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Tasmania Project:

Mt. Nicholas-Fingal Geothermal Play

Statement of Geothermal Resources

Prepared for KUTh Energy Ltd

5th March 2010

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(This document is formatted for double-sided printing)

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1.0 Introduction

The Mt. Nicholas-Fingal Geothermal Play lies within Geothermal Exploration Licence SEL26/2005 in the eastern half of Tasmania (Figure 1), and represents an engineered geothermal system (EGS) target reservoir. KUTh Energy Ltd (KEN) aims to produce geothermal fluids from the reservoir for the purpose of electrical power generation. KEN controls 100% of SEL26/2005. This document details the process and outcomes of a Geothermal Resource estimation within the Mt. Nicholas-Fingal Geothermal Play. The Play lies mainly on the 'St. Marys' and 'Ben Lomond' map sheets of the 1:50,000 Geology of Tasmania series (Brown *et al*., 2005[1]).

The Mt. Nicholas-Fingal Geothermal Play is centred on the Fingal Valley of NE Tasmania. The Fingal Valley has been a commercial producing coal region since the 1886.A number of historical coalmines, and one active mine (Cornwall Colliery), are located in the valley. Surface geology in the area is well constrained. Sub-surface geology is also well constrained from gravity modelling (granite isobaths) and a large number of coal exploration bores.

Relevant geothermal exploration data were extracted from a number of sources. KEN has drilled 35 shallow (<300 m) bores within SEL26/2005 for the purpose of surface heat flow measurements (Figure 2). Data are also available for deeper lithological units from previous mineral exploration drilling, gravity interpretations and 2D seismic acquired for recent onshore oil exploration, although most of the seismic data are located in the western portion of the tenement (Figure 1). These surveys and wells generated relevant data for an interpretation of major geological structures and formation boundaries within the Tasmania Basin, and facilitated the construction of a 3D earth model for the region. Temperature was directly measured within the KEN heat flow wells using Precision Temperature Logging methods, and thermal conductivity was measured on core specimens from different locations and stratigraphic depths using a divided bar apparatus.

[1] **Brown A.V. (comp), 2005.** Geology of Tasmania. Edition 2005.1. *Geological Atlas 1:50,000 digital series*. Mineral Resources Tasmania.

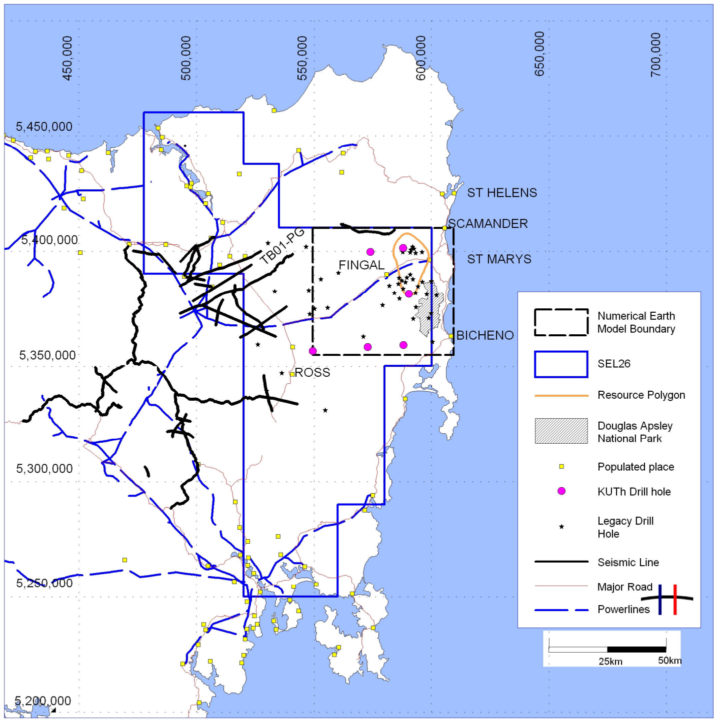

Figure 1. Location of SEL26/2005 in eastern Tasmania (blue); the area of the numerical earth model (black dashes—see Section 4) incorporating the Nicholas-Fingal Geothermal Resource (orange); drill holes and 2D seismic lines used to constrain the earth model. Grid coordinates in AMG 94, Zone 55.

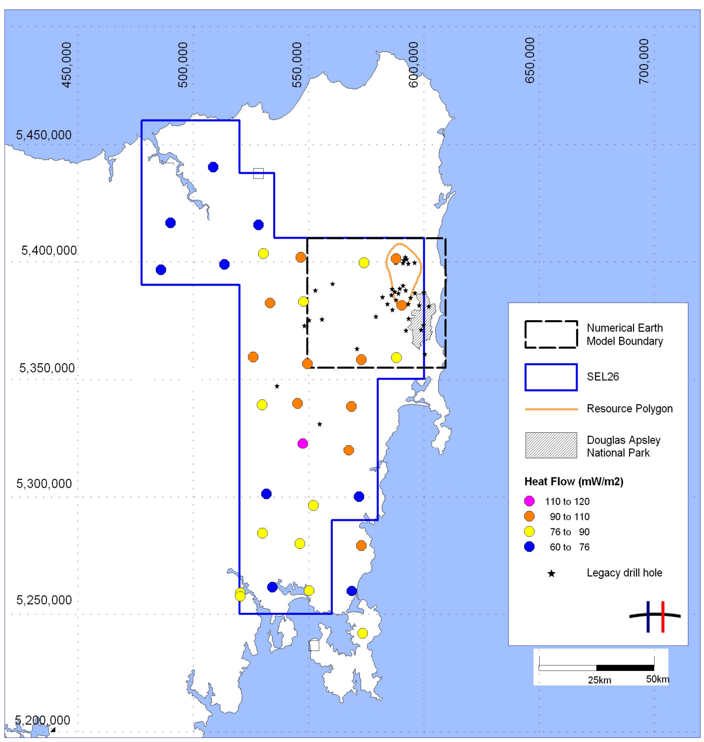

Figure 2. Locations of 'heat flow' wells and exploratory holes within SEL26/2005.Area of numerical earth model (black dashed—see Section 4) and the Mt. Nicholas-Fingal Geothermal Resource (orange).

2.0 Geological setting

The first order controls on temperature and geothermal resource distribution within the Mt. Nicholas-Fingal Geothermal Play are the structure and thermal properties of the geological formations. These must be understood in order to model heat flow and the temperature away from borehole control points. The Mt. Nicholas-Fingal Geothermal Play lies in the NE portion of the Tasmania Basin, an area comprised of Permo-Triassic foreland basinal deposits and smaller Tertiary sub-basins bounded to the east and north by Devonian granites and to the west by the elevated Central Plateau Precambrian metasediments and dolomites. The Permo-Triassic succession unconformably overlies the Ordovician-Devonian turbidite sequence, which comprises the Mathinna Supergroup.

Surface outcrop along the northern margin of the Fingal Valley is mainly Ordovician Mathinna Supergroup with some outcrop of the Perm-Triassic Parmeener Supergroup. Tertiary sedimentary rocks dominate the axis of the valley and the southern margin of the valley has a veneer of Jurassic dolerite, which crops out along the Fingal Tier. Devonian granites crop out to the east and north of the play.

2.1 Structure

The Mt. Nicholas-Fingal Geothermal Play lies in the northeast part of the greater Tasmania Basin, a Permo-Triassic foreland basin bounded to the east and north by Devonian granites and the Ordovician-Devonian Mathinna Supergroup metasediments. To the west, the basin is generally regarded as terminating against the Western Tiers of the Central Plateau (outside the boundary of SEL26/2005). The basin succession comprises the Permo-Triassic sediments of the Parmeener Supergroup, which unconformably overlie the Ordovician-Devonian Mathinna Supergroup. The Permo-Triassic sediment pile is relatively thin, typically less than 500m thick within the Mt. Nicholas-Fingal area based on well intercepts.

An example of the structural style on the central northern area of SEL26/2005 is shown in seismic line TB01-PG (Figure 3), which approaches the northwest margin of the Mt. Nicholas-Fingal Geothermal Play (see Figure 1 for location).The structural style of the area is dominated by NE-dipping faults (half graben) established during the Permo-Triassic deposition of the Parmeener Subgroup and later reactivated during the Tertiary.

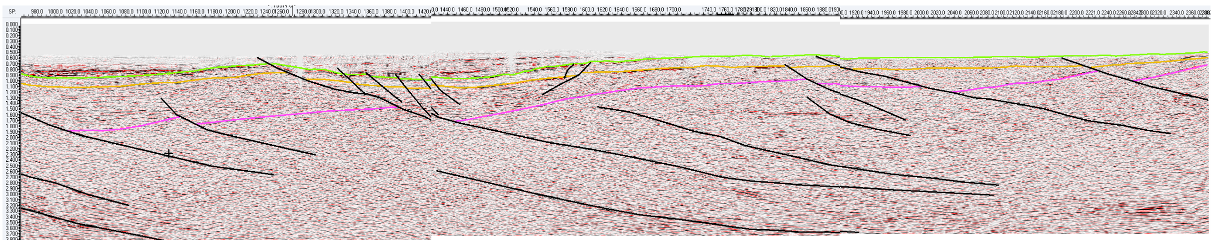

Figure 3.Northeast end of seismic line TB01-PG approaching the western margin of the Mt.Nicholas-Fingal Geothermal Play (at the right hand end of the line). The structural style is dominated by northeast dipping faults with thickening of the Permo-Triassic Parmeener Group towards the faults. Depth scale is in two-way-time. Base Permo-Triassic (Top MathinnaSupergroup) is pink, top Permo-Triassic is orange and top dolerite is green. Line location shown on Figure 1.

The Mathinna Supergroup rocks are a deep marine turbidite sequence, which was subsequently folded and faulted during the Tabberabberan Orogeny in the Middle Devonian (Cayley *et al*., 2002[2]). Whilst the provenance of the Mathinna Supergroup remains a matter of debate, many workers regard it to be a southern extension of Lachlan Orogen, which was accreted and cratonized during the Early-to-Late Palaeozoic (Gray *et al*., 2006[3]; Gray and Foster, 2004[4]).

Hot Dry Rocks Pty Ltd (HDRPL) interpreted the geological structure in the central and western portion of SEL26/2005 from moderate quality 2D reflection seismic data, constrained by drilling intersections where possible(Cooper *et al*., 2009[5]). Although largely outside the Mt. Nicholas-Fingal Geothermal Play, surface mapping and gravity data suggest that the structural style of the play is consistent with that interpreted from seismic data in the west (Figure 3). That interpretation shows the Mathinna Supergroup reaching depths of 3–5 km within SEL26/2005. A footwall high

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[2] **Cayley, R.A., Taylor D.H., Vandenberg, A.H.M. & Moore D.H., 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.

[3] **Gray, D.R., Foster, D.A., Korsch, R.J. & Spaggiari C.V., 2006.** Structural style and crustal architecture of eastern Australia: example of a composite accretionary orogen. Geological Society of America, Special Paper 414, 119-132.

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

[5] **Cooper G., Waining B. & Pollington, N., 2009.** Interpretation of selected reflection seismic data in SEL26/2005, Eastern Tasmania. *HDRPL report prepared for KUTh Energy Ltd.*

to the west of the tenement boundary (Central Tasmanian Tablelands) comprises Precambrian metasediments and dolomites, which may exist at depth within SEL26/2005 beneath the Mathinna Supergroup. There is no evidence of Mathinna Supergroup rocks being deposited on the footwall high to the west.

The Permo-Triassic succession is fault controlled with westward thickening of succession in a number of half grabens (Cooper *et al*., 2009[5]). Some Permian faults sole into older Mathinna-aged faults, suggesting reactivation of older compressional structures. The Permian aged faults generally trend to the NNW. The individual fault planes appear to have limited length with extension accommodated by fault overlap (relay ramps), producing *enechelon* geometry in plan view with apparent offset of half grabens.

The Jurassic Dolerite most commonly forms a flat-lying sill, providing a blanket of thermally insulating rock typically >250 m in thickness (Leaman and Richardson, 1981[6]). Dolerite thickness may increase significantly in the region of feeders and dual or parallel intrusions have been observed in parts of SEL26/2005 (Hergt *et al*. 1989[7]; Forsyth, 1989[8]). The dolerite displays some minor offset due to Tertiary, and possibly Cretaceous, faulting.

2.2 Stratigraphy

For the purposes of this Resource estimation, the stratigraphy of the Tasmania Basin (Table 1) has been simplified into seven (7) units, namely:

- Tertiary
- Jurassic Dolerite
- Upper Parmeener
- Lower Parmeener
- Mathinna Supergroup
- Granite

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[6] **Leaman D.E and Richardson, R.G., 1981**. Gravity survey of the east coast coalfields, *Tasmanian Geological Survey Bulletin*, 60.

[7] **Hergt, J.M., McDougall, I., Banks, M.R. and Green, D.H., 1989**. Jurassic Dolerite in Burret CF & Martin EL (eds). Geology and Mineral Resources of Tasmania. *Special Publication of the Geological Society of Australia*, 15, 375 – 381.

[8] **Forsyth, S.M., 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.

- Precambrian

Table 1. Simplified stratigraphy of the Tasmania Basin.

Age	Period	Rock Unit	Lithology
Cainozoic	Tertiary	Sediments and Basalt	Predominantly non-marine gravel, sand, silt and clay sequences and some basalt.
Mesozoic	Jurassic	Dolerite	dolerite sills and dykes
	Triassic	Upper Parmeener Supergroup	Coals, sandstone and siltstone and mud-stone sequences.
	Late Carbon-iferous to Permian	Lower Parmeener Supergroup	Marine/shallow marine successions of glacial tillite, mudstone, siltstone and sandstones
	unconformity surface		
Palaeozoic	Devonian	Intrusive plutonic rocks (granites and granodiorites)	I-type and S-type granitoid bodies
	Early Ordovi-cian to Early Devonian	Mathinna Super-group	Micaceous quartzwacke turbiditic se-quences, and mudstone sequences.
Precambrian			Undifferentiated metasediments, dolomite, mafic volcanoclastics

2.2.1 Tertiary sedimentary rocks

A thin veneer of mainly non-marine sandstone, siltstone and gravel lies in isolated sub-basins throughout the Tasmania Basin and very minor amounts cropout in the axis of Fingal Valley. A significant amount of quaternary doleritic talus occurs at the base of most topographic highs such as Ben Lomond and the Fingal Tier.

2.2.1 Jurassic Dolerite

The top ~300 m of the Tasmania Basin stratigraphy is dominated by a relatively uniform, flat-lying Jurassic Dolerite sill that mainly crops out along the Fingal Tier—an elevated region in the southern portion of the Mt. Nicholas-Fingal Geothermal Play. The dolerite also occurs as minor sills and dykes and in thick feeder zones.

2.2.2 Upper Parmeener

The Upper Parmeener Supergroup directly overlies the Lower Parmeener Supergroup. It is comprised of Late Permian to Triassic fluvial and lacustrine deposits including siltstone, sandstone and discontinuous coal seams (Forsyth, 1989[8]), and represents a probable transitional succession from the earlier marine sequences.

The Late Triassic sediments were possibly deposited by high sinuosity rivers and comprise volcanolithic sandstones with laterally extensive coal seams (of economic significance in the northeast of Tasmania). These sediments attain their maximum thickness of ~200 m near Fingal, within the study area. The Middle Triassic deposits consist of lithic sandstone and mudstone sequences deposited in a possible deltaic environment. The earlier fluvial deposits of the Upper Parmeener Supergroup, up until the Late Permian, comprise sandstones, siltstones with some coal seams, carbonaceous silts and mudstones. The Late Permian to Early Triassic deposits show a tendency towards more quartz and feldspar dominated sand deposits but are relatively poorly developed in the area (Forsyth, 1989[8]).

2.2.3 Lower Parmeener

The Lower Parmeener Supergroup consists of late Carboniferous to Permian glacial tillites and related sediments with overlying siltstones deposited in a quiet marine setting. A thin marine algal oil shale occurs near the base of this succession. Clarke (1989[9]) interpreted a number of half grabens, generated by Permian faulting, as supplying the accommodation space for the deposition of the Lower Parmeener marine succession. Subsequent fault movement continued to control deposition of siltstones and shallow water sandstone in to the Late Permian.

The Parmeener Supergroup unconformably overlies the Mathinna Supergroup, Precambrian basement and Devonian Granites.

2.2.4 Mathinna Supergroup

The Mathinna Supergroup is Ordovician to Devonian in age and comprised of a series of marine turbidite sequences. It has been extensively folded and reaches a thickness of 3–5 km throughout the area of interest. The Ordovician units include turbiditic sandstone and silts within a succession of slate and phyllites (Baille *et al*.

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[9] **Clarke, M.J., 1989**. Lower Parmeener Supergroup, in Burrett CF & Martin EL (eds). Geology and Mineral Resources of Tasmania. *Special Publication of the Geological Society of Australia,* 15, 295-308

1989[10]). The Siluro-Devonian units of the Mathinna Supergroup contain more arenaceous rocks, including poorly sorted sandstones, siltstones and mudstones. Recent surface field mapping by Mineral Resources Tasmania in areas of exposure to the northwest of the Geothermal Play has also identified thick units of shale-siltstone as part of the Silurian-Devonian succession of the Mathinna Supergroup (D. Seymour, MRT unpublished). Towards the east, the sediments of the Mathinna Supergroup are interpreted to be intruded by sub-cropping Devonian Granites, lying at depths between surface and 4.5 kilometres in the study area (Leaman and Richardson, 2003[11]).

2.2.5 Granitoids

The eastern Tasmanian granites intruded the Ordovician to Early Devonian Mathinna Beds in the Early-Late Devonian (McClenaghan, 1989[12]). Granite and granodorite plutons crop out in the north and east of the area of interest, and gravity data suggest that the granitoids continue beneath the Mt. Nicholas-Fingal Geothermal Play. Leaman and Richardson (2003[11]) interpreted the granitoids as deepening towards the west, although depth constraints from gravity modelling are imprecise.

2.2.6 Precambrian

Precambrian basement rocks are assumed to lie at the base of the succession within the Mt. Nicholas-Fingal area, but have only been encountered in limited well intersections in the central and western Tasmania Basin, outside the area of interest of this document (Forsyth, 1989[13]).

3.0 Target reservoir

KEN aims to develop an Engineered Geothermal System (EGS) within the Mt. Nicholas-Fingal Geothermal Play. The critical requirements for an EGS reservoir are

[10] **Baille, P.W., Powell, C.M., Banks, M.R. & Hills P.B., 1989.** Mathinna Beds, in Burrett CF & Martin EL (eds). Geology and Mineral Resources of Tasmania. *Special Publication of the Geological Society of Australia,* 15, 234-237

[11] **Leaman, D.E. & Richardson, R.G., 2003.** A geophysical model of the major Tasmanian granitoids. Report Department of Mines Tasmanian,2003/11, pp8.

[12] **McClenaghan, M.P., 1989.** Mid Palaeozoic Granitoids**.** in Burrett CF & Martin EL (eds). Geology and Mineral Resources of Tasmania. *Special Publication of the Geological Society of Australia,* 15, 253-261

[13] **Forsyth, S.M., 1989**. Geological Atlas 1:50,000 series. Sheet 61 (8313N). Interlaken. Explan. Rep. Geol. Surv. Tas.

that it lie within a target temperature range and have suitable hydro-geo-mechanical properties. The great majority of EGS projects globally have so far been attempted in granite because of that rock's considerable strength. Host rocks must be competent and strong enough to sustain open fracture networks. Upon reviewing the stratigraphy of the Mt. Nicholas-Fingal Geothermal Play, HDRPL identified the Devonian granitoids as the principal target reservoir.

4.0 3D earth model

HDRPL developed a numerical 'earth model' for the purpose of estimating the stored heat within the target reservoirs. The earth model was constructed to cover an area of 60.0 km x 55.0 km (549500–609500 E, 5355000–5410000N; AMG 94, Zone 55) to a depth of 7,000 m (Figure 4). The model divided the stratigraphy of the Geothermal Play into five (5) units—**Dolerite**, **Upper Parmeener**, **Lower Parmeener**, **Mathinna Beds** and **Granite**—and incorporated surface topography.

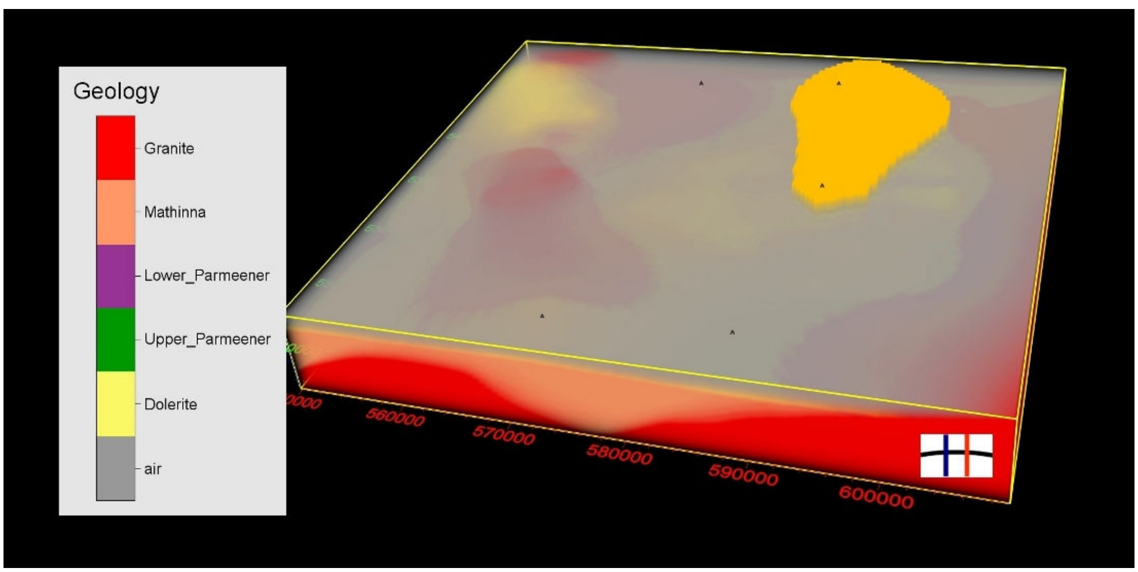

Figure 4. Representative view of the 3D numerical earth model, showing the surface trace of the Mt. Nicholas-Fingal Geothermal Resource (pale orange region in upper-right of model) and the locations of wells (black dots) constraining the thermal state of the model. The earth model measures 60 km x 55 km x 7 km. North is to the top of the figure.

HDRPL derived the geological structure of the modelled section of crust from a combination of new and pre-existing data. KEN utilized existing MRT geological mapping and well data to construct a regional model of the likely geology at depth.

These data also incorporated the results of gravity modelling (Leaman and Richardson, 2003[11]) to estimate the distribution and depth of granitoids. HDRPL has reviewed KEN's procedure and agrees with the results. In addition, HDRPL interpreted regional reflection seismic data to the west of the play, which assisted in constraining the structural style of the area.

The Mt. Nicholas-Fingal Geothermal Play area is bordered by rugged topography, with the mountain region of Ben Lomond located to the northwest of the area. Digital surface geological maps and the Tasmanian digital elevation model (MRT) were also incorporated into the 3D earth model.

The projected temperature at depth is sensitive to the thermal conductivity values used in the model. HDRPL assigned average thermal conductivity values to the different units, based on data measured for KEN and summarised in Table 2. While HDRPL considers the values assigned in this study to be reasonable averages for the formations under consideration, the number of measurements made on actual samples of the formations is currently insufficient to determine potential lateral and vertical variation. Uncertainty in projected temperatures and estimated Resource therefore increases with distance from, and depth beneath, borehole control points. Thermal conductivity was assumed to be isotropic for all units except the Upper and Lower Parmeener Supergroups.

The bulk rock thermal conductivity of both the Upper and Lower Parmeener Supergroups is strongly influenced by the silty and coaly nature of these units in the Fingal Valley area. KEN provided detailed lithology logs for wells Fingal-1 and Mt. Nicholas-1, and a subsequent conductivity-lithology mixing exercise demonstrated a minor statistical difference between the arithmetic and harmonic mean thermal conductivities, indicating minor thermal anisotropy as might be expected for finely bedded sedimentary rocks.

The Mathinna Supergroup is also known to exhibit anisotropic thermal conductivity from triaxial measurements by HDRPL and Goh (2008[14]). Surface mapping of out-cropping Mathinna units in the area of interest indicate significant variation in the fo-

[14] **Goh, H.K.H., 2008**. Properties of north eastern Tasmanian rocks for geothermal exploration petrophysical, geochemical and thermal characteristics of the Mathinna Group and Devonian granites. Unpublished Honours Thesis, University of Tasmania.

liation orientation with sub-horizontal foliations associated with recumbent folding observed in the west and sub-vertical foliations associated with upright folding observed in the east (Reed, 2001[15]). Rocks of the Mathinna Supergroup cropout along the northern margin of the model area and within parts of the Fingal Valley axis. These rocks display evidence for multiple episodes of folding and deformation and typically exhibit a wide range of bedding orientations and a moderate to upright foliation. Further to the north and west the foliation angle is observed to vary widely and no information is known regarding variations in rock fabric with increasing depth in the Mathinna Supergroup.

The orientation of the dominant foliation is largely unknown throughout the south and east of the modelled area where the Mathinna Supergroup is completely obscured by younger formations but, by analogy, may be assumed to vary considerably. HDRPL ran a number of 'high' and 'low' case models utilising the measured upper and lower values of Mathinna Supergroup anisotropic thermal conductivity. The results of this work indicate that expected temperature, and hence the estimated Resource, at depths approaching 5,000 m may vary significantly (by up to 10's of degrees Celsius) depending on the orientation of the dominant foliation in the Mathinna Supergroup. In the absence of definitive information on the local rock fabrics, the Resource estimate therefore assumes a mean case with an average dip of foliation of 45° throughout the modelled area.

Predicted temperature at depth (and hence the estimated Geothermal Resource) decreases with increasing heat generation in the overlying sediments. In this case, the impact is unlikely to be large and most probably lies well within the precision limits of this resource assessment. The impact of heat generation within the Devonian granites, however, is likely to be more significant. Whilst the reported heat generation values of Tasmanian granites are highly variable, many samples of granite from eastern Tasmania have elevated values. Geochemical data from the Coles Bay Granite on the eastern margin of Tasmania, for example, show elevated levels of uranium and thorium (Geoscience Australia OzChem database) suggesting

[15] **Reed, A.R., 2001**. Pre-Tabberabberan Deformation in Eastern Tasmania: a Southern Extension of the Benambran Orogeny, *Australian Journal of Earth Sciences*, 48, 785-796.

heat generation values in the range 5–10 μW/m^3.Goh (2008[14]) measured heat generation within the Mathinna Supergroup and Granites, deriving mean values of 1.61 μW/m^3 and 7.33 μW/m^3, respectively. Heat generation of 0 μW/m^{3}was assumed for all other units (Table 2).

Table 2. Mean thermal conductivity (at 25°C) and heat generation values assigned to earth model units

Unit	Thermal conductivity (W/mK)		Heat generation (μW/m^3)
	Horiz.	Vert.	
Dolerite	2.17	2.17	0.00
Upper Parmeener	1.88	1.69	0.00
Lower Parmeener	2.09	2.05	0.00
Mathinna Supergroup	3.80	3.80	1.61
Granites	3.50	3.50	7.33

5.0 Thermal data

The results of 1D heat flow modelling for six (6) wells around the Mt. Nicholas-Fingal Geothermal Play were used as constraints for subsequent 3D temperature modelling. Figure 5 shows a sample 1D heat flow model (Mt. Nicholas-1). The locations of wells and heat flow values are presented in Table 3. The uncertainties quoted for the heat flow values in Table were derived from the uncertainties in the thermal conductivity values measured on the different stratigraphic units intersected by the wells. Temperature data were derived from high-precision (±0.001°C) temperature logging and contribute no significant uncertainty to the heat flow models.

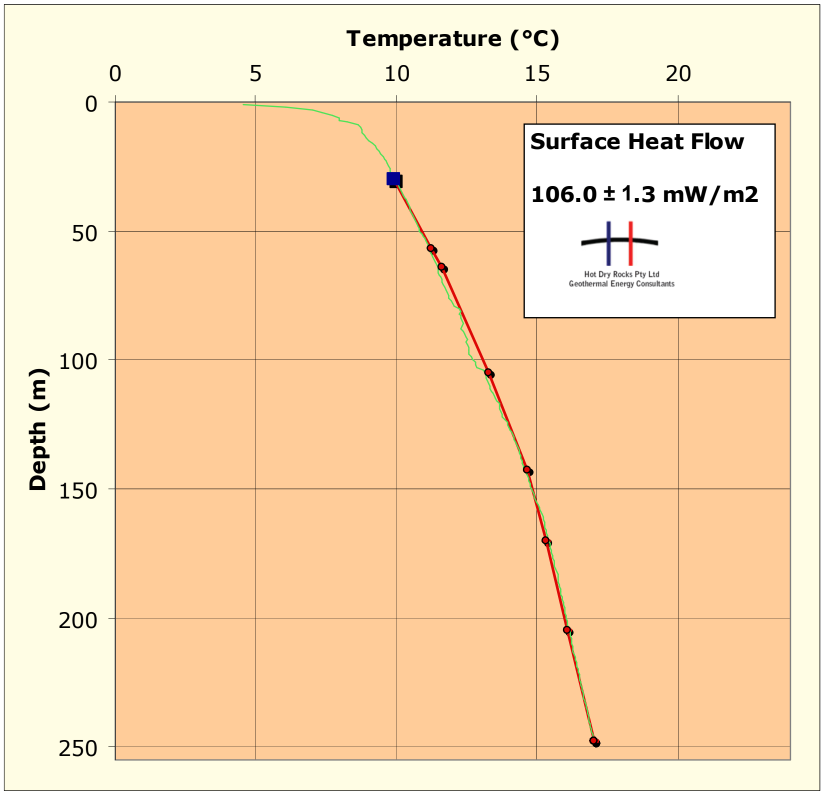

Figure 5. 1D conductive heat flow model of well 'Mt. Nicholas-1'. Red line is the predicted temperature profile for a 1D conductive heat flow model and the green line is measured temperature profile. Blue square is the top of the cored (modelled) interval.

Table 3. Heat flow constraints on the 3D temperature inversion. Coordinates are in GDA94 MGA Zone 55.

Well	East	North	Heat Flow (mW/m^2)
Tower Hill-1	573964	5399699	83 ± 1.0
Fingal-3	590381	5381540	97 ± 2.9
Snow Hill-1	572873	5358389	92 ± 2.3
Mt. Nicholas-1	587962	5401440	106 ± 1.3
Swan-2	588102	5359269	85 ± 1.2
Elizabeth-1	549501	5356701	94 ± 2.4

The temperature data fit conductive models (within uncertainty limits) in each of the wells. There is no thermal, or other, evidence of convection within the drilled and logged intervals of the Mt. Nicholas-Fingal Geothermal Play.

Surface temperature varied across the model in accordance with topographic elevation, constrained by temperature logs collected in shallow bores in the area.

6.0 Resource estimation methodology

6.1 Stored heat assessment

HDRPL used a 'stored heat' method to estimate the Geothermal Resource in the target reservoirs. This is a technique for estimating the total heat energy contained within a target volume, for which a realistic chance exists for economic extraction. The method requires the estimation of the **volume**, **density**, **specific heat capacity** and **temperature** of the target reservoir formations, a consideration of the realistic lowest economically extractable temperature ('**cut-off temperature**') and the amount of thermal energy that might be extracted from the resource fluids (related to the '**base temperature**').

6.2 Cut-off and base temperature

For the purposes of this stored heat assessment, HDRPL defines the cut-off temperature as *the minimum economic reservoir fluid temperature for commercial energy extraction*. The cut-off isotherm is an essential input to the volumetric Resource estimations as it defines the upper surface of the Resource volume. Similarly, for the purposes of this stored heat assessment, HDRPL defines the base temperature as *the temperature of the geothermal fluid once it has passed through a power conversion process, prior to reinjection*. It puts an upper limit on the amount of thermal energy that can be extracted from a Geothermal Resource of any given temperature. Both of these values depend strongly on the technology used to convert thermal energy into electrical energy.

It is technically feasible to generate power from geothermal fluid down to 100°C or lower (eg a geothermal plant at Birdsville in Queensland generates power from 98°C water), but the efficiency of power conversion at low temperatures makes it economically unviable in most situations. HDRPL assumed **a cut-off temperature of 150°C** as the minimum required for power generation from the Mt. Nicholas-Fingal Geothermal Play.

A base temperature of 70°C is the average temperature at which an air-cooled binary cycle geothermal plant rejects the geothermal fluid (e.g. Bombarda and Macchi, 2000)[16]. HDRPL has assumed this value in estimating the Geothermal Resource stated below.

HDRPL believes the cut-off and base temperatures above are appropriate for low-temperature organic rankine cycle binary technology that KEN proposes to use for power generation. Should technological advances decrease the base temperature, the estimated Resource may increase over time.

6.3 Reservoir volume

The areal extent of the Mt. Nicholas-Fingal Geothermal Resource was determined (in consultation with KUTh Energy) using a combination of isothermal and geological constraints to delineate the area of highest confidence. This outline is shown, for example, on Figure 4.

The vertical extent of the reservoir interval is constrained by top and bottom surfaces. The top surface is the deeper of the 150°Cisotherm (for reasons explained in Section 6.2) or the top of the Devonian Granitoid. The base of the reservoir is 5000 m (judged by HDRPL to be the maximum practical depth for drilling and fracturing programs).

The total estimated reservoir volume of the Mt. Nicholas-Fingal Geothermal Resource, below the 150°C cut-off isotherm and above 5000 m, is **384 km^3**.

6.4 Reservoir density and specific heat

Specific heat is temperature dependent and typically increases with temperature. While specific heat has not been measured for the projected reservoir rocks, HDRPL has estimated a relationship based on Equations 18 and 19 of Waples and Waples (2004)[17], assuming a reference temperature of 25°C and a surface Cp = 750 J/kgK:

Equation 1 $$CpT = (8.859\text{x}10^{-7} \text{ x } T^3) - (2.108\text{x}10^{-3} \text{ x } T^2) + (1.703 \text{ x } T) + 708.7$$

Where CpT is the specific heat at temperature T(°C).

[16] **Bombarda, P. & Macchi, E., 2000**. Optimum cycles for geothermal power plants. *Proceedings World Geothermal Congress 2000, Kyushu–Tohoku, Japan, May 28–June 10, 2000*. 3133–3138.
[17] **Waples, D.W. & Waples, J.S., 2004**. A review and evaluation of specific heat capacities of rocks, minerals, and subsurface fluids. Part 1: Minerals and nonporous rocks. *Natural Resources Research*, 13(2), 97–122.

Goh (2008[14]) measured the densities of specimens of the Devonian granites and determined a mean density of 2,580 kg/m^3. Goh (2008[14]) also reported specific heat values for the granite, and these are lower than the values predicted by Equation 1. Goh cautioned, however, that “aluminium and brass samples used as calibration pieces returned a lower than expected heat capacity”, so Equation 1 is preferred over the reported values.

6.5 Reservoir temperature

Hot Dry Rocks Pty Ltd utilized a numerical three-dimensional temperature inversion algorithm to estimate the stored heat within the reservoir. The methodology incorporated the three-dimensional numerical earth model described in Section 4, constrained by the thermal data presented in Section 5.

The algorithm operated on the principle of ‘inversion’. Known information about surface temperature and surface heat flow was entered into a software module. The algorithm ‘voxelated’ the earth model; that is, divided it into discrete rectangular prismatic cells, with the thermal properties of each cell determined by the geological unit within which the cell lay. The dimensions of the individual cells were 500 m by 500 m horizontally, by 50 m vertically. A numerical iterative process then computed in three dimensions the distribution of temperature that best matched the observed surface heat flow distribution, while respecting the laws of conductive heat transfer and the thermal properties of the geological strata. The temperature dependence of thermal conductivity was also taken into account, using a formula published by Sekiguchi (1984[18]).

The algorithm employed did not exactly match the observed heat flow values, but optimised the fit to observed values within a predefined precision. The ‘root mean square’ (RMS) misfit of the model to the six heat flow constraints was 1.38 mW/m^2. The model fit the heat flow data within uncertainty limits (Table 3) for all wells except Swan 2, which lies outside the Resource area.

The 3D inversion process predicted reservoir temperature in the range 150.0–220.0°C,with an average temperature of 177.5°C.The predicted minimum depth to the 150°C isotherm within the Resource area is 3,200 m,just east of Mt. Nicholas.

[18] **Sekiguchi, K., 1984.** A method for determining terrestrial heat flow in oil basinal areas. *Tectonophysics*, 103, 67–79.

7.0 Estimated Geothermal Resource

7.1 Total resource

The numerical algorithm revealed the simplest temperature distribution to explain the observed surface heat flow values. For each discrete cell of the reservoir units lying beneath the cut-off isotherm and above 5000 m, the stored heat was calculated from the volume, density, specific heat and temperature of the cell. The total stored heat in all individual cells was 101,450PJ_{th} within a volume of 384 km^3.

7.2 Classification of Resource

7.2.1 Inferred Geothermal Resource

The Australian Code for Reporting of Exploration Results, Geothermal Resources and Geothermal Reserves, 2008 Edition ('The Code'), defines an 'Inferred Geothermal Resource' as "*that part of a Geothermal Resource for which thermal energy in place can be estimated only with a low level of confidence…This category of Geothermal Resource is inferred from geological, geochemical and geophysical evidence and is assumed but not verified as to its extent or capacity to deliver geothermal energy. There must be a sound basis for assuming that a Geothermal Play exists, estimating the temperature and having some indication of its extent.*"

HDRPL judges that **the stored heat estimated in Section 7.1 is best classified as an Inferred Geothermal Resource**. In reaching this decision, HDRPL took into account the following points:

- Gravity, surfacing mapping and regional 2D reflection seismic data provided the basis of an interpretation of the 3D geology of the Mt. Nicholas-Fingal Geothermal Play, which defined the extent and thickness of the potential reservoir units.
- The Geothermal Resource has not yet been penetrated in the Mt. Nicholas-Fingal Geothermal Play.
- The lithological interpretation of deep seismic reflections throughout Tasmania is currently unproven by drilling.

7.3 Tabulated Resource estimate

Table states the estimated Geothermal Resource for the Mt. Nicholas-Fingal Geothermal Play as classified by the criteria in Section 7.2.

Table 4. Estimated Geothermal Resource within the reservoir unit of the Mt. Nicholas-Fingal Geothermal Play. Resource estimates are rounded to the nearest 1,000 PJ_{th}.

Reservoir	Stored Heat (PJ_{th})	Volume (km^3)	Inferred Geothermal Resource (PJ_{th})
Devonian Granites	101,450	384	**101,000**

8.0 Key Assumptions and Geological Constraints

Apart from the parameters described above, the following key assumptions underpin this Geothermal Resource estimate:

- The proposed product to be generated from the Geothermal Resource is electricity using commercially available organic rankine cycle binary plants utilizing air-cooling fans.
- The estimated Geothermal Resource does not include any additional heat that might conduct or convect into the reservoir volume during production.
- The estimated Geothermal Resource assumes that advective or convective processes within the Geothermal Play transfer no significant heat. Advective heat transfer with groundwater has been observed in some shallow wells. These occurrences are assumed to relate to shallow, gravity-driven systems. If convection occurs in the deeper sections, it will suppress geothermal gradients and reduce the estimated stored heat resource.
- The heat is contained entirely within the matrix of the reservoir rock and there is little expectation for significant *in situ* water.
- This work is based on a numerical model of a section of the Earth's crust. A model necessarily simplifies the true complexity of the Earth and as such is inherently prone to error. The results of modelling stated within this report have been generated using the best available estimates of critical parameters,

but future work may yield new information that modifies or falsifies some of these assumptions. All modelling results should be treated as provisional.

9.0 Recoverable energy

Hot Dry Rocks Pty Ltd is unaware of any geotechnical, access, environmental or land use issues that could affect future drilling locations or sterilise potential geothermal resource sectors within the Mt. Nicholas-Fingal Geothermal Play.

No well has yet been tested for production of a geothermal fluid in the Mt. Nicholas-Fingal Geothermal Play. The existence of an economically extractable Geothermal Energy Resource remains speculative until the target reservoir has been drilled and production testing has been conducted. Likewise, there is no good basis yet for determining the proportion of thermal energy that might be recovered and converted to electrical energy.

10.0 Future Work

The Code defines an 'Indicated Geothermal Resource' as "*that part of a Geothermal Resource which has been demonstrated to exist through direct measurements that indicate temperature and dimensions so that the thermal energy in place can be estimated with a reasonable level of confidence…It is based on direct measurements and assessments of volumes of hot rock and possibly fluid, with sufficient indicators to characterise the temperature and chemistry. Direct measurements are sufficiently spaced so as to indicate the extent of the Geothermal Resource.*"

The Code defines a 'Measured Geothermal Resource' as "*that part of a Geothermal Resource for which thermal energy in place can be estimated with a high level of confidence…It is based on direct measurements and assessments of drilled and tested volumes of rock and/or fluid within which well deliverability has been demonstrated, and which have sufficient indicators to characterise the temperature and chemistry. Direct measurements are sufficiently spaced to confirm continuity.*"

Reclassification of any portion of the Inferred Geothermal Resource stated in this report to an Indicated or Measured Resource will require drilling and testing of the target reservoir to directly determine temperature and reservoir properties.

11.0 Competent Person

This report has been prepared under the direction of Dr Graeme Beardsmore, an employee of HDRPL. Dr Beardsmore was assisted by other employees within Hot Dry Rocks Pty Ltd but takes sole responsibility and is accountable for the report as a Competent Person as defined by the Australian Code for Reporting of Exploration Results, Geothermal Resources and Geothermal Reserves (2008 Edition). Dr Beardsmore is a member of the Australian Society of Exploration Geophysicists and abides by the Code of Ethics of that organization.

HDRPL provides consulting services to KUTh Energy Ltd.

Dr Beardsmore consents to the public release of this report in its entirety.

Signed: ______________________ 5th March2010

Graeme Beardsmore *Date*

Appendix-1 Glossary of terms in their context as used in this report

Base temperature	The temperature of the geothermal fluid once it has passed through a power conversion process, prior to reinjection.
Basement	The deepest geological horizon considered in an assessment.
Basin	A three dimensional accumulation of sediments, usually thicker on the down-thrown side of a major fault or in the centre (as defined by the outer geographic margins of basin succession).
Cut off temperature	The minimum economic reservoir fluid temperature for commercial energy extraction.
Thermal Conductivity	A measured property of a rock indicating its ability to transfer or 'conduct' heat energy, usually measured directly in Watts per metre Kelvin (W/mK).
Density	A physical property of matter, such as rocks, measured in mass per unit volume (eg kilograms per cubic metre, kg/m^3)
Depth conversion	The process of converting reflection seismic data from the time domain to the depth domain through the use of rock velocity data.
Earth model	A three-dimensional computer model of part the earth based on grided inputs such as depth maps from well data, gravity data or seismic mapping.
Fault	A break in geological strata caused by movement along a plane of weakness.
Footwall	The up-thrown (higher) portion of a fault block (see hangingwall).
Hangingwall	The down-thrown (deeper) portion of a fault block
Heat Flow	The amount of thermal energy passing through a square metre at the earth's surface, usually expressed as milli-

	Watts per square metre (mW/m^2).
Heat Generation	The amount of heat generated by a rock through the natural decay of radiogenic elements, usually calculated in micro watts per cubic metre (μW/m^3).
Isotherm	A line or surface joining points of equal temperature.
Organic rankine cycle	An electricity production process whereby heat can be exchanged from a hot fluid to a cooler one via the use of a liquid organic compound which has a lower boiling point than the source fluid. Used in certain geothermal electricity generating plants where the fluid temperature is suitable.
Permeability	The ability of a rock to flow fluid, such as water, usually measured in milli-Darcies (mD).
Play	An exploration concept or system which consists of four principle geothermal components; heat flow, thermal insulation, reservoir and access to water.
Porosity	The 'free' space in a rock, not occupied by minerals, cement or clay. A dimensionless unit, expressed as the % of rock volume which may hold fluid.
Reservoir	A body of rock with certain permeability and porosity characteristics which enable it to hold fluids of economic interest.
Rifting	The geological process in which tectonic plates extend and fault as plates begin to pull-apart.
Sandstone	A coarse grained sedimentary rock chiefly composed of sand-sized grains of silica, feldspar and/or lithic material.
Seismic line	A line across the ground surface along which a seismic survey (involving the reading of vibrations induced in the shallow earth by a source) has or will be read.
Specific heat	The amount of energy required to raise the temperature of 1 kg of substance by 1°C; otherwise known as relative heat capacity, usually measured in Joules per kilogram per degree Kelvin (J/kg^{-1}K^{-1}).

Stored heat	The amount of geothermal energy ‘trapped’ as heat within a volume of rock. Quantified as in-place petajoules (PJ).
Stress	A vector force within the earths crust in three dimensions and magnitudes, created by pushing and subduction at plate boundaries as well as gravity. Usually quantified in mega-pascals (MPa) towards a certain direction (north, south, east or west).
Well	A bore hole