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Interpretation of selected reflection seismic data in SEL26/2005, Eastern Tasmania.

Prepared for KUTh Energy Ltd (KEN)

15 June 2009 Final

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Executive summary

HDRPL was commissioned by KUTh Energy Ltd (KEN) to interpret selected 2D seismic reflection data from the Tasmania Basin, on the western margin of SEL26/2005. These data, whilst generally poor in quality due to noise attenuation, provide useful insights into the geology of the area and should assist in constraining 2D and 3D heat flow models as well as providing input into the construction of a 3D earth model for resource calculation.

The following key outcomes are described:-

- Seismic data suggest that the gross structural style of the area is dominated by NE-dipping faults which sole into a major detachment at ~7.5km depth. A major bounding fault in the west controls much of the structural and stratigraphic development of the area. This fault may be a southern extension of the Tiers Fault and subcrops approximately beneath Lake Woods in the Central Tablelands. This fault may have been extensional in the Ordovician-Devonian and created the accommodation space required for the deposition of Mathinna Supergroup equivalent sediments.
- Deeper sub-parallel reflections beneath ~7.5km have a thrust duplex geometry similar to that described for the Lachlan Orogen in Victoria. These may represent an older (Tyennan) event.
- Major faults along the western margin of the tenement were inverted and over-thrust prior to the Permian (probable Tabberabberan Orogeny). The footwall of the western bounding fault probably created a rigid “buttress” over which hangingwall rocks were thrust. The development of a low-angle “over-riding” thrust fault allowed the deeper (possible ?Precambrian) rocks to be brought close to surface. This fault subcrops beneath Lake Sorell. There is no evidence of significant thrusting on the eastern margin of the seismic data suggesting that the western bounding fault and the over-riding thrust fault were the focal points for reverse movement.

- Mathinna Supergroup equivalent rocks appear to have been deposited east of the bounding fault in a basinal setting and reach a maximum thickness of about 5.5km adjacent to the bounding fault in the west, but are otherwise 4-5 km thick on the eastern margin of the seismic survey area.
- The Permo-Triassic succession thins towards the east and reaches a maximum depth of ~3.6km beneath the Tertiary sub-basins, but in general is less than 1km deep throughout much of SEL26/2005.
- The Jurassic dolerite is a relatively un-complex blanket which varies between 205 and 320m in thickness, but typically has a relatively uniform thickness of ~300m. The dolerite is offset by minor Tertiary and ?Cretaceous faulting.
- Permian faults sole into older Mathinna-age faults and have a similar NNW-trend, although a change towards NW -trending faulting may occur near Macquarie Tier. Most faults are not laterally continuos and are en-echalon, indicating displacement transfer across fault overlap zones.
- There is no solid evidence in the seismic data for Palaeozoic igneous rocks in the survey area, although this is to be expected as the interpreted granite isobaths are generally east of the seismic survey. The eastern end of line TB01-PB (Blessington) may show evidence of possible igneous rocks.
- Heat flow contours generally agree well with the interpreted granite isobaths. Seismic data suggest that some heat flow values on the western margin of the tenement may be influence by heat refraction across large faults.
- Seismic line TB01-PG (Blessington-Cressy-Poatina) intersects the axis of the Tamar Valley at the South Esk River neat Evandale-Epping Forest. This axis defines the trend of the assumed Tamar Fracture Zone. A large NE-dipping fault (mainly Permian and Tertiary in age) is present on the seismic line at this location, but there is no discernable change in seismic character either side of the fault. The fault is also of limited lateral extent. The seismic data do not support the notion of the Tamar Fracture Zone, although this does not negate the possible existence of an older, deeper crustal or lithospheric boundary beneath this point, or further east outside the survey area.

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1.0 Introduction & location

Hot Dry Rocks Pty Ltd (HDRPL) was commissioned by KUTh Energy Ltd (KEN) to undertake 2D reflection seismic interpretation in areas of the Tasmania Basin (eastern onshore Tasmania). The selected seismic lines largely straddle the western margin of KENs tenement SEL26/2005 (Figs 1 and 2).

HDRPL was principally requested to provide hardcopy interpretations of the following lines and a report covering the same:-

- TB01-PG
- TB01-PT
- TB01-PF
- TB01-ST
- GAST4
- GAST3

In addition to the above, HDRPL interpreted other suitable lines within the tenement to enable the generation of regional depth grids in the event that these data may provide useful inputs into any 3D earth model which may be constructed for the tenement.

The quality of seismic data is generally poor, largely due to the attenuation of noise caused by near-surface dolerites which blanket much of onshore Tasmania. However most of the TB lines, acquired by GSLM in 2001 and processed by Robertson, provided adequate data to enable the interpretation of key mega-sequence boundaries and faults, from which regional grids have been generated.

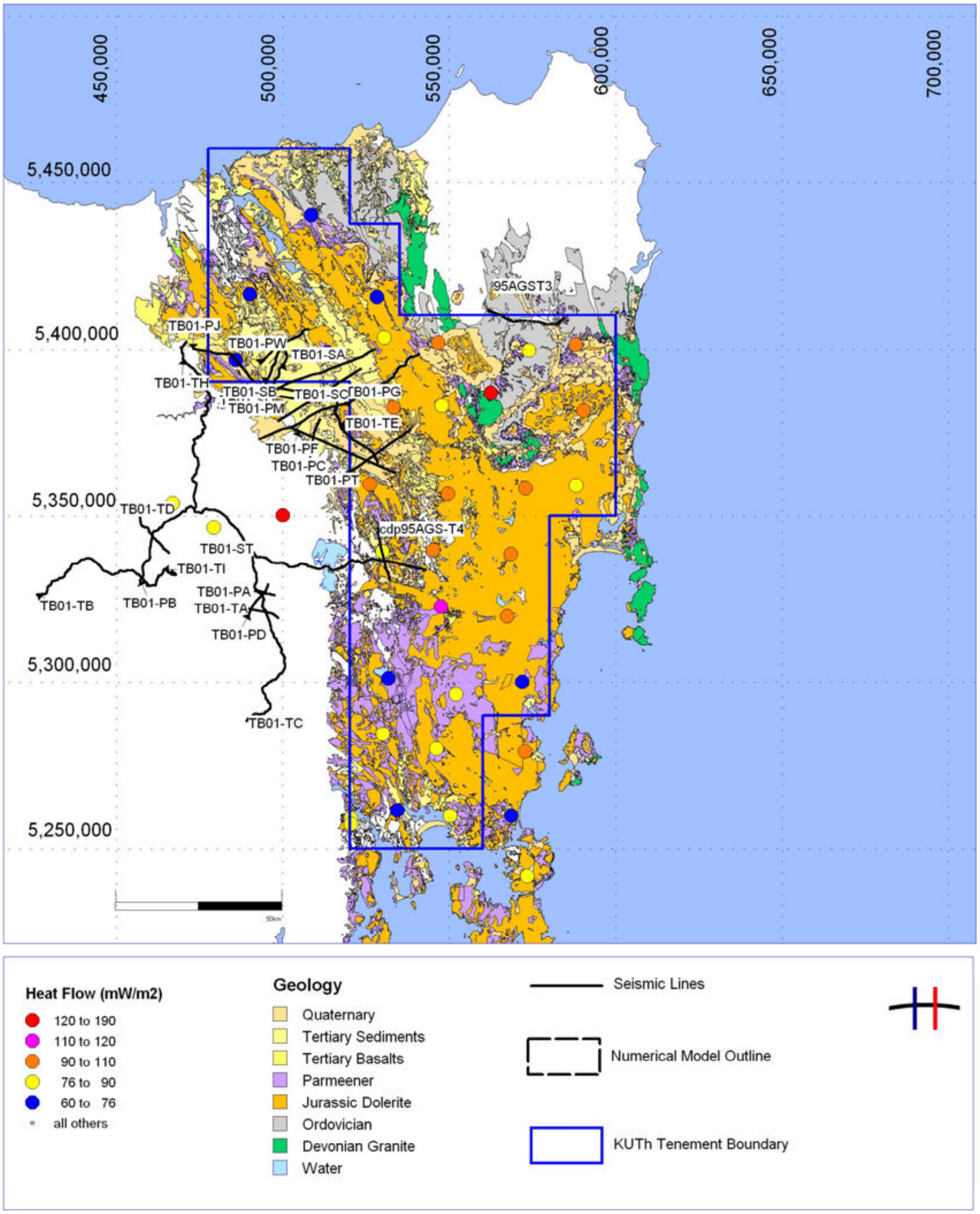

Figure 1. Regional geology and seismic line location. Heat flow data are also shown.

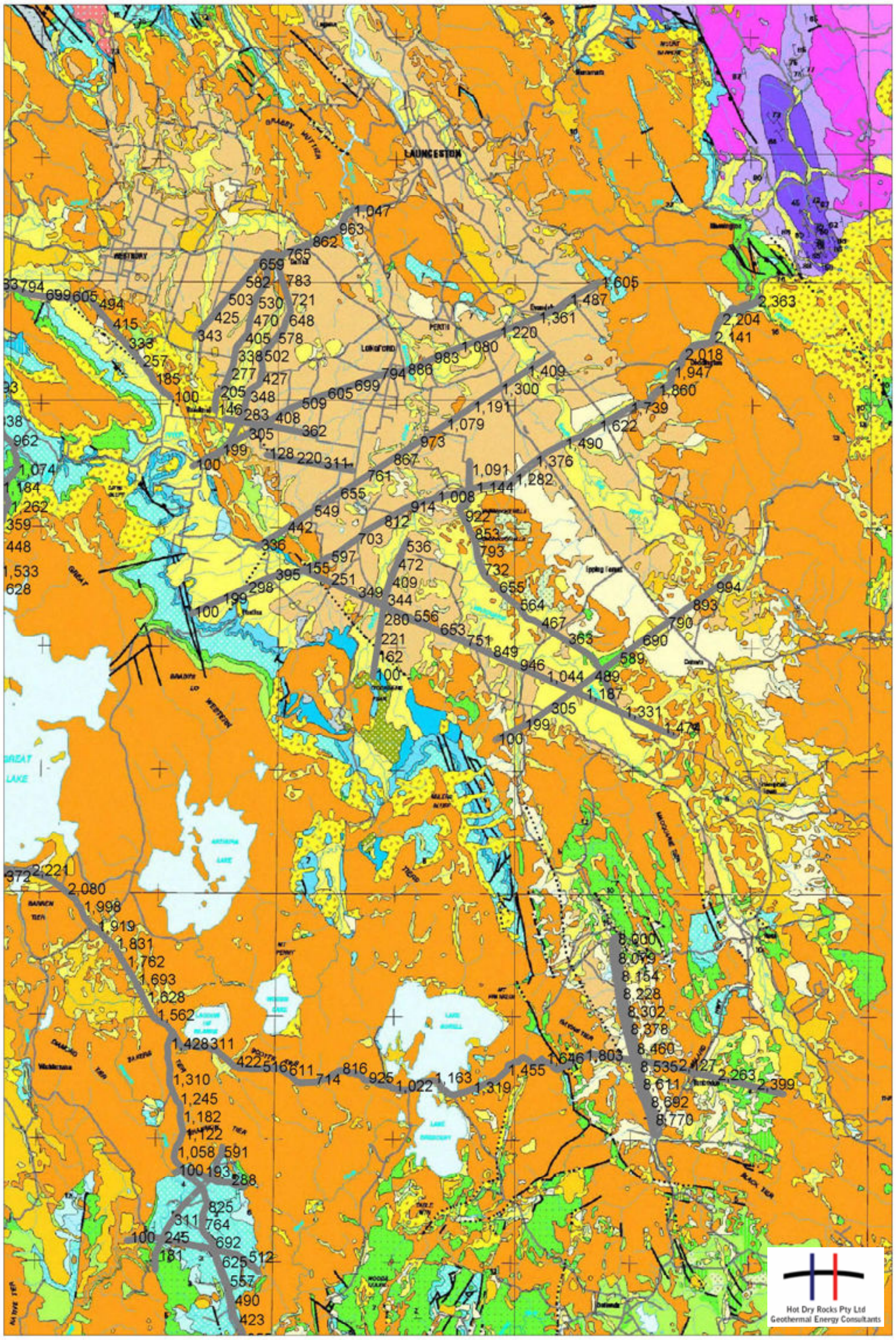

Figure 2. Seismic line location map, showing shot points for key lines, overlain on the Geology of Tasmania Map Sheet. See figure 3 for map legend.

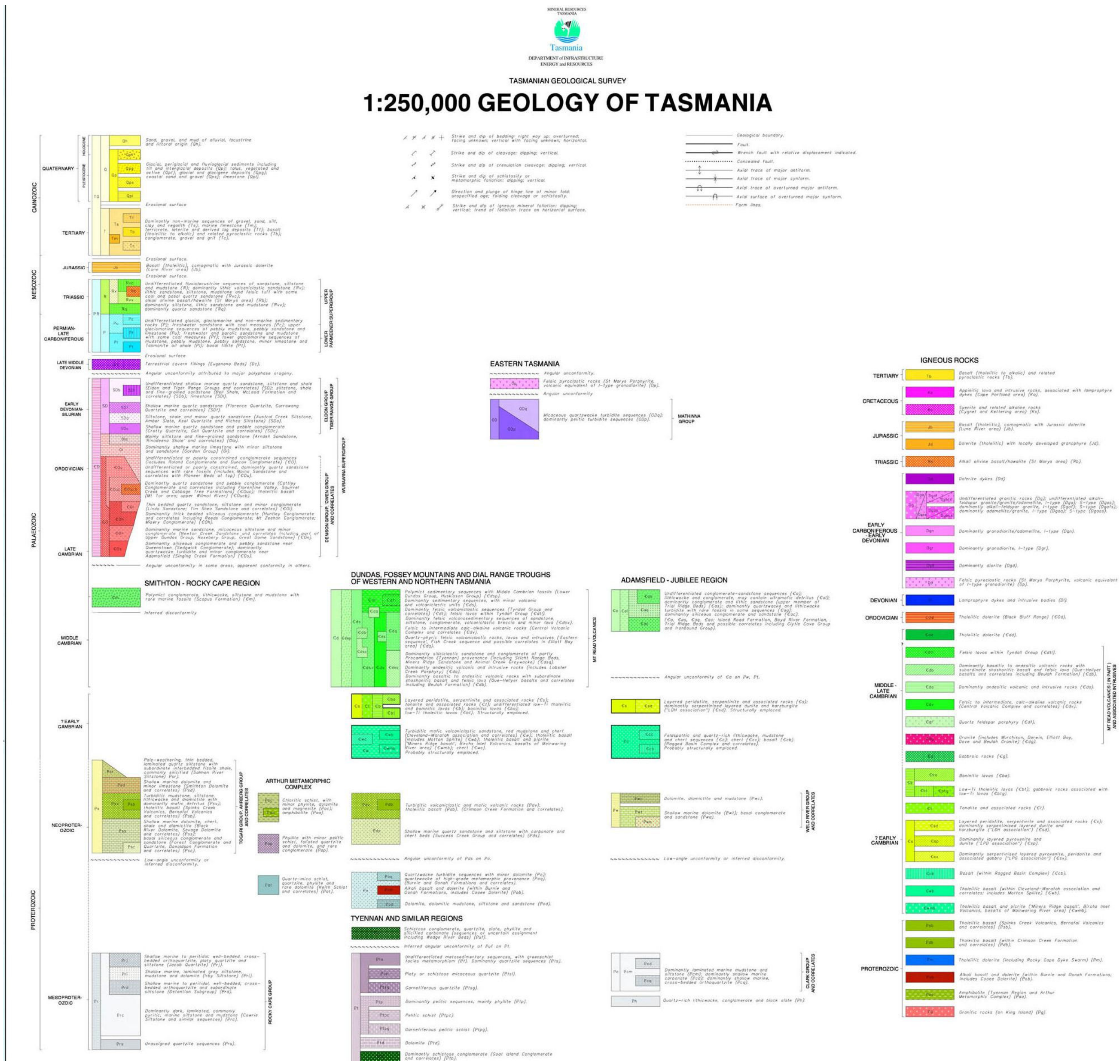

Figure 3. Map legend (figure 2). From MRT.

The GA lines, acquired in 1995, were very poor in quality, probably due to the energy source used during acquisition – typically for the purpose of imaging deep structure. However line GAST4 near Tunbridge provided useful data, whilst GAST3 near Mathinna was generally uninterpretable, with one minor exception.

2.0 Seismic data issues and depth conversion

Apart from the poor quality of the data, the SEGY files themselves provided other challenges. As most of the data were acquired along tortuous roads, many of the lines suffered from "crooked line effect" further complicating interpretation. In particular the XY positions of the shotpoints are offset from the CDP locations, and caution should be applied when designating positions (such as drill sites) based on shotpoint display along a line view, without first cross-referencing the CDP locations.

The most significant problem with the seismic files provided by the MRT, is the absence of specified datum, or Time to First Sample (TFS), usually noted within byte 105 or 107. The TB seismic lines have been set to a datum to account for topography, and are approximately 600 msec TWT beneath the standard zero reference, for lines within the boundaries of SEL26/2005.

Consequently, after discussions with KEN, HDRPL set a datum for depth conversion at 600 msec TWT and applied this datum to the whole project. The two GA lines (which where correctly datumed) were then manually reset to 600mesc TWT to match the TB dataset. This process, whilst not best practice, allows an adequate grid depth conversion for selected horizons, referenced approximately to ground level.

The Hunterston-1 well is the only well in onshore Tasmania for which velocity data exist. The well TDed in ?Neo-Proterozoic dolomite at 967m and a velocity survey was undertaken by the University of Tasmania (Stacey, 2007). However the Hunterston velocity data do not fit a polynomial curve, possibly due to their shallow nature, and cannot be used for accurate depth conversion. The only other velocity data available for onshore Tasmania are stacking velocities acquired for the GA seismic surveys in 1995. Figure 4 shows the polynomial best fit for a group of corrected stacking velocities along line GAST4 near Tunbridge.

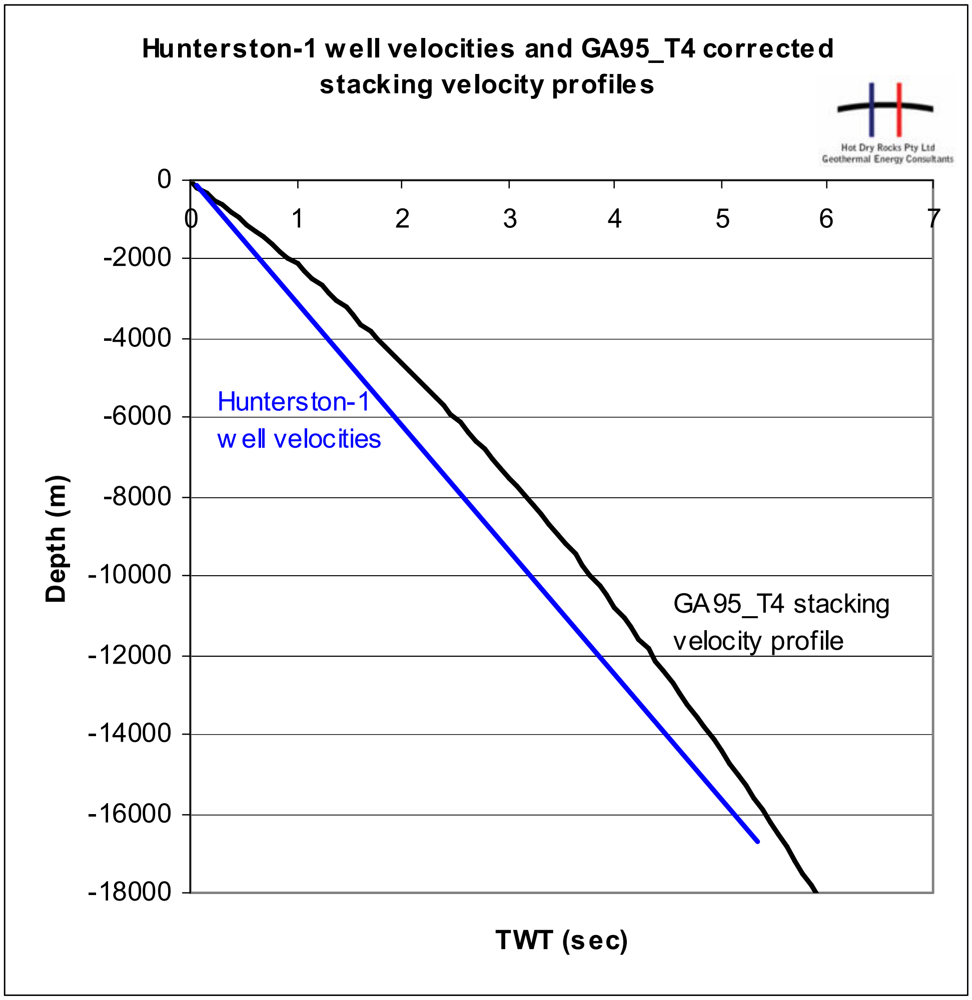

Figure 4. Projected velocity profiles from Hunterston-1 (blue line) and combined and corrected stacking velocities at zero depth offset from seismic line GAST4 (black line) near Tunbridge. Velocity data from Hunterston-1 only fit a simple linear profile and are probably inadequate for depth-conversion in this study. Consequently the GAST4 profile was used.

3.0 Geological setting of eastern Tasmania

3.1 Setting & stratigraphy

Much of SEL26/2005 lies in the Tasmania Basin, which comprises a Permo-Triassic foreland basin and smaller Tertiary sub-basins which have experienced varying degrees of fault reactivation up to the Mio-Pliocene (Stacey, 2007[1]). The Tasmania Basin extends through the central midlands of Tasmania from George Town in the north, to South East Cape, at the southern extremity of Tasmania. It is bounded to the east by Devonian granites and the Ordovician-Devonian metasediments of the Mathinna Supergroup. In the west, only a thin veneer of Permo-Triassic sedimentary rocks crop out along the elevated Central Tablelands of Tasmania and the onset of the Tablelands, along the probable southern extension of the Tiers Fault, is generally regarded to mark the western edge of the basin. The pre-Jurassic succession throughout most of eastern Tasmania is often obscured at surface by a veneer of dolerite.

The Permo-Triassic succession is relatively thin and shallow, reaching a maximum depth of ~3.6km beneath the Longford sub-basin, but it is typically less than 1km deep throughout much of the central Midlands. The basal Permian rocks (Lower Parmeener Supergroup) are comprised of glacial-marine tillite, claystone and mudstone. This is overlain by the Tasmanites oil shale. The unit becomes fluvial towards the top and contains a number of thin coal beds (Banks and Clarke, 1987[2]). The Upper Parmeener Group is largely fluvial with a number of coal measures (Forsyth, 1989[3]).

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[1] **Stacey A, 2007.** The structural history of Tasmania from the Devonian to the Recent. PhD thesis (unpublished), University of Tasmania, pp 365.

[2] **Banks MR & Clarke MJ, 1987.** Changes in the geography of the Tasmania Basin in the Late Paleozoic, in. McKenzie, GD (ed) Gondwana Six: Strartigraphy, sedimentology and paleontology . *Geophysical Monograph American Geophysical Union*, 41, 1-14.

[3] **Forsyth, SM. 1989**. Upper Parmeener Supergroup, in Burrett CF & Martin EL (eds). Geology and Mineral Resources of Tasmania. *Special Publication of the Geological Society of Australia,* 15, 309-333.

The Permo-Triassic succession in the central Tasmania Basin unconformably overlies Ordovician-Devonian metasediments of the Mathinna Supergroup and potentially Devonian granites in the area east of the seismic dataset. The Mathinna Supergroup is a deep marine turbidite sequence which was subsequently folded and faulted during the Tabberabberan Orogeny in the Middle Devonian (Cayley et al., 2002[4]), although an earlier phase deformation of the Ordovician succession during the Benambran Orogeny has been suggested by other authors (Reed, 2002[5]). These rocks represent the most southern extension of the Tasman orogenic system, which is comprised of the Delamerian, Lachlan and New England orogens. These orogens were successively accreted and cratonized during the Early-to-Late Palaeozoic (Gray et al., 2006[6]). Eastern Tasmania is thought to have the greatest affinity with the Lachlan orogen (Cayley et al., 2002, Gray and Foster, 2004[7]).

The relationship between the Late Cambrian-Early Devonian rocks of the Wurawina Supergroup, which crop out on the western side of the Tamar River, and the rocks of the Mathinna Supergroup on the eastern side of the Tamar River has been a matter of conjecture for many years. The shallow marine depositional environment of Wurawina Supergroup and deep marine depositional environment of the Mathinna Supergroup has been difficult to reconcile for rocks of assumed penecontemporaneous deposition – although it is noted that relative age constraints are generally poor for both Supergroups. Likewise both Supergroups exhibit opposite fold vergence. This lead Williams (1979)[8] to suggest that the two Supergroups represent different terranes, separated by the Tamar Fracture Zone – an assumed crustal boundary which approximates the axes of the Tertiary sub-basins along the

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[4] **Cayley, RA, Taylor DH, Vandenberg AHM & Moore DH, 2002.** Proterozoic-Early Palaeozoic rocks and the Tyennan Orogeny in central Victoria: the Selwyn Block and its tectonic implications. Australian Journal of Earth Sciences, 49, 225-254.

[5] **Reed, AR, 2002.** Pre-Tabberabberan deformation in eastern Tasmania: a southern extension of the Benambran Orogeny. *Australian Journal of Earth Sciences*, 48, 785-796.

[6] **Gray, DR, Foster, DA, Korsch, RJ & Spaggiari CV, 2006.** Structural style and crustal architecture of eastern Asutralia: example of a composite accretionary orogen. Geological Society of America, Special Paper 414, 119-132.

[7] **Gray, DR & Foster, 2004.** Tectonic evolution of the Lachlan Orogen, southeast Australia: historical review, data synthesis, and modern perspectives. *Australian Journal of Earth Sciences*, 51, 773-817.

[8] **Williams, E, 1979**. Tasman fold belt system in Tasmania. Explanatory notes for the 1:500 000 structural map of Pre-Carboniferous rocks of Tasmania. Department of Mines, Tasmania, Revised Edn, 29p.

Tamar Valley and south towards Maria Island. This model suggests that the Mathinna Supergroup was accreted to Tasmania during the Middle Devonian.

The notion of the Tamar Fracture Zone has experienced periodic revivals (Elliott et al., 1993[9]; Seymour et al., 2006)[10]. However the physical evidence for the Tamar Fracture Zone remains highly circumstantial.

A passive seismic array established in northern Tasmania in 2001-2002 collected data from 101 distant earthquakes over a period of 5 months. Tomographic modeling of these data suggest that p-wave velocities are higher in eastern Tasmania, leading Rawlinson et al (2006[11]) to postulate that eastern Tasmania may be underlain by dense rocks (possible oceanic crust). This modeling suggests that the boundary between the two velocity zones occurs in NE Tasmania, but some 20-30km east of the Tamar Valley.

4.0 Seismic interpretation & mapping

4.1 Seismic structural style

The structural style of SEL26/2005, where seismic data are available, is best characterised by seismic lines TB01-ST (Tunbridge-Lake Crescent) and TB01-PG (Blessington-Cressy-Poatina).

The gross structural style of the area is dominated by north-east dipping faults in the shallow crust (upper 3.6 seconds TWT or approximately 7.5km depth), with apparent extensional offset along major bounding faults in the west and apparent

[9] **Elliott, CG, Woodward, NB & Gray, DR, 1993**. Complex regional fault history of the Badger Head region, northern Tasmania. *Australian Journal of Earth Sciences*,40,155-168.
[10] **Seymour, DB, Green, GR & Calver, CR, 2006**. The geology and mineral deposits of Tasmania: a summary. Mineral Resources Tasmania, Geological Survey Bulletin 72. 32p.
[11] **Rawlinson A, Reading AM & Kennett BLN. 2006**. Lithospheric structure of Tasmania from a novel form of teleseismic tomography, *Journal of Geophysical Research*., 111, 1-21.

compressional offset along some faults in the central and eastern part of the area (Fig.5). Most of the deep faults were probably extensional at the time of Mathinna deposition and were subsequently inverted along the western bounding fault (a possible southern extension of the Tiers Fault which is obscured at surface). This fault has a ramp-flat-ramp geometry and the seismic data suggest that it may subcrop beneath Woods Lake-Lagoon of Islands in the Central Tablelands). The fault detaches between ~3.0 and 3.6 sec TWT (~6.5-7.5 km depth) and most other faults in the area coalesce into this detachment surface which dips shallowly to the north-east. This is consistent with the “thin-skinned” tectonic style which dominates much of the western and central Lachlan Orogeny (Gray et al., 2006).

All faults tend to appear steep in seismic data due to the effects of both velocity and scale. However most of the major faults in the area dip at an angle of ~18-25° at mid-depths between 2 and 3 seconds TWT and become steeper (45-52°) at the shallowest level (upper 1 second TWT).

Beneath the detachment, multiple high amplitude sub-parallel reflections are common, and may represent an older duplex system, possibly related to the Tyennan Orogeny. These structures do not appear to be linked to the shallow thrust faults described above and are similar to the “inferred lower crustal duplexing” described beneath the Victorian Lachlan orogen (Gray et al., 2006). These deeper structures in the Melbourne Structural Zone also appear to be detached from the shallower fold-dominated deformation of the Silurian-Devonian turbidite succession at a depth of about 4 sec TWT (consistent with observations in this study).

High amplitude reflections on line TB01-ST, possibly representing the Precambrian basement, are interpreted as a series of thrust sheets in a duplex or imbricate fan style, with most of this movement being accommodated by a shallow-dipping thrust fault in the centre of the seismic line (11-18° dip). This fault appears to override much of the westerly section. This fault, and many other similar sub-parallel reflections, is truncated by the base-Permian unconformity, suggesting a pre-Permian age for compression (probable Tabberabberan orogeny).

The shallow thrust fault subcrobs beneath Lakes Sorell and Crescent such that the three major western faults in the seismic line are well inboard of the present escarpment which defines the Central Tablelands. Indeed the topographic expression of the escarpment can be seen on line TB01-ST (Fig. 5) and is not fault plane controlled, but has an angular relationship with the detachment point of the major bounding fault which suggests that the present physiography of the Central Tablelands escarpment may be controlled by the hangingwall geometry and movement along the western bounding fault and detachment surface.

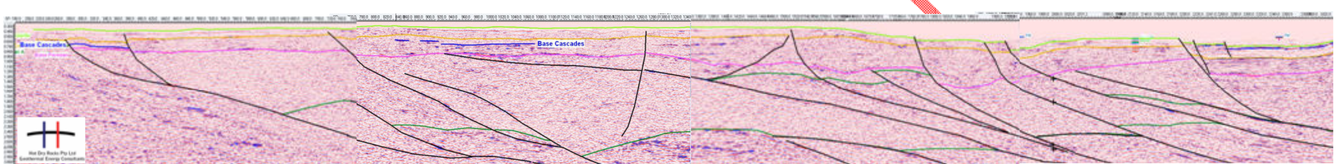

Figure 5**. Seismic line TB01-ST from Lake Crescent in the west (left) to Tunbridge and Ross-Quoin in the east (right) showing the characteristic structural style of the Tasmania Basin and basement. The upper 3.2 seconds TWT (shown) is characterised by north-east dipping faults with apparent extensional offset along major bounding faults in the west and compressional offset on faults further east. Fault dips appear steeper than true dip due to the influence of velocity and scale.**

The interpreted ?Mathinna Supergroup rocks generally appear to thicken towards the western bounding fault, suggesting that this fault may have been the major controlling influence during deposition, although subsequent thrusting complicates this trend.

Faults higher in the section (particularly in the east) have a steeper dip and sole into the deeper thrust faults. These faults probably developed during both Permian and Tertiary extension and reactivated the older thrust faults at depth. The Permo-Triassic succession shows westward thickening and local growth of reflections towards some faults, indicating that a number of half-graben were active during this time.

The same faults were reactivated again during the Tertiary, and possibly during the Jurassic-Cretaceous, resulting in the extensional offset of the Jurassic dolerite. Some seismic lines also suggest possible Mio-Pliocene inversion along these faults with minor compressional offset of the dolerite. These Mesozoic structures are regionally consistent with those mapped in the offshore Bass and Otway Basins during both Gondwana and Tasman rifting (Cooper and Hill 1997[12]; Hill et al., 1995[13]).

4.2 The pre-Mathinna Basement (?Precambrian)

Four shallow wells in the study area are reported to have intersected Proterozoic metasedimentary rocks near their TD (Stacey, 2007). However for at least three of these wells (Tunbridge, Ross and Ross-Quoin), the age determination is based on thin section description and cleavage (Forsyth et al., 1989[14]). The descriptions are somewhat indeterminate and in the absence of dating control (eg. achritarchs), the presence of Proterozoic rocks in these wells should be treated with caution.

The more recent description of Neo-Proterozoic dolomite at the base of the Hunterston-1 well may be more convincing (Stacey, 2007). In addition to this, a small outcrop of Proterozoic "turbiditic volcaniclastics" is mapped south of Poatina, suggesting that Proterozoic-Cambrian rocks may subcrop beneath the Tasmania Basin.

Hunterston-1 was drilled on a structural high and TDed in ?Neo-Proterozoic domolite without intersecting any Mathinna-equivalent rocks. The well was drilled along

[12] **Cooper GT & Hill KC. 1997**. Cross-section balancing and thermochronological analysis of the Mesozoic development of the Eastern Otway Basin. *The APEA Journal* 37, 259-283.

[13] **Hill KC, Hill KA, Cooper GT, O'Sullivan A, O'Sullivan P & Richardson MJ**. 1995. Inversion around the Bass Strait Basins, SE Australia. In Buchanan J. (ed.) Proceedings of the Basin Inversion Symposium, Oxford University. *Geological Society of London Special Publication* No 88., 525-547.

[14] **Forsyth S.M, Sutherland FL & Bacon CA, 1989**. Geological atlas 1:50 000 series. Sheet 61 (8313N). Inter-laken. Explanatory Report, Geological Survey, Tasmania. 90p

seismic line TB01-PA which shows that the seismic character of the Proterozoic succession is dominantly high amplitude parallel reflections. When projected along strike, the position of the well coincides with the footwall of the major western bounding on line TB01-ST where the same high amplitude reflections can be interpreted (Fig. 6). This reflection character is typical of very competent layered lithologies such as meta-sandstones and limestones which may support low-angle thrusting, as interpreted in this study. This reflection characteristic is not typical of the Silurian-Devonian turbidite succession of the Lachlan orogen as previously interpreted by the author beneath much of the offshore and onshore Otway and Bass Basins.

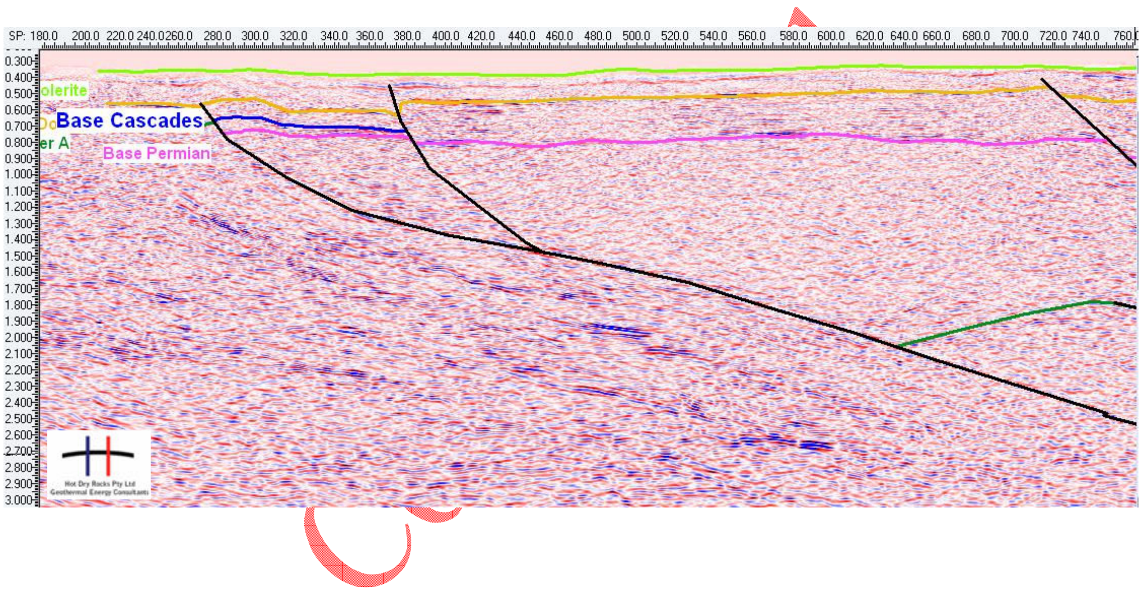

Figure 6. **Seismic line TB01-ST (western end). The seismic character in the footwall of the major bounding fault is dominated by high amplitude sub-parallel reflections. This position in the footwall is along strike from the Hunterston-1 well which intersected Neo-Proterozoic dolomite at TD and no Mathinna Supergroup equivalents. Note also the marked change in seismic character in the adjacent hangingwall section.**

4.3 The pre-Permian (?Mathinna Supergroup equivalents)

The seismic character of Mathinna Supergroup rocks is interpreted as a package of chaotic and bland reflections. In rare instances broad folding can be seen, but this is more often beyond the resolution of the seismic data. The base of the package is approximated by the commencement of the high amplitude sub-parallel reflections of the ?Precambrian succession (where this can be determined) and the top of the package is defined by a marked angular unconformity with the overlying Permo-Triassic succession (Fig. 7).

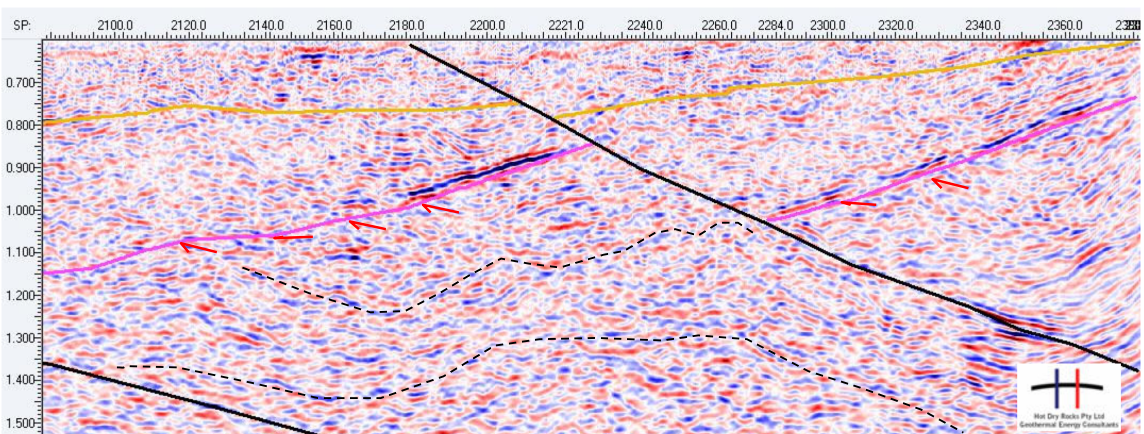

Figure 7**. Seismic line TB01-PG (eastern end). The seismic character of ?Mathinna Supergroup equivalent rocks comprising generally chaotic reflections and a marked angular unconformity with the overlying Permo-Triassic succession (red arrows) and possible broad folding (black dotted lines).**

The package appears to thicken towards the western bounding fault where it reaches a maximum thickness of about 5.5km, however throughout much of the area constrained by reasonable seismic data, the package remains 4-5km thick. Both the thickness and seismic character of the interpreted Mathinna Supergroup is consistent with that of the Silurian-Devonian turbidite succession of the Melbourne Structural Zone in Victoria.

The absence of Mathinna Supergroup rocks at Hunterston-1 and the structural style of line TB01-ST, strongly suggest that the western bounding fault (southern extension of the ?Tiers Fault – Fig. 5) was the major extensional fault at Mathinna time, which created the accommodation space required for the deposition of the Mathinna Supergroup in eastern Tasmania. The absence of these rocks on the footwall may suggest that either limited or no deposition of Mathinna Supergroup occurred to the west of the fault.

The top of the Mathinna Supergroup is interpreted to be shallow (or potentially non-existent) along the western margin of SEL26/2005 where thrust faults are interpreted to bring the ?Precambrian basement close to surface (Fig. 5). However, immediately east of this point, the base of the Mathinna Supergroup is gridded to a depth of 4-5km.

Interpreted fault polygons suggest a NNW trend for Mathinna-age faults, and whilst interpreted as continuous faults due to limited data, the curved shape of the polygons suggests that they may in fact comprise several en-echalon overlapping faults. Limited data suggest that some faults may change orientation towards the NW near the Macquarie Tier (west of Campbell Town).

Seismic line GA95ST3 through the Mathinna area shows a shallow dipping fault and detachment surface which separates an upper package of low amplitude reflections from a deeper package of high amplitude reflections. This may represent the eastern continuation of the detachment faults mapped in the west of the tenement and may approximate the base of the Mathinna Supergroup. This interpretation enables the generation of a broad depth grid across the tenement, which assumes a deepening Mathinna Supergroup to the east without the influence of Devonian granites (Fig. 8).

However in reality, the base Mathinna grid (Fig. 8) in the east of the tenement will be truncated by subcropping granites which are interpreted to exist from gravity data between 1 and 9 kms depth (Leaman and Richardson, 1992[15]).

[15] **Leaman DE & Richardson RG, 1992**. A geophysical model of the major Tasmanian granitoids. Report Department of Mines Tasmania 1992/11.

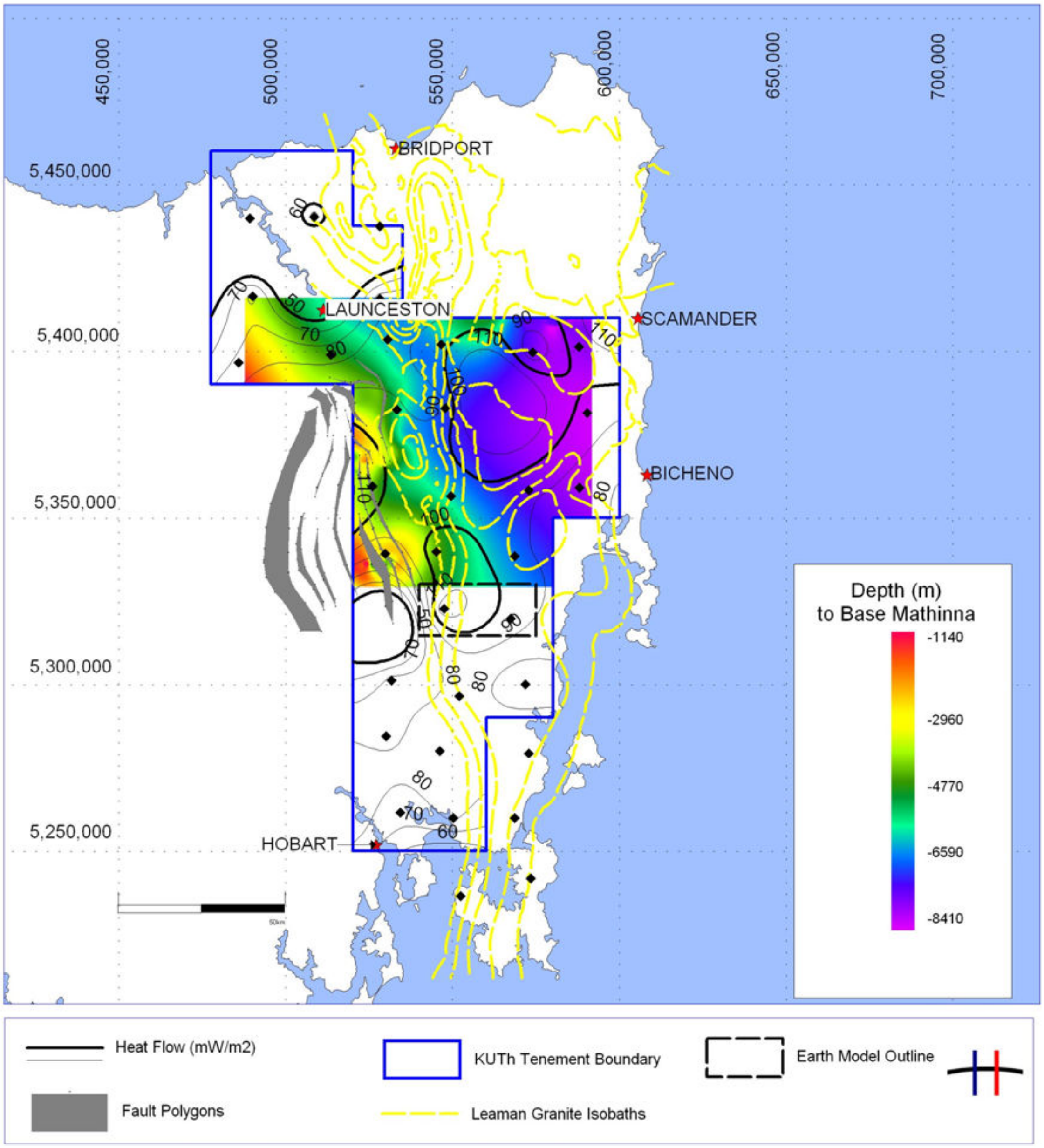

Figure 8. **Interpreted colour depth grid for the approximate base of the Mathinna Supergroup equivalent rocks and interpreted fault trends. Gridding has been extended to the eastern margin of the tenement, however subcropping Devonian granites (yellow dotted lines) will replace the base Mathinna grid in the east. Heat flow wells and contour values are also shown (black).**

4.4 Palaeozoic intrusive rocks

The seismic expression of intrusive rocks, particularly granites, is always difficult to reconcile. In general granites tend to be represented as seismically "dead" zones where amplitudes are very bland or "washed-out". This is however not always the case and granites can display a range of seismic characters.

No convincing evidence was seen in any of the seismic data to define granite subcrop. However this is to be expected as that the gravity and magnetic anomalies interpreted to be related to subcropping granite (Leaman and Richardson, 1992) are located further east, generally outside the area of seismic coverage.

Most of the TB-survey seismic lines end just before the onset of the interpreted granite isobaths. The only exception is line TB01-PG (Blessington-Cressy-Poatina), the northeast end of which may just intersect the edge of the interpreted granite isobaths. This line does show an unusual feature in this area, characterised by high amplitude reflections at about 1.6 sec TWT and an underlying bland package of mainly horizontal reflections (Fig. 9). This is distinctly different from the chaotic nature of the surrounding inferred Mathinna Supergroup reflections. The horizontal reflections are also offset by Tertiary (and possibly Permian) extensional faults suggesting that they may predate the Permian.

It is possible that these reflections may represent either basic sills or a granite body where the horizontal reflections represent possible unloading fractures (as recently mapped in the Coles Bay granite by HDRPL staff). Although far from definitive, this is the only example from the TB seismic dataset which may indicate possible intrusive rocks other than the Jurassic dolerite.

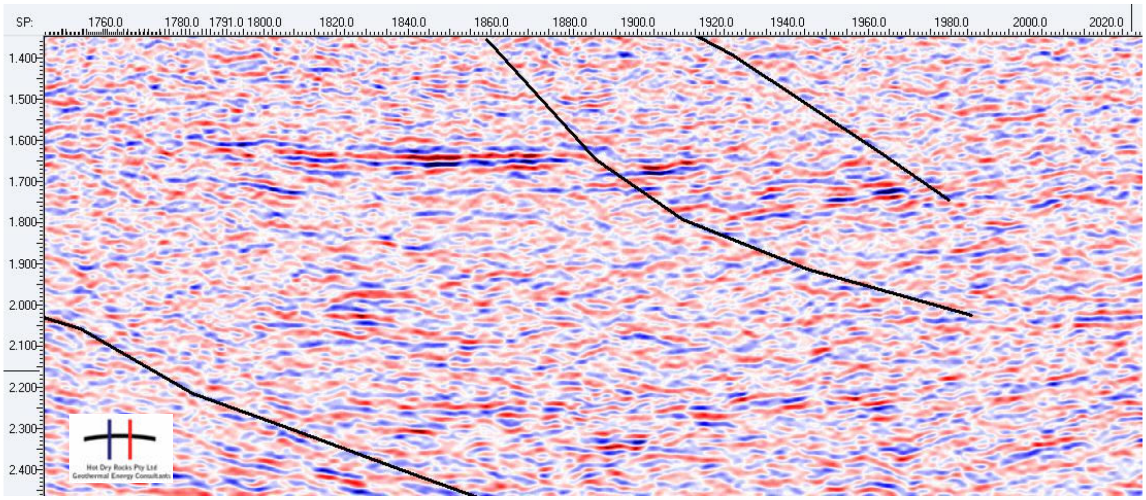

Figure 9**. The north-east end of seismic line TB01-PG (approaching Blessington). Horizontal reflections of an unknown origin occur at 1.6 sec TWT (~2.2km depth) and extend to about 2.3 sec TWT. The bland seismic character of the horizontal reflections <u>may</u> suggest a possible igneous body of pre-Permian age.**

4.5 The Permo-Triassic succession

The Permo-Triassic succession shows localised growth towards the west of the study area, with thickening of section in the NE-dipping half graben. The succession is generally shallower and thinner towards the east as the overall hangingwall geometry returns to regional elevation. The Permo-Triassic reaches a maximum depth of ~3.6km beneath the northern Tertiary basins, but throughout much of SEL26/2005 it is less than 1km deep (Fig. 10).

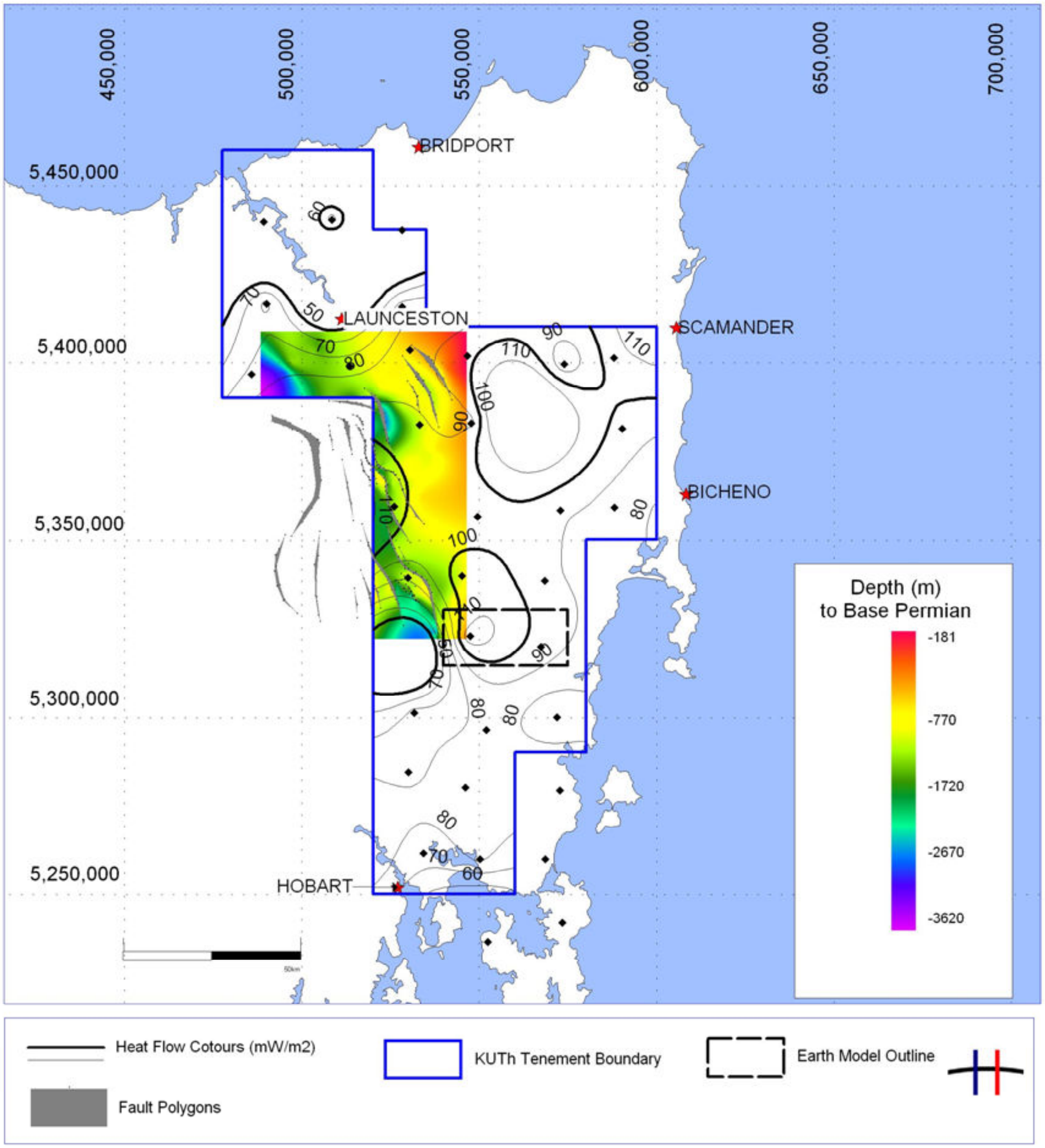

Figure 10. **Interpreted colour depth grid for the approximate base of the Permo-Triassic succession. Heat flow wells and contour values are also shown (black).**

Permian-aged fault polygons also trend NNW and appear to change trend towards the NW near Macquarie Tier (as is the case with the Mathinna fault polygons). In general the Permo-Triassic faults sole into the older Mathinna faults and tend to share similar orientations (Fig. 11). Notably the Permo-Triassic faults can not be mapped as laterally continuous between most seismic lines, suggesting that individual fault planes have limited length with extension accommodated by fault overlap (relay ramps), producing an en-echalon geometry in plan view with apparent offset of half-grabens. This is typical of extensional fault development by fault-tip propagation (eg. Childs et al., 1995[16]; Peacock and Sanderson, 1994[17]). Such fault overlap zones can be important areas of increased fluid permeability for critically stressed faults (eg. Bachler et al,, 2003[18]).

The base of the Permo-Triassic succession is marked by an erosional (scour) surface, indicating a major period of base level drop prior to transgression. The basal glacio-marine tillite infills the scour surface and transgressive onlap is dominant (Fig. 11). Internal sequence boundaries within the Permo-Triassic succession (such as the base of the Cascades Group) can be locally identified, but in general the data are not adequate to allow the tying of internal markers with sufficient confidence (Fig. 12). Some seismic lines suggest that the basal part of the Permo-Triassic succession exhibits deltaic progrades and potential floor-fan sands, whilst the seismic character of the upper Permo-Triassic succession is more typical of fluvial deposition.

[16] **Childs C, Walsh JJ & Watterson J. 1995**. Fault overlap zones within developing normal fault systems *Journal of the Geological Society of London*, 152, 535-549
[17] **Peacock DCP & Sanderson DJ, 1994**. Geometry and development of relay ramps in normal faults systems. *The American Association of Petroleum Geologists Bulletin*, 78, 147-165.
[18] **Bachler D, Kohl T & Rybach L, 2003**. Impact of graben-parallel faults on hydrothermal convection—Rhine Graben case study. *Physics and Chemistry of the Earth* 28, 431–441

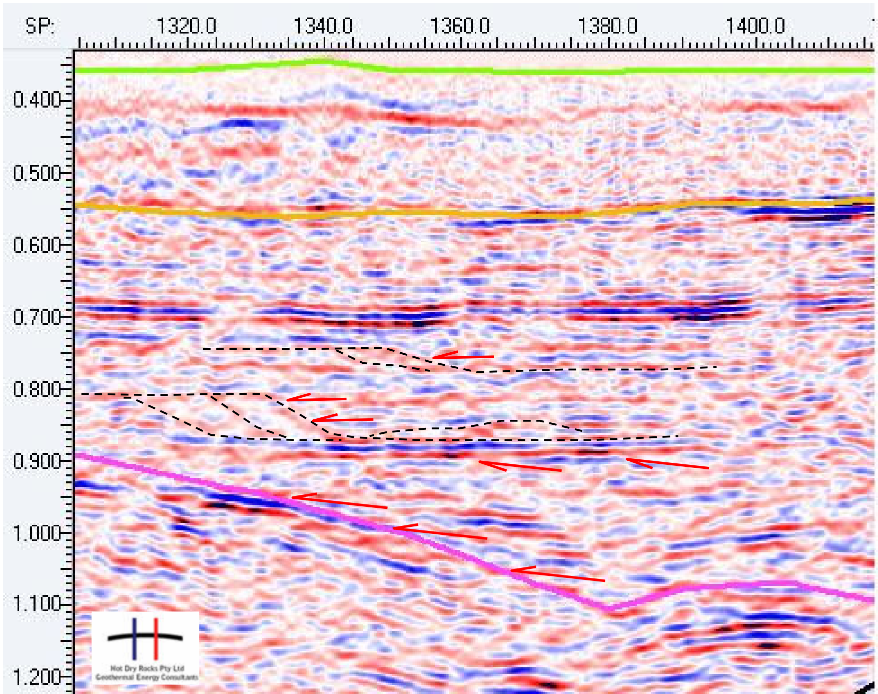

Figure 1**1. Seismic line TB01-ST showing erosional base Permian unconformity (pink horizon) with transgressive onlap. Several other sequences can be seen within the Permo-Triassic succession including a number of unconformities and a possible eastward prograding delta showing eastward migration of the shelf break prior to transgression and the onset of fluvial deposition in the upper portion of the package.**

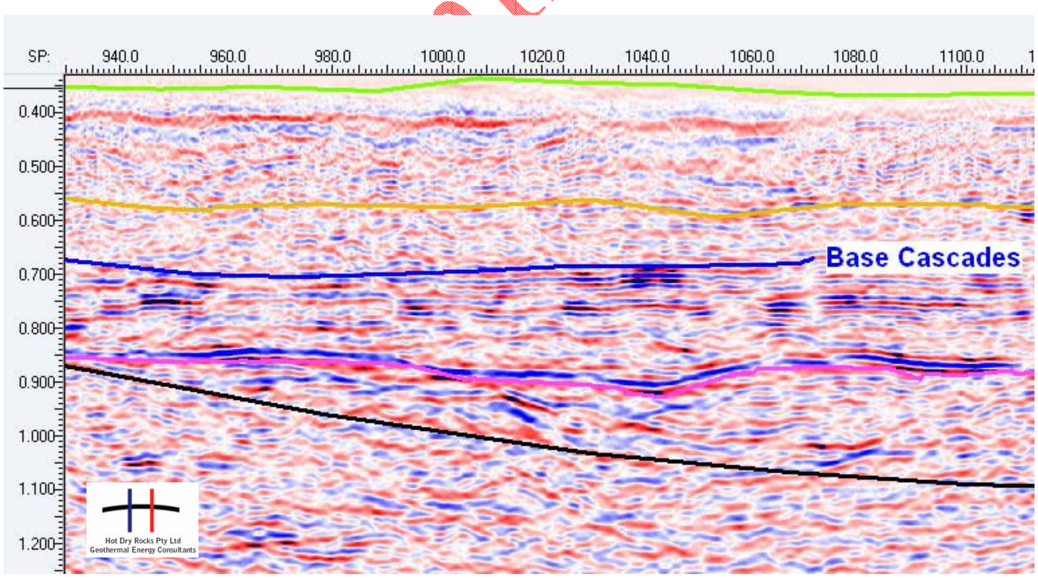

Figure 12**. Seismic line TB01-ST showing the ?Base Cascades unconformity (blue) which can be locally interpreted.**

4.6 The Jurassic dolerite

Many wells in the tenement intersect Jurassic dolerite which may occur as multiple sills, however the seismic resolution of the dolerite is not sufficient to delineate multiple layers, hence this study maps a top and base dolerite horizon only. The dolerite has a relatively uniform layer across most of the tenement varying from about 205 to 320m in thickness, but typically ~300m thick. The dolerite crops out in much of SEL26/2005 but is buried beneath Tertiary section in the north and reaches a maximum depth of ~1400m beneath the Longford sub-basin (Figs 13 and 14).

The top dolerite horizon is usually a “fuzzy” zone, about one cycle above a dominant high amplitude reflection. This zone may mark the weathered top of the dolerite. The central portion of the dolerite (about 0.2 sec TWT in thickness) is characterised by chaotic reflections which are often “opaque”. The base of the dolerite is the next high amplitude reflection beneath the opaque zone (Fig. 15).

The seismic quality of the dolerite horizon is variable on most seismic lines. The dolerite generally appears as a simple blanket across the study area, offset by minor Tertiary faults, with no seismic evidence of feeder conduits in the seismic survey area.

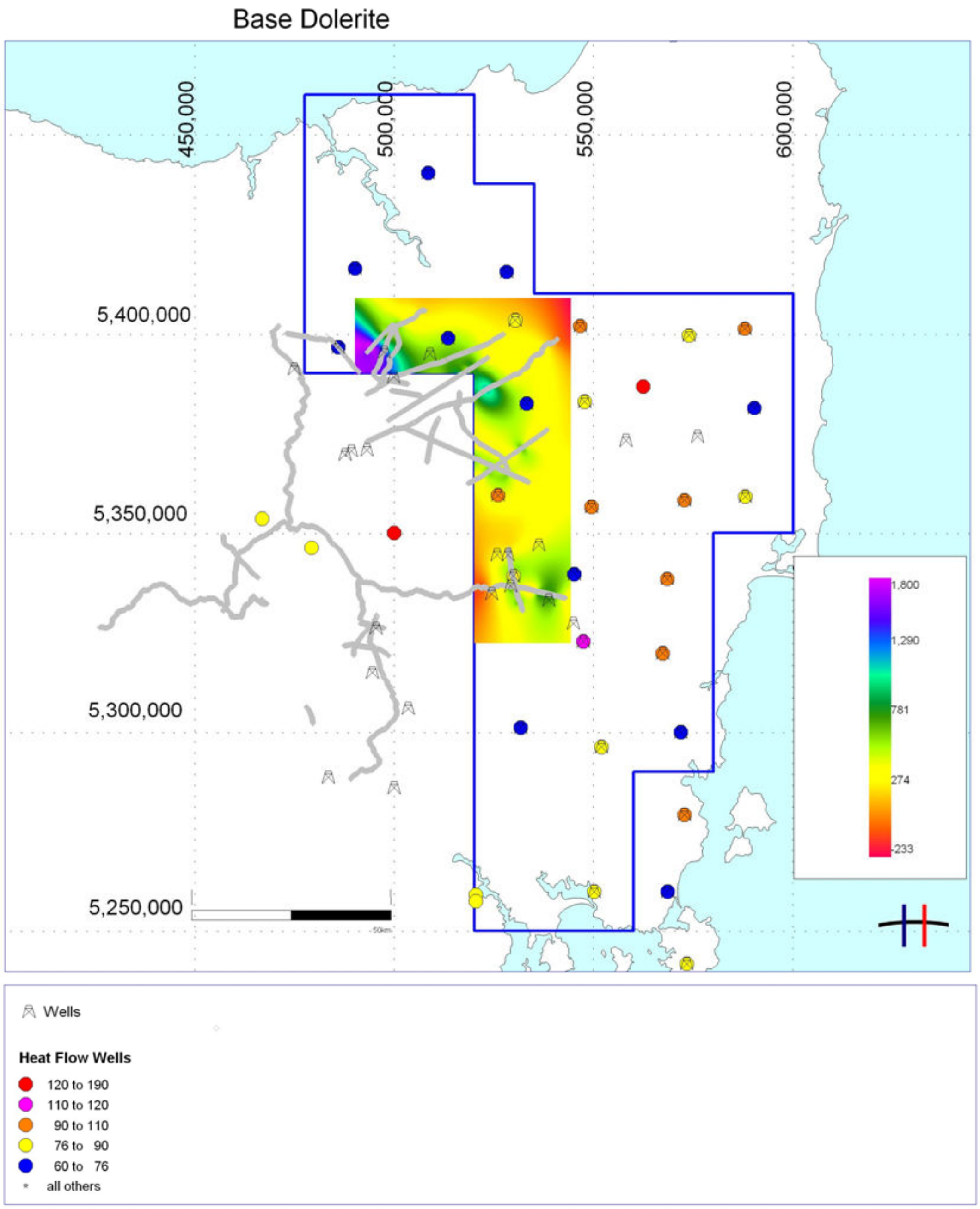

Figure 13**. Interpreted colour depth grid for the approximate base of the Jurassic Dolerite. Negative values (red) approximate topography. Fault polygons have not been generated for this horizon. Heat flow wells are also shown.**

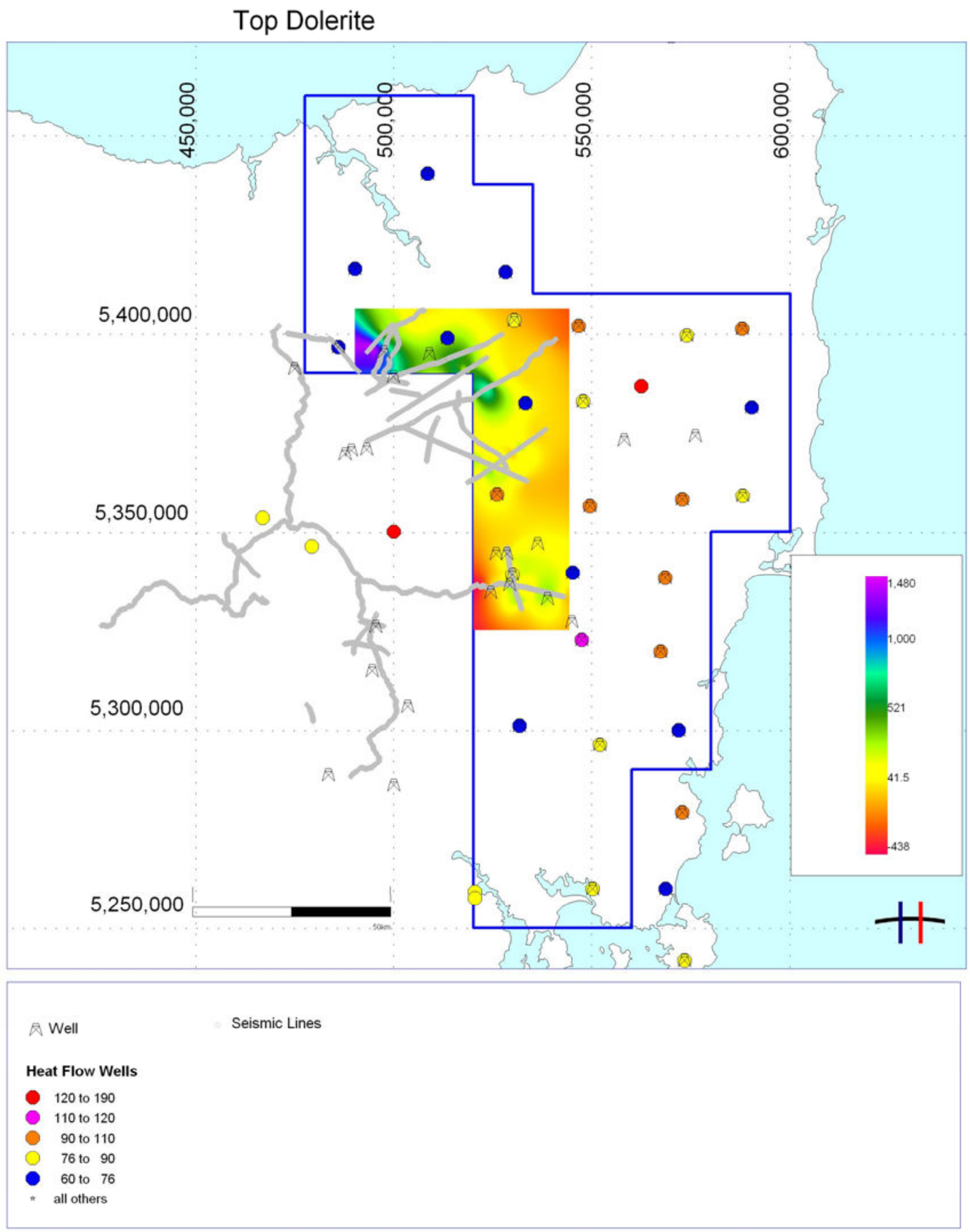

Figure 14. **Interpreted colour depth grid for the approximate top of the Jurassic Dolerite. Negative values (red) approximate topography. Fault polygons have not been generated for this horizon. Heat flow wells are also shown.**

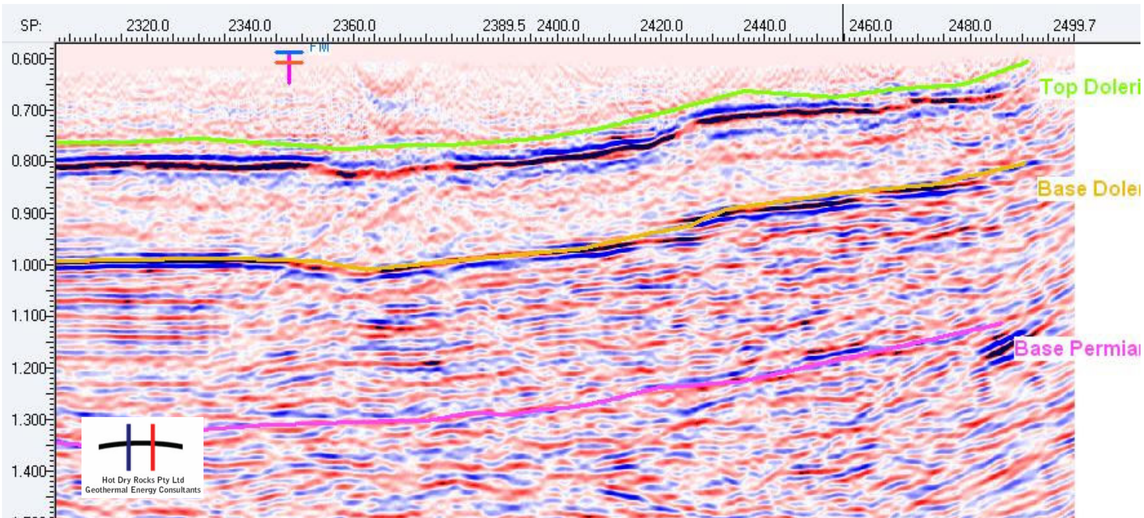

Figure 15. **Seismic line TB01-ST showing the top of the Jurassic dolerite (bright green) and base (brown) with the opaque and chaotic nature of the centre of dolerite sandwiched in between.**

4.7 The Tertiary succession

The top of the Jurassic dolerite approximates the base of the Tertiary succession (Fig. 14). A number of small Tertiary sub-basins have been mapped in the area with the Longford sub-basin being the deepest (~1400m).

The Tertiary succession onlaps the top dolerite and is characterised by mainly parallel, low amplitude reflections, typical of poorly consolidated sediments (Fig. 16). Although offset along some faults occurred during Tertiary extension, the Tertiary sub-basins are more typically symmetrical and may be influenced by compaction and/or thermal relaxation above the Permian half graben (Fig. 16).

Although fault polygons have not been mapped at the Tertiary level, contouring shows that Tertiary sub-basins exhibit the same en-echalon geometry of the Permian half grabens, suggesting that the apparent offset of Tertiary sub-basins seen in figure 14 is a function of the development of the same fault overlap zones seen at the Permian level.

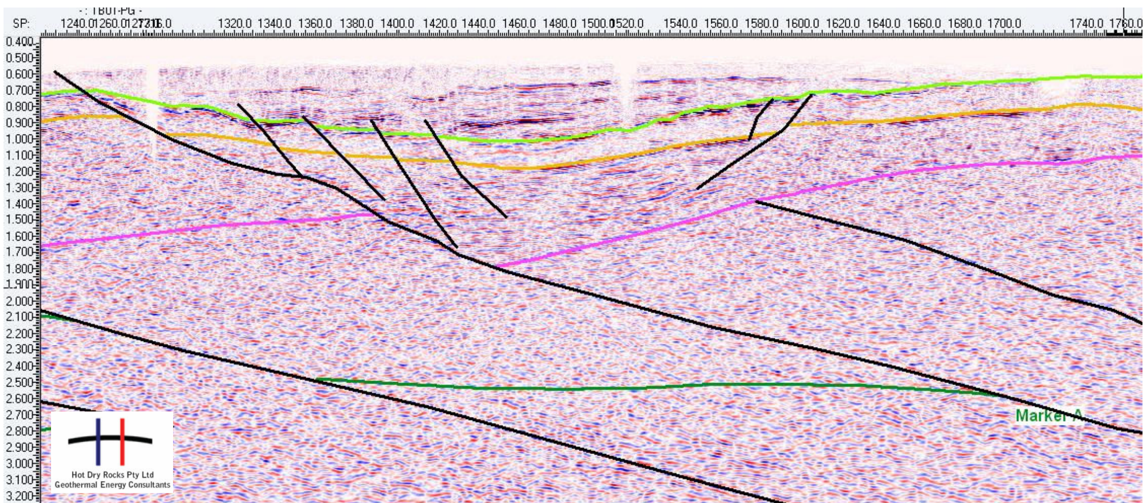

Figure 16. **Seismic line TB01-PG showing a Tertiary sub-basin developed from the extensional reactivation of a Permian fault which coalesces into a Mathinna-age fault. Tertiary sediments onlap the top Jurassic dolerite (bright green). The axis of this sub-basin approximates the position of the South Esk River between Epping Forest and Evandale.**

5.0 Discussion

5.1 Model for structural and tectonic development

The geological development of eastern Tasmania prior to the Early Palaeozoic has been a matter of great contention. This is partly due to the blanket of Jurassic dolerite which obscures older rocks and has been generally thought, mistakenly, to render seismic interpretation impracticable. It is also due to the general lack of palynological age controls. Consequently many ideas about the geological development of eastern Tasmania have been based on structural style alone and in particular cleavage relationships and fold vergence. This can be problematic as structural style is often only consistent on a basin-scale. Cross-regional comparisons of structural style can be misleading.

The depositional setting, lithology and relative age of the Matthina Supergroup suggests that it is a southern correlate of the Melbourne Zone turbidites (Gray and Foster, 2004). Figure 17 shows the deposition of the Mathinna Supergroup in a basinal setting east of a Precambrian basement high in central Tasmania. This interpretation is supported by the seismic data in this study. A schematic representation of the development of the western end of seismic line TB01-ST shows ?Ordovician-Devonian turbidites deposited in a fault-controlled basin, abutting Precambrian rocks in the western footwall (Fig. 18). The extensional hangingwall geometries on line TB01-ST are remarkably similar to the interpreted structures mapped from seismic data from offshore eastern Tasmania (Drummond et al., 2000[19]).

[19] **Drummond BJ, Barton TJ, Korsch RJ, Rawlinson N, Yeates AN, Collins CDN & Brown AV, 2000**. Evidence for crustal extension and inversion in eastern Tasmania, Australia, during the Neoproterozoic and Early Palaeozoic. *Tectonophysics*, 329, 1-21.

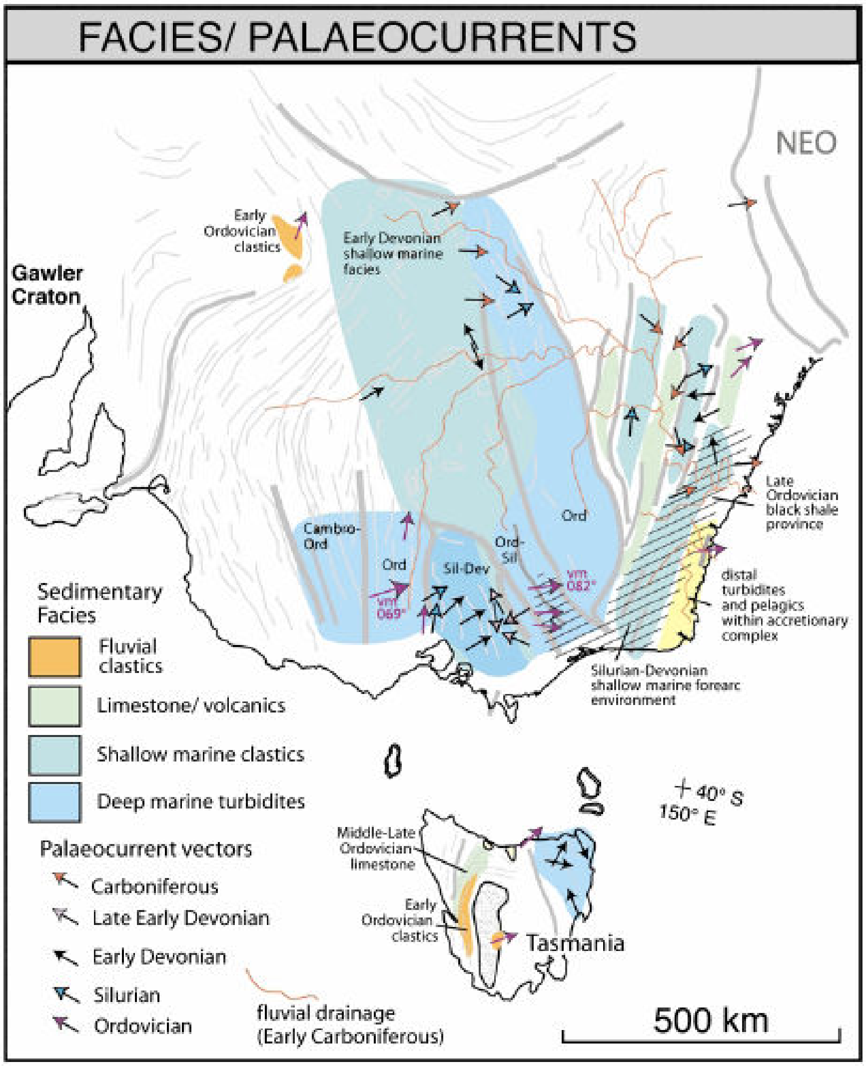

Figure 17. **Depositional setting of turbidite sequences in the Lachlan Orogen (from Gray and Foster, 2004) showing similar depositional settings between NE Tasmania and the Melbourne Structural Zone, however a major difference in structural setting. The Melbourne Structural Zone borders similar rocks in the west (Ballarat-Bendigo Zone) whereas the Matthina Super-groups borders a Precambrian basement high in the west (analogous to the setting of the mar-gin of the Delamerian Orogen).**

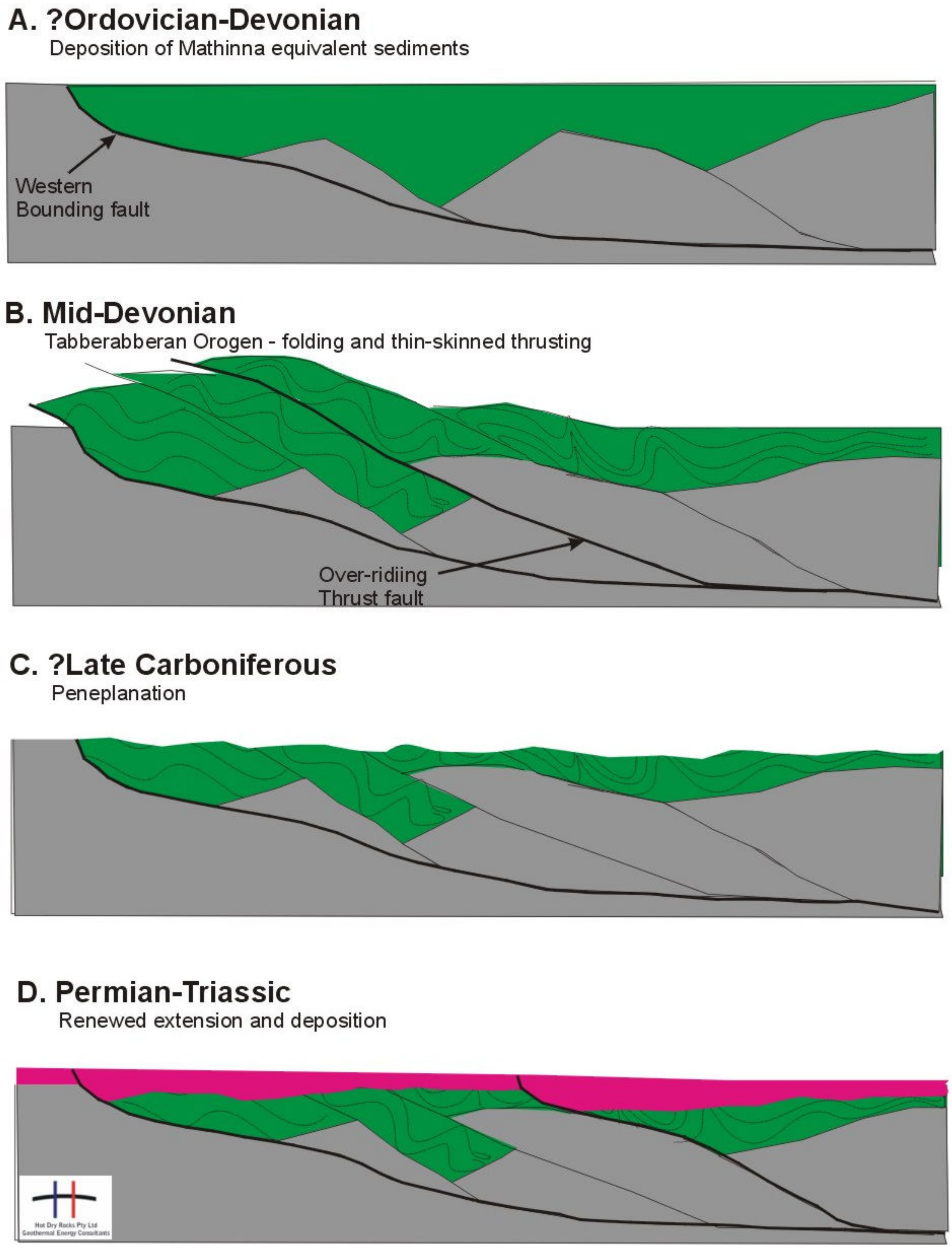

Figure 18. **Schematic cross-sections representing the development of the western end of seismic line TB01-ST from the ?Ordovician to the Permo-Triassic.**

Models which do not accept an exotic origin for the Mathinna Supergroup in the east have attempted to relate the Mathinna Supergroup, and underlying basement, to various parts of the Tasman Orogen. Gray et al., (2006) have however demonstrated that structural style across the Tasman Orogen varies considerably from east to west. Seismic data in eastern Tasmania exhibit similarities with the structural style of parts of the western and central Lachlan Orogen, namely thin-skinned faulting and NE-fault vergence. However the greatest structural affinity is with the margin of the Delamerian Orogen where Kanmantoo turbidites have been inverted and thrust over the rigid Precambrian continental basement during the Tabberabberan event (Flottmann et al., 1994[20]).

Whilst Gray and Foster (2004) note that there is some evidence for inversion of the turbidite sequences of the Lachlan Orogen, the most significant evidence for inversion occurs on the margin of the Delamerian Orogen where the less competent mudstones deform mainly by chevron folding whilst the more competent units form an imbricate thrust fan. A similar structrural style has been modeled for the Papuan Fold Belt in Papua New Guinea, where inversion of the older basin sequences occurs adjacent to the rigid footwall of the Fly Platform along the bounding fault. As compression continues, the frontal inversion anticline "locks up" and a low angle over-riding or "decapitating" thrust fault develops on the back limb of the inversion anticline. This over-riding fault then becomes the main mechanism for crustal shortening (Cooper et al., 1996[21]; Hill et al., 2008[22]). This may be analogous with the low angle thrust fault interpreted to subcrop near Lake Sorell on line TB01-ST (Fig. 18).

[20] **Flottmann T, James P, Rogers J & Johnson T, 1994**. Early Palaeozoic foreland thrusting and basin reactivation at the Palaeo-Pacific margin of the southeastern Australian Precambrian craton: A reappraisal of the structural evolution of the southern Adelaide Fold-thrust belt. *Tectonophysics,* 234, 95-116.

[21] **Cooper GT, Hill KC and Baxter K, 1996**. Rifting in the Timor Sea and New Guinea: a template for compressional forward modelling. In Buchanan PG (ed) Petroleum Exploration, development and Production in Papua New Guinea: Proceedings of the Third PNG Petroleum Cenvention, 133-146.

[22] **Hill KC, Bradey K, Iwanec J, Wilson N & Lucas K, 2008**. Structural exploration in the Papua New Guinea Fold Belt. PESA Eastern Australasian Basins Symposium III, 225-238.

Modelling of inversion structures in Papua New Guinea also suggests that the development of thrust duplexes is usually constrained to the more competent lithologies above the over-riding fault. This may suggest that thrusting in eastern Tasmania may be concentrated near the area of the western bounding fault (western margin of SEL26/2005), whilst further east the less competent turbidite sequence is mainly shortened by folding rather than faulting. This would be consistent with the structural style as mapped in the Devonian turbidites at Cape Liptrap, Victoria (Gray et al., 2006).

In summary the seismic data suggest that the Matthina Supergroup equivalent rocks in the study area have much in common with the turbidites of the Melbourne Structural Zone, but have a different structural setting.

5.2 Integration of seismic structure with heat flow data

Figures 8 and 10 show the interpreted depth grid of the ?base Mathinna Supergroup and top Mathinna Supergroup overlain with heat flow and granite isobath contours. In general the contoured surface heat flows show a good correlation with the interpreted granite isobath data. Heat flow contours show a central ridge of high values (90-100 mW/m^2) in the centre of the tenement which declines to 70-80 mW/m^2 along the western margin of the tenement. This is broadly consistent with the deepening isobath data towards the west.

The only exception to this trend is at Macquarie-1, west of Campbell Town, where the surface heat flow (103 mW/m^2) appears anomalously high. Whilst there are several possible explanations for this, the seismic mapping shows that Macquarie-1 was possibly drilled on, or very close to, a major fault (Fig. 19). Whilst it is possible that this high heat flow may be influenced by the advective movement of hot fluids along the fault plane, there is no evidence in the temperature log to support this. The heat flow model for Macquarie-1 fits a conductive model with no need for advective heat addition. Likewise the fault at this location appears to approach the surface and there is no record of hot or cold springs in the area.

It may possible that vertical displacement of the fault at the Permian level (~900m) has juxtaposed high conductivity rocks and, combined with the dolerite insulation, has resulted in refraction of heat across the fault plane and up the footwall (approximate position of Macquarie-1). HDRPL recommends that this model be tested using simple 2D conductive heat flow software.

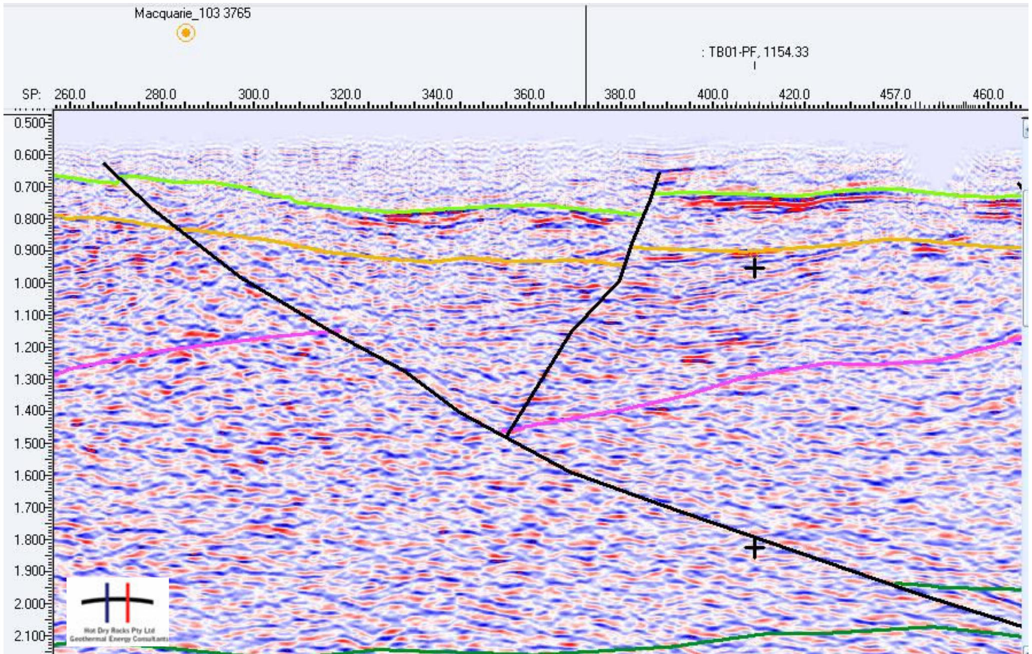

Figure 19**. Seismic line TB01-PT (west of Campbell Town) showing the projected position of well Macquarie-1 located above a large NE-dipping fault. Heat flow at this well may be influenced by heat refraction across the fault plane.**

5.3 Seismic structure and major crustal boundaries

The Tamar Fracture Zone is an assumed major crustal boundary, the position of which is though to approximate the axis of the Tertiary sub-basins of the Tamar Valley. Seismic line TB01-PG (Blessington-Cressy-Poatina) intersects the trend of this axis near the South Esk River between Epping Forest and Evandale. Seismic quality in this area is reasonable, and whilst there is a major fault at this location (Fig. 20) there does not appear to be any significant change in seismic character either side of the fault beneath the Permian unconformity. This does not preclude the possibility that an older, deeper crustal or lithospeheric boundary may occur at a deeper level or that such a boundary may occur further east of the seismic line termination.

Likewise the "Tamar Fracture Zone" model assumes that the Wurawina Supergroup (west of the Tamar River) and the Mathinna Supergroup (east of the Tamar River) were largely deposited at the same time, prior to the accretion of the exotic Mathinna Supergroup in the Mid-Devonian. However the western end of seismic line TB01-PG, near Poatina, shows a series of high amplitude sub-parallel reflections beneath a generally chaotic group of reflections (Fig. 21).

Stacey (2007) suggested that the sub-parallel reflections may be small localised faults, however the reflections appear to define a series of sequence boundaries within a possible low-stand systems tract followed by transgression. This package of reflections may represent a prograding delta, implying shallow marine deposition. This character is unlikely for the Mathinna Supergroup turbidites, but may be consistent with the shallow marine depositional environment of Wurawina or older units. Notably, the chaotic reflections which sit above the high amplitude package are folded, suggesting less competent rocks typical of Mathinna Supergroup turbidites. This relationship may suggest that the Wurawina and Mathinna Supergroups were not deposited penecontemporaneously, but that the Mathinna Supergroup is a younger sequence which lies unconformably on the Wurawina Supegroup. This interpretation may negate the need for any crustal boundary in eastern Tasmania.

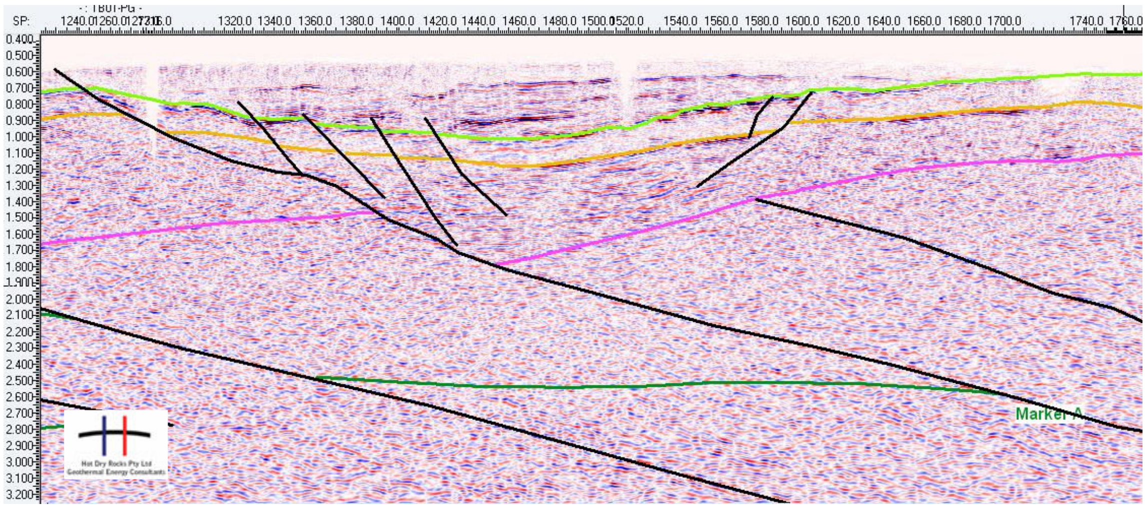

Figure 20**. Seismic line TB01-PG showing a major NE-dipping fault which controls the development of Tertiary sub-basin at the South Esk River between Epping Forest and Evandale (along the trend of the assumed Tamar Fracture Zone). There is no significant change in seismic character either side of the fault beneath the Permian unconformity. Whilst the fault soles into an older Mathinna-age fault, most of the apparent movement of the fault has occurred during the Permian and Tertiary.**

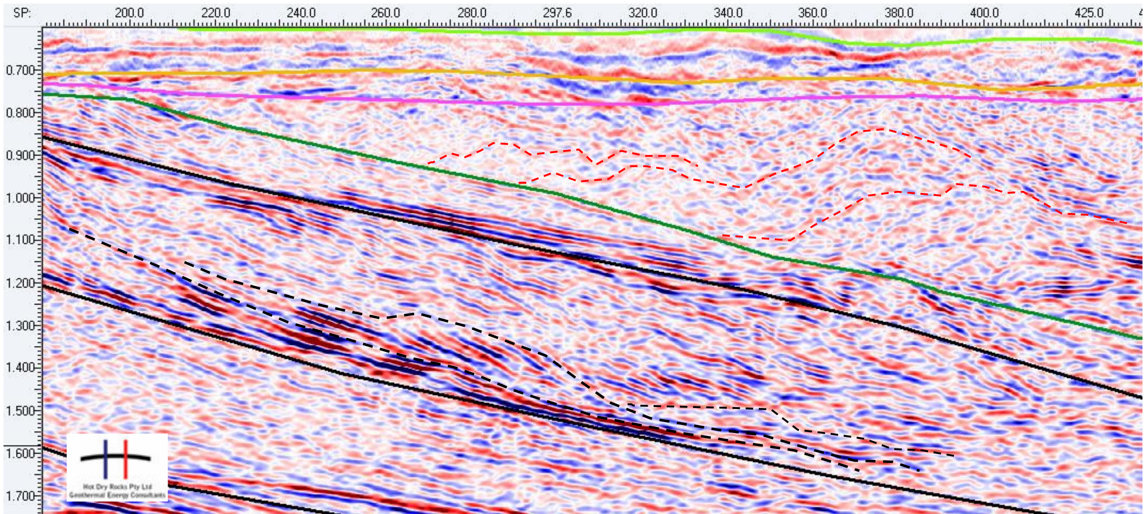

Figure 21**. The western end (near Poatina) of seismic line TB01-PG showing shallow dipping high amplitude parallel reflections (possible thrust sheets) similar to those seen in the footfall of the major bounding fault of TB01-ST beneath Lake Woods. However internal reflections in this package may represent a prograding delta system. This interpretation of a deltaic-shallow marine depositional environment is consistent with that of the Wurawina Supergroup and not the Mathinna Supergroup. The package of bland and apparently folded reflections above the green marker may represent the Mathinna Supergroup. This relationship may suggest that the Wurawina Supergroup is an older unit and is not penecontemporaneous with the Mathinna Supergroup.**

6.0 Conclusions & recommendations

Although a number of uncertainties still remain, the seismic mapping exercise undertaken in this study has yielded useful information for understanding geothermal systems in eastern Tasmania. Gridded data should provide useful constraints for the construction of a 3D earth model.

HDRPL presents the following specific recommendations for KENs consideration:-

- KEN may consider the acquisition of new 2D seismic data across the central portion of the tenement to fill the current "data gap". It is possible that seismic acquisition and processing designed to minimize noise attenuation could yield useful information.
- Related to the recommendation above, KEN may plan future MT acquisition to coincide with existing seismic lines so as to provide greater controls on possible sources of MT anomalies.
- The ?Proterozoic rocks intersected in a number of wells in the tenement have no contemporary age constraint and KEN may find value is having the rocks analysed for palynomorphs and/or achritarchs.
- Seismic depth data from this report can be used to constrain 1D, 2D and 3D heat flow models.
- 2D heat flow modeling of selected seismic lines and 3D heat flow modeling in general may better constrain the possible influences of heat refraction across large faults.

- Numerical stress modeling using mapped fault geometries may elucidate information about the stress state of faults and give some insights into those faults which may be critically stressed.
- To reduce risks within the resource area, KEN may consider the reservoir character through the use of analogues from other areas of Tasmania and the acquisition of geomechanical data. These data can be incorporated into a numerical stress and hydromechanical model. This may provide useful information about fracture network stimulation under in-situ stress conditions.