Approaches for identifying geothermal energy resources in coastal Queensland

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The Coastal Geothermal Energy Initiative is a Queensland Government Program designed to investigate sources of hot rocks close to existing transmission lines along the east coast of Queensland where modelled crustal temperatures at 5km are generally <150°C. The modelled low temperatures in this coastal region could reflect insufficient and poorly distributed data rather than an absence of suitable geothermal targets. The initiative involves a series of drill holes for the specific purpose of taking downhole temperature readings and obtaining cores for measurement of thermal conductivity to calculate heat-flow. The drill holes are to be sited in areas considered to have potential to contain hot rocks. Selection of these areas is based largely on an understanding of the geological setting and history of this part of Queensland. This paper highlights five different geological targets identified for further investigation. These targets include an extrapolated buried granitoid, inferred granitoids from geophysical anomalies, and three sedimentary basins that contain either low thermal conductivity coal or oil shale. A variety of techniques have been used in the assessment of these targets, involving the integration of different geological and geophysical data.

Keywords: Queensland, Coastal Geothermal Energy Initiative, Texas beds, Stanthorpe, Tarong Basin, Styx Basin, Hillsborough Basin, geothermal exploration

Background

In June 2007, the ClimateSmart 2050 *Queensland climate change strategy 2007: a low-carbon future* was released, embracing a commitment to investigate sources of hot rocks for geothermal energy close to existing transmission lines. The Coastal Geothermal Energy Initiative (CGEI) is the project that has been established to undertake this investigation. The CGEI is a cooperative project between the Office of Clean Energy and the Geological Survey of Queensland, within the Department of Employment, Economic Development and Innovation (DEEDI).

CGEI will obtain continuous temperature logs in the purpose drilled holes to augment existing data. These holes will be cored from surface to total depth of 300-320m and then be allowed to re-equilibrate before being logged. Thermal conductivity measurements will be taken from core samples to calculate heat-flow.

Coastal regions of Queensland have not been previously considered to be prospective for geothermal energy as modelled crustal temperatures are generally <150°C (Chopra & Holgate, 2005). These low temperatures could reflect a lack of data in the appropriate areas.

The absence of temperature and heat-flow data highlights the need for a different approach to identifying geothermal energy resources in coastal Queensland. The CGEI is the first government program in Australia designed to directly target gaps in temperature and heat-flow data coverage across the state.

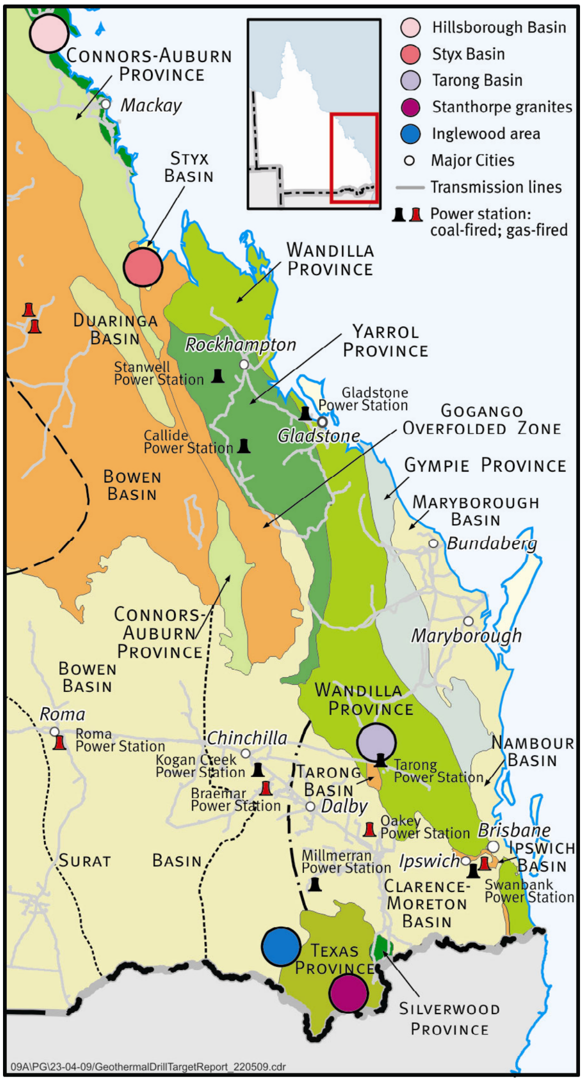

Figure 1: Map showing locations of five geological targets for assessment in the CGEI.

Initially, target areas were identified from an understanding of the geology and tectonic history of eastern Queensland. These areas were considered to have the potential to have elevated temperatures at a shallow depth. No specific geothermal-energy model has been applied to their selection.

Detailed assessment of the target areas is being undertaken using the available geological and geophysical data. Geophysical modelling is being undertaken over target areas where geophysical datasets are suitable, to better define the geothermal target.

Heat production values referred to in this paper have been calculated from whole-rock geochemistry data of granitoids across the state. A heat-production equation (Rybach, 1988) has been used to determine locations of values greater than five microwatts per cubic metre ($\mu W/m^3$).

This paper presents five examples (Figure 1) of the types of geological targets to be tested and the approaches used in their assessment. These targets include an extrapolated buried granitoid, inferred granitoids from geophysical anomalies, and three sedimentary basins that contain low thermal conductivity lithologies such as coal or oil shale.

Inglewood area

Geological Outline

In the Inglewood area, Jurassic-Cretaceous rocks of the Clarence-Moreton and Surat Basins unconformably overlie Carboniferous Texas beds basement. These rocks are unconformably overlain by Tertiary-Quaternary flow remnants of the Main Range - Lamington Basalt Province. Mesozoic units that outcrop/subcrop over the area include the Marburg Subgroup (Lower-Middle Jurassic), the Walloon Subgroup (Middle Jurassic) and the Kumbarilla beds (Middle Jurassic-Early Cretaceous).

The Texas beds form part of the Texas Subprovince, within the central part of the New England Orogen. The turbidite-dominated Texas beds are intruded by Permian-Triassic mainly I-type plutons assigned to the New England Batholith.

Regional Geophysics

The regional magnetic data highlight the structural grain of the western limb of the Texas Megafold. The most obvious surface features are strongly magnetic and magnetically altered rocks in the Texas beds, and moderate to strongly magnetic basalt lavas. These units contrast with the weakly magnetic Clarence-Moreton and Surat Basin successions. Unexposed, moderate to strongly magnetic granitoid intrusions vary in shape and size. The most prominent of these is located west of Inglewood and forms the basis of this investigation. The Stanthorpe Granite farther east also has a moderate to strong positive total magnetic intensity (TMI) response, and is high-heat producing. A number of unexposed, non-magnetic granitoid intrusions have also been interpreted in the Inglewood area (Purdy et al., 2005).

Target Rationale

The premise to be tested is that Carboniferous accretionary wedge rocks and Mesozoic fluvio-lacustrine rocks are insulating a high-heat producing intrusion.

The target is a north-south trending, elliptical, magnetic anomaly west of Inglewood (Figure 2). This anomaly (~90km^2) has a strong positive TMI response. Preliminary modelling demonstrates that the magnetic anomaly may be explained by a diapiric-shaped pluton intruding basement, with the most magnetic material occurring more than 500m below the surface. Donchak et al. (2007) suggested a Permian-Triassic age range for this magnetic unit.

A water supply bore drilled on the anomaly bottomed in Marburg Subgroup at 227m. No bottom-hole temperature was taken. If the unit is high-heat producing and there is sufficient insulation, it could be a viable geothermal target.

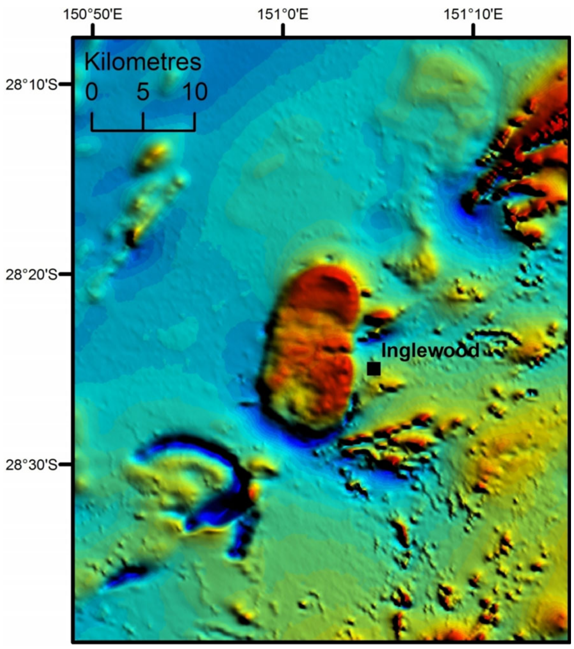

Figure 2: Total magnetic intensity image – colour drape of the Inglewood area.

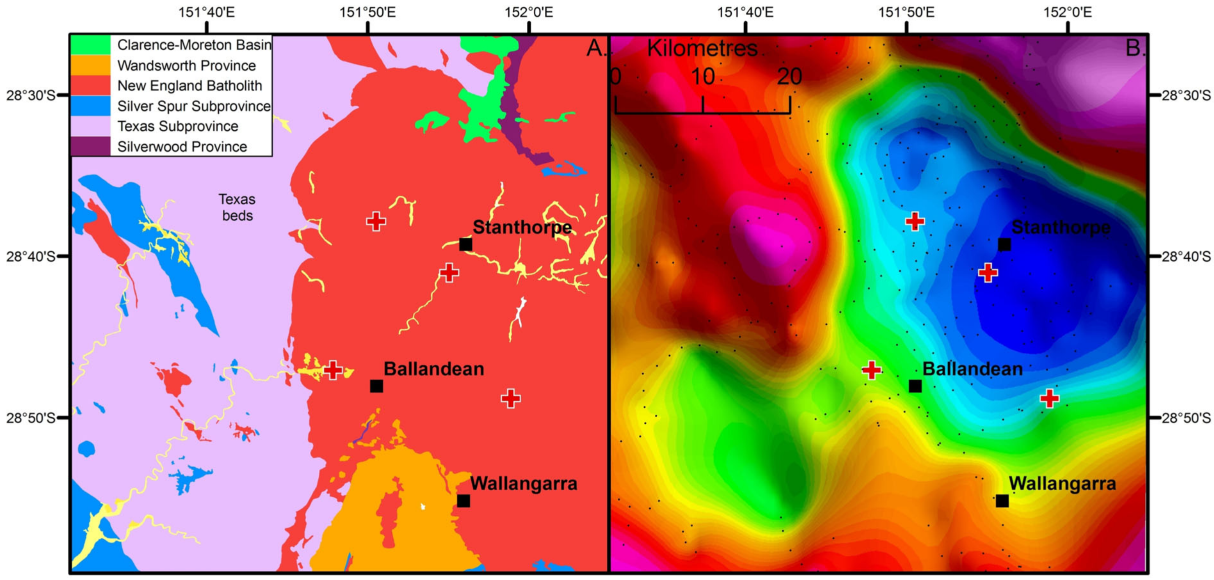

Figure 3: A. Structural elements map of the Stanthorpe area. B. Regional Bouguer gravity image (National Gravity Database). Regional gravity trend removed. Red crosses denote heat-production values greater than 5 W/m^3. Note irregular gravity station spacing.

Stanthorpe area

Geological Outline

Another target area of the CGEI is the Stanthorpe area, in the Texas region of south-east Queensland. The Texas beds (Carboniferous) form the most extensive unit in this region (Figure 3A). The unit is dominated by volcaniclastic turbidites, altered mafic volcanics, and limestone. Granitic rocks (Permian-Triassic) intrude the Texas beds. Intrusions are mainly I-type plutons assigned to the New England Batholith. The most widespread bodies of granite crop out in the Stanthorpe area, where they are mapped as the Ruby Creek Granite (Early Triassic), the Ballandean Granite (Late Permian-Early Triassic) and variants of the Stanthorpe Granite (Early Triassic). The Ruby Creek Granite and Stanthorpe Granite are leucogranites; the Ballandean Granite is dominantly monzogranite.

Regional Geophysics

The highly evolved Stanthorpe and Ruby Creek Granites of the Stanthorpe complex show mainly white tones on a ternary radiometric image, indicating enrichment in all three radioactive elements. The Stanthorpe Granite has three high-heat production values (max. 6.15 µW/m^3), and the Ruby Creek Granite one high-heat production value (6.31 µW/m^3) (Figure 3).

As part of a preliminary geophysical assessment, local-area stretching techniques have been applied to regional Bouguer gravity data from the National Gravity Database. The effects of regional trend have been removed. Figure 3B shows an enhanced stretch of anomalies in the Stanthorpe area.

Target Rationale

The target for investigation is an area where Stanthorpe complex granites extend under insulating cover. The Texas beds may have facilitated the development of a steep thermal gradient relative to surrounding areas.

Although gravity station spacing is sparse, a second gravity low to the west is likely to be granite. The Ruby Creek Granite crops out over part of the anomaly. Tin/polymetallic deposits in this area are hosted within hornfelsed Texas beds, capping very shallow-level and possibly extensive plutons of the Ruby Creek Granite (Donchak et al., 2007).

The continuation of high-heat producing granites under cover favours the Stanthorpe area as a geothermal energy source. Geophysical modelling will be used to infer the dip of granite contacts and to better define the geothermal target.

Tarong Basin

Geological Outline

South-east Queensland contains a number of isolated, coal-bearing, intermontane basins that formed during the extensional phase of the Late Triassic (e.g. Callide, Tarong and Ipswich Basins). These basins are underlain by a range of older rocks of variable derivation, which in most cases can only be determined with uncertainty by extrapolation from outcrops on the margins of the basins.

The Tarong Basin, an arguably 1.86 kilometre deep accumulation of conglomerate, pebbly sandstone, sandstone, shale and coal is of interest owing to the presence of the radiogenic granites within the Boondooma Igneous Complex (Late Permian to Early Triassic) to the west and north-west of the basin.

This basin contains coals of moderate rank with a maximum vitrinite reflectance (R^{o}, max) of 0.68%, which suggests that they were subject to higher temperatures in the past.

Regional Geophysics

The regional gravity coverage broadly outlines the extent of the basin as a north-north-west trending graben (Figure 4). The Boondooma Igneous Complex crops out along the western margin of the basin and is also coincident with a well defined gravity anomaly to the north-west. Sediments of the basin have been locally derived from granitic rocks of the Boondooma Igneous Complex, and basal conglomerates contain granitic boulders and cobbles. Consequently, these sediments have a high radiometric signature on a ternary RGB image.

Although it is unknown what underlies the Tarong Basin, the gravity response does not rule out the presence of granitic basement under the coal-measures sequence. Geochemical analyses suggest heat production from radiogenic granites of the Boondooma Igneous Complex can be considered to be moderate.

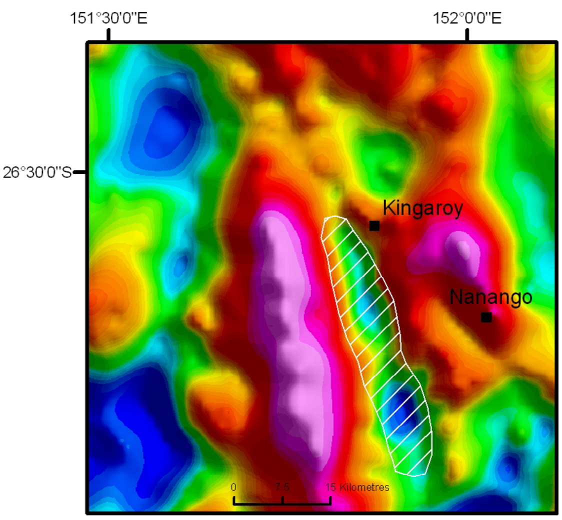

Figure 4: Regional Bouguer gravity image over Tarong Basin and Boondooma Igneous Complex (National Gravity Database). Regional gravity trend removed.

Target Rationale

The Tarong Basin has been selected as a potential geothermal target owing to the thickness of the sedimentary succession and the presence of coal to act as an effective insulator. Based on the available geological and geophysical data, the Boondooma Igneous Complex is present to the west and north-west and is interpreted to underlie the western part of the basin. The combination of Boondooma Igneous Complex at depth and the sedimentary cover provided by the infill of the Tarong Basin suggests that this is a valid geothermal target.

Hillsborough Basin

Geological Outline

A number of narrow, linear, fault-bounded Tertiary grabens occur along the Queensland coast. These structures developed during an active phase of extension associated with the opening of the Tasman and Coral Seas, beginning in the Late Cretaceous (Day et al., 1983).

The Hillsborough Basin is defined by a north-west south-east asymmetrical graben, extending from Proserpine area offshore to Cape Hillsborough. The basin is also interpreted to extend north from Proserpine to Edgecumbe Bay.

Basin infill (Paleocene-Middle Oligocene) consists of minor conglomerate, sandstone, siltstone, oil shale with volcanics and volcaniclastics in the basal sequence. Acid volcanics and sediments crop out at Cape Hillsborough (Cape Hillsborough beds) and may be correlate to the lower part of the basin sequence (Gray, 1973).

Campwyn Volcanics? (Late Devonian-Early Carboniferous) were intersected in an exploration well in the southern onshore part of the basin and are interpreted to form basement. North of Proserpine basement can only be inferred from rocks exposed adjacent to the basin margin. Carmila beds (Permian) crop out along the north-western margin and Edgecumbe beds (Carboniferous) and silicic volcanic rocks of the Whitsunday Volcanic Province (Cretaceous) are exposed along the north-eastern margin.

Oil shales and lignites are present within the sedimentary sequences of the Hillsborough Basin and include the McFarlane Oil Shale deposit.

Regional Geophysics

A seismic refraction and reflection survey over the southern onshore part of the Hillsborough Basin resulted in definition of an asymmetrical syncline with a maximum stratal thickness of 2100m (Gray, 1973). The basin deepens to the north-east and is bound by the Proserpine Fault. The south-eastern flank slopes more gently and basin infill onlap basement. The deepest part of this structure (south of Proserpine) is coincident with a well defined gravity low anomaly (Figure 5).

A second, weaker gravity low occurs to the north of Proserpine. An early oil shale exploration drill hole (PDD01) intersected approximately 509m of Tertiary rocks, indicating the basin continues to the north-west. Interpretation of the gravity coverage suggests a ridge separates the sub-basins.

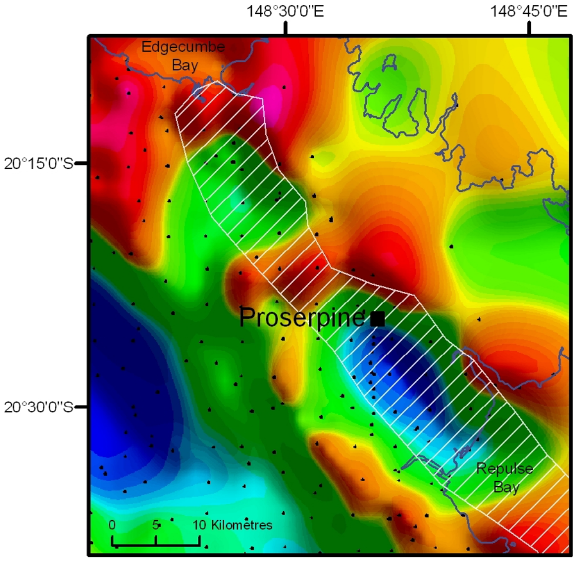

Figure 5: Regional Bouguer gravity image (with gravity stations) over the north-western (onshore) Hillsborough Basin (National Gravity Database). Regional gravity trend removed. Note lack of gravity stations in the east.

Target Rationale

The Hillsborough Basin has been selected as a potential geothermal target owing to the thickness of the sedimentary succession, particularly in the southern onshore part of the basin, and inferred high-heat-flow conditions induced by an extensional history. The presence of siltstone and oil-shale sequences may be an effective insulator.

The extensional history of the basin suggests there may be a significant amount of heat remaining within the lithosphere. Cooling may have been slowed by the presence of a thick sedimentary sequence. The target philosophy will be to determine the effectiveness of siltstone and oil-shale sequences as insulators. Geophysical modelling may be used to advance this geological assessment and to better define the geothermal target.

Styx Basin

Geological Outline

The Styx Basin is a small Early Cretaceous sag(?) basin, straddling the central Queensland coast near St Lawrence.

The Styx Coal Measures are predominantly fluvial, with occasional marine incursions, and comprise fine-grained sandstone, mudstone, conglomerate and coal-bearing units (Malone, 1970). The Styx Coal Measures unconformably overlie a folded sequence of Permian Back Creek Group and Boomer Formation of the Bowen Basin. Sediments and volcanic rocks of the Carmila beds (Early Permian) underlie Bowen Basin strata. Styx Basin sediments onlap Permian strata to the west, and are faulted against the Back Creek Group to the east. Adjacent to the fault, Cretaceous strata have been folded and faulted.

The nature of the basement rocks beneath the Bowen Basin in this area can only be inferred from exposed rocks outside the basin. The Connors Arch (Late Devonian-Late Carboniferous) is exposed to the west and consists predominantly of silicic volcanic rocks of the Connors Volcanic Group, which have been intruded by Late Carboniferous granites. It is plausible to infer Connors Arch rocks may form basement to Permian strata underlying the Styx Basin.

The Connors Arch is separated from the basal strata of the Bowen Basin by the Carmila beds. The Carmila beds and Bowen Basin strata have been deformed as part of the Gogango Overfolded Zone.

Numerous coal seams occur within the Styx Coal Measures, but they are generally variable in thickness and lateral extent (Svenson & Taylor, 1975). Coals are considered high volatile bituminous coals with vitrinite reflectance (R^o, max) between 0.8-0.95%, indicating a history of higher temperature.

Regional Geophysics

The regional gravity data reflect the location of the Styx Basin and underlying Permian strata of the Bowen Basin as a gravity-low anomaly. The basin deepens to the north and is reflected by a decrease in gravity values.

The Back Creek Group is characterised by a 'hot' radiometric signature (moderate to high in all three channels), appearing as whitish on a composite RGB radiometric image (Figure 6) (Withnall et al., 2009). Carboniferous granitic intrusions of the Connors Arch also exhibit a radiogenic (enriched in all three radioactive elements) signature on the ternary radiometric image (Figure 6). Geochemical analyses of radiogenic granitic rocks in the southern part of the Connors Arch suggest heat production can be considered to be moderate. Some felsic volcanic units within the Connors Volcanic Group also show a high radiometric signature.

Target Rationale

The target for investigation in the Styx Basin includes insulating sedimentary strata overlying radiogenic units of the Permian Back Creek Group and inferred radiogenic granites of the Connors Arch.

The Styx Basin is unlikely to have been deeply buried considering the relative stability of eastern Queensland since the Early Cretaceous. Therefore, the high rank of the coals is unlikely to have been achieved through deep burial. An elevated heat flow seems a more likely explanation to produce a higher rank at a shallow depth. The elevated heat flow suggests contribution from several sources, including the Back Creek Group and, potentially, granitic intrusions of the Connors Arch. If the Permian Bowen Basin and Cretaceous Styx Basin sedimentary rocks provide effective insulation, then the radiogenic granites of the Connors Arch could be a prime geothermal target.

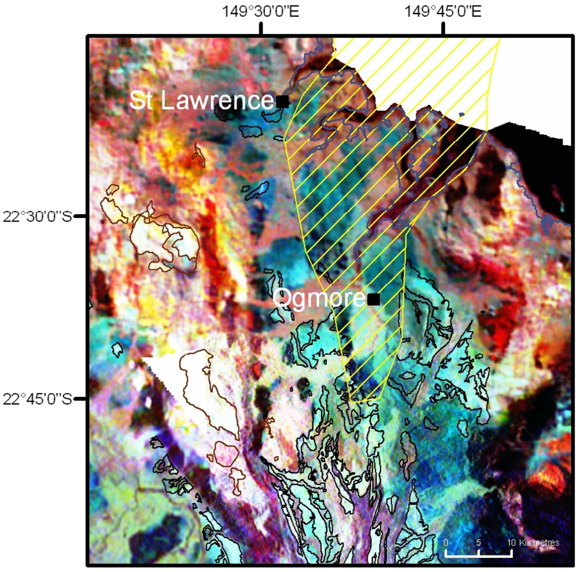

Figure 6: Ternary radiometric image over the onshore part of the Styx Basin and surrounding area. Units of the Back Creek Group are shown by a black outline. Maroon outline denotes Late Carboniferous granitic intrusions of the Connors Arch which have whole-rock geochemical data.

Summary

The Coastal Geothermal Energy Initiative will investigate sources of hot rocks close to existing power transmission lines along the coastal area of Queensland. The major aim of the initiative will be to increase knowledge of the crustal temperatures in selected areas along the coast. It is the first government program in Australia designed to directly target gaps in temperature and heat-flow data coverage in Queensland. The work program will identify potential geothermal targets where high temperature and heat flow may be present. The initiative will test these targets by obtaining temperature and thermal conductivity data within these areas via a cored-drilling program.

No specific geothermal-energy model has been applied to the selection of areas. Five examples of the types of targets that are currently being assessed, through the integration of different geological and geophysical data, are addressed.

Future work will include geophysical modelling of these targets and expanding the assessment process to include other geological settings likely to contain potential geothermal targets.

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