Hot Dry Rocks Pty Ltd
Geothermal Energy Consultants

HEAD OFFICE
PO Box 251
South Yarra, Vic 3141
Australia
T +61 3 9867 4078
F +61 3 9279 3955
E info@hotdryrocks.com
W www.hotdryrocks.com

ABN: 12 114 617 622

SERVICES
Exploration
Rock Property Measurements
Project Development
Portfolio Management
Grant Applications

Geothermal Systems Assessment of SEL 9/2009, north-west Tasmania

Compiled for
Gullewa Geothermal Limited
By Hot Dry Rocks Pty Ltd

Driscoll, Mortimer, Cooper & Pollington

04 February 2010

Executive summary

Hot Dry Rocks Pty Ltd (HDRPL) was commissioned by Gullewa Geothermal to review and assess the potential Engineered Geothermal System (EGS) reservoir targets that may occur within SEL 9/2009 (western Tasmania). This report is a scoping study which addresses principle geological risks at a tenement scale which has been undertaken using a risk assessment framework developed by Hot Dry Rocks Pty Ltd. The principle risk areas addressed in this study include the presence of an adequate thermal insulating cover sequence and adequate temperatures for geothermal prospectivity; the presence of a suitable reservoir unit and the availability of water.

The principle findings of this report are:

- The tenement exhibits some potential for EGS exploration and development, particularly the presence of high heat generating granites and high heat flow, although this is restricted to one value within the tenement (104 mW/m^2 at Rosebery).
- Heat generation in granites is variable throughout the tenement, but is typically high and often above 8-10 $\mu W/m^3$. These values are similar to those inferred for the Cooper Basin (South Australia) and greater than the value estimated for granite at Habanero-1 (7.3 $\mu W/m^3$).
- Preliminary modelling, based on estimated conductivity profiles and stratigraphy, suggest that the 150°C isotherm may occur at 3.5-4.5 km depth within the tenement, although this will vary significantly with local geology, heat flow and rock thermal conductivity.
- Areas where granite isobath data suggest that granite is between 3.5 and 4.5km may be broadly regarded as prospective for EGS, subject to further measurement and modelling. Four broad areas (Figure 19) have been identified as having some particular interest for geothermal exploration based on the assessment made in this study.

- There is a lack of geothermal-specific data within SEL 9/2009 and the principle risk is seen to the lack of rock thermal conductivity data and how this may vary rock anisotropy (cleavage). Although temperature and heat flow data are also lacking, a targeted campaign of sample collection for conductivity should also be integrated with a precision temperature logging exercise for selected bores in the area. This will greatly improve understandings of heat flow and temperature distribution within the tenement.
- The stress state in Tasmania is presently unresolved and further data collection from selected earth quake and bore data may assist this. Available data suggest that the regional principle stress tensor may be broadly oriented E-W, although this is poorly constrained.
- The geomechanical properties of basement rocks are poorly constrained. Field and core mapping of facture patterns, stiffness and uniaxial stress tests of selected samples may assist in mitigating these risks. These data should be combined with numerical modelling of stress and fracture distributions. Likewise numerical reservoir modelling (TOUGH2) at a later stage of the project may assist in mitigating flow risks.

Table of Contents

1. Introduction

Gullewa Geothermal Pty Ltd (GUL) is the sole licensee of geothermal exploration license SEL9/2009 which was granted by Mineral Resources Tasmania (MRT) in late 2009.

Hot Dry Rocks Pty Ltd (HDRPL) has been commissioned to undertake a Geothermal Systems Assessment (GSA) of the license. A GSA is a holistic, systematic review of existing data relevant to geothermal energy exploration.

Although minerals exploration drilling and other works have historically occurred within the tenement, there is a paucity of geological data relevant to geothermal systems, in particular quality temperature data. This has restricted the scope of 1D heat flow modeling in the area. This assessment is based on existing data only, and further detailed data acquisition will be required at a later date to progress knowledge of geothermal systems in the area.

This assessment is principally geological and makes no comment on land access or regulatory issues.

2. Geothermal Systems Assessment (GSA) methodology

2.1. GSA Introduction

The Geothermal Systems Assessment (GSA) approach is a risk assessment framework developed by Hot Dry Rocks Pty Ltd and shown in Figure 1, as described in Cooper and Beardsmore (2008).

The GSA framework addresses principle geological risks at basin or regional scale. Further detailed work at a prospect scale is recommended to progress areas which have been highlighted in this study.

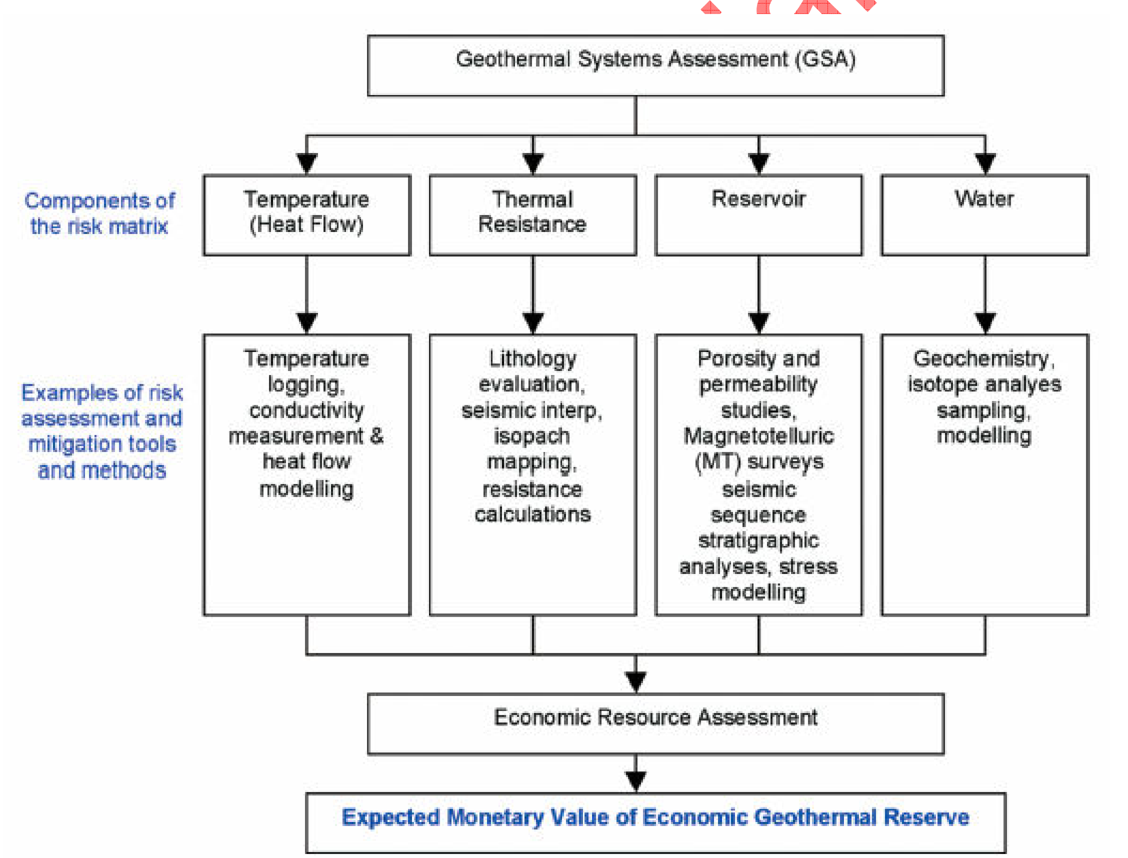


Figure 1: The Geothermal Systems Assessment (GSA) Framework as developed by HDRPL (from Cooper and Beardsmore, 2008).

A GSA of SEL9/2009 has been undertaken to highlight the principle risks associated with geothermal prospectivity, namely the presence of an adequate thermal insulating cover sequence and adequate temperatures for geothermal prospectivity; the presence of a suitable reservoir unit (either a porous or fractured medium or other suitable lithology which may be susceptible to artificial permeability enhancement; and the availability of water.

The GSA is a desktop scoping study of the tenement but may incorporate regional data proximal to the tenement, utilising open-file data and encompasses the following:-

- A review of pertinent published literature on the geology of Western Tasmania.
- Compilation of heat flow data and quality assessment from several sources: the Global Heat Flow Database, Geoscience Australia OZCHEM database, and a previous MRT gamma-ray spectrometry study of Tasmanian granites.
- Compilation of rock thermal conductivity data north-west Tasmania.
- Acquisition and assessment of petroleum, minerals, water or other borehole data relevant to thermal information (MRT website).
- Review of selected borehole data and/or cross-sectional data, where suitable, and calculation of heat flow.
- Collation of published stress data for the area and quantitative assessment of stress, fault and other data with regards to potential fault permeability.
- Assessment of MRT granite isobath data relevant to this study.
- Generation of base maps for well locations and contoured heat flow and heat generation.
- Overall synthesis of all data using a Geothermal Systems Assessment approach to define preliminary areas of prospectivity.

The GSA framework utilised by HDRPL recognises the geothermal resource as being the product of four largely independent, geological factors- heat flow (conductive and advective), thermal resistance (insulation), reservoir characteristics (including prevailing stress regime) and access to a working fluid (water or steam). This approach is synonymous with risk methodologies used in Petroleum Systems Analyses.

3. SEL9/2009 Geological Setting

SEL 9/2009 covers an area of over 3,000km^2 in the north-west of Tasmania (Figure 2) and is centred on two large Early Palaeozoic features referred to as the Dundas Trough and the Fossey Mountains Trough (Figure 3).

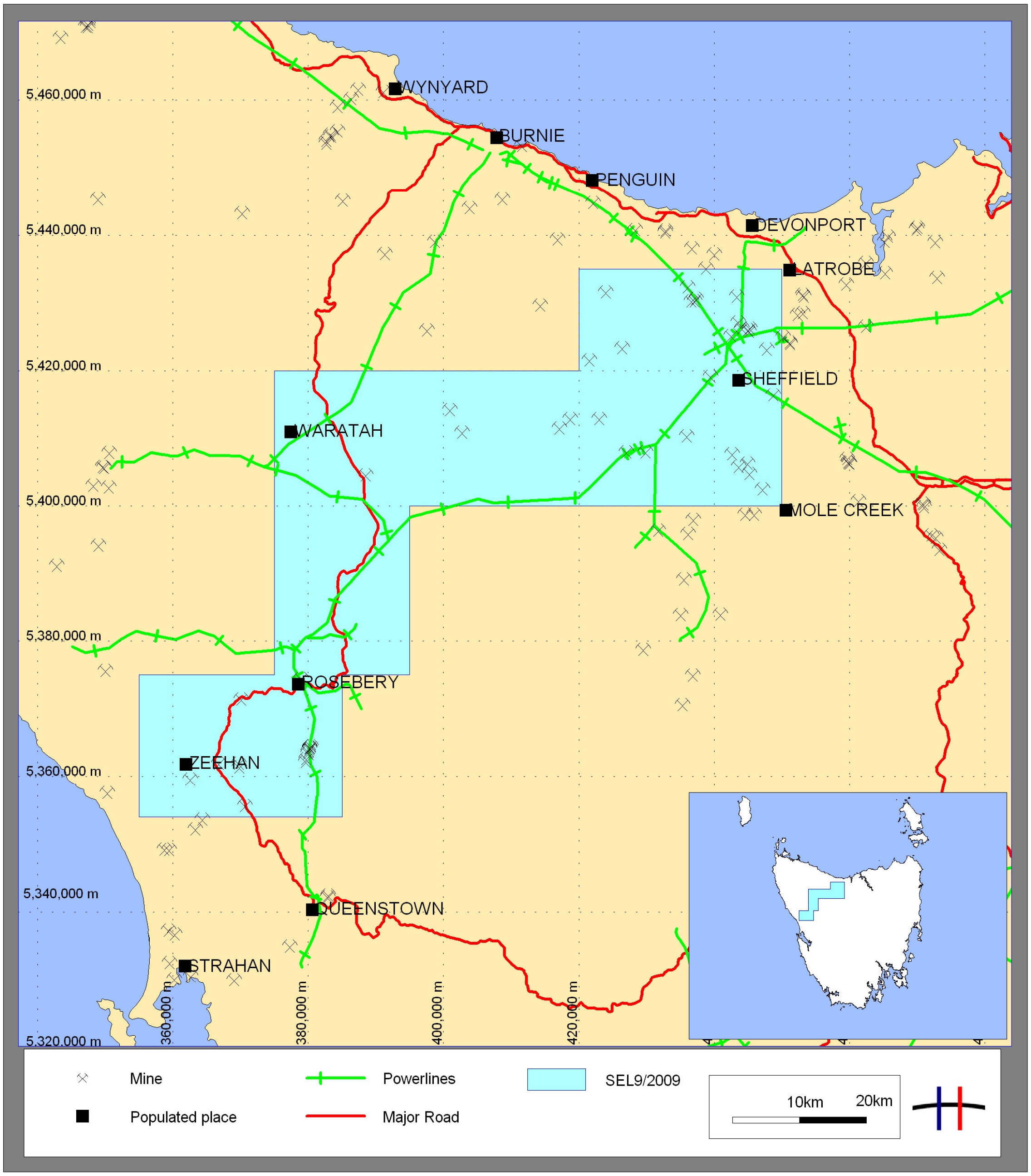


Figure 2: Location of SEL9/2009 in north-west Tasmania and major infrastructure (roads and power lines).

These troughs are regarded as a single entity for the purpose of this report. The Dundas-Fossey Mountains Trough is the largest of several Early Palaeozoic depositional features lying between, around and, in some cases, above areas of Mesoproterozoic to Neoproterozoic basement.

The tectonostratigraphic evolution of north-west Tasmania is complex and a number of structural trends have been recognised (Figure 4). The geology of the study area is shown in Figure 5 and a significant amount if the Cambrian succession of the Dundas Trough is partly masked by Tertiary basalt in the Guildford region (central portion of SEL9/2009). A diverse suite of metamorphic, volcaniclastic and sedimentary packages have been identified throughout the area and a stratigraphic column showing major successions is shown in Figure 6.

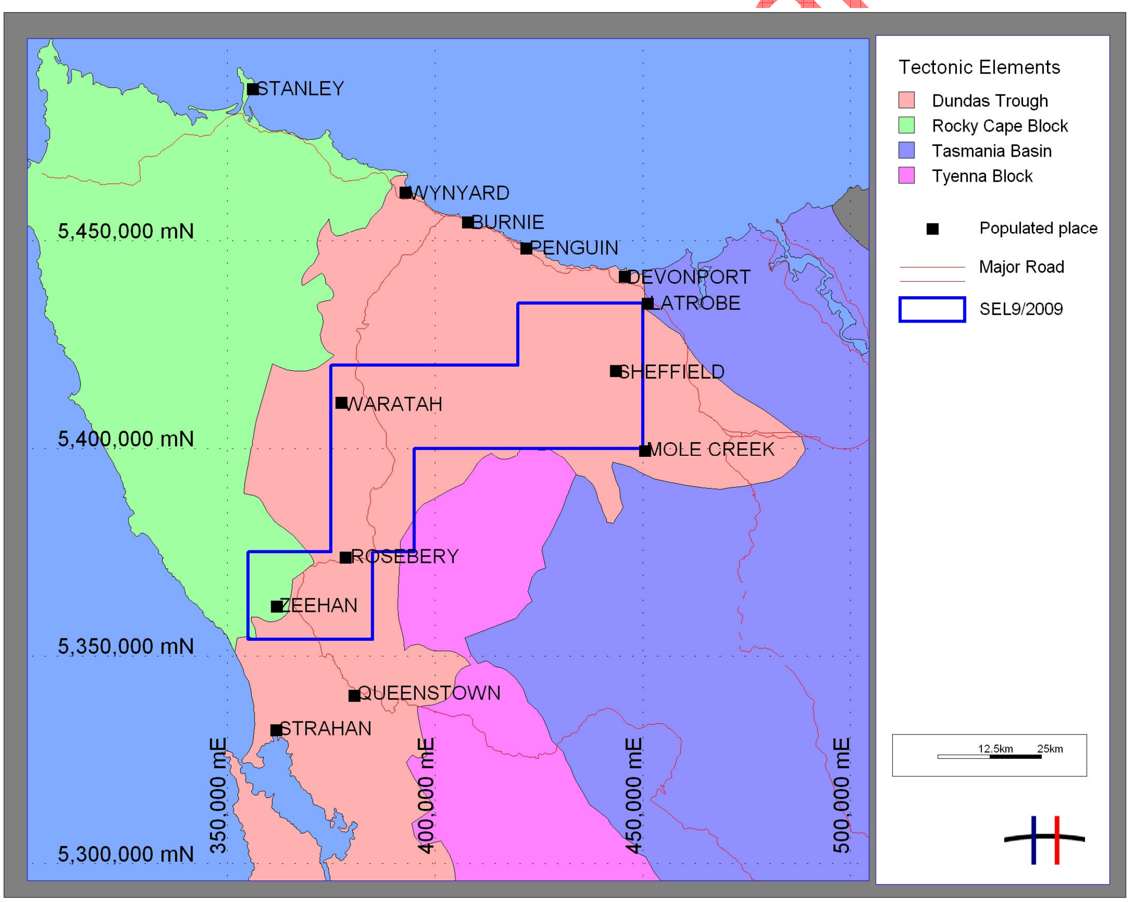


Figure 3: Tectonic Elements of north-west Tasmania.

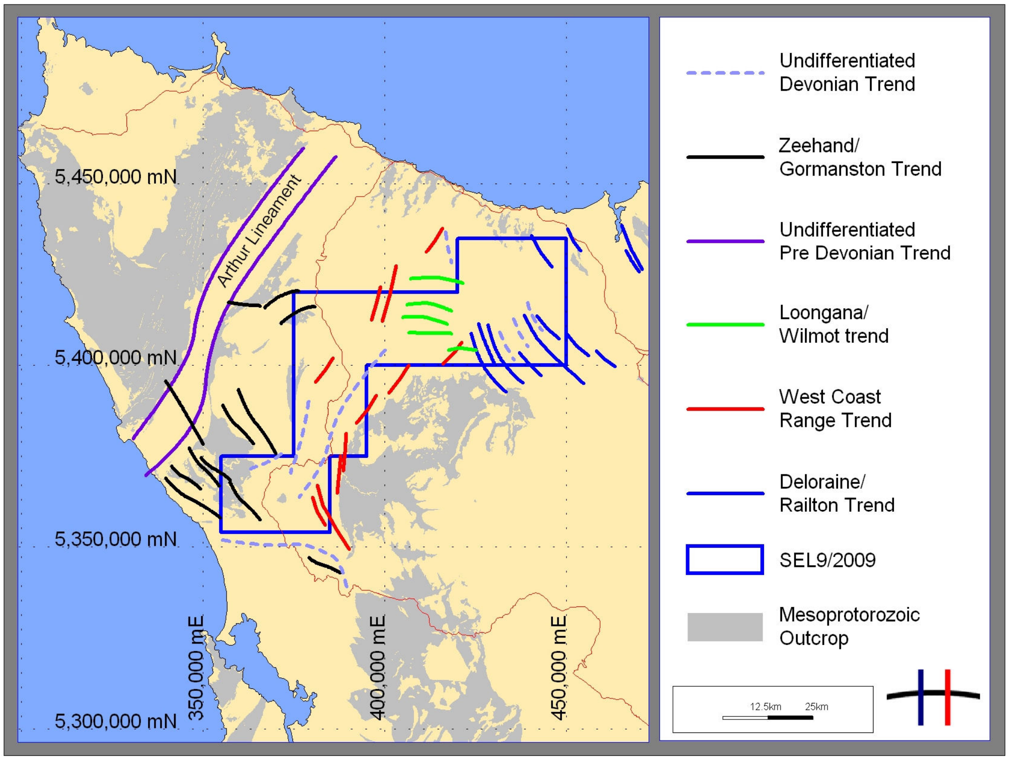


Figure 4: Major structural trends of western Tasmania, illustrating differential Middle Devonian and pre-Middle Devonian fold and fault trends, with Proterozoic terranes marked for reference (from Noll, 2004).

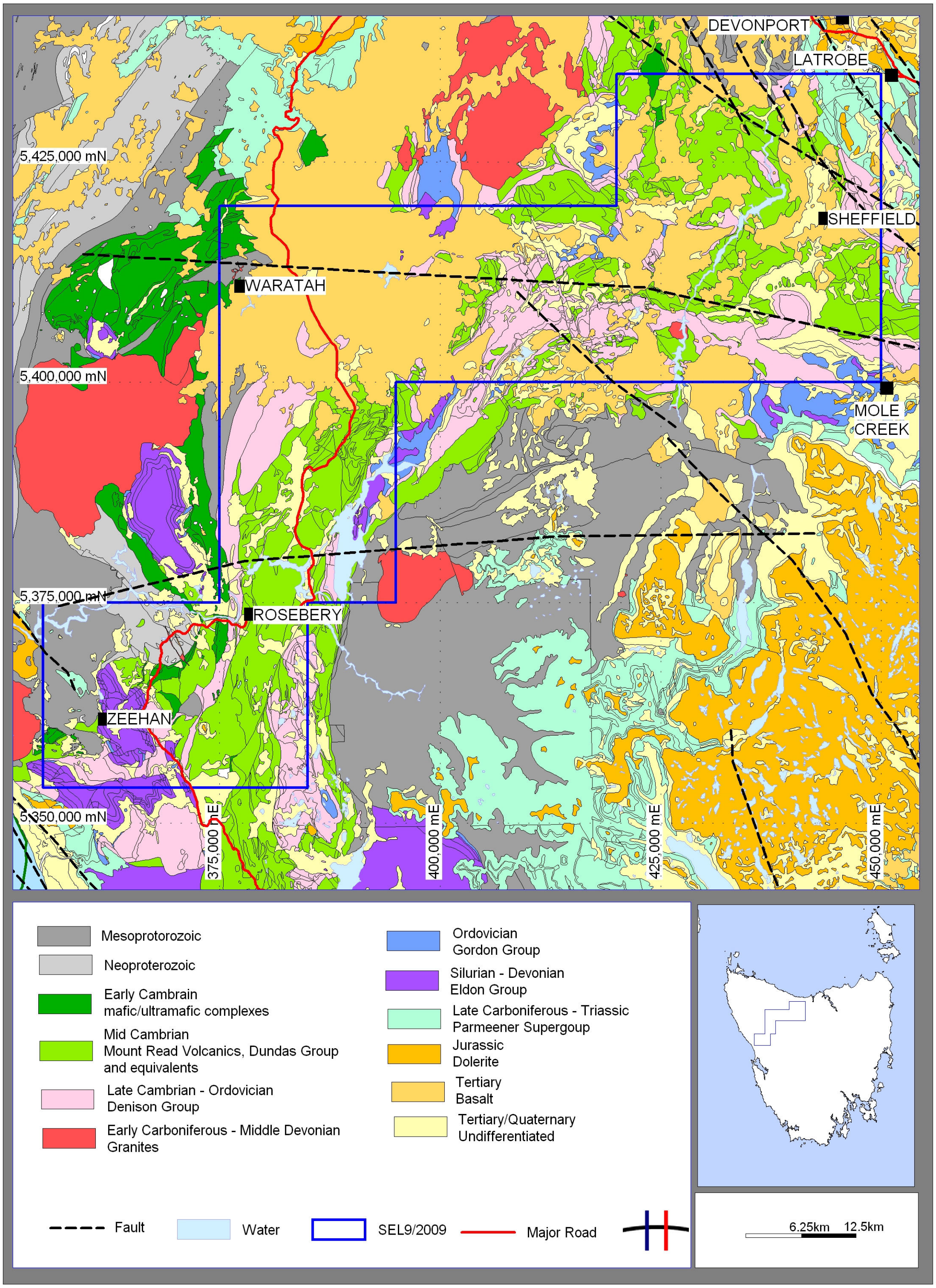


Figure 5: Regional surface geology of north-west Tasmania (source Geoscience Australia).

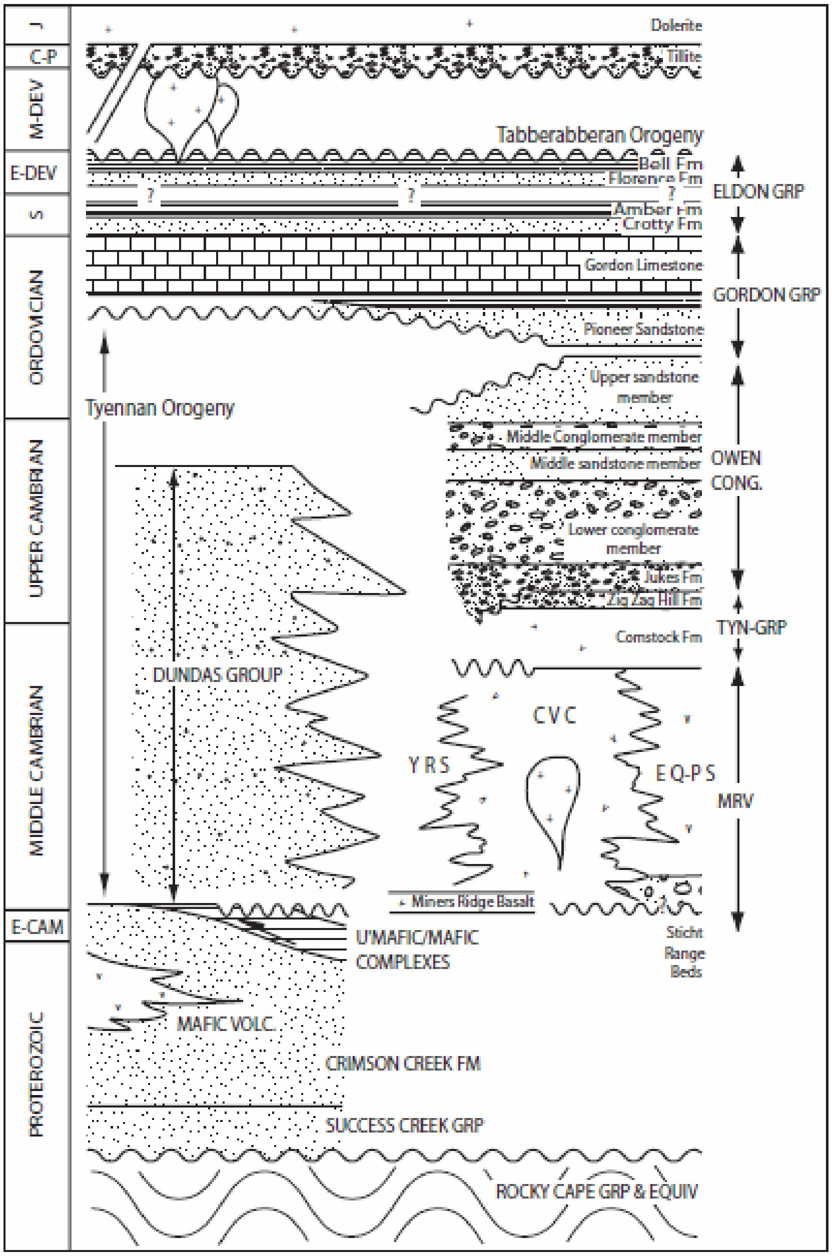


Figure 6: Stratigraphic framework of north-west Tasmania (from Noll, 2004).

A series of Mesoproterozoic to Neoproterozoic blocks, referred to as the Tyennan, Forth and Rocky Cape terranes, surround and presumably underlay SEL9/2009. These terranes are often metamorphosed quartzarenites and pellites whilst the volcanic-sedimentary sequences are heavily mineralised and host a number of economically important metalliferous mines including the Lyell, Rosebery, Tullah, Renison Bell and Hellyer mines.

A number of different tectonic models have been proposed for the Lower Palaeozoic sequences of western Tasmania (Corbett & Turner, 1989), and there remains much speculation and conjecture.

The Tyennan Orogeny initiated during the Early to Middle Cambrian (~520 Ma) as a result of an arc-continent collision. It has been reported that the stress regime changed rapidly during the initial phase of the orogenic event, and the resultant locus and styles of deformation are complex. The status of timing and origin of many of these early tectonic elements remains contentious. The first stage of the event was emplacement of allochthonous ophiolite complexes and metamorphic complexes onto western Tasmania. The Dundas-Fossey Mountains Trough was initiated with shallow marine to turbidite sequences being deposited. The development of these troughs has resulted in spatial restriction of the Proterozoic terranes at surface.

The second stage of the Tyennan Orogeny was a Middle Cambrian extensional event that resulted in rapid subsidence and deposition of thick sequences of post-collisional felsic-dominated volcanic-sedimentary sequence (Mount Read Volcanics) within the Dundas-Fossey Mountains Trough.

The Late Cambrian-Early Ordovician saw the final stage of the Tyennan Orogeny; a compressional event which resulted in basin inversion of many of the earlier extensional features and associated uplift of the Tyennan terrane. A series of folds eventuated and a thick, generally fining up, syndepositional siliciclastic package was deposited (Denison Group).

By the Middle Ordovician, many of the topographic highs associated with the Tyennan Orogeny had been eroded and a new structural cycle began. The lower section comprises a thin basal sandstone followed by a widespread carbonate sequence of intertidal to shallow marine carbonates (Gordon Group) overlain by a Silurian-Early Devonian shallow marine clastic succession (Eldon Group).

North-west Tasmania was strongly affected by the Devonian Tabberabberan Orogeny which was associated with the emplacement of granitic intrusives throughout Tasmania and south-eastern Australia. These granites are both a principle heat source and reservoir target for Engineered Geothermal Systems (EGS) exploration within SEL9/2009 and around Australia.

During the Late Carboniferous to Late Triassic, much of Tasmania was unconformably overlain by sedimentary rocks of the Tasmania Basin succession comprising mainly glaciogenic-marine to non-marine sediments. These rocks are relatively flat-lying but are not common in Western Tasmania.

A Middle Jurassic thermal anomaly within the eastern margin of Gondwana has been proposed to account for the extensive volumes of tholeiitic dolerite intruded throughout Tasmania.

Late Jurassic to Early Cretaceous Rifting between Australia and Antarctica associated with the breakup of Gondwana resulted in a series of half grabens, mainly located in the offshore parts of northern (Bass and Duroon basins) and western (Sorrell Basin) Tasmania. Late Cretaceous to Early Tertiary extension associated with Tasman Sea rifting produced a number of small Tertiary graben in Tasmania, often capped with basalts. The central and northern portion of SEL9/2009 is covered by a veneer of Tertiary basalts with an average thickness of about 300m.

3.1. Stratigraphy

3.1.1 Mesoproterozoic Basement

Proterozoic basement is exposed throughout north-west Tasmania, and comprises similar parent lithologies including quartzarenite, phyllite, garnetiferous peilitic schist and minor carbonates. Metamorphic grade is variable and ranges from greenschist to eclogite facies in the Tyennan terrane, whilst only low or sub-greenschist facies are evident in the Rocky Cape terrane (Turner, 1989).

Sedimentary features within Tyennan terrane quartzarenites include herringbone cross stratification (Boulter, 1978), an indication of deposition within a shallow water environment influenced by a tidal regime.

The Rocky Cape Group comprises a series of shallow marine clastics (Gee, 1968; Gee *et al*., 1970) and includes the following units in ascending stratigraphic order: Pedder River Siltstone, Lagoon River Quartzite, Balfour Subgroup, Cowrie Siltstone, Detention Subgroup, Irby Siltstone and Jacob Quartzite.

Black *et al*. (2004a) noted that quartzarenite-dominated sections of most of the Proterozoic terranes were remarkably similar in both their lithological characteristics, and in their SHRIMP U-Pb detrital zircon dating records (two main population clusters of 1,450-1,400 Ma and 1,800-1,650 Ma). The results constrained deposition of the Tyennan and Forth terranes to the Early Neoproterozoic with a maximum age being 1,000 Ma based on the minimum age of the zircons, and a minimum age of 750 Ma provided by the basal age of the overlying Togari Group and correlates. Black *et al*. (2004a) also suggested the closest geographical match for sourcing the zircons during the Proterozoic is the Arunta Block of central Australia. Plate reconstructions also suggest rocks currently exposed in Mexico and the southwest US could also be potential source rocks for the Proterozoic terranes of northern and western Tasmania.

These datasets are consistent with model Rb-Sr depositional ages of approximately 1,100 Ma based on highly radiogenic schists near Strathgordon in the Tyennan terrane (Raheim and Compston, 1977).

There has been much debate as to whether the Proterozoic terranes are allochthonous (Leaman, 1992; Powell, 1992; Elliott *et al*., 1993; Leaman *et al*., 1994; Meffre *et al*., 2000; Turner and Bottrill, 2001; Holm & Berry, 2002) or autochthonous as evidenced by their commonalities in source terrane ages (Black *et al*., 2004a).

3.1.2 Neoproterozoic Units

The Togari Group is restricted to the Rocky Cape terrane and comprises an impersistent basal siliceous conglomerate and sandstone (Forest Conglomerate, Donaldson Formation); a shallow marine dolomite-chert-shale sequence (Black River Dolomite); turbiditic mafic-derived volcaniclastic sandstone (Keppel Creek Sandstone), shale, diamictite (Croles Hill Diamictite) and tholeiitic basalts (Spinks

Creek Volcanics) of the Kanunnah Subgroup; and shallow marine interbedded dolomite and dolomitic limestone (Smithton Dolomite).

Elsewhere in the Rocky Cape Terrane, the stratigraphically younger Burnie Formation is a thick, monotonous sequence of turbiditic greywacke and slaty mudstone with a minor component of mafic pillow lava. A correlate of the formation is the Ooonah Formation, a more varied succession of turbiditic fine - to coarse-grained sandstones, siliceous slaty mudstones, carbonates and conglomerates.

The Arthur Metamorphic Complex is a southwest-trending tectonic lineament of metamorphics, dominated by chloritic schists and phyllites, that lies on the eastern margin of the Rocky Cape terrane.

The youngest Neoproterozoic units in north-west Tasmania are the shallow marine to fluvial Success Creek Group (basal section dominated by siliceous sandstone whilst upper section comprises siliceous siltstone, mudstone, dolomite and chert), conformably overlain by the thick, turbiditic mafic volcaniclastic Crimson Creek Formation. The Barrington Chert in northern Tasmania has also been tentatively correlated with the Success Creek Group (Jennings 1979, Jennings *et al* 1959).

3.1.3 Early Cambrian

At least three ultramafic-mafic complexes have been mapped in western Tasmania (Brown, 1989) along the western margin of the Dundas-Fossey Mountains Trough, related to the initial stages of the Tyennan Orogeny.

3.1.4 Mount Read Volcanics (MRV)

The Mount Read Volcanics (MRV) forms a discrete 10-15 km wide belt proximal to the western and northern margin of the Tyennan Terrane from Elliott Bay in the south to Sheffield/Deloraine in the north. The sequence is economically important as it hosts a number of base and precious metal mines including the Hellyer, Que River, Rosebery, Hercules and Mount Lyell mines. The succession is a diverse suite of basalt-andesite-dacite rhyolite units with abundant interbedded pyroclastics, epiclastics and shale horizons; marked by rapid facies changes and complex internal stratigraphy and structure. The MRV overlaps the Tyennan Terrane margin to the east and interfingers with Cambrian to late Neoproterozoic units in the west. There is a paucity in fossils, outcrop is usually weathered and very poorly exposed, and pervasive alteration is often observed; all of which makes it difficult to describe the dating, evolution of, and the tectonostratigraphic architecture of the sequence.

The Henty Fault System is a major north-northeast trending lineament that divides the MRV with significant differences in stratigraphy and composition across the fault zone. The succession to the west comprises the White Spur Formation and Central Volcanic Sequence (CVS); whilst to the east are the Tyndall Group, Central Volcanic Sequence (CVS) and Western volcano-sedimentary sequence (Figure 7).

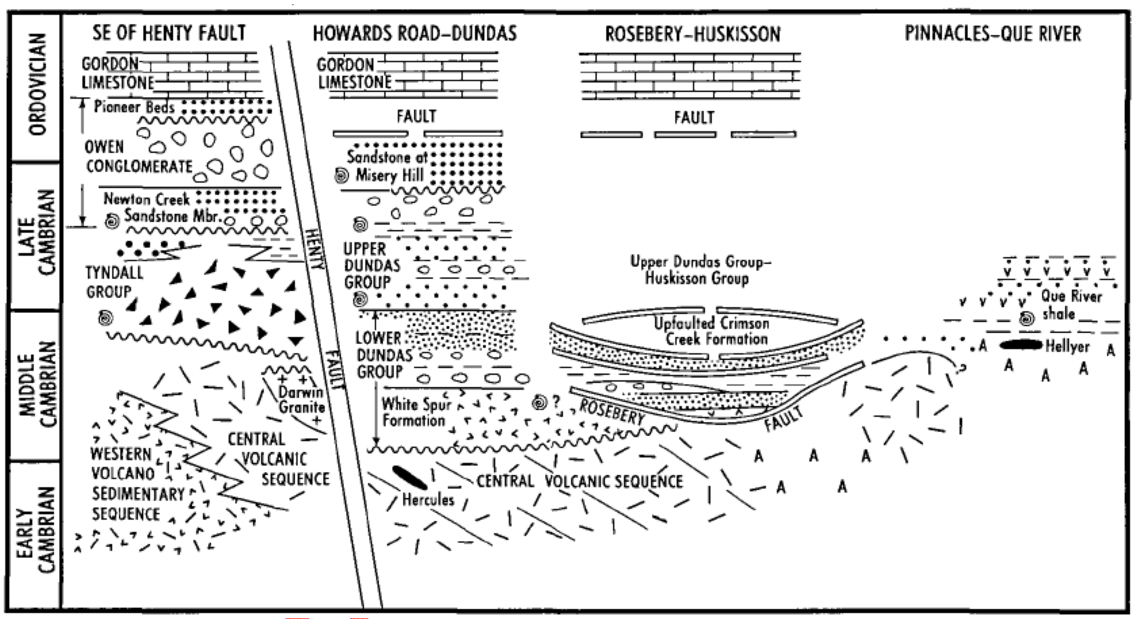


Figure 7: Diagrammatic longitudinal section from Mount Lyell to Que River, showing stratigraphic relationships across the Henty Fault System (from Corbett & Lees, 1987).

Western volcano-sedimentary sequence

This sequence is a thick succession of shale, vitric tuff, volcanogenic turbidites, crystal tuff and minor quartzwacke sandstone. The sequence is seen to both underlie and interfinger with the CVS.

Central Volcanic Sequence (CVS)

The CVS is a rhyolitic to dacite feldspar-phyric lava, pyroclastics and intrusive, with minor epiclastic units and shale. The Darwin Granite intrudes the CVS sequence at Mount Darwin and is reported to have been unroofed and partially eroded prior to deposition of the Tyndall Group (Corbett & Lees, 1987). Dating of the intrusive Darwin Granite yielded a U-Pb age of 510 Ma (Adams *et al.*, 1985), whilst K-Ar dates ranged from 407–528 Ma (Crawford, 1989).

3.1.5 Tyndall Group

The Tyndall Group is the uppermost stratigraphic unit of the MRV, and comprises two main formations: the basal Comstock Formation and the overlying Zig Zag Hill Formation. The Comstock Formation was deposited within a mainly turbiditic realm and is dominated by volcaniclastic sandstones and breccias with common rhyolitic lava and pyroclastic sequences. Minor shallow water carbonates are also a feature. The Zig Zag Hill Formation comprises volcaniclastic conglomerates (pebble to boulder], sandstones rare interlaminated mudstone.

Jago *et al.*, 1972, report late Middle Cambrian to early Upper Cambrian fossils within a limestone horizon near the base of the Tyndall Group.

3.1.6 Dundas Group

The Dundas Group is a diverse sequence; the basal White Spur Formation comprising felsic tuff, siltstone, greywacke and slate. The remaining Dundas Group is not divided into formations. Lithologies include quartzwacke-conglomerate sequences; interbedded siltstone, lithic wacke, mudstone and conglomerate with minor felsic tuffs. The uppermost unit is the Misery Conglomerate, a thickly bedded proximal conglomerate succession. Middle to late Cambrian fossils have been recovered from the sequence (Corbett & Solomon, 1989).

3.1.7 Wurawina Supergroup

The Wurawina Supergroup comprises three main groups: Denison Group, Gordon Group and Eldon Group and ranges from the Late Cambrian-Early Ordovician to Early Devonian.

It is clear from even a cursory look at the literature that the stratigraphic architecture of the Early Palaeozoic successions is confusing and in need of refinement. This is especially evident in the nomenclature of the basal coarse-grained siliciclastic unit of the Denison Group which has historically been based on geographical extent rather than a lithostratigraphic basis. For example, the basal unit is variously known as the Roland Conglomerate, Owen Conglomerate, Reeds Conglomerate, Jukes Conglomerate, Duncan Conglomerate, Dial Conglomerate and Cabbage Tree Formation.

In addition, there has historically been a tendency for authors to 'force fit' the stratigraphic sub-divisions seen in the West Coast Ranges to the northern Tasmanian sections.

3.1.8 Dension Group

The Denison Group comprises a Late Cambrian to Ordovician siliciclastic sequence. The lower section is dominated by massive to poorly bedded conglomerates (pebble through boulder grade) with occasional interbeds of coarse-grained to pebbly sandstone. As mentioned above ,the stratigraphic nomenclature of this conglomeratic sequence has historically been based on geographical extent rather than a lithostratigraphic basis with various names. For the purpose of this report, the unit is referred to as the Owen Conglomerate. Noll and Hall (2003) subdivided the Owen Conglomerate in the West Coast Range into four upward-fining successions of coarse-grained siliciclastic sediments; informally named the basal lower conglomerate member, middle sandstone member, middle conglomerate member and upper sandstone member. The Owen Conglomerate was deposited in an alluvial fan/braided river setting proximal to large extensional bounding faults.

There is a transitional change from the Owen Conglomerate to the Moina Sandstone; a moderately bedded sandstones with common pebble (occasionally cobble grade) conglomerate horizons and infrequent interlaminated siltstones and mudstones. The Moina Sandstone is interpreted to be deposited within a braided river to tidal-influenced transitional marine environment.

The considerable lateral variations in thickness within the Denison Group, especially with respect to the conglomeratic sequence, indicate deposition was within a syn-rift regime with perhaps temporal migration of depocentres.

3.1.9 Gordon Group

The Gordon Group comprises the basal Pioneer beds and overlying Gordon Limestone sequence. The Pioneer beds are pink to grey quartz sandstones and granule-pebble conglomerates with detrital chert clasts that are interpreted to mark the initial onset of a marine transgression recorded over much of northern and western Tasmania. The unit conformably grades into the Gordon Limestone, a micritic limestone interpreted to be a warm-water, shallow-marine, continental shelf environment. Lagoonal mud facies with algal mats and pellet beds are common. There is an increasing dark grey calcareous mudstone component towards the top of the section, an indication of an increasing clastic input to the system.

3.1.10 Eldon Group

The Eldon Group comprises a series of interbedded sandstones (calcareous and quartzose), siltstones and mudstones. The section can be broadly categorised into two fining up sequences; the lower Crotty Formation quartz sandstone and interbedded mudstone, and cross-bedded fine-grained sandstone, siltstone and mudstone of the Amber Formation/Keel Quartzite; and an upper sequence of fine-grained sandstone with minor interbeds of siltstone and mudstone of the Florence Sandstone, and the mudstone-dominated Bell Shale.

3.1.11 Middle Devonian–Early Carboniferous Granites

The Tabberabberan Orogeny is dated at approximately 390 Ma (Black et al., 2004b) and affected much of eastern Australia. This deformational event resulted in the complex structural features seen in north-west Tasmania where reactivation of older lineaments and tightening of fold structures is common.

Whilst large-scale granitoid intrusions in northeastern Tasmania were emplaced prior to, and after, the Tabberabberan Orogeny (400-380 Ma); the granitoids in north-west Tasmania are more spatially restricted and post-date peak deformation (374.8-360 Ma: Black et al., 2004b).

3.1.12 Parmeener Supergroup

Following the Tabberabberan Orogeny, a period of erosion ensued and deposition did not recommence until the Tasmania Basin formed during the late Carboniferous. Approximately 1,500 m of sediments accumulated over 100 Ma (Stacey & Berry, 2004). The basin is divided into two on the basis of lithostratigraphic association and environmental conditions.

The late Carboniferous to Permian Lower Parmeener Supergroup comprised of glaciomarine sediments including mudstone, pebbly mudstone, pebbly sandstone and minor limestone. The Tasmanite Oil Shale is present in the basal section.

The succession is unconformably overlain by Triassic fluviolacustrine sandstone, siltstone, mudstone and coal measures of the Upper Parmeener Supergroup.

3.1.13 Jurassic Dolerite

Middle Jurassic tholeiitic dolerite occurs as large intrusive sills—commonly over 300m thick—and dykes, and covers approximately half of Tasmania (30,000 km^2) with an estimated volume of 15,000 km^3 (Hergt *et al.*, 1989). Much of the dolerite is thought to be associated with a thermal anomaly within the eastern margin of Gondwana. K-Ar dating of five dolerite bodies gave a mean age of 170.5 ± 8 Ma, and it was estimated the dolerites were emplaced over an interval time of less than 20 Ma (Schmidt & McDougall, 1977). This date has since been recalculated to 174.5 ± 8 Ma based on Steiger & Jäger,1977 (Hergt *et al.*, 1989).

3.1.14 Tertiary to Quaternary

The Tertiary sequence in north-west Tasmania is largely undifferentiated and is typically non-marine sand, gravel, silt, clay and regolith. In addition, approximately 250 km^2 of basalt covers north-west Tasmania. The Guildford area of SEL 9/2009 has a significant amount of Tertiary basalt cover sequence.

4. Geothermal Systems Assessment

4.1. Temperature Distributions (T)

The principle aim of geothermal exploration is to locate anomalously high temperatures at an economically and technically viable drilling depth. Temperatures are usually expressed at the surface in the form of heat flow units (mW/m^2) and it is generally assumed that heat is transported to the surface by conductive means. However, this broad assumption would require detailed measurement and modelling which is presently outside the scope of this report.

In a conductive heat regime the temperature **T**, at depth **z** is equal to the surface temperature $\mathbf{T_0}$ plus the product of heat flow **Q** and thermal resistance **R**, such that:

$\mathbf{T=T_0+QR}$, where **R**=**z**/(average thermal conductivity between the surface and **z**).

Consequently, the most highly prospective regions for geothermal exploration are those which have geological units of sufficiently low conductivity (high thermal resistance) in the cover sequence combined with high heat flow.

4.1.1 Surface temperature (T_0)

Bureau of Meteorology records (www.bom.gov.au) indicate that the average annual air temperature of Western Tasmania is between 9-12°C, although regional variations can occur. Average air temperature values often understate the actual rock temperature at surface, which can be up to 4°C above stated average air temperatures (Howard and Sass, 1964). This study utilises a value of 13.5°C for the average surface temperature for generalised modelling, taking in to account probable rock temperature effects.

The topography within SEL 9/2009 can, in part, be rugged. As such, there are large fluctuations in surface air temperature depending on the elevation of the prospect area. Table 1 details climate data from three localities in north-west Tasmania proximal to SEL09/2009. Further weather stations are recorded on the BOM website; however, these have been closed for a number of years and it is inadvisable to use these data in this instance.

Location	Mean annual air temperature (°C)	Elevation (m)
Waratah [Mount Road]	7.95	609
Savage River Mine	10.3	352
Strahan	12.15	21

Table 1: Climate data for three weather stations surrounding SEL09/2009 [source Bureau of Meteorology].

Topographic elevation and the proximity to the coastal fringe results in substantial average temperature variance within the project area. For this reason it is advisable to use the climate station closest to the well site when determining the average annual air temperature of the Dundas-Fossey Mountains Trough.

4.1.2 Temperature measurements

Petroleum wells routinely record temperature data during their drilling and logging procedures, however this is generally not the case with minerals wells.

There are no petroleum wells within SEL 9/2009, or nearby, and known records of down-hole temperature data are presently restricted to some maxi-bore temperature logs from the Renison Bell mine. These data are collected as the directional tool is extracted from the bore hole and are raw values (uncorrected).

The temperature profile for individual Renison Bell bores often shows a characteristic deflection, probably related to the process of tool extraction. This renders temperature analysis by individual well impracticable. Where the combined data for all wells is utilised, a more useful correlation is show, although the absence of circulation data, means that temperatures are still uncorrected.

The raw temperature profile for all Renison Bell wells produces a geothermal gradient of about 39°C/km (Figure 8). It is highly likely that these uncorrected temperatures understate the true thermal regime of the area, as indicated by the extrapolation of the gradient to approximate surface level (8°C). The corrected mean annual surface temperature in the region is ~13.5°C. This variation in surface temperature may suggest that the deeper bore temperature data understate the true temperature regime. The light blue line in Figure 8 shows the same gradient but with a surface intercept at 13.5°C.

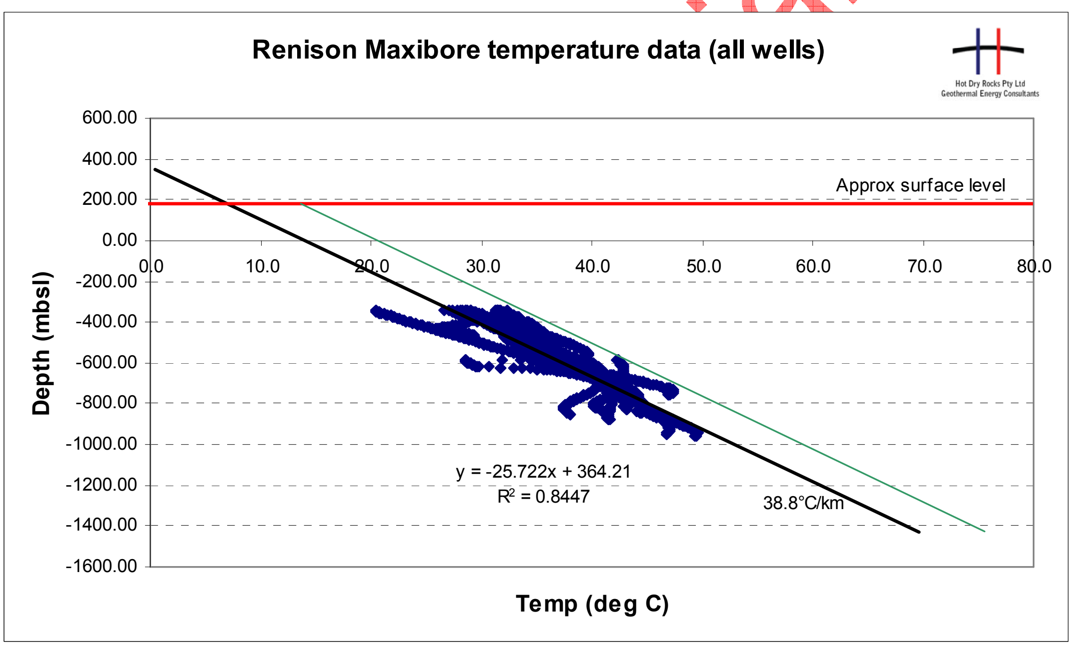


Figure 8: Temperature profile for all Renison Bell bores based on maxibore data. The indicated geothermal gradient (black line) is 38.8°C/km. The light blue line represents the same gradient using a surface intercept of 13.5°C. The maxi-bore temperatures are uncorrected and probably under-state the true temperature.

It is however possible that the individual maxima recorded from the maxi-bore logs may be more representative of formation temperatures. Consequently these maxima were extracted and used for heat flow modelling and temperature projections (Section 4.3).

Precision temperature logs are a powerful tool for understanding the true thermal state of a well and its geothermal potential. Precision temperature logging requires a thermistor to descend a well in a controlled manner so that changes in electrical resistance across the thermistor can be monitored and recorded at sub-metre intervals. A properly calibrated thermistor is capable of measuring temperature to a precision of 0.001°C. There are a large number of minerals bore holes within SEL9/2009 drilled since 1990 and at least 100m deep or greater (Figure 9). These bores may be principle targets for temperature logging (HDRPL's temperature winch has a capacity to 1000m).

Recommendation: *that all available bore holes with core, greater than 100 m in depth and that are open be identified (Figure 9). HDRPL can then collect temperature data using the precision temperature logging unit and determine heat flow values. The resultant data can then be used to focus geothermal exploration.*

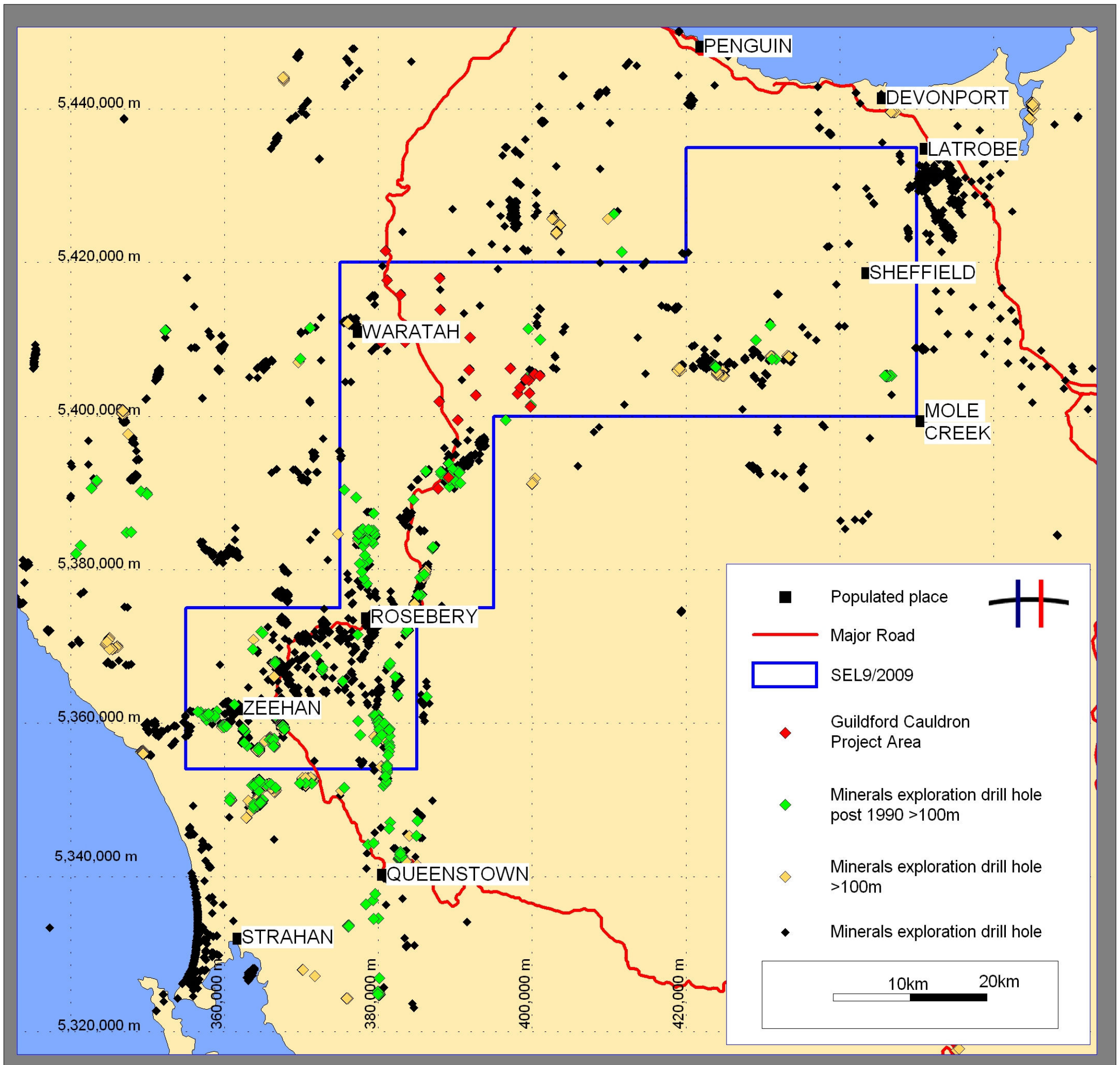


Figure 9: Location map of historic mineral exploration drill holes located in the Dundas region. Note Guildford Cauldron wells marked in red.

4.1.3 Rock thermal conductivity measurement (λ)

Thermal conductivity is the physical property that controls the rate at which heat energy flows through a material in a given thermal gradient. In the S.I. system of units, it is measured in watts per metre-Kelvin (W/mK). In the earth, thermal conductivity controls the rate at which temperature increases with depth for a given heat flow. The thermal conductivity distribution within a section of crust must be known in order to calculate crustal heat flow from temperature gradient data, or to predict temperature distribution from a given heat flow.

HDRPL has undertaken rock thermal conductivity studies over much of eastern and central Tasmania, however, the results are presently confidential. Thermal conductivity values, for a limited number of samples, for various lithologies in western Tasmania have been reported in the published literature, and these have been utilised to assist in estimating possible conductivity ranges for this study. However, as these historical data were not measured by HDRPL and are not specific to SEL9/2009, it is not possible to comment on the veracity of the measurement process, nor on the results. The vintage of these data should be acknowledged (1953 and 1963), as well as the bias in sample data towards Cambrian felsic volcanics, and Jurassic dolerite.

The structural complexity of north-west Tasmania has been discussed previously in this report. Recent laboratory analysis by HDRPL has demonstrated that thermal conductivity is very sensitive to rock anisotropy such as cleavage and bedding-plan angle.

Recommendation: *It is recommended that representative samples from selected formations in the Dundas-Fossey Mountains Trough be collected in order to undertake thermal conductivity measurements. It is probable that the use of vintage and generic thermal conductivity data will result in considerable errors in heat flow modelling, and adversely affect the geothermal exploration risk.*

4.1.4 Heat Generation (A)

Heat generation is a physical property of rocks determined from the elemental concentrations of U, Th and K and also incorporating rock density. It is reported in micro-Watts per cubic metre ($\mu W/m^3$). It is often viewed as a critical indicator if geothermal prospectivity in Australia. In reality heat generation, as a measure in itself, has no direct bearing in prospectivity as it simply reflects one input into crustal heat flow. Heat generation, plus other considerations such as thermal resistance and mantle heat flow, need to be combined in a heat flow model to accurately determine both heat flow and predict temperature. It is however reasonable to assume that high heat generating granites may be associated with areas of elevated heat flow.

Heat generation is best determined from the analytical measurement of uranium, thorium and potassium within rock samples. HDRPL has previously interrogated and performed a quality check on the Geoscience Australia geochemical database (OZCHEM).

The quality checked OZCHEM dataset has been combined with data collected during a ground gamma-ray spectrometry study of Tasmanian granites by MRT in 1981. A colour contour map of heat generation on north-west Tasmania is shown in Figure 10 and indicates that much of SEL9/2009 has high heat generating rocks. Consequently it may be reasonable to expect that heat flow throughout much of the area is also equally elevated, although the exact values of heat flow are yet to be determined.

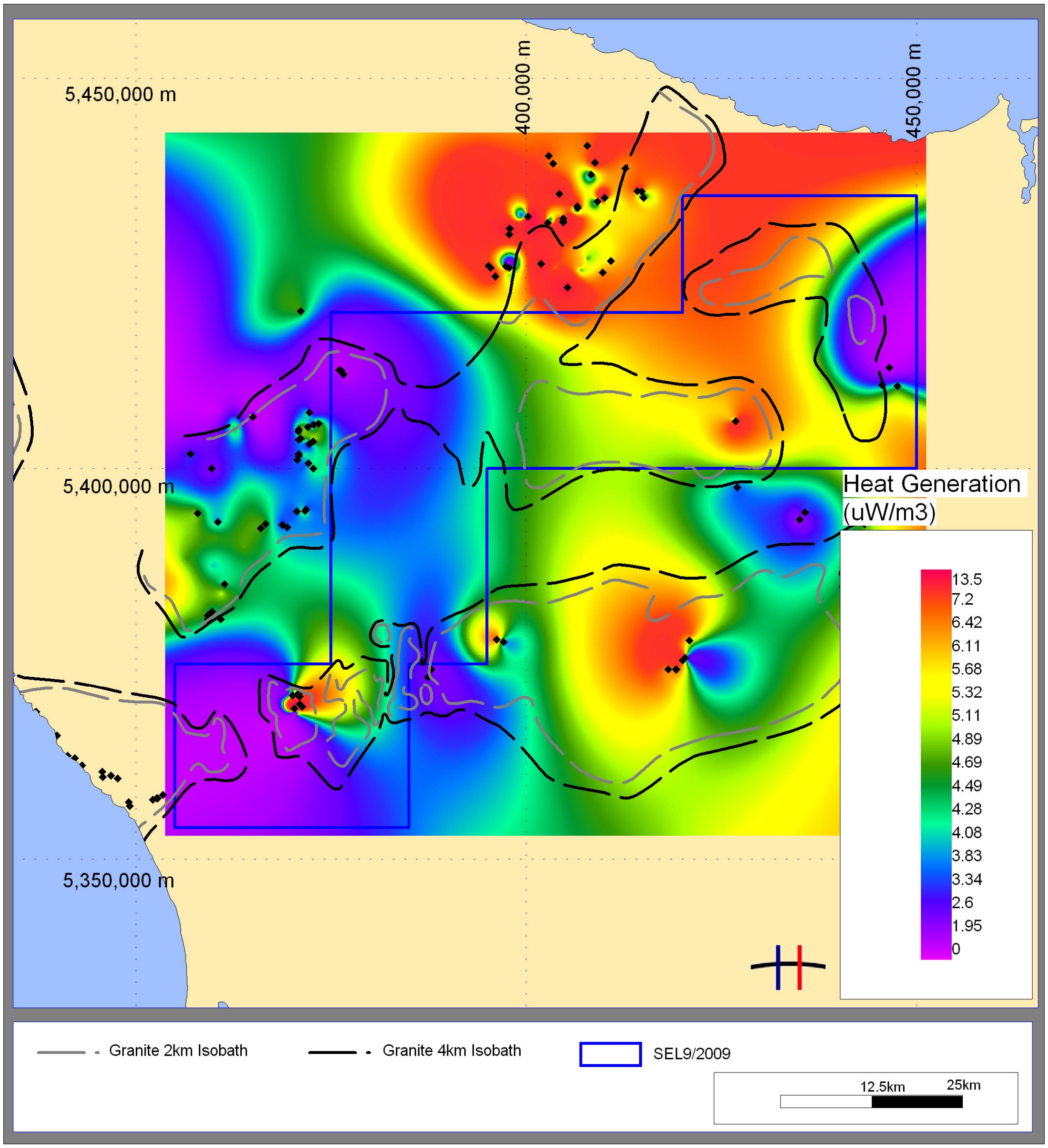


Figure 10: Colour contour map of heat generation (uW/m^3) and granite isobaths (2 and 4 km) for north-west Tasmania showing 'hot spots'. It should be noted the contours are derived from limited data density.

The GA elemental geochemistry data suggest that heat generation potential for some granites in western Tasmania are significantly elevated compared with other areas of Australia. The Birthday, Heemskirk (red), Housetop and Renison granites have average values of 7.17, 7.26, 7.74 and 8.27 μW/m^3 respectively. Some of these granites have maximum values in excess of 10µW/m^3. In comparison, it has been assumed, for modelling purposes, that the Big Lake Suite granite in the Cooper Basin of South Australia has average heat generation of ~10µW/m^3, although whole rock geochemical data from the Habanero-1 well completion report suggests that the granite target in this well has a heat generation of ~7.3µW/m^3. This is much the same as the average heat generation of the Coles Bay Granite in eastern Tasmania (Figure 11).

Recommendation: *further validation of heat generation in SEL9/2009, via geochemical data from hand specimen or core samples may benefit future heat flow modelling. Whole Rock Fusion [WRF] analysis of outcrop or core samples is a fast an inexpensive means of determining heat generation.*

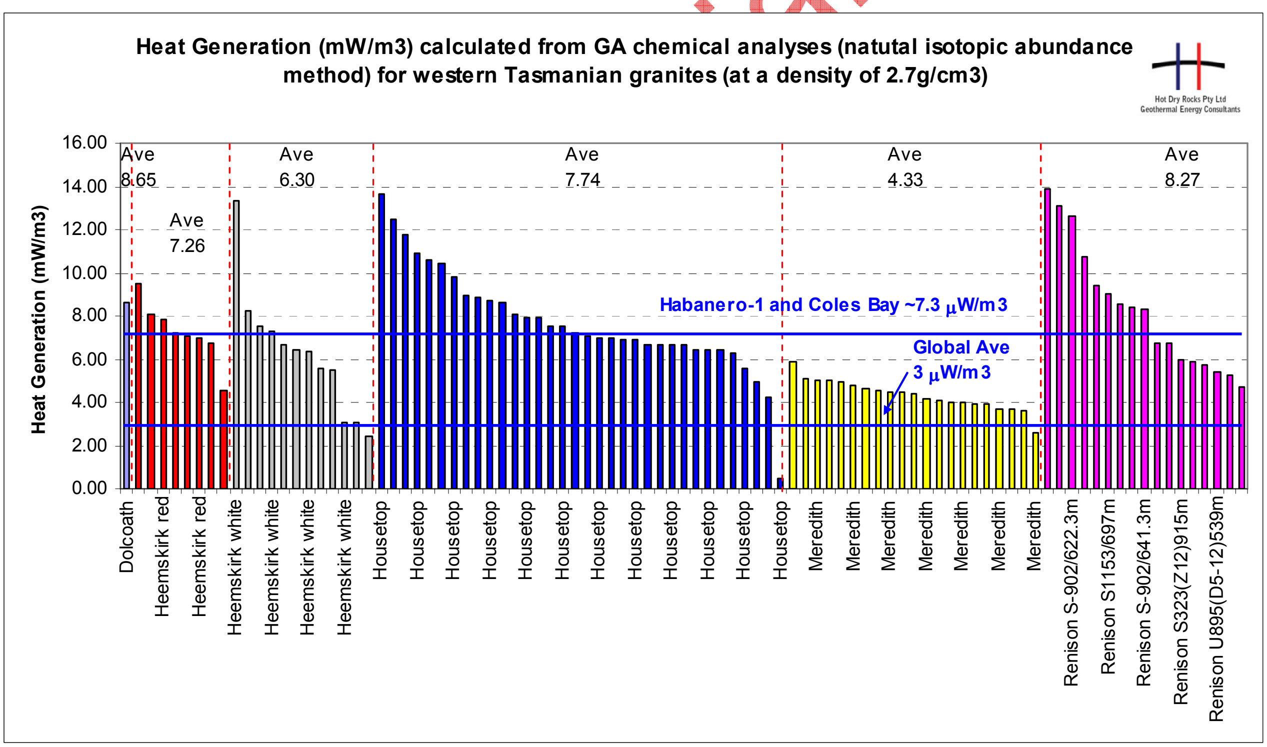


Figure 11: Histograms of calculated heat generation (uW/m^3) for western Tasmanian granites based on GA OzChem database geochemistry data. Many granites in western Tasmania have heat generation which is equivalent to, or exceeds, heat generation values from the Cooper Basin (South Australia).

4.1.5 Heat Flow (Q)

Heat flow modelling provides a firm basis for accurate extrapolation of temperatures to depth, as it takes the thermodynamic principles of heat transfer into account. Heat flow is a product of temperature gradient and rock thermal conductivity and is therefore a modelled value (not directly measured). The modelling of heat flow is a precision skill that requires a detailed understanding of physical conditions in the bore hole and the physical properties of the rocks; including advective processes that may influence bore temperature (such as ground water flow) and the temperature dependence of conductivity.

Heat flow estimates are only as accurate as the data that have been used to generate them. It is therefore important that the temperature and conductivity data used to model heat flow represent as closely as possible the actual thermal conditions.

Heat flow is a power unit expressed at the Earth's surface (mW/m^2) and is a function of heat generated within the crust plus heat conducted from the mantle. A review of measured heat flow data for Tasmania from the Global Heat Flow Database (http://www.heatflow.und.edu/index2.html) shows very limited information (five locations) of which just one location is within north-west Tasmania (Rosebery). These locations and their respective heat flow values are shown in Table 2.

Between 2007 and 2009, KUTh Energy Ltd drilled 35 shallow heat flow wells in eastern Tasmania, of which 34 yielded heat flow values as modelled by HDRPL. Whilst not directly applicable to SEL9/2009, these values in eastern Tasmania, also underlain by Devonian granite, reached a maximum of 119 mW/m^2 with an average of 84 mW/m^2. This is consistent with most of the reported values from the Global Heat Flow database, suggesting that Tasmania, in general, has elevated heat flow (Figure 12).

Site	Heat Flow (mW/m^2)	Year of Publication
Great Lake	80	1963
Great Lake/Dee	83	1982
Rosebery	104	1982
Storey’s Creek	159	1963
Glenorchy	87	1977
Olga Ridge	57	1977

Table 2: Heat Flow values from global heat flow database

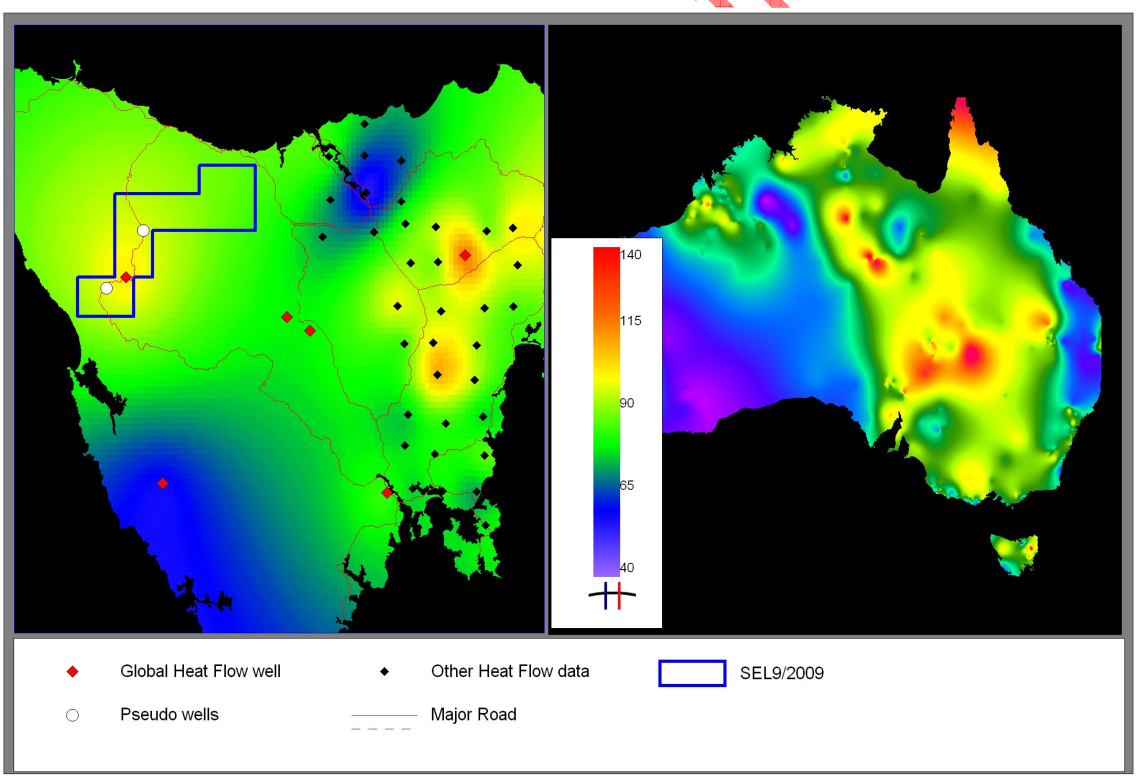


Figure 12: HDRPL Heat Flow Map of Australia showing subset of data for Tasmania. Most of Tasmania has elevated heat flow with an average of 84 mW/m^2. Position of SEL9/2009 and two pseudo heat flow wells is also shown.

4.2. Thermal Resistance (R)

Thermal resistance is synonymous with the "trap" and "seal" concepts of petroleum systems analysis. Thermal resistance (m^2K/W) is the cumulative sum of overburden thickness (m) divided by thermal conductivity (W̃/mK). A geothermal prospect must have an adequate "thermal blanket" to retain heat at depth. This is best provided by a thick sequence of low conductivity lithologies, in particular shales, mudstones and coals.

As there are no measured conductivity values specific to SEL9/2009, the exact thermal resistance of the area is unknown. However by adopting values, as approximations, from published literature and using HDRPLs experience, some first-pass assumptions of thermal resistance have been made in this study.

Stratigraphic profile data from the Renison Mine (Morland, 1990) and in the Waratah-Guildford region (Burrett and Martin, 1989; McKay, 1991) were used to construct pseudo wells for these locations (Figure 12 and Section 4.3). Heat flow models for these pseudo wells were populated with estimated rock thermal conductivity data. The estimated thermal resistance of the Renison Mine pseudo well is **~370 m^2K/W** for the first kilometre. This value lower than recorded values of thermal resistance for the Cooper Basin succession (Beardsmore, 2004), and may suggest that thermal resistance in SEL9/2009 may have elevated risks due to rock anisotropy, unless heat flow is sufficiently high to counter the influence of low thermal resistance.

The Guildford pseudo-well has an estimated thermal resistance of **~1450 m^2K/W** for the upper 3km. This is value is somewhat greater, on a kilometre basis, than at Renison, due to the presence of Tertiary sedimentary rocks and basalts, of probable lower conductivity. This value is also closer to expected values for the Cooper Basin at a similar depth (~1600 m^2K/W) and suggests that thermal resistance risks in the Guildford area are probably lower than elsewhere in SEL9/2009.

However it is emphasised that this assessment is based on approximated rock thermal conductivity values and this assessment may change considerably after measured data are acquired.

4.3. Temperature Projection

1D heat flow models were created, using estimated rock thermal conductivity values and available stratigraphic information from cross-sections and bore hole data, for the Renison Mine site and the Waratah-Guildford region. The positions of the pseudo-wells are shown on Figure 12, and the values used for modelling, and the source of the data, are shown in Table 3 and 4.

Formation	Lithology	Depth	Estimated Conductivity
Well Top		0	0
Tertiary basalt	basalt	120	2
Tertiary Sediments	silty sediments	130	2.7
	basalt	220	2
	sediments and glassy breccia	270	3
	basalt	320	2
	sediments and glassy breccia	350	2.7
Eldon Group	Shale, quartzite and slate	1150	2.4
Ordovician Gordon Group	bedded grey micritic, layers dark dolomitic silt	2050	4
U. Cambrian Owen Group	conglomerate, quartzie, sandstone and shale	2950	3.3
Cambrian Tyndall Group	felsic volcaniclastics, slates, granite and conglomer-ate	3900	3.1
MRV correlate – cambrian volcanics	thinly bedded turbidites, siltstone	4050	2.5
	felsic volcaniclastics, med grained	4100	3.3
	felsic pumiceous tuff - breccia	4110	3.5
	black siltstone	4120	2.1
	feldspar phyric andesite	4130	2.5
	aphyric andesite	4150	2.5
	andesitic breccia - med coarse grained mass flow, containing blocks aphyric andesite	4190	2.4
	aphyric andesite, some zones auto breccia	4250	2.5
Eo - Cambrian	greywacke, mudstone, quartzwacke, conglomerates	4300	2.3
Granite	Granite	4400	3.41

Table 3: Depths and conductivity inputs (median case) based on lithology descriptions (MRT UR2002/15, Burrett and Martin 1989, McKay 1991, UR 1990/05, UR1987/44) for the Guildford-Waratah pseudo well.

Formation	Lithology	Depth	Estimated Conductivity
Well top		0	0
Dreadnought Hill Member	Proterozoic siltstone, mudstones, tuffs, tuffaceous sediments and cherts	200	3
Dolomite No.1	Laminated dolomite, locally sandy	225	4.5
Red Rock Member	Conglomerates, cherts, tuffs, minor shales and sand-stones	260	2.8
Dolomite No.2	Laminated sideritic dolomite	290	4.5
Silty sandstone unit	Silty sandstone	295	2.8
RB2	Dolomite, sandy	305	3.5
Renison Bell Member 1	Siltstone, shales, sandstone, quartzite, dolomite	340	3
RBP Member	pebbly sandstone	345	3.1
Renison Bell Member 2	Siltstone, shales, sandstone, quartzite, dolomite	375	2.8
Dolomite No. 3	Stylolitic laminated sideritic dolomite	385	4.5
Dalcoath Member	Siltstone, shales, sandstone, quartzite, dolomite	1250	3
Pine Hill (Devonian) Granite	Granite	1350	3.41

Table 4: Depths and conductivity inputs (median case) based on lithology descriptions (Morland R, 1990) for the Renison Mine pseudo well.

As rock thermal conductivity data are poorly constrained in SEL9/2009 and due to the probable influence of rock anisotropy in Mid-Palaeozoic and Proterozoic rocks in Tasmania, an upper, median and lower range of conductivities was used to model the possible variance in temperature distribution.

The Renison model assumes a heat flow of 104 mW/m^2 as per the nearest recorded value from the Global Heat Flow database (Table 2). The maxima of measured temperature from the maxi-bore data (Figure 8) were extracted from the logs and used to constrain the heat flow model. For the median-case conductivity profile, the maxi-bore temperatures agreed well using a heat flow of 104 mW/m^2. This may suggest that the assumptions of the model are reasonable, although this can only be verified after detailed sampling and measurement. Devonian granite is intersected in the area at ~1350m depth, so whilst this would not necessarily be regarded as a viable geothermal drilling site, the model provides some useful constraints on the likely thermal properties of the region.

The median conductivity profile (B) suggest that the 150°C isotherm may be intersected at about 4300m depth (Figure 13). However the high conductivity profile (A) and the low conductivity profile (C) suggests that considerable variation in target depths may be expected, depending on the measured rock thermal conductivity data.

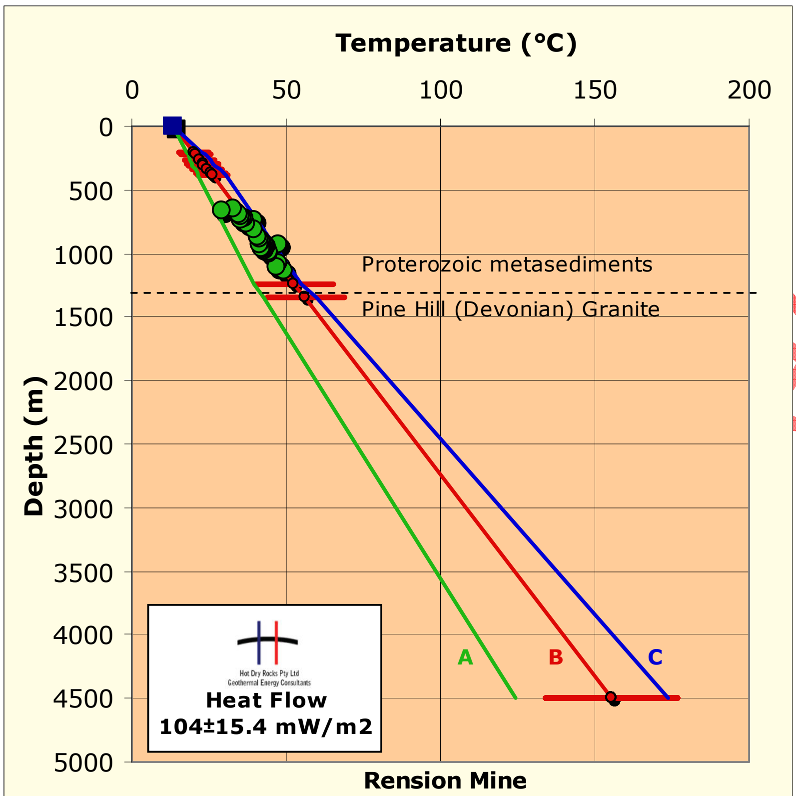


Figure 13: Pseudo well model for the Renison Mine area based on estimated stratigraphy from Morland (1990). Position is shown on Figure 12. Three cases are shown for a high conductivity (A), median conductivity (B) and low conductivity (C) profile. The median conductivity profile at 104 mW/m^2 suggests that the 150°C isotherm will be intersected at about 4300m depth. Most notably, the median conductivity case agrees well with the temperature maxima extracted from the maxi-bore logs (green dots).

The Waratah-Guildford model is located in a thick section of the Dundas Trough and is based on stratigraphic data derived from well completion reports for UR1990/05, UR1987/44 and UR2002/15 as well as cross-section data from McKay (1991) and Burrett and Martin (1989). Again rock thermal conductivity values are poorly constrained for the area, so three profiles (high, low and median conductivity) have been tested (Figure 14). In the absence of either temperature or heat flow data for the area, the model assumes a heat flow of 90 mW/m^2, consistent with the low end of the standard deviation from the Renison model and close to average for all Tasmanian values. Although unconstrained, this heat flow value is probably conservative for the area.

The median conductivity profile (B) for the model suggests that the 150°C isotherm may be intersected at ~4000m depth. The high and low conductivity profiles (A and C respectively) would suggest that the 150°C may be between ~3500 and 4500m depth. In this particular model this isotherm would be consistent with the Lower Owen Group and the Mount Read Volcanics (MRV). The influence of low conductivity basalt in the upper section of the model is distinct, pushing the shallow isotherms higher (Figure 14).

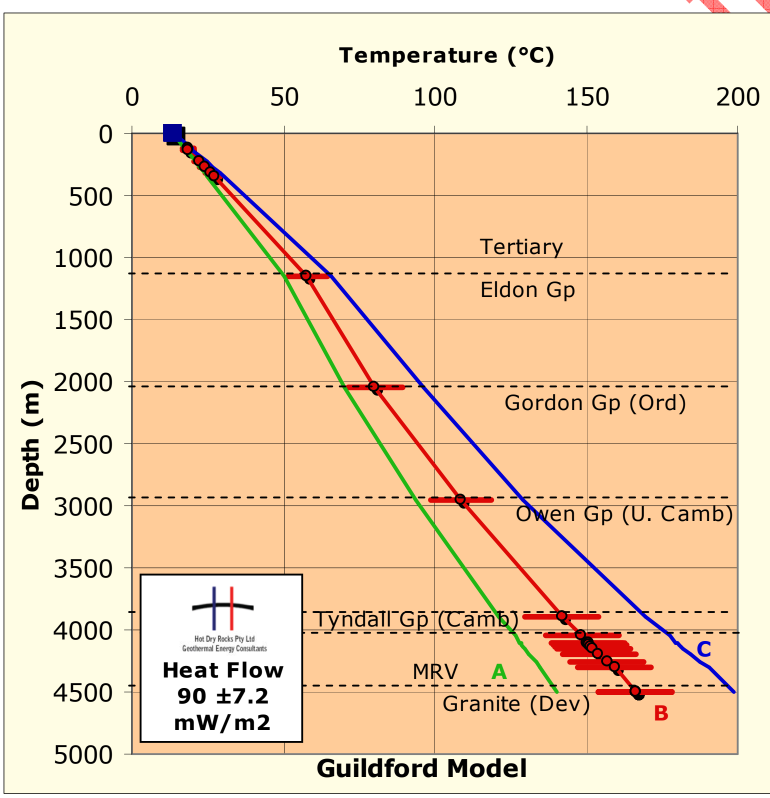


Figure 14: Pseudo well model for the Waratah-Guildford area based on estimated stratigraphy from multiple sources. Position is shown on Figure 12. Three cases are shown for a high conductivity (A), median conductivity (B) and low conductivity (C) profile. The median conductivity profile at 90 mW/m^2 suggests that the 150°C isotherm will be intersected at about 4000m depth.

4.4. Heat flow and thermal resistance conclusions

In the absence of precision temperature data throughout western Tasmania the acquisition of new temperature data will be a critical component of future work programs. However available data at Renison suggests that the only heat flow value within the tenement (104mW/m^2) is consistent with the regional geology and presence of high heat generating granites.

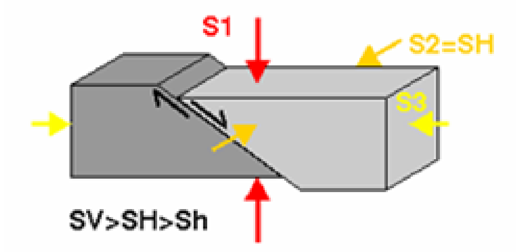
The absence of rock thermal conductivity data specific to SEL9/2009 means that risks associated with thermal resistance in the tenement are poorly constrained. The nature and influence of anisotropy, such as cleavage, on rock thermal conductivity will be critical in mitigating risks. However based on assumptions from regional conductivity data, it seems reasonable to suggest, based on the analysis in this report, that the 150°C is likely to lie between 3500 and 4500m depth in most parts of the tenement.

4.5. Reservoir

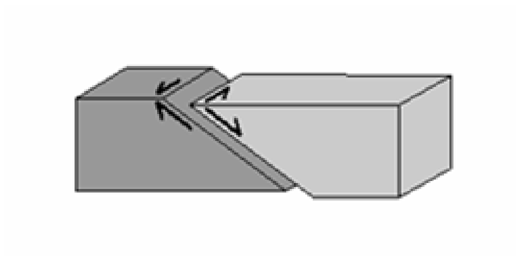
4.5.1 The relationship between in situ stress fields and EGS

The successful development of an EGS is dependent upon several factors, but one of the most critical factors is the response of the fractured rock mass to the influence of the *in-situ* stress field. Stress-dependant permeability of deep-seated, fractured rocks is well documented in studies relating to both hydrocarbon and geothermal reservoirs as well as nuclear repositories (e.g. Gentier *et al*., 2000; Hillis *et al*., 1997; Hudson *et al*., 2005). In particular, *in-situ* stress fields are known to exert a significant control on fluid flow patterns in fractured rocks with a low matrix permeability. For example, in a key study of deep (>1.7 km) boreholes, Barton *et al*. (1995) found that permeability manifests itself as fluid flow focussed along fractures favourably aligned within the *in-situ* stress field, and that if fractures are critically stressed this can impart a significant anisotropy to the permeability of a fractured rock mass. Preferential flow occurs along fractures that are oriented orthogonal to the minimum principal stress direction (due to low normal stress), or inclined ~30° to the maximum principal stress direction (due to dilation).

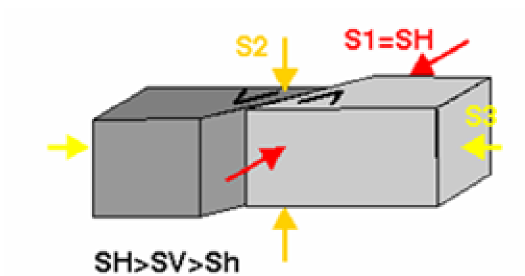
Knowledge of both the local and regional-scale stress regime is important in order to understand the effects of stress-dependent fracture permeability and, in EGS operations, potential reservoir growth and flooding directions under hydraulic stimulation. In general, stress fields are anisotropic and inhomogeneous. They are defined in simplified terms by three mutually orthogonal principal axes of stress, being the maximum (S_1), intermediate (S_2) and minimum (S_3) stress axes. In practice, the classification of far-field stress regimes is based upon the Andersonian scheme, which relates the three major styles of faulting in the crust to the three major arrangements of the principal axes of stress i.e. the vertical principal stress (S_V) and the maximum and minimum horizontal principal stresses (S_H and S_h, respectively) (Anderson, 1951). These three major stress regimes are: (a) the normal faulting stress regime where $S_V > S_H > S_h$; (b) the strike-slip faulting stress regime where $S_H > S_V > S_h$; and (c) the reverse (or thrust) faulting stress regime where $S_H > S_h > S_V$ (Figure 15). The determination of the local stress field is important as the theory of stress-dependent fracture permeability predicts enhanced permeability associated with critically stressed faults or fractures that are either undergoing dilation (~parallel to S_1) or shear reactivation (<45° to S_1) under the influence of the contemporary stress field.



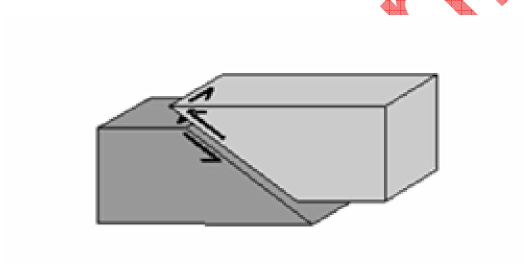
NF: Normal faulting



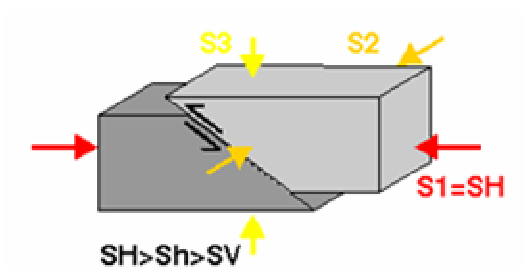
NS: Predominately normal faulting with strike-slip component



SS: Strike-slip faulting
(includes minor normal or thrust component)



TS: Predominately thrust faulting with strike-slip component



TF: Thrust faulting

Figure 15: The World Stress Map stress regime classifications (NF, NS, SS, TS, TF) and their associated styles of faulting (from Heidbach *et al*., 2008).

4.5.2 Contemporary Stress Field of Tasmania

As part of this GSA, a search for contemporary *in situ* stress field data in Tasmania failed to find any publicly available datasets. The World Stress Map shows the closest stress field indicators are located within the Bass Basin, although, these were interpreted from four-arm dipmeter logs (borehole breakouts) with considerable scatter and are considered to have a certain degree of uncertainty (Figure 16; Heidbach *et al.*, 2008; Nelson *et al.*, 2006). Furthermore, borehole breakout data only provides 2D information on the orientation of S_H. Therefore, the state-of-stress of Tasmania is currently unresolved, however, evidence exists that suggests that Tasmania is currently seismically active similar to that documented for mainland SE Australia (Figure 10; Hillis and Reynolds, 2000; Nelson *et al.*, 2006; Sandiford *et al.*, 2004). This present-day seismic activity was initiated by coupling and/or convergence between the Pacific and Australian plates during the late Miocene period (<6 Ma) (Hillis and Reynolds, 2000; Sandiford *et al.*, 2004). In addition to earthquake records, other possible evidence cited for contemporary seismic activity includes Late Quaternary reactivation of large fault structures in SW Tasmania. For example, the Lake Edgar Fault in SW Tasmania has been interpreted as an originally Cambrian-age fault that was been reactivated several times since the Late Quaternary-Holocene period (McCue *et al.*, 2003). In particular, the Lake Edgar Fault is an approximately north-trending, westerly dipping fault that has experienced recent reverse-style movement and vertical displacement suggesting that it is under the influence of approximately east-west horizontal compression (S_H?) (McCue *et al.*, 2003).

Possible alternative sources of *in situ* stress field data for SEL9/2009 includes: (1) local mine-based data associated with standard mine site geotechnical investigations; (2) Hydro Tasmania who should have a long record of passive earthquake monitoring of their dam sites; and (3) re-processing and interpretation of earthquake focal mechanism data (Figure 16; note the vintage of the data is unknown). Of these three alternatives, the first two possible sources may be less reliable stress field indicators if the measurements are collected at shallow depths (<700m below surface) and/or in close proximity to mine or dam workings although large numbers of data points over a wide area may be adequate. In regards to earthquake focal mechanism data, these are considered to be a reliable indicator of the far-field stress regime and orientation (no magnitude) if a sufficient number of data points exist.

Recommendation: *In situ stress field data listed above be acquired and checked for quality. Once this data has been obtained HDRPL will be in a better position to perform further stress field analyses.*

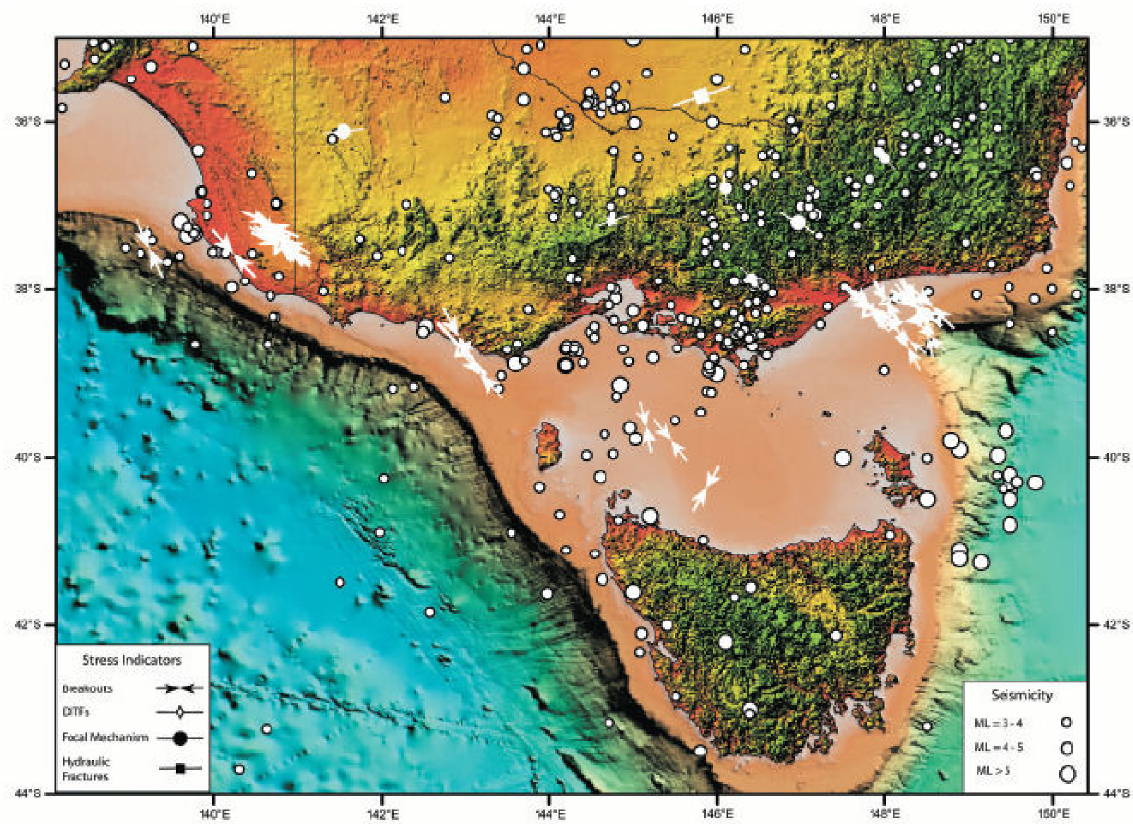


Figure 16: Location of earthquakes of magnitude three or greater that have occurred in SE Australia since 1960 (Nelson et al., 2006).

4.5.3 Potential EGS Reservoir Rock Types

A summary of the potential rock types within SEL9/2009 is provided in Section 3, which describes a diverse suite of Mesoproterozoic- to Jurassic-age metamorphic, volcanic, intrusive, volcano-sedimentary and sedimentary rock types. It is important to note that the reservoir characteristics of these rock types described below are inferred from only a minimal amount of data and that the basement geology is largely also inferred. Due to the geological complexity, a more thorough investigation involving rock and core sample collection, geomechanical analyses and/or numerical modelling would provide a more definitive characterisation, particularly, if a more specific target site has been identified.

The key features of the rock types relevant to the development of an EGS reservoir in SEL9/2009 are as follows:

a. The Mesoproterozoic to Neoproterozoic Tyennan, Forth and Rocky Cape terranes, surround and presumably underlay SEL9/2009 although this needs to be confirmed. These terranes are composed of a mixed succession of variably metamorphosed quartzarenites, pellites and volcano-sedimentary sequences. Similarly, the entire younger overlying Early Cambrian to Late Carboniferous sequences consist of a mixed interbedded sequence of sedimentary, volcanic, volcano-sedimentary and carbonate sequences.

b. These Proterozoic basement rocks and overlying Palaeozoic sequences represent an interlayered, geomechanically inhomogeneous rock mass. The potential for such a sequence to host an EGS type play is yet to be demonstrated, although this model is presently being tested by Petratherm Ltd at Paralana. Potential risks may include: (1) the less competent rock types (relative to massive crystalline rocks) may develop weak fractures with low shear strengths and poor hydromechanical coupling; (2) the potential for local stress field perturbations associated with an interbedded sequence of contrasting rock types and/or proximity to major basin faults; and (3) an increased risk that hydraulic stimulation may favour a relatively weaker unit within the overall sequence (i.e. a preferential short-circuit). These rock sequences are likely to contain a relatively higher inherent *in situ* permeability due to their relatively high density of bedding planes and jointing. Potentially, this is a favourable characteristic, which may result in relatively easier reservoir development and exploitation. However, reservoir development may also prove more difficult to constrain, with a higher risk of fluid losses.

c. If geochemically reactive rock types are present within the Palaeozoic sequences, these should be avoided to lessen the risk of long-term operational problems such as well bore and plant scaling and corrosion. The geochemistry of units such as the Gordon Group Limestone should be investigated.

d. Major basin and rift related fault structures exist within SEL9/2009 that may act as relatively more permeable fluid conduits. It is recommended that all major fault structures at depth be avoided to lessen the risk of opening up a preferential fluid pathway that may short-circuit the reservoir. Relatively high permeability faults can dominate a flow system and may achieve higher production flow rates but the decreased fluid residence and wall rock contact time results in lower temperature fluids at the production well head. Ideally, the reservoir should consist of a large volume of high density, interconnected, **small** fractures that allow the fluid to achieve a sufficient fluid-rock contact time to heat up.

e. The Cooper Basin granite-hosted EGS reservoir recently developed by Geodynamics has the approximate dimensions of approximately 3 km (long) x 3 km (wide) x 0.1 km (thick). Geodynamics now plan to increase the thickness to 1km to attain commercial flow rates. It is estimated that a commercial electricity operation in SEL9/2009 will require at least a similar sized development. Within the diverse range of interlayered sequences, a reservoir of this size is likely to capture multiple different rock units and several fault structures as described above.

f. The interlayered metamorphic, sedimentary and volcano-sedimentary sequences represent a relatively inhomogeneous, low permeability and possibly low competency rock mass, however, recent innovations and experience with developing “tight gas” reservoirs in rock sequences of similar properties by the petroleum industry indicates that reservoir stimulation within these types of rock sequences is possible. If successful, this will not only open up large areas along strike for future EGS development but will also make a great technical advance in the potential to develop EGS over a greater range of rock types.

g. In comparison, the Middle Devonian to Early Carboniferous granites potentially offer a lower technical risk if they occur as large, massive competent rock masses. As this granite suite intruded into north-west Tasmania post-Tabberabberan Orogeny they are more likely to be relatively undeformed. The potential advantages of massive crystalline rock types include: (1) easier to constrain reservoir growth development during hydraulic stimulation; (2) lower probability of significant fluid losses; (3) competent rock types tend to develop strong rough fractures with high shear strengths and good hydro-mechanical coupling; and (4) the development of an EGS in granites has already been demonstrated (e.g. Cooper Basin, Soultz). The potential disadvantages include: (1) may require high injection pressures to open fractures and sustain high fluid volume circulation; (2) may experience high flow impedance and poor circulation; and (3) high injection pressures may increase the risk of runaway reservoir growth, flow path short-circuiting and fluid loss.

h. The Jurassic dolerite intrusions are not considered a viable EGS reservoir target due to their unpredictable geometries and thicknesses. It is unlikely that Jurassic dolerites will occur within the target isotherm.

4.5.4 Summary of the stress state in Tasmania

The state-of-stress of Tasmania is currently unresolved, however, evidence exists which suggests that Tasmania is currently seismically active similar to that documented for mainland SE Australia. This issue may be resolved by obtaining *in situ* stress data from previously identified local sources.

The geomechanical reservoir characteristics of the contrasting and interlayered Proterozoic and Palaeozoic sedimentary and volcano-sedimentary sequences presented above do not present a typical EGS-style target. EGS experience elsewhere in the world has demonstrated that hydraulic stimulation and reservoir development can be successfully achieved in large volume, ~homogeneous, competent, brittle rock types such as granite. In this regard, the Middle Devonian to Early Carboniferous granites present a more "traditional" and lower technical risk EGS-style target. There are no known examples of successful EGS development within a layered sedimentary or volcanic sequence of varying hydromechanical properties. Although sedimentary rock hosted EGS Plays are being promoted by other Australian geothermal companies these remain untested. Recent innovations and experience with developing tight gas reserves in the oil and gas industry indicate that this is achievable and this presents an opportunity to make a significant technological advance in EGS developments.

4.6. Water

4.6.1 Water access

With regards to geothermal plays, the availability of water can only be assessed on a case-by-case basis when more detail is available regarding the location of specific prospects. The actual water needs of a proposed EGS project changes with each stage of its development. An indication of the water requirements for an EGS project was recently compiled by HDRPL on behalf of Primary Industries and Resources, South Australia (PIRSA) and can be accessed online at:
http://www.pir.sa.gov.au/__data/assets/pdf_file/0018/110556/TIG_4_PIRSA_Water_Project_26May09.pdf

In Tasmania, the authority responsible for the granting of surface and groundwater licences and extraction allocations is the Department of Primary Industry, Parks Water and Environment (DPIPWE). Furthermore, Tasmania has been sub-divided into eight designated water management regions and SEL9/2009 straddles the Arthur-Pieman, Mersey-Forth and partially the Inglis-Cam water management regions (Figure 17). Whether permits are sought for either surface or ground water licences and allocations will depend on the final location of specific prospects.

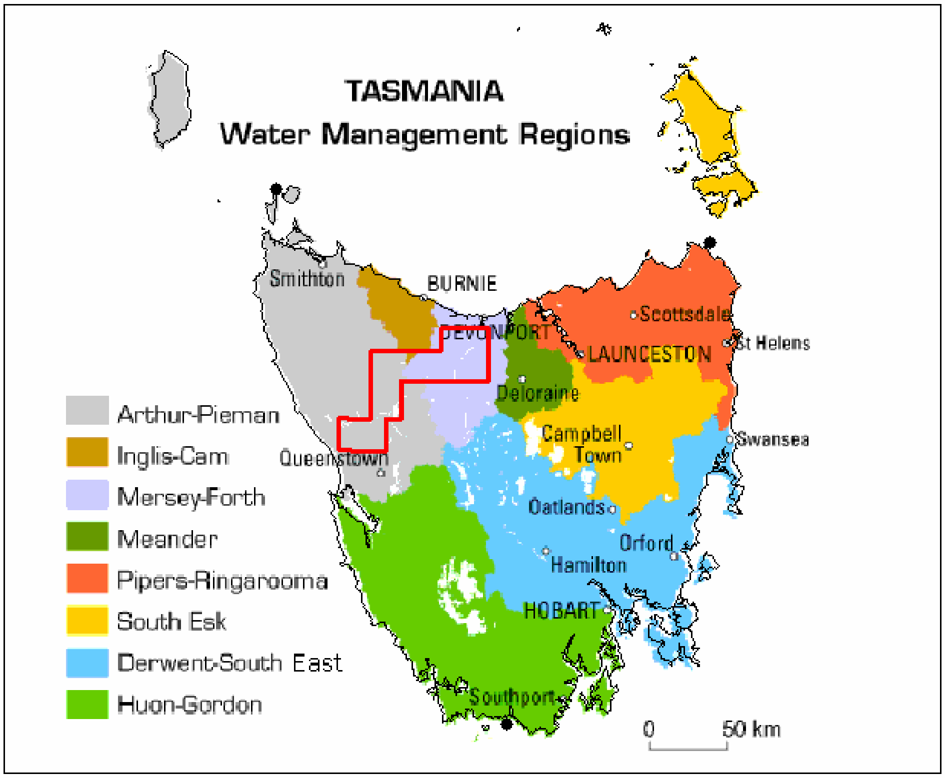


Figure 17. Location of Tasmania's water management regions with respect to SEL9/2009.

4.6.2 Surface Water

DPIPWE has been delegated the power to grant or refuse water licence applications in accordance with the *Water Management Act 1999*. This Act states that both a water licence and water allocation is required if you intend to take water from a river or stream, or store water in a farm dam, for farming or other commercial purposes with the exception of users listed under Part 5 of the *Act.* Geothermal exploration companies are not listed under exempted users. You can hold a water licence without necessarily having a water allocation but you cannot have a water allocation without holding a water licence. A water allocation states how much water can be taken in a given time period (specific megalitre limit stated on your licence). A water allocation can be obtained through application to the Minister, or by transferring water from another licence.

Conditions can be placed on both the water licence and/or allocation. Under Section 59 of the *Water Management Act 1999* (WMA), conditions on a water allocation may relate to the area that the water is able to be taken from, the area the water is to be used on, the specific purpose for which the water may be used and/or that the water is only to be taken to fill a specific dam.

Useful Tasmanian surface water web links include:

General Tasmanian Government water licence information web page:

http://www.dpipwe.tas.gov.au/inter.nsf/ThemeNodes/SSKA-4Y38HT?open

DPIPWE Water licence application web page:

http://www.dpipwe.tas.gov.au/inter.nsf/WebPages/JMUY-4YA86N?open

4.6.3 Ground Water

Currently a licence is not required for ground water unless the site is located in a specified "Groundwater Area" or where a Water Management Plan exists that states the requirement for a licence. A Groundwater Area is an area of land that has been appointed as a Groundwater Area by an order made by the Minister. Groundwater Areas are specifically defined areas in which the groundwater resources are intensively used and require a groundwater licence. At present, there are no declared Groundwater Areas in Tasmania, however, it has been publicly announced that parts of the State will be progressively appointed as Groundwater Areas over the coming years. Furthermore, it has also been stated that a system for the licensing of groundwater use is also being developed and will be implemented progressively across the State in high priority areas and situations, through the appointment of Groundwater Areas. Mineral Resources Tasmania (2003) provides a good summery review of Tasmanian groundwater systems.

The drilling of groundwater wells requires a “Well Works” permit. "Well works" means an excavation undertaken to give access to groundwater, any other works undertaken to repair or modify the structure of a well or any works undertaken to plug, backfill, seal or decommission a well. Well works can only be undertaken by holders of a Tasmanian Well Driller’s Licence.

Useful Tasmanian ground water web links include:

General Tasmanian Government Groundwater information web link:
http://www.dpipwe.tas.gov.au/inter.nsf/WebPages/RPIO-4YH6NZ?open#TakingGroundwater

DPIPWE “Well Works” permitting web link:
http://www.dpipwe.tas.gov.au/inter.nsf/WebPages/JMUY-7UC7W8?open

5. Areas of Interest

5.1. Delineation of areas of exploration interest

The components studied in the Geothermal Systems Assessment of SEL 9/2009 allow a preliminary delineation of areas of exploration interest (Figures 18 and 19). It should be noted that these areas are only broadly defined as part of the scoping nature of this study and that further detail should be ascertained at a prospect scale to gain a better understanding of potential risks in each area.

It is believed that the most probable type of system to exist in the tenement will be Engineered Geothermal Systems (EGS), although there may be some possibility of Fault Permeability Plays (FPP), however knowledge of fault and fracture systems in the tenement is not presently at a stage to comment specifically about this type of play.

In general, any area of SEL9/2009 where the Devonian granite (likely reservoir target) is prognosed to be within 3.5-4.5km depth may be considered prospective for EGS exploration and development (subject to further study as recommended in this report). Areas where the granite is greater than this depth range may also be prospective for EGS development, however the reservoir is likely to be hosted within Proterozoic metasediments rather than granite. Figure 18 shows the distribution of granite isobaths as 2 and 4 km relative to the surface geology of SEL9/2009.

Combining other aspects of the geothermal system, as described in this report, enables a further delineation of areas of exploration interest and these are shown in Figure 19 and described as:-

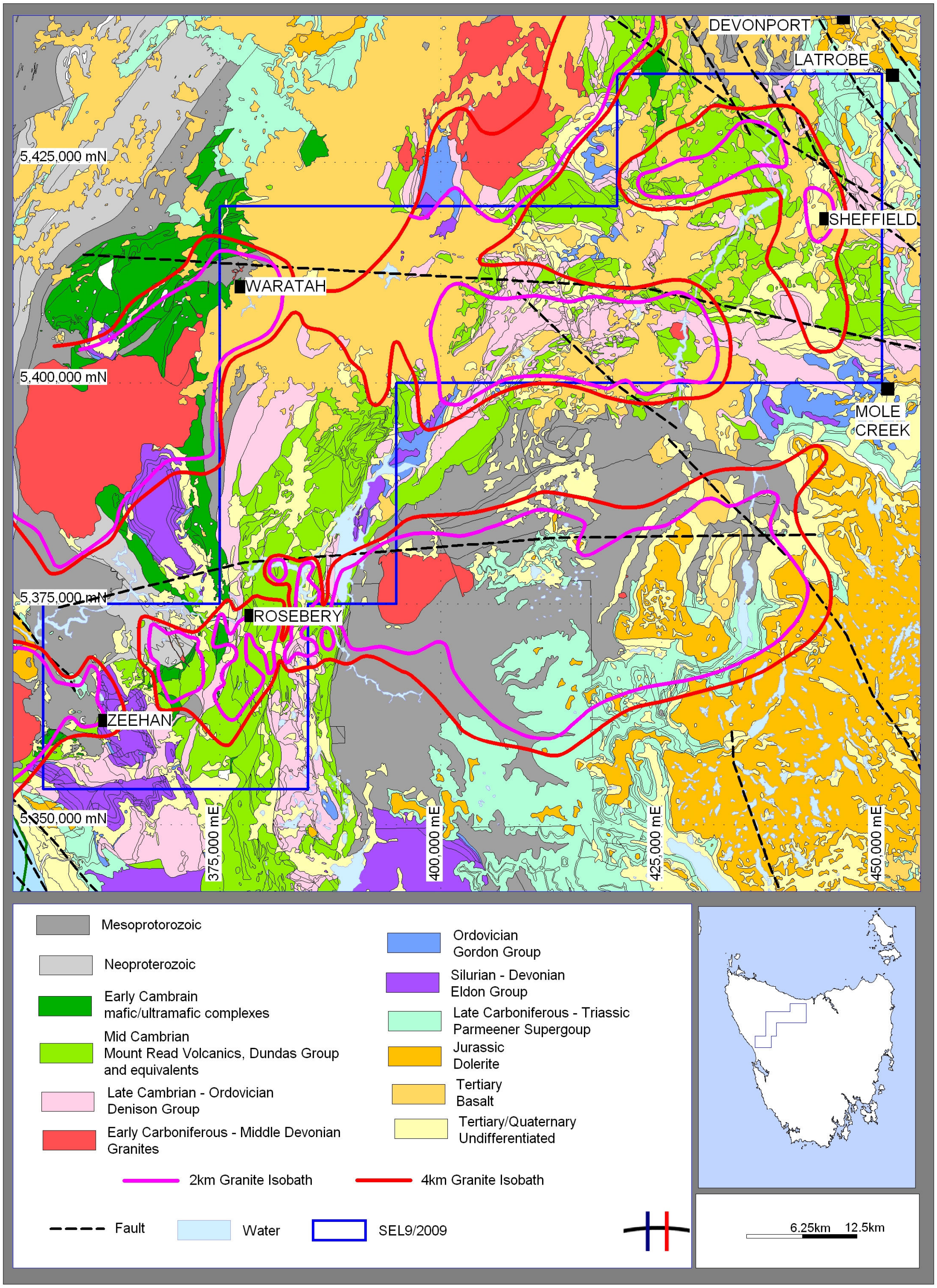


Figure 18. Granite isobaths at 2 and 4km depth. Any areas of SEL9/2009 where granite is between 3.4-4.5km depth may be prospective for EGS.

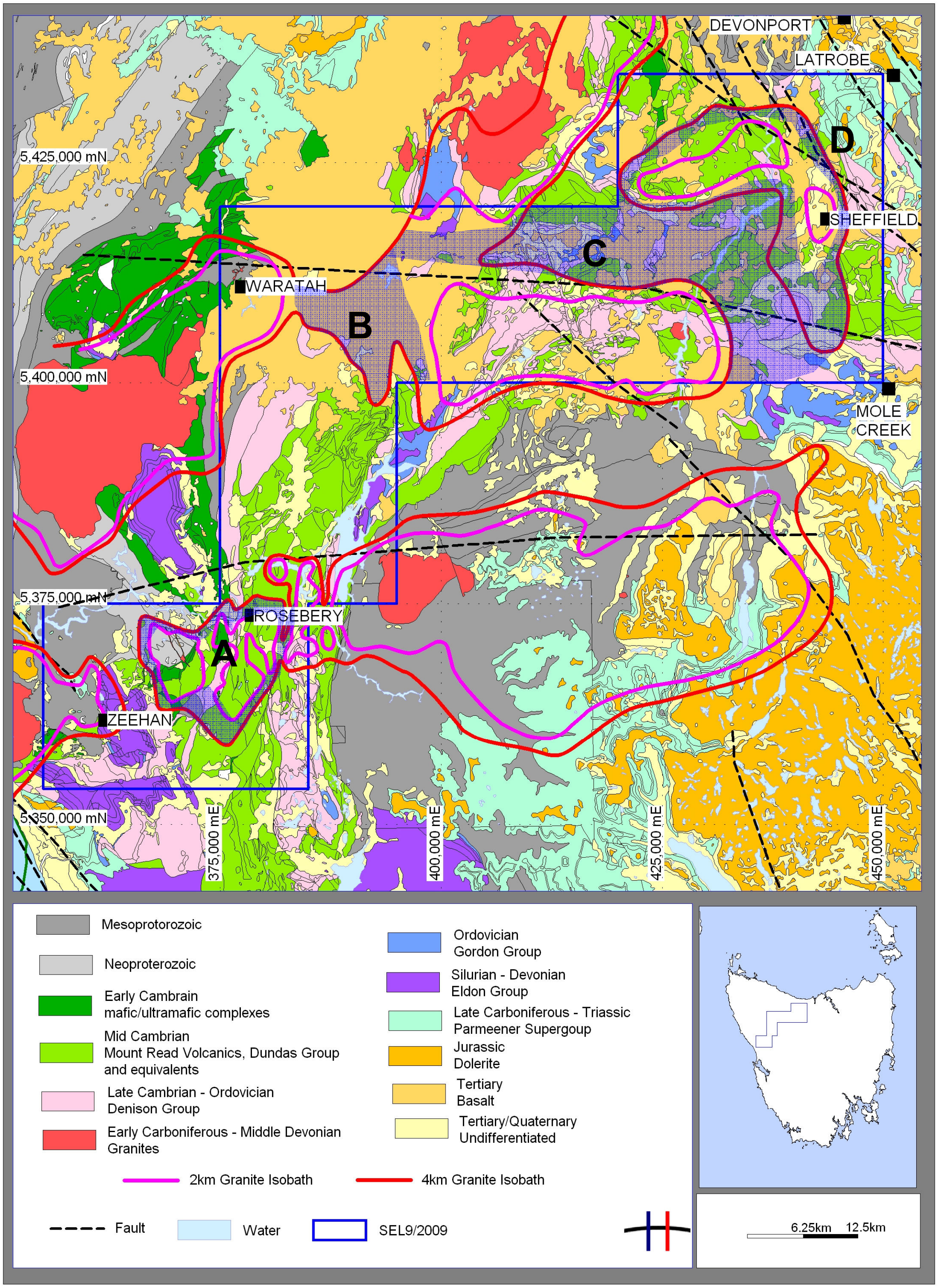


Figure 19. Broad areas of exploration interest (A,B,C and D) as defined by this study. Shown by blue shaded polygons.

- **Area A** – Rosebery Area. This area has the benefit of proximity to the only known heat flow and temperature data in the tenement. Heat flow of 104mM/m^2 suggests that the area may be prospective for EGS exploration and development where adequate cover can provide insulation. A possible draw-back of the area is the granite isobaths suggest that the granite near the target depth range is areally small compared to other parts of the tenement, suggesting that the margins of the granite body may steeply dip away from the Rosebery area.

- **Area B** – Waratah-Guildford Area. The Tertiary succession in this area, particularly the basalts, may provide reduced temperature risks. The underlying metasedimentary rocks of the Dundas Trough trend directly beneath this area towards the NNE. Subject to the insulative properties of these rocks, a thick succession within the Dundas Trough may provide the require resistance for an EGS target within the underlying Granite and 3.5-4.5km depth, subject to modeling outcomes.

- **Area C** – Wilmont Area. Has much the same characteristics as Area B, except that available fault trace data suggest that structural trends in this area are striking towards the NNW (Figure 19). If the prevailing stress direction for Tasmania is approximately E-W (see section 4.5), then these faults may be optimally oriented for shear reactivation, subject to modeling outcomes.

- **Area D** – Sheffield Area. Has much the same characteristics as Area C, although granite isobaths suggest that the underlying granite may be areally restricted as the granites dips more steeply towards the NE.

6. Conclusions & Recommendations

SEL9/2009 exhibits a number of characteristics which appear to be attractive for geothermal exploration and development with respect to Engineered Geothermal Systems (EGS). The area has significant subcrop of high heat generating granites and indications of high heat flow, although restricted to only one value within the tenement. The area also has major infrastructure, including power lines, and is located in a cool climate with large surface water reservoirs.

However the lack of geothermal-specific data in the tenement restricts a full assessment of the potential of the tenement and here is presently insufficient data available for SEL9/2009 to fully rank areas of interest in terms of probable risks. However in general terms, the principle risks in the tenement can be defined as:-

- The poorly constrained rock thermal conductivity of rocks in the area and in particular in probable influence of anisotropy of heat distribution.

- The poorly constrained reservoir characteristics of basement rocks.

It is recommended that further study at a prospect-scale and new data acquisition be undertaken to better define the risks identified in this scoping study. In particular the following new data may help to better define risks:-

- Sampling of core and outcrop rocks for thermal conductivity measurement and geomechanical properties.

- Local surface mapping of fracture patterns within granite outcrops (where granite is viewed as the probable reservoir target).

- Precision temperature logging of selected bores in the region and subsequent 1D heat flow modelling.

- Balanced cross-section construction as an input into 3D model building for resource calculation and reservoir modelling.

- 3D heat flow modelling and resource estimation to better define temperature distribution at depth and stored heat.

- Collation and detailed review of local stress and geomechanical data. Possible numerical stress modelling (UDEC) to determine possibility of fracture reactivation.

- Geothermal reservoir modelling of selected prospects to better define probable recovery rates using TOUGH2.

References

Adams, C.J., Black, L.P., Corbett, K.D. and Green, G.R., 1985. Reconnaissance isotopic studies bearing on the tectonothermal history of Early Palaeozoic and Late Proterozoic sequences in Western Tasmania. *Australian Journal of Earth Sciences* **32**, 7–36.

Anderson, E.M., 1951, The dynamics of faulting and dyke formation with application to Britain, Edinburgh, Oliver and Boyd.

Barton, C.A., Zoback, M.D., and Moos, D., 1995, Fluid flow along potentially active faults in crystalline rock, *Geology* **23**, 683–686.

Black, L.P., Calver, C., Seymour, D. and Reed, A., 2004a. SHRIMP U-Pb detrital zircon ages from Proterozoic and Early Palaeozoic sandstones and their bearing on the early geological evolution of Tasmania. *Australian Journal of Earth Sciences* **51**, 885–900.

Black, L.P., McClenagan, M.P., Korsch, R.J., Everard, J.L., Calver, C.R., Seymour, D.B., Reed, A. and Foudoulis, C., 2004b. Using SHRIMP to decipher the history of middle Palaeozoic magmatism in Tasmania. Geological Society of Australia Abstracts, v. 73, 55.

Boulter, C.A., 1978. The structural and metamorphic history of the Wilmot and Frankland Ranges, southwest Tasmania. PhD thesis, University Tasmania (unpublished).

Burrett, C.F. and Martin E.L., 1989. Geology and Mineral Resources of Tasmania. Special Publication of *Geological Society of Australia*, 15, pp 574.

Cooper, G.T., and Beardsmore, G.R., 2008. Geothermal systems assessment: understanding risks in geo-thermal exploration in Australia. Proceedings of PESA Eastern Australasian Basins Symposium III, Sydney 14–17 September, 411–420.

Corbett, K.D. and Lees, T.C., 1987. Stratigraphic and structural relationships and evidence for Cambrian deformation at the western margin of the Mt Read Volcanics, Tasmania. *Australian Journal of Earth Sciences* **34**, 45–67.

Corbett K.D. and Solomon M., 1989. Cambrian Mt Read Volcanics and Associated Minerals Deposits. *In*: Burrett, C.F. and Martin, E.L. (Eds), Geology and mineral resources of Tasmania, *Geological Society of Australia, Special Publication 15*, 84–153.

Corbett K.D. and Turner N.J., 1989. Early Palaeozoic Deformation and Tectonics. *In*: Burrett, C.F. and Martin, E.L. (Eds), Geology and mineral resources of Tasmania, *Geological Society of Australia, Special Publication 15*, 154–181.

CRAWFORD, A.J., 1989. Geochemistry and correlation of lavas in Mount Cattley drillholes MCDD2 and 3, EL14/85 Tasmania. Unpublished. 82 pp.

ELLIOTT C.G., WOODWARD N.B. AND GRAY D.R., 1993. Complex regional fault history of the Badger Head region, northern Tasmania. *Australian Journal of Earth Sciences* **40**, 155–168.

GEE, R.D., 1968. A revised stratigraphy for the Precambrian of north-west Tasmania. *Pap. Proc. R. Soc. Tasm.* ***102**, 7-10.*

GEE, C.E., JAGO, J.B. AND QUILTY, P.G., 1970. The age of the Mt Read Volcanics in the Que River area, western Tasmania. *Journal of the Geological Society of Australia* **16**, 761-763.

GENTIER, S., HOPKINS, D., AND RISS, J., 2000, Role of Fracture Geometry in the Evolution of Flow Paths under Stress. In B. Faybishenko, P.A. Witherspoon and S.M Benson (eds) Dynamics of Fluids in Fractured Rocks, Washington, D.C., AGU Geophysical Monograph 122, 169–184.

HEIDBACH, O., TINGAY, M., BARTH, A., REINECKER, J., KURFEß, D., AND MÜLLER, B. (2008): The World Stress Map Database Release 2008, doi:10.1594/GFZ.WSM.Rel2008, 2008.

HERGT, J.M., MCDOUGALL, I., BANKS, M.R. AND GREEN, D.H., 1989. Jurassic Dolerite. *In*: Burrett, C.F. and Martin, E.L. (Eds), Geology and mineral resources of Tasmania, *Geological Society of Australia, Special Publication 15*, 375–381.

HERMANRUD, C., CAO, S. AND LERCHE, I., 1990. Estimates of virgin rock temperature derived from BHT measurements: Bias and error. *Geophysics* **55**(7), 924–931.

HILLIS, R.R. AND REYNOLDS, S.D., 2000. The Australian stress map. *Journal of the Geological Society of London* **157**, 915–921.

HILLIS, R.R., COBLENTZ, D.D., SANDIFORD, M., AND ZHOU, S., 1997, Modelling the Contemporary Stress Field and its Implications for Hydrocarbon Exploration: *Exploration Geophysics* **28**, 88–93.

HOLM O.H. AND BERRY R.F., 2002. Structural history of the Arthur Lineament, northwest Tasmania: an analysis of critical outcrops. *Australian Journal of Earth Sciences* **49**, 167–186.

HOWARD, L.E. AND SASS, J.H., 1964. Terrestrial heat flow in Australia. *Journal of Geophysical Research* **69**, 1617–26.

Hudson, J.A., Stephansson, O., and Andersson, J., 2005, Guidance on numerical modelling of thermo-hydro-mechanical coupled processes for performance assessment of radioactive waste repositories, *Int. J. Rock Mech. Min. Sci*. **42**, 850–870.

Jago, J.B., Reid, K.O., Quilty, P.G., Green, G.R. and Daily, B., 1972. Fossiliferous Cambrian limestone from within the Mt Read Volcanics, Mt Lyell mine area, Tasmania. *Journal of the Geological Society of Australia* **19**, 379-382.

Jennings, I.B., Burns, K.L., Mayne, S.J., and Robinson, R.G., 1959. Sheffield, Tasmania. Tasmanian Department of Mines, Geological Atlas 1 Mile Series, Sheet 37.

Jennings, I.B., 1979. Sheffield, Tasmania. Tasmanian Department of Mines, Geological Atlas 1 Mile Series Explanatory Report, Sheet 37 (8115S).

Leaman D.E., 1992. The Tasmanian Precambrian and basement involved thrusting. *Geological Society of Australia Abstracts* **32**, 28–29.

Leaman D.E., Baillie P. W. and Powell C. McA., 1994. Precambrian Tasmania: a thin-skinned devil. *Exploration Geophysics* **25**, 19–23.

McCue, K., van Dissen, R., Gibson, G. Jensen, V and Boreham, B., 2003. The lake Edgar Fault: an active fault in Southwestern Tasmania, Australia, with repeated displacement in the Quaternary. *Annals of Geophysics* **46**(5), 1107–1117.

McKay., G., 1991. Annual report EL14/85 – Mt. Cattley. Outokumpu Exploration Australia Pty Ltd. Mineral Resources Tasmania.

Meffre S., Berry R.F. and Hall M., 2000. Cambrian metamorphic complexes in Tasmania: tectonic implications. *Australian Journal of Earth Sciences* **47**, 971–985.

Mineral Resources Tasmania, 2003. A review of groundwater in Tasmania. Mineral Resources Tasmania, Tasmanian Geological Survey, Record 2003/01.

Morland., R., 1990. Renison Bell tin deposit, in FE Hughes (Ed), Geology of the Mineral Deposits of Australia and Papua New Guinea, pp. 1249-1251.

Nelson, E., Hillis, R., Sandiford, M., Reynolds, S. and Mildren, S., 2006. Present-day state-of-stress of southeast Australia. *APPEA Journal* **46**, 283–305.

Noll, C.A., 2004. Structural and stratigraphic evolution of the Owen Conglomerate, West Coast Range, Western Tasmania. PhD thesis, Monash University (unpublished).

POWELL C. MCA.,1992. New perspectives on Tasmanian geology. In: Tasmania: an Island of Potential; New Perspectives on Mineral Exploration, pp. 177–187. *Tasmanian Geological Survey Bulletin 70*.

RAHEIM, A., AND COMPSTON, W., 1977. Correlations between metamorphic events and Rb-Sr ages in meta-sediments and eclogite from western Tasmania. *Lithos* **10** 271–289.

SANDIFORD, M., WALLACE, M. AND COBLENTZ, D., 2004. Origin of the *in situ* stress field in south-eastern Australia. *Basin Research* **16**, 325–338.

SCHMIDT, P.W. AND MCDOUGALL, I., 1977. Palaeomagnetic and potassium-argon dating studies of the Tasmanian Dolerites. *Australian Journal of Earth Sciences* **24**(5) 321–328.

STACEY, A.R. AND BERRY, R.F., 2004**.** The structural history of Tasmania: A review for petroleum explorers. *In*: Boult, P.J., Johns, D.R. and Land, S.C. (eds). Eastern Australasian Basin Symposium II, Petroleum Exploration Society Special Publication, Adelaide, 537–552.

STEIGER, R.H. AND JÄGER, E., 1977. Subcommission on Geochronology: Convention on the use of decay constants in geochronology and cosmochronology. *Earth and Planetary Science Letters* **36**, 359–362.

TURNER, N.J., 1989. Precambrian. *In*: Burrett, C.F., and Martin, E.L. (Eds.). Geology and mineral resources of Tasmania. *Geological Society of Australia Special Publication* **15**, 5–46.

TURNER N.J. AND BOTTRILL R.S., 2001. Blue amphibole, Arthur Metamorphic Complex, Tasmania: composition and regional tectonic setting. *Australian Journal of Earth Sciences* **48**, 167–181.