Petroleum Generating Potential and Thermal History of the Neoproterozoic Officer Basin, Western Australia.

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Abstract

Geochemical analyses confirm the presence of good quality but thin oil source rocks within the Neoproterozoic succession of the western Officer Basin. The available geochemical dataset, however, is insufficient to positively identify the source of oil and bitumen shows observed in petroleum and mineral wells.

Excellent oil source-beds are present in finely laminated shale and siltstone facies within an evaporitic succession penetrated in mineral corehole NJD 1 located on the Kingston Shelf, and are marginally mature for oil generation.

Within the Yowalga Sub-basin fair to good oil source-beds are identified in thin organic-rich shales of the Browne, Hussar and Kanpa formations at Kanpa 1A, Yowalga 3 and Empress 1A respectively. In this sub-basin the Neoproterozoic succession is very thick and its maturity varies from immature to overmature for different formations, depending on the maximum depth of burial.

Fair source-beds have also been identified in mineral corehole LDDH 1 located in the northwestern Gibson Sub-basin. The highest measured maturity in the northeastern part of this sub-basin is from Dragoon 1 where over 2500 m of section has been removed during compressional and halokinitic uplift. Along the southern margin of the Gibson Sub-basin the Neoproterozoic is partly within the oil window, whereas in the northwestern part of the sub-basin it is mature to overmature (in LDDH 1).

Modelling indicate that the main phases of oil generation within the Neoproterozoic succession occurred during the latest Neoproterozoic, Cambrian and Permo-Triassic. These phases vary both stratigraphically and geographically across the basin, depending on the depositional and structural history of the area.

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Introduction

The Western Australian part of the Officer Basin is referred to here as the western Officer Basin and occupies an area of about 260 000 km^2 in the southeast central part of Western Australia (Fig. 1).

The first petroleum exploration drilling in this part of the basin was undertaken by a consortium consisting of Hunt Oil, Hunt Petroleum, Placid Oil and Exoil. They drilled five shallow wells up to 989 m deep in 1965–66 (Browne 1 and 2, Lennis 1, and Yowalga 1 and 2). Minor oil and gas shows were encountered within the Browne Formation in Browne 1 and 2 (Jackson, 1966).

The second phase of drilling started in 1980; five wells were drilled. The deepest well in the basin, Yowalga 3 (4196 m) was drilled by Shell during their three well drilling program in 1980–84. Kanpa 1A (3803 m) possibly penetrated the full Neoproterozoic section and Lungkarta 1 was terminated in the Hussar Formation at 1770 m (Townson, 1985). An oil-show in a cuttings sample from Kanpa 1A was investigated by gas chromatography and shown to be a low maturity petroleum generated from an algal source (Analabs, 1983). The consortium consisting of News Corporation, Eagle Corporation and Swan Resources drilled two stratigraphic tests, Dragoon 1 (2000 m) and Hussar 1 (2040 m) in 1982; no significant hydrocarbon shows were encountered (Phillips et al., 1985), but a wireline log interpretation for Hussar 1 suggests there may be some immoveable hydrocarbons in the Kanpa Formation (Karajas & Taylor, 1983b).

The recent phase of drilling started in 1995, when the Geological Survey of Western Australia (GSWA) drilled Trainor 1 (709 m) in the Savory Sub-basin, followed in 1997 by Empress 1/1A (615 m/1624.6 m) in the Yowalga Sub-basin. The most recent wells were drilled by Amadeus Petroleum in the Savory Sub-basin in 1997: Akubra 1 (181 m), Boondawari 1 (1367 m) and Mundadjini 1 (600 m).

In addition to these fifteen petroleum exploration wells,

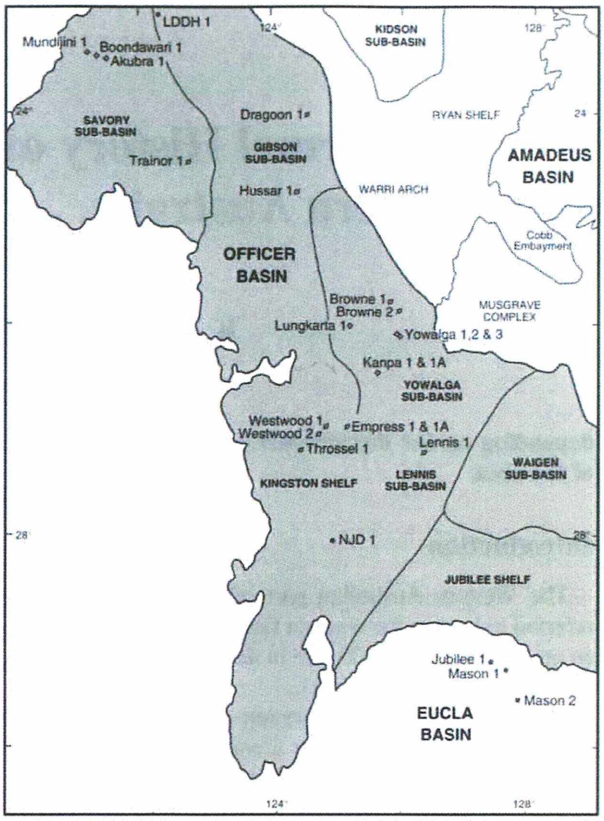


Figure 1: Location map of wells and sub-basins.

forty-seven other shallow stratigraphic and mineral wells up to 1000 m deep were drilled by the BMR and the mineral industry (Perincek, in press). Western Mining reported bleeding oil in core from mineral corehole NJD 1 located on the Kingston Shelf; this is the best hydrocarbon indication within the basin. Minor oil, gas and bitumen shows were observed in many wells, showing that hydrocarbon generation and migration has occurred within the Neoproterozoic sequences of the basin.

The aim of this paper is to identify and characterise the source rock intervals in the Neoproterozoic succession and determine their hydrocarbon generation histories.

Geology

The geology of the basin is documented by many studies including Jackson and van de Graaff (1981), Karajas and Taylor (1983a, 1983b), Shell Development (Australia) Pty Ltd (1981), The Shell Company of Australia (1983, 1985), Phillips et al. (1985), Townson (1985), Walter and Gorter (1994), Williams (1992, 1994), Walter et al. (1995), and Perincek (1996).

The western Officer Basin is an elongate northwest-southeast trending depression filled with over 8000 m of Neoproterozoic to lower Palaeozoic rocks. Depocentres of the basin include the Gibson, Lennis, Savory, Waigen and Yowalga sub-basins. Of these, the Yowalga Sub-basin mainly contains Neoproterozoic to Lower Cambrian rocks and has the most subsurface data available. Parts of the sub-basins are underlain by older Proterozoic strata (Townson, 1985; Perincek, 1996).

The depositional history of the basin is interpreted from petroleum and mineral exploration wells, scattered outcrops on the margins of the basin and geophysical information (Fig. 2).

The Townsend Quartzite is the oldest Neoproterozoic unit and has been intersected only in Kanpa 1A. The unit is a massive, pink to white, very hard, quartz sandstone and is, in places, overlain by the Lefroy Formation, which consists of fine sandstones, siltstones and grey marine shales.

Thick evaporite, carbonate and shale units of the Browne, Hussar, Kanpa, and Steptoe formations respectively overlie the Townsend Quartzite. All these units were penetrated in Kanpa 1A and Empress 1A. The evaporitic Browne Formation is intersected in most wells and consists of green, red-brown, grey and black shales and siltstones, with interbedded halite, anhydrite and dolomite. Palynomorphs and stromatolites from Yowalga 3 indicate a Late Riphean or Vendian age (Grey, 1981). The Browne Formation was intersected in many wells and the Hussar, Kanpa and Steptoe formations overlie it with apparent conformity. These units are equated with Supersequence 1 of the Centralian Superbasin (Walter & Gorter, 1994; Walter et al., 1995), and are considered to be the most prospective part of the succession for petroleum exploration.

The lower Neoproterozoic is overlain by tillites and fluvio-glacial deposits (Lupton and Turkey Hill formations) which are known from scattered outcrops along the margins of the basin and in Empress 1A. These deposits are equated with either Supersequence 2 or 3 of the Centralian Superbasin (Walter & Gorter, 1994; Walter et al., 1995).

In the subsurface, the ?Lower Cambrian McFadden Formation unconformably overlies the units of Supersequence 1 and 3. It consists of white to red-brown, very fine- to coarse-grained clastics and is regarded as part of Supersequence 4 (Perincek, 1996) of the Centralian Superbasin. A major regional unconformity underlying the McFadden Formation is associated with the Petermann Ranges Orogeny. The culmination of this orogeny separated the western Officer Basin from the Centralian Superbasin in the latest Neoproterozoic and was the most intensive structuring event of the basin. This orogeny produced low-angle thrust faulting, massive uplift and a major erosional episode within the region (Lambeck, 1984; Walter & Gorter, 1994; Perincek, 1996).

The Cambro-Ordovician Table Hill Volcanics unconformably overlies the Neoproterozoic–Lower

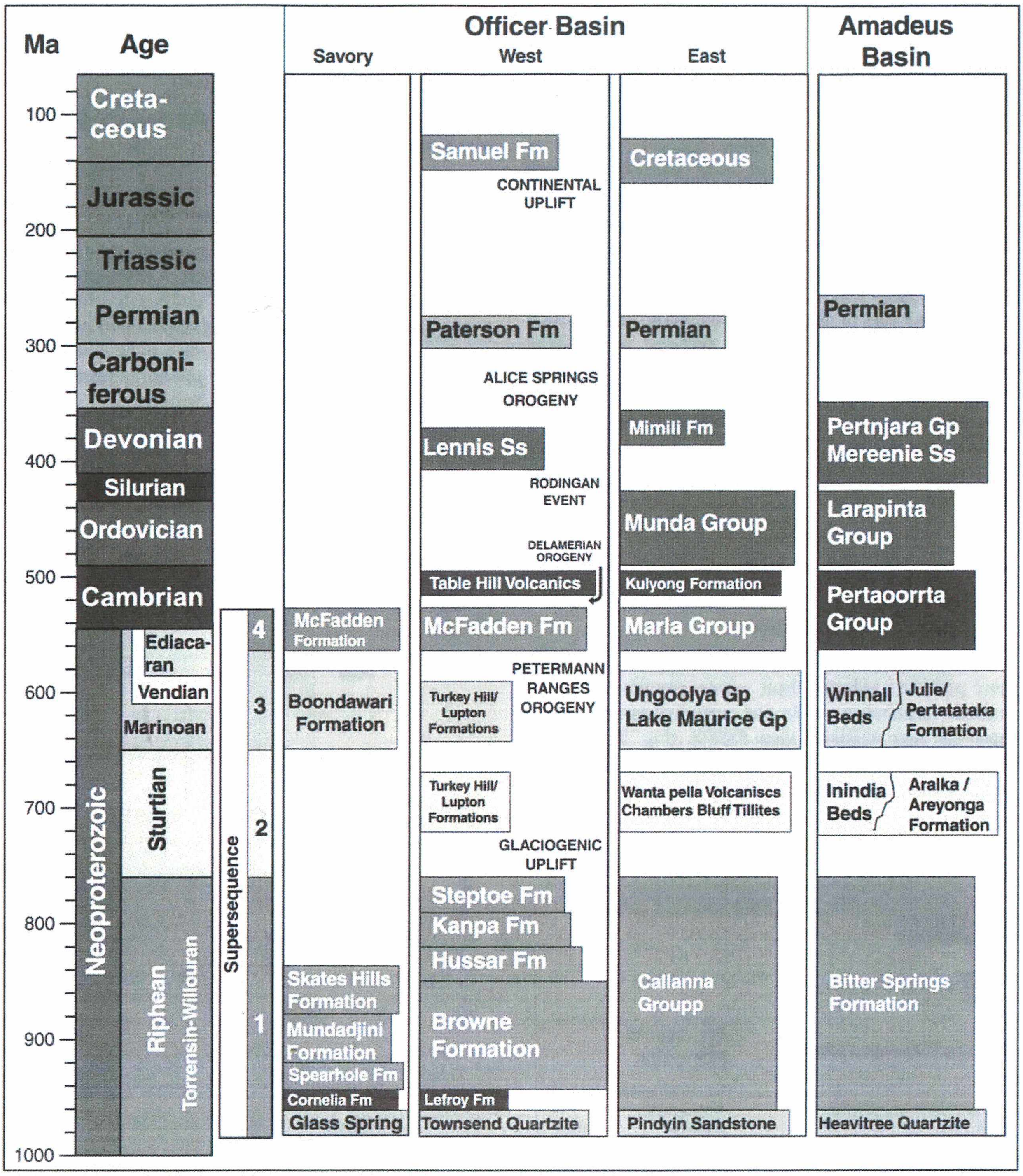


Figure 2: Generalised time-stratigraphy of the Officer and Amadeus basins.

Cambrian successions. This widespread, thin, plateau basalt outcrops on the southwest and northeast margins of the basin and has been intersected by many wells. An angular unconformity between the McFadden Formation and the overlying Table Hill Volcanics, as well as the extrusion of the Table Hill Volcanics, has been related to the Cambrian Delamerian Orogeny (Perincek, 1996).

Undated massive sandstones of shallow marine origin (Lennis and Wanna sandstones) unconformably overlie the Cambro–Ordovician volcanics: a Devonian–Carboniferous age is inferred from fission track analysis (Green & Gleadow, 1984). The Upper Carboniferous–Lower Permian Paterson Formation unconformably overlies these units. The tillites and fluvioglacial to lacustrine sandstone and claystone of the Paterson Formation are widespread and equated with the Grant Group of the Canning Basin to the northwest (Jackson & van de Graaff, 1981; Phillips et al., 1985; Townson, 1985).

The mid-Carboniferous Alice Springs Orogeny is considered to be the second most intensive tectonic episode of the region, and was responsible for final structuring and separation of the western Officer Basin from the Centralian Superbasin. This orogeny reactivated diapiric movements within the Browne Formation and folded the Table Hill Volcanics and Lennis Sandstone in the Yowalga and Lennis sub-basins; subsequent erosion led to an angular unconformity between the Permian Paterson Formation and the underlying units (Townson, 1985).

Interbedded sandstones and claystones of marine origin (Lower Cretaceous Samuel Formation and Bejah Claystone) blanket the northwestern portion of the basin (Phillips et al., 1985).

Petroleum Geochemistry

Database

New geochemical analyses were obtained for over 15C core samples collected from seven petroleum and six mineral exploration wells and were incorporated with open-file data available from GSWA (Fig. 3). Samples that, on the basis of Rock-Eval pyrolysis, appeared to be contaminated were excluded from the interpretation in this study. The analytical work of new samples were carried out by Geotechnical Services Pty Ltd (GEOTECH) for source potential, Keiraville Konsultants Pty Ltd for source maturity, and Geotrack International Pty Ltd (GEOTRACK) for maximum palaeotemperatures and their timing.

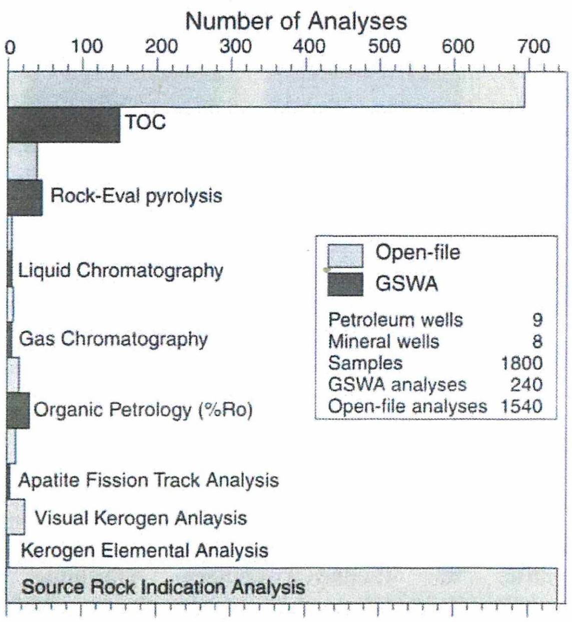


Figure 3: **Project and open-file geochemical data used in this study.**

Source Rock Potential

Organic richness (TOC%) and potential yield ($S_1 + S_2$) from Rock-Eval pyrolysis are used to determine source rock potential. Samples with TOC and $S_1 + S_2$ values equal to or greater than 0.5% and 1 mg/g respectively are shown on Figure 4, and indicate that source rocks with fair to excellent generating potential are present in Empress 1A, Kanpa 1A, LDDH 1, NJD 1, and Yowalga 3.

Empress 1A: a total of sixty-nine TOC and ten Rock-Eval analyses were conducted on core samples in Empress 1A. Three core samples from 737.4 m, 757.6 m, and 768.2 m have poor to fair oil and gas generating potential (Figs 4 & 5).

Kanpa 1A: a total of 529 TOC and eight Rock-Eval analyses are available from Kanpa 1A. Two of eight organic-rich samples are classified as source rocks: a

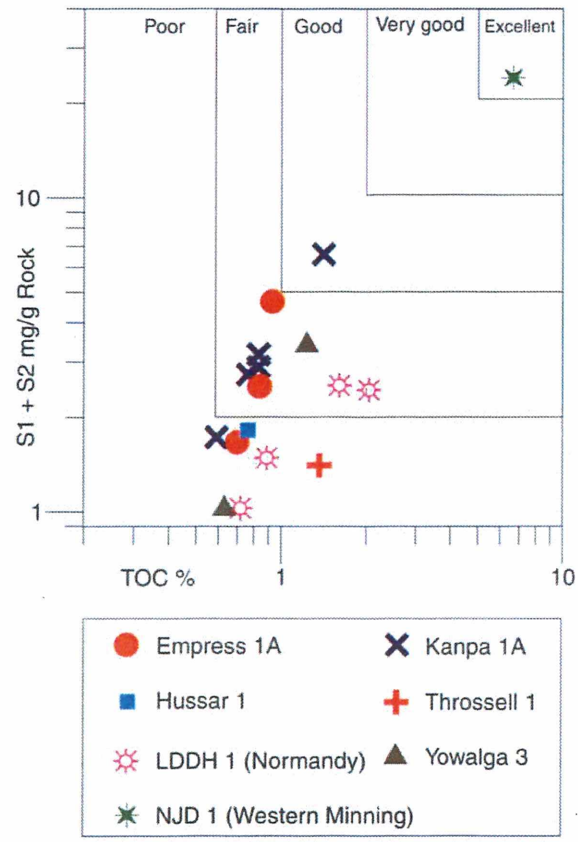


Figure 4: **Petroleum generating potential as TOC versus $S_1 + S_2$ plot.**

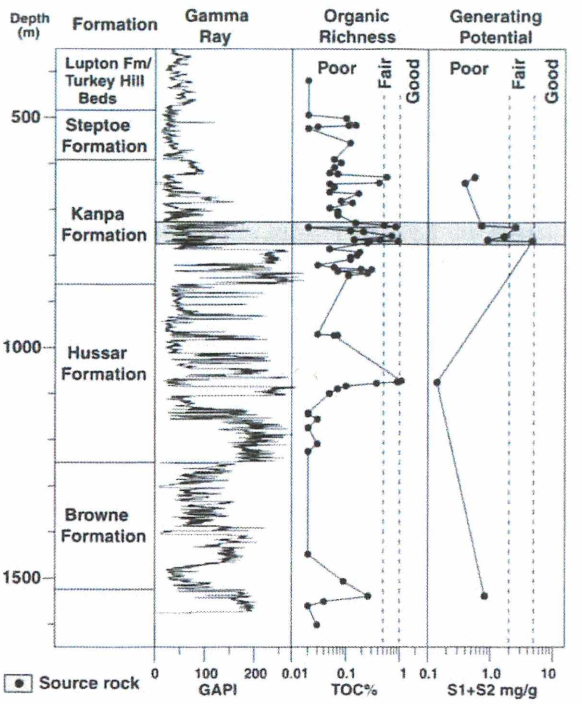


Figure 5: **Organic richness and petroleum generating potential of rocks in Empress 1A.**

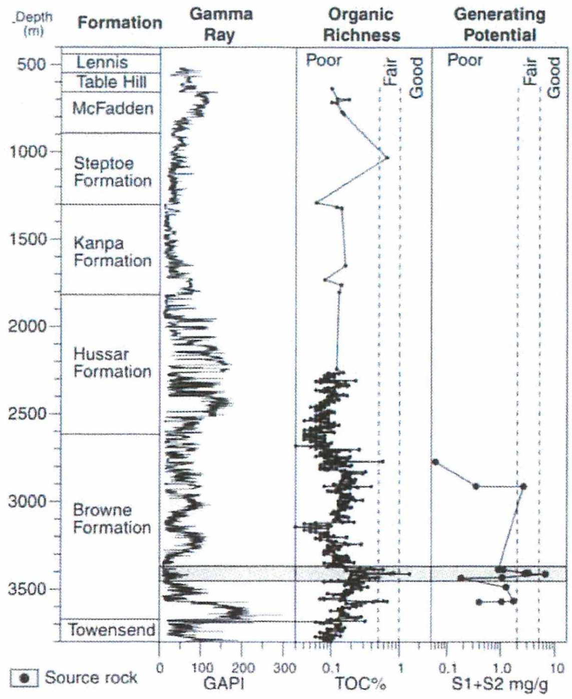


Figure 6: **Organic richness and petroleum generating potential of rocks in Kanpa 1A.**

cuttings sample from 3407–3410 m is a fair oil source; a sidewall core from 3412.2 m is a good oil source rock (Figs 4 & 6). Most of these TOC analyses were performed on cuttings samples, and are not suitable for identifying thin source-beds.

NJD 1: fourteen TOC and four Rock-Eval analyses were carried out on core from Western Mining's mineral corehole NJD 1. One organic-rich sample (6.64% TOC) from 327.5 m has excellent hydrocarbon generating potential (Fig. 4); Rock-Eval pyrolysis was conducted on the solvent extracted sample which yielded $S_1 + S_2$ of 24.2 mg/g. This result has also been confirmed by extract liquid chromatography.

LDDH 1: seventeen TOC and eleven Rock-Eval analyses were carried out on core from Normandy Poseidon's mineral corehole LDDH1. Two cores from 222.8 m (1.61% TOC & $S_1 + S_2$ of 2.53 mg/g) and 529.6 m (2.05% TOC & $S_1 + S_2$ of 2.45 mg/g) can be classified as fair source rocks (Fig. 4).

Yowalga 3: fourteen TOC and eleven Rock-Eval analyses were available for Yowalga 3. The interval between 1481 m and 1505 m is organic rich with TOC values between 0.7% and 2.9%: a cuttings sample from 1484 m has fair petroleum generating potential, with $S_1 + S_2$ of 3.5 mg/g (Figs 4 & 7).

Other wells: no source rocks were identified in Browne 1, Dragoon 1, Hussar 1, Lungkarta 1, Mason 1 and 2, and Yowalga 2 on the basis of available TOC and Rock-Eval

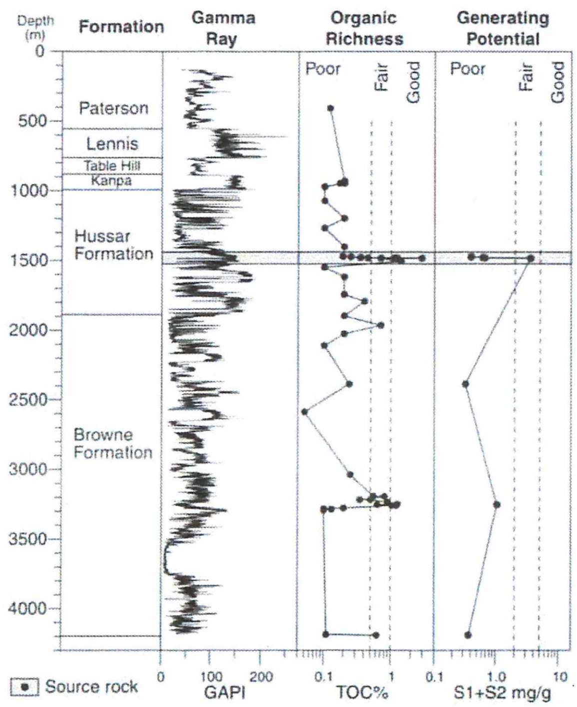


Figure 7: **Organic richness and petroleum generating potential of rocks in Yowalga 3.**

analyses. A 100 m thick organic-rich interval with up to 3.65% TOC was encountered in the Cornelia Formation of Trainor 1 in the Savory Sub-basin but was overmature; its age is uncertain, either Neoproterozoic or Palaeozoic (Stevens & Adamides, 1998).

Kerogen Type

Rock-Eval Pyrolysis

A plot of Hydrogen Index (HI) versus T_{max} is used to illustrate the type of kerogen in source rock from the basin. T_{max} is a maturity indicator and represents the temperature at which the maximum amount of pyrolytic hydrocarbon (S_2) is generated. HI is a kerogen quality indicator and has a direct relationship with elemental atomic hydrogen to carbon (H/C) ratio (Espitalie et al., 1977; Tissot & Welte, 1978). High HI values generally indicate oil-prone kerogen for those samples which are not high in inertinitic kerogen (Horstman, 1994). Samples from Empress 1A, Kanpa 1A, LDDH 1, NJD 1 and Yowalga 3 that yielded S_1 + S_2 equal to or greater than 2 mg/g are plotted on Figure 8 and show that the kerogen is predominantly oil and gas generating type II.

Pyrolysis Gas Chromatography (PGC)

PGC analysis provides a more accurate guide than Rock-Eval pyrolysis to oil- versus gas-generating potential of kerogen (Larter, 1985; Scott, 1992). Oil proneness, expressed as C_5 to C_{31} alkane plus alkene (values as a percentage of S_2 from Rock-Eval), is plotted against the gas-oil generation index (GOGI), expressed as $(C_1–C_5)/C_6+$. Three PGCs from Empress 1A and NJD 1 (Figs 9 & 10) were available for cross-checking the Rock-Eval kerogen typing. In Figure 9 increases in kerogen quality generally correspond to a decrease in GOGI, and confirm that the kerogen within the Neoproterozoic rocks is predominantly oil and gas generating type II.

Geothermal Gradient

Present-day subsurface temperature data include fifty-two bottom-hole temperatures (BHTs) recorded during

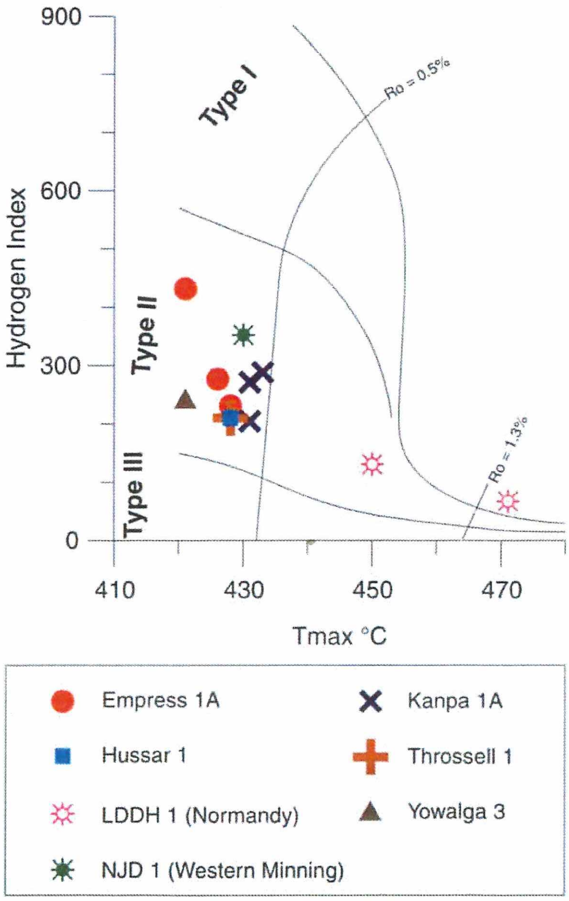
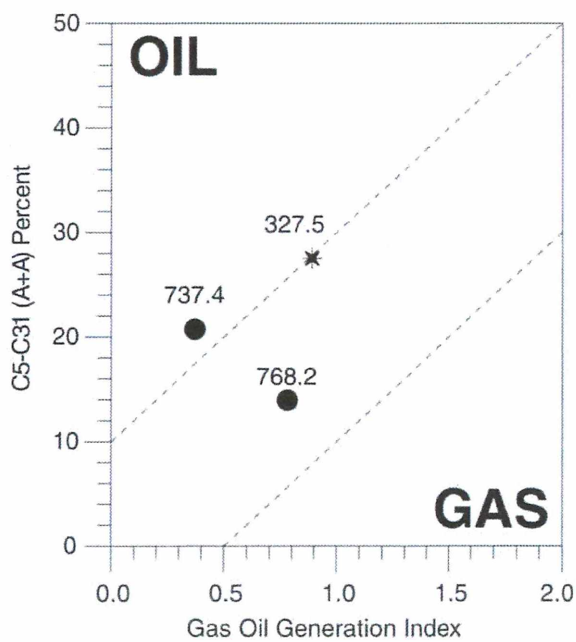


Figure 8: **Rock-Eval kerogen typing as Hydrogen Index versus T_{max} plot.**



Well	Depth (m)	TOC (%)	Potential Yield (mg/g)
NJD 1	327.5	6.64	24.17
Empress 1A	737.4	0.84	2.51
Empress 1A	768.2	0.93	4.68

Figure 9: **PGC kerogen typing as gas-oil generation index versus % C_5–C_{31} alkanes + alkenes plot.**

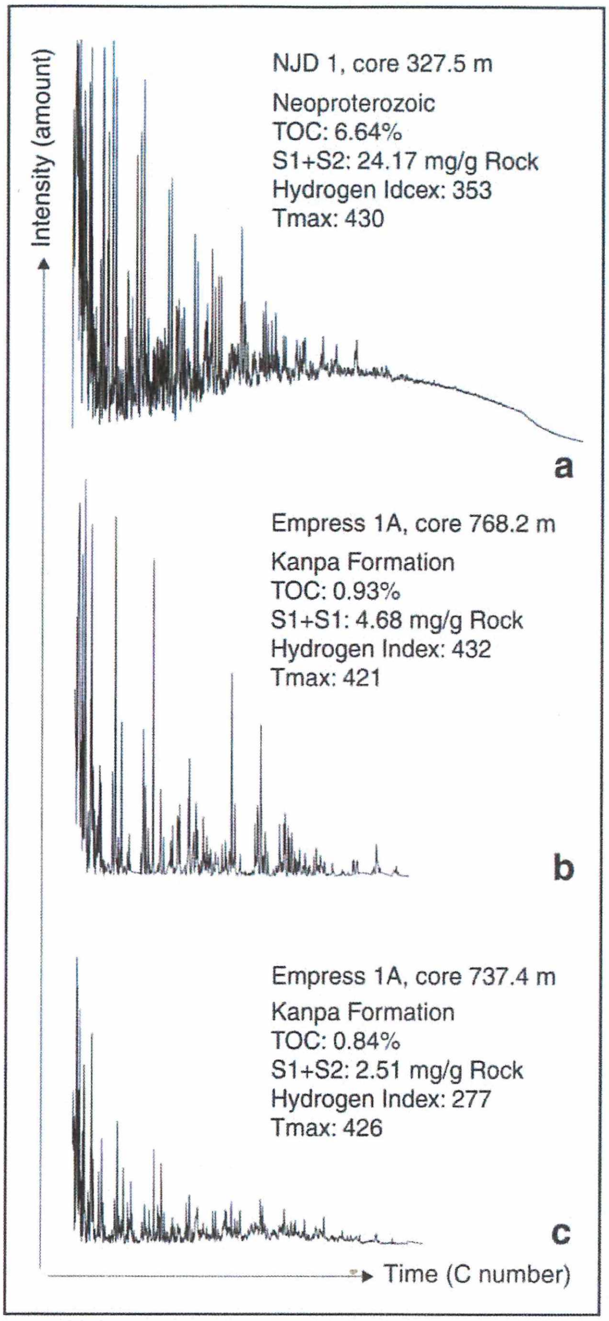


Figure 10: Pyrolysis gas-chromatograms of core samples from: a) 327.5 m in NJD 1; b) 768.2 m in Empress 1A; c) 737.4 m in Empress 1A.

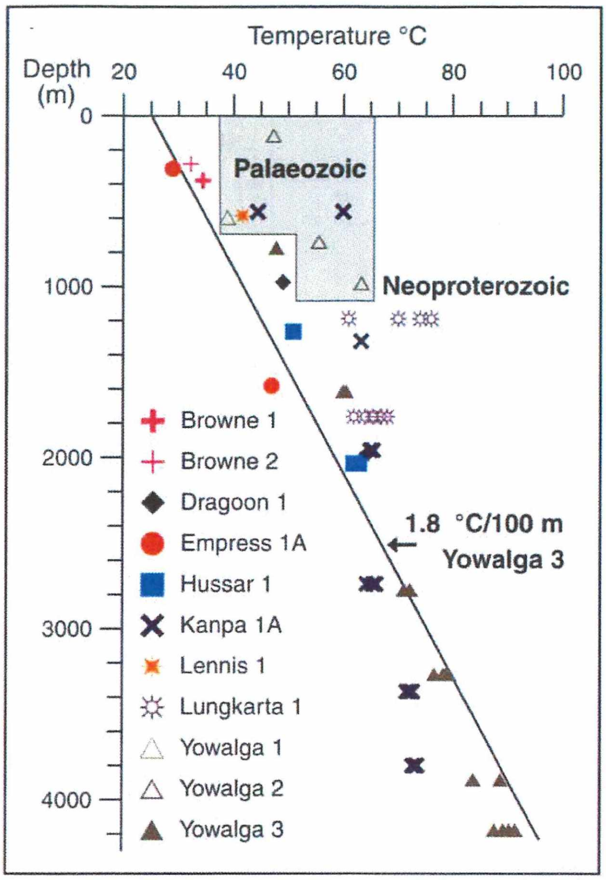


Figure 11: Present-day sub-surface temperature (BHT) versus depth.

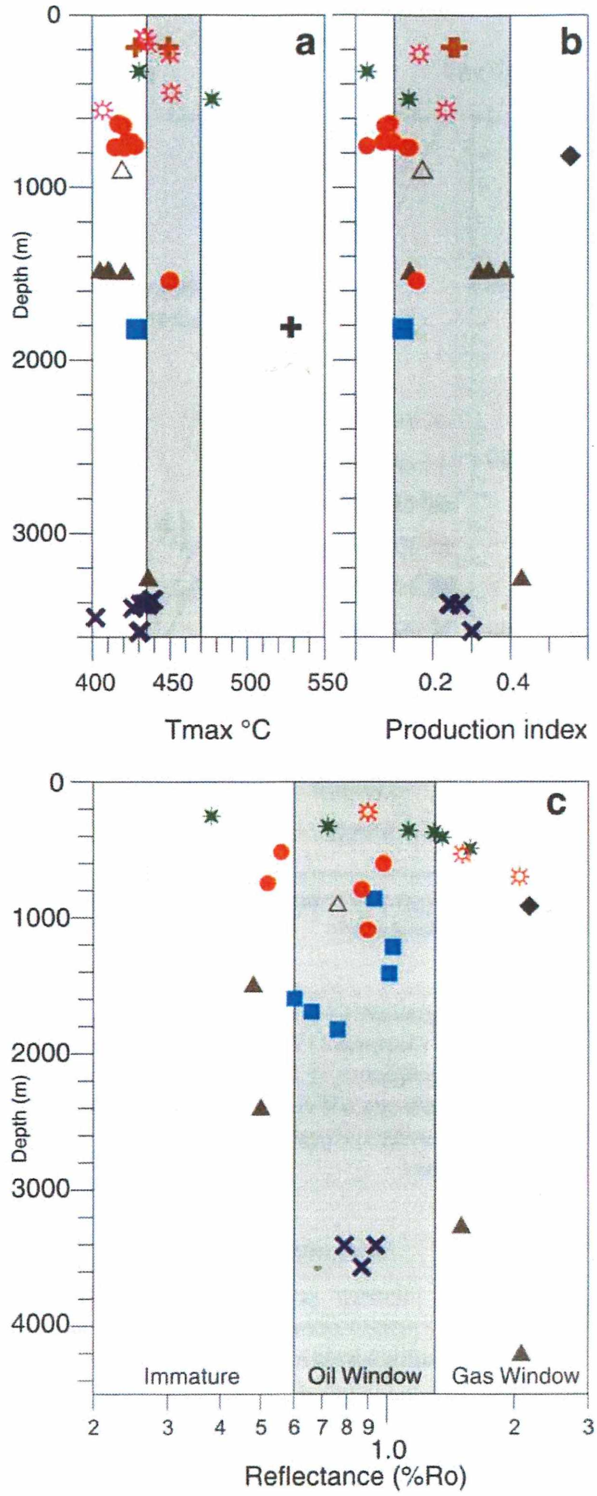
wireline logging in ten wells. A depth plot (Fig. 11) indicates that the BHTs recorded from depths shallower than 1500 m are unreliable for estimating geothermal gradients. Geothermal gradients are calculated from the estimated BHTs (Kehle, 1971; Fertl & Wickmann, 1977) using 25°C as the surface temperature. Yowalga 3 and Kanpa 1A are the deepest wells and provide reliable geothermal gradients for the Yowalga Sub-basin, with temperature gradients of 1.8°C/100 m and 1.5°C/100 m respectively. Empress 1A, where the present-day geothermal gradient is 1.7°C/100 m, confirms these temperature gradients. No conclusions can be drawn from the existing dataset on geothermal gradients within the other sub-basins.

Measured Maturity

Rock-Eval thermal maturity indicators, organic petrology and apatite fission track analysis were used to evaluate maturation levels in the Neoproterozoic rocks.

Rock-Eval Pyrolysis

T_{max} is a maturation parameter, specifying the temperature (centigrade) at which the pyrolytic yield of hydrocarbons (from a rock sample) reaches its maximum. Production Index (PI) is also a maturation parameter: the ratio of already generated hydrocarbons (S_1) to potential hydrocarbons (S_2) and calculated as $\{PI = S_1/(S_1 + S_2)\}$. Twenty-four T_{max} and twenty-one PI values from seventy Rock-Eval analyses are interpreted to be reliable for



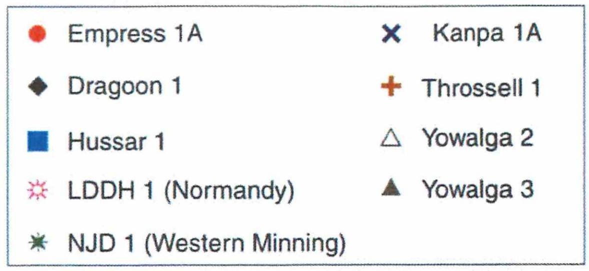


Figure 12: Measured maturity plots as depth versus: a) T_{max}; b) Production Index; c) equivalent %Ro.

maturity evaluation. These T_{max} and PI values are from nine wells and are plotted versus depth on Figures 12a and 12b respectively. Both plots indicate that, except in Dragoon 1 and the basal parts of Yowalga 3 and NJD 1, all samples are either immature or within the oil window. However, the T_{max} values are comparatively lower than the PI values.

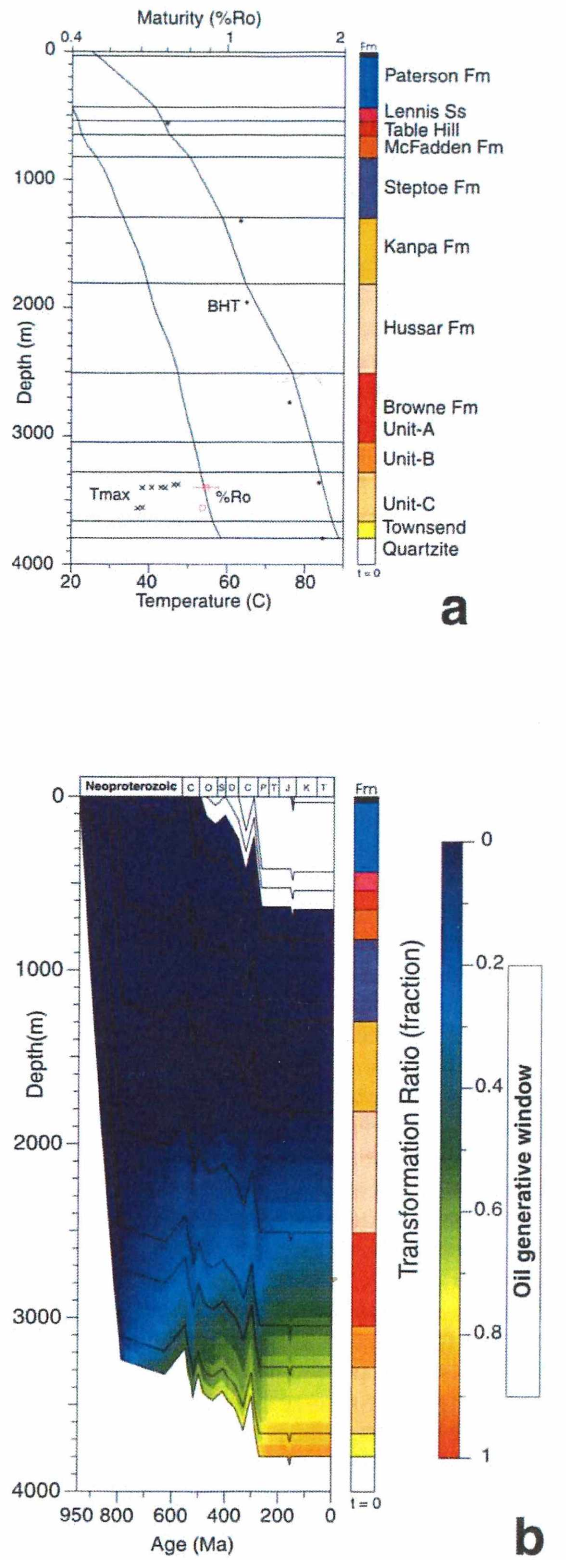
Organic Petrology

Lamalginite and bitumen reflectance can provide maturity levels for rocks older than Devonian (Crick et al. 1988). The reflectance values of lamalginite are more reliable for moderate to high maturation levels (Cook, 1995). Thucholitic bitumen (solid bitumen) that encases radioactive minerals displays that their reflectance values at the outer rim are very similar to that of the co-existing vitrinite. Fluorescing lamalginite becomes non-fluorescing at higher levels of maturation, and both forms can occur in a single sample.

Over thirty-five reflectance measurements on fluorescing and non-fluorescing lamalginite, reservoir and thucholitic bitumen were available. Most of the organic matter consists of lamalginite (alginite). The reflectance values of non-fluorescing lamalginite from eight wells are plotted versus depth on Figure 12c. This plot indicates that Dragoon 1 and the basal parts of NJD 1, LDDH 1, and Yowalga 3 are overmature, whereas the remaining samples are immature or within the oil window. Both the organic petrology and Rock-Eval data indicate that the oil window in Kanpa 1A and Yowalga 3 (Yowalga Sub-basin) is about 1000 m deeper than in Hussar 1 (Gibson Sub-basin).

Apatite Fission Track Analysis (AFTA)

The fission-track age is largely a function of fission-track annealing in response to increasing temperature between 70°C and 120°C, whereas fission-track length reflects the style of cooling. Apatite fission track analysis is therefore useful in understanding the geothermal history of the host rocks. Green and Gleadow (1984) provide an interpretation of fission-track data for ten cuttings samples from Kanpa 1A (5) and Yowalga 3 (5). They suggest that most of the Neoproterozoic section in Kanpa 1A and Yowalga 3 may have been mature to overmature relatively early in the history of the basin.



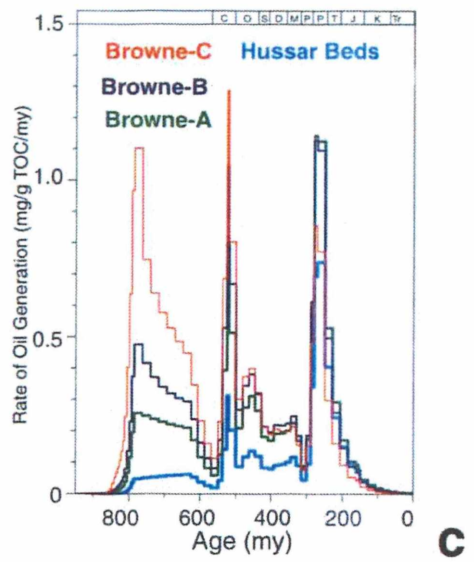


Figure 13: Hydrocarbon generation modelling in Kanpa 1A: a) maturity calibration; b) oil-window; c) rate of oil generation. Well locations are shown in Figure 1.

AFTA data available on three samples from Empress 1A indicate two cooling events, between 600–300 Ma and between 40 Ma to present.

The 600–300 Ma palaeo-thermal event encompasses the Petermann Ranges Orogeny (570–540 Ma) and the Alice Springs Orogeny (~ 290 Ma). The Petermann Ranges Orogeny is considered to be the most intense structuring event of the basin (Lambeck, 1984; Perincek, 1996), and was taken as the major erosional episode in maturity modelling for this study.

Petroleum Generation Modelling

Kinetic modelling of petroleum generation as a function of geothermal history and type and amount of kerogen was used to determine the oil window, utilising BasinMod of Platte River Associates, Inc., USA. A vitrinite reflectance value of 0.65% has been adopted for the onset of the oil window, based on the kerogen type estimated from geochemical data as 10% type I kerogen, 70% type II and 20% type III. The depth of the oil window is taken to be equivalent to burial depths required for the conversion of 10% to 90% of the available kerogen to petroleum. The thermal histories were constructed by adjusting thermal conductivities and heat flow to constrain maturity models versus measured data. Corrected BHTs, equivalent %Ro, T_{max}, and information from AFTA were used to constrain present temperatures and palaeotemperatures. Predicted maturity and oil windows are based on Lawrence Livermore National Laboratory (LLNL) vitrinite and kerogen kinetics, respectively.

For this study basin modelling was carried out for Empress 1A, Dragoon 1, Hussar 1, Kanpa 1A, and Yowalga 3, because they are the deepest wells in the western Officer Basin and contain most of the available subsurface data for maturity and hydrocarbon generation modelling. Kanpa 1A is used to illustrate maturity and hydrocarbon generation modelling results (Fig. 13). A maturity calibration plot compares measured with calculated temperatures and measured with calculated maturity (Fig. 13a); a burial plot shows the oil window as a function of transformation ratio of kerogen to petroleum (Fig. 13b). The time of petroleum generation is a function of kerogen conversion to petroleum and is illustrated as rate of generation versus time plot (Fig. 13c). This model suggests that the Neoproterozoic succession progressively passed through the oil window from the latest part of the Neoproterozoic to the Permo–Triassic, depending on stratigraphic position, maximum depth of burial, and structural history. Figure 14 illustrates thermal maturity (%Ro) from Dragoon 1 in the north to Empress 1A in the south.

Discussion

Proterozoic Petroleum

The petroleum prospectivity of Proterozoic successions is well established worldwide. The oldest indigenous dry gas has been encountered within the Palaeoproterozoic (2500–1600 Ma) on the Kola Peninsula, Russia, and in the McArthur Group, Northern Australia (Jackson et al., 1988; Summons et al., 1988; McKirdy & Imbus, 1992). The world's oldest proven oil source rock is from the Mesoproterozoic (1600–1000 Ma) Roper Group in the McArthur Basin, Northern Australia (Taylor et al., 1994). The world's oldest petroleum in a proven commercial accumulation occurs in the Neoproterozoic (1000–540 Ma) in Siberia (Kontorovich et al., 1990), Oman (de la Grandville, 1982), and China (Mo et al., 1984).

Within Australia, the search for Proterozoic petroleum started in 1963 with the drilling of Ooraminna 1 in the Amadeus Basin; it flowed non-commercial gas (12000 cfd) from the Areyonga Formation (~760 Ma) and proved the presence of hydrocarbons in the Neoproterozoic of central Australia (Murray, 1965). This test was followed by a gas discovery at Dingo 1 in 1981, where a small gas flow (5 MMcfd) was obtained from the basal Ediacaran–Lower Cambrian Arumbera Formation. Magee 1 was drilled in late 1992 to test the sequence below the salt of the Bitter Springs Formation (Fig. 2), and flowed gas from the Heavitree Quartzite (870 Ma) to the surface at a stabilised rate of 63.1 Mscfd. The geochemistry of the extracted oil suggested that the source rock is still within the oil window, which was also indicated by ethylphenanthrene index (MPI) of 1.02 obtained on bitumen from a 20 m thick black shale above the reservoir (Wakelin-King, 1994).

To date, drilling in the Officer Basin has failed to locate significant Proterozoic petroleum and source rocks. However, several oil shows and reservoir bitumen have been encountered within the Neoproterozoic successions (Townson, 1985; Morton & Drexel, 1997; McKirdy & Imbus, 1992).

Source Rocks

Geochemical studies for the source of Siberian Platform hydrocarbons suggest that Riphean and, to a lesser extent, Vendian rocks are the main source rocks for these commercial oil and gas accumulations. The average TOC content is less than 0.2% but there are several horizons in which organic richness is greater than 8% (Kontorovich et al., 1990; Kuznetsov, 1997). The infra-Cambrian (650 Ma) Huqf Group source rocks of Oman are organic-rich, laminated, dark marly to shaly rocks with TOC values greater than 2% and which contain type II kerogen (Mattes & Morris, 1990; Grantham et al., 1990). Similar source facies consisting of laminated dark marly to thin shaly beds are present in the western Officer Basin; they contain type II kerogen and have fair to excellent generating potential.

On the Kingston Shelf Neoproterozoic beds with excellent oil-generating potential are present within mineral corehole NJD 1 at 327.5 m (Fig. 5), and at 328.5 m to 329 m (Clark, 1983). In NJD 1, the interval down to approximately 330 m is marginal mature to mature for oil generation, whereas the interval from 330 m to the total depth of 517 m is mature to overmature. The section below 330 m was interpreted as Mesoproterozoic by Shell Development (Australia) Pty Ltd. Oil shows were reported from NJD 1 but no geochemical and depth information is available (Western Mining Corporation, 1981). Bitumen veins are present between 502 m and 517 m. The high reflectance values of bitumen indicate an overmature section (Fig. 12c). In this part of the Officer Basin, the Neoproterozoic is comparatively thin (~230 m in NJD 1) and shallow, but is marginally to fully mature for oil generation. No other geochemical information is presently available for this part of the western Officer Basin.

In the Yowalga Sub-basin laminated, thin organic-rich beds with fair to good characteristics for hydrocarbon generation are present within the Browne Formation of Kanpa 1A (Figs 4 & 6), the Hussar Formation of Yowalga 3 (Figs 4 & 7), and the Kanpa Formation of Empress 1A (Figs 4 & 5). In this sub-basin the Neoproterozoic section is very thick: over 3316 m in Yowalga 3, 2974 m in Kanpa 1A, and 1060 m in Empress 1A. The maturation level of the Neoproterozoic ranges from immature to overmature, depending on the maximum burial depth.

In Kanpa 1A the section below 2100 m is presently within the oil window. The oil-prone organic-rich beds identified in this well lie within unit C of the Browne Formation and are presently within the late stage of oil

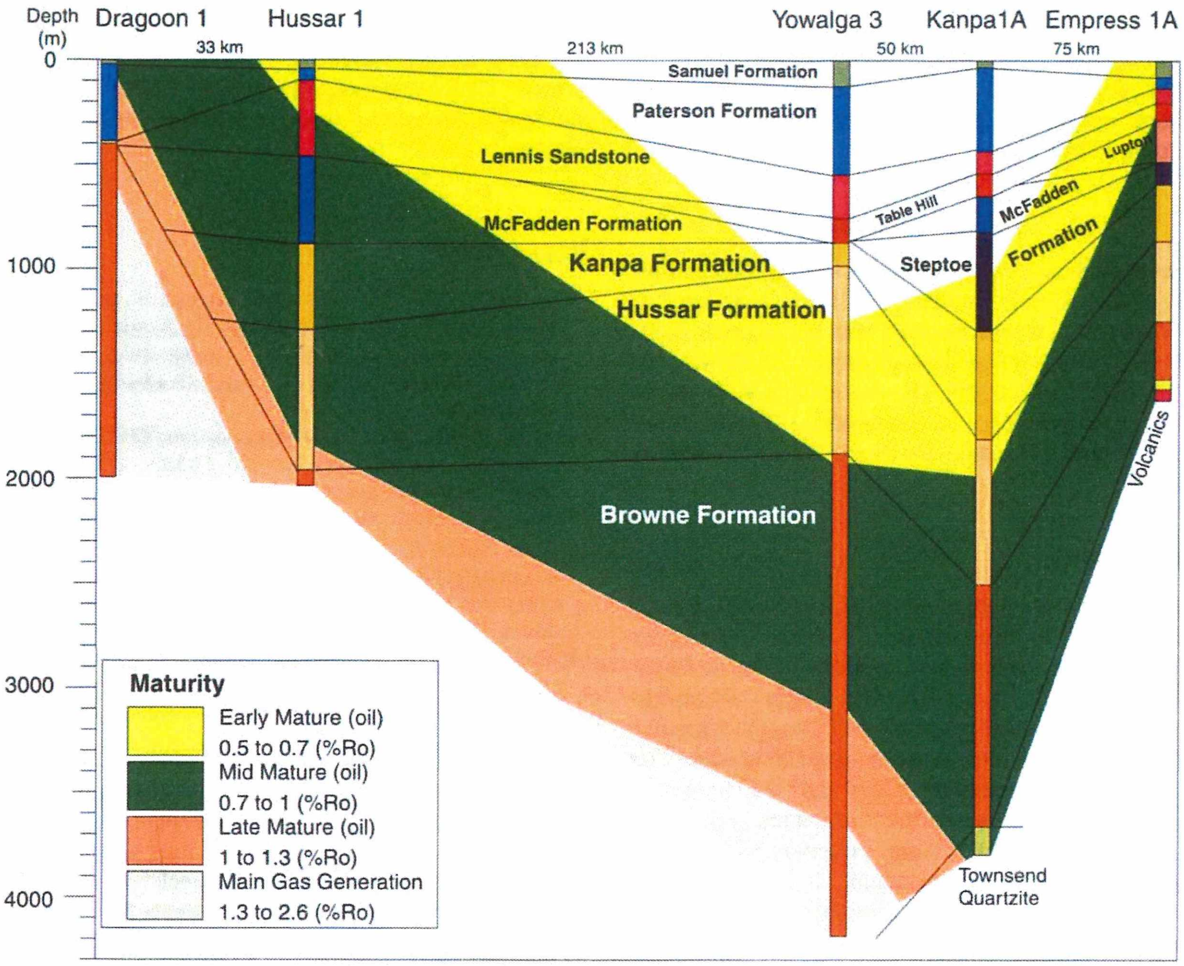


Figure 14: Neoproterozoic thermal maturity across the Yowalga and Gibson sub-basins from Dragoon 1 in the north to Empress 1A in the south. Well locations are shown in Figure 1.

generation (Figs 6 & 14). In Yowalga 3 the interval between 2200 m and 3200 m is within the oil window. The potential oil source bed in the Hussar Formation at 1484 m is immature for oil generation (Figs 7 & 14). In Empress 1A oil-prone organic-rich beds are present within the dolomitic carbonate facies of the Kanpa Formation and their organic richness ranges from 0.70 to 0.93% TOC, with genetic potential yield ($S_1 + S_2$) of 1.67 to 4.68 mg/g. These beds are mature for oil generation and rated as fair in their generating potential (Figs 4, 5, 12 & 14).

In the Gibson Sub-basin thin Neoproterozoic beds with fair generating potential for oil are present within mineral corehole LDDH 1, located near the northwestern margin of the sub-basin (Fig. 4). LDDH 1 was drilled to a total depth of 701 m and penetrated laminated dolomitic and calcareous shales. Samples from 222.8 m and 529.6 m have fair source potential and are late mature to overmature for oil generation (Fig 4 & 12). No source rocks were identified in Dragoon 1 and Hussar 1.

In the Gibson Sub-basin, maturity of the Neoproterozoic rocks varies geographically. In Hussar 1 near the southern margin, the section between 1100 m and 1900 m is within the oil window (Fig. 14). In this well one sample from 1822.1 m with marginal generating potential (TOC 0.76% and $S_1 + S_2$ (1.6 mg/g) lies within the late stage of oil generation. In the northeastern portion of the sub-basin in Dragoon 1 the Neoproterozoic was intersected at 403 m and is overmature for oil generation (Fig. 14). The maturity data from LDDH 1 suggest that the Neoproterozoic section is mature to overmature along the northwestern margin of the Gibson Sub-basin.

The equivalent %Ro and Rock-Eval maturity data for samples from different present-day depths in different locations indicate a similar level of maturation (Fig. 12), suggests that the maximum palaeo-burial depth were similar in many locations.

The existing information suggests, in general, that thermal maturity within the Neoproterozoic succession of the western Officer Basin increases from the Kingston Shelf in the southwest to the northeastern part of the Gibson Sub-basin in the north. This is consistent with the greater degree of structural deformation along the northern margin of the basin (Phillips et al., 1985; Townson, 1985).

Generation Timing

Kerogen kinetics was used to simulate the timing of oil and gas generation in Empress 1A, Hussar 1, Kanpa 1A, and Yowalga 3. It was assumed that organic-rich rocks (1% TOC) contain oil-generating kerogen as follows: type I 10%, II 70% and III 20%. The modelling suggests three phases of oil generation: Neoproterozoic, Cambrian, and Permo–Triassic. The model for Kanpa 1A is illustrated on Figure 13.

Conclusions

Thin beds with excellent to fair oil generating potential are present in the Neoproterozoic of the western Officer Basin. The best source rock potential exists in finely laminated shale and siltstone within evaporitic successions of mineral corehole NJD 1 on the Kingston Shelf, where the Neoproterozoic is up to 200 m thick. The organic-rich shale between 327 m and 329 m in that corehole is rated as an excellent oil source with up to 6.64% TOC and 23.47 mg/g potential yield; it is marginally mature for oil generation.

In the Yowalga Sub-basin, fair to good quality but thin source-beds are present in the Browne Formation of Kanpa 1A, the Hussar Formation of Yowalga 3, and the Kanpa Formation of Empress 1A. These beds are marginally mature to mature for oil generation. Within the Gibson Sub-basin beds with fair oil-generating characteristics are present in mineral corehole LDDH 1, and are late mature to overmature for oil generation.

The source rocks for minor oil and numerous bitumen shows found throughout the western Officer Basin have not yet been identified. Either the source for these shows has not yet been penetrated or it is too thin to be identified by standard sampling practice.

The maturity of the Neoproterozoic succession ranges from immature to overmature. However, in all the studied wells, except Dragoon 1, Trainor 1, the basal parts of LDDH 1, NJD 1, and Yowalga 3, the Neoproterozoic succession presently lies within the oil window.

Three phases of oil generation during the Neoproterozoic, Cambrian, and Permo–Triassic are suggested for the western Officer Basin from modelling the maturation and oil generation histories of Empress 1A, Hussar 1, Kanpa 1A and Yowlga 3.

The vast area covered by the western Officer Basin is very poorly explored and the sparse well control precludes a complete assessment of the source rock potential for the Neoproterozoic successions. Effective source rock units cannot be identified from the available dataset. However, thin good quality source units has been verified in the Browne, Hussar and Kanpa formations and that the part of the Neoproterozoic section is presently within the oil window.

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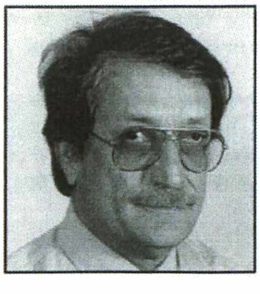

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