Gippsland Basin

The offshore Gippsland Basin covers an area of approximately 41,000 km^2, and is situated in the S/E corner of mainland Australia, off the coast of Victoria (eastern Bass Strait). The first commercial oil/gas discovery was made in 1964 at Barracouta 1.
Current annual production is 3446.5 million barrels of oil and 4779.5 trillion cubic of gas. Identified commercial reserves (2P) have been estimated at 4073.5 million barrels of oil and 9617.6 billion cubic feet of gas (Geoscience Australia, 2004).

Otway Basin

The offshore Otway Basin covers an area of approximately 150,000 km^2, and is situated off the southern mainland coast of Victoria and South Australia (western Bass Strait). The first commercial oil/gas discoveries occurred in 1979 (Victoria) and 1987 (SA). With the first commercial Otway Basin gas supplied to the processing plant in 1986.
Current production is 0.72 million barrels of oil equivalent, with identified gas reserves estimated to be 1,775 billion cubic feet (2P. Geoscience Australia, 2004).

Bass Basin

The offshore Bass Basin covers an area of approximately 42,000 km^2, and is situated between the south coast of Victoria and north coast of Tasmania, in the central region of Bass Strait. The basin has a drilling density of approximately 35 wells per 1,200 km^2, similar to other basins along the southern margin of Australia (Victorian Government).
Exploration of the Bass Basin commenced in the early 1960's and 15 wells were drilled between 1966 and 1974. The first commercial test well: Yolla 1 was drilled in 1985 by Amoco and is sited on the crest of a four-way dip and fault closure. Later; the Yolla 2 and White Ibis wells identified the Bass Basin resource to contain 450-600 billion cubic feet of gas and 70 million barrels of oil. Yolla 3 and 4 were drilled in 2004 by Origin Energy and partners, which resulted in the Yolla field being upgraded to a 2P reserve of 422 billion cubic feet of gas (Origin, 2007).

Sorell Basin

The offshore Sorell Basin currently has 8 tenements, and is situated off the west coast of Tasmania. Exploration of the basin commenced in the late 1960's, with a seismic survey conducted by Esso. Two exploration wells have since been been drilled; Clam 1 near King Island in 1967 and Sorell 1 near Strahan in 1981. Since exploration began in the 1960's, extensive 2D seismic , aeromagnetic and swath mapping of the basin has continued. Additional sedimentary and structural data has since been gathered with a deep ocean well drilled to the west of Cape Sorell 1 in 1973 (DSDP, Leg 29).

Shale Smear in Tasmanian Faults: Providing an effective seal for hydrocarbons; linked to Conductivity Anomalies and Iodine Occurrences.

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November, 2007.

Introduction:

The Tasmania Basin has experienced many periods of active faulting which have occurred well into the Tertiary. Much of the faulting in Tasmania is complex and often associated with movement along existing lineaments following trends within the underlying basement structure. The faulting history of Tasmania is reasonably well understood and has been documented in many past and recent structural surveys (Stacey, 2007).

In response to such a complex tectonic history, many researchers have the opinion when looking at the oil and gas prospectivity of the basin; that recent faulting events in The Tasmania Basin have reduced the hydrocarbon trap potential, by allowing oil and gas to escape through potential sealing structures. Unfortunately, negative opinions of The Tasmania Basin do not take into account the growing international research indicating that fault smear sealing of hydrocarbon reservoirs occurs in many types of hydrocarbon plays.

The existence of effective hydrocarbon traps created by fault sealing within The Tasmania Basin can also be studied through the use of conductivity anomalies and iodine measurements. The high conductivity anomaly associated with the Tamar Lineament shows that the Tasmania Basin has oilfield potential and should be explored for its hydrocarbon potential. Natural iodine occurrences and saline lakes along The Tamar Lineament also indicate the potential for the existence of hydrocarbons. Iodine and brine are often used as effective oil indicators.

1.1. How Does Fault Smear Work?

Fault smear is a natural process where a layer of shale or similar sediments are trapped within a fault and then act as a seal, thus preventing fluid flow across the faulted surface. This process is similar to what we see in the wet areas of our homes, where grout or silicon can form a seal across a joint between two surfaces, thereby preventing unwanted fluid flow.

Effective seals across faults are often created by a shale, coal or sandstone layer being trapped within a fault zone (figure 1). Research indicates that the effectiveness of the seal is strongly dependent on the fault offset and the thickness of the smear layer, and is not necessarily dependant on the age of faulting. "Where a shale layer is offset by a fault with throw greater than the vertical thickness of the layer, a shale smear may be entrained into the fault zone" (Faerseth, 2006. p741).

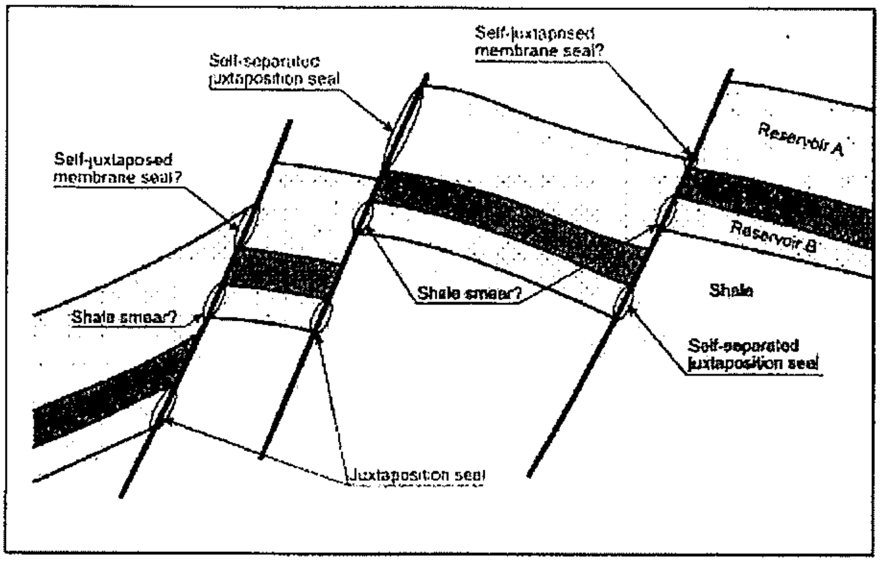

Fig. 1. Schematic illustration showing potential hydrocarbon traps (fault-blocks) resulting from normal faults that offset a sand–shale sequence. Juxtaposition of sedimentary units across the large faults introduces a number of potential seal types. Where reservoir A and reservoir B are juxtaposed across faults, the shale interval that is stratigraphically situated between the two reservoirs may be smeared along faults to form a seal that hydraulically separates the sandstones.

(Source: Faerseth, 2006)

Current research on fault smear properties indicate that normal and reverse faults, regardless of age, can maintain an effective seal for hydrocarbons when the necessary conditions are present. The Tertiary age faulting within the Tasmania Basin has often been given as a reason for the basin being un-prospective for oil and gas. Unfortunately, this opinion does not follow the current research into shale smear; which has found that fault sealing is not dependent on the age of the structure; but is primarily dependent on whether an effective seal has been created during the faulting process.

Studies of well known petroleum basins in Asia and Europe, have shown that the sealing of faults with a shale smear works most effectively when the ratio between the throw of the fault and the thickness of the sealing sediment is below a factor of 4. In effect; this means that when the throw of the fault is equal to or less than 4 times the thickness of the sealing bed, an effective seal across the fault can be formed. Alternatively, if the throw of the fault is higher than 4 times the bed thickness, there is less chance of seal preservation as the smear may become too thin and allow fluid to pass (figure 2).

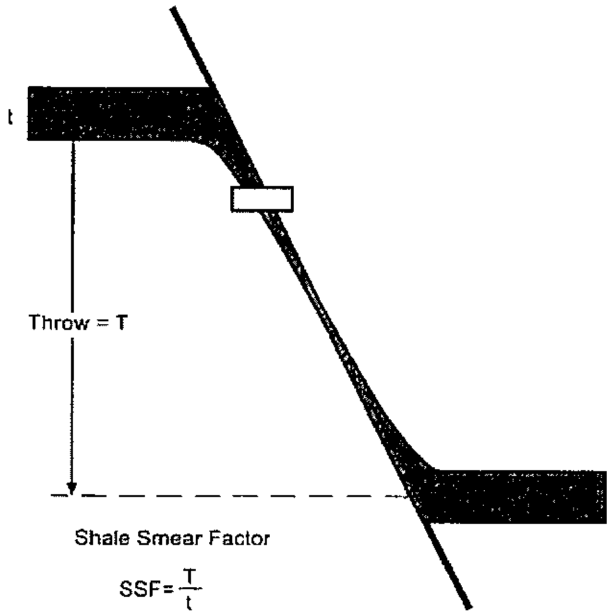

Fig. 2. The shale smear factor (SSF) (Lindsay *et al.* 1993) is given by the fault throw divided by the vertical thickness of the offset shale source layer. Smears may have a significant thickness in exposures and wells, and the point at which smears become discontinuous is generally not exposed. Based on the measured smear thickness at the study location (light grey box) and assuming a gradual thinning of the smear away from this location, a shale smear factor has been calculated for throw values for which the smear is assumed to become discontinuous.

(Source: Faerseth, 2006)

In Tasmania, there are many sites where mature hydrocarbon source and reservoir rocks are common and the fault offset has been measured to be at or below the SSF of 4. By analysing the existing data that shows local fault offsets and bed-thickness using 2D seismic and field observations, it is possible to conclude: that fault smear could provide an effective seal above the known source and reservoir rocks in Tasmania.

1.2. Testing Shale Smear

Shale smear sealing of hydrocarbon reservoirs is often observed in the field.either by measuring the differential pressure across fault zones, or by measuring outcrop/drill-core lithology and thickness. A differential pressure of 7 atmospheres is typical of a well sealed fault zone that has previously been measured in The North Sea (figure 3). "Where normal faults offset sand-shale sequences, shale smear along faults is commonly involved in hydrocarbon exploration a likely membrane seal, assumed to prevent leakage across large faults and thereby to seal potential traps" (Faerseth, 2006. p741).

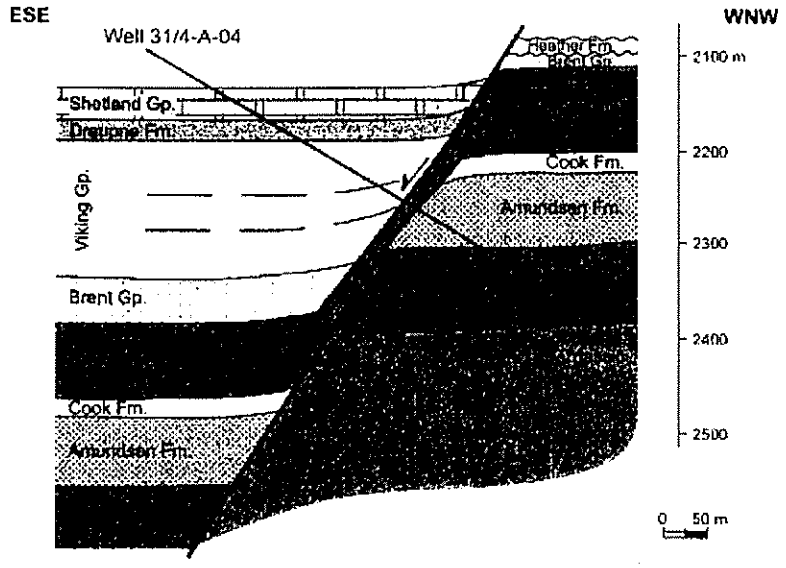

Fig. 3. A normal fault with a throw of 200–250 m at reservoir level delineates the Brage Field in the northern North Sea. Between the two slip zones that have accommodated the displacement, shale-dominated lithologies of the Lower Jurassic (Toarcian) Drake Formation provide a 20 m thick smear at the well location about 50 m below the footwall cutoff. The fault juxtaposes oil-bearing sandstones of the Lower Jurassic Statfjord Formation in the footwall (Brage Field) against water-bearing sandstones of the Middle Jurassic Brent Group in the hanging wall. The fault is a major seal and a pressure difference of 7 bars was recorded across the fault zone.

(Source: Faerseth, 2006)

2D Seismic surveys are also used to test and provide valuable information about fault offset and bed thickness at local sites. The seismic information; when applied to a fault sealing system, can often be used to predict the existence of any fault smear sealing at a particular site. Armed with a detailed knowledge of 2D seismic, plus outcrop and drill-core lithology, an interpretation of the existence of a fault smear can often be determined by using standard geophysical methods.

1.2. The Probability of Shale Smear in Tasmania

In the Tasmanian basin, thick sequences of sedimentary shale and sandstone are known to be abundant within the Permian and Triassic sequences. Although the local lithology has not been tested for specific fault sealing qualities, the possibility of shale smear within local faults is considered likely as the local shale qualities are similar to those outlined in the Faerseth study. It is observed that many Tasmanian faults of Tertiary age are full of fine grained mudstones.

An extensive program of 2D seismic acquisition has been acquired within the Tasmania Basin since 2001. As a result of the previous seismic surveys, approximately 1,350 line kilometres of data has been collected and processed since 2001. At Tunbridge to the southeast and Bracknell in the north of the basin, preliminary seismic interpretation has shown that shale smear sealing of many faults is possible.

The Tunbridge area of the Tasmania Basin is of particular interest, as it has many fault and sedimentary features similar to those identified for fault smear qualities. Through detailed interpretation of the Tunbridge seismic data (TB 01-ST), it has been found that fault smear would be less likely to occur within the 'flower structure' west of Tunbridge, as it is bounded by the Tamar Lineament has an observed fault throw of approximately 1000m west of Tunbridge.

The Late Permian, Ferntree Fm has a measured thickness of approximately 250m in a nearby drill-hole (Tunbridge #1), which would give a SSF value of 4 for this location (fig 3a). This SSF result is close to the cut-off point for reliable sealing (Faerseth, 2006). Therefore, a fault offset of this magnitude may have breached the shale smear sealing capabilities of the Permian sediments (SSF = to or >4). Imperfect fault sealing at this site may be indicated by the high iodine levels found in the surface water at Tunbridge (see 3).

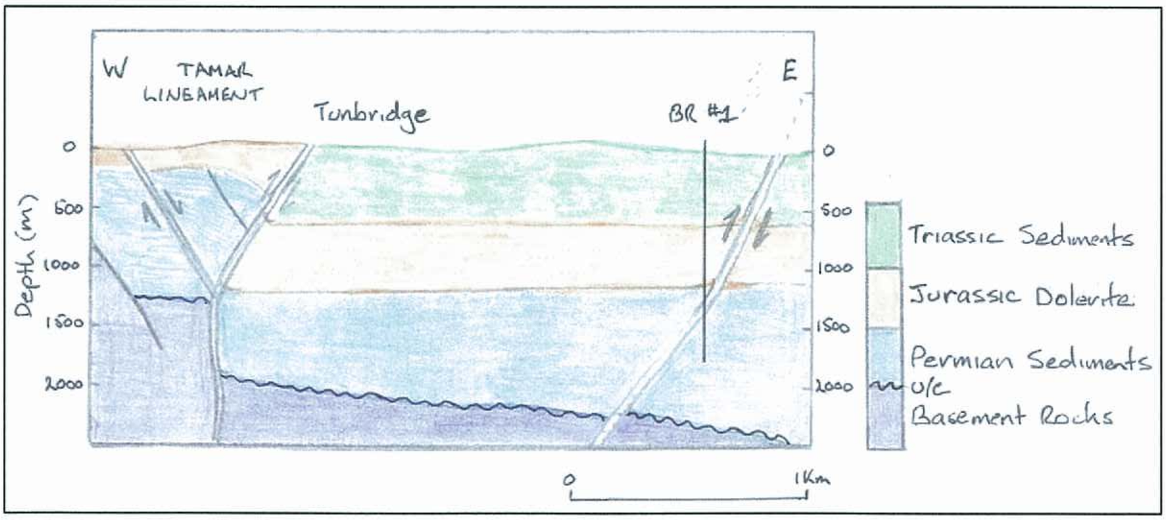

Figure 3a. Seismic line TB-01ST interpretation.

To the east of Tunbridge however, the fault offset observed in the TB01-ST seismic section is interpreted to be in the order of 100 metres or less and the Ferntree Fm is approximately 250m thick (SSF 0.4). The low offset and thick shale sequence observed presents a good case for fault smear sealing of the reservoir to have occurred at this site (fig 3a).

At Bracknell, in the north of The Tasmania basin, another promising case for shale smear may exist. The interpreted seismic line TB-01 SA indicates an anticline structure in contact with the Tamar Lineament (fig 3b). After interpretation of seismic line TB-01SA, it has been found that the Permian shales would have sealed the faults to the east, and could possibly seal The Tamar Lineament to the west. An SSF of 0.5 in predicted at the eastern end of TB-01 SA, and an SSF of 4.0 is predicted on the western end (Tamar Lineament).

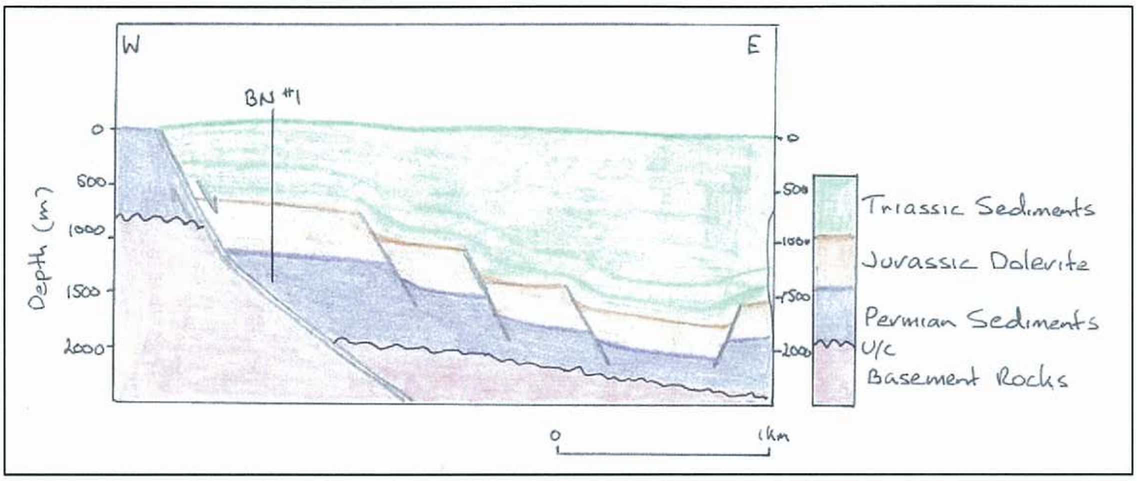

Figure 3b. Seismic line TB-01SA interpretation.

By using the examples form Tunbridge and Bracknell, the conditions for fault sealing can be demonstrated and shale smear is therefore considered possible. Tasmania has several analogous sedimentary sequences which also contain suitable attributes for SSF to occur, similar to those studied in other hydrocarbon basins.

2. High Conductivity Anomalies

In addition to the use of 2D seismic and lithology studies, the presence of effective fault sealing for hydrocarbons can also be confirmed using additional geophysical methods such as gravity, magnetic and conductivity analyses. Gravity and magnetic methods are generally useful for determining the local and regional trends of ore-bodies, faults and lineaments, but they poorly depict any dip trends occurring within the underlying structure.

By using a fluxgate magnetometer; the dip and direction of the local magnetic field can be plotted on a map. The map can then be used to show the local and regional gradient or dip of subsurface conductivity. The 'induction arrow' indicated on the following map, is created by plotting the magnetometer measurements taken from the field which depicts the plane of dip towards the better conductor; with the arrow length showing the angle of tilt (figure 4).

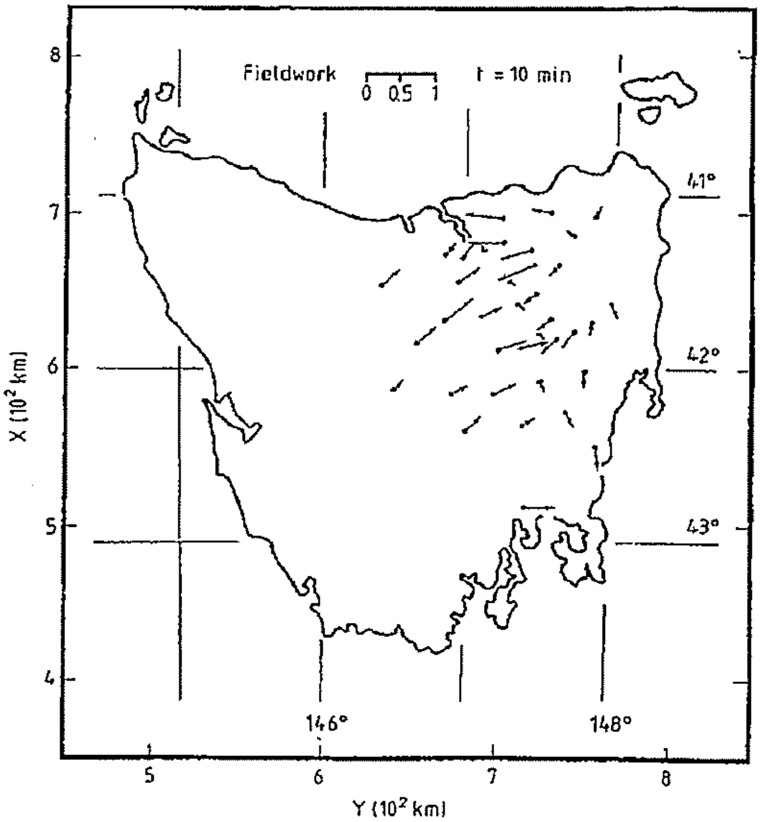

Fig 4., Induction arrows for north-east Tasmania showing the presence of the Tamar conductivity anomaly. The arrows indicate the directions of horizontal magnetic field change which cause maximum vertical magnetic field change at each site. The lengths of the arrows indicate the effectiveness of the process. The arrows point towards a zone of high electrical conductivity.

(Source: Parkinson and Hermanto, 1986)

Shallow depth conductivity anomalies can often indicate semi-conductors such as graphite or hydrocarbons which are present in the subsurface. As there is an absence of a significant magnetic anomaly associated with the measured conductivity anomaly in The Tamar Lineament, graphite can be ruled out as a likely cause and either oil or basinal brines can be assumed. Parkinson and Hermanto, 1986 concluded from their study of the Tamar Lineament that:

> The shallow depth makes the presence of graphite unlikely and a sufficiently high temperature out of the question. The most likely cause seems to be fractured rock saturated with highly conducting fluids. Archies Law suggests that a porosity of 20-40% is necessary with a fluid conductivity of the order of 10 Sm^{-1}. Fluids with such a high conductivity have been reported, but are generally confined to oilfields.

3. Iodine Occurrences

As the natural concentration of iodine is generally low in areas isolated from oceanic sources, it is most unusual that the Tamar Lineament was found to have very high concentrations of iodine and several brine lakes located over 100 km from the nearest sea. This discovery was made when Dr Paul Richards found high iodine concentrations in surface waters during his survey of inland eastern Tasmania (fig 5, Jo Zantuck, 2007. Surfer plot of Richards, 2005 data). The observations found in the Richards survey are unusual, as high iodine concentrations and subsurface brines are often associated with petroleum-bearing basins "About 26% of annual USA production of iodine is from sodium iodide in deep subsurface brines..." (Burrett et al, 2007).

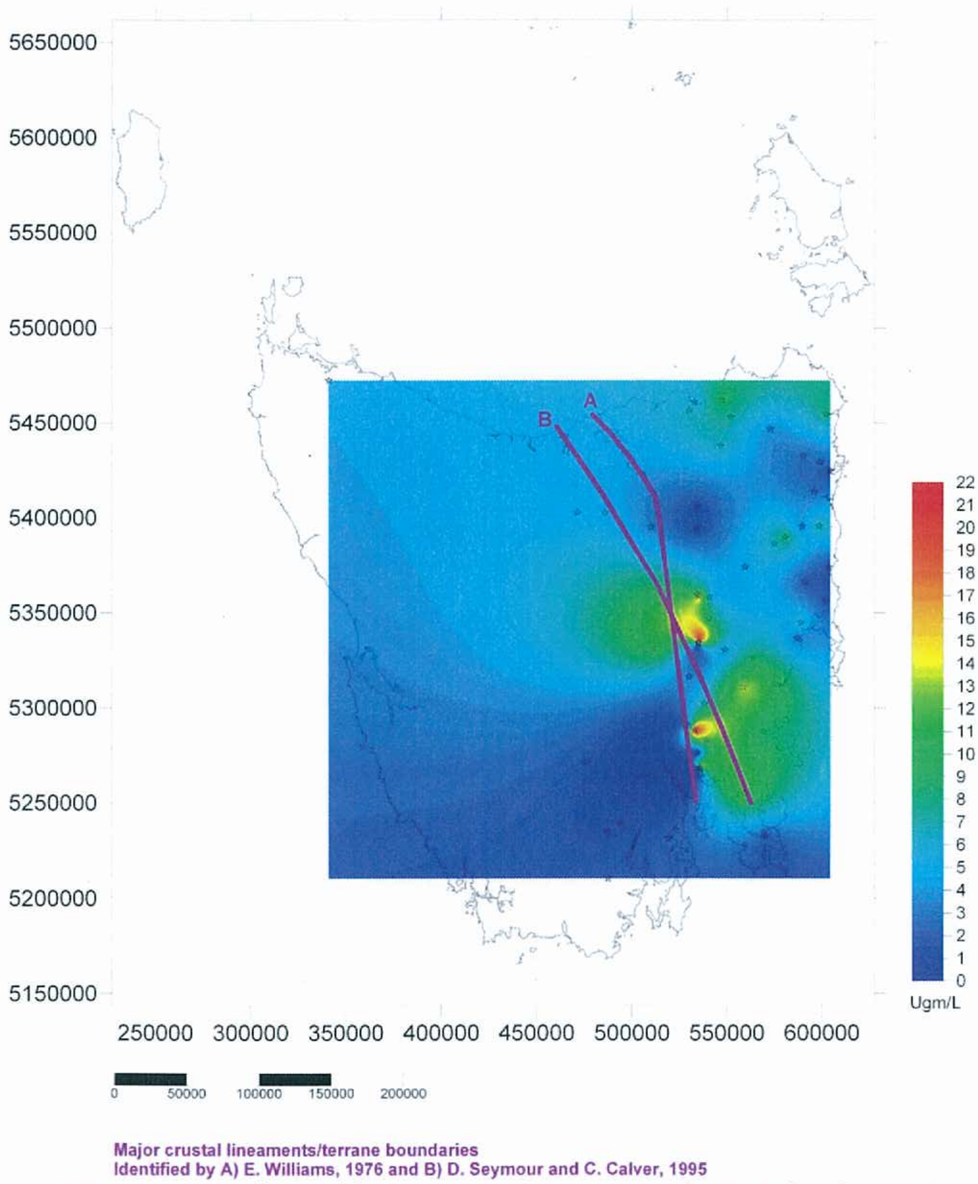

Figure 5. Iodine/crustal lineaments, data average from Richards, 2005. Zantuck, 2007.

Iodine and brine seepages along the Tamar Lineament could be interpreted individually as evidence for the presence hydrocarbons. As the high iodine data is also confirmed by the presence of a high conductivity anomaly associated with hydrocarbons along the Tamar Lineament, the only reasonable conclusion which could be made of the combined evidence is that a connection to a common oil source must exist.

Conclusion

After an interpretation of the all the seismic and geological data collected in The Tasmania Basin, it is considered likely that fault sealing has occurred in many locations. This interpretation is considered likely for two reasons: 1, The Tasmania Basin contains up to 800m of sedimentary source and reservoir rocks, many of which occur within the potential oil producing Permian succession. 2, The Tasmania Basin contains similar lithology and fault structures to those studied in other countries.

The presence of high subsurface conductivity anomalies, indicate the presence of either oil or gas in The Onshore Tasmania Basin. Shows of iodine and brine along the Tamar Lineament, suggest that trapped hydrocarbon reservoirs may be leaking in some locations where known faults occur.

Shale smear sealing of faults above hydrocarbon reservoirs and in areas with an SSF below 4, should be further explored for evidence of sealing. By looking at all of the evidence which has been presented a conclusion can be reached: that effective fault seal qualities can be assumed to exist above many of the potential oil and gas reservoirs in The Tasmania Basin.

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