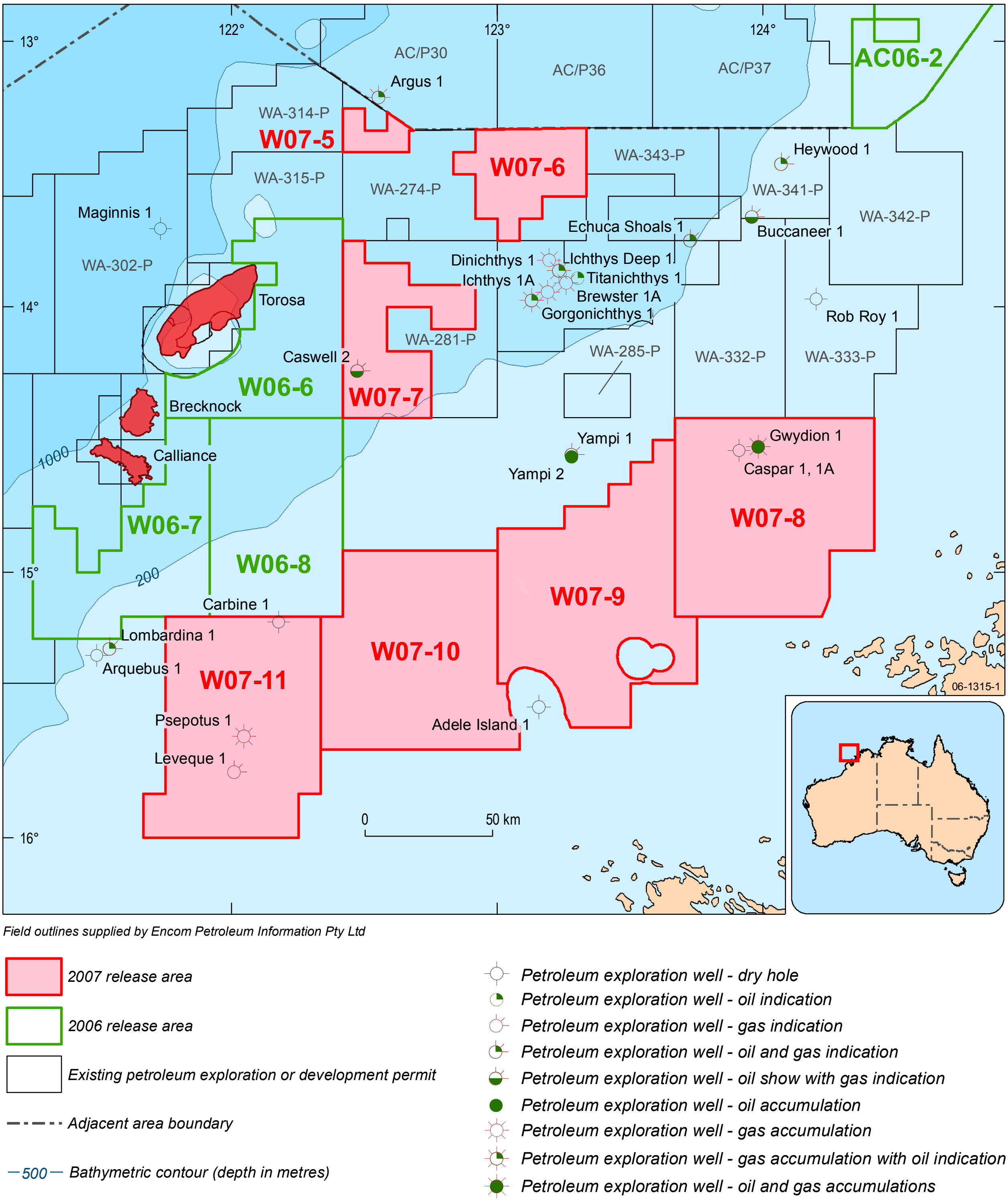

Figure 1. Location map of areas W07-5 to W07-11 in the Browse Basin showing existing petroleum title areas, and known petroleum fields and discoveries.

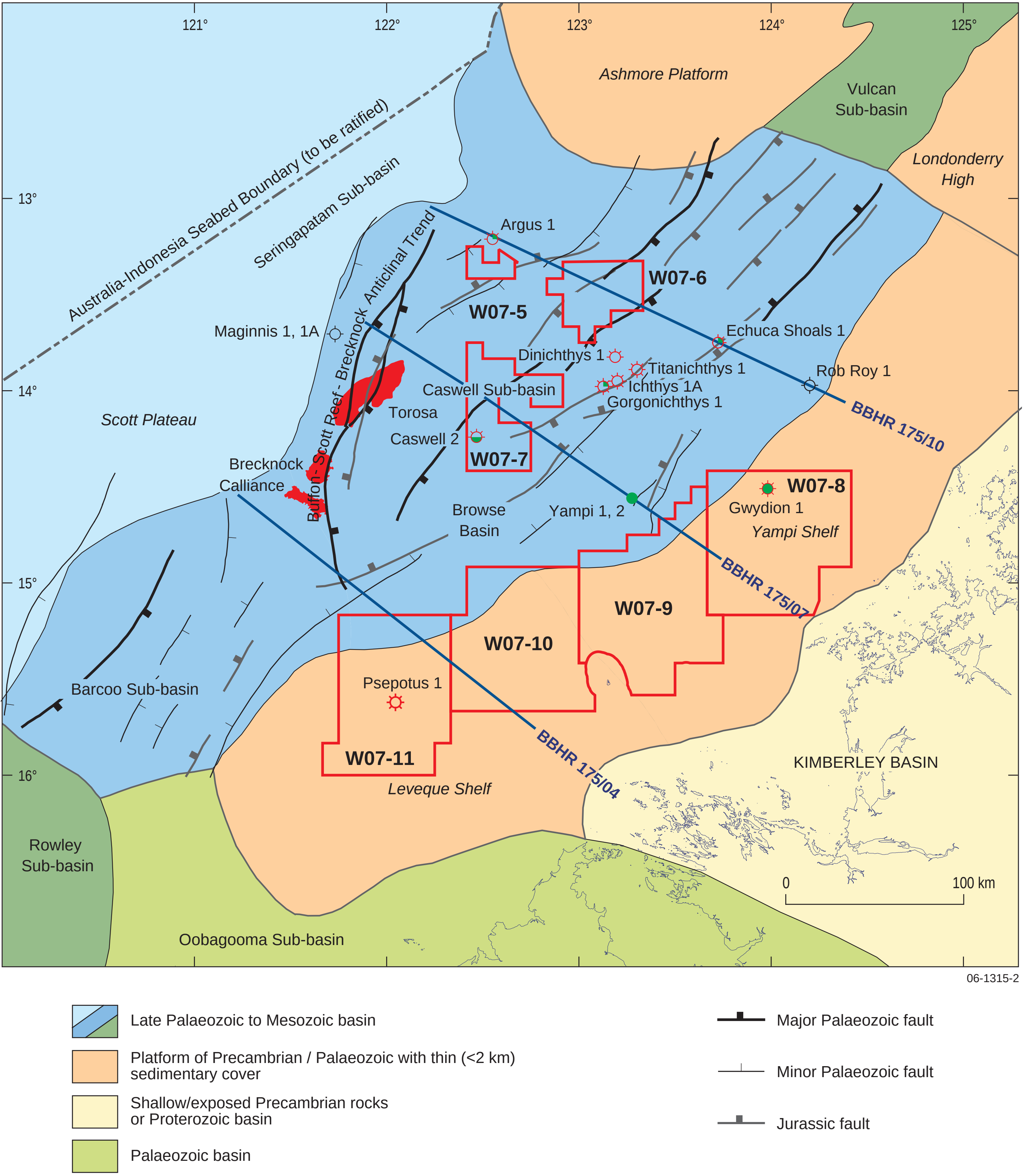

Figure 2. Regional setting of the Browse Basin (after Struckmeyer et al, 1998), also showing the location of seismic lines BBHR 175/10, BBHR 175/07 and BBHR 175/04.

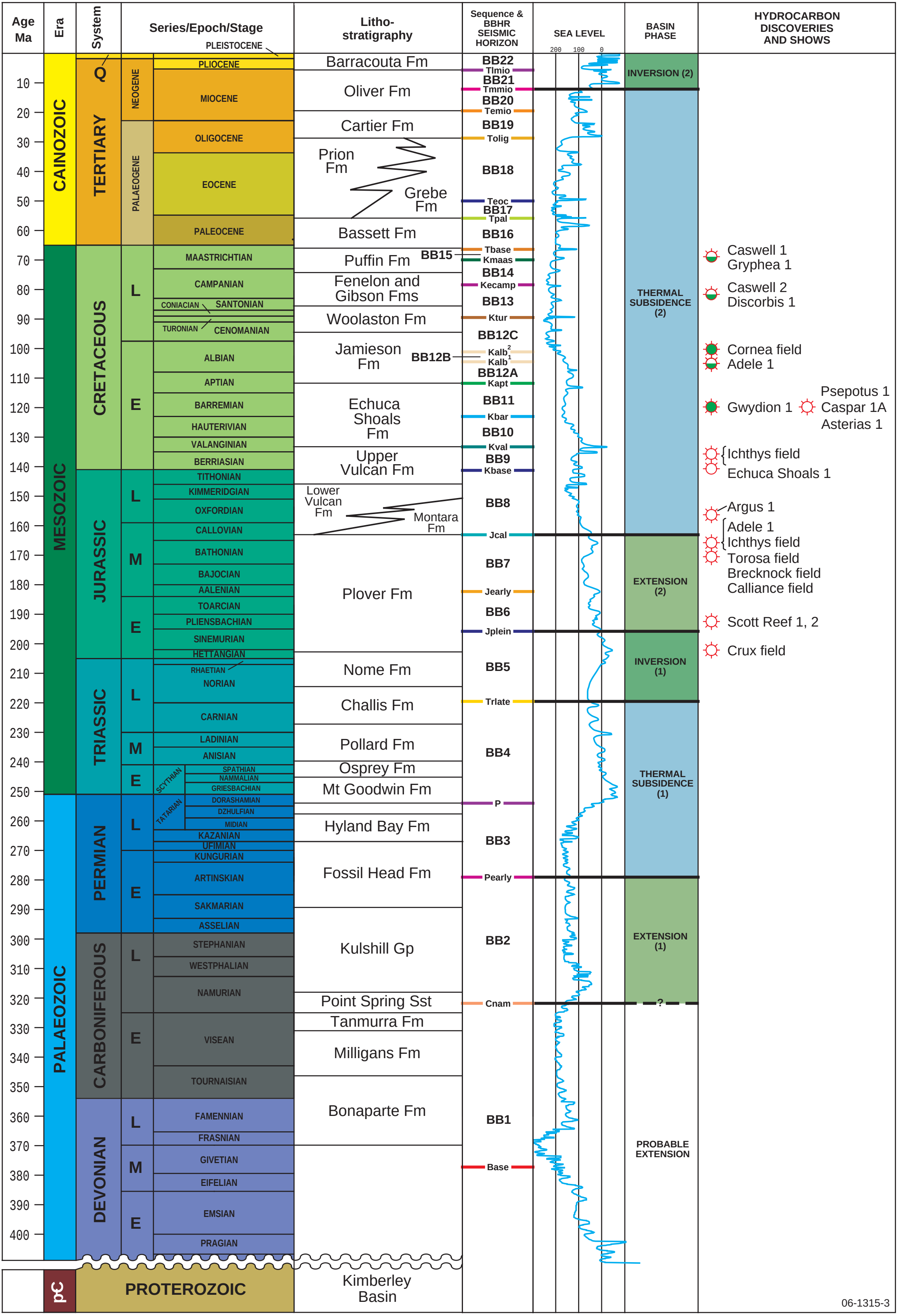

Figure 3. Tectonostratigraphic summary and hydrocarbon discoveries for the Browse Basin (after Blevin et al, 1998a; Struckmeyer et al, 1998).

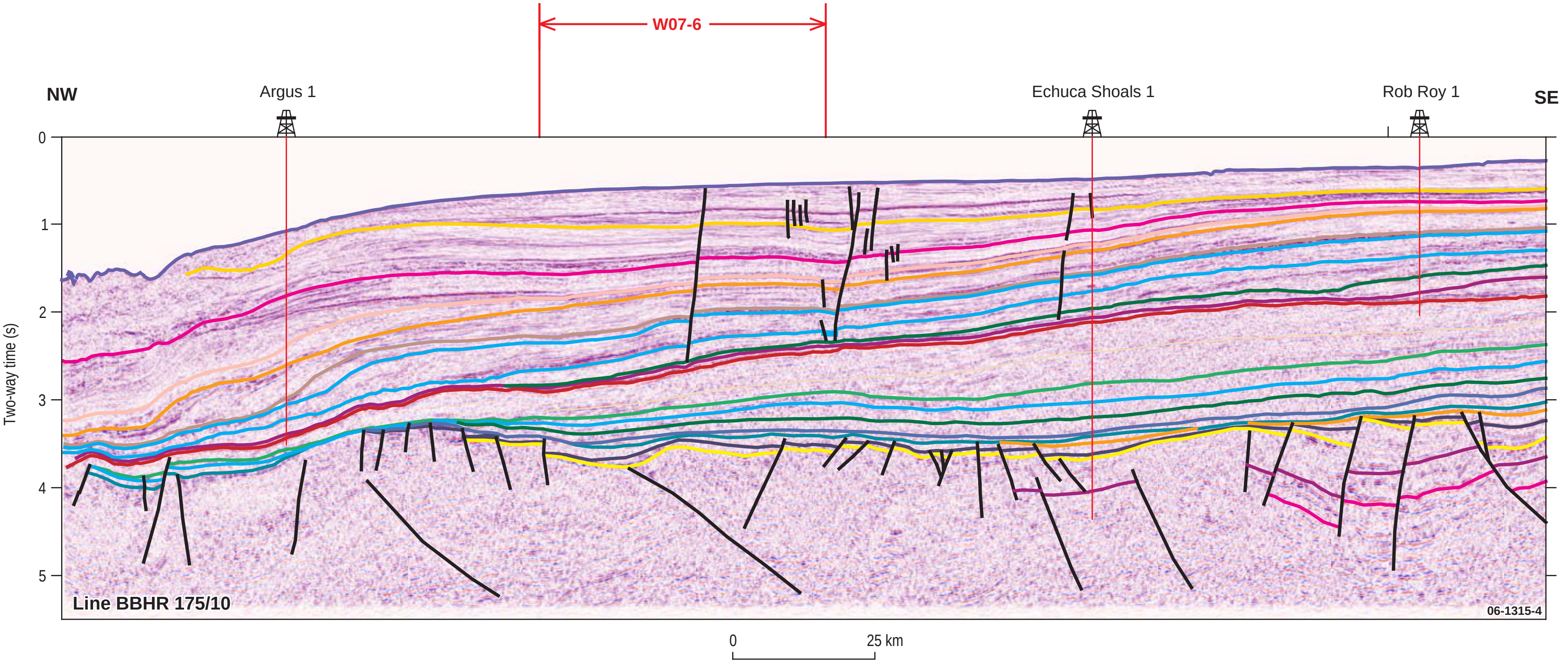

Figure 4. Seismic line BBHR 175/10 through Argus 1, Echuca Shoals 1 and Rob Roy 1, northern Caswell Sub-basin. Location of the line is shown in Figure 2. Regional seismic horizons are shown in Figure 3.

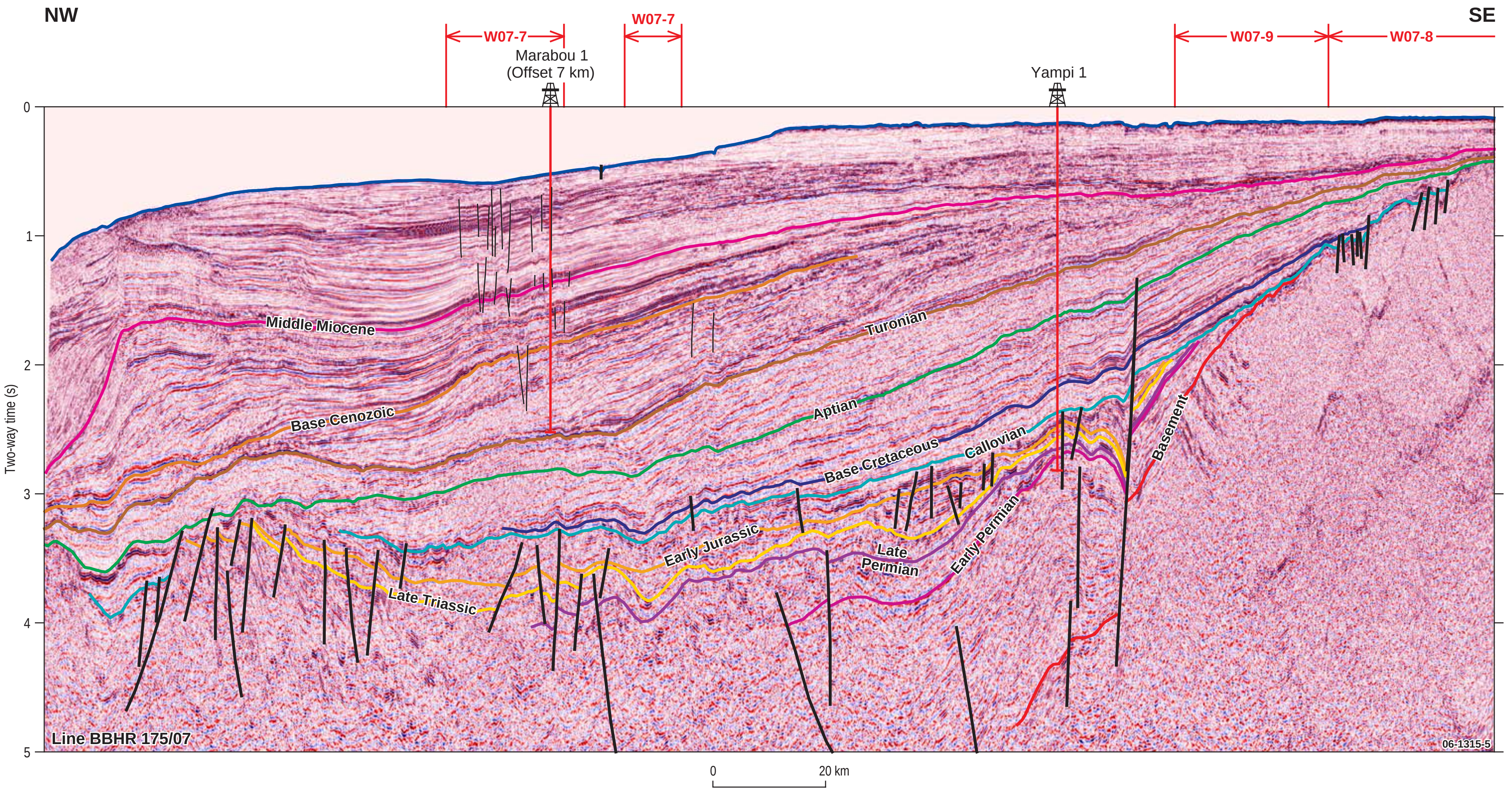

Figure 5. Seismic line BBHR 175/07 through Marabou 1, central Caswell Sub-basin to Yampi 1 on the Yampi Shelf. Location of the line is shown in Figure 2. Regional seismic horizons are shown in Figure 3.

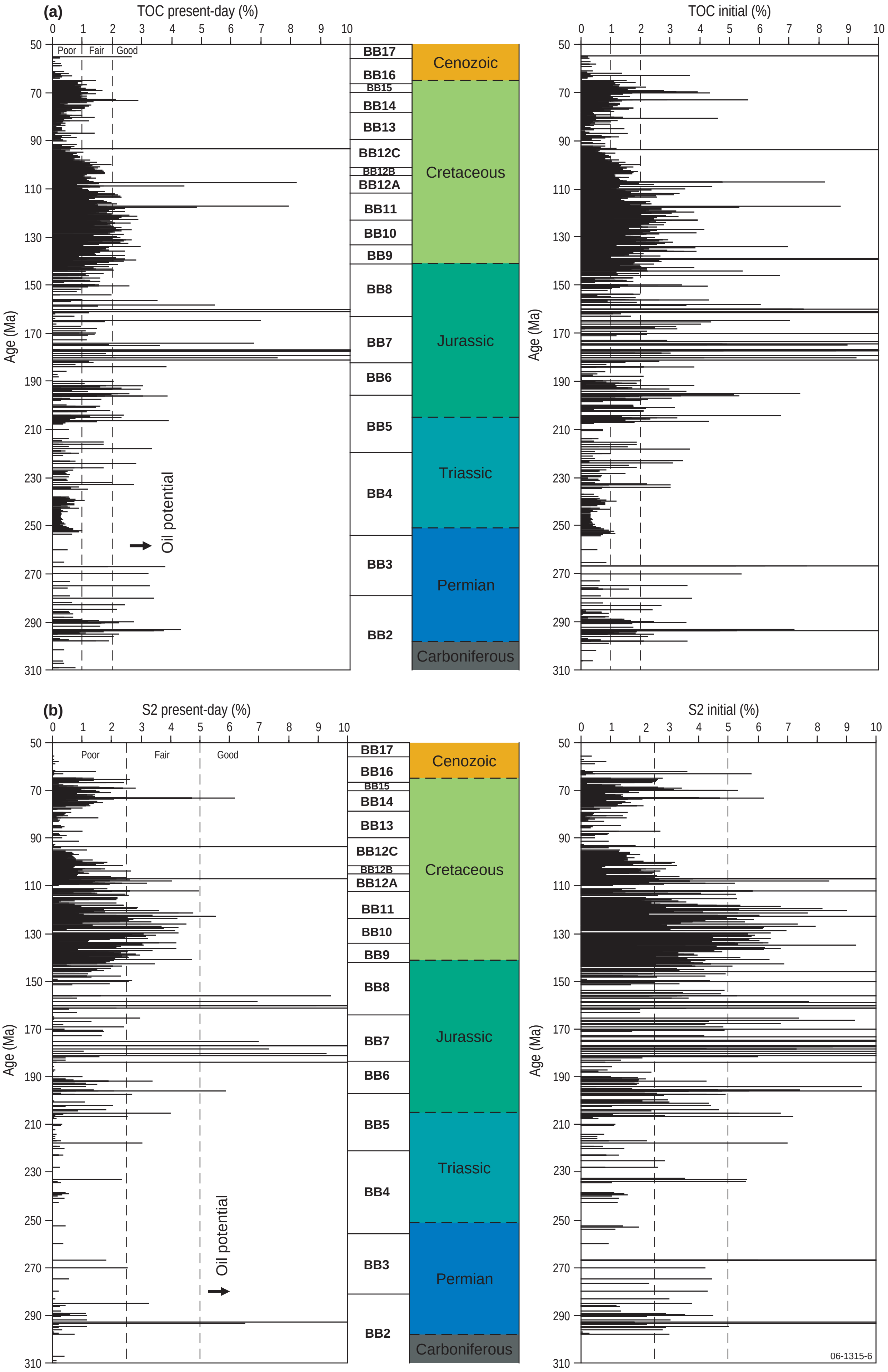

Figure 6. Plots of age (a) present day and initial TOC, and (b) present day and initial S2 values for the Browse Basin wells drilled prior to 1998 (Blevin et al, 1998b).

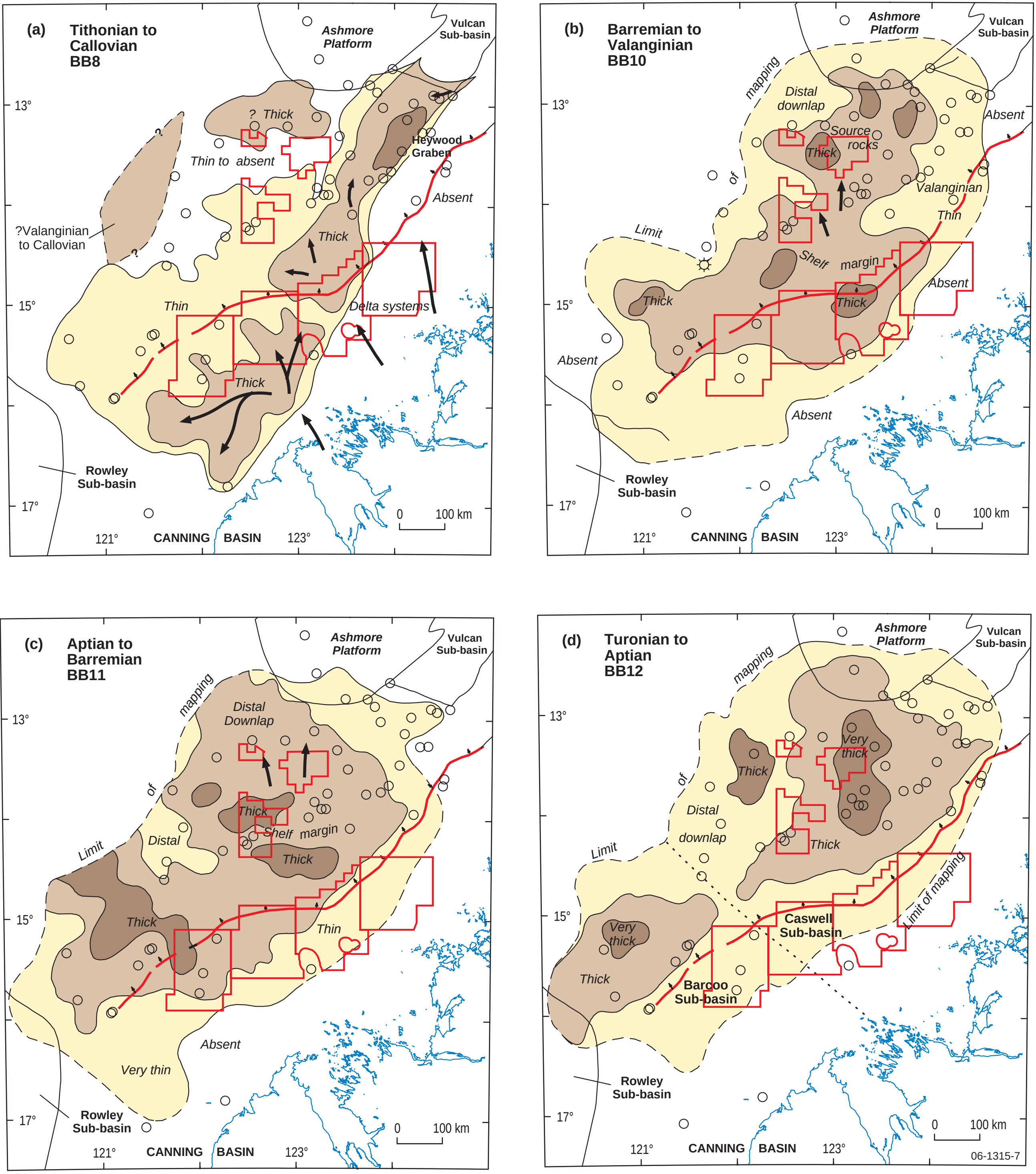

Figure 7. Generalised distribution map of (a) Tithonian to Callovian, (b) Barremian to Valanginian, (c) Aptian to Barremian, and (d) Turonian to Aptian sediments in the Browse Basin (based on two-way time isopachs maps; after Blevin et al, 1998b) The shelf margin hinge is shown in red and arrows indicate the direction of sediment transport.

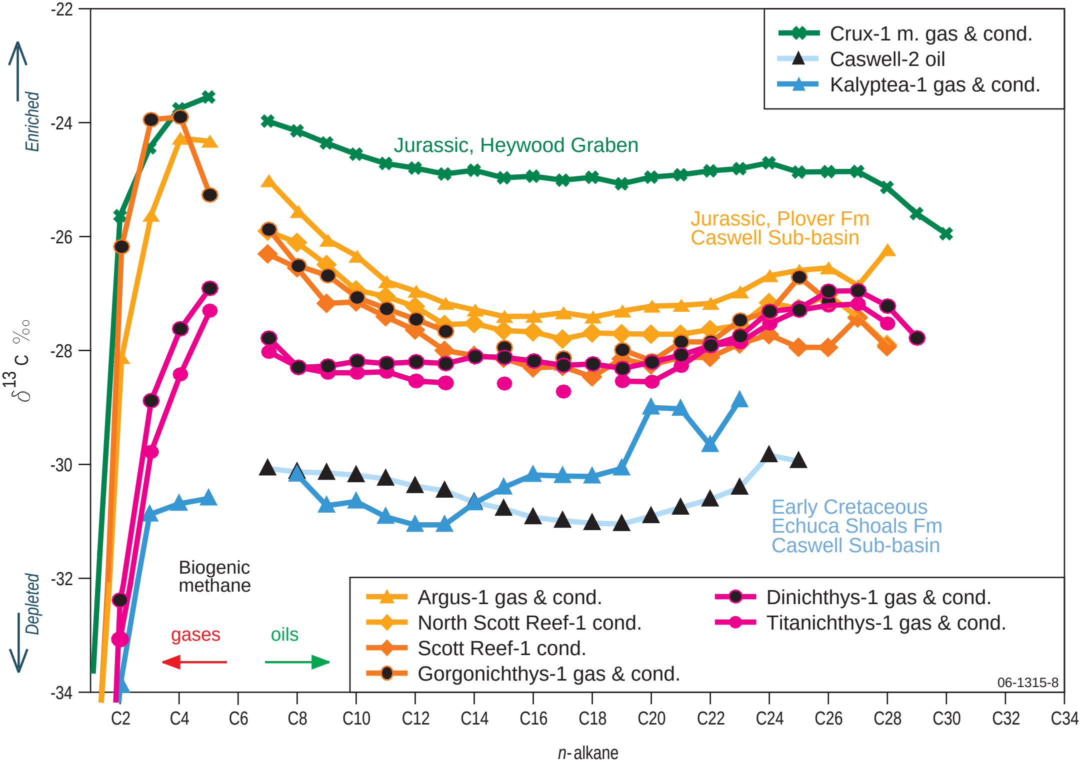

Figure 8. Carbon isotopic composition for C_7+ *n*-alkanes of gases, condensates and oils recovered from the Browse Basin (after Edwards et al, 2004, 2006).