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Mines and Petroleum

**REPORT
124**

PETROLEUM GEOCHEMISTRY AND PETROLEUM SYSTEMS MODELLING OF THE CANNING BASIN, WESTERN AUSTRALIA

by KAR Ghori

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Perth 2013

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Cover photograph:
Lake Dora on the southwest margin of the Canning Basin (photograph by Peter Haines)

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Petroleum geochemistry and petroleum systems modelling of the Canning Basin, Western Australia

by

KAR Ghori

Abstract

Petroleum geochemistry, organic petrology, apatite fission track analysis (AFTA), heat flow, subsurface temperatures and other exploration data from the onshore Canning Basin indicate that the Ordovician Goldwyer and Bongabinni Formations contain oil-prone source rocks. Up to 60% total organic carbon (TOC) is found in the Bongabinni Formation on the Admiral Bay Fault Zone, and up to 6% TOC is found in the Goldwyer Formation on the Barbwire Terrace. The Devonian Gogo Formation and lower Carboniferous Laurel Formation contain oil-prone source rocks with up to 4% TOC, based on limited geochemical data. The Permian sequence contains gas- and oil-prone source rocks with up to 8% TOC and the Noonkanbah Formation shows the best sourcing possibility, but its low thermal maturity is the main risk.

Geochemical analyses show that Pictor oil was derived from Ordovician source rocks and Blina oil from Devonian source rocks. Oil from the Boundary, Lloyd, Sundown, West Kora, and West Terrace fields correlates with early Carboniferous source rocks, on the basis of geochemistry. AFTA data, combined with basin modelling for Acacia 1 and 2, Blackstone 1, Kidson 1, Lake Betty 1, and Yulleroo 1 indicate that maximum burial occurred during the Triassic–Jurassic in the Kidson and Gregory Sub-basins and the Fitroy Trough. In contrast, AFTA data and basin modelling of Willara 1 indicate that maximum burial occurred in the Willara Basin during a Cretaceous event. These burial events affected the timing of petroleum generation across the different sub-basins.

The Ordovician, Devonian, and Carboniferous sequences are also expected to contain self-contained petroleum systems. Ordovician shales of the onshore Canning Basin are estimated to contain up to 8.2 trillion cubic metres or 288 trillion cubic feet of gas. Shale gas exploration is at a very early stage and more work is needed to verify these estimates. Recent discoveries of oil at Ungani, gas at Valhalla, and emerging shale plays have revived exploration in the Canning Basin.

KEYWORDS: petroleum geochemistry, petroleum systems, source rock quality, thermal maturity

Introduction

The Canning Basin is the largest onshore basin in Western Australia covering about 530 000 km² onshore of a total area of 640 000 km² (Fig. 1). It is mainly of Ordovician – Early Cretaceous age (Fig. 2), and has been explored for petroleum since the 1920s (Fig. 3). Oil has been produced since 1983 although oil production is insignificant relative to the basin's size and potential. Only 13 886 kL (87 340 barrels) of oil and 4 461 000 m³ (157 539 000 ft³) of gas were produced in 2012.

Buru Energy's Ungani 1 is the most recent major oil discovery (December 2011) and emerging shale plays have provided impetus for further exploration. Active exploration within the basin for conventional and tight oil and gas reservoirs includes appraisal of the Yulleroo, Valhalla, Ungani, and Pictor discoveries and shale-gas plays within the Ordovician Goldwyer Formation, as well as organic-rich intervals within the Devonian, Carboniferous, and Permian successions. The Canning Basin is very large, compared to world standards, and the density of drilling is very low. In addition, only limited wells were drilled in locations that would test valid structures for petroleum trapping.

Since 2004, the Geological Survey of Western Australia (GSWA) has collected new petroleum geochemical data, apatite fission track analyses (AFTA), subsurface temperature, and heat-flow data (Liu and Fenton, 2005; Ghori and Haines, 2006a; Chopra and Holgate, 2007; Driscoll et al., 2009; Ghori, 2010; Ghori, 2011).

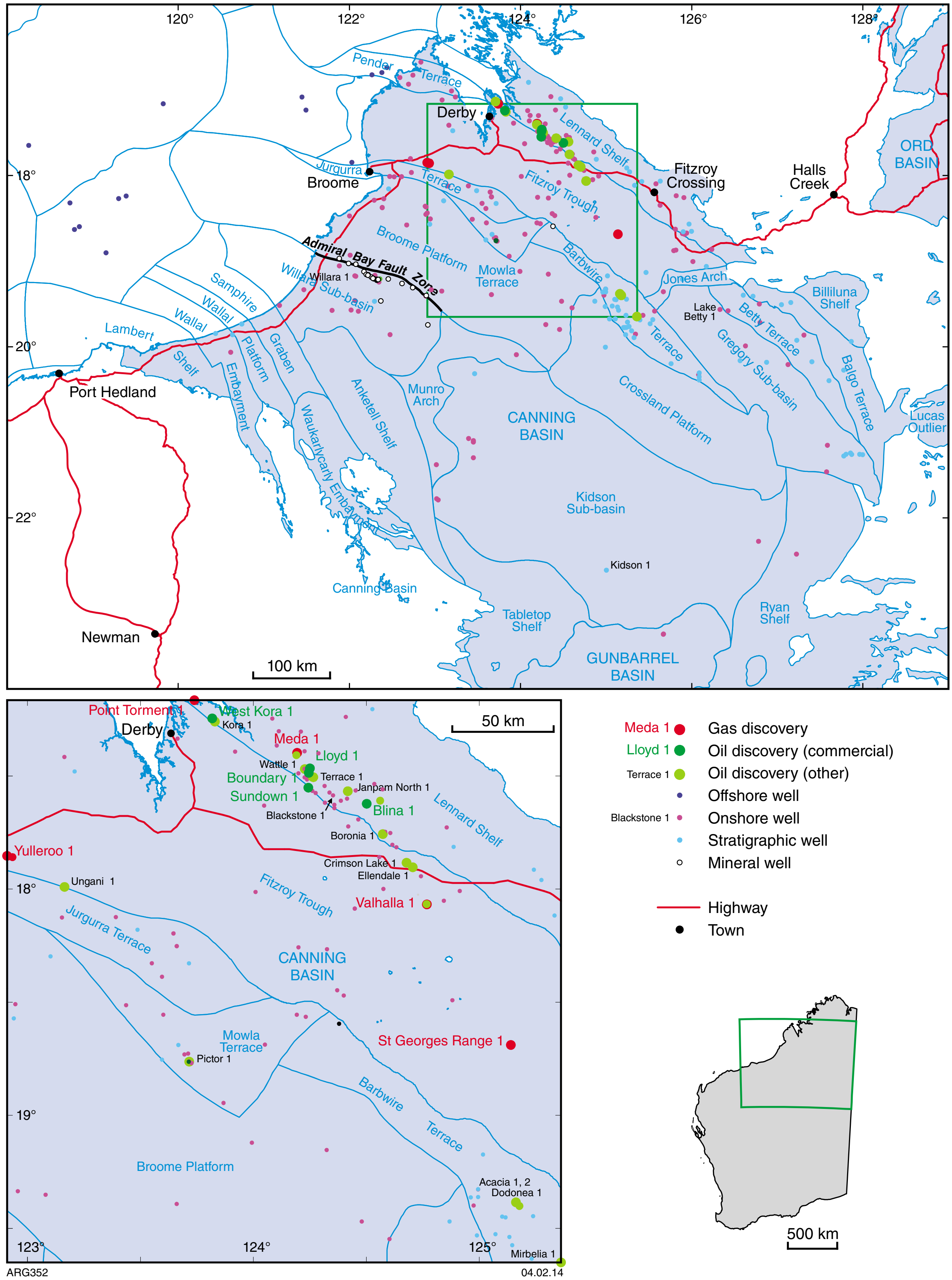

Figure 1. Tectonic units, exploration wells, and petroleum discoveries of the Canning Basin (after Hocking, 1994)

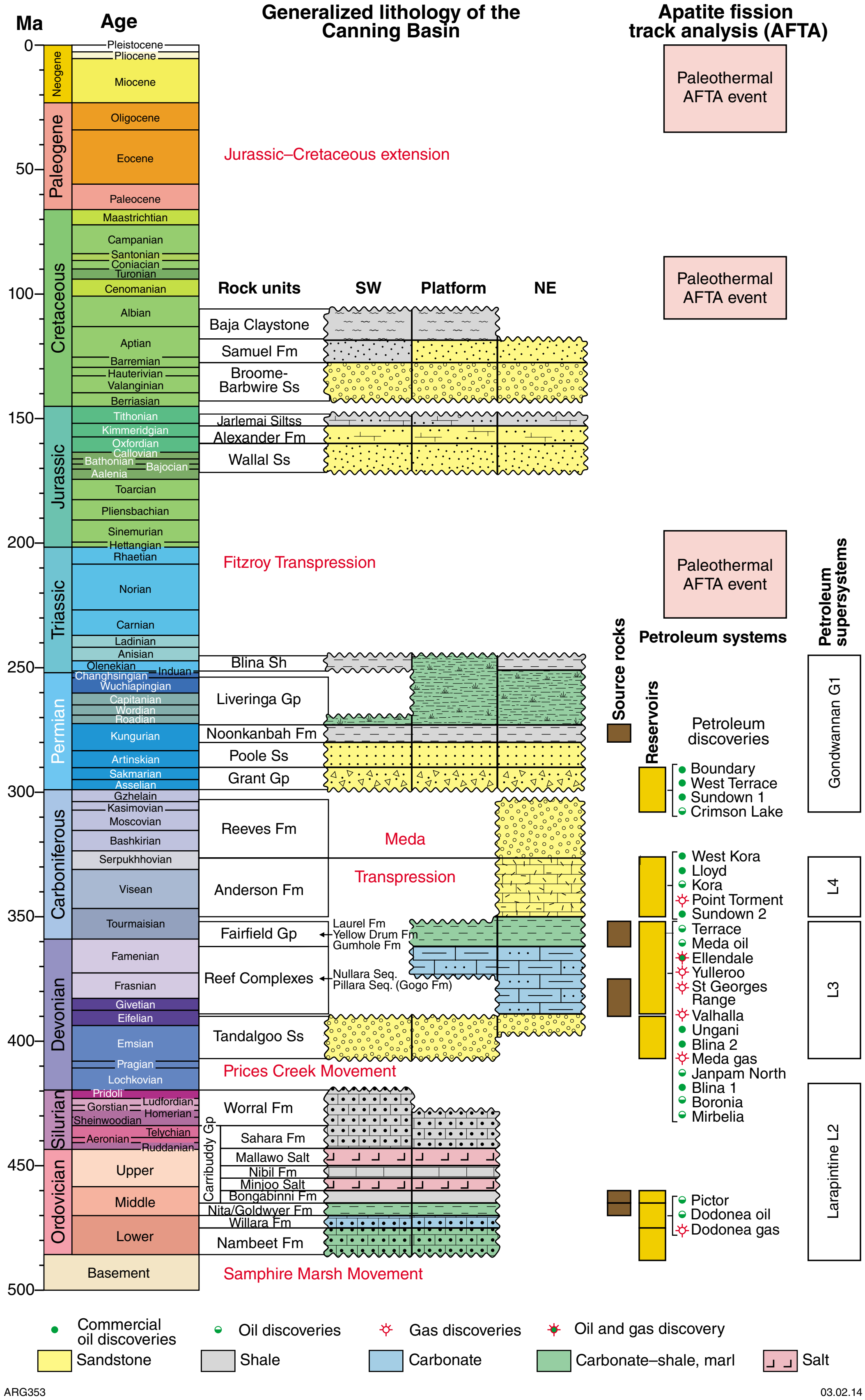

Figure 2. Stratigraphy of the Canning Basin showing the distribution of source and reservoir rocks, petroleum systems and discoveries, and AFTA paleothermal events (timescale after International Commission on Stratigraphy, 2013)

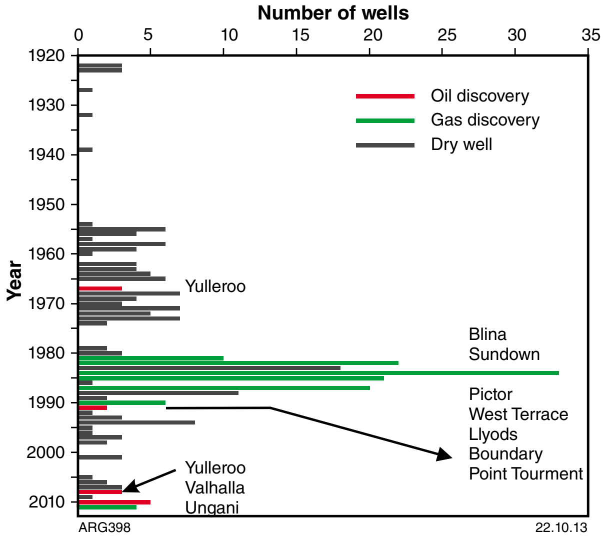

Figure 3. Petroleum drilling and discovery history of the Canning Basin

New analyses include total organic carbon (TOC) content (23 wells), Rock-Eval pyrolysis (20 wells), pyrolysis – gas chromatography (PGC) (nine wells), extractions of organic matter (EOM) (six wells), liquid chromatography (nine wells), saturated and aromatic gas chromatography – mass spectrometry (six wells), organic petrology (17 wells), AFTA (seven wells), and Quantitative Grain Fluorescence (QGF) and QGF Extract (QGF-E) (five wells). In addition to petroleum geochemistry, 274 wells were evaluated for equilibrium temperatures and heat flow, based on thermal conductivity measurement on 50 core samples and heat-flow modelling in 101 wells (Fig. 4). Data generated recently by GSWA have been incorporated with other available exploration data to provide an inclusive dataset for this study. Geochemical analyses that appeared to be contaminated have been excluded from interpretation.

Geological setting

The Canning Basin contains two major northwest-trending troughs separated by a mid-basin arch and marginal shelves (Fig. 1). In the north, the Fitzroy Trough and Gregory Sub-basin contain up to 15 km of predominantly Paleozoic rocks. In the middle, the Broome and Crossland Platforms produce a central arch. In the south, the Kidson and Willara Sub-basins contain up to 5 km of predominantly Ordovician to Silurian and Permian sediments with extensive Mesozoic cover (Figs 1 and 2).

The geological history of the Canning Basin started with extension and rapid subsidence in the Early Ordovician, followed by four major and several minor phases of deposition and erosion. The major tectonic events that affected the sedimentary history of the basin are: the Samphire Marsh Movement preceding Ordovician to Silurian deposition; the Devonian Prices Creek Movement prior to Devonian – lower Carboniferous deposition; the Carboniferous Meda Transpression before upper Carboniferous to Lower Triassic deposition, the Triassic–Jurassic Fitzroy Transpression preceding Jurassic to Lower Cretaceous deposition, and finally the Jurassic–Cretaceous extension (Fig. 2). These events were responsible for the evolution and preservation of at least three petroleum systems within the Ordovician–Silurian and Devonian–Carboniferous–Permian successions (Fig. 2). These successions comprise sedimentary rocks of continental to marine-shelf, mixed carbonate and clastic origin. Major evaporitic basins were present in the Ordovician, with lesser accumulations in the Silurian and Early Devonian (Haines, 2009).

Published and unpublished reports archived in the library of the Department of Mines and Petroleum (DMP) provide detailed information on the petroleum geology of the Canning Basin. Purcell (1984) edited the first comprehensive symposium on the petroleum geology of the basin. The petroleum systems were investigated by Bradshaw et al. (1994), Kennard et al. (1994), Romine et al. (1994), and Edwards et al. (1995), while Cadman et al. (1993) and Crostella (1998) described petroleum occurrences. Foster et al. (1986) and Wulff (1987) analysed the petroleum-generating capacity of source rocks, and SRK Consulting (1998) and D'Ercole et al. (2003) provided information on prospectivity. Haines (2004 and 2009) studied and reinterpreted the Lower Paleozoic stratigraphy and Mory (2010) reviewed the mid-Carboniferous to Triassic stratigraphy. The petroleum geochemistry of the Canning Basin, including the results of recent analyses by GSWA (2004–2010), was described by Carlsen and Ghori (2005), Ghori and Haines (2006a,b), Haines and Ghori (2006), and Ghori (2011). Chopra and Holgate (2007), Driscoll et al. (2009) and Ghori (2010) provided information on temperatures, and Scott (1998) and Kuuskraa et al. (2011) identified self-sourcing reservoirs and provided an initial assessment of shale-gas resources in the Canning Basin.

Petroleum geochemistry

Source rocks

Petroleum source rocks of the Canning Basin are identified from analytical data available on about 2000 samples including over 200 samples analysed by the GSWA (Fig. 5, Ghori and Haines, 2006a; Ghori, 2011). The source rock characterization generally used by the petroleum industry (Baskin, 1997; Dembicki Jr, 2009) was followed for this study, albeit with some modifications as discussed below.

The petroleum-generating capacity of a source rock depends on four factors: organic richness (amount of kerogen), organic facies (type of kerogen), organic maturity (kerogen to petroleum transformation ratio), and expulsion efficiency. Organic richness is measured by TOC content. Source-rock samples with TOC content >0.5% are classified as of fair organic richness, between 1 and 2% as good, between 2 and 4% as very good, and over 4% as excellent.

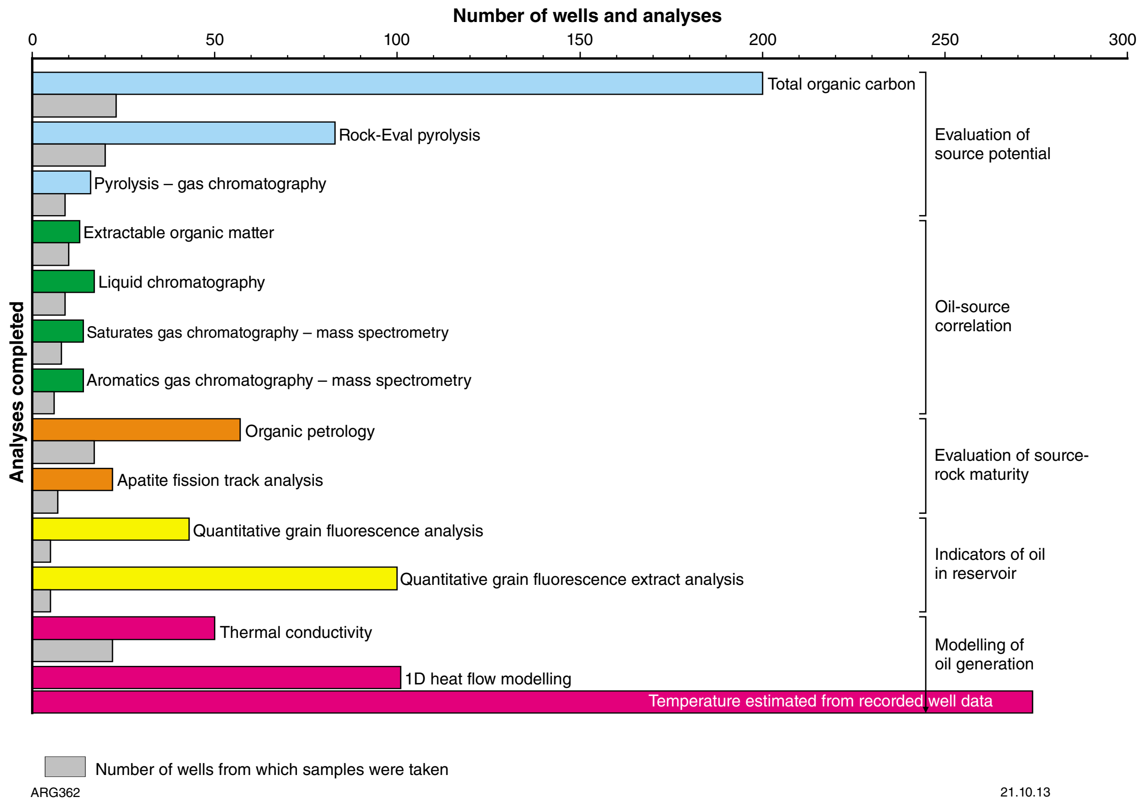

Figure 4. Petroleum geochemistry, organic petrology, fluid inclusions and geothermal data for wells in the Canning Basin, obtained by GSWA from 2004 to 2011

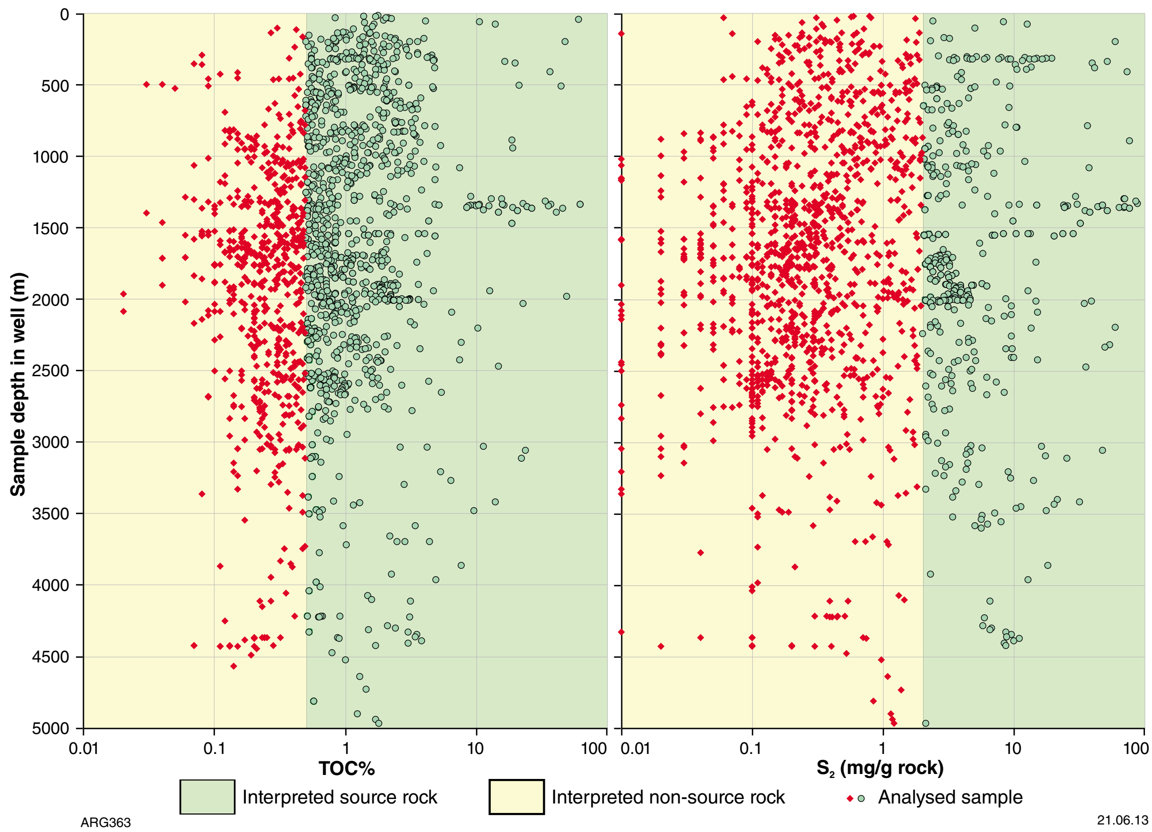

Figure 5. TOC and Rock-Eval pyrolysis discrimination between non-source- and source-rock samples (from combined data in the GSWA database)

Thermal and pyrolysate yield of organic compounds from Rock-Eval pyrolysis is expressed as $S_1 + S_2$ or potential yield, which quantifies the hydrocarbon-generating capacity of rocks. S_1 represents existing indigenous or migrated hydrocarbons in a rock and is approximately equivalent to the extractable organic matter (bitumen). S_2 represents the organic compounds generated from kerogens during pyrolysis. S_1 and S_2 are both measured as milligrams in a gram of rock (mg/g rock). Samples with potential pyrolysate yield (S_2) from 2 to 5 mg/g rock are classified as fair, those with 5 to 10 mg/g rock as good, those with 10 to 20 mg/g rock as very good, and those over 20 mg/g rock as excellent.

Source-rock facies classification of the kerogen type is determined using a crossplot of TOC versus the Hydrogen Index (HI). The HI from Rock-Eval corresponds to the quantity of hydrocarbon compounds (HC) that can be pyrolyzed relative to the total organic carbon (mg HC/g TOC). Source rocks with HI values less than 150 are classified as gas generating, while those with HI values over 150 are classified as oil and gas generating.

Source-rock maturity level is determined using a crossplot of T_{max} and the Production Index (PI). T_{max} provides an indication of source-rock maturity but can be affected by organic facies type. T_{max} less than 435ºC is classified as immature, between 435 and 460ºC as oil generating, between 460 and 470ºC as wet-gas generating, and over 470ºC as dry-gas generating.

Pyrolysis – gas chromatography (PGC), extraction of organic matter (EOM), liquid and gas chromatography, and mass spectrometry of samples are used to identify the type of kerogen or organic facies, and oil-to-oil and oil-to-source correlation.

Vitrinite reflectance (VR) data and T_{max} from Rock-Eval indicate thermal maturity; AFTA indicates maximum paleotemperatures and their timing, whereas present-day temperatures are estimated from recorded temperatures in petroleum wells. Finally, organic maturity and timing of oil and gas generation from source rocks can be estimated from basin modelling.

No direct method is available to measure expulsion efficiency, although a mass balance approach can be used to estimate petroleum expulsion efficiency (PEE) using Rock-Eval parameters (Cooles et al., 1986; Powell and Boreham, 1991).

TOC and Rock-Eval pyrolysis

TOC and Rock-Eval pyrolysis data are used to discriminate between source- and non-source-rock samples (Espitalié et al., 1985; Peters, 1986; Bordenave et al., 1993). Those samples with <0.5% TOC and <2 mg HC/g rock pyrolysate yield (S_2) are discriminated as non-source-rock samples (Fig. 5), and excluded from further interpretation. For source-rock samples, a crossplot of T_{max} versus PI is used to further discriminate between oil and gas shows or contaminated samples and source-rock samples (Fig. 6). T_{max} represents the analysis temperature (ºC) at maximum hydrocarbon generation during the S_2 cycle. PI represents kerogen conversion indices ($S_1/(S_1 + S_2)$); its value increases with hydrocarbon generation as a function of increasing maturity. Higher than normal values (0.4) are observed in migrated or accumulated hydrocarbons, non-source rock, or contaminated samples, whereas lower than normal (0.1) values are due to the expulsion of hydrocarbons from the source rock. Parameters for source-rock richness, facies,

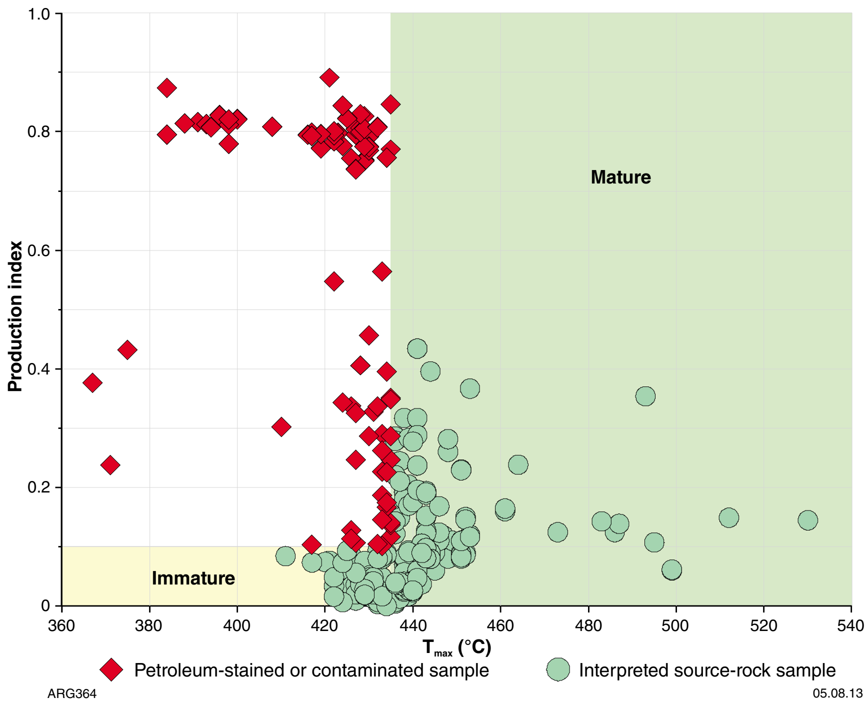

Figure 6. Rock-Eval pyrolysis discrimination between interpreted source-rock samples and petroleum-stained or contaminated samples

and maturity discussed above are used to characterize petroleum source rocks (Espitalié et al., 1985; Peters, 1986; Bordenave et al., 1993). The petroleum-generating potential of the Ordovician, Devonian and Carboniferous, and Permian source rocks are summarized in Figures 7, 9 and 11, respectively. The composite TOC and Rock-Eval logs of Ordovician, Devonian and Carboniferous, and Permian source rocks are shown in Figures 8, 10, and 12, respectively.

Pyrolysis – gas chromatography

GSWA analysed 20 samples by PGC to determine the detailed molecular configuration of kerogen and its oil versus gas-generating potential. Of these, 14 samples are from the Ordovician Goldwyer (four), Nita (one), and Bongabinni (nine) Formations, one is from the Carboniferous Reeves Formation, and five are from the Permian. The PGC data and pyrograms are provided by Ghori and Haines (2006a) and Ghori (2011). The most important parameters from such analyses (Larter and Douglas, 1980; Larter, 1985; Larter and Senftle, 1985) include: Gas–oil generation index (GOGI = $(C_1–C_5)/C_{6+}$ abundance); oil yield = $C_5–C_{31}$ (alkenes + alkanes); and aromatics content or type index (R) = (m + p-xylene/n-octene).

The aliphatic carbon content of a kerogen and its distribution within various structural elements dictate the type of product, i.e. oil versus gas. Oil proneness, expressed as C_5 to C_{31} alkanes plus alkenes (values as a percentage of S_2 from Rock-Eval), is plotted against the gas–oil generation index (GOGI), expressed as $(C_1–C_5)/C_{6+}$ (Fig. 13) and determines whether the type of kerogen is oil and gas generating. Core samples from the Ordovician Bongabinni Formation contain the best oil-prone source rock of the analysed samples. The normalized composition of pyrolysate indicates high concentrations of aliphatic (alkanes + alkenes) hydrocarbons (Fig. 14), and that the hydrogen-rich kerogen is capable of generating hydrocarbons. The aliphatic compounds in the pyrolysate have 6–14 carbon atoms, which indicates they are predominantly from the gasoline to kerosene range of hydrocarbons (Fig. 15).

Gas chromatography

Crude oil and bitumen extracted from rock have been analysed by gas chromatography (GC) to confirm the source rocks of oils from the Canning Basin. Table 1 lists the selected GC biomarkers for 29 samples used in this study; 13 of these samples were analysed by GSWA. These ratios are sensitive to secondary processes and need support from other geochemical and geological data (Peters et al., 2005) in order to confirm the source.

Isoprenoid/n-paraffin ratios (Figs 16 and 17, and Table 1) show that oils from Blina and Janpam North wells have low (<1) pristane/phytane and pristane/n-C_{17} ratios and high (>1) phytane/n-C_{18} ratios indicating oil-prone, marine source rocks deposited in a reducing carbonate environment (the Gogo Formation). The Devonian oils are different from the Ordovician and Carboniferous oils.

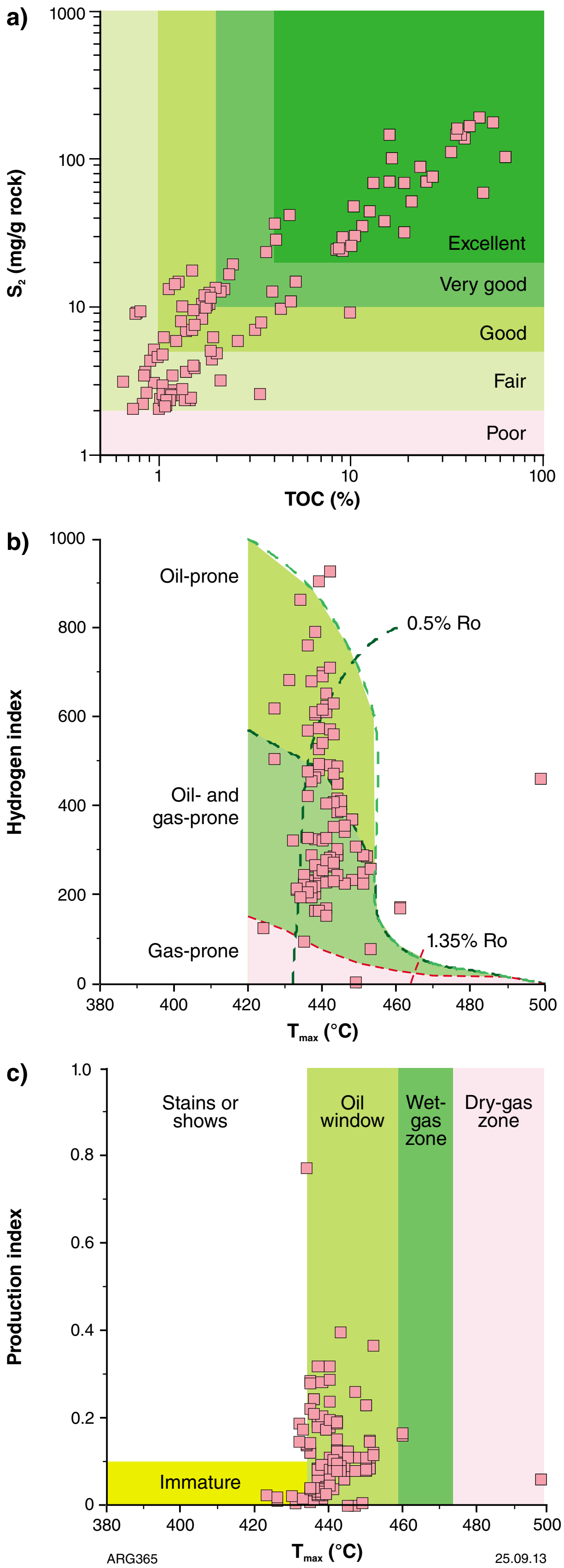

Figure 7. Summary of available Rock-Eval data for the Ordovician source-rock samples showing: a) generating potential; b) kerogen type; c) thermal maturity

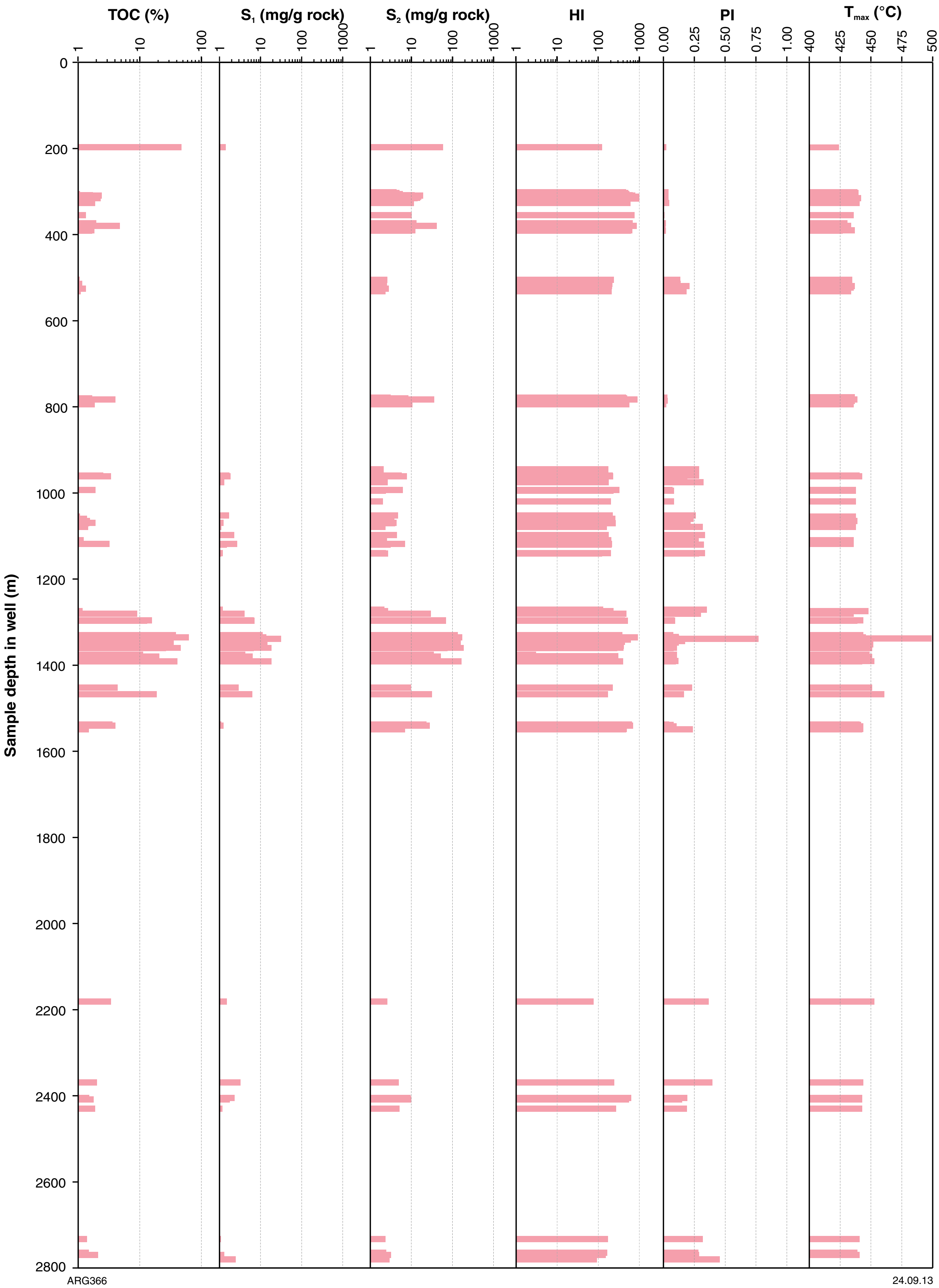

Figure 8. **TOC and Rock-Eval pyrolysis composite log of the Ordovician source-rock samples from well data**

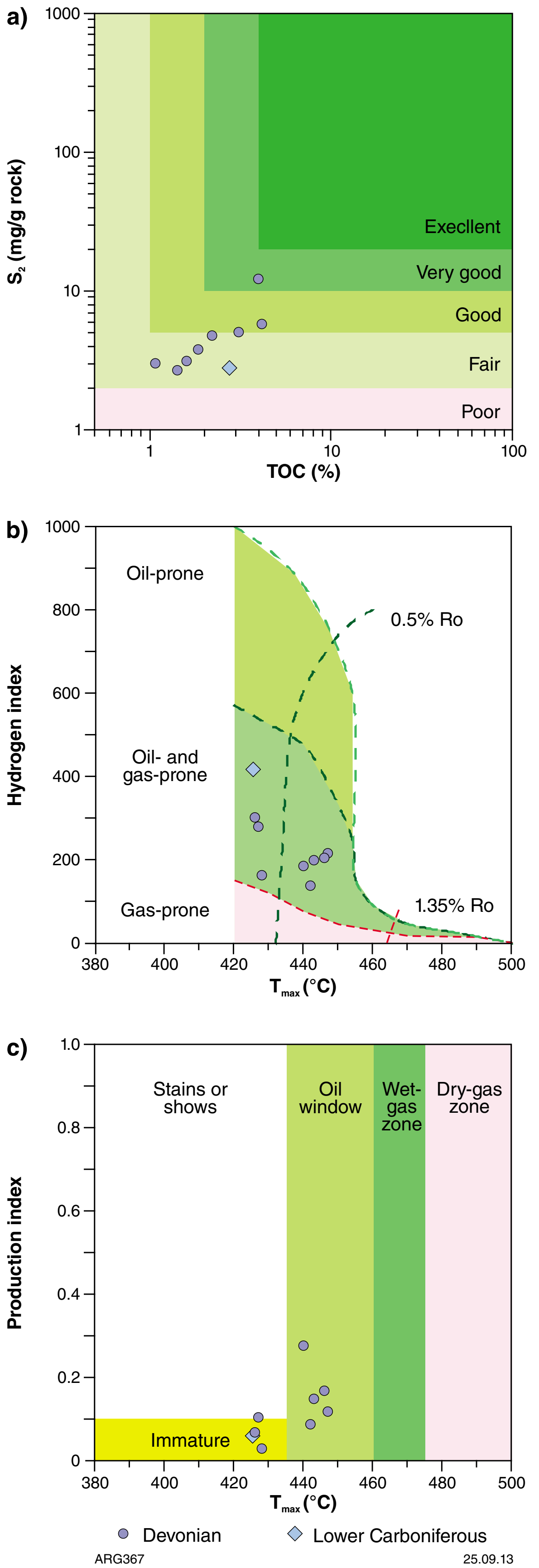

Figure 9. Summary of available Rock-Eval data of the Devonian and lower Carboniferous source-rock samples showing: a) generating potential; b) kerogen type; c) thermal maturity

The Ordovician oils from the Dodonea, Great Sandy, Mirbelia, and Pictor wells have both pristane/n-C_{17} and phytane/n-C_{18} ratios less than 0.5, indicating that they are sourced from oil-prone marine shale of the Goldwyer Formation. The Carboniferous oils have high pristane/n-C_{17} ratios and low phytane/n-C_{18} ratios indicating that they are sourced from the oil- and gas-prone marine shale of the Laurel Formation (Peters and Moldowan, 1993).

GSWA analysed oil from Dodonea 1, Great Sandy 1, and Pictor 1 and rock extract from three mineral bore holes (Kagara ABRD009, Pasminco BW26, and BHP 158) for saturated branch and cyclic hydrocarbons and aromatic hydrocarbon biomarkers (Ghori and Haines, 2006a; Ghori, 2011). Comparison of selected saturated and aromatic biomarker parameters show similar signatures (Figs 18 and 19).

The Australian Geological Survey Organisation (now Geoscience Australia) and GeoMark Research, Inc. analysed 13 oil samples from the Canning Basin for their physical, chemical, biomarker, and isotopic characteristics (AGSO and GeoMark, 1996). These oil characteristics were used to describe the organic type, depositional environment, and mineralogy of the source rocks. AGSO and GeoMark (1996) used chemometric analysis to identify different oil families by removing noise from the large, regional database (Peters et al., 2005) and statistically analysed a multivariate dataset. This enabled AGSO and GeoMark (1996) to recognize three major, genetically related oil families based on Principal Component Analysis (PCA) techniques (Fig. 20).

Blina crude oil is paraffinic, low in sulphur and has an American Petroleum Institute (API) gravity of 36°. It is reservoired in the Nullara Limestone and Yellow Drum Formation. The source rock of the Blina crude oil is markedly different from other oils of the Canning Basin because it was deposited in highly anoxic conditions in a carbonate environment of the Gogo Formation (Moors et al, 1984; Alexander et al, 1984; AGSO and GeoMark, 1996, Ghori and Haines, 2006a; Ghori, 2011).

The richest organic intervals are present in the Ordovician Goldwyer and Bongabinni Formations in wells drilled on the Barbwire Terrace and Admiral Bay Fault Zone. The Goldwyer Formation can be equated globally with Cambrian–Ordovician source rocks and regionally with source rocks of the Mereenie Oil Field of the Amadeus Basin. This is especially true for their organic richness and facies type. Globally, Cambrian–Ordovician source rocks have the capacity to charge giant oilfields, such as the Permian Basin of Texas (Foster et al., 1986; Taylor, 1992).

Within the Devonian – early Carboniferous sequence, the best source rocks of the upper Devonian Gogo and lower Carboniferous Laurel Formations can be equated with global black shale facies of Late Devonian – Tournaisian age that contain type II kerogen (Klemme and Ulmishek, 1991). The upper Carboniferous – lower Permian source is equated with global Pennsylvanian – lower Permian rocks, which are oil and gas prone. No petroleum system sourced by this interval is currently recognized in the onshore Canning Basin. Based on these interpretations, the richness and oil proneness of source rocks decreases from the Ordovician to the Permian.

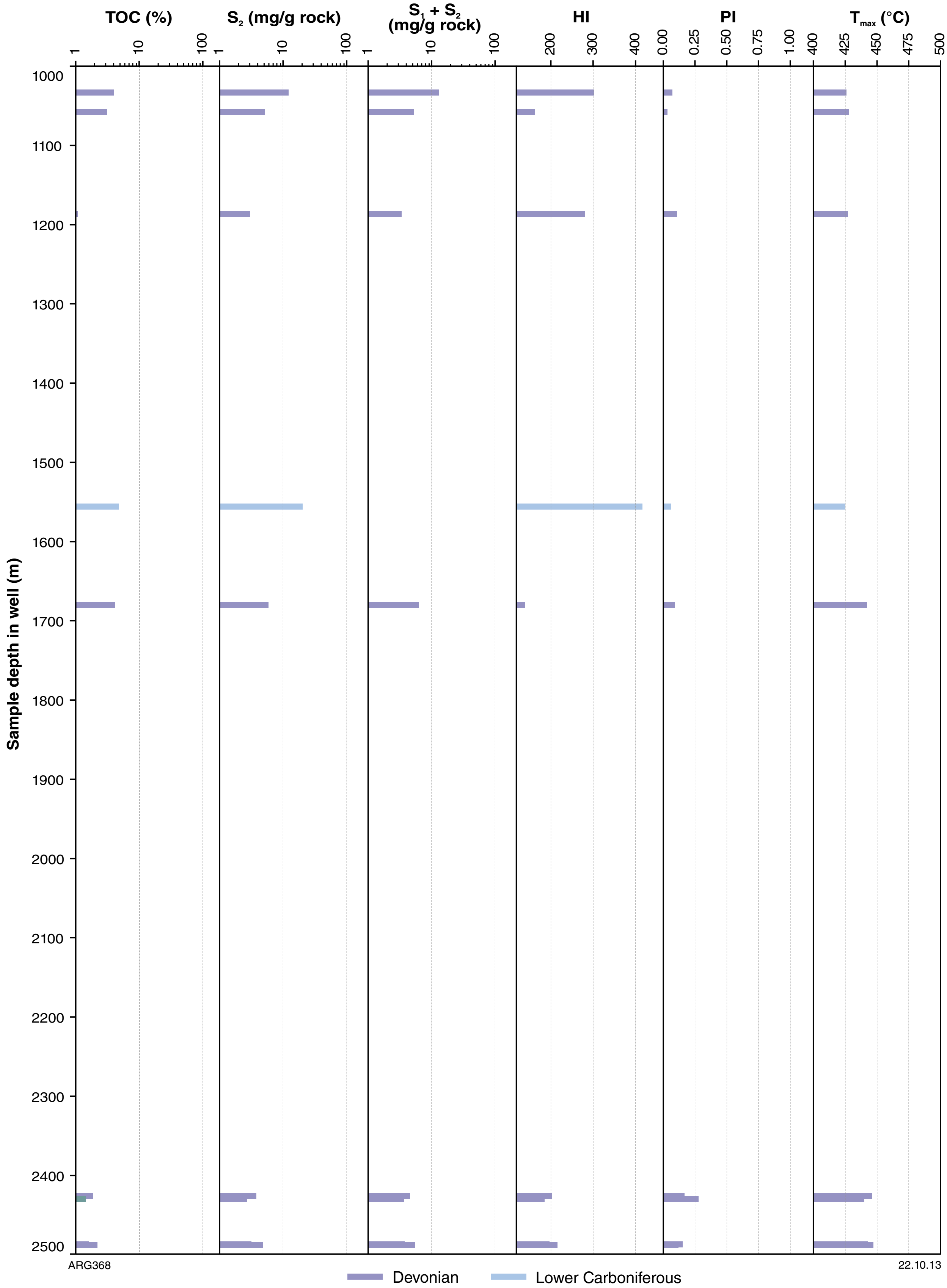

Figure 10. **TOC and Rock-Eval pyrolysis composite log of the Devonian and lower Carboniferous source-rock samples from well data**

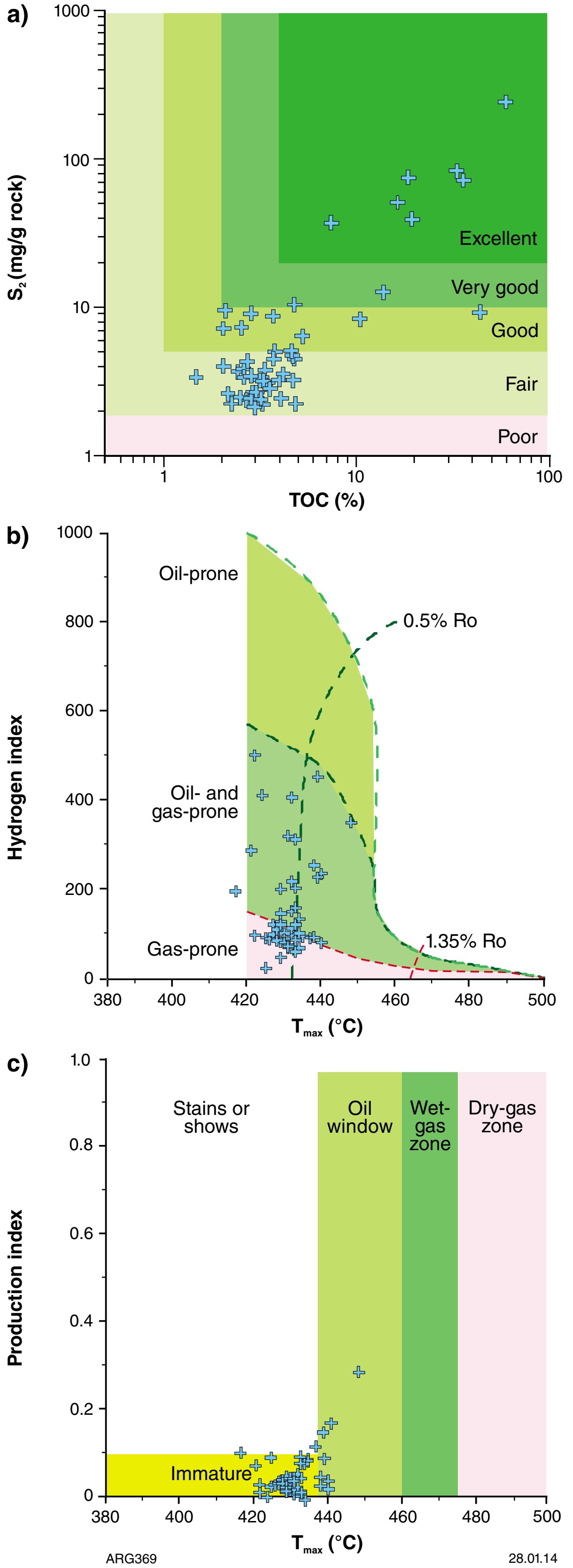

Figure 11. Summary of available Rock-Eval data of the Permian source-rock samples showing: a) generating potential; b) kerogen type; c) thermal maturity

Basin modelling

The thermal and petroleum-generation history of the Canning Basin was reconstructed using data from these wells: Acacia 1 and 2 on the Barbwire Terrace, Blackstone 1 on the Lennard Shelf, Kidson 1 in the Kidson Sub-basin, Lake Betty 1 at the margin of the Betty Terrace and Gregory Sub-basin, Willara 1 in the Willara Sub-basin, and Yulleroo 1 on the southern margin of the Fitzroy Trough (Fig. 1). These modelled reconstructions were constrained using data from GSWA studies for thermal history reconstructions in seven wells (Duddy, 2006; Green, 2006), present-day temperatures (Chopra and Holgate, 2007; Driscoll et al., 2009), 50 thermal conductivity measurements, and present-day heat-flow values in 101 wells (Driscoll et al., 2009; Ghori, 2010).

Temperatures

In the Canning Basin, the deepest recorded and corrected temperature data are from 4969 m (157ºC) in Phoenix 2 offshore, and 121ºC at 4573 m in Yulleroo 1 onshore (Ghori, 2010). The highest geothermal gradients are recorded in wells on platform areas, where basement rocks that generate high heat are shallower than 3000 m. Temperature data for shelves and terraces are only available for depths shallower than 3500 m, and for sub-basins for depths shallower than 4500 m. The lowest geothermal gradients are recorded in offshore wells. The highest temperatures observed at shallower depths are 126ºC at 3133 m in Lake Betty 1 and 150ºC at 4115 m in White Hills 1; both wells are located within the Gregory Sub-basin. Lake Betty 1 is near the boundary with Betty Terrace and the estimated geothermal gradient from the best fit is 31.54ºC/1000 m (Fig. 21).

Thermal conductivity

Thermal conductivity was measured on 50 core samples from 21 wells in Quaternary to basement rocks (Fig. 22), in the laboratories of Hot Dry Rocks Pty Ltd (Driscoll et al., 2009). The lowest measured thermal conductivity is 1.06 ± 0.28 W/mºC for a dark brown claystone sample from Goldwyer 1 at 979.9 – 983.6 m (Goldwyer Formation), whereas the highest thermal conductivity is 5.82 W/mºC for a fine-grained sandstone sample from St George Range 1 at 1362.1 – 1362.2 m (Reeves Formation). Most of the measured thermal conductivities are within the lower to medium range (1–3 W/mºC) with conductivities of 19 samples within the medium to high range (3–6 W/mºC). In modelling thermal history, uncertainty in measured thermal conductivity is due to the effect of in situ high temperatures and variations in lithology and porosity across the modelled formations and must be considered.

Heat flows

Estimation of present-day heat flow in 101 wells (Driscoll et al., 2009) suggests that it ranges from 20 to 160 mW/m², with a median value of 68 mW/m². An anomalously low heat flow (20 mW/m²) was modelled in Solanum 1, and an

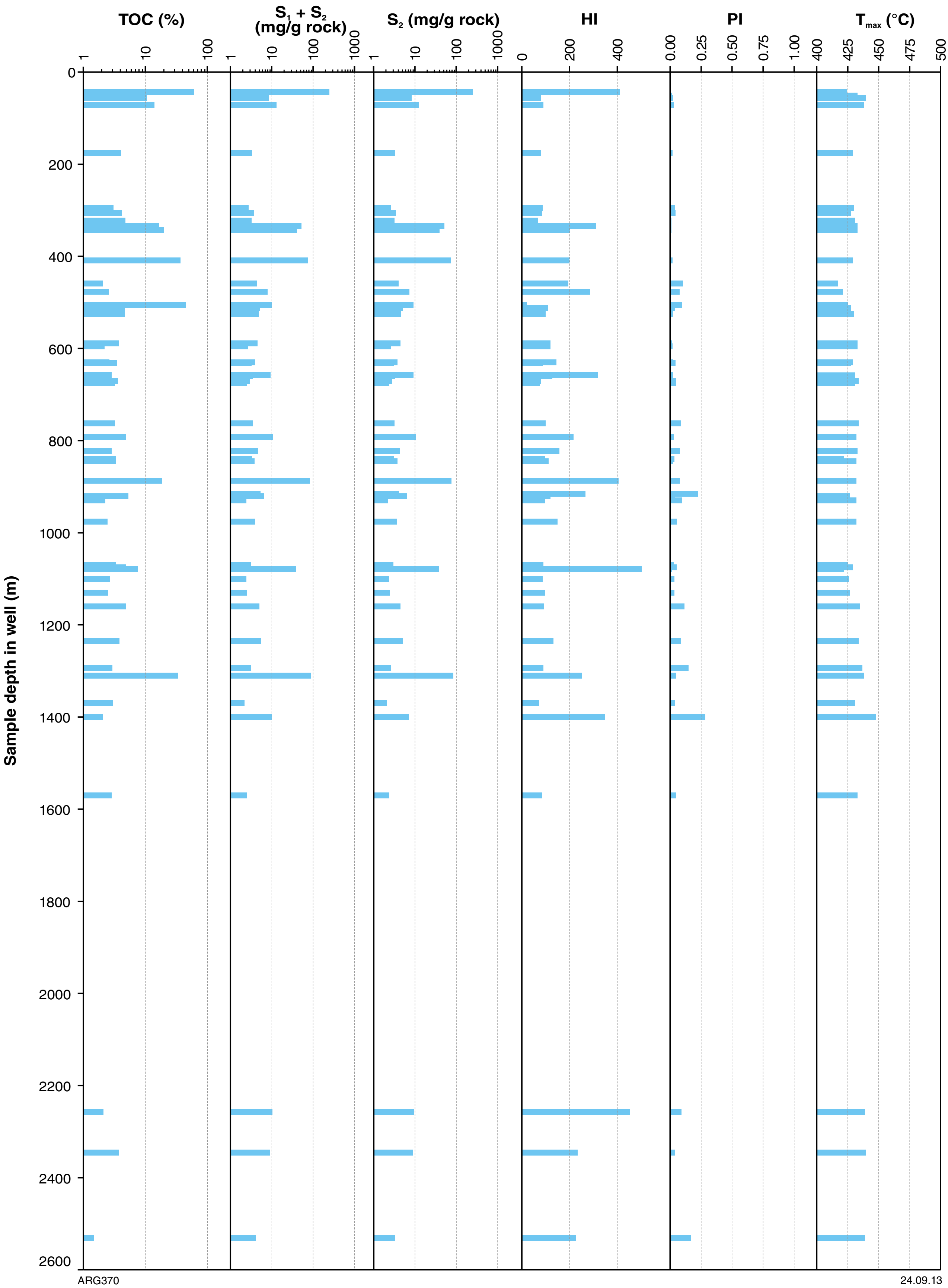

Figure 12. TOC and Rock-Eval pyrolysis composite log of the Permian source-rock samples from well data

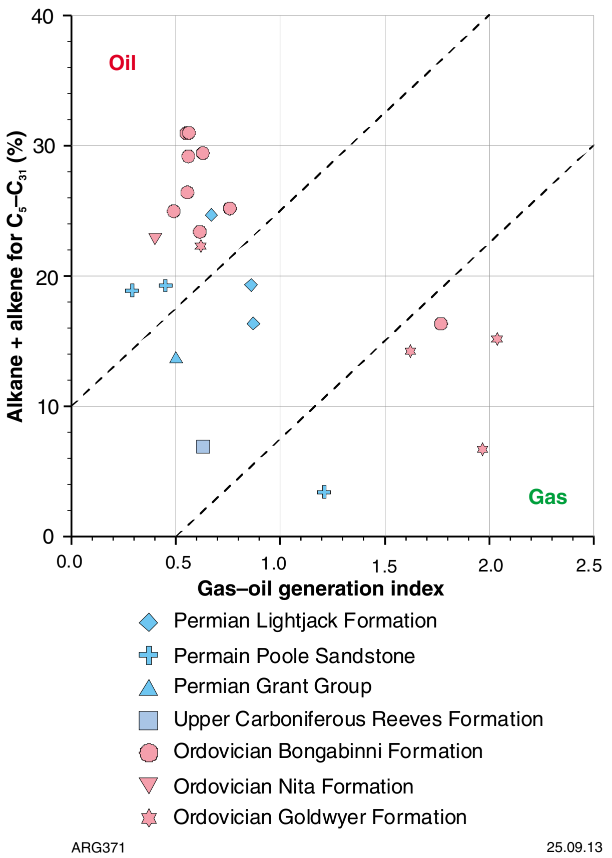

Figure 13. Pyrolysis – gas chromatograpy typing of the Ordovician, upper Carboniferous, and Permian samples, showing the combined percentage of alkane and alkene for C_5–C_{13} by formation

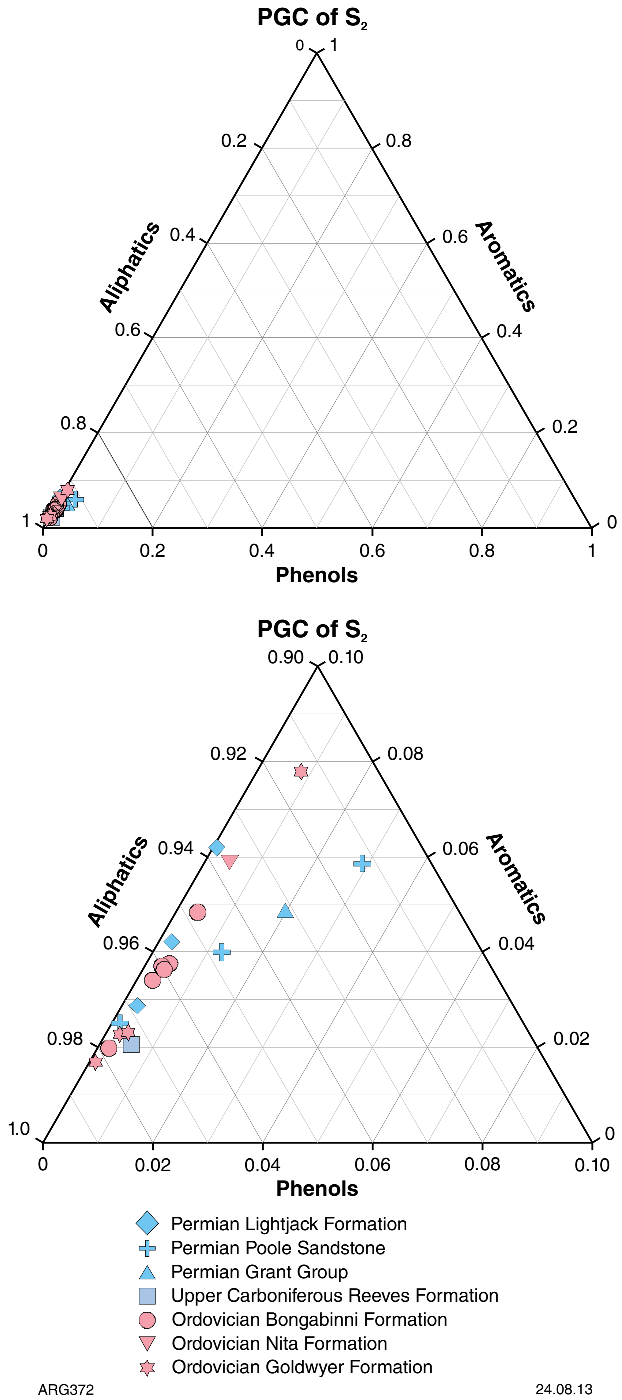

Figure 14. Normalized aliphatic, aromatic, and phenolic compounds in pyrolysate yield (S_2) of the Ordovician, upper Carboniferous, and Permian samples analysed by GSWA

anomalously high heat flow was modelled in Goodenia 1 (160 mW/m²); both wells were located on the Barbwire Terrace. Estimated heat-flow values are generally lower in sub-basins and higher on uplifted platforms and terraces (Figs 23 and 24).

Apatite fission track analysis (AFTA)

AFTA constrains paleotemperatures and the time of cooling from peak temperatures. Fission-track ages are largely a function of track annealing in response to an increase in temperature of between about 50 and 120°C, and track length reflects the style of cooling. Vitrinite reflectance (VR) data are used to constrain the range of paleotemperatures, since apatite fission tracks are totally annealed above approximately 110ºC. This temperature corresponds to a vitrinite reflectance range of 0.7 – 0.9%.

GSWA analysed 40 rock samples for AFTA (Fig. 25) from Precambrian, Ordovician, Devonian, Carboniferous, Permian, and Jurassic successions that were intersected in seven wells. The quantity and quality of apatite grains, the basic analytical results, and their interpretation are reported by Duddy et al. (2006), Ghori and Haines (2006a), Green (2006), and Ghori (2011). AFTA data indicate at least three major regional episodes of heating and cooling (burial and erosion); the first occurred between 230–195 Ma (Triassic–Jurassic), the second between 110–85 Ma (Cretaceous), and the third between 35–0 Ma (Cenozoic). These regional paleothermal events vary locally, from sub-basin to sub-basin or well to well.

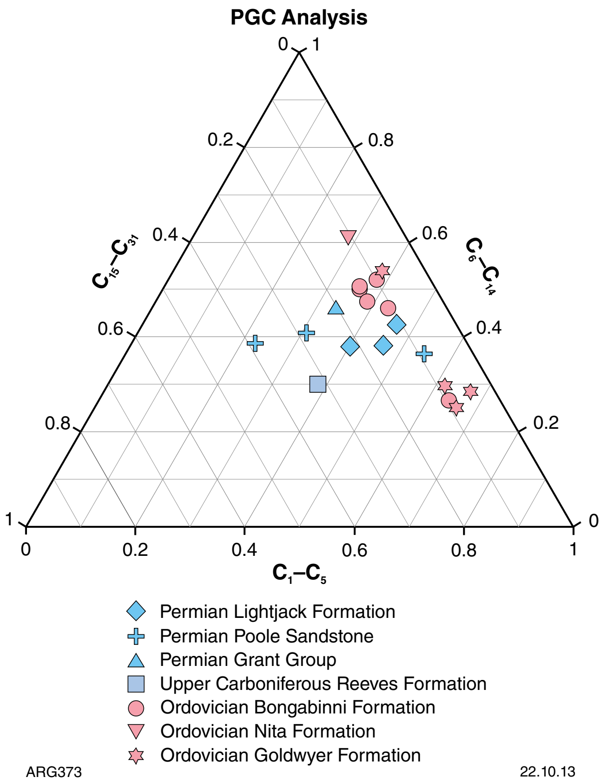

Figure 15. Normalized C_1–C_5, C_6–C_{14}, and C_{15}–C_{15+} aliphatic compounds in pyrolysate yield (S_2) of the Ordovician, upper Carboniferous, and Permian samples analysed by GSWA

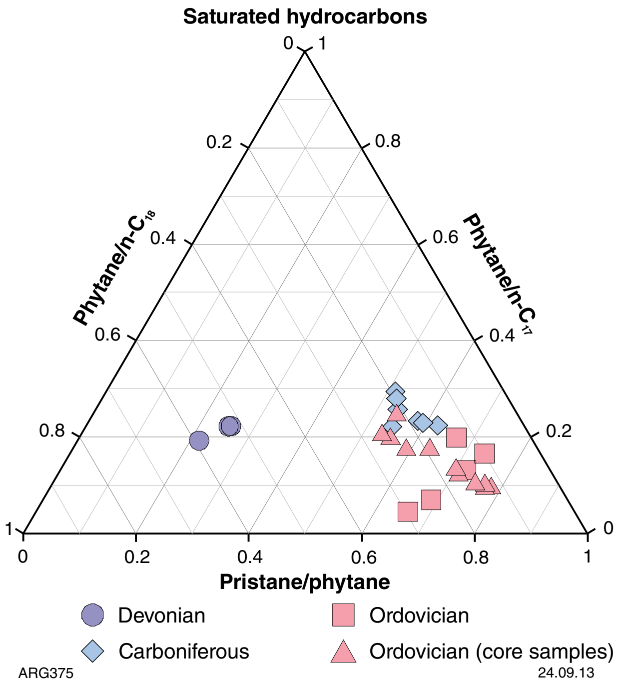

Figure 17. Correlation by gas chromatography of saturated hydrocarbons for the Ordovician, Devonian, and Carboniferous crude oil and rock-extract samples, analysed by GSWA, based on pristane/phytane, phytane/C_{18}, and pristane/C_{17} plot

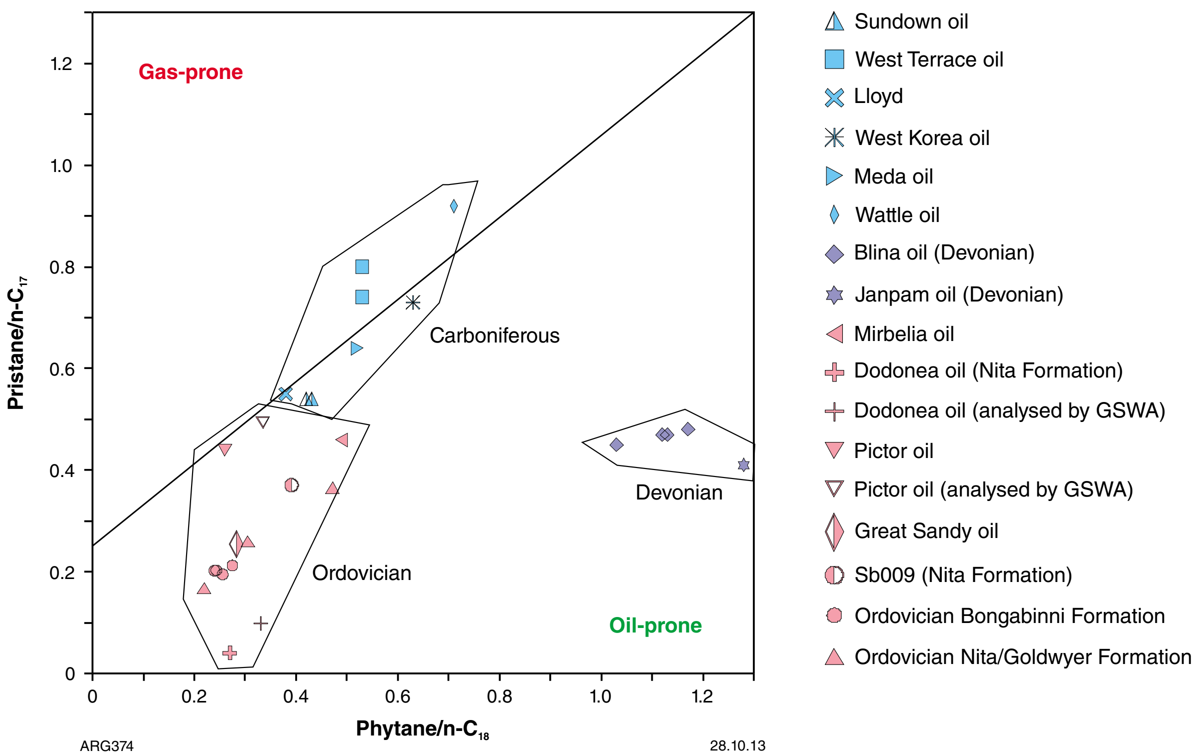

Figure 16. Correlation by gas chromatography of saturated hydrocarbons for the Ordovician, Devonian, and Carboniferous crude oil and rock-extract samples, based on phytane/C_{18} versus pristane/C_{17} plot

Table 1. Selected gas chromatography parameters for samples from the Canning Basin

Well	*Depth (m)*	*Sample type*	*Pristane/ phytane*	*Pristane/ n-C_{17}*	*Phytane/ n-C_{18}*	*CPI*[(a)]	*Formation*	*Age*
Sundown		Crude oil	1.41	0.54	0.43	1.08	Grant Gp	Carboniferous
Sundown		Crude oil	1.44	0.54	0.42	1.14	Grant Gp	Carboniferous
Wattle		Crude oil	1.40	0.92	0.71	0.99	Grant Gp	Carboniferous
West Terrace		Crude oil	1.47	0.80	0.53	1.08	Grant Gp	Carboniferous
West Terrace		Crude oil	1.46	0.74	0.53	1.08	Grant Gp	Carboniferous
Lloyd		Crude oil	1.60	0.55	0.38	1.11	Anderson	Carboniferous
Meda		Crude oil	1.40	0.64	0.52	1.14	Laural	Carboniferous
West Kora		Crude oil	1.42	0.73	0.63	nd[(b)]	nd	Carboniferous
Mirbelia		Crude oil	1.19	0.46	0.49	0.95	Millinjierie	Devonian
Blina		Crude oil	0.57	0.47	1.12	1.12	Nullara	Devonian
Blina		Crude oil	0.58	0.48	1.17	0.97	Nullara	Devonian
Blina		Crude oil	0.58	0.47	1.13	1.00	Nullara	Devonian
Blina		Crude oil	0.59	0.45	1.03	0.95	Nullara	Devonian
Janpam North		Crude oil	0.47	0.41	1.28	1.08	Nullara	Devonian
Dodonea		Crude oil	0.62	0.04	0.27	0.88	Goldwyer	Ordovician
Dodonea 1[(c)]	1519.0	Crude oil	0.97	0.10	0.33	nd	Goldwyer	Ordovician
Great Sandy 1		Crude oil	1.39	0.25	0.28	1.05	Nita	Ordovician
Pictor		Crude oil	1.97	0.44	0.26	1.12	Nita	Ordovician
Pictor 1		Crude oil	1.70	0.49	0.33	1.03	Nita	Ordovician
ABRD009	1423.8	Core	1.34	0.37	0.39	1.02	Nita	Ordovician
CRA DD86SS3	1451.9	Core	1.34	0.26	0.31	1.02	Nita	Ordovician
CRA DD88SS9	1360.1	Core	1.48	0.20	0.24	nd	Bongabinni	Ordovician
CRA DD88SS9	1390.6	Core	1.35	0.19	0.26	nd	Bongabinni	Ordovician
CRA DD86SS3	1467.7	Core	1.31	0.17	0.22	1.04	Goldwyer	Ordovician
Kunzia 1	373.9	Core	1.25	0.37	0.47	nd	Goldwyer	Ordovician
Sally May 2	1920.5	Core	1.25	0.44	0.54	1.05	Willara	Ordovician
Sally May 2	1988.2	Core	1.22	0.46	0.57	1.04	Willara	Ordovician
Pasminco BW26	281.5	Core	nd	0.45	nd	nd	Worral	Silurian
Pasminco BW26	386.9	Core	0.92	0.41	0.35	nd	Carrabiddy Gp	Ordovician

NOTES: (a) CPI = carbon preference index
(b) nd = no data
(c) Bold text = samples analysed by GSWA

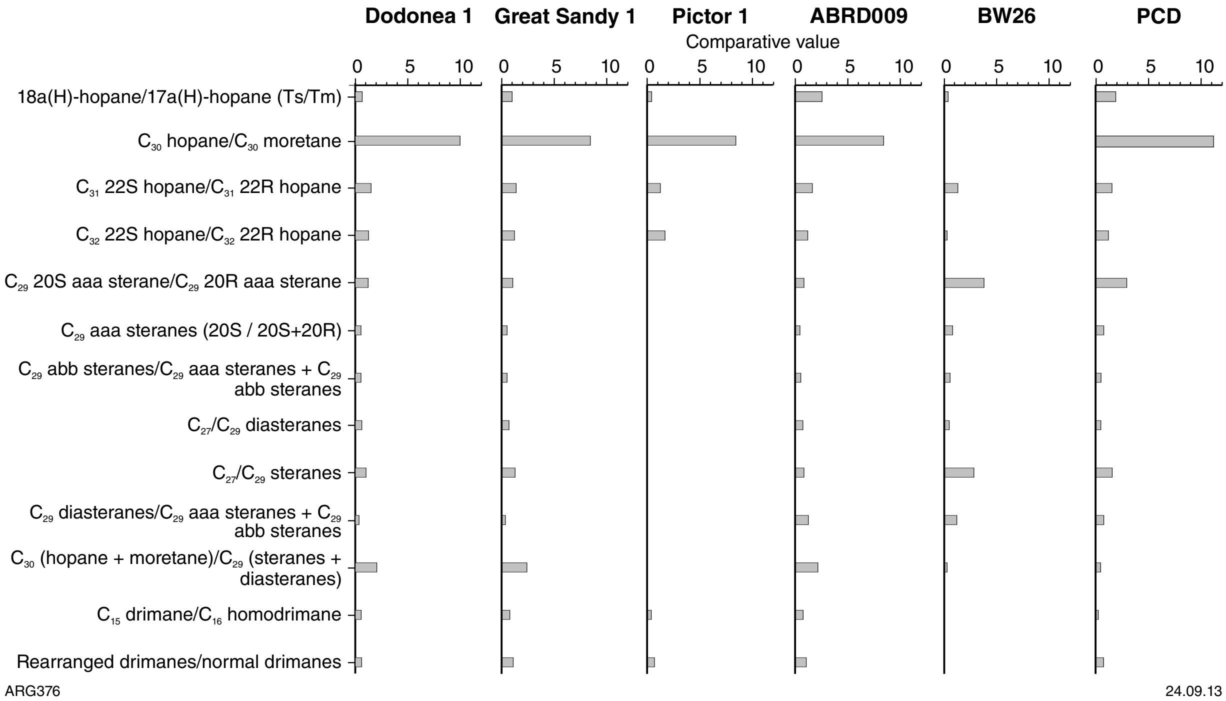

Figure 18. Comparision of selected saturated biomarkers for crude oil and rock-extract samples, analysed by GSWA

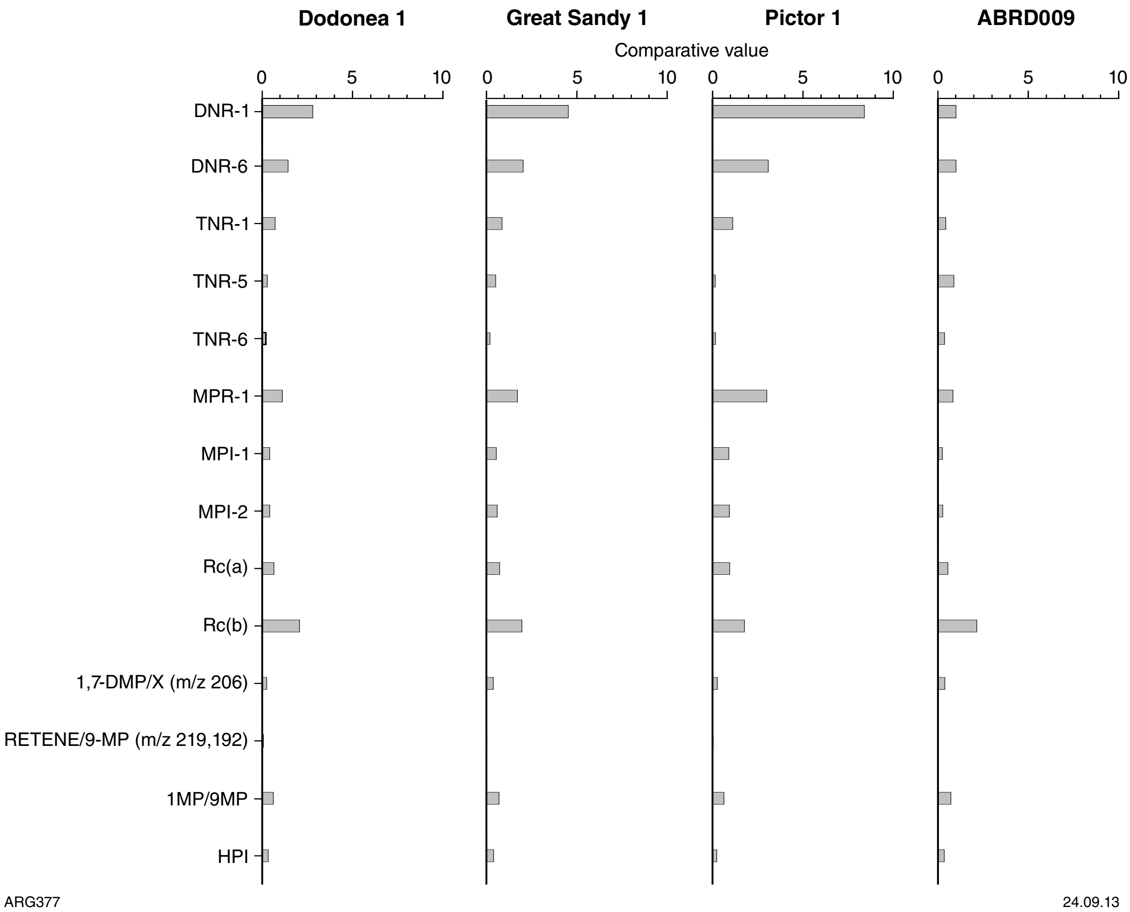

Figure 19. Comparision of selected aromatic biomarkers for crude oil and rock-extract samples, analysed by GSWA

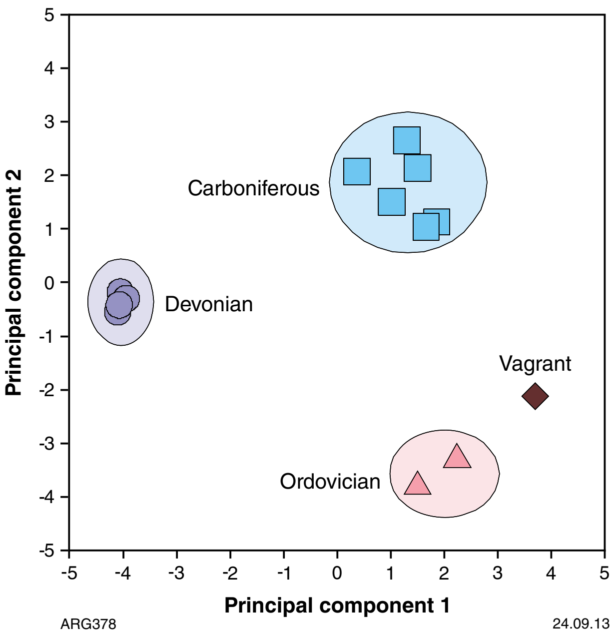

Figure 20. Chemometric charcterization of crude oil of the Canning Basin showing strong clustering by age (analyses by AGSO and GeoMark, 1996)

Modelling

BasinMod 2011 software (Platte River Associates) is used to model maturation and petroleum-generation history. In the modelling, transient heat flow was applied in order to link the thermal history with tectonically induced heat changes. This provides a direct interpretation in terms of the physical processes involved in basin formation (Gallagher and Morrow, 1998). BasinMod fluid-flow parameters are applied for estimating compaction, pressure, and reduction in porosity and permeability. Predicted maturity and oil windows are based on the Lawrence Livermore National Laboratory vitrinite and kerogen kinetics used by BasinMod.

The burial history was reconstructed from the rock unit thicknesses and lithologies interpreted in modelling wells, as well as events that occurred during times represented by unconformities. Then, the thermal history was reconstructed by adjusting thermal conductivities and heat flow to constrain the maturity model against measured corrected bottom hole temperatures (BHTs), % Ro, T_{max}, and AFTA to constrain present and paleotemperatures. Finally, kinetic modelling and reconstruction of petroleum generation, as a function of geothermal history and the type and amount of kerogen, was used to estimate the time of petroleum generation. The depth of the oil window is believed to be equivalent to the burial depths necessary to convert 10–90% of the available kerogen to petroleum. On the basis of the geochemical data, the Ordovician and Devonian – lower Carboniferous source rocks are assumed to contain mostly type II kerogen.

This study includes 1D modelling, which is generally referred to as maturity modelling, whereas multi-dimensional (2D) modelling is generally referred to as fluid-flow modelling. Most of the geological framework used in 1D maturity modelling is also used in 2D fluid-flow modelling; the latter uses the kinetics of hydrocarbon generation to produce the expulsion model. The thermal regimes used in 1D and 2D models are the same except for lateral heat transfer by convection or diffraction (Waples, 1998).

Lithology, TOC, Rock-Eval, VR, and temperature data available for modelling Acacia 1 and 2, Blackstone 1, Kidson 1, Lake Betty 1, Willara 1, and Yulleroo 1 are summarized in Figures 26 to 31. AFTA and VR data constrain the timing of paleothermal events (Fig. 25), temperature data constrain present-day subsurface temperatures, and TOC and Rock-Eval data constrain petroleum-generating potential of rocks.

Acacia 1 and 2

Acacia 1 and 2 are 98 m apart and located on the Barbwire Terrace, a narrow northwest-southeast trending structural high between the Crossland Platform in the southwest and the Fitzroy Trough and Gregory Sub-basin in the northeast (Fig. 1). Acacia 2 was used to model the petroleum charging time.

The Goldwyer Formation is 284 m thick in Acacia 2 and was penetrated at 758 m, whereas it is 287.5 m thick in Acacia 1 and was penerated at 750.5 m. It consists of interbedded calcareous shale, siltstone, and argillaceous limestone (Watson and Derrington, 1982). In these wells, oil-prone source beds have up to 4% TOC, a potential yield (S_2) of up to 37 mg/g rock, HI of up to 900 mg/g TOC, and T_{max} of up to 439ºC (Fig. 26). AFTA and VR data identified two paleothermal events: one in the Triassic–Jurassic and the second in the Cenozoic (Fig. 25). Modelling of Acacia 2 indicates that petroleum generation–migration–accumulation was during the Triassic–Jurassic paleothermal event (Fig. 32).

Blackstone 1

Blackstone 1 was drilled on the Lennard Shelf (Fig. 1); the shelf is producing commercial oil sourced from Devonian and lower Carboniferous rocks. In this well, the Goldwyer Formation consists of 740 m of interbedded limestone, dolomite and shale, and was penetrated at 2311 m; whereas the Laurel Formation consists of 93 m of interbedded shale, siltstone, and limestone (Johnson, 1968) and was intersected at 1486 m.

Source-rock analyses are available for 26 samples (Fig. 27). Of these, only one sample from the Laurel Formation is classified as having excellent oil-prone source beds with organic-richness up to 5% TOC, hydrogen index up to 419 mg /g TOC, and T_{max} up to 425ºC. AFTA and VR data identified one paleothermal event during the Triassic–Jurassic (Fig. 25). Modelling of Blackstone 1 indicates that petroleum generation–migration–accumulation took place during the Triassic–Jurassic paleothermal event for both the Goldwyer and Laurel Formations (Fig. 33).

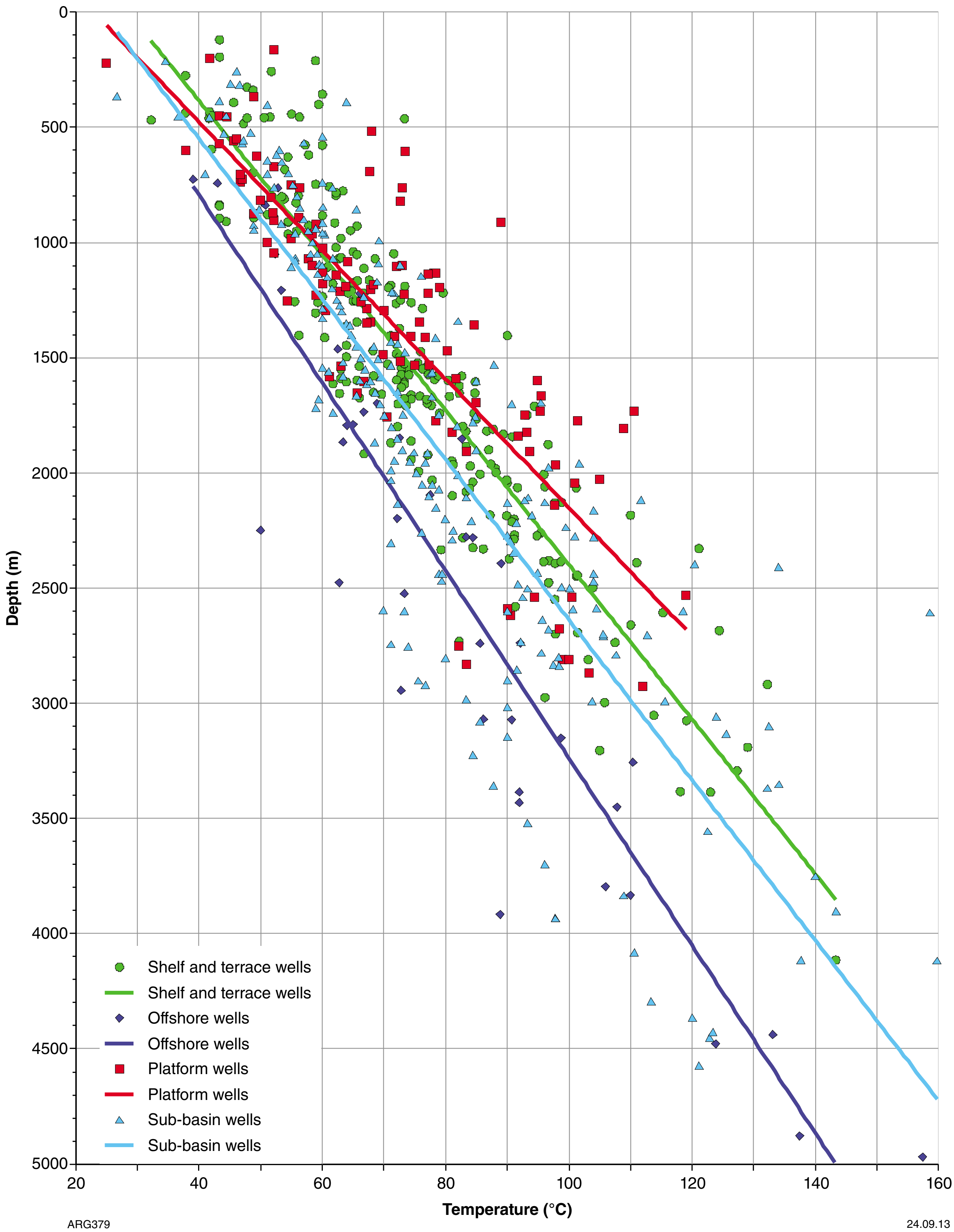

Figure 21. Estimated subsurface temperatures of the Canning Basin, based on recorded bottom hole temperatures (BHT) in petroleum wells

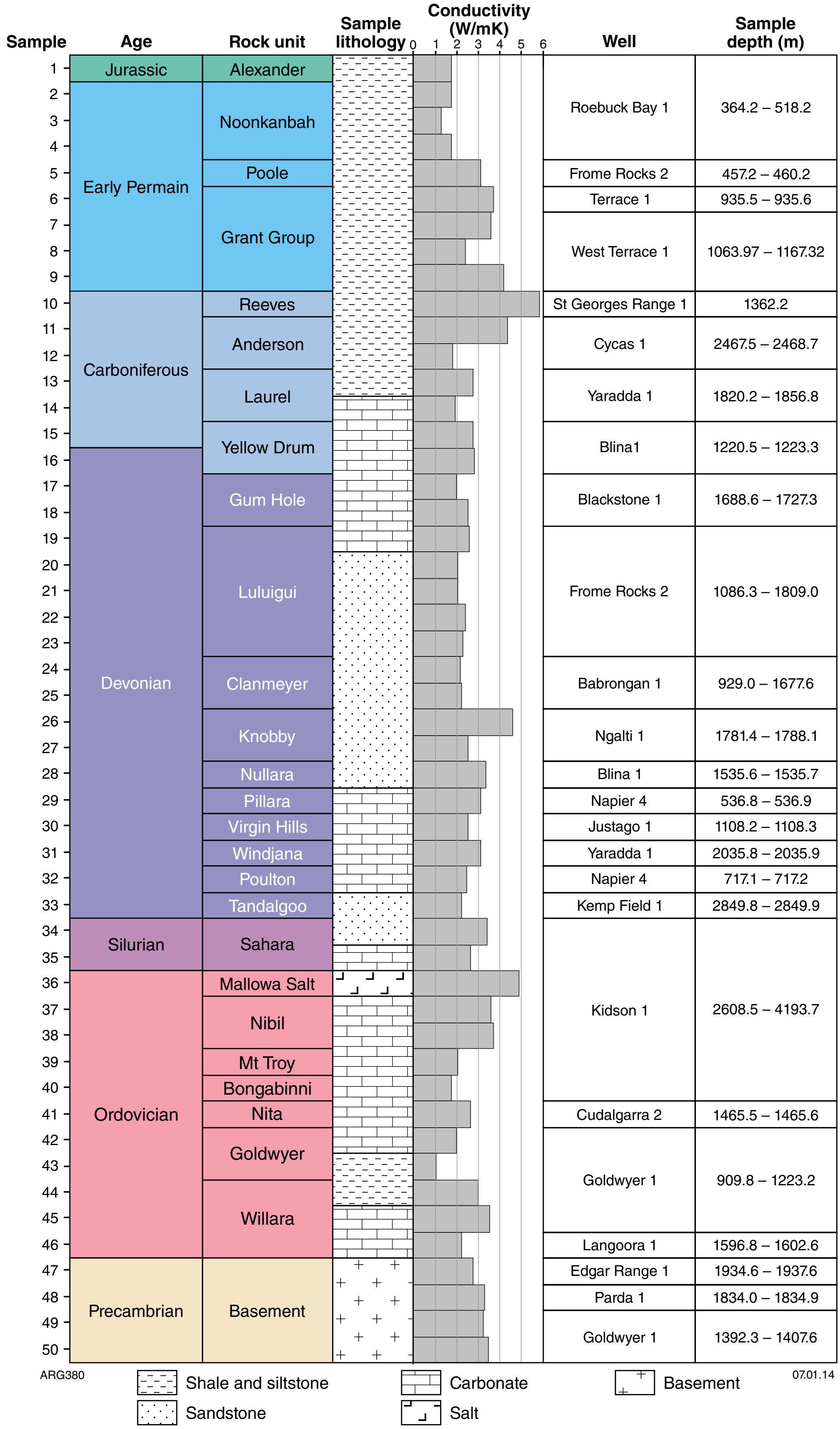

Figure 22. Measured thermal conductivity of the rock units in the Canning Basin (Driscoll et al., 2009)

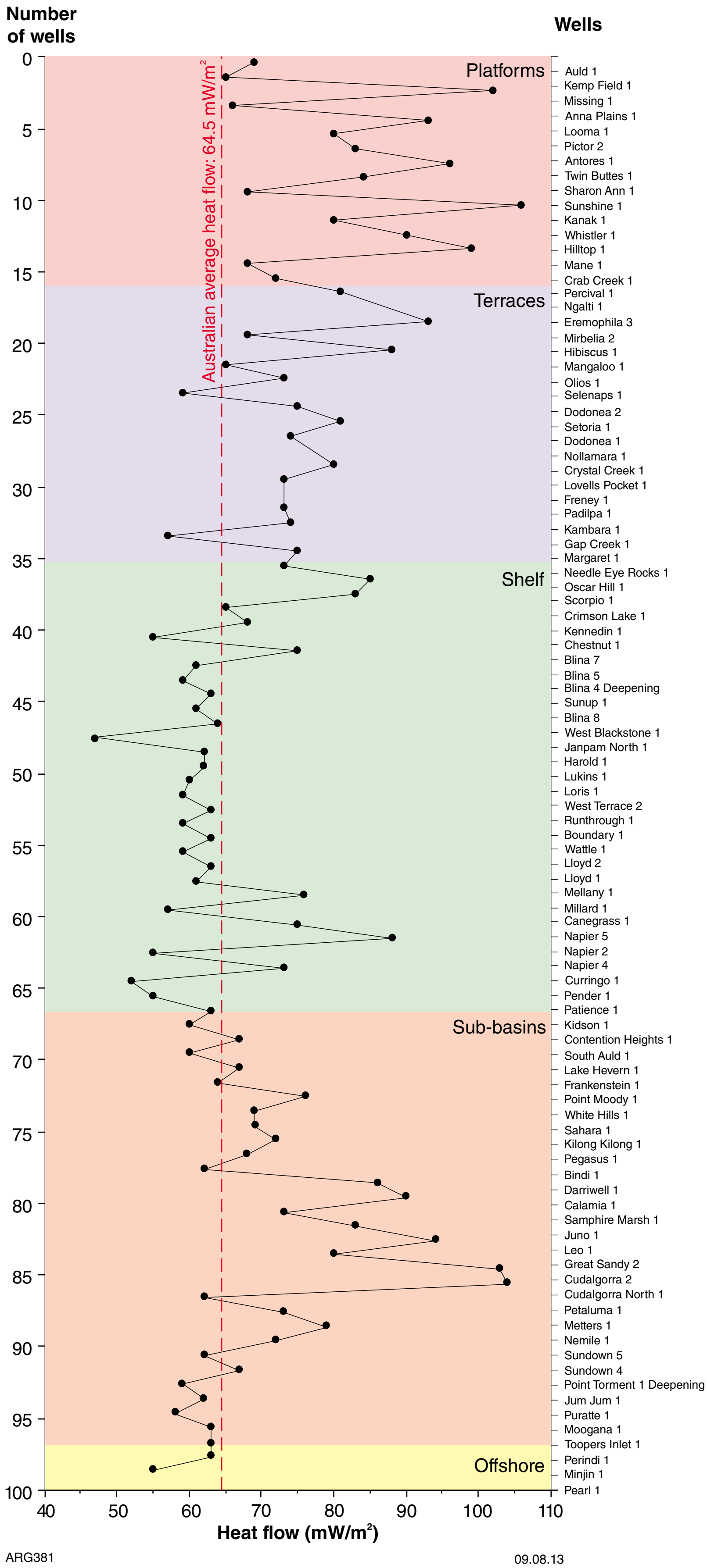

Figure 23. Estimated present-day heat flow from individual wells in the Canning Basin, based on one-dimensional modelling (Australian average heat flow, Driscoll et al., 2009)

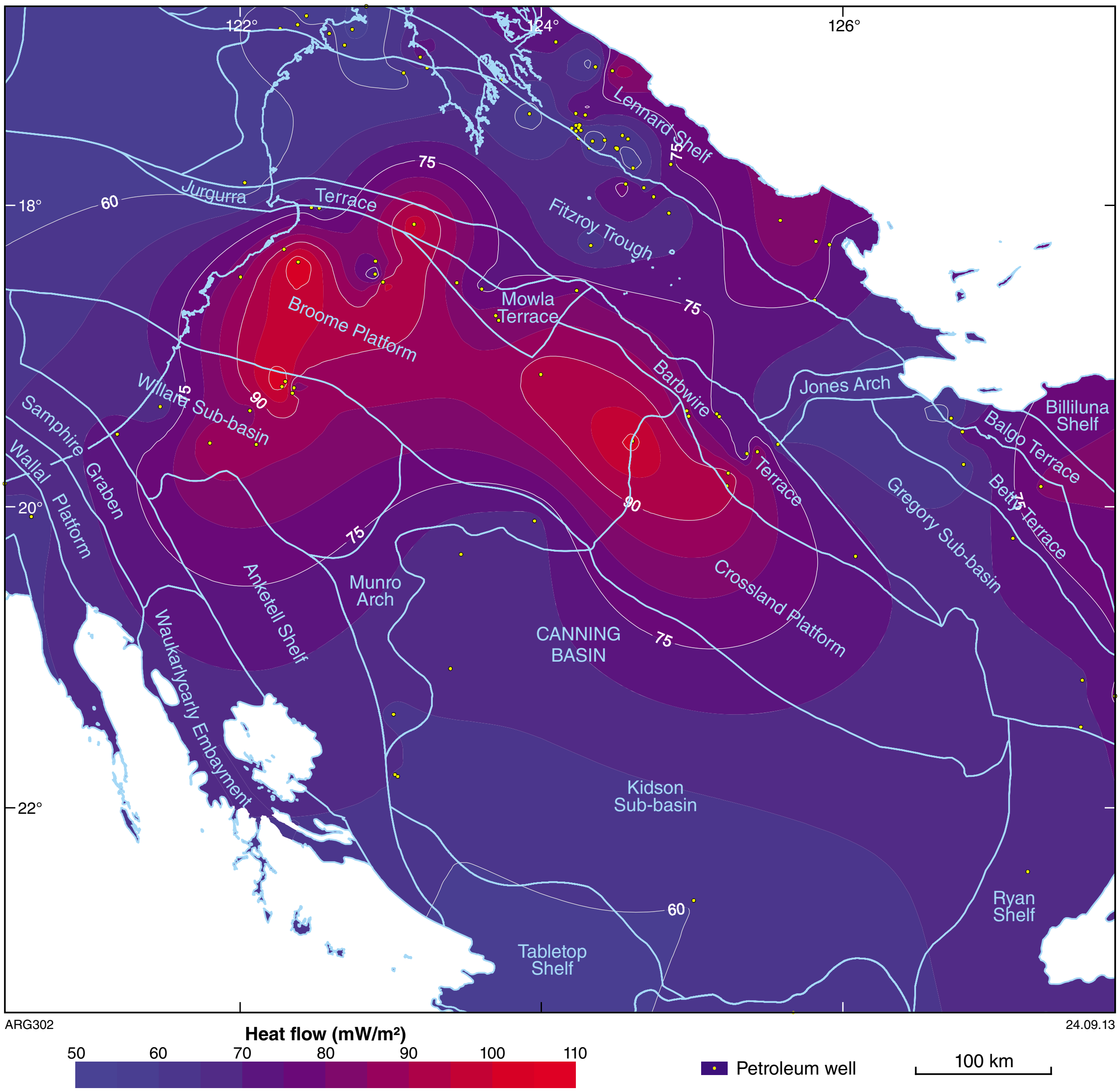

Figure 24. Map of the estimated present-day heat flow of the Canning Basin (Ghori, 2010)

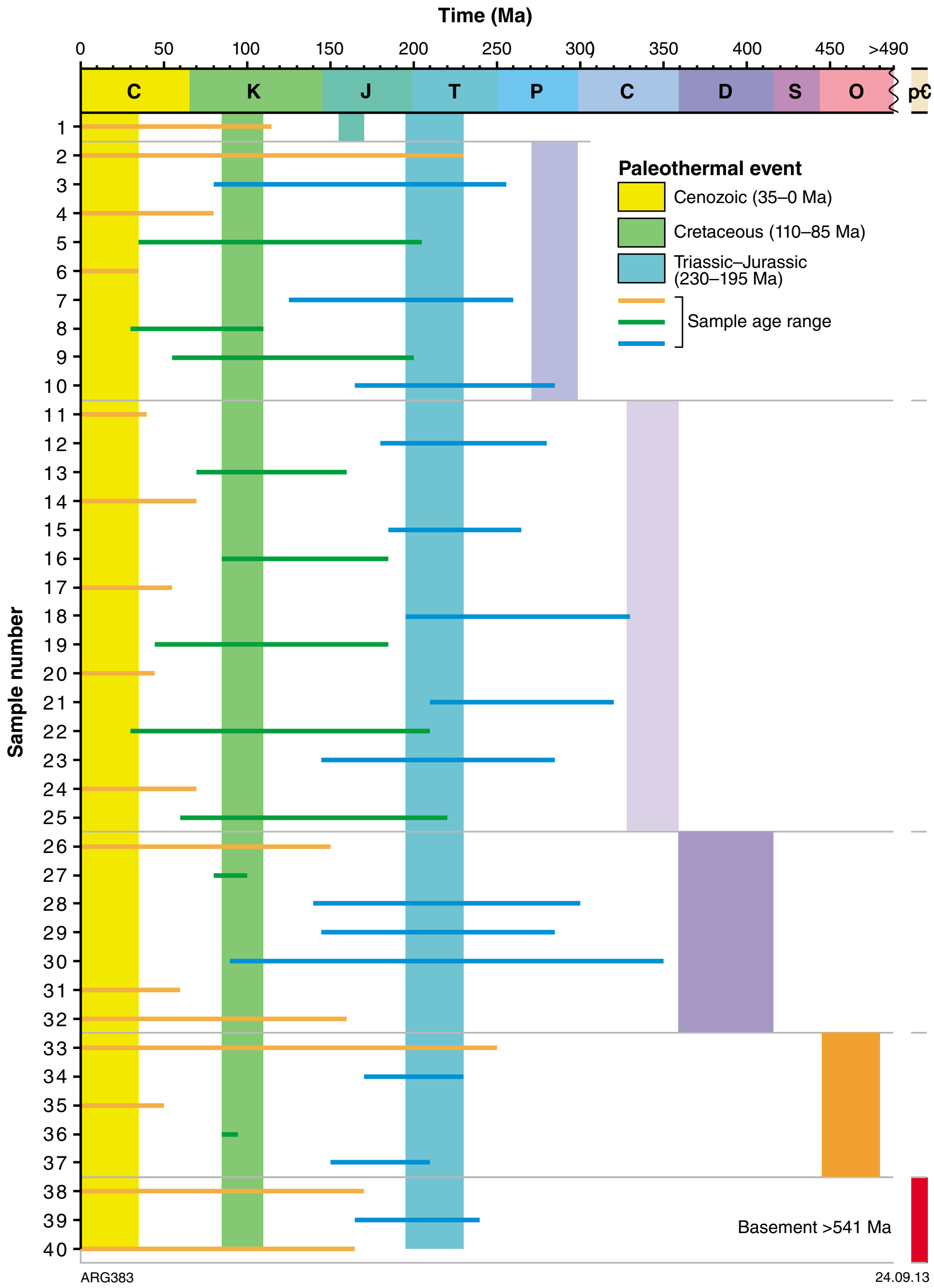

Figure 25. Timing of regional paleothermal events in the Canning Basin based on 40 apatite fission track analyses

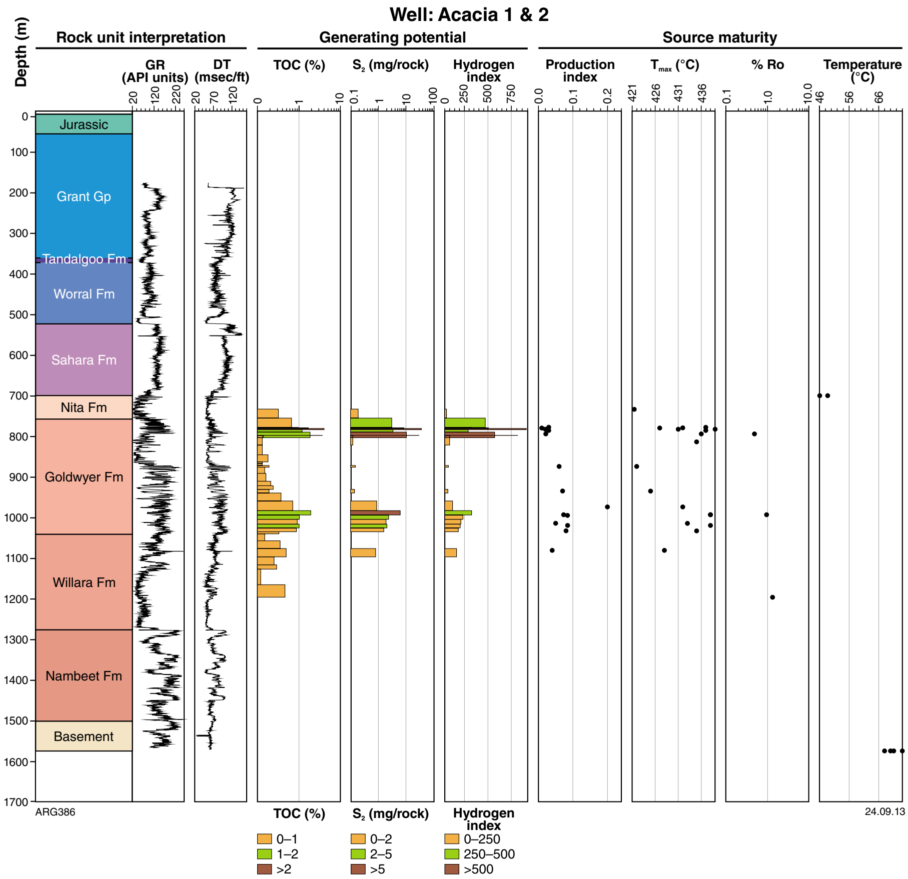

Figure 26. Geochemical log of Acacia 1 and 2 showing rock units and data used in modelling: gamma ray, sonic log, organic richness (TOC), generating potential (S_1 + S_2), kerogen type (HI), and maturity (% Ro)

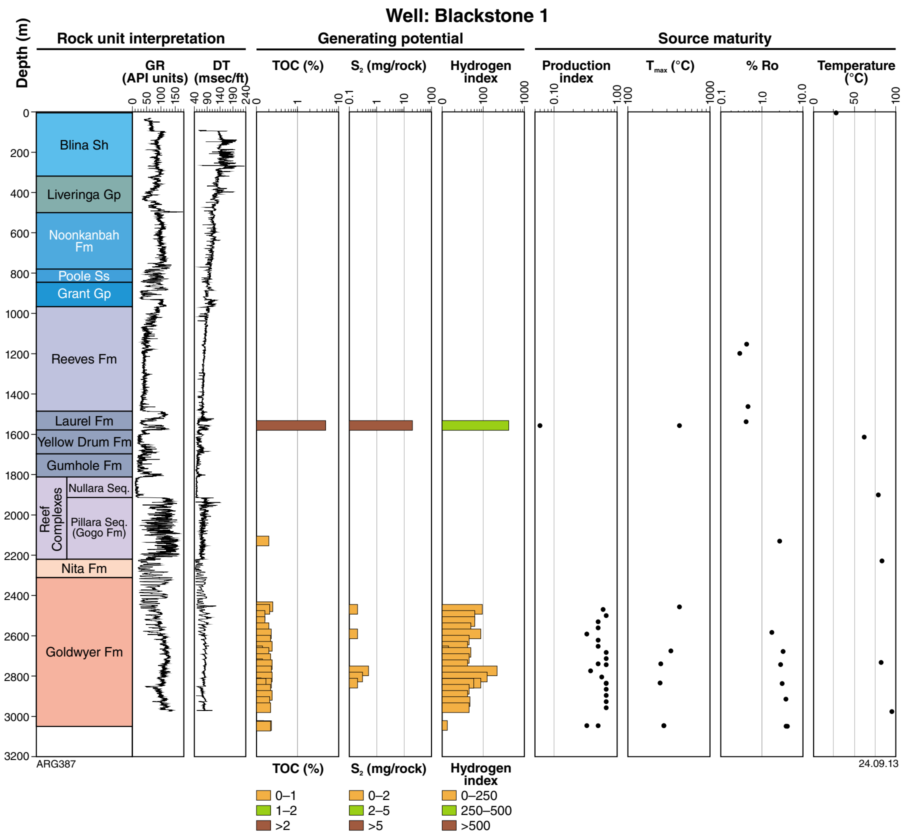

Figure 27. Geochemical log of Blackstone 1 showing rock units and data used in modelling: gamma ray, sonic log, organic richness (TOC), generating potential (S_1 + S_2), kerogen type (HI), and maturity (% Ro)

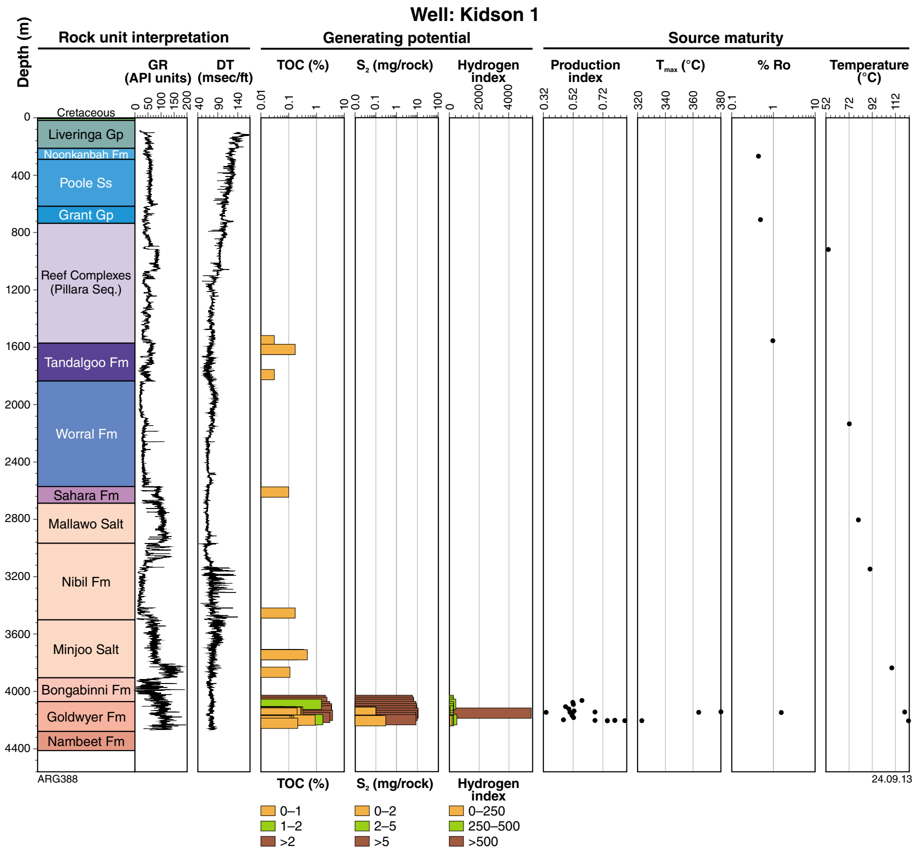

Figure 28. Geochemical log of Kidson 1 showing rock units and data used in modelling: gamma ray, sonic log, organic richness (TOC), generating potential (S_1 + S_2), kerogen type (HI), and maturity (% Ro)

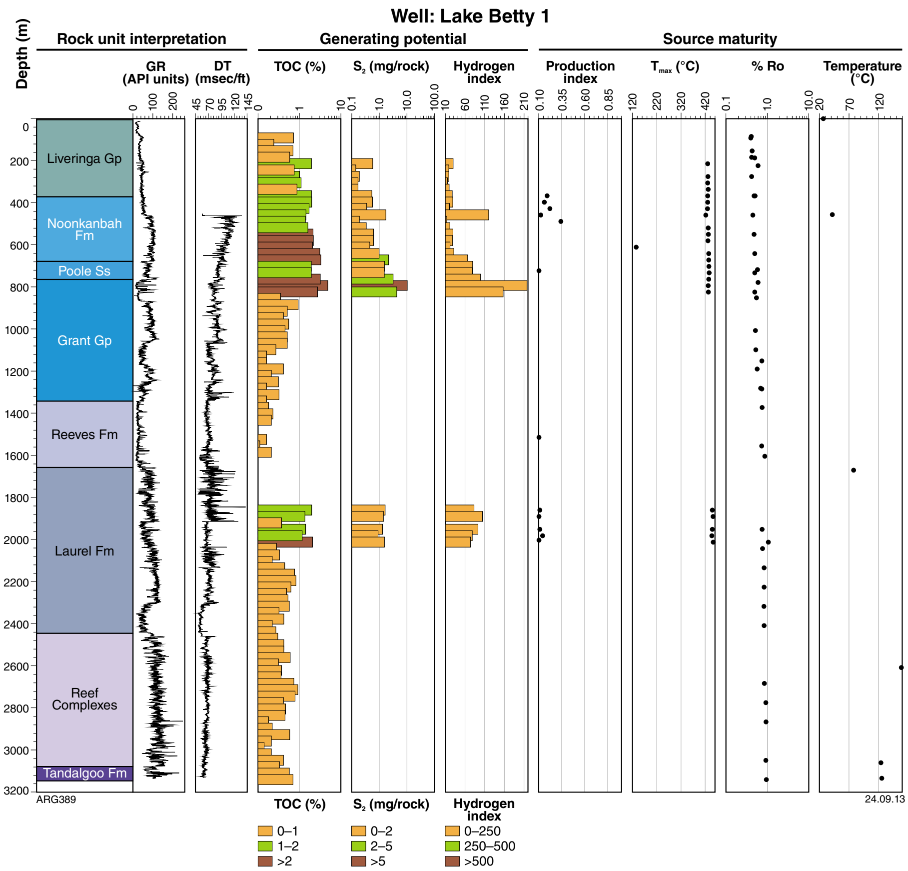

Figure 29. Geochemical log of Lake Betty 1 showing rock units and data used in modelling: gamma ray, sonic log, organic richness (TOC), generating potential (S_1 + S_2), kerogen type (HI), and maturity (% Ro)

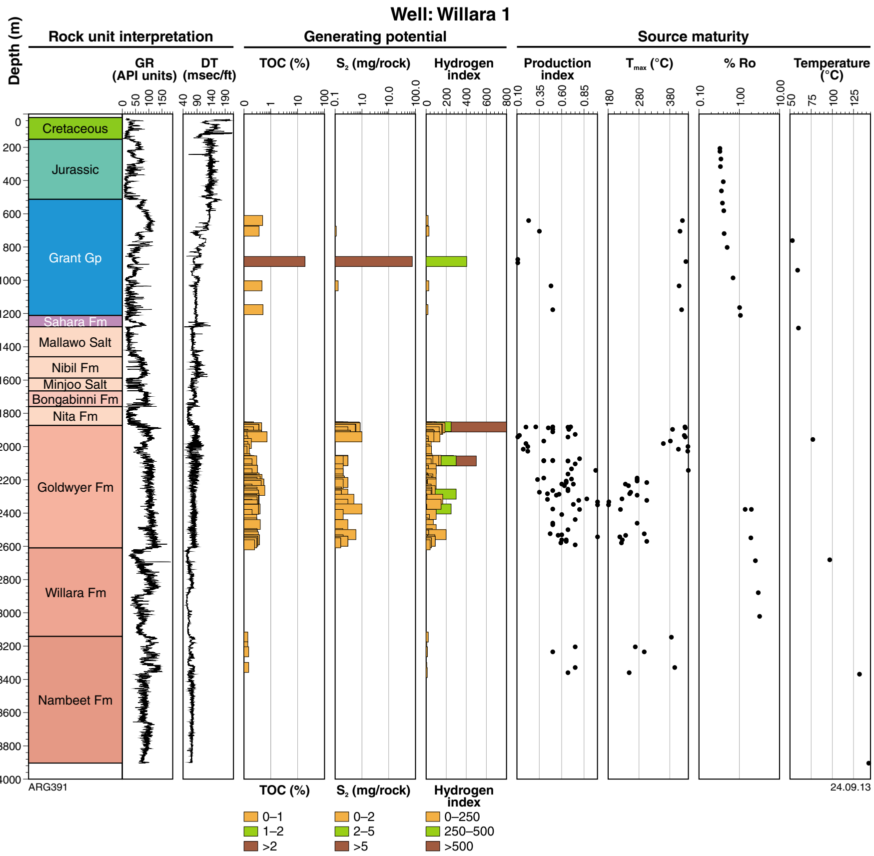

Figure 30. Geochemical log of Willara 1 showing rock units and data used in modelling: gamma ray, sonic log, organic richness (TOC), generating potential ($S_1 + S_2$), kerogen type (HI), and maturity (% Ro)

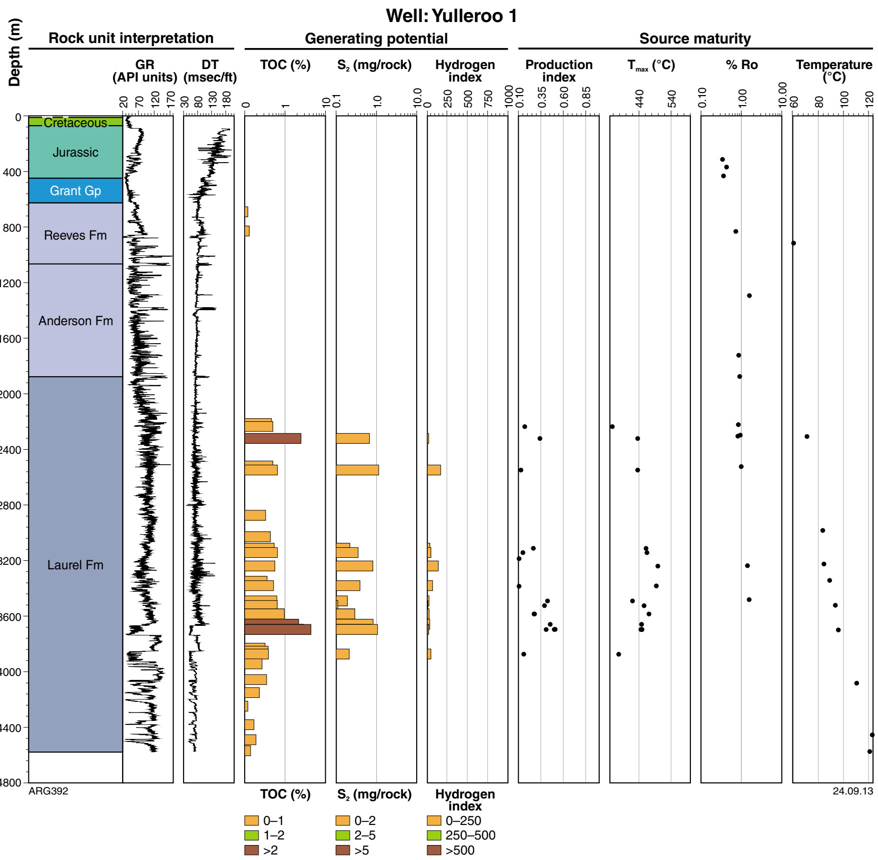

Figure 31. Geochemical log of Yulleroo 1 showing rock units and data used in modelling: gamma ray, sonic log, organic richness (TOC), generating potential ($S_1 + S_2$), kerogen type (HI), and maturity (% Ro)

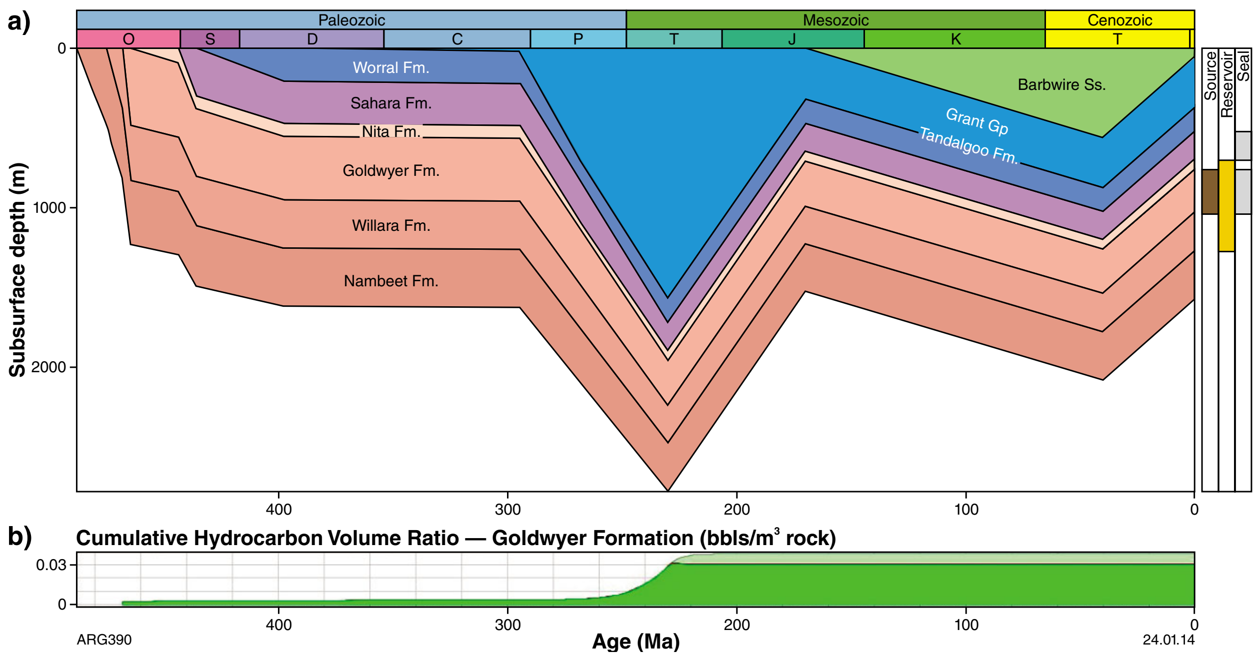

Figure 32. Basin modelling of Acacia 1 and 2 showing: a) burial history of the rocks; b) hydrocarbon-generation history of the Goldwyer Formation

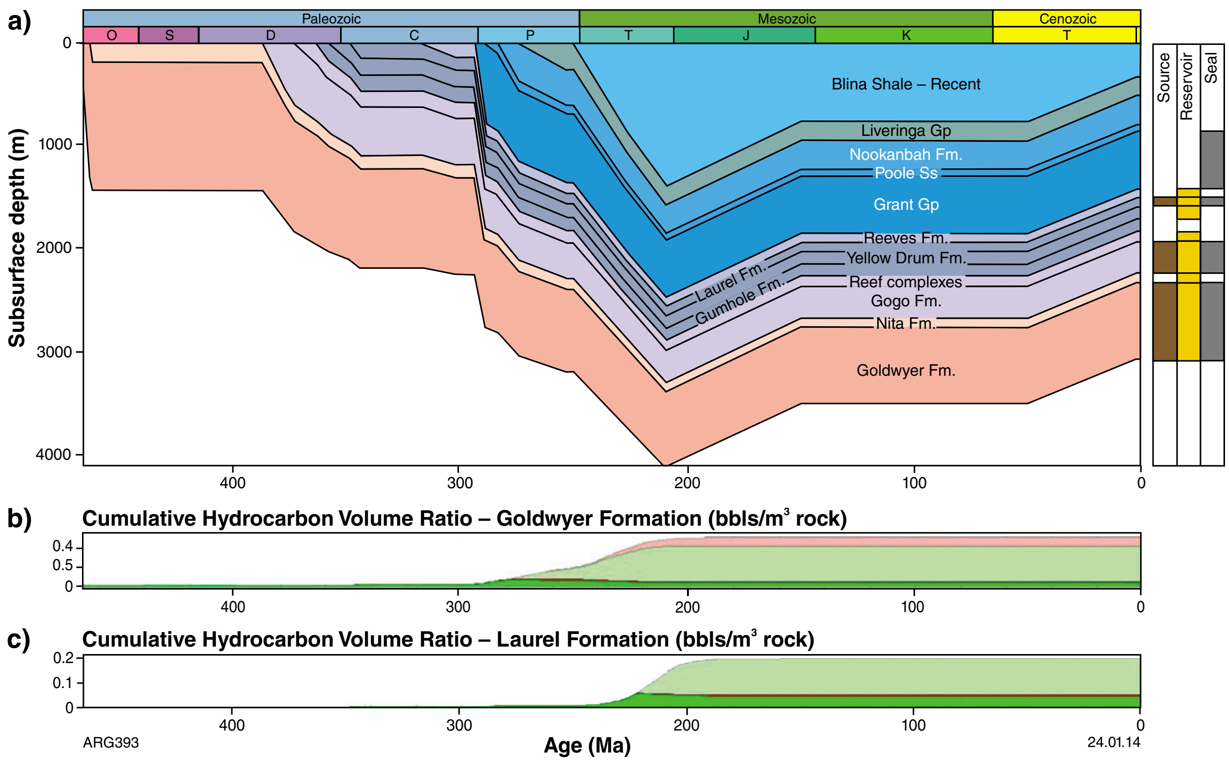

Figure 33. Basin modelling of Blackstone 1 showing: a) burial history of the rocks; b) the hydrocarbon-generation history of the Goldwyer Formation; c) the hydrocarbon-generation history of the Laurel Formation

At present, the thermal maturity of the Goldwyer Formation is at gas-generation level and the Laurel Formation is at oil-generation level.

Kidson 1

Kidson 1 was drilled as a stratigraphic test on a local high of a major structural terrace on the southern flank of the Kidson Sub-basin (Fig. 1). It is the deepest well in the Kidson Sub-basin, with a total depth of 4428.4 m. The Goldwyer Formation consists of interbedded shale, siltstone with minor limestone (Johnson, 1966a). It is 133.5 m thick and was penetrated at 4279.4 m in this well.

Source-rock analyses are available for 47 samples from Kidson 1 (Fig. 28), but these data are interpreted as unreliable due to contamination from oil used during drilling of the well. Limited TOC analysis of solvent-extracted samples indicates poor organic-richness. AFTA and VR data identified three regional paleothermal events: during the Triassic–Jurassic, Cretaceous, and Cenozoic (Fig. 25). Modelling for Kidson 1 indicates that petroleum generation–migration–accumulation took place before the Triassic–Jurassic paleothermal event (Fig. 34).

Lake Betty 1

Lake Betty 1 was drilled on the Betty Terrace which is the edge of the shelf associated with the Gregory Sub-basin (Fig. 1). The Laurel Formation mainly consists of a clastic sequence of shale, siltstone, and sandstone with minor limestone (Crank, 1972). In Lake Betty 1, it is 788 m thick and was penetrated at 1657 m.

Source-rock analyses are available for 95 samples. There are gas-prone, organic-rich intervals within the Liveringa Group, Noonkanbah Formation, Poole Sandstone, Grant Group, and Laurel Formation (Fig. 29). AFTA and VR data identified two paleothermal events: the first during the Triassic–Jurassic and the second during the Cenozoic (Fig. 25). Modelling of Lake Betty 1 indicates that petroleum generation–migration–accumulation took place during the Permian–Triassic paleothermal event (Fig. 35).

Willara 1

Willara 1 was drilled as a stratigraphic test within the Willara Sub-basin (Fig. 1), where the Goldwyer Formation is predominantly shale with minor limestone and siltstone (Johnson, 1966b). The Goldwyer is 736.5 m thick and was intersected at 1873.5 m in Willara 1.

Source-rock analyses are available for 99 samples (Fig. 30). All samples generally lack organic matter except one oil-prone, organic-rich sample within the Grant Group. AFTA and VR data identified one paleothermal event during the Cretaceous (Fig. 25). Modelling of Willara 1 indicates that petroleum generation–migration–accumulation took place during the Early Cretaceous. The basin has subsided gradually since the Silurian and it attained its maximum burial depth during the Cretaceous paleothermal event (Fig. 36).

Yulleroo 1

Yulleroo 1 is located in the western part of the Fitzroy Trough near the northern flank of the Jurgurra Terrace (Fig. 1). It was drilled on the south-eastern flank of the Yulleroo structure, where structure development was initiated during the upper Carboniferous after the deposition of the Carboniferous succession. The Laurel Formation consists of shale and sandstone with minor carbonates, and in Yulleroo 1 it is 2695 m thick and was penetrated at 1876.5 m. Gas was recovered from 3243–3355 m at an estimated rate of 1700 cubic meters per day (60 000 cubic feet per day) during well testing (Bischoff, 1968).

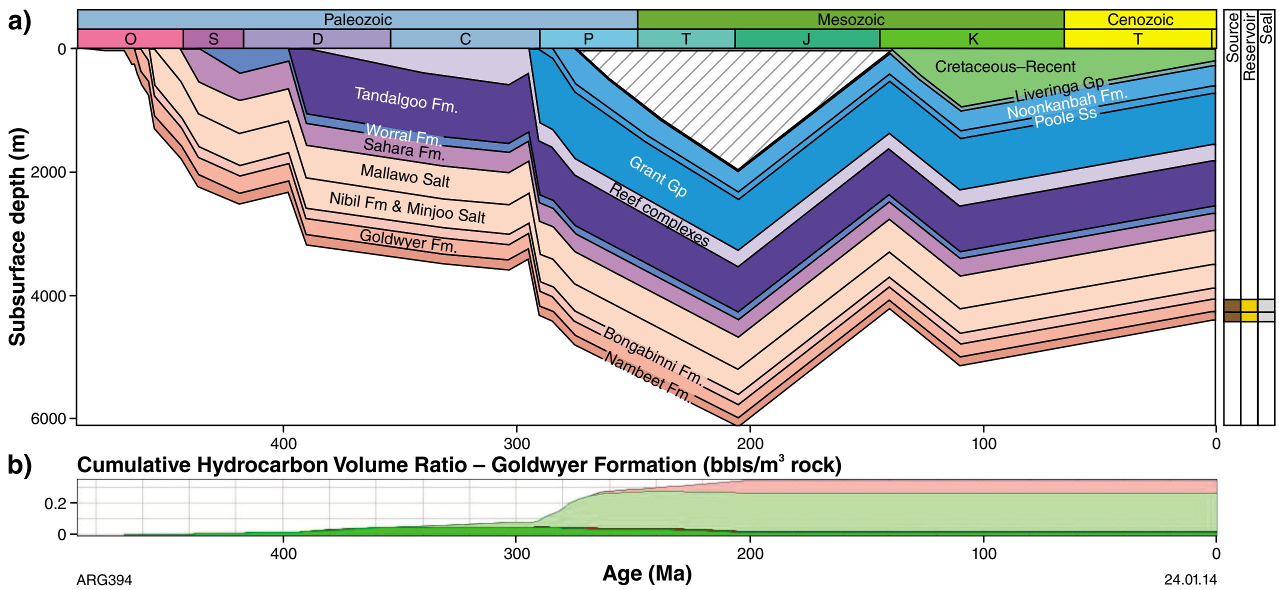

Figure 34. Basin modelling of Kidson 1 showing: a) burial history of the rocks; b) the hydrocarbon-generation history of the Goldwyer Formation

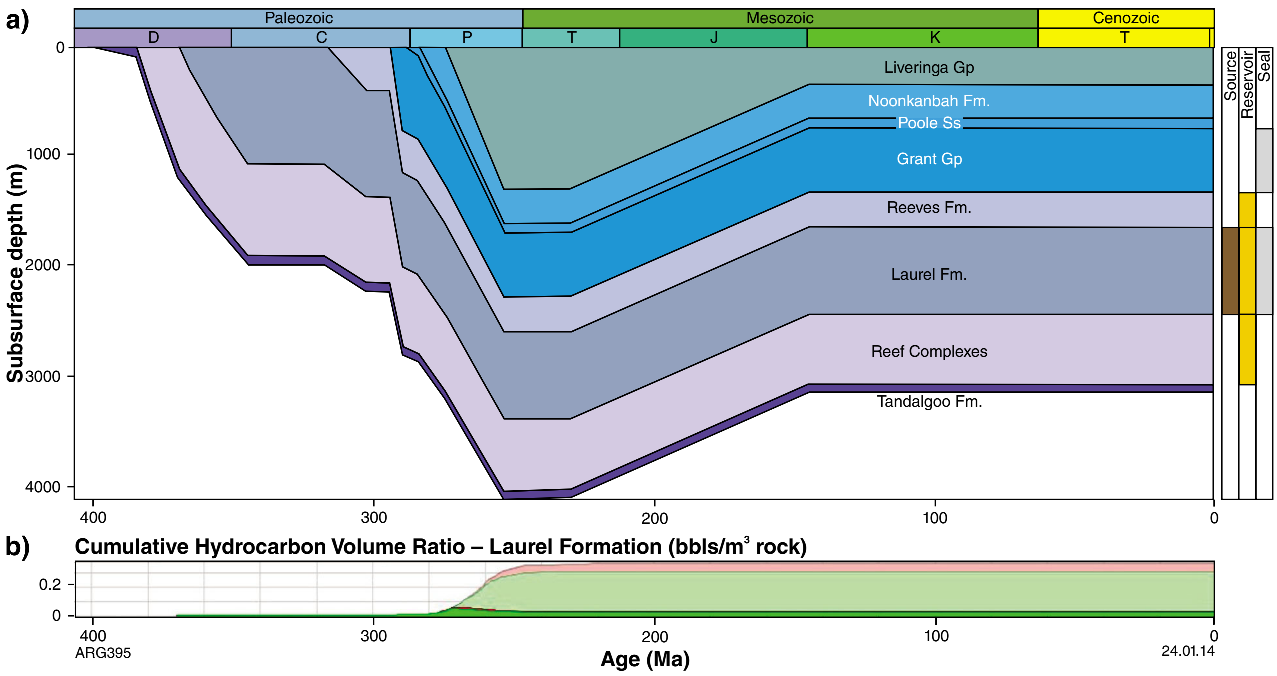

Figure 35. Basin modelling of Lake Betty 1 showing: a) burial history of the rocks; b) the hydrocarbon-generation history of the Laurel Formation

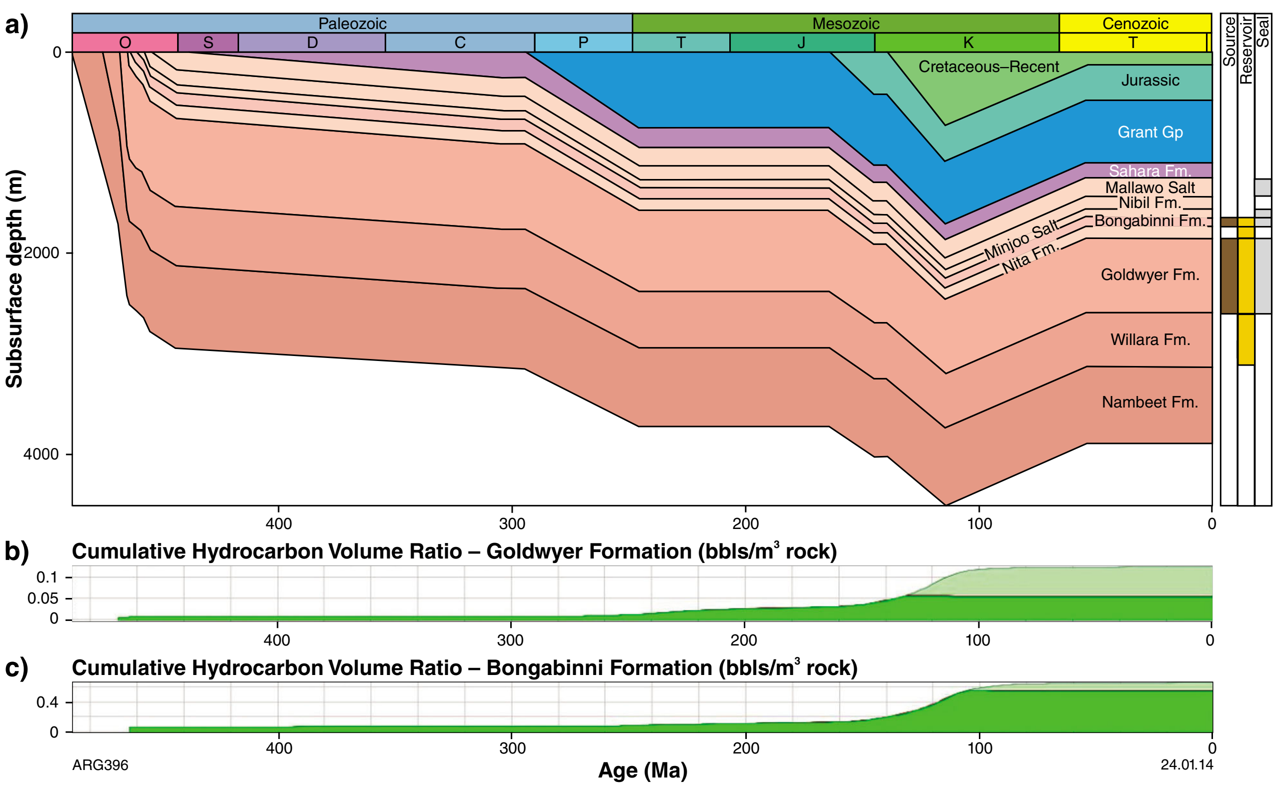

Figure 36. Basin modelling of Willara 1 showing: a) burial history of the rocks; b) the hydrocarbon-generation history of the Goldwyer Formation; c) the hydrocarbon-generation history of the Bongabinni Formation

Source-rock analyses for 32 samples (Fig. 31) indicate gas-prone, organic-rich intervals with low generating potential within the Laurel Formation at Yulleroo 1. AFTA and VR data identified three local paleothermal events: during the Carboniferous–Triassic, Jurassic– Cretaceous, and the Cenozoic. Modelling of Yulleroo 1 indicates that petroleum generation–migration–accumulation took place during the Carboniferous–Triassic paleothermal event (Fig. 37).

Potential self-contained petroleum systems

Recent work on porosity in petroleum reservoirs indicates that there is a continuum from a pore-throat size greater than 2 µm in conventional reservoirs, to 2 – 0.03 µm in tight-gas sandstone, and 0.1 – 0.005 µm in shale (Nelson, 2009). In tight-reservoir systems, trapping mechanisms are typically subtle and can cover large basinal areas (Curtis, 2002; Law and Curtis, 2002), and the timing of charge versus trap formation is not as critical as it is in conventional reservoir systems.

Shale source rocks retain a vast quantity of petroleum even after expelling significant petroleum to conventional reservoirs. These are texturally and mineralogically heterogeneous, so that apparently similar looking shales often have different source-rock characteristics (Durham, 2010; Aplin and Macquaker, 2011). The geochemical, geomechanical, and petrophysical properties of source rocks determine the potential difficulty of unlocking petroleum retained in the source rock. Unlocking to commercialize shale petroleum is mostly accomplished by horizontal drilling and hydraulic fracturing (Jacobi et al., 2008; Jacobi et al., 2009).

In the Canning Basin, organic-rich shale beds within the Ordovician Goldwyer and Bongabinni Formations are oil prone; organic richness is up to 60% in the Bongabinni Formation and >5% in the Goldwyer Formation. The Devonian Gogo Formation and its equivalents, and the lower Carboniferous Laurel Formation, contain organic-rich (>5%) oil-prone intervals. These shale plays are comparable to producing plays within the lower Carboniferous (Mississippian) Barnett, Fayetteville, and Woodford Shales, and the Devonian Marcellus Shale of the US. Scott (1998) compared the Pennsylvanian carbonate–evaporite, self-sourcing reservoir within the Cane Creek Shale of the Paradox Basin, with the Goldwyer–Nita–Carribuddy system of the Canning Basin. Kuuskraa et al. (2011) estimated the shale-gas resource for the Ordovician Goldwyer Formation to be up to 229 trillion cubic feet (Tcf), or 6.49 trillion cubic metres (Tm^3), of gas. Kuuskraa et al. (2013) revised the estimated shale-petroleum resource for the Goldwyer Formation to be up to 235 Tcf (6.67 Tm^3) of gas and 9.75 billion barrels (1.55 billion kilolitres) of oil. Exploration is at a very early stage and more work is needed to verify these estimates. New Standard recently drilled the Nicolay 1 well to evaluate shale-gas potential within the Goldwyer Formation.

Foster et al. (1986) estimated that the richest oil-prone source beds in the upper Goldwyer Formation on the Barbwire Terrace could generate more than 61 billion barrels (9.7 billion litres). For the eastern Canning Basin, Wulff (1987) estimated the cumulative petroleum-generative potential for the Goldwyer Formation at about 11 080 million barrels (1.76 billion litres) per cubic kilometre. These estimates, even if highly optimistic, rank the petroleum-generating potential of the Goldwyer Formation as enormously higher than anything yet discovered within the Ordovician–Silurian succession of the Canning Basin.

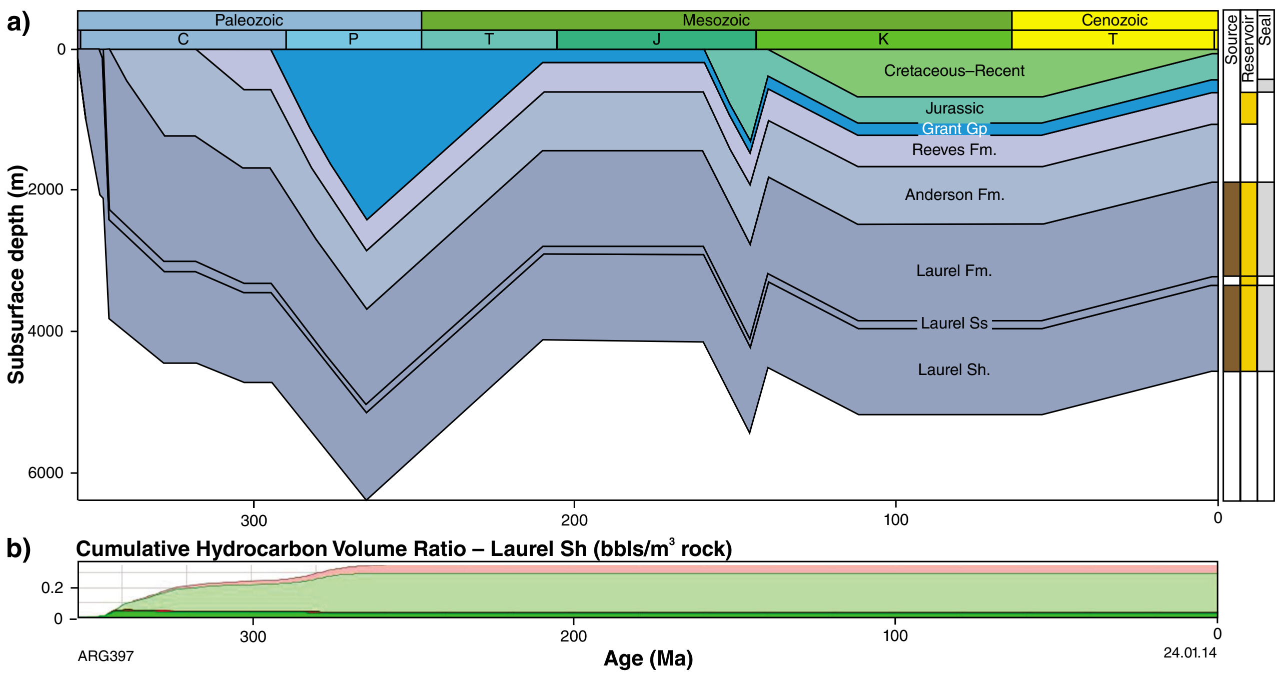

Figure 37. Basin modelling of Yulleroo 1 showing: a) burial history of the rocks; b) the hydrocarbon-generation history of the Laurel Formation

Exploration for organic-rich shale plays in the Canning Basin will benefit from new geological techniques, as well as new drilling and production technologies, most of which have been developed in the US. Over the last 30 years, the US has enjoyed vast increases in production, with drilling of over 102 000 successful production wells. By comparison, the Canning Basin remains vastly under explored, as it is remotely located to markets, has few roads and little or no infrastructure.

Petroleum systems

GSWA and legacy petroleum company data indicate that the Larapintine Petroleum Supersystem is composed of three separate petroleum systems (L2, L3, and L4 in Fig. 2) sourced from: the Ordovician Goldwyer Formation, the Devonian Gogo Formation, and the lower Carboniferous Laurel Formation. These source rocks, and the organic-rich Permian succession (Gondwannan Superpetroleum System), may comprise potential self-contained petroleum systems within the onshore Canning Basin.

Ordovician source rocks

Petroleum systems sourced by the Ordovician Goldwyer and Bongabinni Formations are present within the Ordovician–Silurian succession (Fig. 2); reservoirs within the Nita and Willara Formations are overlain by thick salts of the Carribuddy Group with excellent sealing capacities. The succession is sandwiched between tectonic events favourable for trap development: Early Ordovician extension (Samphire Marsh Movement) followed by Early Devonian compression (Prices Creek Movement). Significant oil and gas have been discovered in the Pictor and Dodonea areas and oil has been recovered in Percival 1, Solanum 1, Edgar 1, Cudalgarra 1, Great Sandy 1, and Leo 1 (Cadman et al., 1993). These wells are located on the terraces at the northern border of the platform areas (Figs 1 and 2).

The Goldwyer Formation has an average thickness of about 400 m across the basin. The thickest estimated section is 739 m in Blackstone 1 on the Lennard Shelf, and it is 736 m thick in Willara 1 in the Willara Sub-basin. The formation has been intersected in about 60 petroleum and 13 mineral exploration wells, most of which are located south of the Fitzroy Trough. The exceptions are Blackstone 1, West Blackstone 1, Lovell's Pocket 1, and Tappers Inlet 1 which are all located to the north of the Fitzroy Trough.

The Goldwyer Formation is mudstone dominated in deeper basinal areas and carbonate dominated on platforms and terraces (Haines, 2004). The distribution of laminated-mudstone source facies and the petroleum-generating potential of the Goldwyer Formation vary greatly across the basin. Current available geochemical data indicate that the best source potential is found on the platform and terrace south of the Fitzroy Trough, with lower potential in the Willara and Kidson Sub-basins.

The Bongabinni Formation is mainly developed within the southern Canning Basin. The formation is dominated by red-brown mudstone in most areas, except the Admiral Fault Zone where it forms the most organic-rich, oil-prone source rocks of the Canning Basin. It is 208 m thick in Kidson 1 within the Kidson Sub-basin, less than 100 m thick in the Willara Sub-basin and Broome Platform, and about 30 m thick on the terraces (Haines, 2004). Shale-like beds up to about one metre thick are intersected in several fully cored mineral boreholes on the Admiral Fault Zone, where the cumulative thickness of the Bongabinni Formation exceeds three metres in DD86SS3 and DD86SS9 (McCracken, 1994; Edwards et al., 1995; McCracken, 1997; Haines, 2004). Haines correlated the Goldwyer and Bongabinni Formations and showed their distribution across the Canning Basin (Haines, 2004; plates 1 to 4).

Devonian – lower Carboniferous source rocks

Petroleum systems sourced from the Devonian Gogo Formation and the lower Carboniferous Laurel Formation are present within the Devonian – lower Carboniferous and upper Carboniferous – Permian successions (Fig. 2). Within the Devonian – lower Carboniferous succession, reservoirs in the Devonian Reef complexes, lower Carboniferous Fairfield Group, and Anderson Formation are sealed by interbedded basinal shale and tight limestone within the Laurel Formation and its equivalents (Clanmeyer and Luluigui Formations). Devonian extension and the mid-Carboniferous Meda Transpression were responsible for deposition and structure development within the Devonian – lower Carboniferous succession.

Oil from the Blina Oilfield and oil shows in Boronia 1, Ellendale 1, and Janpam 1 are geochemically matched to the Devonian Gogo Formation, whereas oil from the Boundary, Lloyd, Sundown, and West Terrace oil fields are geochemically matched to the lower Carboniferous Laurel Formation (Figs 16, 17, 20). These oil fields are located on the Lennard Shelf at the northern margin of the Fitzroy Trough. On the southern margin of the trough, significant oil and gas has been discovered in the Yulleroo and Ungani areas within the lower Carboniferous Laurel Formation, which is a conventional source-reservoir system. Discoveries on both sides of the Fitzroy Trough indicate that it is a mature source-rock area with substantial oil- and gas-generating capacity.

The Givetian–Famennian reef complexes (Pillara cycle) and basinal (inter-reef) Gogo Formation were deposited during a major Frasnian transgression. Oil-prone, organic-rich shales within platform facies of the reef complexes contain up to 8% TOC, whereas shales within the Gogo Formation contain up to 3% TOC (Ellyard, 1984). Geochemical data available for the lower Carboniferous Laurel Formation is very limited and sparsely distributed; however, the Laurel Formation source beds are correlated to oil discovered on both margins of the Fitzroy Trough.

The upper Carboniferous – Permian succession is producing oil at the Boundary, Sundown, and West Terrace oil fields on the Lennard Shelf. Producing reservoirs are present within the Grant Group and seals are formed by overlying shale units of the Poole Sandstone and the Blina Shale. The succession is sandwiched between two tectonic events favourable for trap development: the mid-Carboniferous Meda Transpression and the Triassic–Jurassic Fitzroy Transpression. The petroleum system sourced from organic-rich Permian rocks is not known in the onshore Canning Basin. However, the upper Carboniferous – lower Permian source can be correlated with global Pennsylvanian – lower Permian source rocks, which are oil and gas prone athough they contain predominantly gas reserves.

Conclusions

Interpretation of petroleum geochemistry, organic petrology, AFTA, heat-flow data, subsurface temperatures, and other exploration data from the onshore Canning Basin indicate that there are three conventionally reservoired petroleum systems. The data also suggest that there are four potential tight-reservoired petroleum systems; three of which are the source rocks of the conventional reservoirs.

The petroleum systems sourced from the Ordovician Goldwyer and Bongabinni Formations are contained in the Ordovician–Silurian succession present along the southern margin of the Fitzroy Trough. Oil in the Pictor, Dodonea, and Great Sandy wells correlates to source rocks within the Goldwyer Formation. Estimated petroleum charge in Acacia 1 and 2, Blackstone 1, and Kidson 1 was during the Triassic–Jurassic paleothermal event, whereas in Willara 1 it was during the Cretaceous paleothermal event. The Goldwyer and Bongabinni Formations may also form self-contained petroleum systems, and are presently under evaluation.

The petroleum systems sourced from the Devonian Gogo and lower Carboniferous Laurel Formations are contained in the Devonian – lower Carboniferous and upper Carboniferous – lower Permian successions, present on both margins of the Fitzroy Trough. Blina oil correlates with the Devonian Gogo Formation, and oil from the Boundary, Lloyd, Sundown, West Kora, and West Terrace fields correlates with source rocks in the lower Carboniferous Laurel Formation. These fields are located along the northern margin of the Fitzroy Trough. Gas in Yulleroo 1 and oil in Ungani 1 within the Devonian – lower Carboniferous succession, on the southern margin of the Fitzroy Trough, are part of the petroleum system sourced from the lower Carboniferous sequence. In Blackstone 1, Lake Betty 1, and Yulleroo 1, petroleum charge is estimated to have taken place during the Triassic–Jurassic, Permian–Triassic, and Carboniferous–Triassic paleothermal events, respectively. The Gogo and Laurel Formations are presently under evaluation to determine whether they also form self-contained petroleum systems.

A petroleum system sourced from the upper Carboniferous – lower Permian succession has not been identified in the onshore Canning Basin. The Noonkanbah source beds may form a self-contained petroleum system, but these beds are mostly too immature for petroleum generation within the onshore Canning Basin. Offshore, where the Mesozoic cover is significant, there may be greater potential for petroleum generation.

Recent discoveries of oil at Ungani, gas at Valhalla, and emerging shale plays have revived petroleum exploration and production in the Canning Basin. Much of the renewed interest is due to the global interest in self-contained petroleum systems, which may be abundant in the Canning Basin. However, the basin is far from known markets, infrastructure is limited at present, and logistic costs are very high.

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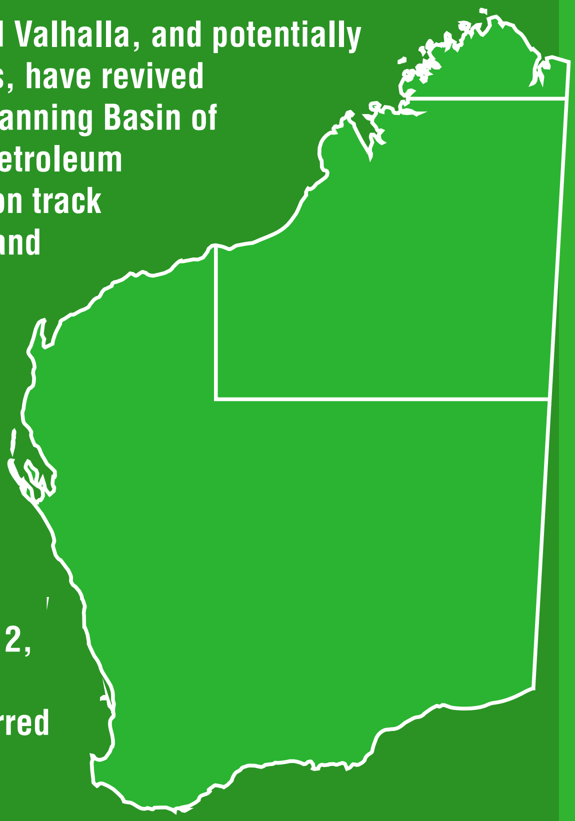
Exploration successes at Ungani, Yulleroo and Valhalla, and potentially abundant emerging shale and tight-sand plays, have revived petroleum exploration and production in the Canning Basin of Western Australia. This report analyses the petroleum geochemistry, organic petrology, apatite fission track analysis, heat flow, subsurface temperature, and other exploration data from the onshore Canning Basin.



Geochemical data indicate that Pictor oil was derived from Ordovician source rocks and Blina oil from Devonian source rocks, while oil from the Boundary, Lloyd, Sundown, West Kora, and West Terrace fields correlates with early Carboniferous source rocks. Petroleum systems modelling of Acacia 1 and 2, Blackstone 1, Kidson 1, Lake Betty 1, and Yulleroo 1 indicate that maximum burial occurred during the Triassic–Jurassic in the Kidson and Gregory Sub-basins and the Fitzroy Trough. In contrast, maximum burial occurred in the Willara Basin during the Cretaceous, based on Willara 1 data. The Ordovician self-contained petroleum systems are estimated to contain up to 8.2 trillion cubic metres or 288 trillion cubic feet of gas. Shale gas exploration in the Canning Basin is at an early stage and more work is needed to verify these estimates.

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