Queensland Coastal Geothermal Energy Initiative – An Approach to a Regional Assessment

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The best-known potential geothermal resources in Queensland are located beneath the Cooper-Eromanga Basins in the south-west of the state. The depth to the resources, and their distance from potential markets and the existing national electricity grid, are the main challenges for their development for power generation in the near term. The $5 million Coastal Geothermal Energy Initiative (CGEI) is the Queensland Government's program to implement the commitment made in the ClimateSmart 2050 strategy through the Queensland Renewable Energy Fund to investigate additional sources of hot rocks for geothermal energy close to existing transmission lines and potential markets. The initiative is a cooperative project between Office of Clean Energy and Geological Survey of Queensland (GSQ) and comprises a structured drilling program of shallow boreholes for the collection of new datasets to identify heat-flow anomalies along the east coast of Queensland. Target areas have been identified based on geological and geophysical characteristics and have been ranked based on their potential for a geothermal resource. The CGEI will reduce exploration risks and assist potential explorers to explore for and develop this source of clean energy in Queensland.

Keywords: Queensland, geothermal exploration, drilling, heat flow, inversion modelling.

Objectives

The main objectives of the CGEI are to identify prospective areas along the east coast of Queensland and collect additional datasets through a shallow drilling program. The purpose of this is firstly to increase knowledge of the crustal temperatures along the coast and secondly to provide an enhanced assessment of geothermal resource potential by generating basic datasets. This new data should assist geothermal exploration and development programs in Queensland.

Heat Flow Investigation

A precise crustal heat-flow determination is the preferred method of identifying the geothermal prospectivity of a target area. Heat flow is the product of the temperature gradient and the thermal conductivity of rocks in the earth's crust, and can be determined through the sampling and logging of cored drill holes. A heat-flow investigation program has been planned as part of the CGEI to evaluate the geothermal prospectivity of selected geological provinces along the east coast of Queensland.

Drill Target Selection

The potential occurrence of suitable heat sources within basement was evaluated, based on available geophysical datasets and regional geological knowledge for each area. The main geothermal source/reservoir targets are felsic crystalline basement rocks such as granitoids and rhyolite with high thermal conductivity values (generally greater than 4 Watt per meter Kelvin (W/mK)) and high radiogenic heat production ability (greater than 5 micro Watt per cubic meter ($\mu W/m^3$)).

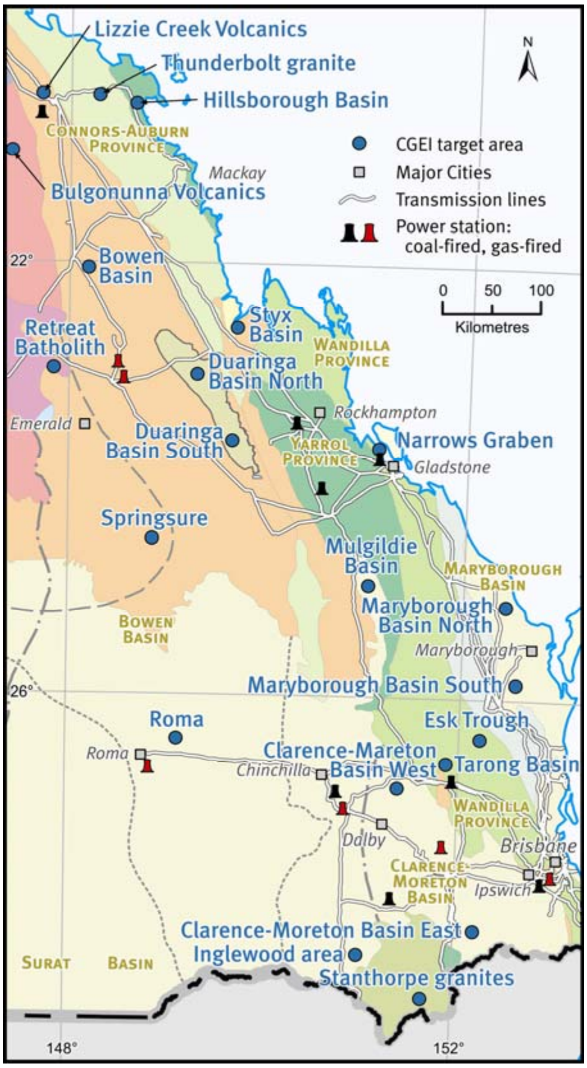

Figure 1a: Location of CGEI drill targets in Central and Southern Queensland

Priority in the CGEI was given to geological provinces where geothermal source/reservoir units are overlain by a thick succession of thermal blanketing sediments with harmonic mean thermal conductivity values generally less than 3 W/mK. The assessment process involved a desktop analysis of each geological province. The provinces were selected as they were considered likely to have a high heat-flow or evidence of previous elevated temperatures. Existing temperature data from available petroleum wells in or adjacent to each geological province were considered to infer subsurface temperature gradients. The main obstacle to this approach has been the variable data quality and availability in eastern Queensland where petroleum drilling is relatively rare. The temperature gradients were integrated with the available geological and geophysical data with the aim of identifying possible sources of heat at depth. Specific targets were then identified that would test the interpretation that this part of the geological province has geothermal potential.

To date, forty-seven targets generally within 100km of the existing national electricity grid have been identified with thirty-two being selected for drilling. These targets are located from near Cairns in the north to the border of New South Wales (Figures 1a, b).

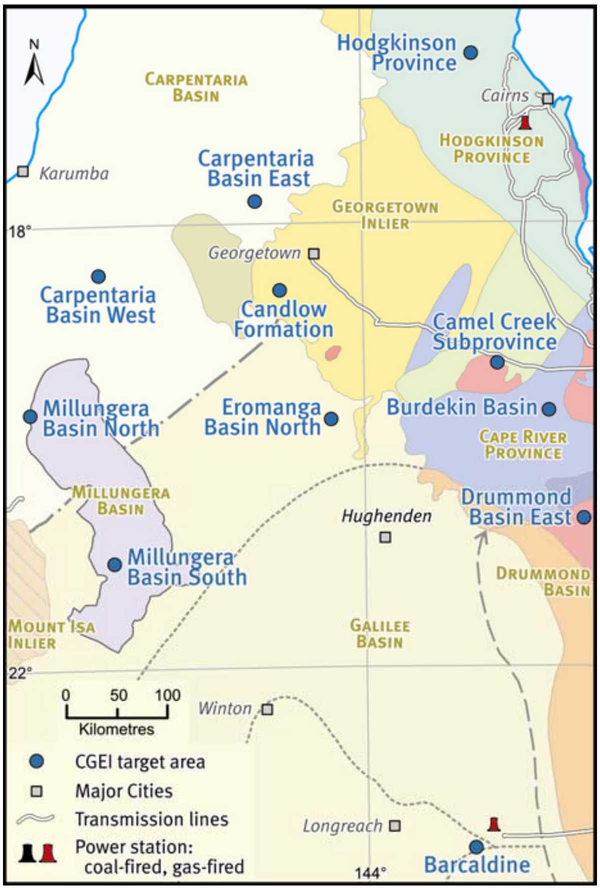

Figure 1b: Location of CGEI drill targets in Northern Queensland

Technical criteria were used to rank targets in order of likelihood of the identification of a geothermal resource. The criteria were based on the nature of the basement and the thermal blanketing sedimentary cover. All targets were ranked against these criteria in order to establish a drilling priority. The final location of each drill hole was determined after consultation with landholders and consideration of terrain condition, environmental and cultural heritage issues. The spatial distribution of the holes effectively requires each site to be considered as a drilling project in its own entity. Consequently, a substantial amount of extra work has been required to obtain the necessary clearances. Phase 1 drilling of the 10 highest priority targets is scheduled to commence in late 2010 (pending contract confirmation).

Geological Setting

Traditionally, rifting margins have been identified as more prospective for geothermal energy exploitation. However, preliminary geological assessment of the geothermal potential of coastal Queensland shows a variety of tectonic settings may host high heat producing (HHP) granites under insulating cover sequences. The assessment process resulted in the identification of five different geological settings which are summarised in Table 1.

Table 1: Geological Setting of CGEI Targets

AGE	Geological Setting	No. of CGEI Targets
Proterozoic	Intercontinental rifting	5
Ordovician-Silurian	Thomson Orogen	4
Early Carboniferous–Early Permian	Tasman Orogenic Zone	13
Late Permian – Mid Triassic	Hunter Bowen Orogen	7
Late Cretaceous - Tertiary	Cretaceous Rifting	3

Intercontinental Rifting: The Proterozoic was a time of elevated heat flow causing the emplacement of voluminous granites and associated volcanics in northern Queensland (McLaren et al, 2003). These granites were emplaced during multi-stage intracratonic rifting events and in some areas they are overlain by sedimentary basins which include the Millungera Basin (no younger than Triassic, Figure 2) and the Jurassic - Late Cretaceous Carpentaria Basin. The heat production values of 5-9 μW/m^3 (GSQ Geochemistry database, 2010) from intrusives of the Croydon Province and the Georgetown and Mt Isa Inliers (including the Esmeralda, Forsayth and Williams Supersuites) delineate a prospective heat source at depth in these areas. A number of geophysical tools including gravity, magnetic, magnetotelluric and radiometric ternary images as well as sporadic drilling data were used to identify five targets which are considered worthy of further investigation. These targets are found beneath the insulating units of the Karumba, Carpentaria and Millungera Basins and the Georgetown Inlier (Figure 1b).

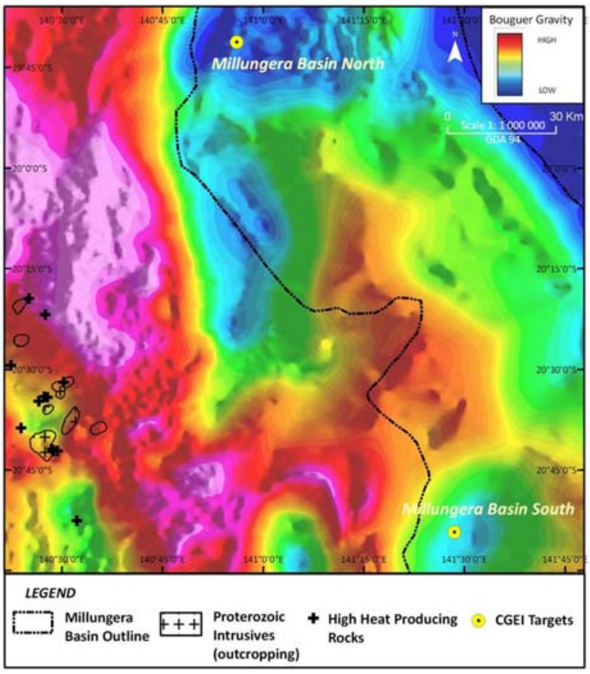

Figure 2: Millungera Basin CGEI rationale, showing gravity response (Bouguer), location and extent of outcropping Proterozoic intrusives and high heat producing rocks

Thomson Orogen: Another region of outcropping potentially HHP granites is located within the basement packages of the Ordovician-Silurian Thomson Orogen. The heat production values of I-type and S-type granites are generally greater than 5 μW/m^3. If properly insulated, these granites would provide a geothermal heat source at depth. A geophysical and geological assessment identified the western and southern Bowen Basin, eastern Drummond Basin,and the Burdekin Basin, as target areas, as inferred HHP granites are present in the basement complexes of these basins with Tertiary volcanics, which could indicate an additional, younger contributing heat source.

Tasman Orogenic Zone: The Carboniferous-Permian intrusions of the Tasman Orogenic Zone (which encompasses the Northern Tasman Orogenic Zone and the New England Orogen) contain medium to high concentrations of the radiogenic elements uranium, thorium and potassium and should be prospective for geothermal energy potential. Within the Northern Tasman Orogenic Zone, the Carboniferous–Permian Wypalla Supersuite and the Purkin Granite have heat production values between 3.5-8.55 μW/m^3 (GSQ Geochemistry database, 2010). The heat production potential of these intrusive units at depth in conjunction with a good insulating capacity and thickness of overlying cover sequences have identified three targets within the Hodgkinson Province, northern Eromanga Basin and Camel Creek Province. The existence of anomalous heat flow within the Hodgkinson Province in particular can be inferred by the Innot hot spring which has a surface temperature of 71°C (Lottermoser & Cleverley, 2007). This spring is located in the southern part of the province.

The New England Orogen contains numerous I-type and S-type intrusions and associated felsic volcanics. Whole rock geochemical analyses of these units indicate medium concentrations of potassium, thorium and uranium. As a result the geological and geophysical assessments undertaken delineated where these intrusives extend at depth underneath insulating basins. The overlying insulating sedimentary packages include oil shale units of the Duaringa Basin and extensive coal measures of the Bowen, Clarence-Moreton and Styx Basins. Nine sites were selected for heat flow determinations including the Bulgonnuna Volcanics, Lizzie Creek Volcanics, Bowen Basin, Roma Granite, Styx Basin, Duaringa Basin, western Clarence Moreton Basin (Jandowae) and Inglewood (Figure 1a).

Hunter Bowen Orogen: The onset of the Permian-Triassic Hunter Bowen Orogen initiated the widespread emplacement of granites along the New England Fold Belt. Elevated heat is likely as the granitic outcrops generally have heat production values greater than 5 μW/m^3. Gravity, seismic and magnetotelluric datasets suggest these potentially HHP granites extend at depth underneath the cover of the Tarong, Mulgildie, Clarence-Moreton, Galilee and Maryborough Basins, which all contain coal measures. A more detailed geological and geophysical assessment of these basins identified seven target sites as prospective for elevated heat flow namely the Thunderbolt Granite, Tarong Basin, eastern Clarence-Moreton Basin, Mulgildie Basin, Stanthorpe Granite, Barcaldine and northern Maryborough Basin (Figures 1a and 3).

Cretaceous Rifting: The Cretaceous saw the cessation of the active convergent margin along the east of the Australian continent and the initiation of rifting of the Tasman and Coral Seas. Cretaceous granites lining the western edge of the Maryborough Basin (Figure 3) may be a prospective geothermal target. The sediment thickness of the overlying Maryborough Basin is up to 3400m with two significant coal sequences, Tiaro Coal Measures and Burrum Coal Measures, forming an excellent insulator to any potential heat producing intrusive at depth.

The Hillsborough Basin (Figure 4) and Narrows Graben sites primarily target the more northern Cretaceous intrusions. These two sites may also benefit from additional heat sources associated with intrusions and related volcanics of the Late

Cretaceous Whitsunday Large Igneous Province. In addition, volcanics resulting from Tertiary rifting and intraplate volcanism suggest that there still may be significant heat production in this area. The insulating capacity of the Hillsborough Basin and Narrows Graben sequences is considered to be good due to the presence of significant intervals of oil shale.

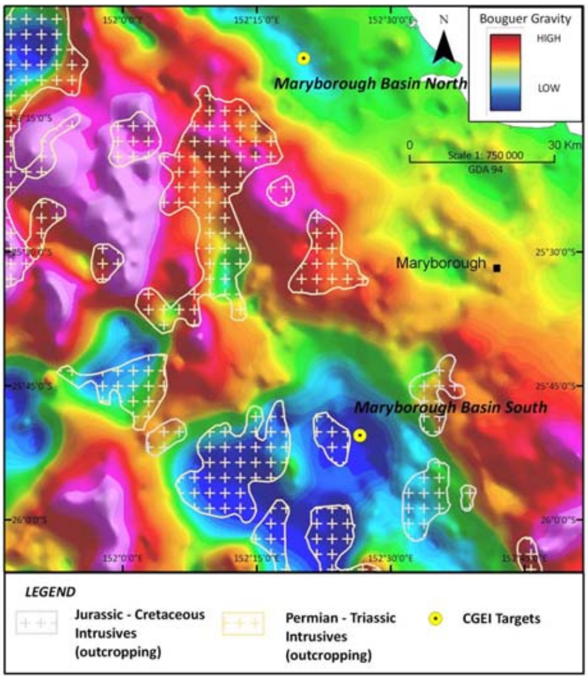

Figure 3: Maryborough Basin CGEI rationale, showing gravity response (Bouguer), location and extent of Jurassic-Cretaceous and Permian-Triassic outcropping intrusives

Drilling Program and Data Collection

An effective heat-flow determination process requires a shallow (300–500m) drill hole, suitably completed to enable a temperature log to be acquired that accurately records the temperature in lithological units intersected. In order to get an accurate temperature log the hole needs to remain undisturbed for sufficient time (typically 5–8 weeks) to minimise any remaining drilling-induced temperature disturbances and essentially ensure that the downhole temperature is adequately re-equilibrated. Each well is then thermally logged from the surface to the bottom of the hole by measuring a temperature at specific intervals (typically every 1 meter). From these measurements, temperature gradients can be calculated for the corresponding intervals down the hole.

The hole should also be continuously cored from the base of unconsolidated units to total depth (~320m) to recover at least 200-250 meters of continuous core enabling samples to be taken and analysed for thermal conductivity properties in order to establish a thermal conductivity profile for the hole. Core samples are usually taken at regular intervals, typically every 10 metres. Sampling is to be undertaken at the drill site immediately after the core has been logged. Each sample is enclosed in plastic wrap to preserve their *in-situ* fluid saturation levels prior to dispatch to a laboratory. Visual assessment of the downhole geology (lithological log) against the temperature log will also be used as a tool for further sampling in case additional thermal conductivity analyses are required at a later stage (Figure 5).

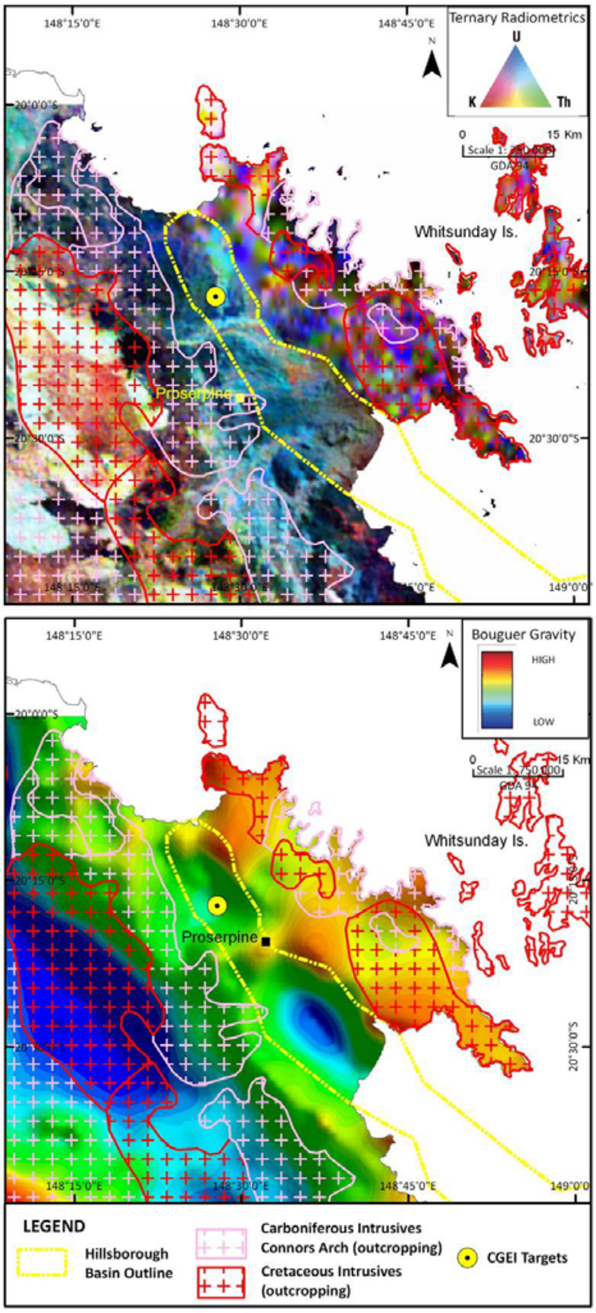

Figure 4: Hillsborough Basin CGEI rationale, showing gravity response (Bouguer), ternary radiometric image, location and extent of outcropping Carboniferous and Cretaceous intrusives

The CGEI drilling program is likely to consist of up to 32 HQ size shallow boreholes to a nominal depth of ~320 metres cased with continuous PVC. The hole design and completion have been optimised to ensure that a high quality data collection process is attained throughout the program (Figure 6). A call for tender was released in June 2010 for the selection of drilling contractors. Geophysical downhole logs such as Resistivity, Spontaneous Potential (SP) and Gamma Ray are being run on an "as–required" basis with the aim of determining possible aquifer leakage into the hole that may interfere with the temperature profile and also for data quality checking purposes.

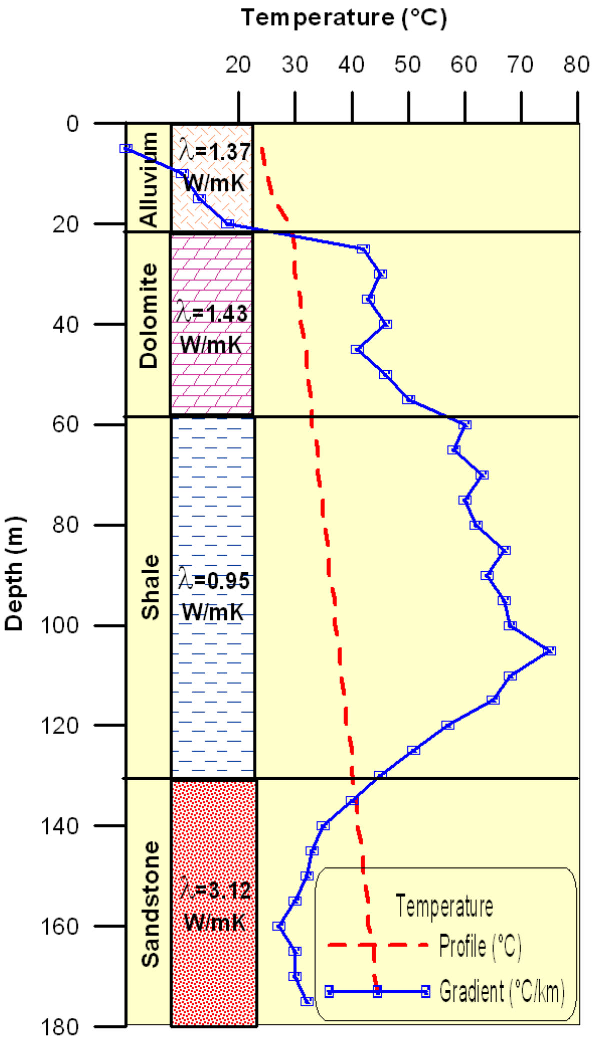

Figure 5: Example of a temperature log versus lithological log

Heat-Flow Modelling

Mathematically, the average vertical conductive heat flow at the earth's surface, q (in W/m^2), can be calculated using the Fourier expression:

$$q = k.\frac{dT}{dz}$$

Where (k) is the rock thermal conductivity (in W/mK) at depth z, and (dT/dz) is the corresponding vertical temperature gradient (in K/m) over the same interval. As shown by the equation, the temperature gradient has an inverse relationship with thermal conductivity (one decreases as the other increases). This assumes a purely conductive regime and therefore a constant heat flow across all lithological units intersected. From the global heat-flow database, the mean surface heat flow of the Australian continent is approximately 65 mW/m^2, so areas with heat-flow values greater than this may indicate promising areas for further geothermal investigation and exploration activities provided that the thermal resistance of the overlying lithological units is sufficient to support presence of economical temperature at depth.

Considering the spatial coverage of the CGEI, one dimensional inversion modelling of the conductive heat-flow regime in the vicinity of each borehole is to be undertaken using the new temperature and thermal conductivity datasets collected (Figure 7). Modelled data will then be extrapolated to 5 km, the economic drilling depth for most geothermal resources, to predict temperatures at this depth range. Generally, temperatures of greater than 200°C are expected at such depths for Engineered Geothermal System (EGS) to be commercially viable for electricity generation.

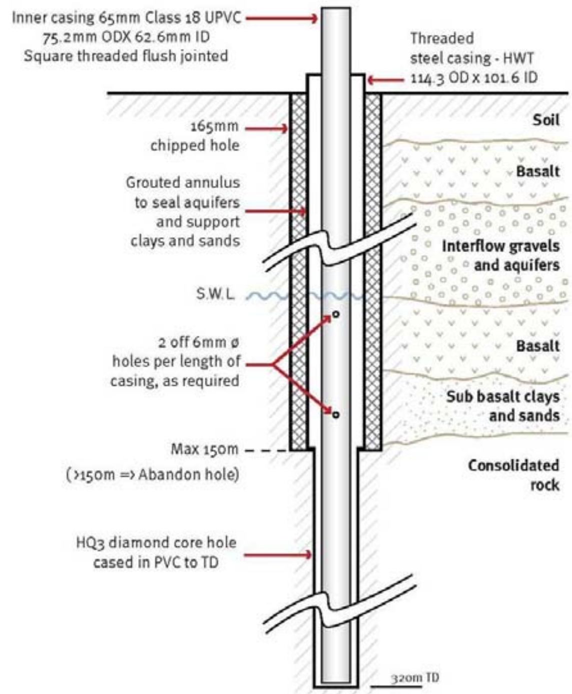

Figure 6: Schematic borehole design

In addition, depth predictions of the 100, 150 and 200°C isotherms may be approached depending on data availability for estimating the formations intersected at those isotherm depths. This will assist in the assessment of the prospectivity of each target area for either Hot Sedimentary Aquifer (HSA) or Engineered Geothermal System (EGS) development in the future.

Collaboration

Collaboration with other government agencies, research centres and industry is an important part of this initiative. In this respect, Geoscience Australia will provide technical support to the CGEI by providing down-hole temperature logging and laboratory analysis services through an agreement under the National Geoscience Accord. Furthermore, additional research over the CGEI target areas has been discussed through collaboration with the Queensland Geothermal Energy Centre of Excellence (QGECE) based at the University of Queensland through post-graduate research studies.

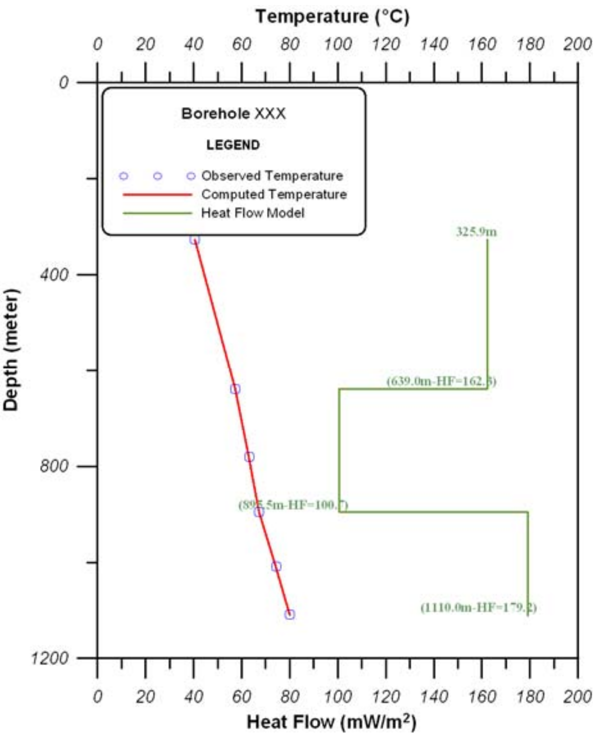

Figure 7: Example of 1D inversion heat flow modelling

Future Work

Future work that would contribute to a better understanding of geothermal prospectivity in eastern Queensland would include the collection of new heat-flow data at a closer spacing for prospective areas identified from the CGEI. An assessment of current regional and local *in-situ* stress fields in those areas could also be undertaken to evaluate the susceptibility of potential reservoir rock to the artificial permeability enhancement process.

Summary

The Coastal Geothermal Energy Initiative is the Queensland Government's program for identifying sources of hot rocks for geothermal energy close to existing national electricity grid and potential markets along the east coast of Queensland. The initiative will be implemented through a structured drilling program of up to 32 shallow boreholes with a nominal depth of ~320 metres to collect new temperature and heat-flow datasets. The major aim of the initiative will be to increase knowledge of the crustal temperatures in selected geological settings along the coast and provide background data for industry that would consequently stimulate exploration activities for geothermal energy in Queensland. It is anticipated that final results of the initiative will be publically available by the middle of year 2012.

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