

# Technical Note on Jarver Source Potential & Implications for Sorell Basin Exploration



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## **INTRODUCTION**

The Jarver Prospect is located in Permit T/33P, in the Sorell Basin, offshore western Tasmania.

The Sorell Basin is considered to be a southern extension of the Otway Basin. The Jarver prospect was designed to test a similar Late Cretaceous play to that which has been proven in the Shipwreck Trough region of the offshore Otway Basin. The nearest discovery is Thylacine South 1 in the Otway Basin, some 240km to the north of Jarver.

The Jarver Prospect targeted a 4-way dip closure with Belfast Mudstone top seal and Thylacine Sandstone Member reservoir, charged from the Eumeralla Formation. This play has been proven in the Thylacine and Geographe Fields in the offshore Otway Basin.

The well was spudded on the 16<sup>th</sup> May 2008 and reached a total depth of 3062m MD. The well failed to intersect any significant hydrocarbon show. Trace amounts of C1 were recorded within the wellbore and Trace spotty fluorescence was reported in the basal Paaratte Fm. Recorded bottom hole temperature (BHT) was lower than pre-drill expectations and anomalously low when compared to surrounding wells in the region. This led to a thermal maturity review of the potential source unit in the area surrounding Jarver-1.

## **PRE-DRILL ASSESMENT**

The nearest offset well, Clam-1, is located ~54 km to the north-northwest in the King Island sub-basin, which is a half graben separated from Jarver by a basement high and large extensional fault. Clam-1 has a condensed section relative to Jarver. The next closest well to Jarver is Cape Sorell-1 located in the Strahan sub-basin 110km to the south.

The pre-drill stratigraphic prognosis was based on long-distance seismic correlations from the Thylacine/Geographe area guided by Santos' regional understanding of the geological history of the basin, with a significant degree of uncertainty.

There is a proven working Petroleum System in the Otway Basin to the north. Coal Measures of the Eumeralla Formation have been identified as the source-rock for discoveries in the offshore Otway Basin. The Eumeralla Formation has been mapped southwards as far as the northern region of the T/33P permit but an intervening basement high makes correlation into the Jarver area difficult.

A potential source unit for the Jarver Prospect was identified based on seismic facies: the sediments appear to have been deposited in a series of grabens and half-grabens consistent with rifting, and they have high amplitudes which may represent the presence of coal-facies. They are separated from the overlying sediments by an angular unconformity and while the younger sediments are more confidently mapped as Late Cretaceous, the postulated source unit age is less certain, though the rift-character suggests they may be younger than latest Jurassic.

### Kerogen Type

All hydrocarbons discovered on the Southern Margins of Australia are derived from Austral Petroleum Systems which relate to latest Jurassic and Cretaceous to Palaeogene source

rocks deposited in the rift systems that developed as Gondwanaland was broken apart by various phases of rifting. These are dominated by Type III kerogens, ie terrestrially-derived, low-HI source rocks that have been historically regarded as gas-generative only. However there are exceptions to this rule, most notably in the Gippsland Basin, ~400 km to the NE, where sapropelic coals of Palaeocene age have sourced large volumes of oil. The Bass Basin, somewhat closer (~250 km) is more gas-prone but oil has also been discovered in several wells including the Yolla Field. The offshore Otway Basin contains no commercial oil-discoveries but several small accumulations have been penetrated which have been typed to the early-Cretaceous Eumeralla Formation. In addition the Cape Sorell-1 well, ~ 110 km to the SSE of Jarver 1, intersected a 300m section of Maastrichtian sands, shales and coals that indicated fair oil-source potential.

It is considered that the most likely kerogen-type is Type III but with potential for oil-proneness. For modelling purposes, in the absence of hard data, Santos has chosen to use BMod's "Waxy Non-marine Organofacies" as their type-kerogen. Sensitivities have also been run using traditional Type III kerogens and Cape Sorell's Maastrichtian coals (kinetics for which have been analysed by Boreham 2001).

Lacustrine (Type I) sources are not considered, due to the absence of any lacustrine-related oil discoveries which is due to the temperate environment of deposition whereby the annual turnover of layered waters leads to oxygenation of bottom waters and failure to develop a deepwater, anoxic environment, conducive to the preservation of kerogen.

### Unconformities

One of the important uncertainties is the magnitude of various unconformities observed on seismic, above the postulated source-rock. Depending on the amount of rock that has been removed by the unconformity the underlying source may already be over mature for generation. Any uplift and erosion will have elevated the source rock shallower than the maturity level it had attained, and even if it still retains generative potential the subsequent overburden may not be sufficient to have pushed it back down into the generative window

The K75 unconformity has been assumed to only erode a few 100s of metres of strata but much greater removed thicknesses cannot be ruled out.

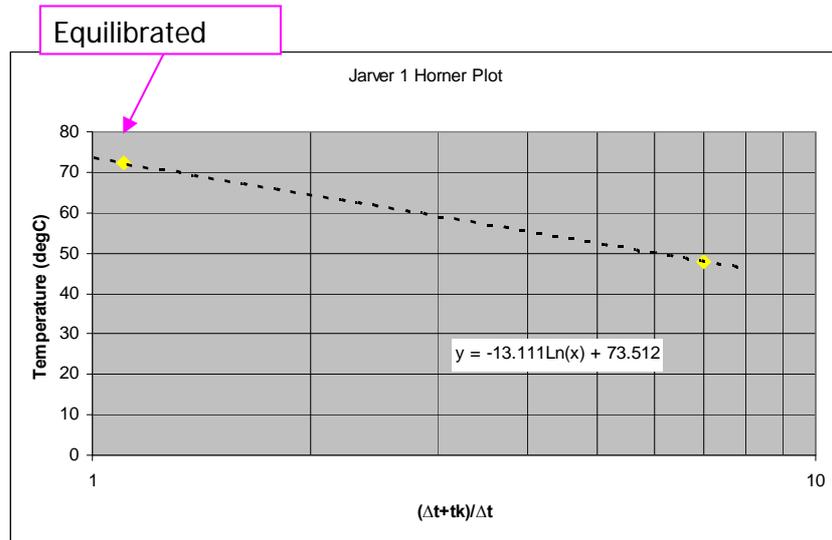
### Heat Flow

Heat-flow varies areally and over time especially in rift basins where rifting phases are associated with particularly high heat flows that decay exponentially as the basin enters the passive margin phase. A high early heat-flow may mean source rocks become over mature early in their thermal history, at depths shallower than their current-day, equivalent maturity levels.

The current day heat flow generally varies from around 55 – 60 mW/m<sup>2</sup>. However most measurements have been made on the current day shelf (where all the wells have been drilled). There is some evidence that the heat-flow may increase basinward into deeper water where the current-day water depth is related to greater degrees of heating and extension and subsequently greater subsidence of the thinned crust. ODP 1168, drilled by the Ocean Deepwater Drilling Programme in 2001 some 144 km south of Jarver-1 location, had a measured heat flow in excess of 75 mW/m<sup>2</sup>.

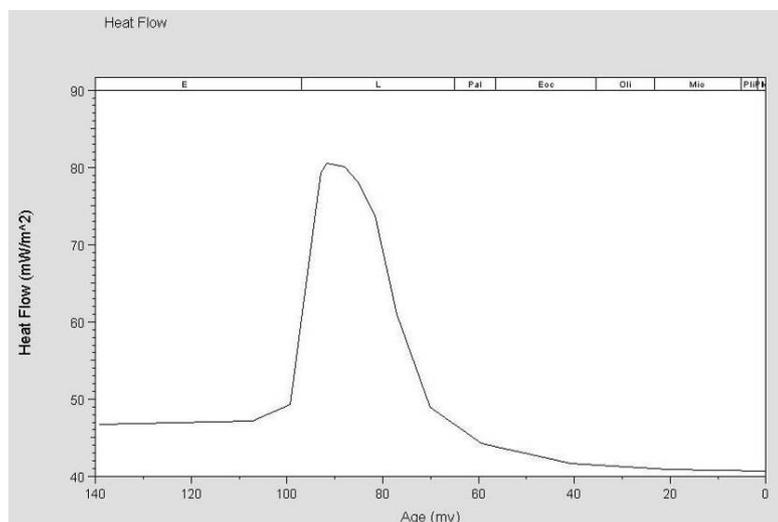
## POST-DRILL MODELLING

As previously stated, the BHT recorded in Jarver-1 was anomalously low for the region & below pre-drill expectations. The extrapolated BHT derived using a Horner plot (figure 1) with inputs from LWD circulating temperatures and recorded BHT from wire line logging indicates a static temp of ~74 deg C. This is ~34 degrees cooler than the pre-drill expected 108 deg C.



**Figure 1** – Jarver-1 Horner plot

The intersected stratigraphic sequence and equilibrated BHT were used to update the geological heat flow model (figure 2) that was input into the maturity models. The updated heat flow model incorporates a higher heat influx during the late Cretaceous rift phase where Australian plate rifted from the Antarctic plate with an exponential decay following the rifting phase down to the modelled present day heat flow. Using the updated geological heat flow model, and the stratigraphy interpreted from electronic and mud logs (lithological sand – shale ratios and layering), the pre-drill thermal model was updated to produce a revised present day heat flow for the Jarver-1 location. This was compared visually to surrounding present day heat flows calculated for surrounding wells in the region (figure 3).



**Figure 2** – Historical heat flow model for Jarver-1 area

The new data acquired from the Jarver-1 well was also used to update the surrounding pseudo-well models updating to gain an insight into the source rock potential in the area surrounding Jarver-1. Pseudo-well models used the same lithological model as Jarver-1 but the intervals were correlated back to seismic interpretation so as to have the correct interpreted thickness of formations at the pseudo-well locations.

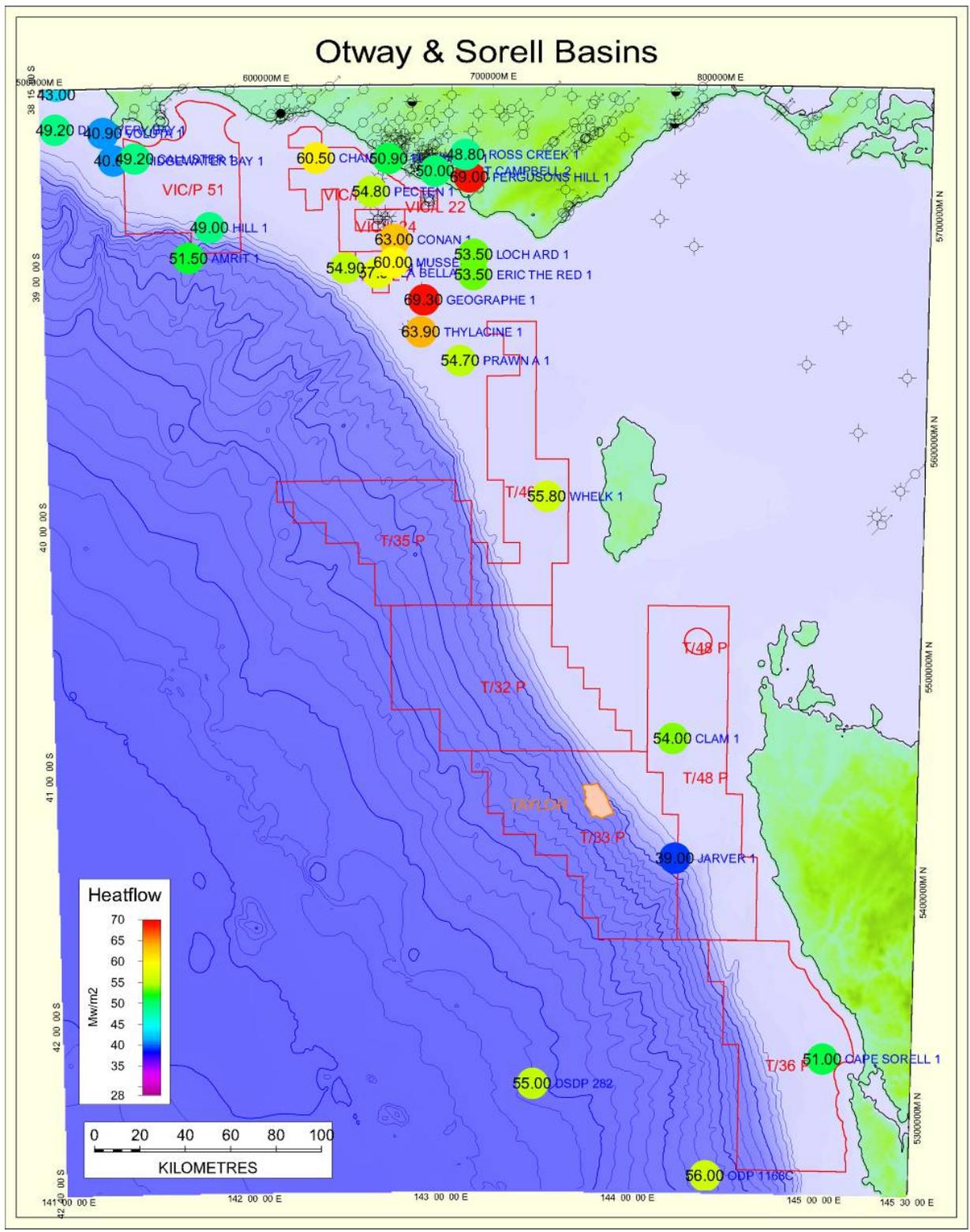


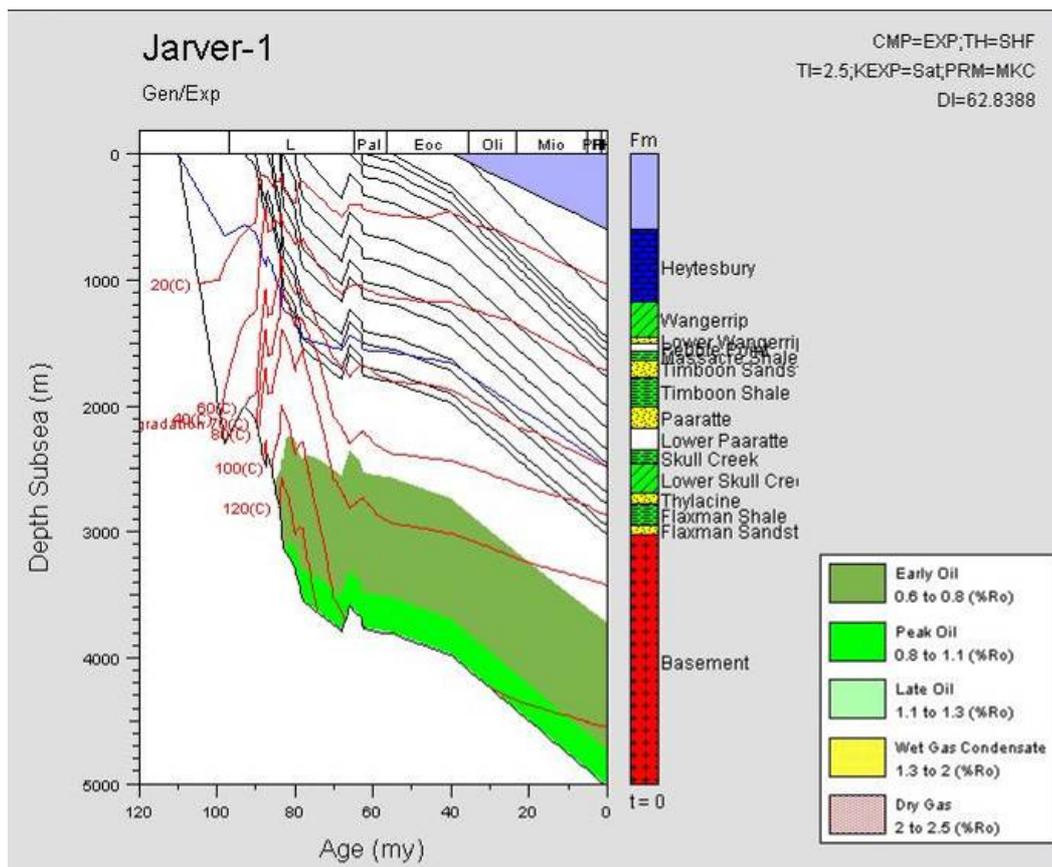
Figure 3 – Heat flow of Jarver-1 and surrounding wells

The Kerogen type used in the post drill models was the same as previously used pre-drill. With the model inputs set up as described, the models were run to see the present day maturity of the area.

## Modelling Results

### Jarver-1

Two models were run for the Jarver-1 location, one with the intersected stratigraphy, and one that substituted an amount of basement for a hypothetical Eumeralla sequence at the base of the well. Not surprisingly the Jarver-1 model had no hydrocarbon generation or expulsion as no source rock was intersected in the well bore (figure 4). The second model which had the hypothetical Eumeralla source rock interval showed that with the current day heat flow, the source pod would need to be buried to a depth of approximately 3300m sub mud before expulsion of generated hydrocarbons would occur (figure 5). This has implications for the pre-drill source pod which used a higher heat flow and subsequently shallower depth of expulsion. The model also indicated that peak expulsion occurred in the late Cretaceous with very little expulsion since that time (figure 6).



**Figure 4** – Jarver-1 burial history showing basement enters the early oil generation window (no kerogen to generate oil is present)

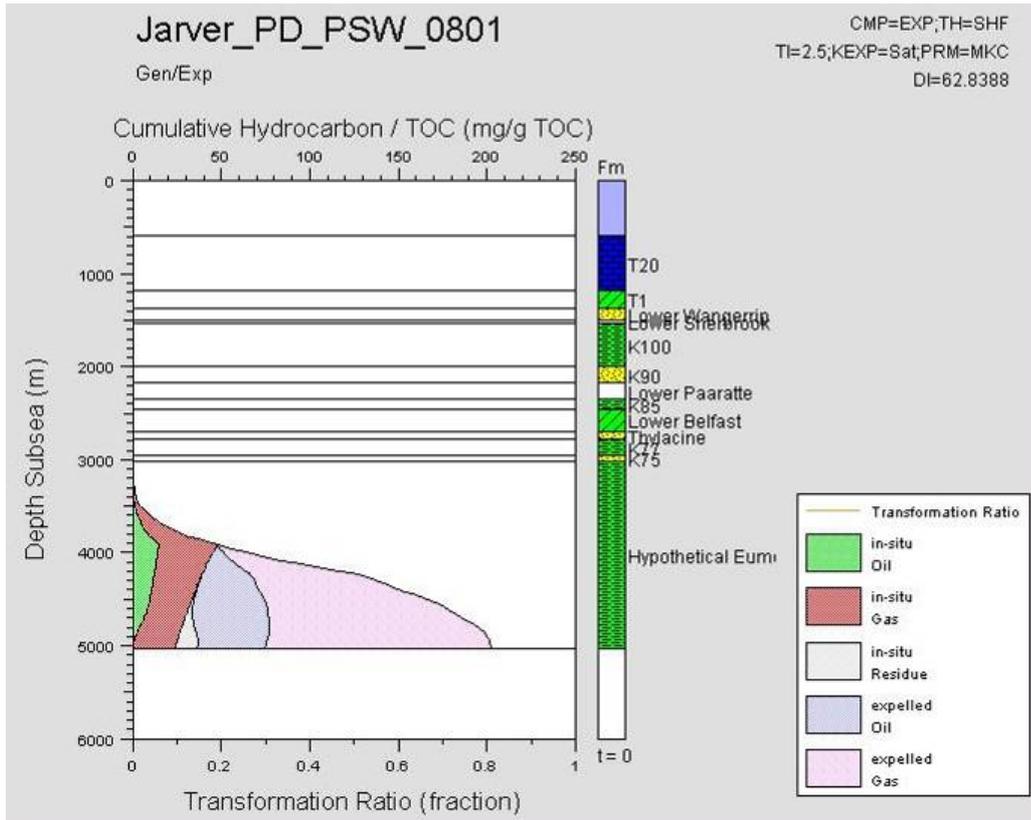


Figure 5 – Jarver-1 pseudo well with hypothetical Eumeralla sequence.

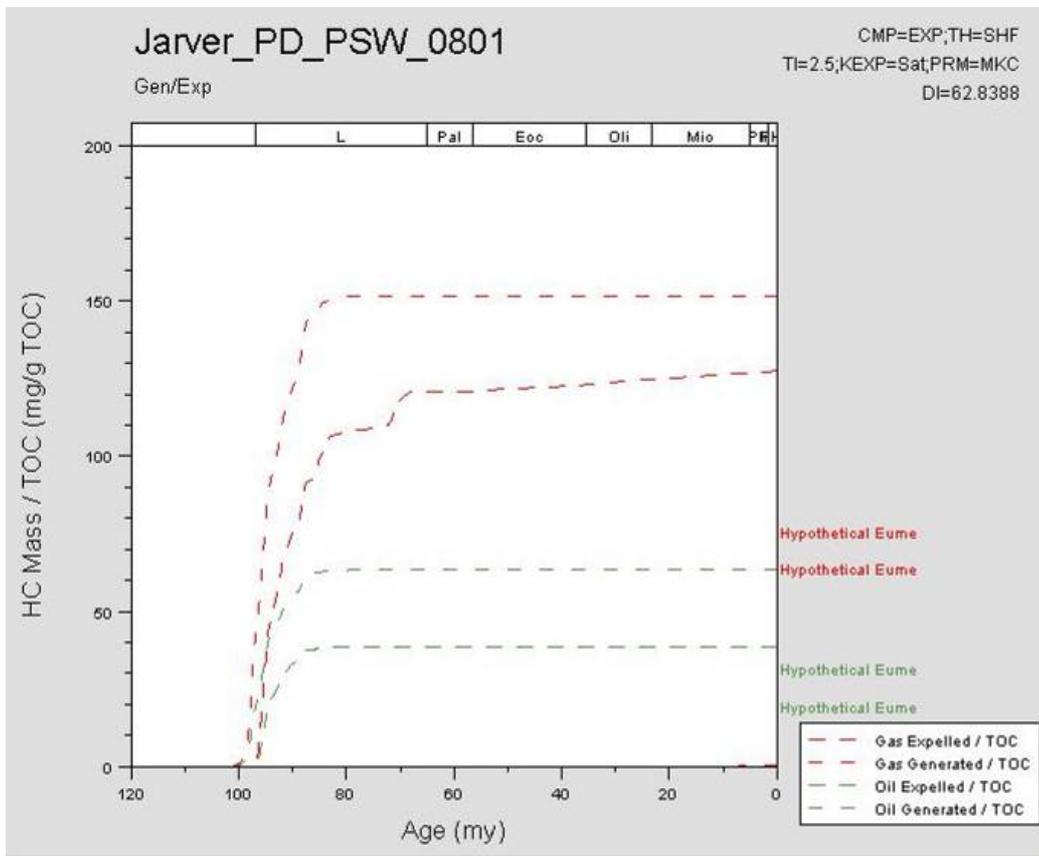


Figure 6 – Expulsion of oil & gas through time at Jarver-1 location with hypothetical Eumeralla sequence.

Five other pseudo well locations surrounding Jarver-1 were also modelled, the locations for these can be seen in figure 7 below.

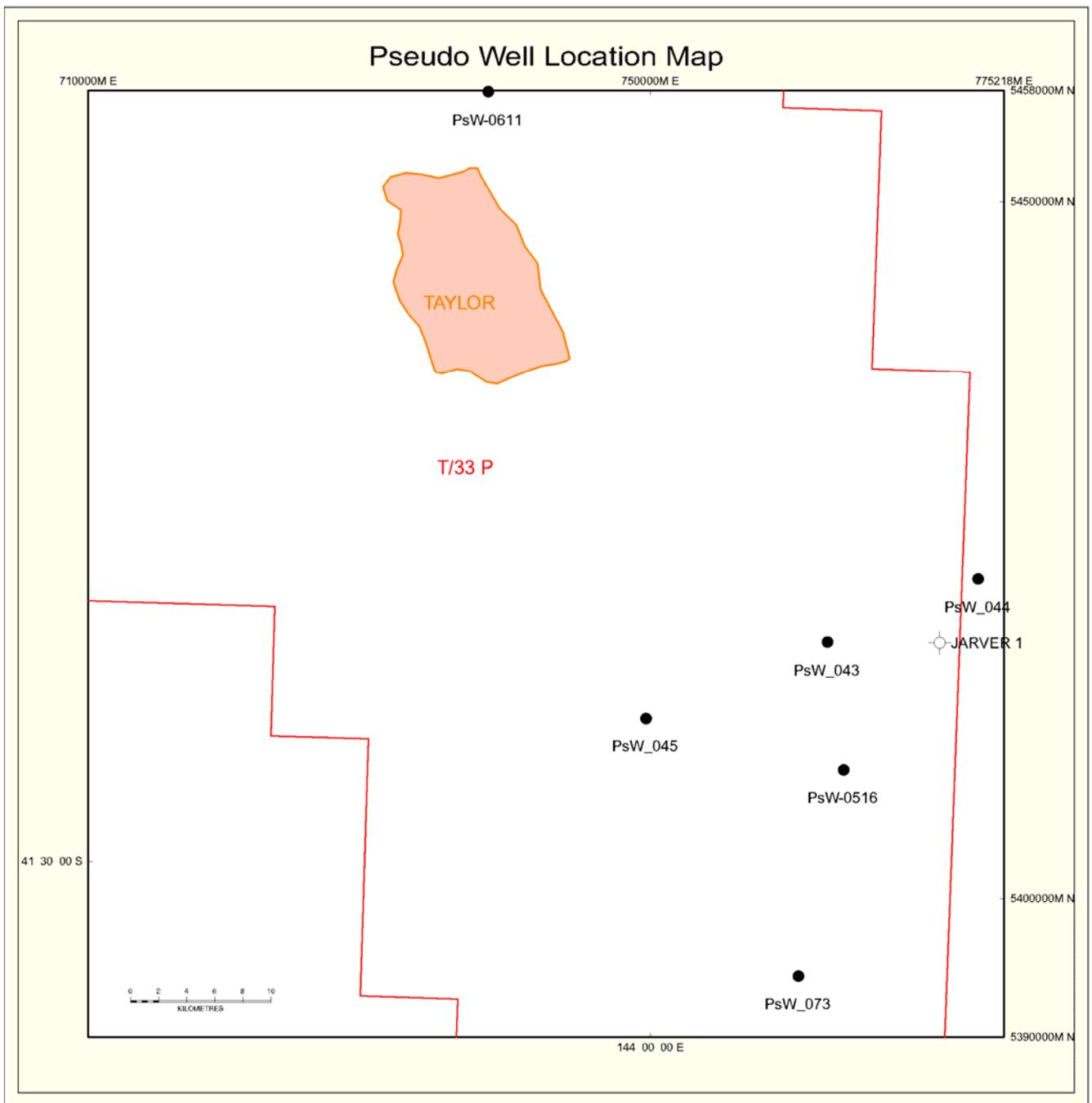


Figure 7 – Pseudo well location map (\* see note on re-naming pseudo wells at end of this report).

PsW\_0802\_043

This pseudo well, located on the downthrown side of a major basement fault, was initially interpreted to be within the source pod for the Jarver-1 well. Post well modelling shows that the basal Eumeralla below approximately 3700mSS (figure 8), if present at this location, has entered the peak oil expulsion window. Seismic amplitudes that indicate a potential source pod are located above this within the top Eumeralla Formation. Peak expulsion of any Kerogen that has entered the window would have occurred in the late Cretaceous with minor expulsion occurring since the Palaeocene to present day (figure 9).

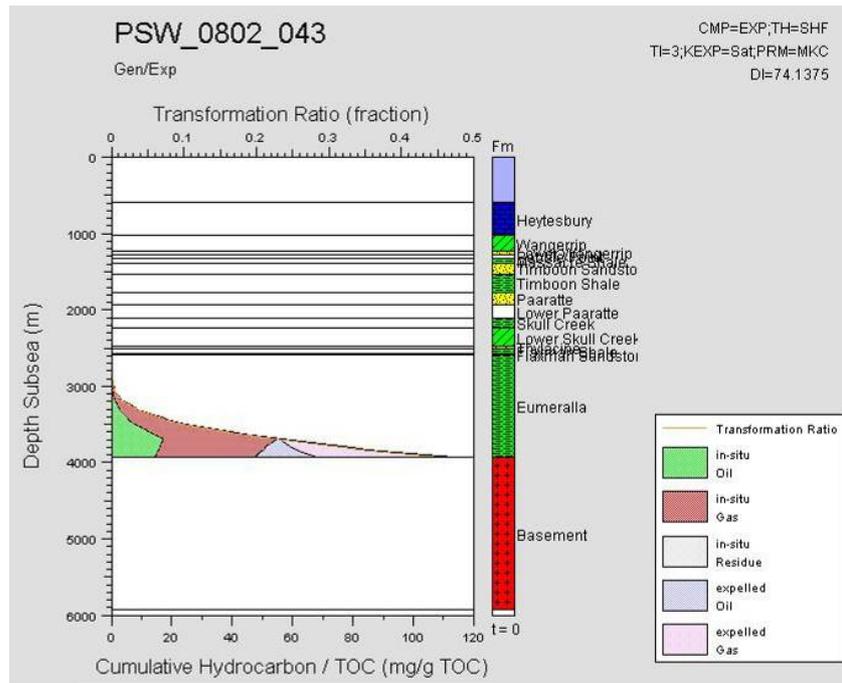


Figure 8 – basal Eumeralla formation entered expulsion window.

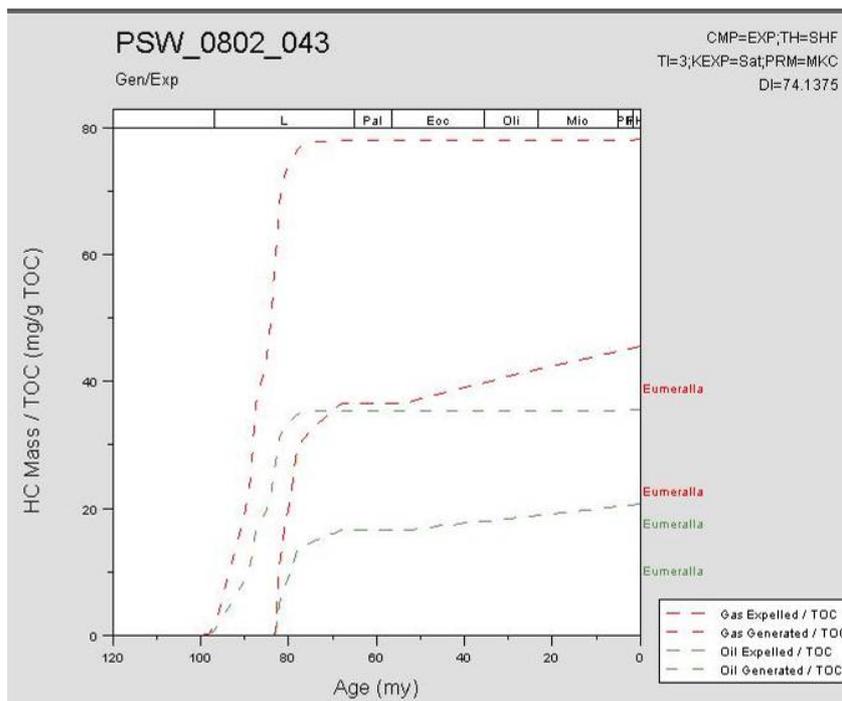


Figure 9 – Oil Expulsion through time for PsW\_0802\_043

PsW\_0803\_044

Pseudo well 0803\_044 is located further up the shelf slope than Jarver-1 (figure 7). The Eumeralla formation, if present, is thin and has less than the 3300m overburden required for expulsion of hydrocarbons (figure 10). At this location the Eumeralla would be immature, only generating hydrocarbons, not yet having entered the expulsion window (figure 10 & 11).

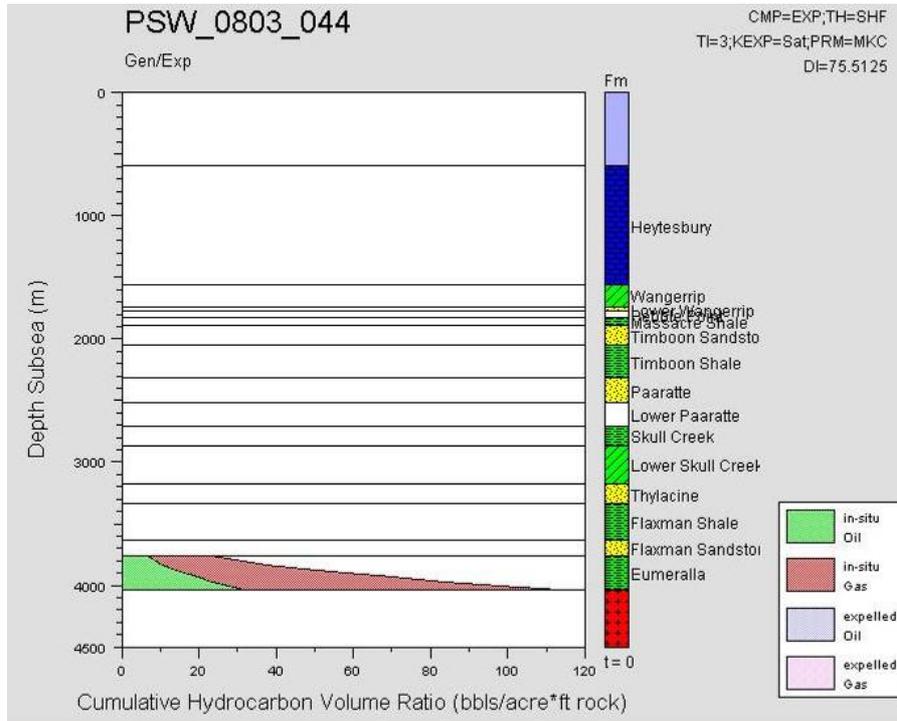


Figure 10 – PsW\_0803\_044 showing in-situ oil and gas generation, no expulsion

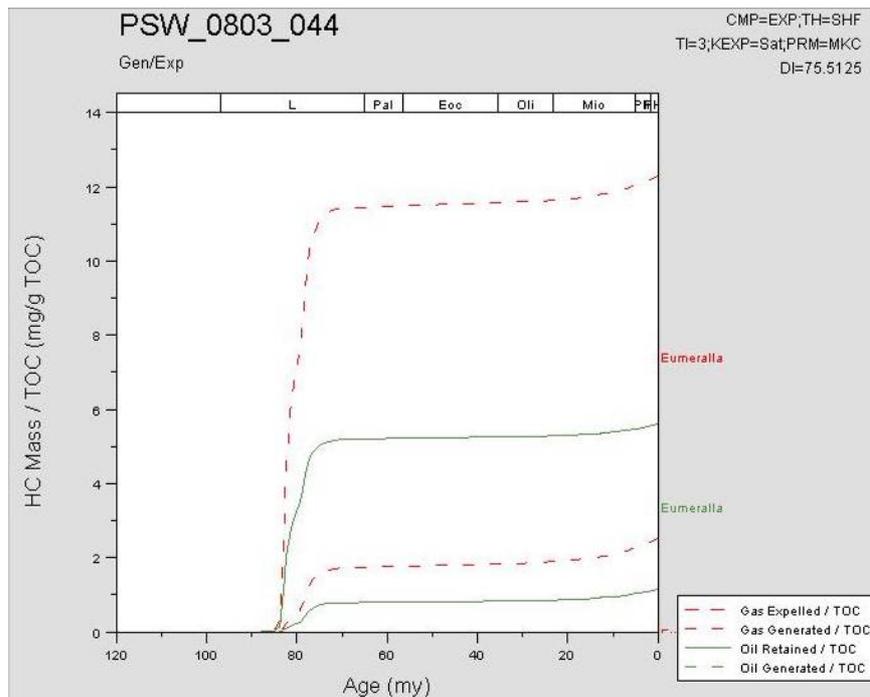
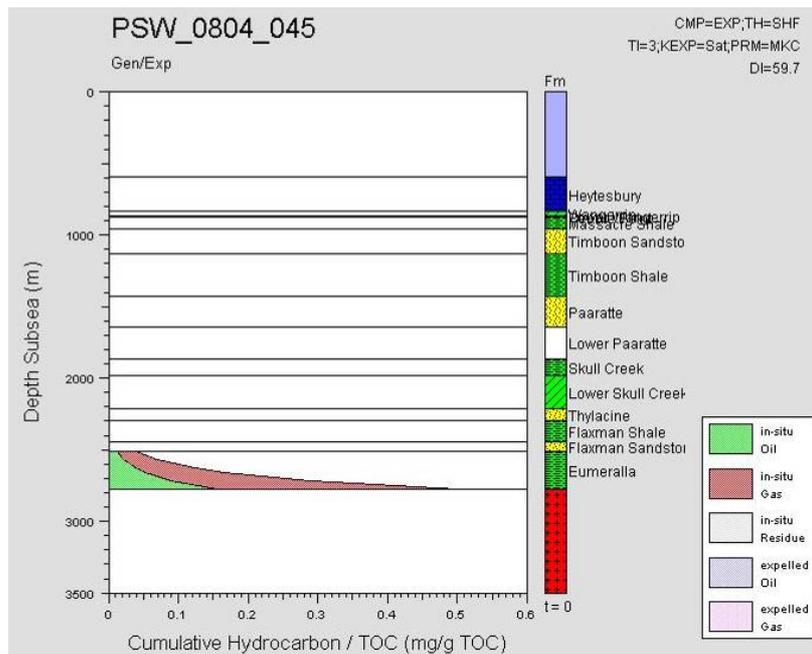


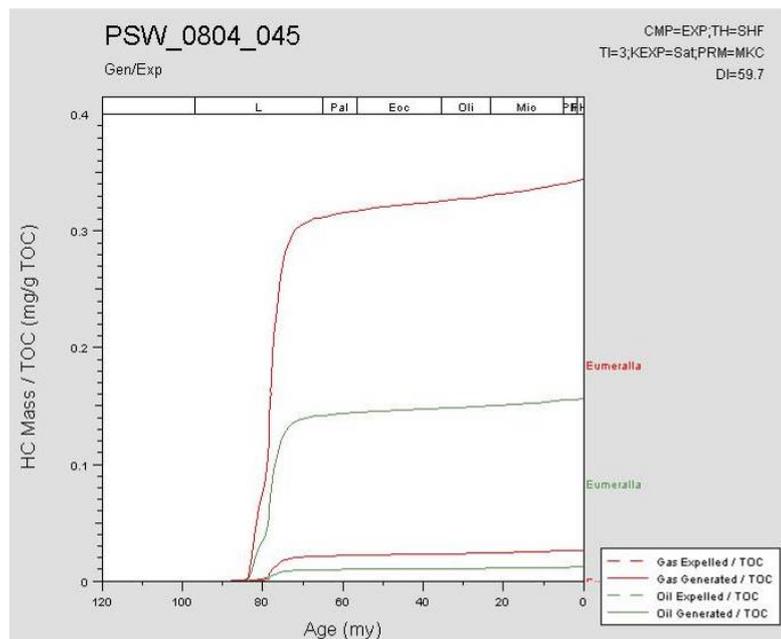
Figure 11 – Initial oil & Gas for top & bottom Eumeralla Fm generated in the late Cretaceous with minor generation post Eocene, no expulsion.

PsW\_0804\_045

Pseudo well 0804\_045 is located further off the shelf slope in deeper water than Jarver-1. At this location the modelled Eumeralla formation has reached a level of thermal maturity to generate both oil and gas at the top and base of the formation. However, due to the thin overlying strata in the deeper basin, it is not buried deep enough below the mud line to have reached expulsive maturity and thus would not have expelled any hydrocarbons that have been generated (figure 12). As seen in previous pseudo wells modelled, the peak generation of hydrocarbons occurred in the late Cretaceous with little hydrocarbon generation since the Palaeocene (figure 13).



**Figure 12** – The entire Eumeralla formation has entered the in-situ oil and gas generation window, however not the expulsion window



**Figure 13** – Peak generation occurred in the late Cretaceous with small amounts of generation still occurring at present day.

PsW\_0805\_0516

Pseudo well 0805\_0516 is located on the downthrown side of the basement fault, further outboard on the shelf slope than Jarver-1. The deeper and thicker deposition of the Eumeralla formation again indicates potential generation and expulsion of hydrocarbons at the base of the unit. It must be noted however, that the interpreted coal measures are usually located at the top of the Eumeralla sequence which has not yet entered the generative window at this location using the current model (figure 14). This again leads to a source risk issue in this area. Should any hydrocarbons be expelled from the base of the Eumeralla formation, a trap would have to be in place and remain competent from the late Cretaceous when maximum expulsion occurred (figure 15).

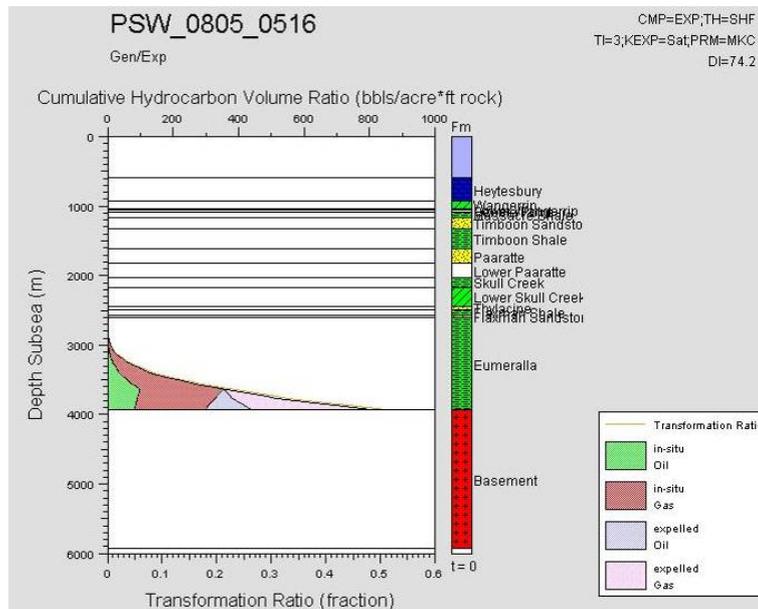


Figure 14 – the base to mid Eumeralla formation has entered the hydrocarbon generation and expulsion window, peak generation/expulsion has not yet been reached.

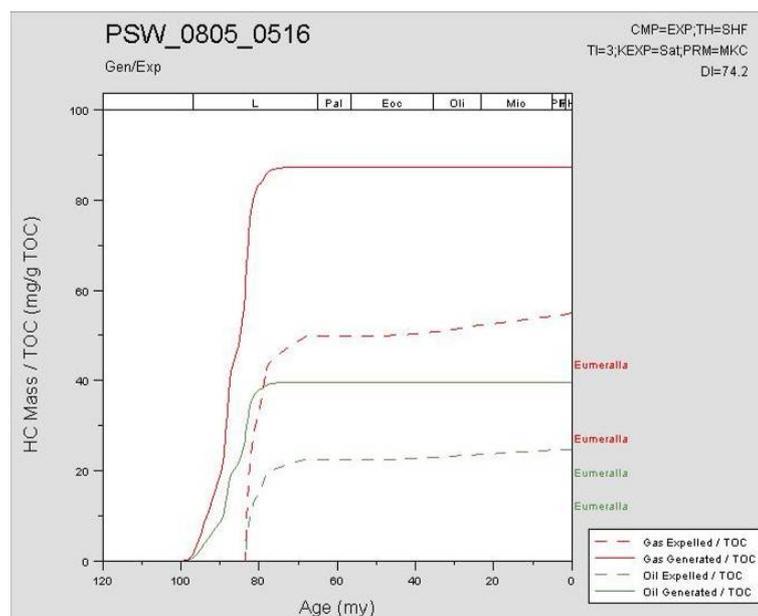


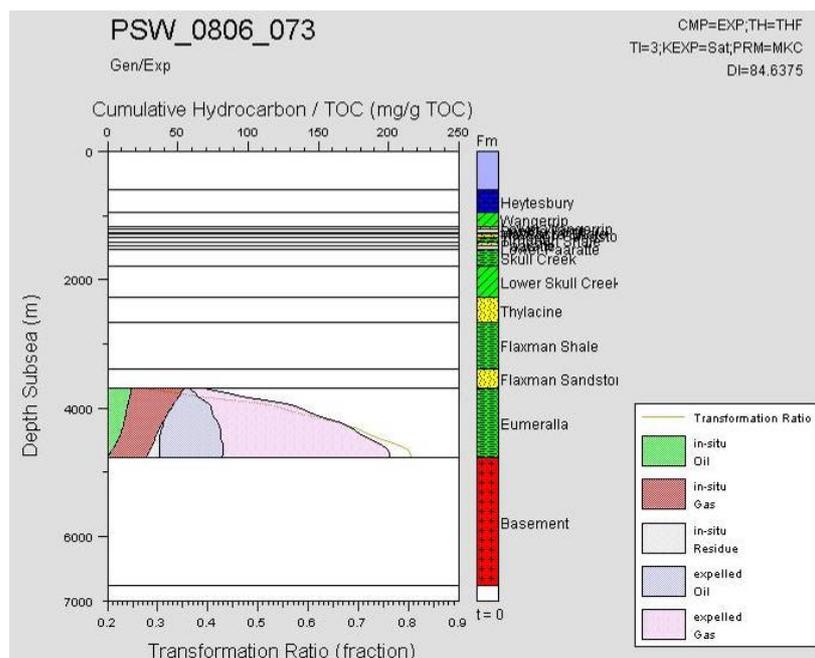
Figure 15 – The maximum expulsion occurred during the late Cretaceous. Later oil and gas expulsion began in the Eocene to present day.

## PsW\_0806\_073 & PsW\_0807\_073

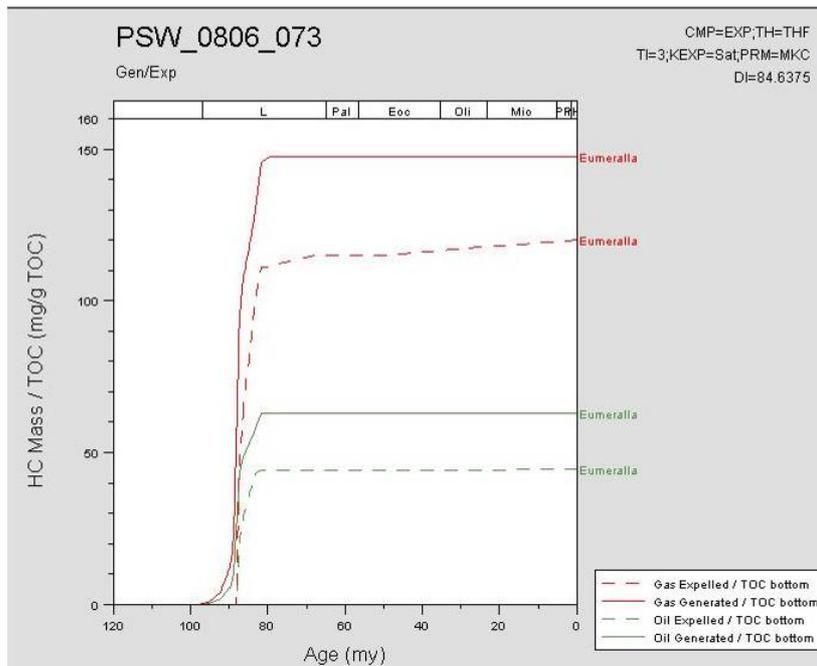
The following two Pseudo wells were modelled at the same location (suffix 073) but were modelled on differing seismic interpretations. Pseudo well PsW\_0806\_073 was modelled on the revised mapping post drill Jarver-1 where some seismic horizons were mapped shallower than pre drill. Pseudo well PsW\_0807\_073 used the new model but run on the original seismic interpretation. This location is further outboard than PsW\_0805\_0516 in a deeper part of the Sorell basin (figure 7).

### PsW\_0806\_073

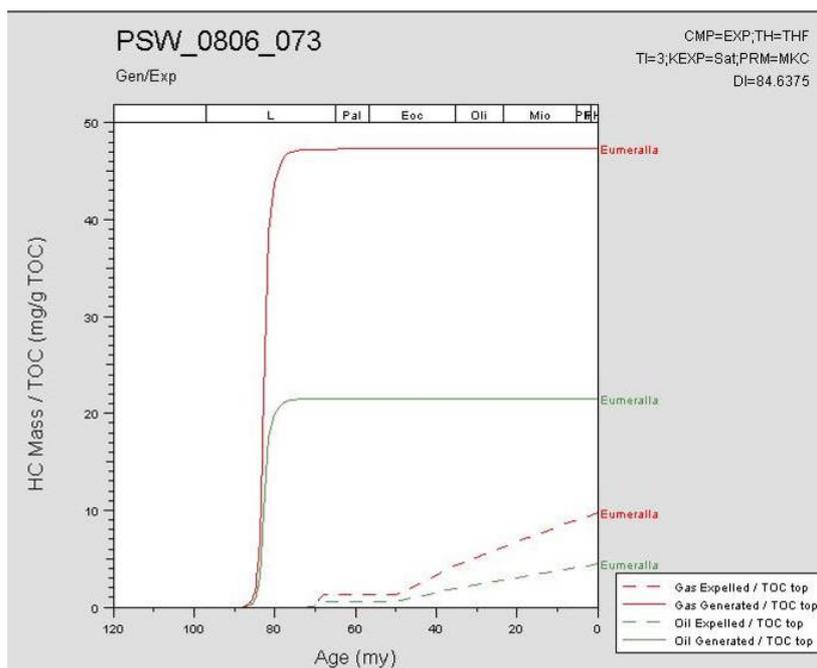
With the shallower interpretation, PsW\_0806\_073 produces a model that has the Eumeralla formation just passing peak generation/expulsion window at the base while having just reached expulsion at the top (figure 16). Once again the base of the formation is modelled to have produced maximum expelled hydrocarbons during the late Cretaceous, with little gas being expelled from the Eocene to present day (figure 17). The top Eumeralla Formation has also generated peak hydrocarbons during the late Cretaceous, but unlike the base, has only expelled a small amount of hydrocarbons at this time, with the bulk expulsion beginning in the Eocene and continuing until present day (figure 18).



**Figure 16** – In this model base Eumeralla formation has just passed peak hydrocarbon expulsion at this location, while top Eumeralla has just entered the expulsion window.



**Figure 17** – base Eumeralla formation has had peak oil generation/expulsion in the late Cretaceous, with minor expulsion of gas to present day. Peak maturity has been reached.



**Figure 18** – top Eumeralla formation had peak generation in the late Cretaceous with expulsion beginning in the Palaeocene, increasing in the Eocene – present day. Peak maturity has not yet been reached.

PsW\_0807\_073

Using the pre-drill seismic interpretation, this model indicates that the Eumeralla formation has entered the oil and gas generation and expulsion windows and is thermally mature. Both the base and top Eumeralla are expelling hydrocarbons with the base past peak expulsion and the top well into the expulsion window (figure 19). At this location, the model again shows that the late Cretaceous rift phase had sufficient heat flow to generate and expel hydrocarbons, with no generation and little expulsion since the Cretaceous (figures 20 & 21).

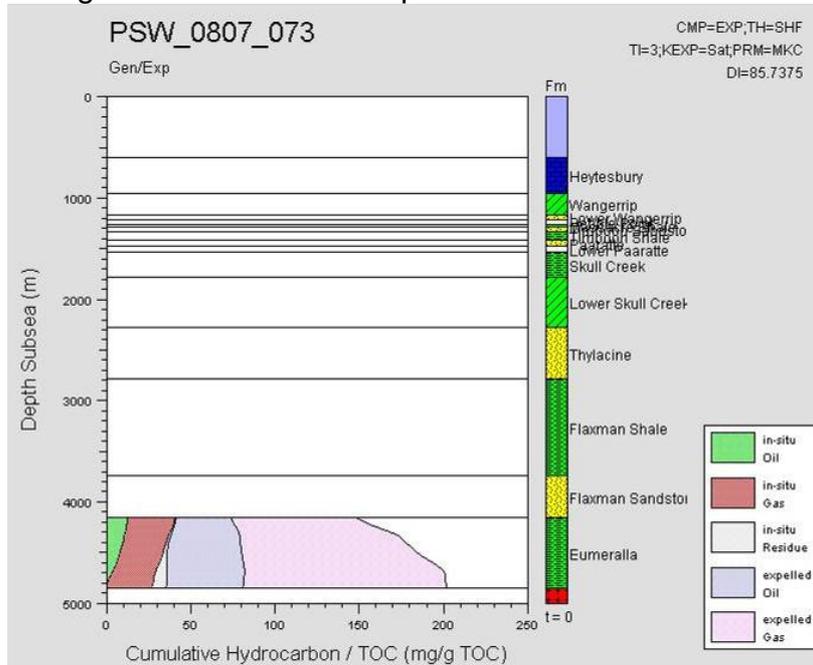


Figure 19 – top and Base Eumeralla have entered the hydrocarbon generation and expulsion windows.

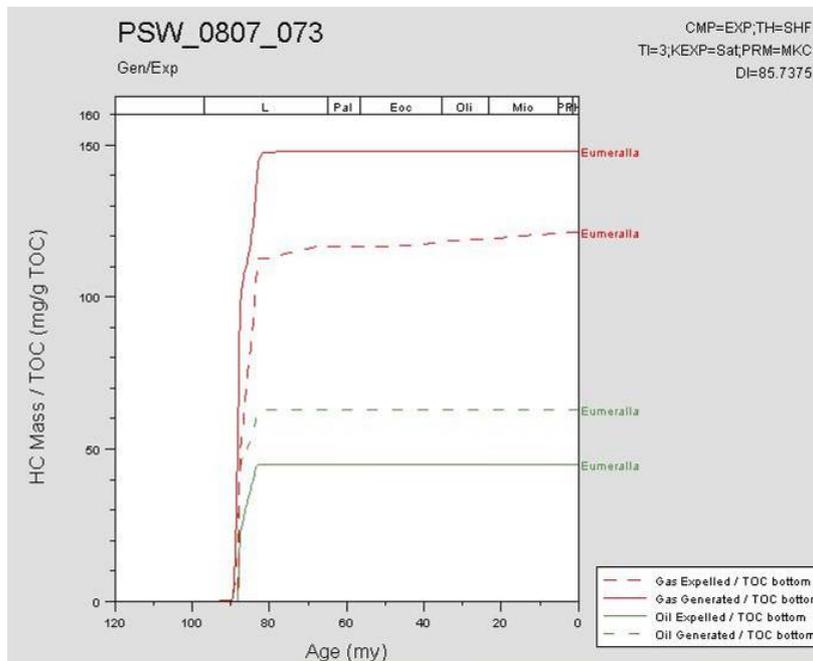
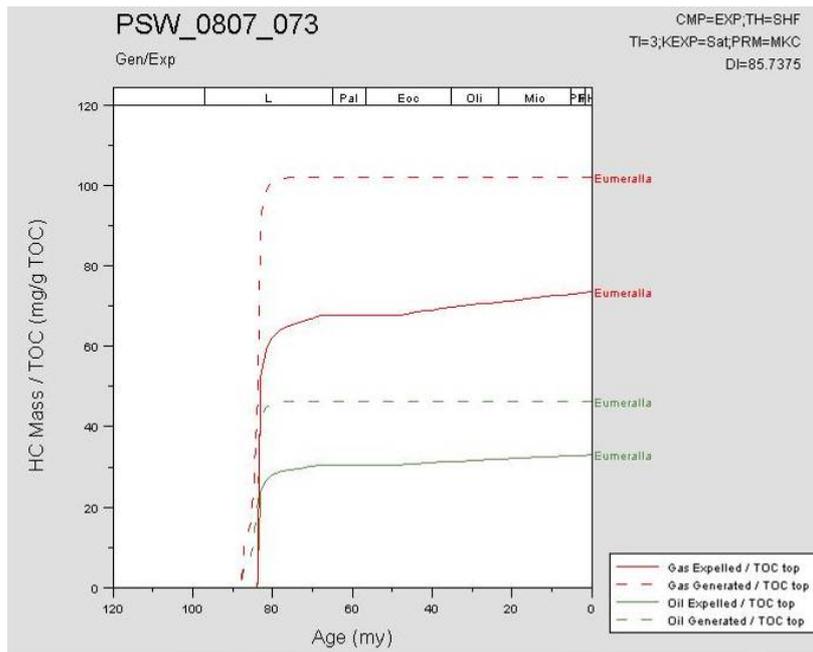


Figure 20 – base Eumeralla formation generation and expulsion peaked in the late Cretaceous with minor gas expulsion continuing to present day.



**Figure 21** – top Eumeralla formation generation and expulsion during the late cretaceous with minor oil and gas expulsion to present day

### Modelling & Discussion

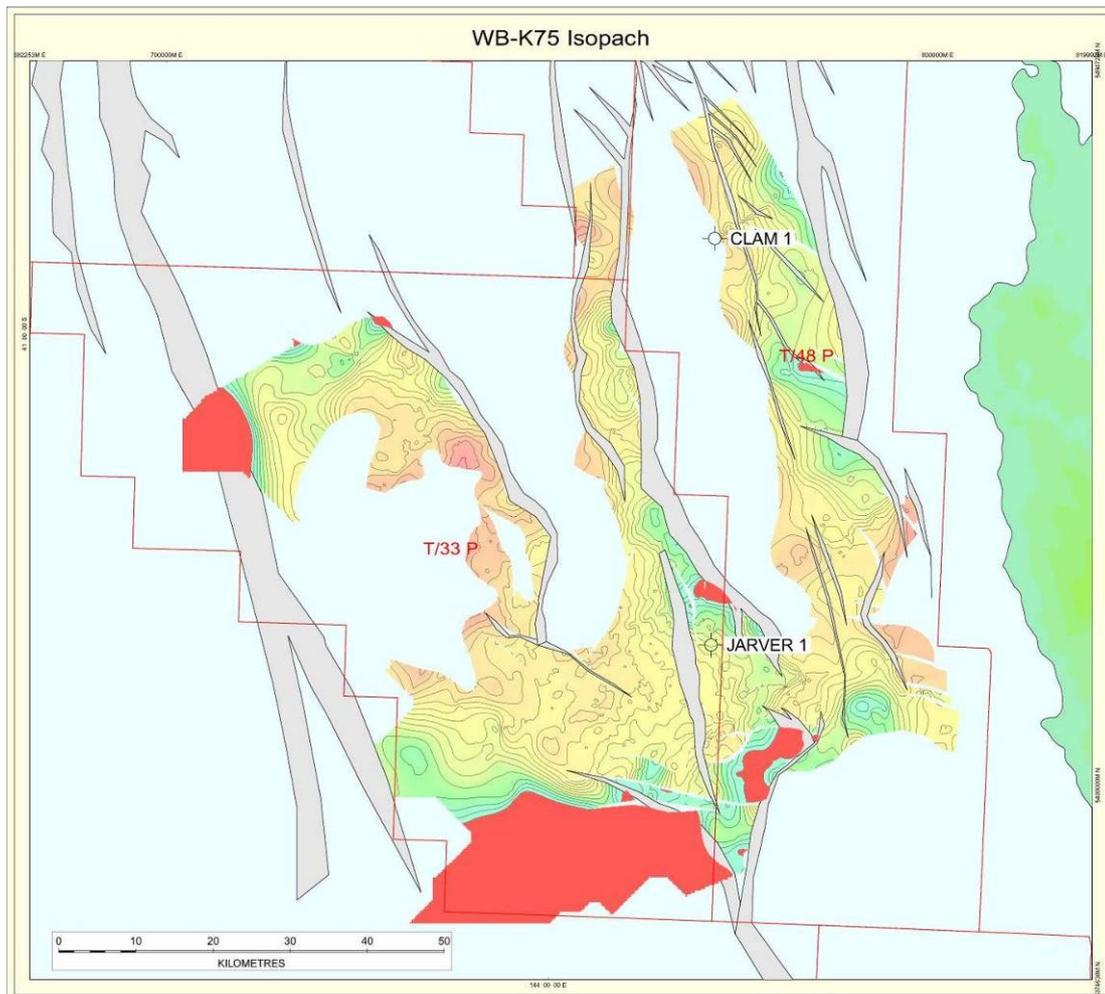
The lower heat flow in the Jarver-1 area had a negative impact on the potential source rock for this location. The source pod, if present, has been reduced in volume due to the greater than expected depth required to enter the generation/expulsion windows (~3300m sub mud). This, along with the bright amplitudes observed on seismic sitting at the top of the Eumeralla formation (interpreted as coal measures) above the expulsion window in much of the area surrounding Jarver-1, has lead to a reduction in the potential source pod volume (figures 22 & 23). Due to the high Cretaceous heat flow, for any source rock material to produce at present day, it is required to have been buried to a depth great enough to exceed the temperature reached in the Cretaceous.

The lack of Eumeralla formation sediments, and presence of conglomerate (rift fill) at the base of Jarver-1 leads to the risk that the high amplitudes seen on seismic down dip of the Jarver-1 location may not be Eumeralla coal measures as initially interpreted, but may be conglomerate rift fill with little or no source potential. Aeromagnetic survey interpretation focuses on this later in this paper.

With the modelled time of peak expulsion occurring in the late Cretaceous, a structure is required to have been present at that time with little to no movement to present day to preserve a hydrocarbon accumulation. Work on palaeo-structure over Jarver indicated that the Jarver structure was not present at the time of peak generation/expulsion at the end of the Cretaceous this is discussed further later in this report.

The lack of any significant hydrocarbon show in the Jarver-1 wellbore indicates a lack of source or migration into the structure. This can be attributed to an immature source pod in Jarver-1 catchment area, a lack of source rock deposited in the catchment area, or a lack of structure at the time of migration.

Paaratte Fluorescence was observed as trace spotty fluorescence with a faint cut and weak residual ring. The origin of this fluorescence is believed to be produced from the carbonaceous flecks in the underlying Skull Creek shale. The presence of this fluorescence and observed Vr of the carbonaceous flecks within the Skull Creek shale indicates that the sediments in the Jarver-1 area have previously been heated to a temperature greater than present day. XRD analysis of clays present throughout the wellbore has been undertaken to determine the ratio of illite to smectite. This ratio can serve as an indicator to help determine thermal history of the sediments. As clays are heated, they lose their absorptive ability as they are converted from smectite to illite. This can be correlated back to Vr and thus serve as an indicator of past thermal history.



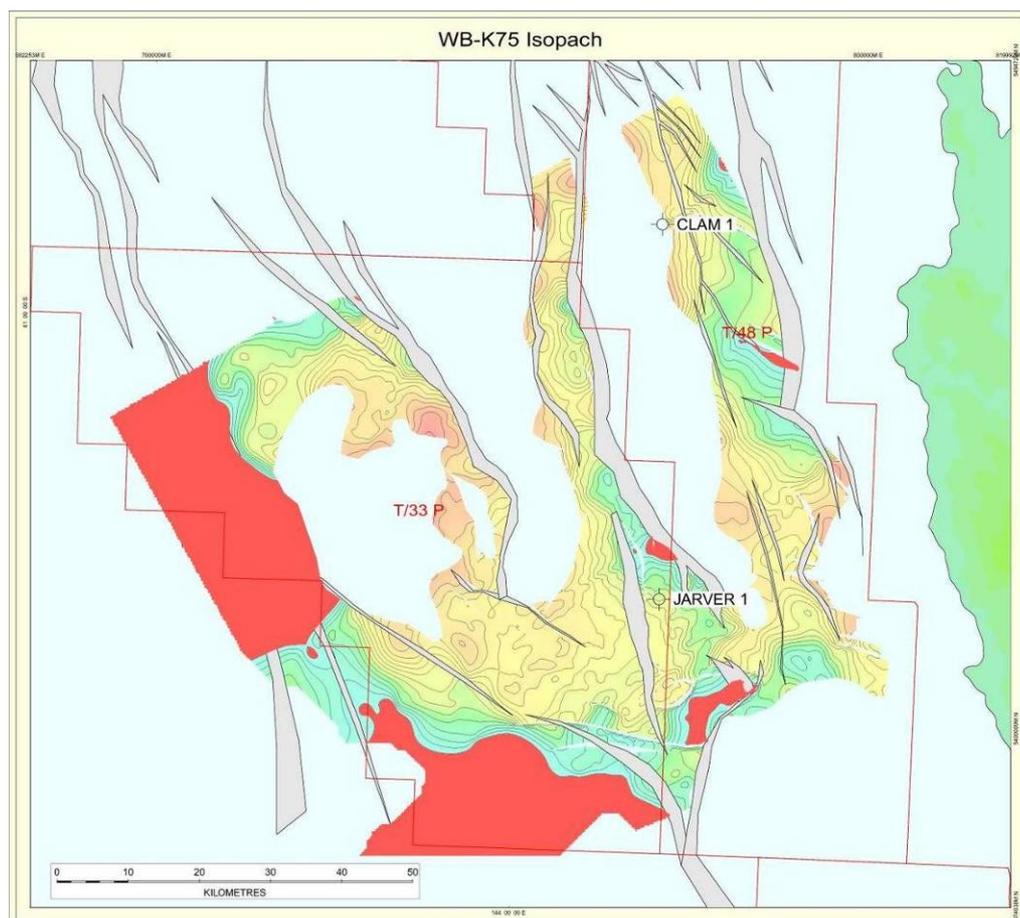
**Figure 22** – pre-drill Jarver-1 isopach map showing water bottom to K75 (top Eumeralla) with area below 3300m sub mud (potential source pod from BMod modelling) shaded red.

The XRD analysis was undertaken by Nick Lemon & Claire Behan (appendix 1 & 2). Results show that the sample from 2604m has a clay dehydration zone equivalent to a vitrinite reflectance of 0.5 (immature to early generation zone), while the sample taken at 3054m has an equivalent vitrinite reflectance of 0.6 (early oil generation zone). The spore colour study undertaken by Geoff Wood (appendix 3) indicates that samples between 2880m – 2904m have a vitrinite reflectance of 0.75 – 0.8 RVe. This is equivalent to the early to mid oil generation zone.

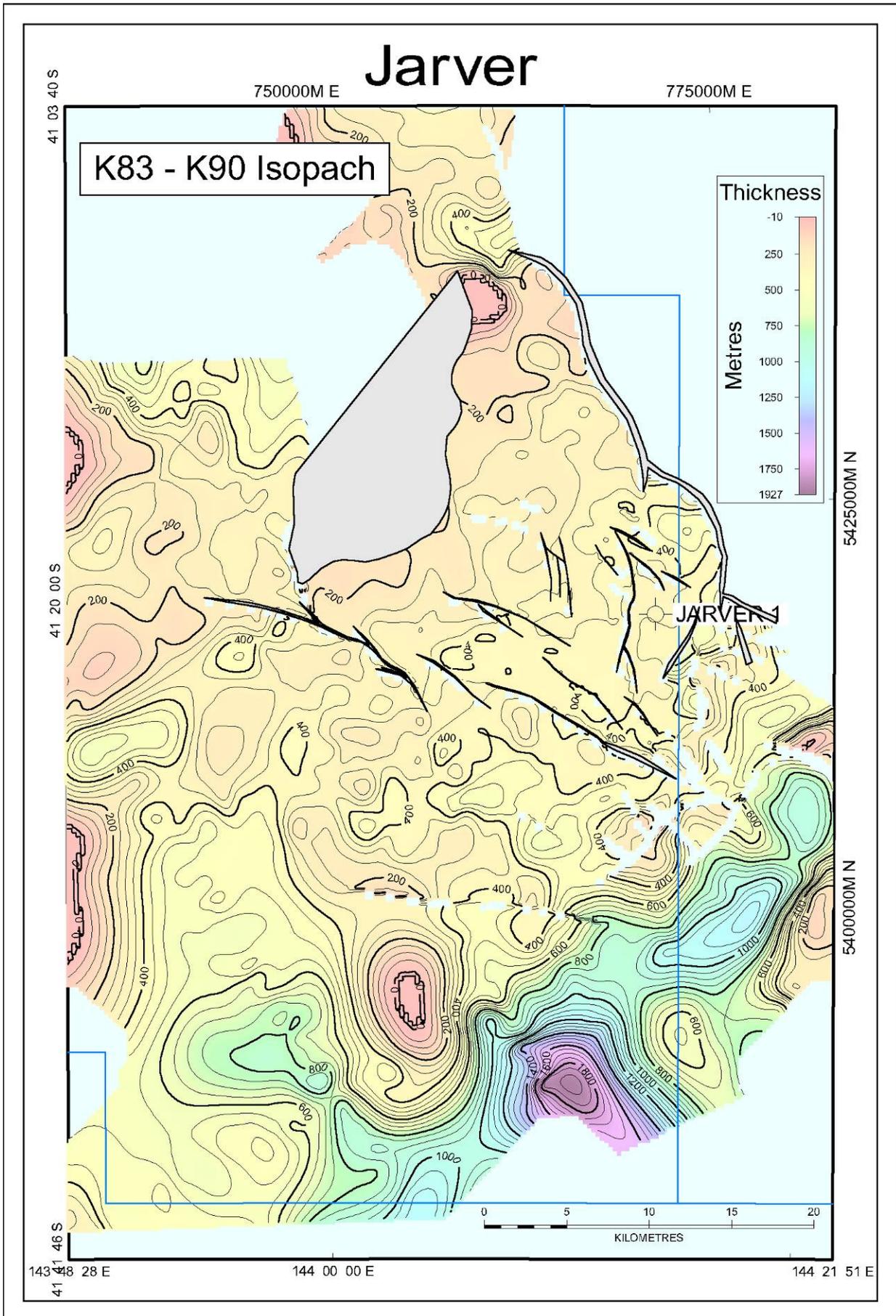
These results from the XRD work and spore colour maturity study indicate that the Jarver-1 area experienced a higher temperature in the past. Alternately, the current thermal regime would need to be stable for a period of approximately 40Myrs, which is highly unlikely as this would lead to a very shallow and hot anomaly at time of deposition.

Palaeo-structure maps were created for the primary target (K83) at time of peak oil expulsion (K90), end Cretaceous (T1), and the Eocene/Oligocene boundary (T20) to determine the presence of the Jarver structure through time (figures 24 – 26). These isopach maps indicate that at time of peak expulsion the Jarver-1 location was most likely not a structure, and that the migration of hydrocarbons out of the depocentre would have bypassed Jarver to the south. The Jarver structure does not appear to have formed until the mid Tertiary. This indicates that there is a phase of Tertiary reactivation along the Sorell margin that affects existing structures and creates new structures during this period. Future exploration must take this into account when evaluating structures to ensure that they have been preserved through out time from the point of expulsion to present day. Significant faulting which post dates the time of expulsion also increases preservation risk.

This then leads to another question. How did the thermal gradient at the Jarver-1 location become anomalously low in comparison to surrounding wells in the region? Five untested and unproven theories are described later in this note.



**Figure 23** – post drill Jarver-1 Isopach of water bottom to K75 (top Eumeralla Fm) with area below 3300m sub mud (modelled source pod) shaded red.



**Figure 24** – K83 – K90 isopach showing no structure at Jarver-1 location at time of peak expulsion.



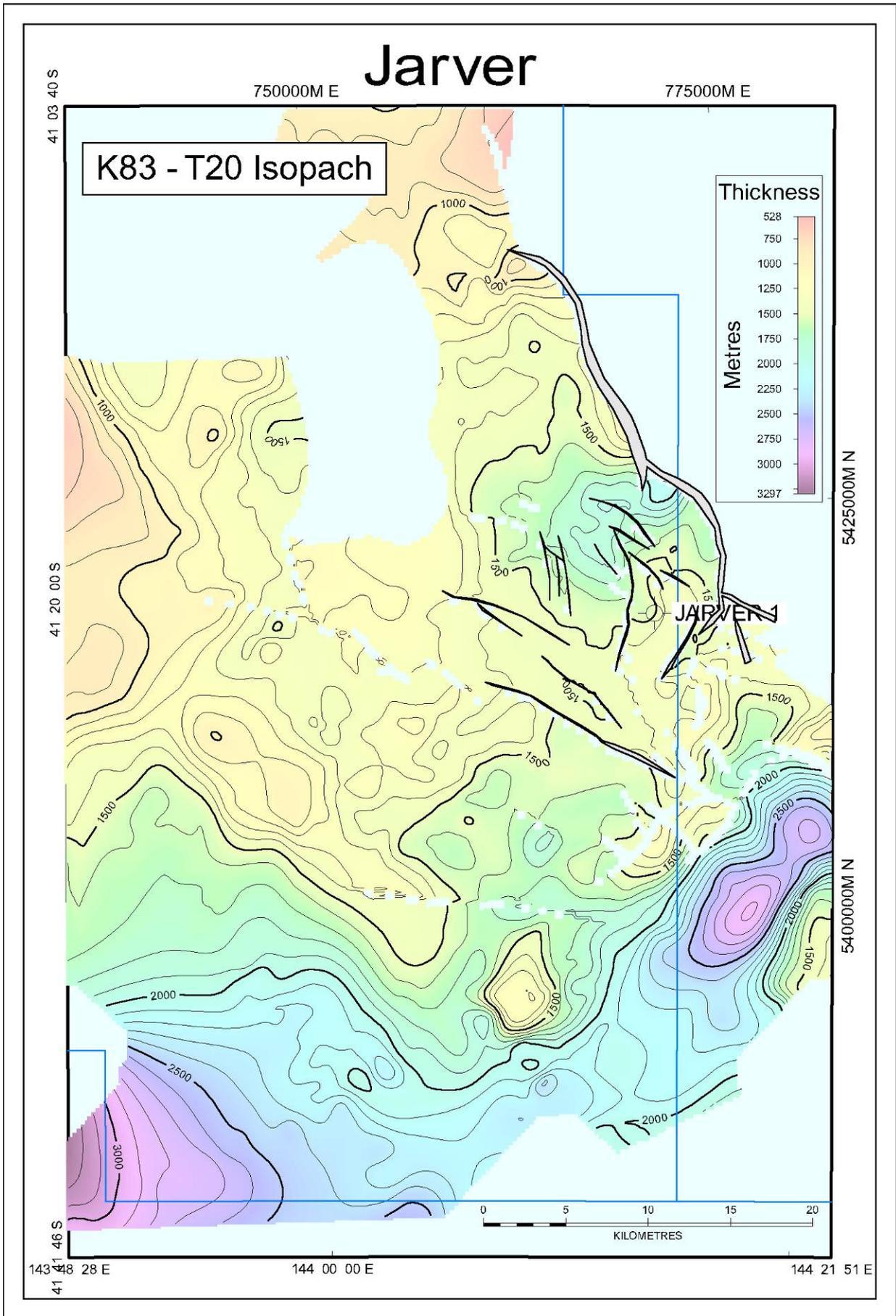
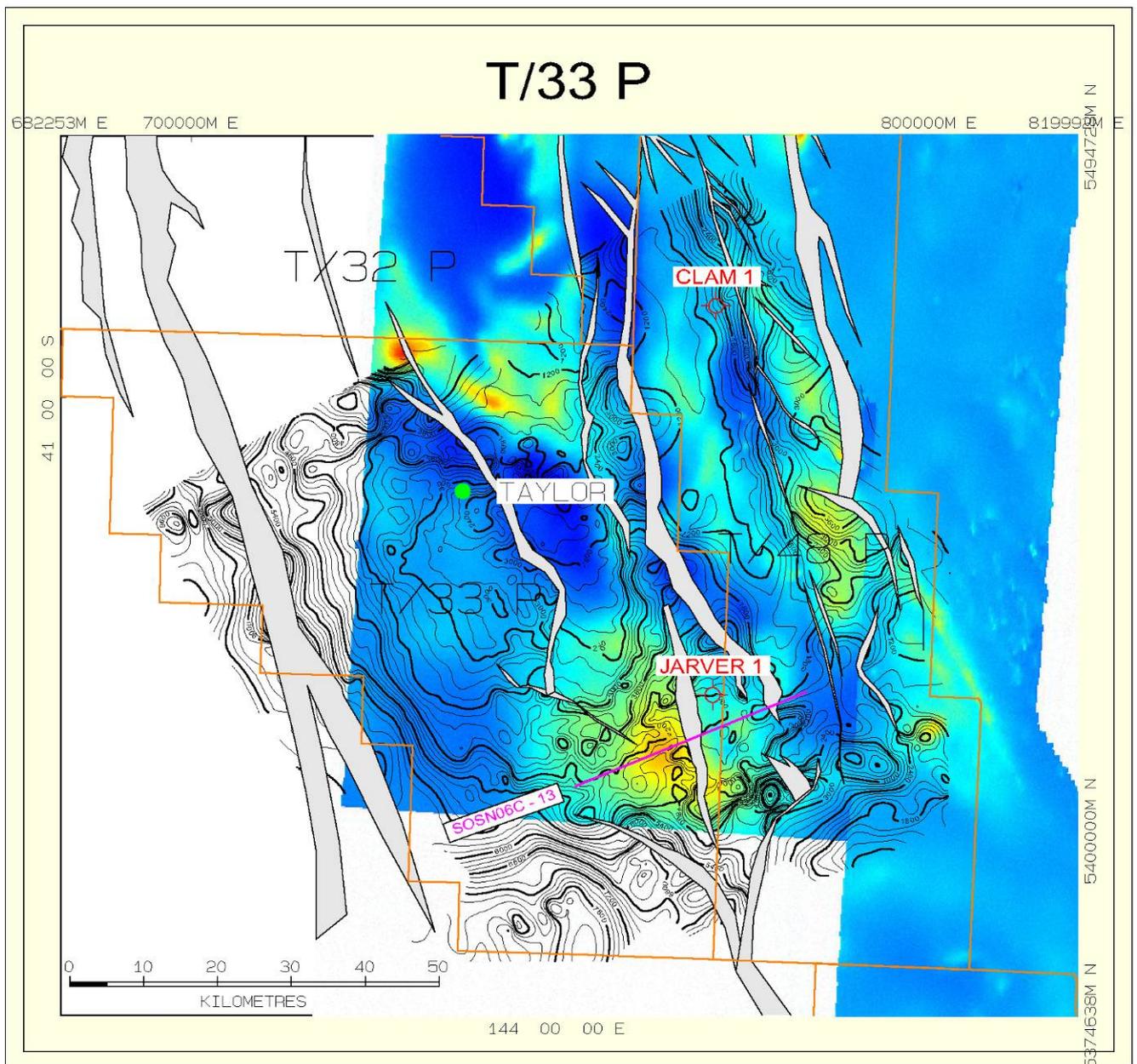
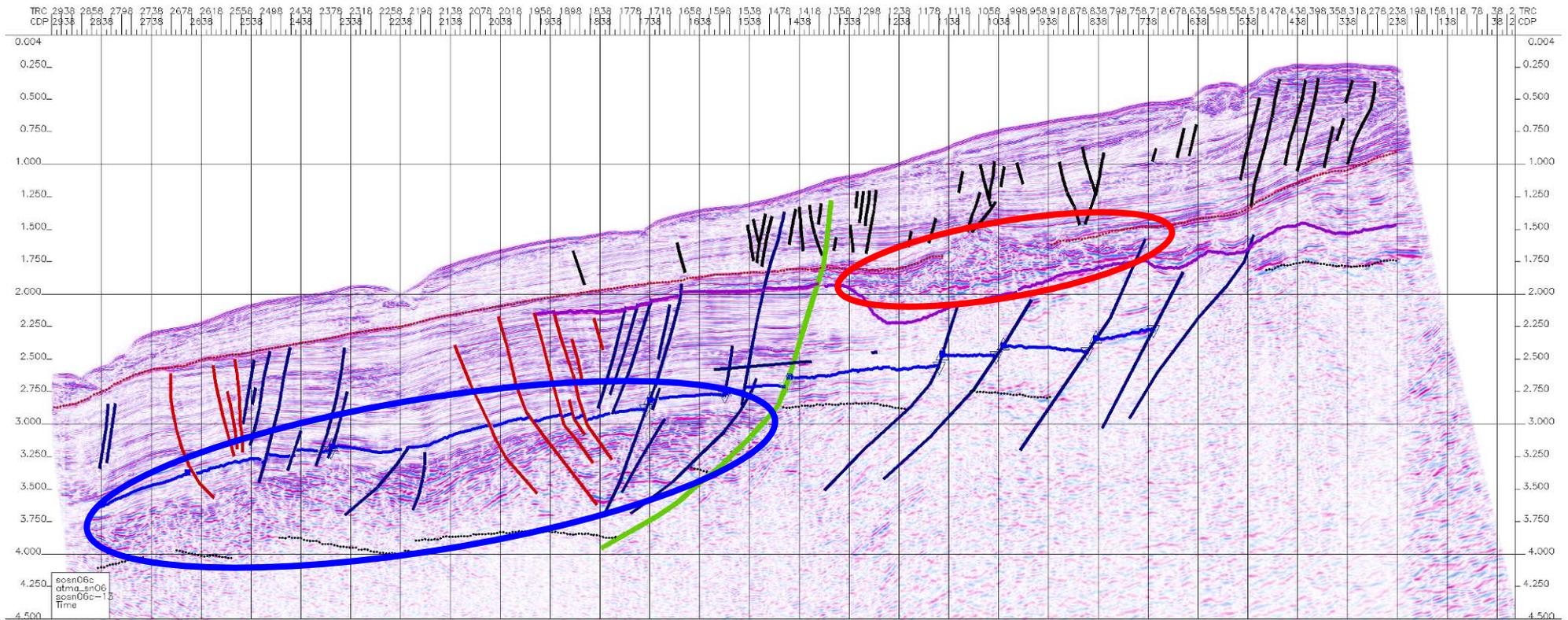


Figure 26 – K83 – T20 isopach showing the beginning of structuring at the Jarver-1 location.

Aeromagnetic data acquired by Mineral Resources Tasmania and made public after the completion of Jarver-1 was also used to evaluate the potential to distinguish any basement trends that could be used in the understanding on heat flow throughout the basin. Although the results were inconclusive for the initial scope of determining basement trends to explain the heat flow anomaly seen at Jarver-1, they did provide information on the previously mapped source pod. A magnetic anomaly is observed down-dip of the Jarver location, which when correlated back to seismic, conforms well with the amplitudes seen in the downthrown blocks initially interpreted as a potential source pod (figure 27 & 28). This anomaly suggests that the rift fill may be re-worked basement sediments, or synrift volcanics, which increases the risk of a potential source pod. An anomaly is also seen to the south east of the Jarver location which correlates to younger volcanics identified previously.



**Figure 27** – Aeromagnetic survey grid overlain by Basement Depth contours, showing magnetic amplitude conforming within the depocentre down-dip from Jarver. Seismic line SOSN06C – 13 shown in pink (figure 28)



**Figure 28** – seismic line SOSN 06C – 13 showing volcanics (circled in red) and rift fill aeromagnetic anomaly (circled in blue)