Canning Basin – Petroleum Systems Analysis

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SUMMARY

New high resolution geochemical information was acquired for fluids from recent Canning Basin wells and interpreted in context with previous work on fluid typing and correlation by Geoscience Australia (GA). Ungani field oils are interpreted to be derived from the same/very similar clastic source rock, comprising bacterial and marine algal matter deposited under anoxic to sub-oxic conditions, and generated within the peak oil window for a high quality marine source rock. Observed low GOR's are the consequence of both source rock type and gas removal. Liquids from the Yulleroo field are derived from a similar source to the Ungani oils, with the addition of dry gas from a higher maturity and/or more gas prone source, and generated and expelled at slightly higher maturity. The current lean gas condensate phase is the result of the addition of dry gas combined with minimal water washing. In nearly all aspects the Ungani and Yulleroo liquids resemble the L4 family previously attributed by GA to a probable Carboniferous age source. Gas-condensate from the Valhalla North-1 field was derived from a more mature source rock deposited in an oxic environment and containing more gas prone (terrigenous) organic matter. Map based modelling incorporated eleven 1D models in the Ungani-Yulleroo and Valhalla-Asgard region, and a map based burial history and maturity model. The source rock model was derived from the liquid geochemistry results rather than the poor quality source rock potential data gathered to date. Burial history modelling and maturity modelling at the top of the Lower Laurel Carbonate shows maturity for gas expulsion in the main trough and oil to light oil expulsion on the flanks of the basin. Maximum burial in the basin took place immediately prior to the Fitzroy Uplift, resulting in the main phase of oil generation and expulsion taking place around 200Ma.

Key words: Canning Basin, Ungani, geochemistry, petroleum systems analysis, basin modelling

INTRODUCTION

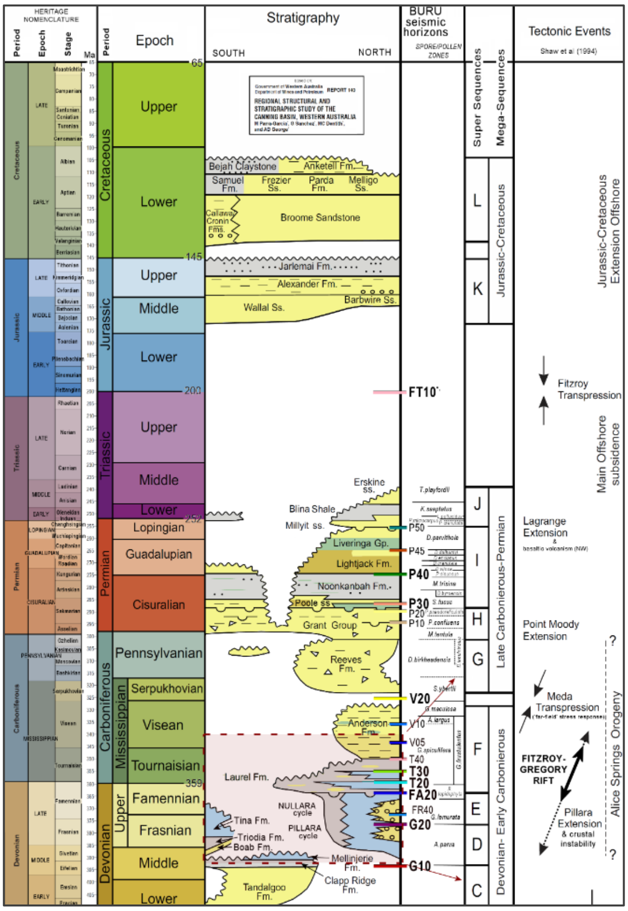


Figure 1: Generalised chronostratigraphy of the Canning Basin, WA (*Geoscience Australia*).

The discovery of the Ungani oil field, in 2011 created renewed interest in the hydrocarbon prospectivity of the Canning Basin. The discovery well, Ungani-1, recovered light (37°API) oil from the Lower Laurel (Tournasian) aged dolomite reservoirs (Figure 1) (Edwards and Streitberg 2013). The hydrocarbon occurrences in the Canning Basin are summarised in Figure 2. Prior to 1999 over 90 exploration wells were drilled on the Lennard shelf leading to a number of modest sized oil discoveries, while drilling in the Fitzroy Trough concentrated on the post Laurel targets. In the last 10 years however exploration focus has shifted into the Fitzroy trough with significant success targeting Laurel Tight Gas at Yulleroo, Asgard and Valhalla and oil in the Ungani oil play (Figure 3).

Lennard Shelf oils have been attributed to both Devonian and Carboniferous source rocks. Preliminary proprietary work by Geoscience Australia indicates similarity of Ungani, Ungani North and Ungani Far West oil to the Carboniferous family. There has previously been no systematic comparison of the oils and none which includes the condensates from the Yulleroo or Valhalla North. Earlier non-published basin modelling suggesting that the Carboniferous in the Fitzroy trough is well into the gas window are at odds with the discovery of low GOR, moderate API oil at Ungani. In early 2016, Buru Energy initiated geochemical and basin modelling studies calibrated to the temperature and maturity information from recent wells studies and aimed at integrating the knowledge obtained from the Ungani trend drilling into the petroleum systems framework previously described by Geoscience Australia/Geomark (Geoscience Australia/GeoMark, 2005).

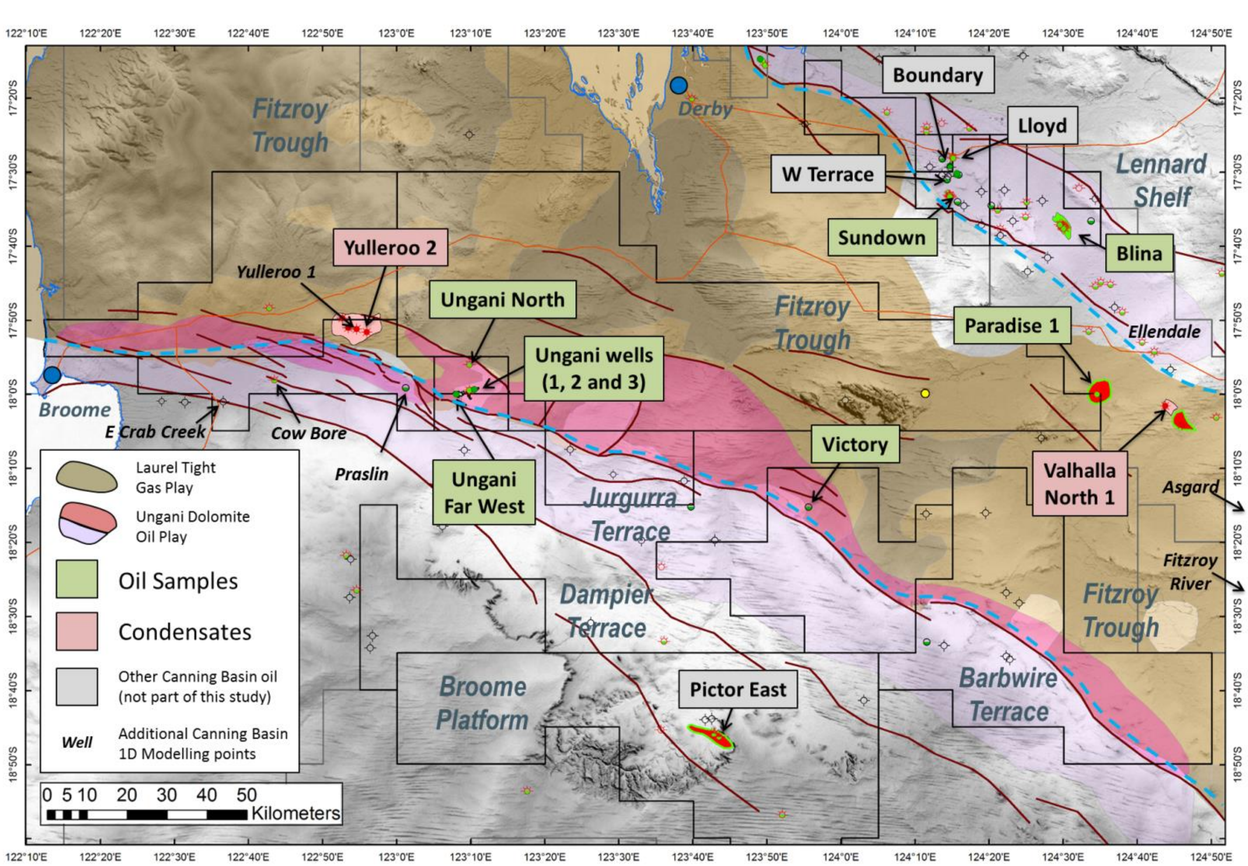


Figure 2: Play Fairway map of the Canning Basin. Fewer than 20 wells actually penetrate the prospective Ungani Dolomite and Laurel tight gas section within the Fitzroy Trough, with 14 drilled since 1998, with an 80% success rate.

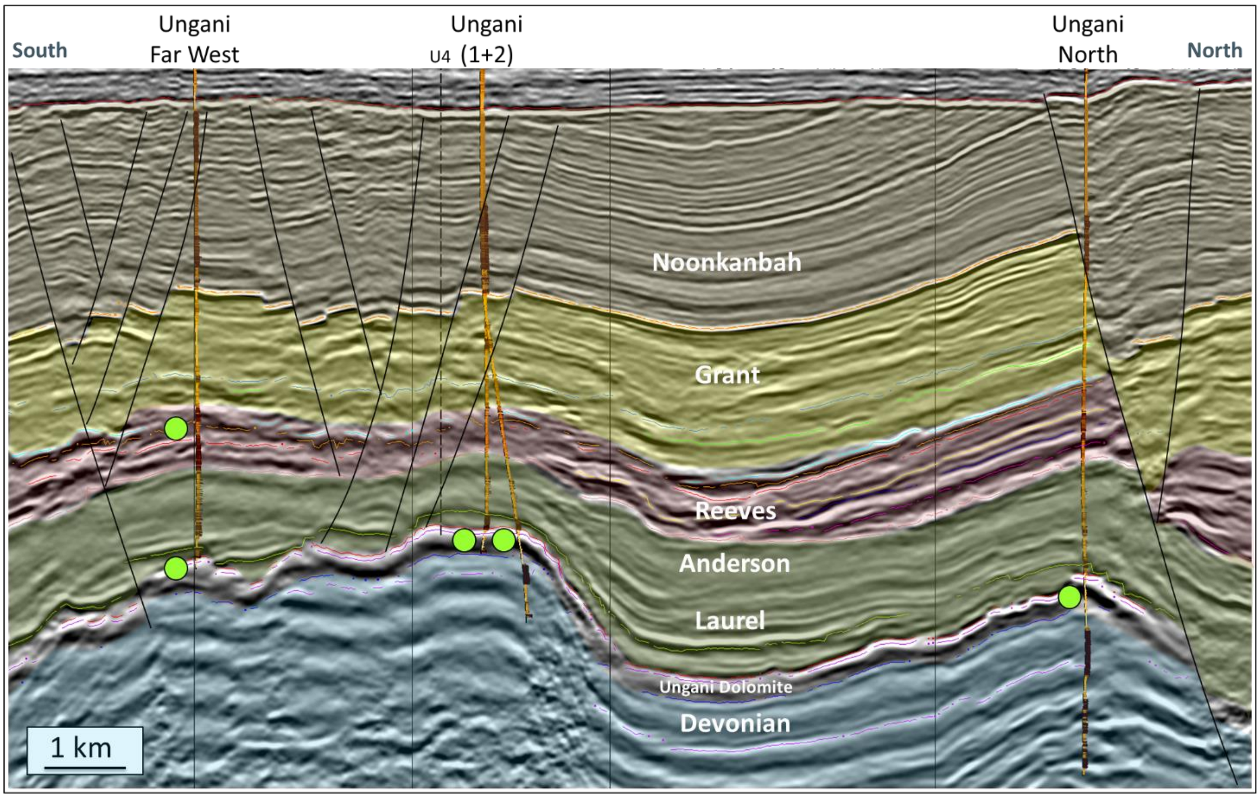


Figure 3: 3D seismic section through the Ungani Field, showing sequence and log lithology. Downhole liquid sample locations are represented by green circles.. Ungani Far West Reeves section has opened up a new play on the south side of the basin.

METHOD AND RESULTS

Oil samples from the fields on the Ungani trend (Ungani-1, -2 and -3, Ungani North-1, Ungani Far West-1) and condensates from the Yulleroo and Valhalla gas fields were subjected to high resolution geochemical analyses. Two Lennard Shelf reference oils (Blina-1, Sundown-1) were obtained from storage and analysed alongside the new samples. This was necessary because analytical technology has moved on since the original work and method-related adjustments must be made to typing criteria. The new analyses included whole fluid gas chromatography (GC) and GC-MS—MS of biomarkers by the triple quadrupole (QQQ) method. Gas geochemical data, where available, were also examined.

Eleven 1D basin models were built and calibrated to corrected temperature and maturity observations for key wells (Figure 2) based on stratigraphy reinterpreted from the well completion reports (WCRs), composite logs, cuttings and core descriptions. A constant temperature at base lithosphere bottom boundary condition was used, with changes in lithosphere thickness derived from rifting history and an interpretation of the basin evolution. Temperature, vitrinite reflectance, pressure, source rock and porosity calibration data were collated from WCR's and wireline logs. Estimates of the timing and extent of erosion were determined by seismic interpretation at primary unconformities, and 1D model calibration with corrected VR and TMax data. Map based burial history and maturity modelling was undertaken to determine the regional maturity and timing of hydrocarbon expulsion for Carboniferous source rocks in the AOI. Depth grids from 2D seismic interpretation was used to extrapolate regionally and estimate basin evolution were and burial history (Figure 4). Calibration data from the 1D models was imported to ensure the map based model was also calibrated with actual measurements, and temperature scaler maps created to account for lateral geological temperature variations.

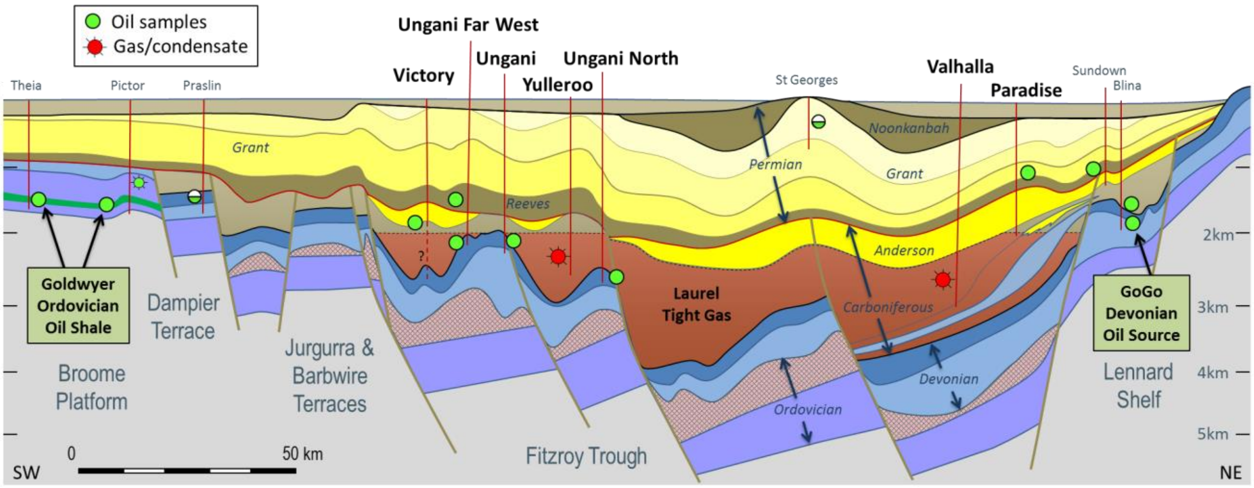


Figure 4: Cross section across the Fitzroy trough, showing wells of importance, hydrocarbon occurrences and main structural regimes

The most striking feature of the fluids discovered in the Fitzroy Trough is the wide range of physical properties (Table 1). The Ungani oils are medium to light (API 33 – 42) but extremely gas under-saturated oils with GORs of only 6 – 65 scf/bbl. In contrast, Yulleroo (CGR ~ 5 bbls/MMscf) and Valhalla (CGR ~ 20 bbls/MMscf based on production data – no PVT information available) are lean gas-condensates. The PVT (pressure-volume-temperature) information for the gas fields are either not available or incomplete, making it difficult to put them fully in geological context. Furthermore, aspects of the reported data for Yulleroo-3 are contradictory with the low liquids content inconsistent with the high saturation pressure. The very low GOR of the Ungani Trend oils requires explanation. Assuming it is not a peculiarity of the source rock, there are three in-reservoir alteration mechanisms which might create such highly gas under-saturated light oils:

1. Capillary seal failure causing loss of a gas cap and then burial of the residual oil without significant gas replenishment
2. Dissolution of gas in moving, gas under-saturated water (water washing)
3. Diffusive loss of gas through the seal rock without capillary failure and occurring over long periods of geological time.

Table 1: Details and bulk properties of Ungani Trend oils and the Yulleroo gas-condensate

Well	Depth (mRT)	Fm.	Press (psi)	T (C)	GOR/CGR (SSF) scfs/bbl	P_{sat} (psi)	API	C1/C2	C2/C3	% Gas Wetness
Ungani-1 and 2	~ 2241	Dolomite	~3014	89-95	~ 12	~107	~ 37	2.9	0.69	70
Ungani FW-1	2392	Dolomite	3279	95	58-65	318	42	3.3	0.49	66
Ungani FW-1	1566.5	Anderson Fm.	N/A	~ 85	6	N/A	33	4.8	1.2	54
Yulleroo-3	~ 3200	Laurel	6050-6550	107	~ 5 bbls/MMscf	6100	46*	10.4	2.7	25

nb: Ungani FW-1 at 15666.5m originally classified as within the Anderson Fm. is now recognised as in the Reeves Fm.

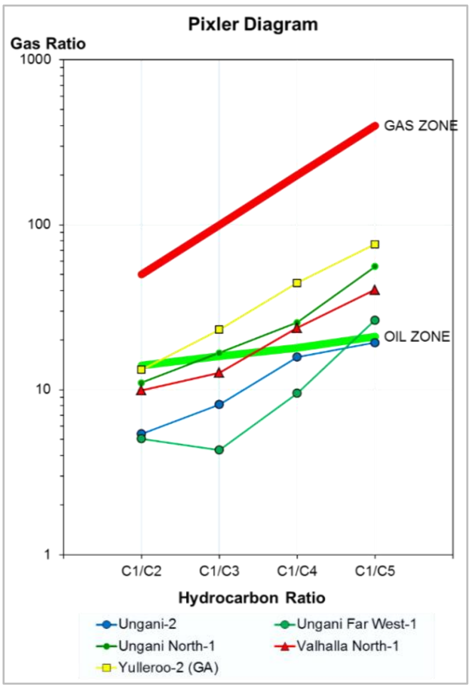


Figure 5: Pixler plot of gas composition for Ungani Trend oil solution gases and Yulleroo-2 (data from Geoscience Australia)

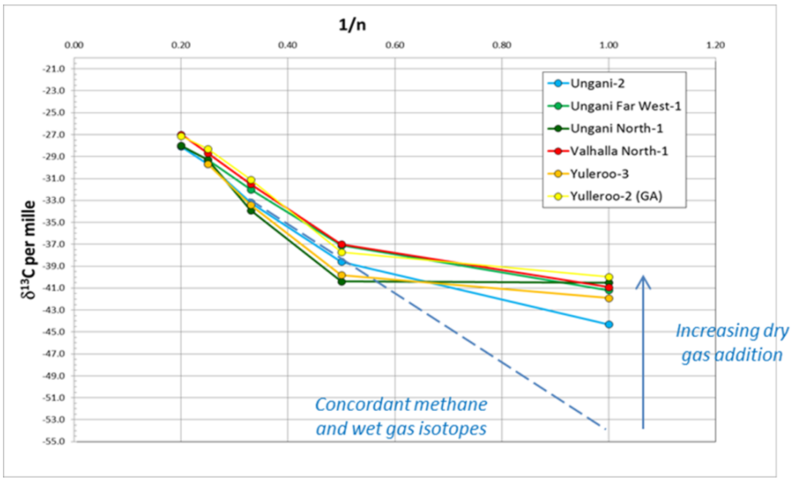


Figure 6: Chung plot of gas component carbon isotopes vs. reciprocal of the carbon number for Ungani Trend oil solution gases, Yulleroo-3 and Yulleroo-2 (data from Geoscience Australia)

Water-washing and diffusion are selective towards methane cf. the heavier gas species. While there is considerable variation in solution gas composition between the Ungani Trend oils, they are not unusually depleted in methane (Figure 5). Isotope data (Figure 6) do, however, show methane enriched in the heavy isotope cf. the other gas species: this could be due to diffusive loss of methane (which is selective toward the light isotope species) or the methane and wet gases coming from different source rocks and/or kitchens. Perhaps the more likely explanation is that uplift of the trap post-charge caused gas ex-solution and expansion leading to capillary seal failure. Reburial with minor addition of late-formed (mature, isotopically heavy) methane could then have led to the present compositional and isotope pattern.

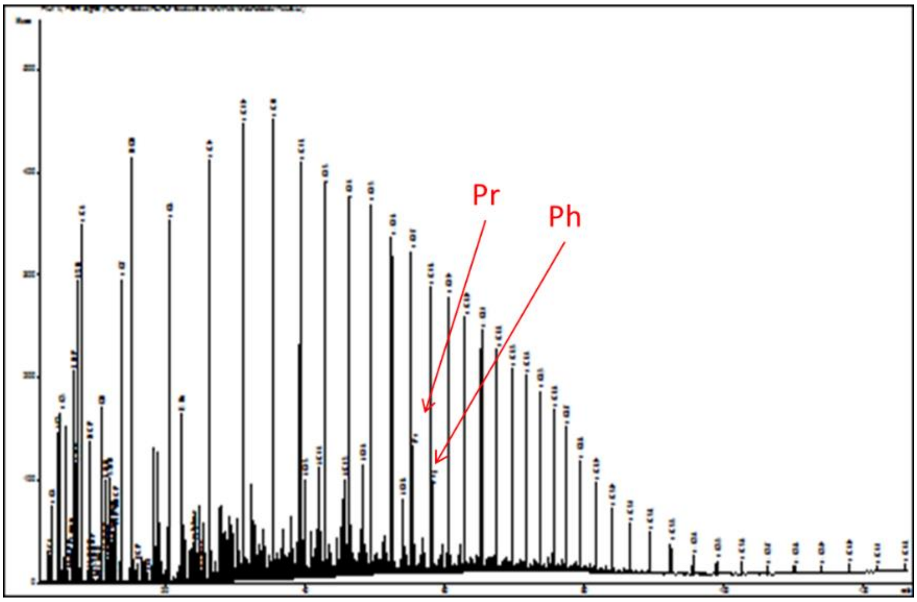


Figure 7: Gas chromatogram of Ungani-1 whole oil. Pr = Pristane, Ph = Phytane

The Ungani Trend oils have a typical distribution of paraffins for fluids derived from a marine algal kerogen (Figure 7) with no evidence of major alteration. Ungani Far West-1 does show evidence of minor biodegradation in the form of enhanced pristane/nC_{17}.

Geoscience Australia recognised three families of oils in the Canning Basin (Figure 8): Family L2 was tentatively assigned to an Ordovician age source rock, L3 to a Devonian source rock e.g. Blina) and L4 to a carboniferous age source rock (e.g. Sundown-1). Two strongly discriminating features of the L3 and L4 families (Devonian and Carboniferous) are the pristane/phytane ratio (Pr/Ph) and the percentage of C_{27} steranes among the C_{27} to C_{29} steranes. The consistency of old and new analyses for these two parameters can be demonstrated by comparing results for the Sundown-1 and Blina-1 oils (Figure 9). The Ungani oils plot among the GA-assigned Carboniferous source oils when comparing these two features (Figure 10). In contrast, the Valhalla North-1 condensate is dissimilar to all other oils, having both higher Pr/Ph and % C_{27} steranes. Unfortunately, cyclic biomarkers are too low for accurate measurement in the Yulleroo-1 condensate. However, the pristane/phytane ratio of 1.6 is similar to the Ungani Trend oils. Most other geochemical features also suggest similarity in the source of the Ungani oils and Yulleroo liquids although there are also some differences. Biomarkers were also too low for measurement in the oil show from Victory-1 but again the pristane/phytane value is similar to the that of the Ungani Trend oils.

The average thermal maturity of expulsion for a fluid is apparent in the degree of isomerisation of alkylaromatics. Figure 11 shows a crossplot of two kinds of maturity indicator (both expressed as vitrinite reflectance equivalents). The Semi-volatile aromatics (SVA) maturity indicator (Van Aarssen et al. 2007) and the GeoMark Research Vreq. indicator both use alkylaromatic isomerisation as the measure of maturity but they operate in different ways.

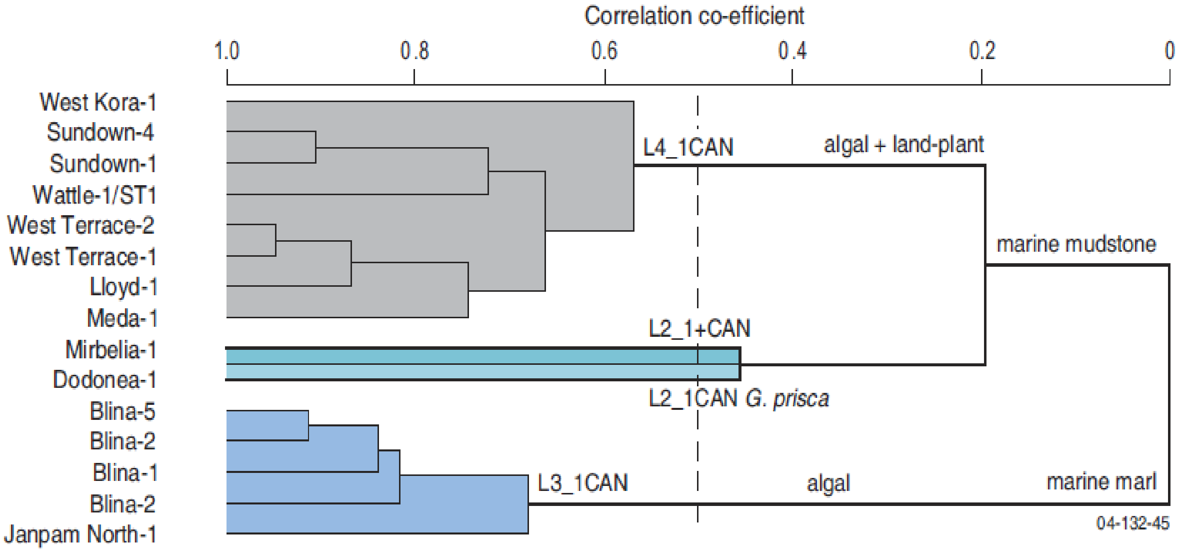


Figure 8: Hierarchical Cluster Analysis (HCA) dendogram showing Canning Basin oil families: From Geoscience Australia/GeoMark Res. Inc. (2005). The Oils of Western Australia II.

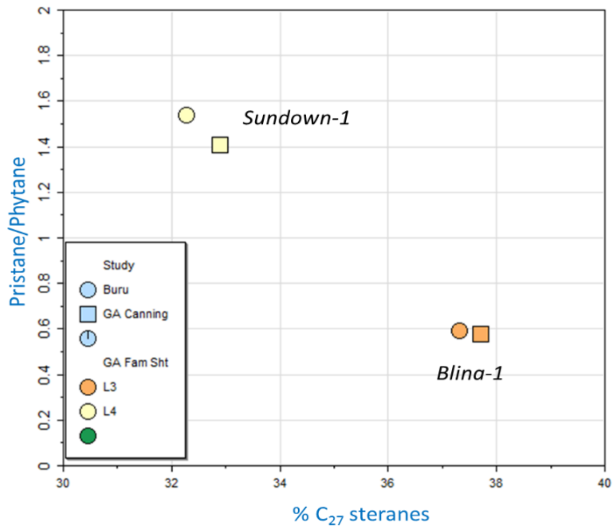


Figure 9: Comparison of geochemical parameter values derived from of old and new (GC-MS-MS) analyses of Blina-1 and Sundown-1 oils and showing good agreement

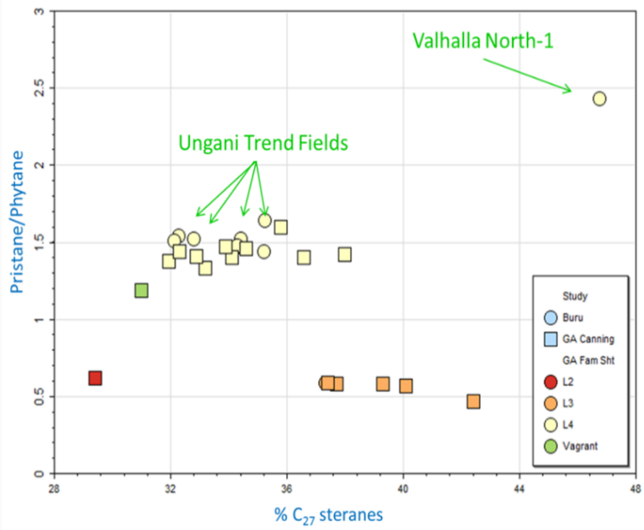
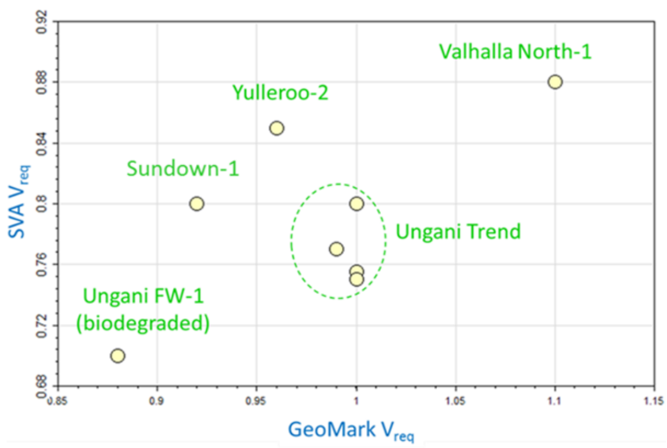


Figure 10: Cross-plot of Pristane/Phytane vs. %C_{27} steranes showing that the Ungani Trend oils correlate closely with the previously described "L4" (Carboniferous source) fluid family while Valhalla North liquids do not

Figure 11: Cross-plot of the SVA and GeoMark Vreq maturity indicators showing that Valhalla North-1 liquids are higher thermal maturity than all others. The shallower reservoir sample from Ungani Far West-1 is slightly biodegraded and this may have affected the maturity indicators.



The SVA maturity refers to the maturity at expulsion from the source rock while Vreq records both pre- and post-expulsion isomerisation. On this basis, the Valhalla North-1 gas-condensate was cleary higher maturity than the Ungani Trend oils overall. The Yulleroo-2 gas-condensate appears to have been expelled at higher maturity than the Ungani Trend oils but the overall maturity is similar. These conclusions are subject to various uncertainties but all geochemical indicators agree in assigning the Valhalla North-1 fluid and its parent source rock a considerably higher maturity than the Ungani oils.Carbon isotope profiles for the n-alkanes are often used to groups fluids into genetic families. Figure 12 shows such profiles for the Ungani Trend, Valhalla North-1 and Yulleroo-2 compared with profiles reported by GA/GeoMark Research for other Canning Basin oils. At first sight, the profiles of the Ungani Trend oils seem to match best with those of Devonian sourced oils (Family L3). However, a closer examination shows the wide variability among the Carboniferous family oils. This implies a similar degree of variability in the source rock depositional conditons and/or age. Whatever the cause, the carbon isotope profiles do not reliably differentiate Carboniferous and Devonian sourced fluids.

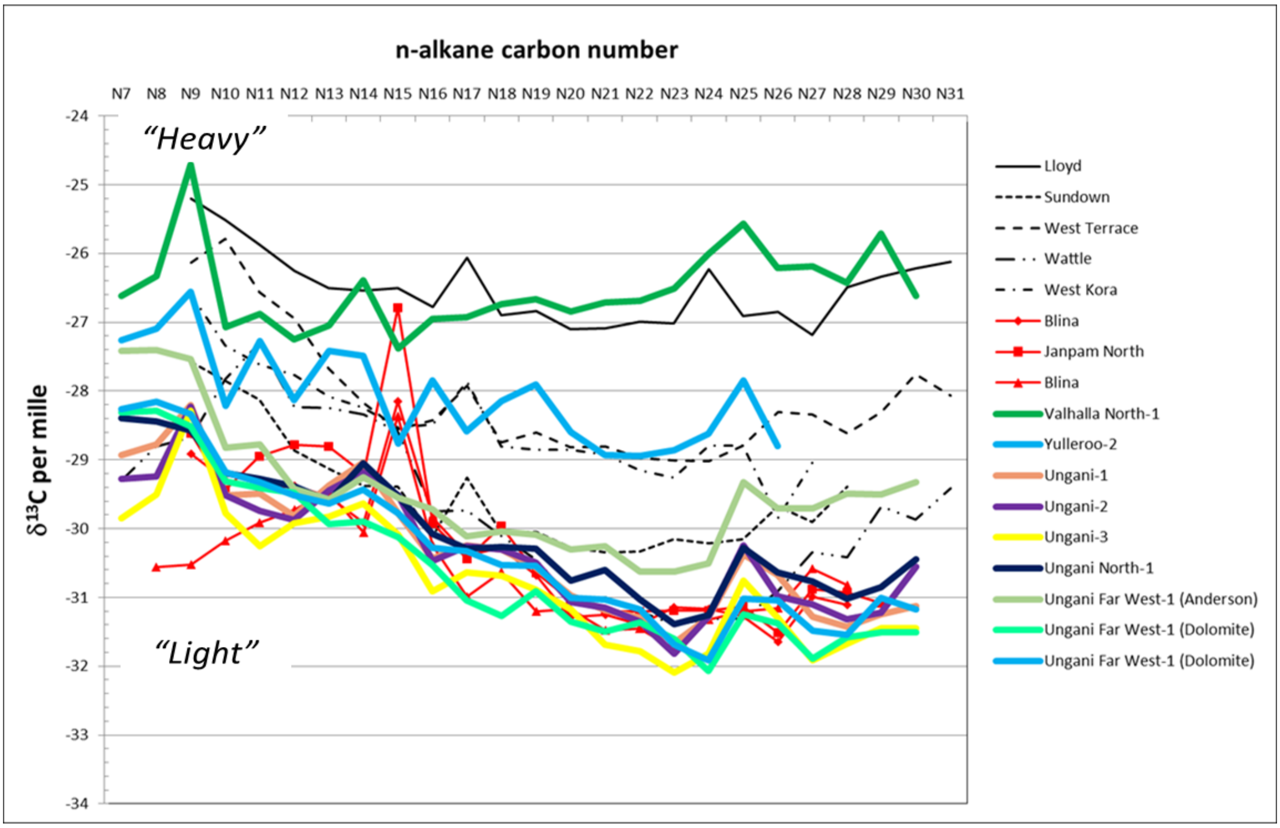


Figure 12: Carbon isotope profiles of n-alkanes in Ungani Trend oils; Valhalla North-1 and Yulleroo-2 condensates. Black lines are comparison profiles for other Canning Basin oils (from Geoscience Australia/GeoMark Res. Inc., 2005).

1D BASIN MODELLING

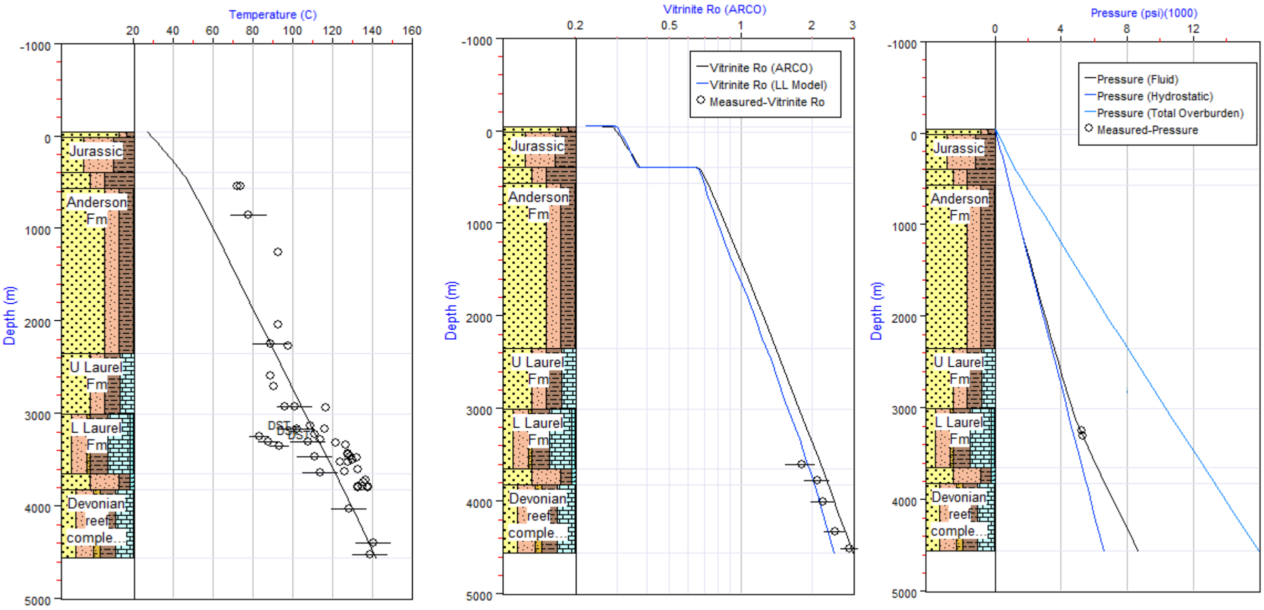


Figure 13: 1D model data and calibration example for temperature, VR and pressure, Yulleroo-1.

Results of the 1D modelling shows generally consistent corrected temperature and pressure trends, with evidence of overpressure at Yulleroo, Ellendale and Valhalla. Porosity data were sourced predominantly from core and show a consistent compaction trend with depth at Yulleroo, however, dolomotisation and other post depositional processes at the Ungani wells have created inconsistencies, resulting in poor calibration with these data. Much of the Vitrinite Reflectance (VR) data available were unreliable, therefore an overall trend for the AOI (discounting wells on the flanks of the basin) was established, and used to 'sense check' those wells where minimal or poor quality data were available

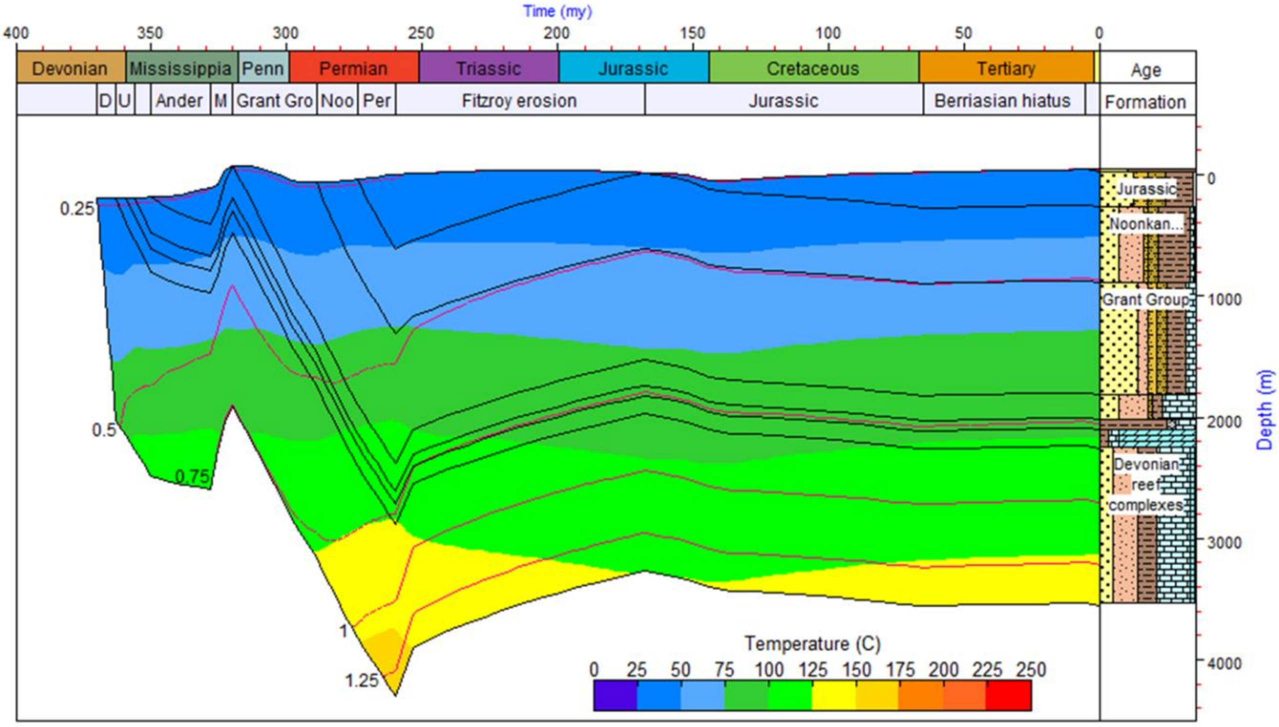


Figure 14: Burial History diagram for Ungani-1, illustrating tectonic evolution of the Ungani structure. Note the calculated present day temperature of 75-100° C at the top of the Ungani Dolomite reservoir

For wells with recovered hydrocarbons, which were previously determined to have similar maturity of liquid to source rock, liquid maturity was also incorporated to constrain VR calibration. RockEval Tmax, Hydrogen Index (HI) and Total Organic Carbon (TOC%) data were used to constrain the thermal and source rock model. Low TOC and contaminated samples were removed to increased accuracy and reliability of the data. Seismic interpretation of the Yulleroo-1 well suggests significant (~2000m) erosion at the Fitzroy unconformity, with minimal erosion evident at the Meda Transpression event. Good calibration with corrected log temperatures was achieved although DST temperatures were considered unreliable due to the gas column (Figure 13). Maximum burial at the Yulleroo-1 well location took place around 260Ma, with a maximum temperature of 225°C reached. Maximum temperatures of the Laurel Formation are modelled to have reached 100-125°C. The modelled Ungani Ungani-1, Ungani North-1 and Ungani Far West-1 wells all show good calibration with temperature data, assuming minimal to moderate erosion at the Meda Transpression and moderate erosion at the Fitzroy unconformity (Figure 3). Maximum burial for all wells occurred around 250-260Ma, with a maximum temperature of 150-175°C reached (Figure 14).

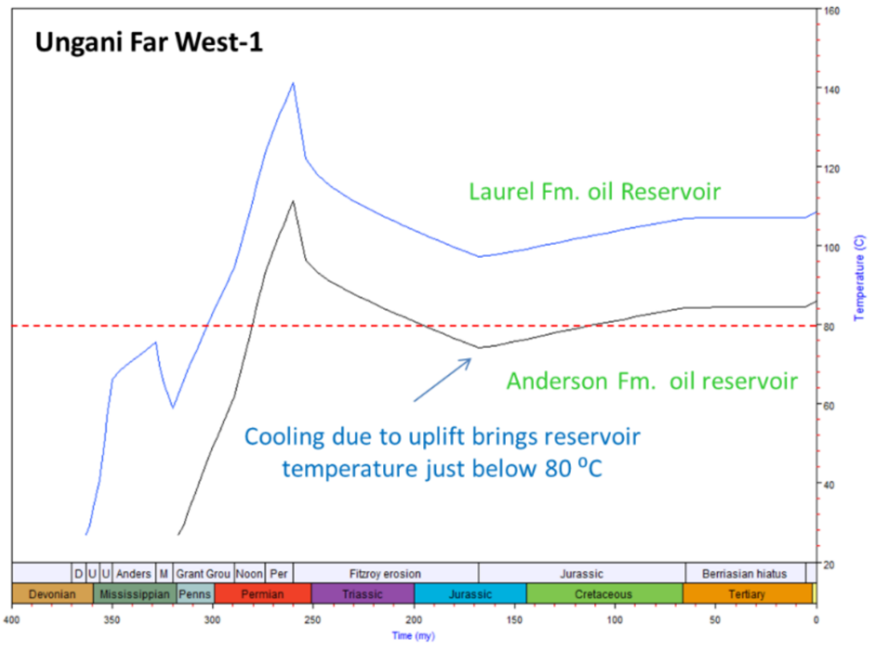


Figure 15: Comparison of 1D model temperature history for two oil reservoirs in Ungani Far West-1, illustrating potential for the observed minor biodegradation

Minimum temperatures of the shallower oil reservoir at Ungani Far West-1 are modelled to have been 75-80°C post maximum burial (due to uplift) and explain the minor biodegradation of these fluids compared to those recovered from the Ungani dolomite (Figure 15). Minimal missing section at both major unconformities is interpreted from seismic data at the Valhalla North-1 location. Moderate calibration with temperature and pressure data were achieved. Maximum burial took place between 250 and 260Ma, with a maximum temperature of 175°C reached in the Laurel Formation. The source rock model for the map based model was based on the geochemistry of the recovered liquids and was therefore classed as Type B organofacies. Kinetics for this source rock suggest oil expulsion takes place around 0.7-0.8% VR, and gas expulsion around 1.5% VR (Figure 16).

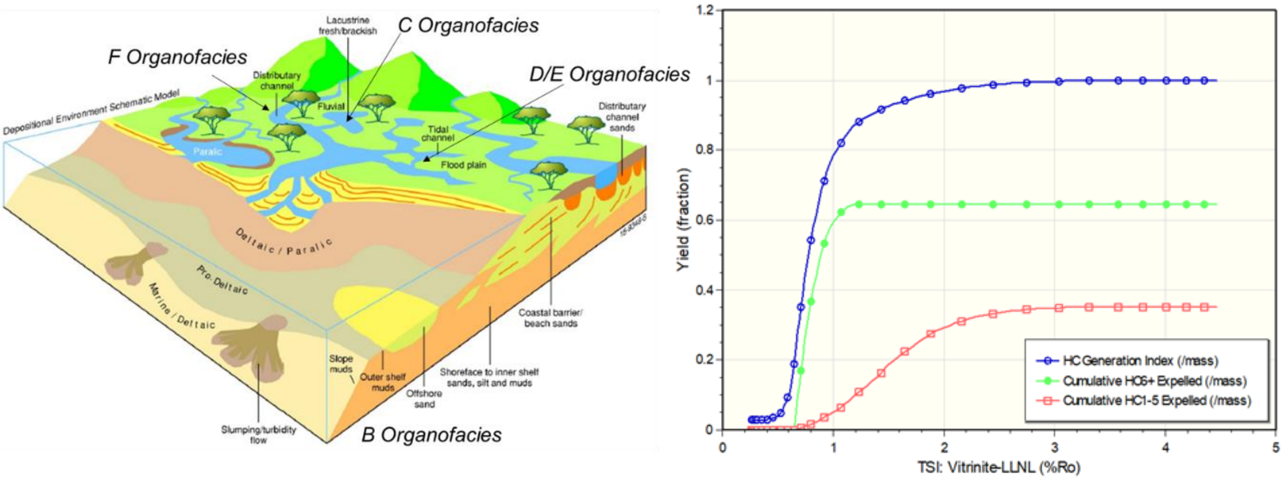


Figure 16: Left, generalised diagram of Organofacies depositional environments (Pepper and Corvi, 1995, Murray Partners PPSA), and right, expulsion kinetics vs maturity for Type B Organofacies.

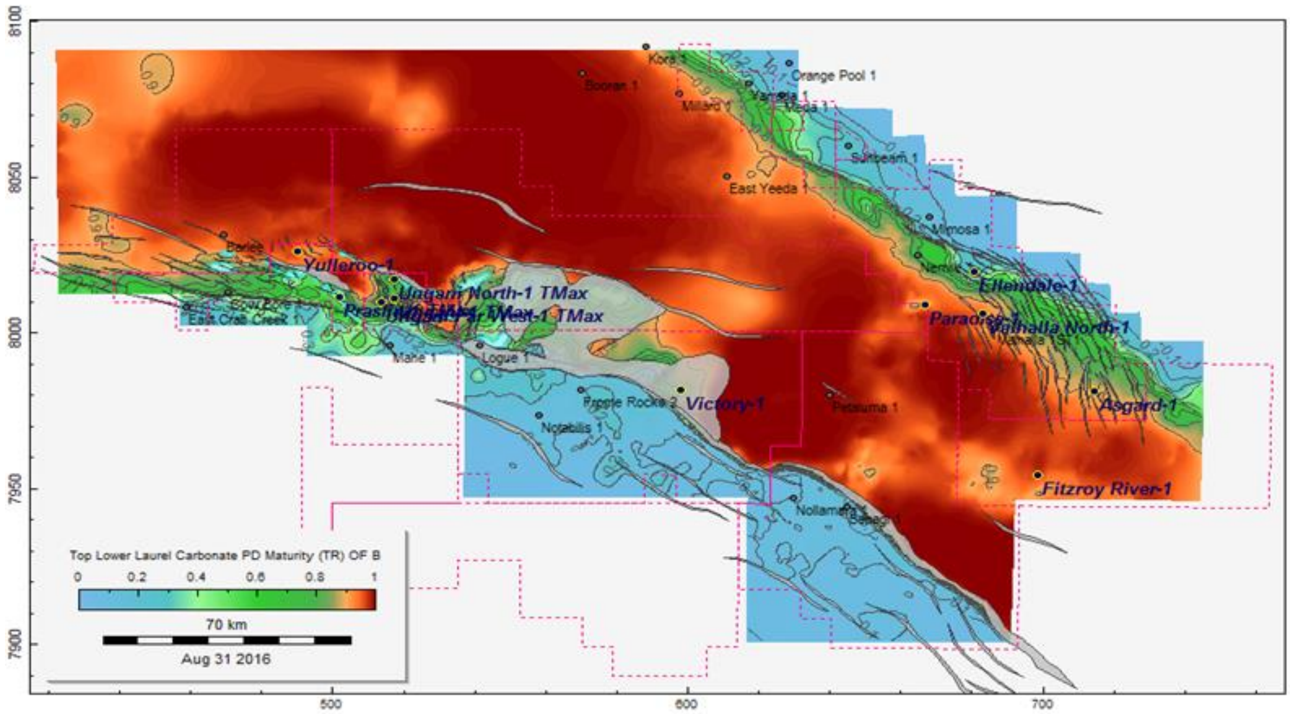


Figure 17: Maturity from TR, top Lower Laurel Carbonate.

Thickness of the modelled source rock was estimated to be a constant 40m, in the absence of detailed lithofacies mapping, based on the thickness of the overall Laurel section and known analogues. An additional model with 50% Type B and 50% Type D/E was scenario tested to account for the variations in fluids recovered from the Valhalla North-1 well. Kinetics for this type of source rock indicate expulsion at a higher maturity (~0.86-0.9% VR) which correlates with the observed higher expulsion maturity of the fluid from this well. Detailed palaeogeographic mapping was not available for this study, thus distribution of Type B and Type D/E source rock 'pods' was not attempted. Hydrocarbon occurrences were recorded from all available well data and incorporated into the model to provide further calibration between modelled source rock maturity and well results. The Upper and Lower Laurel Carbonate surfaces were considered to constrain the Carboniferous source rock package, and were modelled for maturity from VR (%) and Transformation Ratio (TR), and also for GOR. Using the Organofacies B source rock kinetics to tie the colour bar to expulsion, present day maturity from VR (%) and TR of the top of the Lower Laurel Carbonate surface indicates maturity for gas generation and expulsion in the main part of the basin, with oil generation and expulsion taking place from the flanks of the trough. Instantaneous

GOR correlates well with both the fluids recovered from wells in this sequence. Present day maturity from VR (%) and TR of the top of the Upper Laurel Carbonate surface indicates maturity for gas and condensate generation and expulsion in the main part of the basin, with oil generation and expulsion taking place from the flanks of the trough, including in the Asgard/Valhalla area (Figure 17).

CONCLUSIONS

Geochemical analysis suggests the Ungani field oils were all derived from the same or very similar marine (composed of algal/bacterial organic matter) source rock, and were generated within the peak oil window for a high quality marine source rock, with low GOR's the consequence of the source rock type and gas removal, most probably by gas cap development then loss on uplift.. Liquids from the Yulleroo field were derived from a similar source to the Ungani oils, with the addition of dry gas from a higher maturity and/or more gas prone source; generated and expelled at slightly higher maturity. The Valhalla North-1 gas condensate was derived from a somewhat more mature source rock deposited in a more oxic environment, composed of more gas prone (terrigenous) organic matter.

All liquids fall into the L4 category tentatively ascribed to a Carboniferous source by Geoscience Australia. Pepper and Corvi Organofacies B (clay rich marine) was therefore the modelled source rock based on geochemical interpretation of liquids. An additional source rock model with 50% Organofacies B and 50% Organofacies D/E (land plant) was scenario tested to account for differences in Valhalla North-1 hydrocarbons, with minimal effect on maturity, and more gas generated than the primary source rock model, which is consistent with the Valhalla-1 geochemistry results.

Burial history modelling suggests maximum burial took place immediately prior to the Fitzroy Uplift, resulting in the main phase of oil expulsion on the flanks of trough (eg. Ungani region) at around 200Ma. The onset on oil expulsion in the deepest parts of basin is modelled to have taken place prior to the Meda Transpression (end Visean), with gas expulsion from these areas also taking place prior to the Fitzroy Uplift. Map based burial history, maturity and expulsion modelling resulted in an excellent correlation between present day maturity and hydrocarbon occurrences, with good correlation between actual and modelled GOR also achieved, once post depositional processes such as water washing were taken into account.

Extensive hydrocarbon occurrences and type in the Laurel Tight Gas and Ungani Oil plays suggest the presence of a regional charge system across the Fitzroy Trough. A hypothetical petroleum system model for the Ungani region would include short range migration from a rich marine source rock surrounding carbonates (not penetrated in wells drilled to date). Yulleroo gas is contained within marine turbidites containing a local source and minimal gas migration into tight sands ('basin centred' play). The Valhalla/Asgard area is similar to Yulleroo but of higher maturity and with a land plant based component. The under-saturated fluids are believed to have developed due to the uplift and resulting drop in pressure, and consequent evolution of a gas column. Seal failure and gas loss are likely to have occurred over the extensive period of time post charge, with reburial of the initially gas saturated fluids, subsequently under-saturated, to the present day depth.

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REFERENCES

Geoscience Australia and GeoMark Research Inc. (2005) The Oils of Western Australia II: Regional petroleum geochemistry and correlation of crude oils and condensates from Western Australia and Papua New Guinea. Open file study report.

Van Aarssen B., Bastow T. Hill R. and Murray A.P. (2007) Sep arating source and maturity influences on the origin of petroleum liquids. Proc. IMOG 2007 Conference, Torquay, UK, European Association of Organic Geochemists.

Edwards, P.B. & Streitberg E., 2013. Have we deciphered the Canning? Discovery of the Ungani Oil Field. *West Australian Basins Symposium IV.*