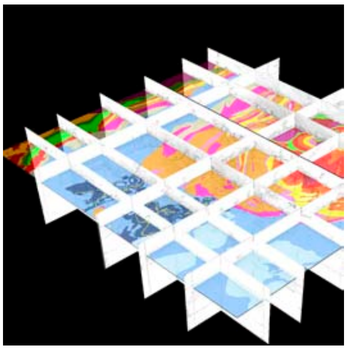
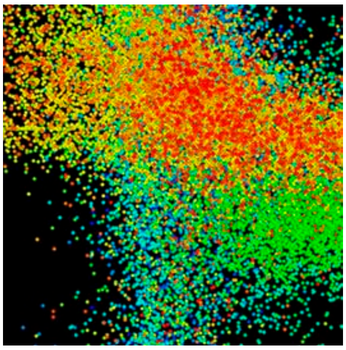
Department of **Employment, Economic Development and Innovation**
Geological Survey of Queensland

Queensland Geological Record 2011/09

Digging Deeper 9 Seminar
Extended abstracts

Geological Survey of Queensland



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Cover: Clockwise from top left; sunrise on the rig at GSQ Dobbyn 2, north-west of Cloncurry; Landsat false colour image of the Mount Isa region; prominent milky quartz vein along the Pilgrim Fault at Kalman; scatterplot of drill hole K47 at Kalman; 3D cross-sections across the Lawn Hill region

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GEOLOGICAL SURVEY OF QUEENSLAND, 2011: Digging Deeper 9 Seminar extended abstracts. *Queensland Geological Record* **2011/09**.

CONTENTS

QUEENSLAND GOVERNMENT EXPLORATION GRANT INITIATIVES

Simon Crouch
Geological Survey of Queensland

Since 2006 the Queensland Government has committed over $10 million to directly support exploration through the grant initiatives under the Smart Mining – Future Prosperity program and Greenfields 2020 program.

The Smart Mining – Future Prosperity program was a 2006 Election Commitment of $29.08 million over four years to increase and accelerate investment in exploration, address skill shortages and promote the involvement of women in mining.

Of this, $7.28 million of grants under the Collaborative Drilling, Cluster Formation and Industry Network Initiatives were provided to directly stimulate exploration in Queensland.

The Collaborative Drilling Initiative of $6 million provided grants of half the drilling costs up to $150,000, to support industry in the testing of new exploration targets by drilling and this initiative is continuing under the Greenfields 2020 program.

The Collaborative Drilling Initiative is open to existing mineral, petroleum, gas, coal and geothermal explorers submitting high risk or innovative drilling projects in frontier areas throughout Queensland.

At the end of the Smart Mining – Future Prosperity program grants of over $3.8 million had been paid to companies successfully completing 56 projects. Twenty-nine of these projects were technical successes.

There are two types of technical success defined; either the discovery of new mineralisation or a newly acquired understanding of the geological causes of the geophysical anomalies. Examples of three projects that discovered new mineralisation include:

- The Champ Prospect, 300km south of Mount Isa, where Krucible Metals Ltd has postulated there are four steeply dipping and north-north-west trending lodes all open to the north and south with intersections under 100m depth of 2m at 1.23% copper, 9m at 0.43% copper, 6m at 0.41% copper, and 12m at 0.16% zinc.
- First pass drilling conducted by Mount Isa Metals Ltd on the Barbara North Lode, 240km north of Mount Isa, returned significant near surface sulphide intersections under 100m depth of 8m at 3.74% copper, 7m at 3.97% copper and 0.26 grams per tonne (g/t) gold, 8m at 3.25% copper and 0.32g/t gold, and 6m at 4.00% copper and 0.29g/t gold.
- The Anglo American Exploration (Australia) Pty Ltd and Falcon Minerals Ltd joint venture with Anglo American (Australia) Pty Ltd finding significant

gold mineralisation at the Saxby Project 225km north-east of Mount Isa. This drilling intersected significant mineralisation of 17m at 6.75 grams per tonne (g/t) gold from 631 to 648m and 7m at 1.98g/t gold from 614 to 621m. Values of nickel up to 1268 parts per million were also intersected.

For Round 1 of the Collaborative Drilling Initiative 16 projects were completed and \$1.27M of grants paid. Ten of these projects resulted in technical successes. Round 2 had 12 successfully completed projects with eight technical successes and \$1.01 million paid to companies. The relatively low number of completed projects reflected the impact of the 2008/09 financial crisis which resulted in 14 company withdrawals. Round 3 is complete with 12 projects successful and to date \$988 715 in grants have been paid to companies. Seven projects were technical successes. For Round 4 of the Collaborative Drilling Initiative 33 submissions were received with 11 projects from 9 companies successful. Five projects were completed with \$220 233 in grants paid. Three projects were technical successes with the round finishing in June 2011.

In July 2010 a further \$3.0 million was assigned to continue the Collaborative Drilling Initiative under the Greenfields 2020 program. Three rounds were planned.

In response to the summer wet season limiting drilling activity, the project period was extended from 12 months to 15 months. Final reports are still to be required three months after completion of the project. Payments are dependent upon successful assessment of the submitted report.

The \$2.2 million Round 5, which closed on 19 November 2010, attracted 56 applications and resulted in 21 projects from 17 companies being allocated \$2.35 million in grants. This round is expected to finish late October 2012.

The \$1.0 million Round 6 closed on 1 April 2011 and 23 applications were received with nine projects from eight companies being allocated over \$1.17 million. This round is anticipated to finish in early 2013.

The demand for grants in Rounds 5 and 6 have reflected not only a continued interest in this initiative but greater competition between companies focused on high quality submissions to win support.

Round 7 closed on 18 November 2011.

Currently \$3.52 million is committed to be paid to projects planned for completion up to 2013.

The grant initiatives have encouraged the expansion of exploration frontiers in the state, with new exploration and the discovery of new mineral and energy resources. Government has also received a significant return on its investment with leverage of some 3:1 under the collaborative drilling program represented by \$11.27 million of direct drilling expenditure by industry supported by grant funding of \$3.8 million.

COASTAL GEOTHERMAL ENERGY INITIATIVE – DRILLING RESULTS FROM MILLUNGERA BASIN

Melanie Fitzell

Geological Survey of Queensland

BASIN DISCOVERY AND LOCATION

The Millungera Basin is located in north-western Queensland (Figure 1), where it is centred on the township of Julia Creek. The basin is concealed by sediments of the southern Carpentaria and northern Eromanga basins.

The basin was discovered as a result of deep seismic reflection surveys conducted under a collaborative program between Geoscience Australia (GA), Geological Survey of Queensland (GSQ), the *pmd*CRC and Zinifex in 2006 and GA, GSQ and AuScope in 2007, aimed at imaging the structure of the upper crust in north

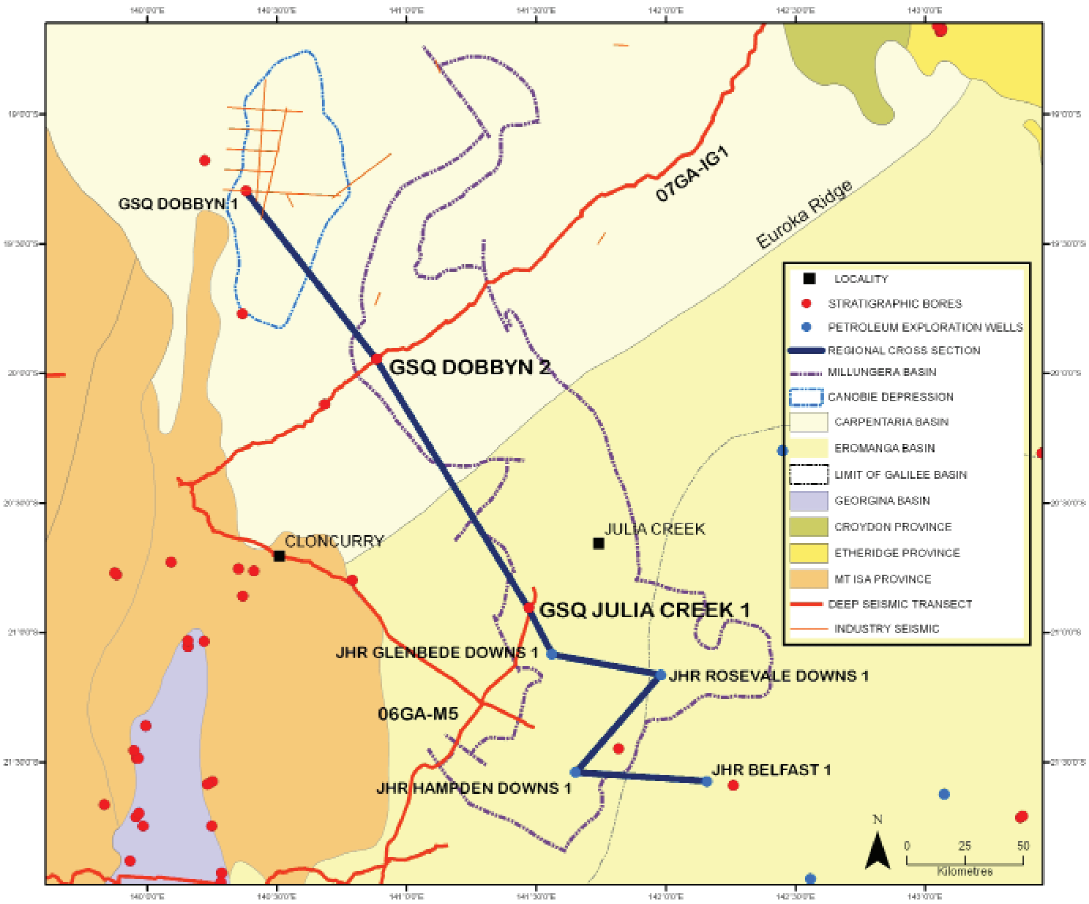

Figure 1: Simplified map of north-west Queensland showing the interpreted distribution of the Millungera Basin and Canobie Depression, the location of GSQ Dobbyn 2 and GSQ Julia Creek 1 and location of regional cross-section. Stratigraphic boreholes, petroleum exploration wells and seismic lines are also shown.

Queensland. One line (07GA-IG1) traverses the entire width of the basin and two others (06GA-M5 and 06GA-M4) are interpreted to cross the western margin.

A possible distribution of the basin has been determined from gravity and aeromagnetic data, but the full extent is still unclear. An interpreted outline of the basin extends for 280km north–south and 85km east–west.

Deep seismic line 07GA-IG1 imaged a 42km section across the entire basin. Flat-lying sediments of the Carpentaria Basin overlie a flat-lying to gently-dipping sedimentary sequence that is now termed the Millungera Basin. The basin has been folded into broad open synclines and anticlines along the eastern margin which have been cut by deep penetrating east-dipping thrust faults.

Three seismically distinct packages have been identified comprising a basal sequence (Sequence 1) with multiple strong reflectors, a middle sequence (Sequence 2) that is predominantly non-reflective, and an upper sequence (Sequence 3) that is highly reflective. The total thickness of the basin using average seismic velocities for shallow crustal sedimentary rocks is estimated to be between 2000–3500m.

The stratigraphic position of the Millungera Basin dates the succession as younger than Paleoproterozoic Soldiers Cap Group of the Mount Isa Province and older than Late Jurassic – Early Cretaceous Gilbert River Formation of the Carpentaria Basin.

DRILLING PROGRAM

Two new stratigraphic bores, named GSQ Dobbyn 2 and GSQ Julia Creek 1, have been drilled within the Millungera Basin (Figure 1) under the Coastal Geothermal Energy Initiative — a drilling program designed to collect new data to aid assessment of the geothermal potential of Queensland.

Both holes were drilled within 10km of the western margin of the basin, on or close to deep seismic reflection lines and were fully cored (HQ) from the base of surface casing to total depth of 500m. Geothermal targets were high-heat-producing granites interpreted beneath the Millungera Basin sequence on deep seismic lines 07GA-IG1 and 06GA-M5.

The key aims for these holes were to:

- obtain lithological information of the Millungera Basin sequence
- collect samples to constrain the age of the basin
- model heat flow and calculate predicted crustal temperature at 5km.

GSQ Dobbyn 2 was drilled in the northern part of the basin approximately 95km north-east of Cloncurry on deep seismic line 07GA-IG1 (SP 6783). 340m of Carpentaria Basin sequence was intersected above 160m of the Millungera Basin sequence (Figure 2). A synthetic seismogram derived from the sonic log was used to tie the hole to the seismic section. The interval drilled within GSQ Dobbyn 2

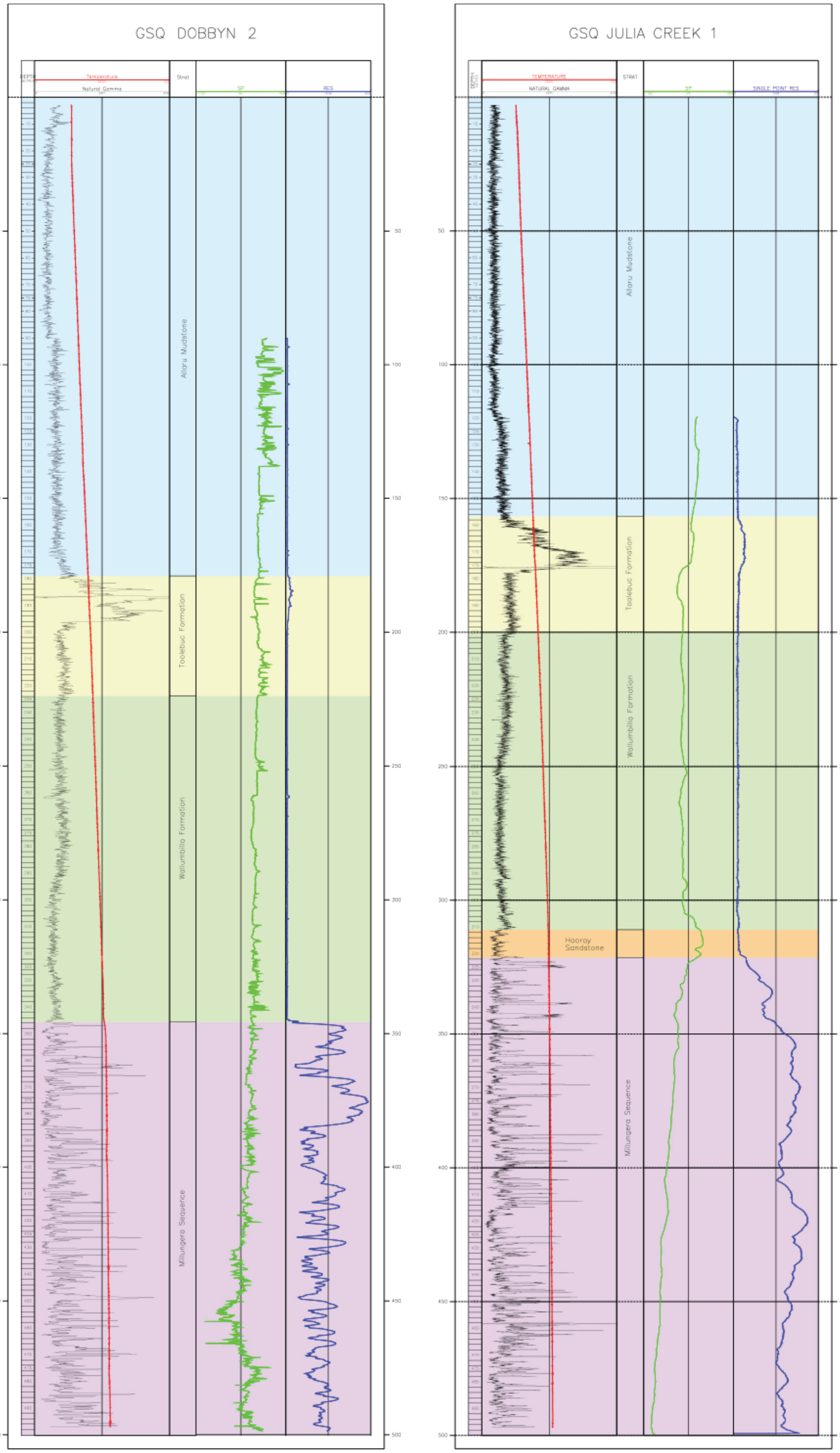

Figure 2: Composite logs for GSQ Dobbyn 2 and GSQ Julia Creek 1

correlates to Sequence 2, the predominantly non-reflective sequence of the Millungera Basin.

GSQ Julia Creek 1 was drilled approximately 40km south-west of the township of Julia Creek at the north-eastern end of deep seismic line 06GA-M5 (approximately 650m off CDP 17275) and intersected 320m of Eromanga Basin sequence and 180m of Millungera Basin sequence (Figure 2). The lithology drilled in GSQ Julia Creek 1 was analogous to that in GSQ Dobbyn 2, inferring GSQ Julia Creek 1 also intersected part of Sequence 2 of the Millungera Basin.

LITHOLOGY

Although the holes were drilled approximately 125km apart, the lithology intersected within the Millungera sequence in both wells was very similar, comprising a mature quartzose sandstone sequence with minor micaceous siltstone and clay bands.

Sandstones ranged between highly indurated, siliceous pink quartz–rich sandstone to quartzite and red hematite altered quartzose sandstone. Bedding was thin to medium and predominantly planar with some graded beds and small-scale cross-bedding. Pebble lags were common towards the basal part of the sequence. Finer-grained intervals also occurred within the sandstone dominant sequence comprising cream to red micaceous siltstone, hematite and chlorite altered claystones and clay bands.

The Millungera sequence in both wells has been highly-altered resulting in a high abundance of iron oxides. Alteration is pervasive and is likely to be associated with hydrothermal fluids. Further work is required to have a better understanding of the alteration history of the sediments.

The unconformity between the Carpentaria Basin and Millungera Basin is well preserved in GSQ Dobbyn 2 as a fault contact between the Wallumbilla Formation and underlying Millungera sequence.

PRELIMINARY SAMPLING RESULTS

Vitrinite Reflectance

- No visible vitrain was found in any samples from the Millungera Basin sequence.

HyLogger

- GSQ Dobbyn 2: Millungera sequence is dominated by quartz and dickite. Dickite may be associated with hydrothermal alteration of feldspar. Further work needs to be done to validate this data.
- GSQ Julia Creek 1: Millungera sequence is dominated by quartz, muscovite and paragonite. Further work needs to be done to validate this data.

- Iron oxide alteration in the form of goethite and hematite was clearly identified by the HyLogger. The higher content of goethite at the top of the sequence may suggest past exposure to surface weathering.

Palynology

- Preliminary results indicate all samples are barren for palyomorphs and no organic material is present.

Other

- U-Pb geochronology on detrital zircons is being undertaken using Geoscience Australia SHRIMP machine. No results to date.
- Thin section analysis and whole-rock geochemistry will be undertaken for composition, provenance, alteration and porosity and permeability studies.

Heat Flow Modelling Results

- GSQ Dobbyn 2: two stage increase in the temperature profile with a bottom hole temperature of 61.1°C at 500.0m. A change in the temperature occurs within the highly conductive sandstones in the Millungera Basin sequences.
- Heat flow modelled over 90.5–500.0m provided a value of 107.4±1.2mW/m^2.
- Projected temperature at five kilometres is 234±15°C.
- GSQ Julia Creek 1: two stage temperature profile, steepening towards the base of the Eromanga Basin then decreasing slightly within the quartzite and clays of the Millungera Basin.
- Near bottom temperature of 54.3°C at 480.5m was recorded.
- Heat flow modelling over 120.1–480.5m provided a value of 103.3±4.2mW/m^2.
- Projected temperature at five kilometres for GSQ Julia Creek 1 is 223±15°C.

Toolebuc Shale Gas

Mud logs from several wells within the Carpentaria Basin and northern Eromanga Basin (e.g. COM Beamsbrook 1) show gas is present over the Allaru Mudstone – Toolebuc Formation – Wallumbilla Formation interval. The Toolebuc Formation comprises limestone (including coquinite), which is subordinate to black, calcareous, bituminous siltstone, labile sandstone, and kerogenous and calcareous shale (oil shale). The organic rich Toolebuc Formation is inferred to be the source of the gas accumulations within the Allaru Mudstone and Wallumbilla Formation.

Vitrinite reflectance value of 0.37% (Rv, max) was measured from a sample within the Allaru Mudstone at 168.2m in GSQ Dobbyn 1, giving a sub-bituminous rank and low maturation level for sediments within the Carpentaria Basin in this region.

To help determine the origin and composition of gas and regional extent of gas accumulation, six 0.70m core samples were collected from both wells with the aim to obtain gas samples from the Toolebuc Formation and overlying Allaru Formation.

No gas was obtained from one week gas desorption (Q2) from samples within the Toolebuc Formation and Allaru Formation from GSQ Julia Creek 1. However, approximately 40ml of gas was obtained from three 100g core samples from the Toolebuc Formation (two) and Allaru Mudstone (one) when the core was crushed (Q3) to liberate gas.

Chemical and isotopic analysis using gas chromatography and GC-IRMS was undertaken at Geoscience Australia on the gas samples collected. Preliminary results indicate the carbon isotope ratios for the Toolebuc Formation gas samples are consistent with a very immature thermogenic gas (unpublished data provided by Dr Chris Boreham, 2011), which is also consistent with the vitrinite reflectance results. The origin of the gas still needs to be confirmed by artificial maturation experiments on the organic rich shales to measure changes in gas isotopes with maturity. Chemical and isotopic analysis of the Allaru Mudstone sample is still being undertaken.

If the composition of the gas from the Allaru Mudstone is the same as the Toolebuc Formation then an assumption could be made that the gas has been generated within the Toolebuc Formation and migrated into the Allaru Mudstone. If the gases are different, the Allaru Mudstone may also be generating gas.

GSQ is still awaiting results from gas desorption and chemical and isotopic analysis from two samples within the Toolebuc Formation from GSQ Dobbyn 2. If gas can be collected from core samples, and the gas is determined to be the same origin as in GSQ Julia Creek 1, an assumption could be made that the gas accumulation is regionally extensive. More detailed work is being planned to determine the potential of the Toolebuc Formation as a regional shale gas play.

REGIONAL CORRELATION

A regional stratigraphic cross-section has been constructed using results from the recent drilling program along with new information from four shallow petroleum exploration wells and one stratigraphic bore in the area.

The section extends approximately 315km north-west to south-east from GSQ Dobbyn 1 in the Canobie Depression through the Millungera Basin to JHR Belfast 1, located outside the current south-eastern basin margin extent (Figure 3).

Summary of notes:

- The Carpentaria Basin is separated from the Eromanga Basin by the Euroka Ridge. The Carpentaria Basin and Eromanga Basin form the cover sequence across the entire region.
- GSQ Dobbyn 1, drilled within the Canobie Depression intersected approximately 250m of unnamed Triassic red beds, considered to be age-equivalent to the Moolayember Formation in the Galilee Basin before intersecting metamorphic and metasedimentary rocks inferred to represent the Soldiers Cap Group. Dating of detrital zircon shows that this succession

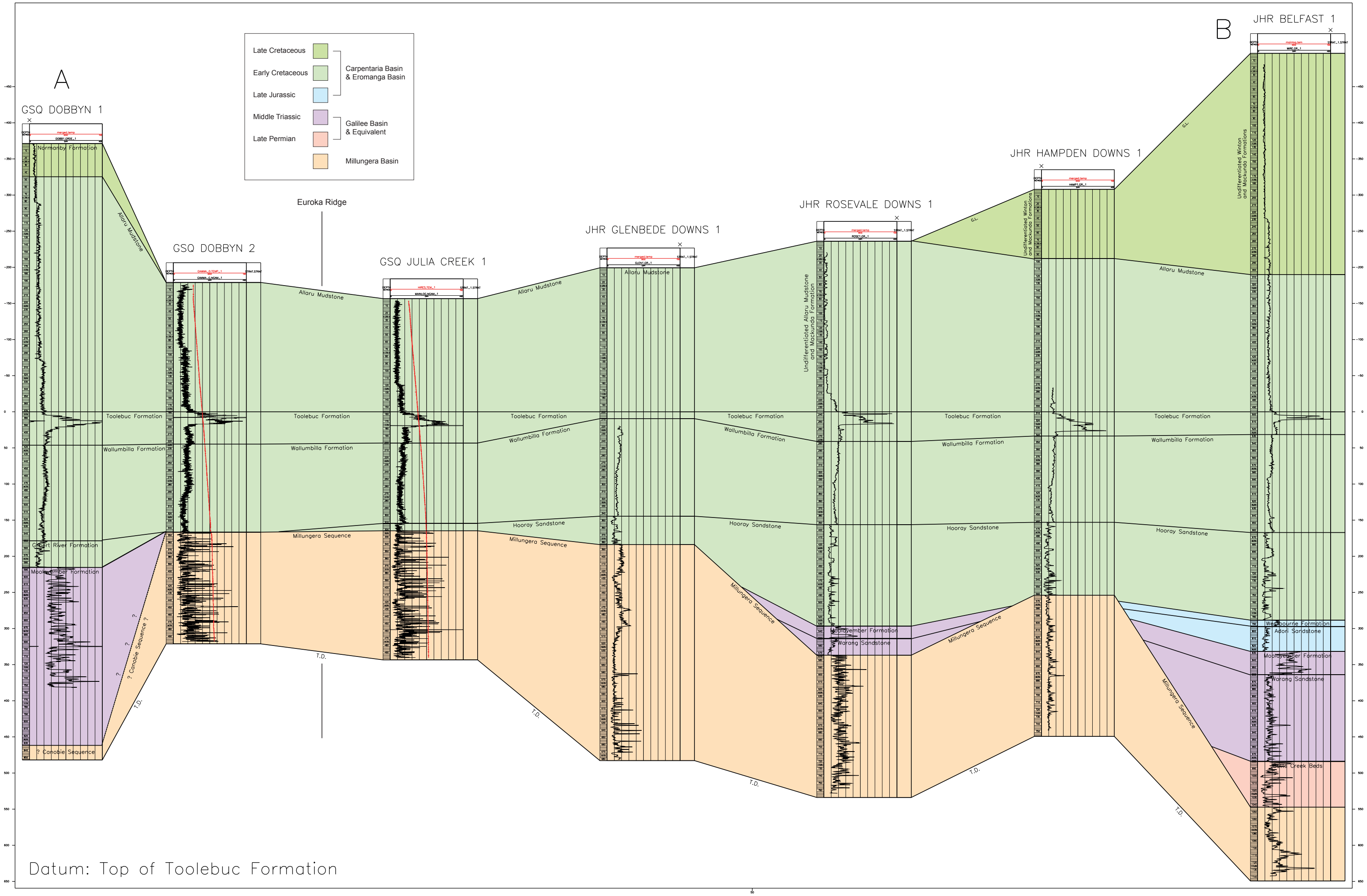

Figure 3: Regional cross-section through the Millungera Basin from north-west to south-east. Location of cross-section is shown on Figure 1.

is clearly younger than the Soldiers Cap Group because it has a maximum depositional age of 1592±5Ma (Carson & others, 2001). These rocks are referred to as the Canobie Sequence (Geological Survey of Queensland, 2011). The stratigraphic position of the Canobie sequence suggests it may be equivalent to part of the Millungera sequence.

- JHR Rosevale Downs 1 and JHR Belfast 1 intersected part of the Triassic and Late Permian – Middle Triassic sequence respectively from the Galilee Basin before intersecting pink quartz-rich sandstone sequence inferred to represent part of the Millungera sequence.
- Pink-red quartz-rich sandstones were intersected in the base of JHR Glenbede Downs, JHR Rosevale Downs, JHR Hampden Downs and JHR Belfast 1. The lithology of the Millungera sequence in GSQ Dobbyn 2 and GSQ Julia Creek 1 is very similar. The interpreted extent of the Millungera Basin is based on the correlation between similar rock types intersected in the wells below the Carpentaria and Galilee basins. If this interpretation is correct the Millungera Basin would be older than Permian Betts Creek Beds, intersected in JHR Belfast 1 as suggested by Korsch & others (2011). Consideration needs to be given to extend the south-east extent of the Millungera Basin to include JHR Belfast 1.
- U-Pb geochronology on detrital zircons from quartz-rich sandstones in JHR Glenbede Downs 1 and JHR Rosevale Downs 1 (inferred to represent the Millungera sequence) yielded a maximum depositional age of about 1555Ma and 1590Ma, respectively (Neumann & Kositcin, 2011). Korsch & others (2011) inferred these results suggest at least some zircons were derived from local sources such as Mount Isa Province to the west or the Etheridge Province to the north-east of the Millungera Basin.
- No definite correlations have been made within the Millungera sequence.

SUMMARY

- Millungera Basin is a frontier area that requires further exploration to fully understand its mineral and petroleum potential.
- Part of Sequence 2 within the Millungera Basin comprises quartzose sandstones to quartzites with minor micaceous siltstones and clay bands.
- The Millungera sequence has been highly altered. Further work is required to understand the alteration history of the Millungera Basin.
- The age and thermal maturity of the basin remains unknown as no palyomorphs or organic matter have been recovered from initial samples collected.
- Preliminary heat flow results indicate the Millungera Basin is prospective for geothermal energy resources.
- Potential for a shallow shale gas resource within the Toolebuc Formation to overlie the basin.

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THE CARBON GEOSTORAGE INITIATIVE STAGE II FIELD DATA COLLECTION PROGRAM PROBABILITIES OF SUCCESS ASSESSMENT AND WELL CONCEPT DESIGN FOR DRILL SITE LOCATION

Jonathan Hodgkinson

Geological Survey of Queensland

INTRODUCTION

The initial drivers behind the Queensland Carbon Geostorage Initiative (CGI) have changed significantly since the group's inception in 2008. The original program was designed based on the standard precompetitive data gathering and provision model, which has been successfully implemented for over ten years within the Geological Survey of Queensland (GSQ). This decision was made based on the notion that an emissions trading scheme would be implemented, which would in turn float a price on carbon. The three stage CGI program for site assessment, selection and characterisation was intended to provide information to support a competitive tender process for greenhouse gas exploration acreage. This process was executed, but has now become redundant, due to the lack of competition and the absence of a workable carbon pricing market.

Without appropriate commercial drivers, governments have had to take a more active role and have refocused carbon capture and storage data collection projects to include broader horizons. The result of this has been the redesign of these programs to include more than geoscientific controls on the location of prospective target areas. This philosophy requires a probability of success assessment for potential future projects, which includes socio-economic and resource conflict issues, in addition to geological controls on the suitability of a given geostorage site.

The Queensland government has adopted the above strategy for the selection of data collection sites. The CGI group within GSQ is now working closely with the Mining and Petroleum Industry Policy group, the federal government and the Australian Coal Industry to design a data collection program that now expands into the exploration and appraisal arena. This requires the implementation of a decision gate strategy, which governs the amount and type of data that can be obtained for a chosen site and dictates an appropriate well design.

The decision to reframe the program strategy was made to provide greater reduction in future exploration risk than that normally necessary to encourage commercial exploration investment in an established marketplace. In addition, a more comprehensive advice statement can be provided to government to assist in resource stewardship decisions for the management of a resource that is dynamic in the context of both short and long timescales.

TARGET AREAS

The primary areas of investigation selected by CGI are the southern, central and south-eastern regions of the Surat Basin, the southern Bowen Basin, several areas in the Eromanga Basin and the southern Galilee Basin (Figure 1). The Permo-Triassic Bowen Basin has a complex burial and exhumation history, beginning with a period of extension and development as a back-arc basin (Baker & others, 1995). This basin initiation period was followed by a period of thermal subsidence and a subsequent change to a compressive stress regime and foreland loading (Green, 1997). The overlying Triassic to Cretaceous age Surat Basin has a less complex history, predominantly governed by a period of thermal relaxation or divergent plate motion and slow subsidence initiated in the late Triassic (Green, 1997; Korsch & Totterdell, 2009). The Carboniferous to Triassic age Galilee Basin in western Queensland exhibits many features similar to the much younger Surat Basin, with generally flat-lying stratal geometries and limited structural development (QCGI, 2009). There have been several hypotheses put forward for the development of the Galilee Basin and the most recent ideas suggest a three phase evolution connected more closely with events governing the history of the Bowen Basin than originally thought (Allen & Fielding, 2007). The Triassic to Cretaceous Eromanga Basin overlying the Galilee Basin is Queensland's most prolific oil producing province (Green, 1997). The predominantly flat-lying strata in the east of the Eromanga Basin are contiguous with the equivalent stratigraphic units in the Surat Basin and, as with the Galilee Basin, there are several basin evolution models (Draper & others, 2002).

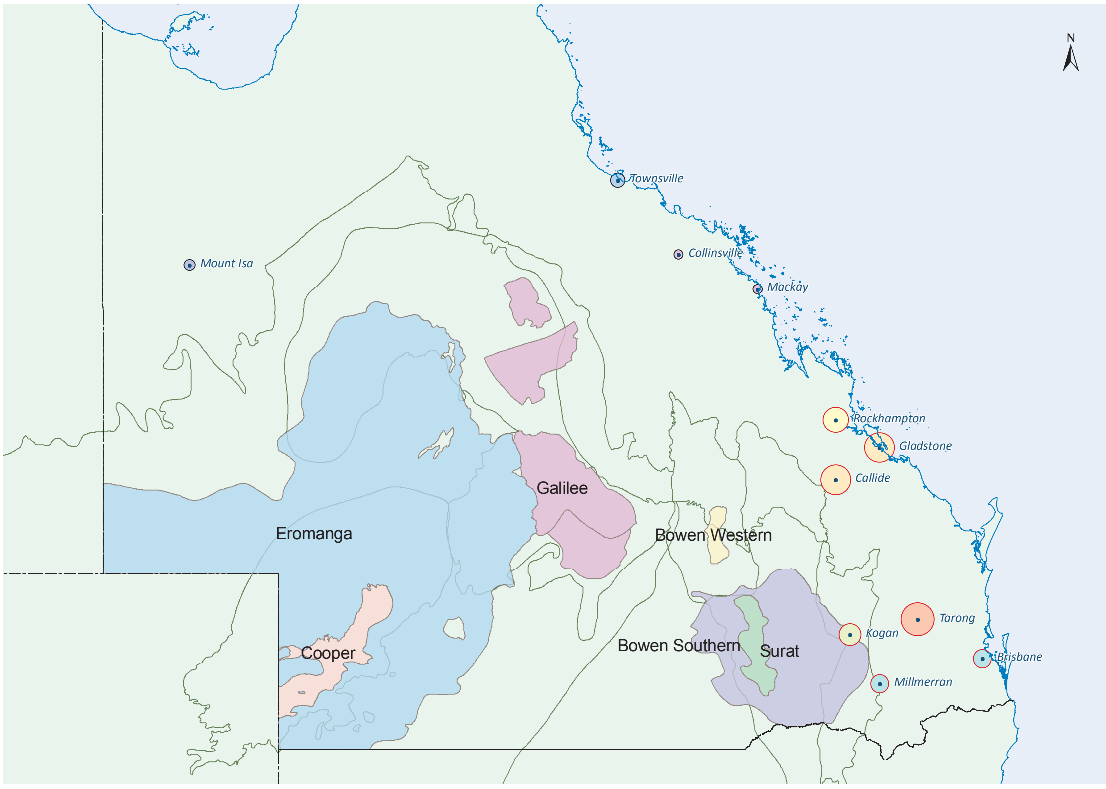

Figure 1: Areas targeted for geostorage investigation, in relation basin outlines and emission points (after Bradshaw & others, 2009)

These basins have been assigned large theoretical geostorage capacity values, which have a high probability of being significantly reduced subsequent to evaluation. The play concept in the Surat and Eromanga basins consists of the Jurassic Precipice Sandstone/Evergreen Formation reservoir/seal pair (Figure 2). The underlying Bowen and Galilee basins host the Triassic Clematis Group/Moolayember Formation reservoir/seal pair (Figure 3). A late Permian play concept in the Galilee Basin may also be feasible with the Colinlea Sandstone potentially sealed by the Black Alley Shale and/or Bandanna Formation equivalents (Figure 3).

The Permian play concept in the Galilee Basin is poorly constrained, due to the dearth of information available. Sedimentary packages of Colinlea Sandstone can be identified in the broad lows of the southern Galilee Basin on seismic profiles, but it is

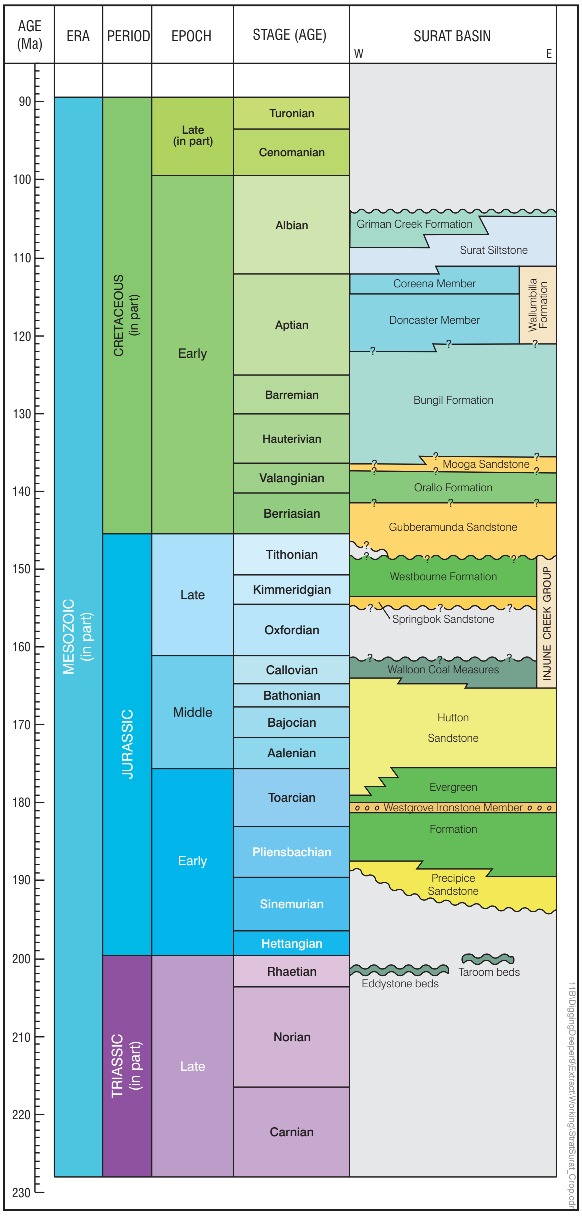

Figure 2: Stratigraphic column for the Surat Basin (modified from McKellar (1998, figure 13; personal communication, October, 2011), with time scale after Gradstein & others (2004)

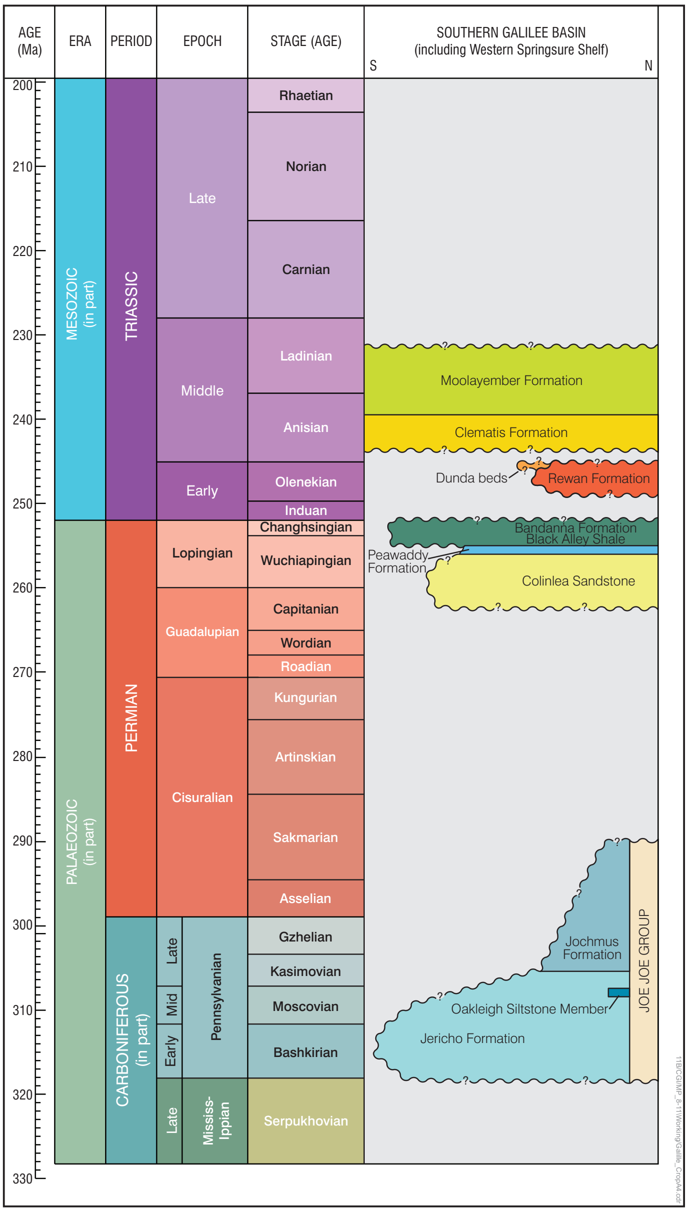

Figure 3: Stratigraphic column for the Galilee Basin (after McKellar, in preparation)

unclear if the overlying strata represent a Black Alley Shale or Bandanna Formation equivalent.

Extensive work has been carried out by the CO2CRC (Hennig & others, 2006) on the Wunga Ridge in the Bowen Basin. This research identified good reservoir quality in the Showgrounds Sandstone Member of the Clematis Group (Hennig & others, 2006) and adequate seal capacity in the overlying Snake Creak Mudstone Member of the Moolayember Formation (Daniel, 2008). Good reservoir quality can be observed in outcropping units of the Clematis Group to the north of the margins of the Surat Basin (Glenidle Formation and Expedition Sandstone). Reservoir quality in the Clematis Group is known to decrease substantially to the east of the Bowen Basin and the Snake Creek Mudstone Member is absent (Green, 1997; Kalinowski, 2006; Patchett, 2006). Studies carried out by CGI show that extensive heterogeneity is evident in the Moolayember Formation in the Galilee Basin (Grigorescu, 2011b). The Clematis

Group is undifferentiated in the Galilee Basin and is referred to as the Clematis Sandstone. It is a quartz-dominated, texturally immature and compositionally sub-mature siliciclastic unit of predominantly fluvial origin (Marsh & others, 2008).

The Jurassic Precipice Sandstone in the Surat Basin and eastern Eromanga Basin is highly quartzose and consists of texturally immature, but compositionally mature terrestrial fluvial sandstones deposited by braided stream systems (Green, 1997; Hodgkinson & Preda (Grigorescu), 2009). The overlying Evergreen Formation is considered to be a regional seal, but exhibits extensive heterogeneity and anisotropy. It is both texturally and compositionally immature and considered to have been deposited in a terrestrial fluvial-lacustrine environment (Green, 1997; Preda (Grigorescu) & Hodgkinson, 2009).

METHODOLOGY

Numerous geological studies have been conducted in the target areas and large datasets are available in areas where exploration has taken place. The CGI has compiled and interpreted the available geological data and conducted a gap analysis and several geological modelling exercises to evaluate and select sites for data collection (e.g. Bradshaw & others, 2009; Hodgkinson & others, 2010a; QCGI, 2009). In addition to this work, the distribution of existing petroleum leases, exploration, appraisal and development wells, known producing oil and gas fields, population centres and landuse (e.g. cropping land, national parks and state forests) have been considered when assessing potential drilling sites (Figure 4).

The reasoning behind this approach is based on a forecast of the likely restrictions that may be placed on geostorage operations in the future. Although appropriate processes exist for managing resource conflicts, it is thought prudent to reduce this probability in the interests of the future commercial attractiveness of a given area.

The revised site selection criteria for collecting relevant data aim to target the areas that have the highest probability of success, based on both geoscientific evidence and projected land use requirements in the future. The geoscientific rationale has been supported by the assessment of reservoir net to gross thickness distribution and seal thickness distribution mapping. The presence or absence of hydrocarbons has also been used as an indicator of seal effectiveness, combined with seismic modelling (Dixon & others, 2011), mineral stability modelling and hydrochemical characterisation (Grigorescu, 2011a; Preda (Grigorescu) & Hodgkinson, 2009) and hydrodynamic analysis (Hodgkinson & others, 2010b).

Well basis of design is primarily governed by target depth and the post drilling data needs (e.g. the amount of core required for laboratory analysis and interpretation and well completion options). A suite of well designs is compiled covering a range of expenditure and showing the extent of core retrieval, the capacity for downhole testing and well completion limitations. Budget constraints are then applied to the well design options in relation to the areas selected for data collection.

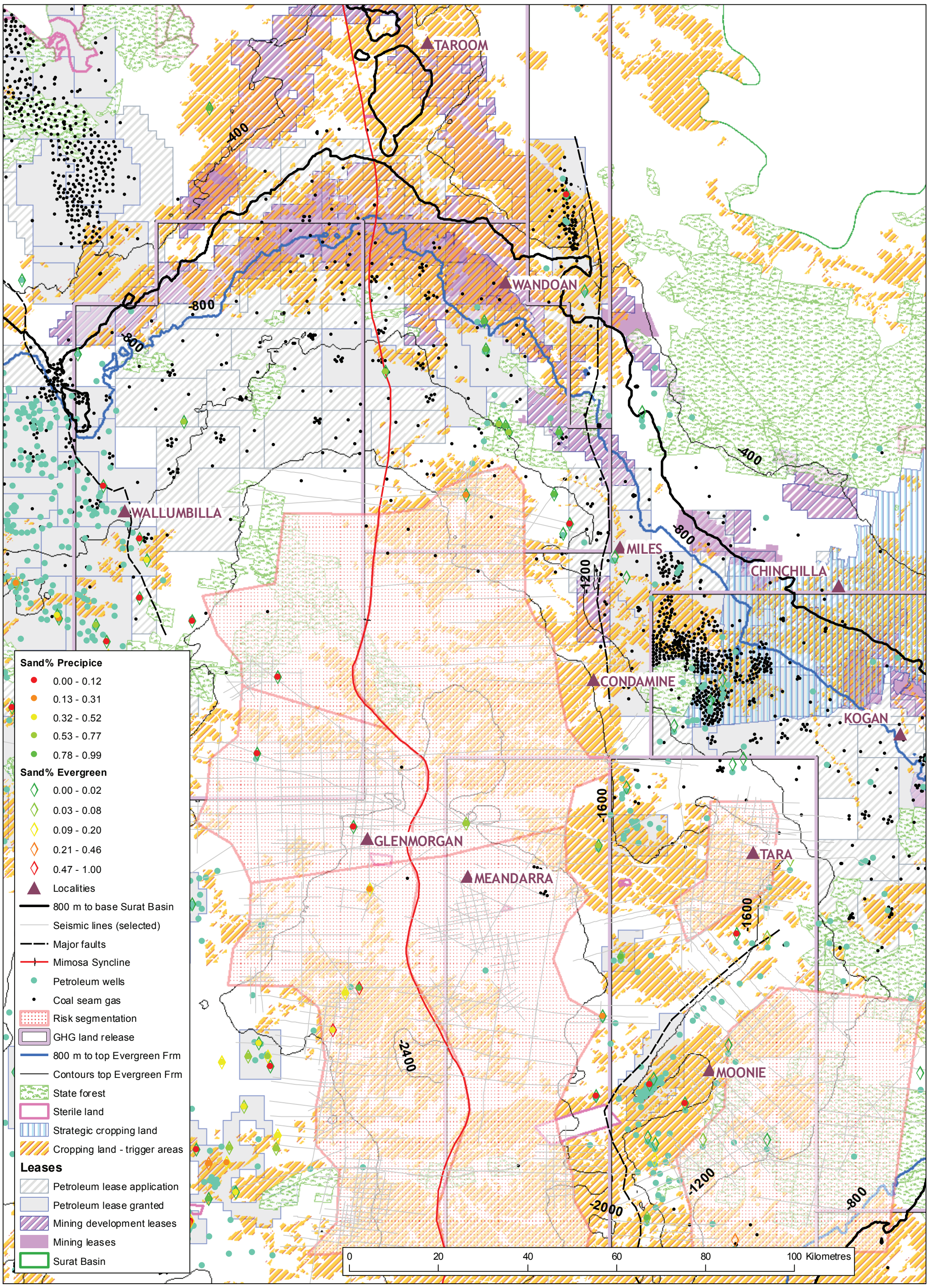

Figure 4: Landuse, economic and technical considerations when assessing potential geostorage sites

RESULTS AND DISCUSSION

The wells to be drilled in the target areas all have an initial proof of concept goal to be achieved, which is demonstration of seal effectiveness for CO_2 containment security. More advanced work will be required to assess injected CO_2 plume migration velocity and trajectory, but there is little value in this type of work if seal effectiveness has not been established.

Trapped hydrocarbons provide clear evidence that a given unit has some level of capacity to inhibit the vertical transport of injected CO_2. Oil has been produced from the Moonie field in the eastern Surat Basin since the 1960s and several hydrocarbon shows have been encountered in other structures to the north (e.g. Leichhardt and Cabawin) (Green, 1997) (Figure 5). The oil accumulations are located in the Precipice Sandstone and within the Evergreen Formation in this region (Green, 1997). Small gas columns have been encountered in exploration wells intersecting the Precipice Sandstone above the Roma Shelf in the west of the Surat Basin (A. Garnett, personal communication, 2011). Although oil is produced in commercial quantities from the Hutton Sandstone in the Eromanga Basin, no hydrocarbons have been encountered to date from this unit in the Surat Basin (Green, 1997).

Hydrodynamic analysis using formation pressure measurements from petroleum wells (Figure 6) (e.g. PPC Wagabba 1) has shown that in the south-east region of the Surat Basin, the Evergreen Formation may provide a seal to prevent vertical migration between the Precipice Sandstone and the Hutton Sandstone (Hodgkinson & others, 2010a). In the central areas the evidence is less conclusive (e.g. SDA Paddy Creek South 1) and may indicate connection between the two reservoir units across the

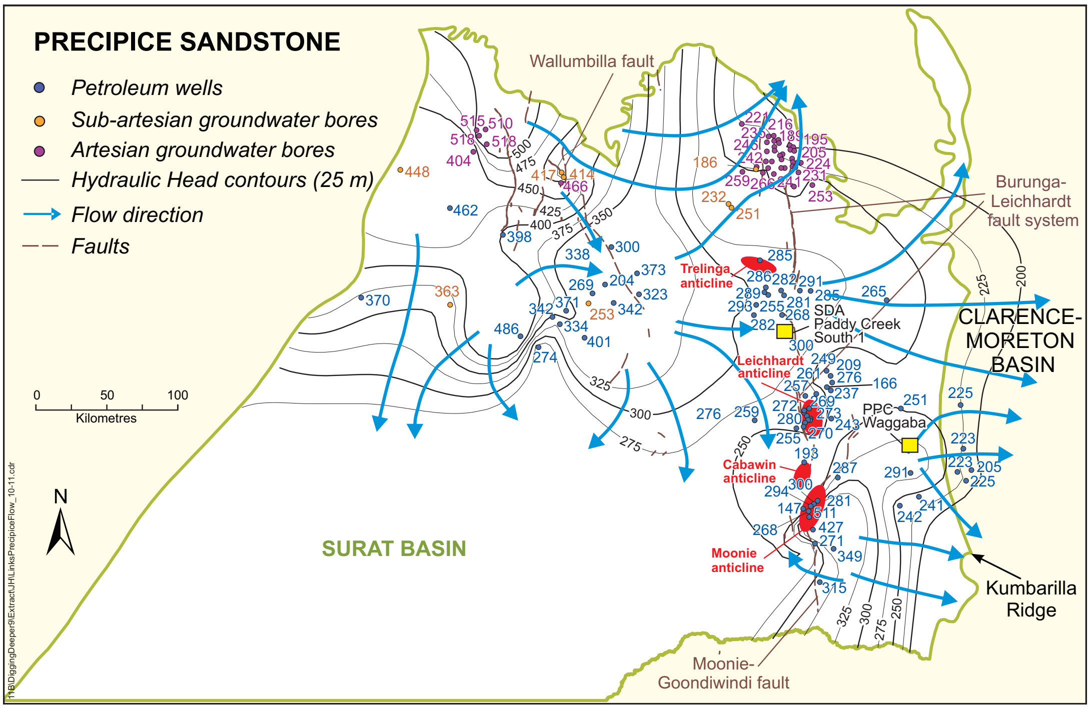

Figure 5: Hydrocarbon fields and shows in anticlines north of Moonie, in relation to groundwater flow directions in the Precipice Sandstone aquifer (after Hodgkinson & others, 2010b)

Evergreen Formation (Figures 5 and 6). Mineral stability modelling indicates that the Evergreen Formation hosts important quantities of reactive phases that could potentially inhibit the vertical migration of CO_2 (Preda (Grigorescu) & Hodgkinson, 2009).

Spatial analysis of the net to gross distributions in the Precipice Sandstone shows some unexpected trends in reservoir quality. Examination of several wells to the central and west regions (e.g. UOD Amolee 1 and SGO Overston 1) indicates that the formation boundary picks are likely to be incorrect. Reservoir isopachs of the unit based only on seismic horizon picks without well ties also indicate disparity, but are inconclusive.

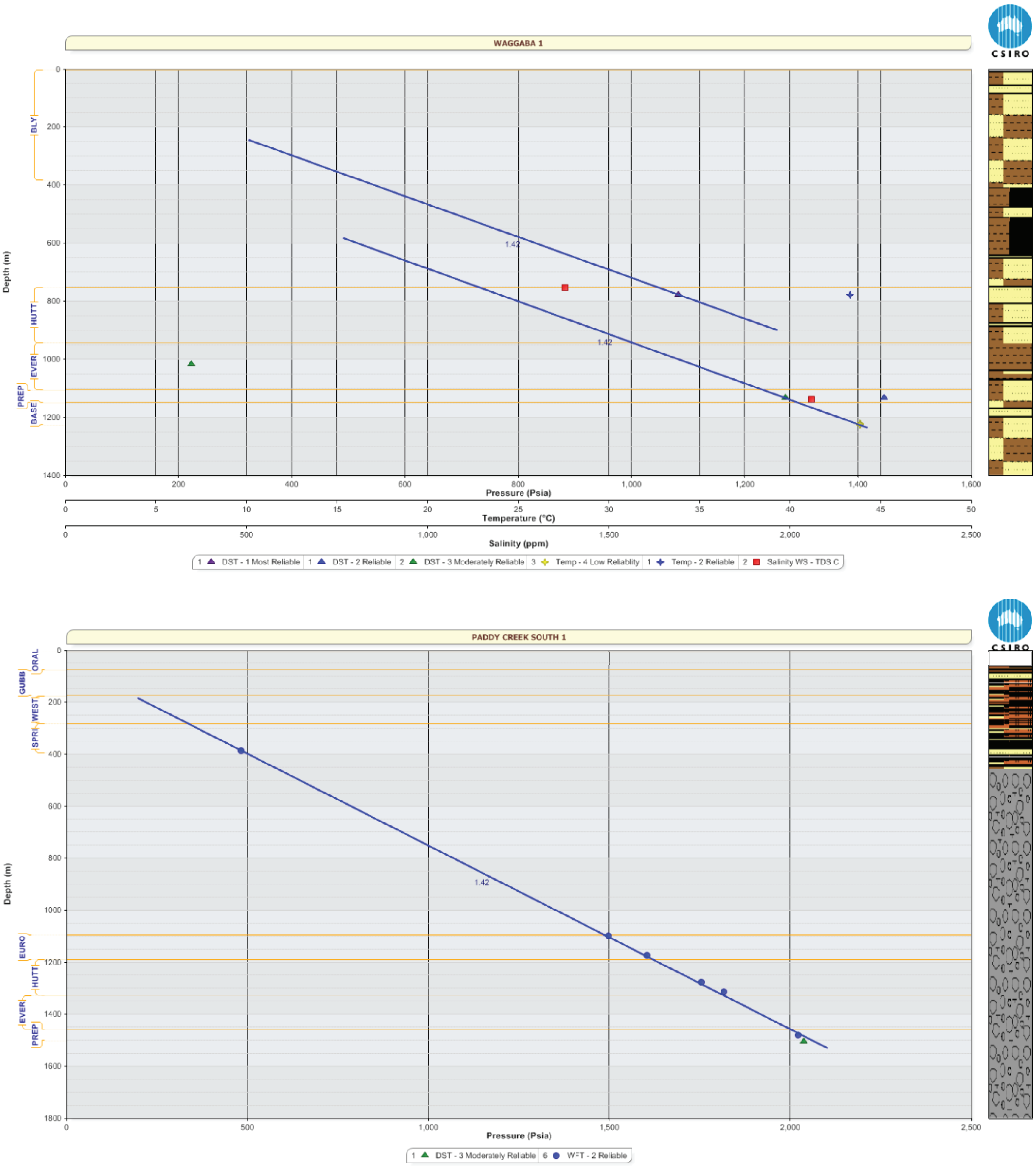

Figure 6: Evaluation of hydrostatic gradients using pressure measurements in petroleum wells

Gross seal thickness maps for the Evergreen Formation interpreted in conjunction with known hydrocarbon accumulations indicate that minimum thicknesses of approximately 50m can potentially offer effective seal capacity. It is important to note, however, that small hydrocarbon columns may indicate low threshold entry pressures that may not be adequate to hold significant columns of CO_2. The heterogeneity distribution within the Evergreen Formation must also be considered in light of the commercial oil accumulations apparent within the unit at the Moonie field in the east.

A major limiting factor in assessing the Evergreen Formation in the context of a regional seal and the continuity and connectedness of the underlying Precipice Sandstone reservoir is the accuracy and applicability of the lithofacies picks used to constrain the modelled horizon geometry. Current geostorage models are largely based on simplistic lithofacies picks that may imply continuity of properties across large areas incorrectly. Sequence stratigraphic analysis of the Surat Basin was started as part of the Sedimentary Basins of Eastern Australia project (Green, 1997; Hoffmann & others, 2009). This initial study needs to be substantially expanded to provide much tighter constraints on the distribution of both reservoir and seal continuity across the Surat Basin. A revised geological model based on this approach may allude to the anomalous net to gross distributions in the Precipice Sandstone, and the variable seal effectiveness evident in the Evergreen Formation. Preliminary sequence stratigraphic analysis carried out by Bradshaw & Bradshaw (2010) in the Galilee Basin shows several miscorrelations apparent between the Clematis Sandstone and the Rewan Formation in the existing models based on lithofacies picks. This work shows that assumptions made based on litholofacies picks, regarding reservoir continuity and compartmentalisation in these units, are fundamentally flawed.

The Moolayember Formation in the Bowen and Galilee basins also shows extensive heterogeneity (Grigorescu, 2011b). Seal capacity is demonstrated in the Bowen Basin where the unit seals several producing gas fields in the west (Green, 1997). This is, however, only apparent where the Snake Creek Mudstone Member is present. Although relatively thick (736m max. in GSQ Taroom 16, Green, 1997), there is no evidence of hydrocarbon trapping by the Moolayember Formation where the Snake Creek Mudstone Member is absent. This is exemplified in the Galilee Basin where no hydrocarbon accumulations have been discovered to date.

Both the Surat and Galilee basins are growing energy provinces. Significant coal seam gas production from the Surat Basin has been taking place for several years and is forecast to grow at a rapid rate over the next 30 years. Open cut coal mining is also set to increase substantially in the northern regions of the basin. Although the Galilee Basin is known to host a multi-billion tonne thermal coal resource, its remote location has precluded exploitation to date. This is set to change in the near term, as indicated by the lodgement of development proposals and the uptake of coal exploration tenure across most of the basin. The southern Bowen Basin underlying the Surat Basin has been exploited for oil and gas for a protracted period of time and the depleted fields are of interest for the interim storage of coal seam gas. There is, therefore, significant competition for the subsurface pore space in many regions that could provide targets for carbon geostorage.

These areas have been ‘quarantined’ in the short term as part of the CGI probabilities of success assessment (Figure 4). Known oilfields, petroleum leases (granted and applications), strategic cropping land areas, sterilised land and highly faulted regions have been excluded from the target areas for drilling sites. Many of the excluded areas could provide suitable geostorage opportunities from a geological perspective, but would be less attractive to future commercial developers if other operations are already established. The remaining area in the Surat Basin is more restrictive than in the Galilee Basin, but still of significant extent. This region has been subdivided into risk segmentation zones that are considered worthy of further investigation (Figure 4). The intention is to provide a balance between satisfying data gaps and providing data for targets that could be prospective. Assessment of the data proximal to the target sites has taken place and the number of potential plays have been identified (Figures 2 and 3).

Zones to the west of the axis of the Mimosa Syncline in the Surat Basin may host Triassic plays in the underlying Bowen Basin, as well as Jurassic plays in the Surat Basin. Zones identified in the axis of the syncline and to the east will only provide opportunities in the Jurassic strata, because of known poor reservoir quality in the underlying Triassic units (Kalinowski, 2006; Patchett, 2006).

The limited data available for the southern Galilee Basin shows that reservoir quality in the Clematis Sandstone is likely to be favourable (Bradshaw & others, 2009; QCGI, 2009) and the principle target is the Triassic reservoir/seal pair. Although the Precipice Sandstone in this region of the basin is deep enough to retain CO_2 in the supercritical state, it is a unit widely exploited for groundwater. This unit is, therefore, considered a secondary target for geostorage and it is intended to obtain hydrogeological data for a greater understanding of the Great Artesian Basin groundwater system if budget constraints permit. The preferred drilling site in the Galilee Basin shows potential for a Permian play, but a decision has not been reached at this stage as to whether it will be targeted as part of the initial campaign.

The base case well design is dictated by the need to obtain a complete core run through the seal unit of interest (Black Alley Shale, Bandanna Formation, Moolayember Formation and Evergreen Formation) and at least to the middle of the deepest reservoir target (Colinlea Sandstone, Clematis Group and Precipice Sandstone). Minimum bottom hole diameter is primarily governed by accepted contingency measures to limit the need for sidetrack drilling. Rig size and hole diameter are also controlled by maximum well depth and in the case of the Permian play concept in the Galilee Basin, the first well may not include this pair as a target. The primary play target in the Galilee Basin is the Clematis Sandstone/Moolayember Formation pair and the merits of drilling an initial well designed specifically to gather data related to this play concept may be considered. The first well could also be suspended and deepened at a later date if initial results prove favourable. This strategy could also provide for advanced well testing and formation evaluation using larger tools. There is also the potential that it may be more economical to spud a second well in close proximity to target a different play and to gather a broader suite of data. The current level of uncertainty regarding the geostorage potential in the Galilee Basin and its remote location requires a lower budget, more focused well design to establish the initial proof of concept for containment security.

A similar well design to that favoured for the first Galilee Basin well is likely to be adopted for the south-east segment of the Surat Basin. The play concept in this area is estimated to be present at depths between 1500m and 1700m and very little information is currently available. Initial drilling requirements in this region could probably be satisfied with a small core diameter stratigraphic well, with the emphasis on core recovery.

More robust well designs are considered appropriate for the central and western target areas in the Surat Basin and underlying Bowen Basin. The same proof of concept applies in that the prime objective is to establish the seal capacity of the Moolayember Formation and the Evergreen Formation. The current datasets for these basins provide a higher level of confidence in the success of encountering adequate seal capacity in these units and the focus of these wells is more likely to be on methods of improving confidence in seal capacity continuity away from the near well area. In this case, the well design needs to incorporate the requirement for extended leak off tests, repeat formation tests and long-term production tests. Minimum size for testing tools has a greater influence on hole diameter in this case.

Hole stability and the prevailing stress regime will control the decision regarding casing weight and the need to screen reservoir intervals for long-term testing and sampling. Analysis of the currently available stress data and geomechanical modelling would also be prudent in some areas. A larger hole diameter may be required for stratigraphic type wells if heavy casing is required, and only available for larger diameter wells.

CONCLUSIONS

The CGI has adopted a revised strategy for targeting drilling sites as part of the stage II field data collection program, which incorporates potential resource conflicts and other socio-economic factors. This is considered a prudent approach based on the most likely probability of success assessment that has been conducted. This philosophy has primarily been driven by the lack of commercial incentives to promote private investment and the absence of competition evident in the carbon capture and storage arena at the present time.

A range of further studies is required to provide higher levels of confidence in reservoir connectivity and seal continuity across the basins of interest. Sequence stratigraphic analysis is considered to be the most appropriate approach to understanding these aspects of subsurface uncertainty and will be used to overcome the limitations in methodologies based on lithofacies horizon picking.

It is anticipated that a range of well designs will be employed to investigate the different target areas. The style of drilling will be based on requirements such as the amount of core desired, the need for formation pressure data, the range of log data desired, the need for geomechanical data, long-term flow tests and uncontaminated groundwater samples. The decision on the investment at each individual site will be governed by the limitations of currently available information balanced with budgetary constraints. It is planned to complete all wells as pressure monitoring bores to provide time series datasets, which could be used to identify seasonal trends in subsurface behaviour.

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COASTAL GEOTHERMAL ENERGY INITIATIVE UPDATE

Sarah Sargent and Mark Maxwell

Geological Survey of Queensland

Heat flow results modelled from the Coastal Geothermal Energy Initiative (CGEI) drilling program have highlighted geothermal potential within the Millungera and Maryborough Basins.

Preliminary heat Flow modelling for GSQ Dobbyn 2, GSQ Julia Creek 1 and GSQ Maryborough 16, have returned values of 107.4±1.2mW/m^2, 103.3±4.2mW/m^2 and 74.3±2.5mW/m^2 respectively.

Excellent insulating cover within the Maryborough Basin and a high heat producing granitic heat source at depth within the Millungera Basin suggest these elevated heat flow values could represent a broader geothermal potential across both basins.

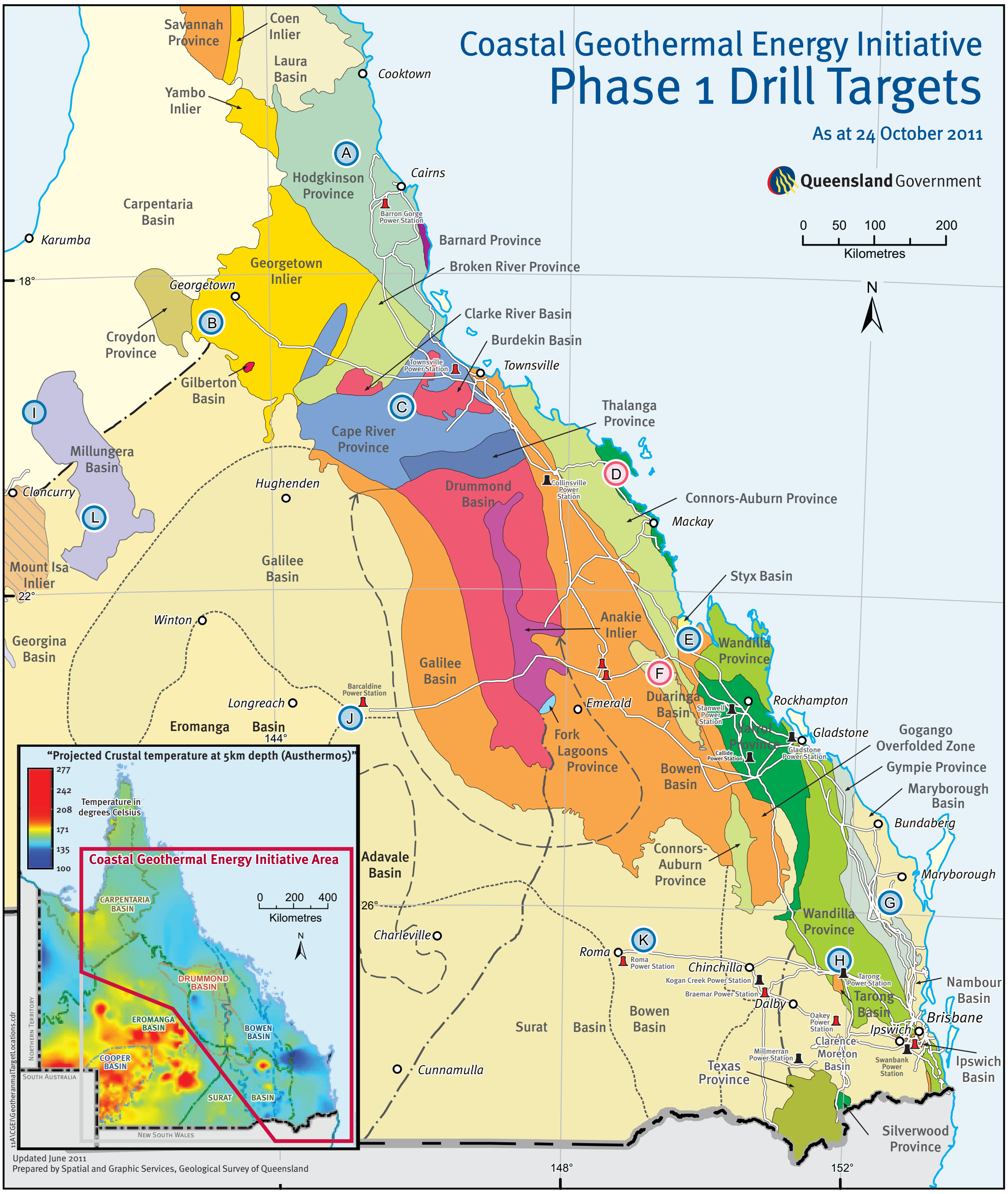
The viability of exploration projects within these two basins is favourable due to the close proximity to population and heavy industry centres. The Millungera Basin is located to the east of the Mount Isa mining area infrastructure and the Maryborough Basin is proximal to the high population density (and power needs) of South-East Queensland.

This abstract gives preliminary heat flow modelling results for three sites drilled as part of the CGEI drilling program; GSQ Dobbyn 2, GSQ Julia Creek 1 and GSQ Maryborough 16.

PROJECT BACKGROUND

The CGEI is a Queensland Government project designed to investigate the potential for geothermal energy close to existing power networks and population or heavy industry centres. In Queensland petroleum exploration and water bore drilling has highlighted the south-west portion of the state as highly prospective for geothermal energy. The CGEI aims to drill targets across other parts of the state where little temperature data is available (Figure 1). The drilling and collection of thermal data will occur through a more rigid scientific method than previously used and the resulting heat flow calculations will contribute to Queensland's heat flow data base. It will also provide a pre-competitive dataset to the state's growing number of geothermal explorers.

The CGEI program is a co-operative undertaking between the Office of Clean Energy and the Geological Survey of Queensland (GSQ).



CGEI Drilling Program Phase 1

- (A) GSQ Mossman 2 – 339.7m
- (B) GSQ Georgetown 8 – 320.2m
- (C) GSQ Townsville 2 – 150m*
- (D) GSQ Bowen 1
- (E) GSQ St Lawrence 1 – 340m
- (F) GSQ Duaringa 7
- (G) GSQ Maryborough 16 – 387.4m
- (H) GSQ Gympie 7 – 338.6m
- (I) GSQ Dobbyn – 500m
- (J) GSQ Longreach 2 – 327.3m
- (K) GSQ Roma 9 – 335.9m
- (L) GSQ Julia Creek 1 – 500m

Drilled
To be drilled
Major cities
Transmission lines
Power station: coal-fired, gas-fired

*GSQ Townsville 2 abandoned

Figure 1: Phase 1 drilling targets.

Table 1: Status of the CGEI program as of the 31st October. Green ticks indicate completed, TBC is to be completed and red crosses indicate unable to be completed due to abandoning the hole.

Site	Drilled	Temperature logging		Heat flow modelling
		GA	HDR	
MARYBOROUGH 16	387.4	✓	✓	✓
GYMPIE 7	338.6	✓	✓	TBC
LONGREACH 2	327.3	✓	✓	TBC
ROMA 9	335.9	✓	✓	TBC
ST LAWRENCE 1	340.0	✓	✓	TBC
JULIA CREEK 1	500.0	✓	TBC	✓
DOBBYN 2	500.0	✓	TBC	✓
GEORGETOWN 8	320.2	TBC	TBC	TBC
MOSSMAN 2	339.7	TBC	TBC	TBC
TOWNSVILLE 2	X	X	X	X
BOWEN 1	TBC	TBC	TBC	TBC
DUARINGA 7	TBC	TBC	TBC	TBC

STATUS

The status of the program as of the 31st October 2011 is summarised in Table 1 with ten sites now drilled. GSQ Townsville 2 was abandoned in October after four attempts to reach consolidated ground within 150m of ground level. GSQ Bowen 1 and GSQ Duaringa 7 are to be drilled in the coming months.

Temperature logging conducted by both Geoscience Australia (GA) and Hot Dry Rocks (HDR) indicated thermal equilibrium had not been reached for GSQ Gympie 7, GSQ Longreach 2, GSQ Roma 9 and GSQ St Lawrence 1. As a result, these sites will need to be cased and cemented again to ensure any permeable rock units are sealed. Consequently heat flow modelling for these sites has been delayed.

WORK PROGRAM

The CGEI work program to date has involved four stages: site selection, drilling, thermal data collection and heat flow modelling.

Site selection

A total of 32 possible targets were initially selected and ranked on the following criteria (Fitzell & others, 2009 and Talebi & others, 2010):

- insulating sediment cover greater than 3500m
- low thermal conductivity of overlying sediments < 3.0W/mK
- target heat source with heat production values > 5µW/m^3
- calculated geothermal gradients > 40°C/km from temperature measurements
- within 100km of population centres or potential electricity markets.

The estimated cost per hole following the receipt of the drilling tenders far exceeded the expected costs at the start of the project. As a result the program was split into three phases of drilling with phase 1 to drill 10–12 targets with the highest prospectivity (Figure 1). Phases 2 and 3 are to follow pending the approval of more funding.

The location of each drill site within Phase 1 was selected to ensure environmental disturbance was minimised, located where topographical influences on crustal heat flow were minimal, underground infrastructure from other explorers avoided and where reasonable access was available. Nearly all of the landholders approached to discuss access were agreeable and quite interested in the project. Access was negotiated prior to the new Land Access Regulations.

There were some delays in locating and then negotiating with the Registered Aboriginal Parties for each site, but all groups were quite cooperative in ensuring that Cultural Heritage was managed and preserved. Local contractors or the landholders concerned were engaged to effect site preparation.

Drilling

Drilling of the Phase 1 targets required chipping to consolidated material with diamond coring to a total depth (TD) between 320–500m. Each hole was cased with HWT steel casing to base of chipping, and with Class 18 PVC to TD to ensure the hole remained open for the 6 to 8 week thermal stabilisation period required before temperature logging.

Drill hole design

Initially, the surface casing in the coal basins was to be PVC, to alleviate the problem of steel casing being left down-hole within coal seams. Steel casing was to be used in non-coal-bearing surface strata where basalts (and associated clays and sands) were expected. However, as we were working under the provisions of the *Petroleum and Gas (Production and Safety) Act 2004*, cemented steel casing was required for all holes to comply with the drilling contractor's Safety Management Plan.

The inability to detect and seal previously unknown aquifers and porous 'thief zones' also demanded a hole design change after temperature logging detected minor circulatory flow in four of the first five holes drilled. Known aquifers, and unknown aquifers, detected during drilling, were to be cemented as the hole progressed to prevent any cross contamination. The change to the hole design was to fully cement the PVC casing annulus once installed to TD. This design also presented some problems, with Sites A and B being left well short of TD due to excessive cement plugging on the inside of the casing.

Thermal data collection

Requirements of the drilling at each target were to:

- retrieve >200m continuous HQ3 core
- collect thermal conductivity samples 150mm long every 20m
- after a period of thermal stabilisation, conduct temperature logging by Hot Dry Rocks (HDR) and Geoscience Australia (GA) and calculate the geothermal gradient down hole.

Heat flow modelling

Following receipt of thermal conductivity results and the collection of temperature data when the hole had reached thermal equilibrium, heat flow modelling was undertaken using customised in-house software called HF1D. The modelling is based on the following equation:

$$q = k.{}^{dT}\!/_{dz}$$

where q is the heat flow in milliwatts per metre squared (mW/m^2), k is the rock thermal conductivity in Watts per metre Kelvin (W/mK) for an interval of a particular lithological unit and dT/dz is the vertical geothermal gradient in Kelvin per metre (K/m) over the same interval.

Firstly, thermal boundaries for each hole were identified from the geothermal gradient, below casing. Thermal conductivity values for the dominant rock type present in each thermal unit was selected for heat flow modelling.

The heat flow was modelled using an inversion technique with theoretical temperature data being computed for a given magnitude of heat flow. This theoretical data was compared against the observed temperature log and the magnitude of the heat flow parameter in the model was adjusted until the computed temperature data best matched the logged temperatures. The vertical heat flow (q) was assumed to be a purely conductive regime and constant across all lithological units.

Once the heat flow was modelled, the values were compared to the average crustal heat flow value of $60mW/m^2$ (Cull, 1982) and the current heat flow map of Australia provided by Hot Dry Rocks (personal communication, 2011) to postulate the regional significance of the result.

The temperature was also extrapolated to 5km depth and values greater than 200°C were considered highly prospective for Enhanced Geothermal Systems (EGS).

HEAT FLOW MODELLING RESULTS

GSQ Dobbyn 2

The temperature profile for GSQ Dobbyn 2 shows a two stage increase with a bottom hole temperature of 61.1°C at 500.0m (Figure 2). A change in the temperature can be seen within the highly conductive meta-sandstones in the Millungera Basin sequences.

The temperature gradient identified 4 thermal units suitable for heat flow modelling (Figure 2). Thermal units 1-3 consist predominantly of mudstone and thermal conductivity values of 1.13, 1.11 and 1.1W/mK respectively were assigned for modelling. The insulating capacity of the fourth thermal unit consisting of siliceous-haematitic sandstone (within the Millungera Sequence) is low, with a thermal conductivity value of 7.4W/mK used for modelling.

Heat flow modelled over 90.5–500.0m provided a value of 107.4±1.2mW/m^2.

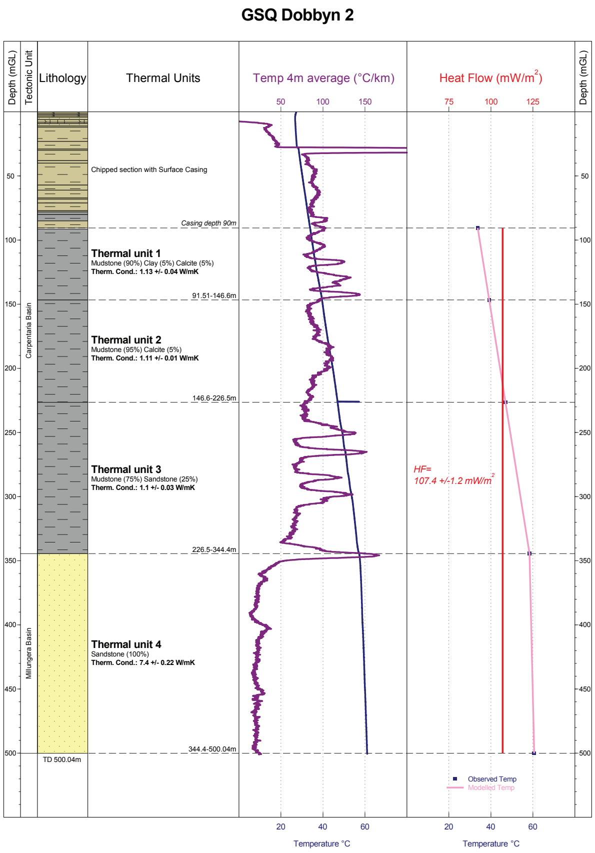


Figure 2: Thermal profile and modelled heat flow of GSQ Dobbyn 2, 107.4±1.2mW/m^2

GSQ Julia Creek 1

The temperature profile for GSQ Julia Creek 1 also showed a two stage temperature profile, steepening towards the base of the Eromanga Basin then decreasing slightly within the quartzite and clays of the Millungera Basin. A near bottom temperature of 54.3°C at 480.5m was recorded (Figure 3).

Three thermal units were identified over the modelled section between 120.1 and 480.5m. Thermal units 1 and 2 consisted predominantly of mudstone and the thermal conductivity values 1.2 and 1.64W/mK respectively were assigned for modelling.

Siliceous-haematitic quartzite with thin bands of altered clay (Millungera Basin) was modelled as the third thermal unit. The thermal conductivity value increased sharply and a value of 6.4W/mK was used to model this interval.

Heat flow modelling over 120.1–480.5m provided a value of 103.3±4.2mW/m².

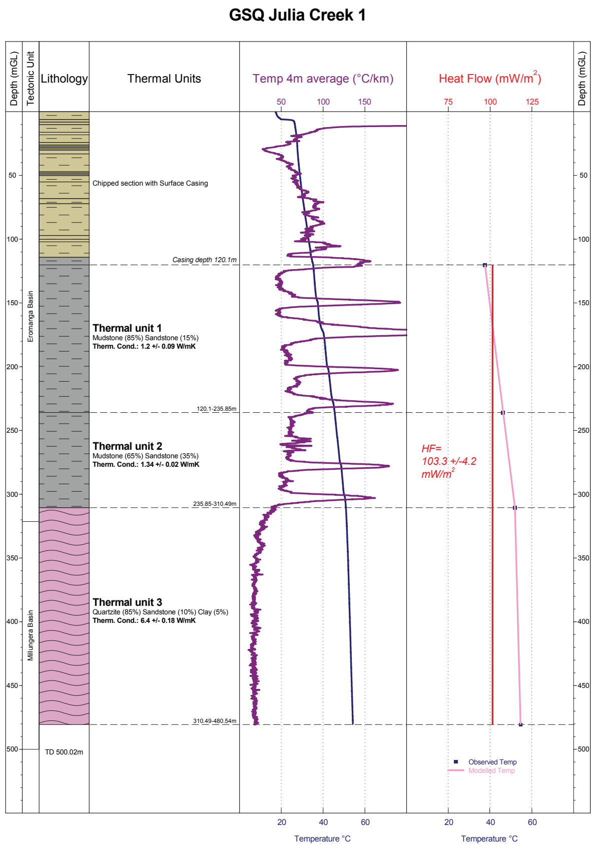


Figure 3: Thermal profile and modelled heat flow of GSQ Julia Creek 1, 103.3±4.2mW/m²

GSQ Maryborough 16

The temperature profile for GSQ Maryborough 16 shows a steady increase with a near-bottom hole temperature of 34.86°C at 380.5m (Figure 4).

Five thermal units were identified for heat flow modelling within GSQ Maryborough 16. The temperature gradient is highly variable reflecting interbedded sandstone, mudstone and coal of the Tiaro Coal Measures. Thermal conductivity values of 2.49, 2.5, 2.5 and 2.39W/mK were used to represent the mainly sandstone rock type within thermal units 1, 3, 4 and 5 respectively.

Thermal unit 2 contained a higher proportion of mudstone and was assigned a thermal conductivity value of 1.87W/mK.

Heat flow modelling over 61.2–380.6m returned a value of 74.3±2.5mW/m^2 (Figure 4).

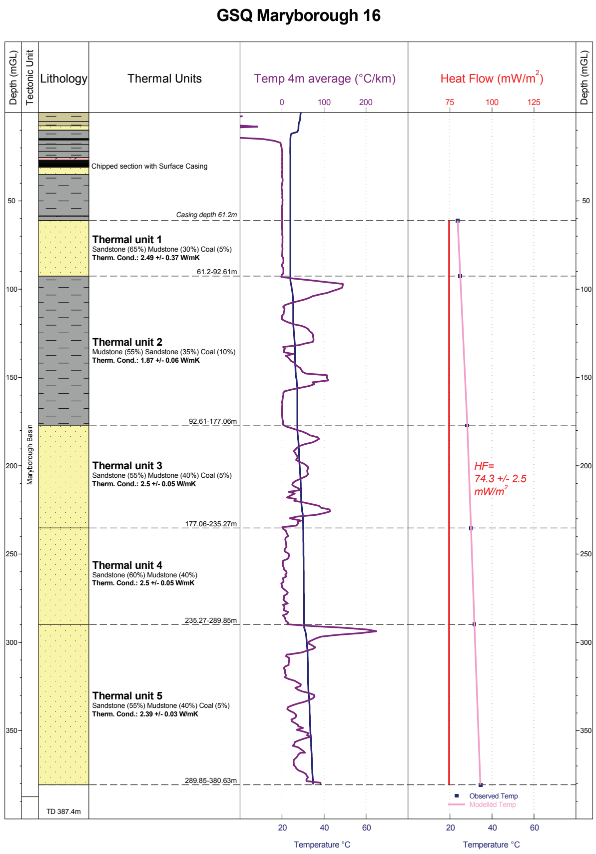


Figure 4: Thermal profile and modelled heat flow of GSQ Maryborough 16, 74.3±2.5mW/m^2

REGIONAL IMPLICATIONS

Millungera Basin

New heat flow values modelled for the Millungera Basin are much higher than 50–60mW/m^2 previously estimated for the area (Figure 5). Temperature extrapolation to 5km depth for GSQ Dobbyn 2 and GSQ Julia Creek 1 were 234±15°C and 223±15°C respectively.

There are several geological factors which suggest the two heat flow values modelled for GSQ Dobbyn 2 and GSQ Julia Creek 1 delineate a larger geothermal potential across the basin.

The insulating capacity of both overlying Eromanga Basin (overlying the Millungera Basin in the south) and the Carpentaria Basin (overlying the Millungera Basin in the north) is excellent with a median thermal conductivity value of 1.13W/mK. In GSQ Dobbyn 2, Carpentaria Basin thickness was 345m whereas the thickness of the Eromanga Basin in GSQ Julia Creek 1 was 320m.

Little information is known about the thermal properties of the entire Millungera Basin however the upper sequence intersected in the two GSQ drill holes consisted of quartzite and siliceous–haematitic altered sandstones. The insulating capacity of these units is low with a median thermal conductivity value of 6.82W/mK across both holes. The maximum thickness of the Millungera Basin has been estimated at up to 3,370m towards the east (Korsch & others, 2011).

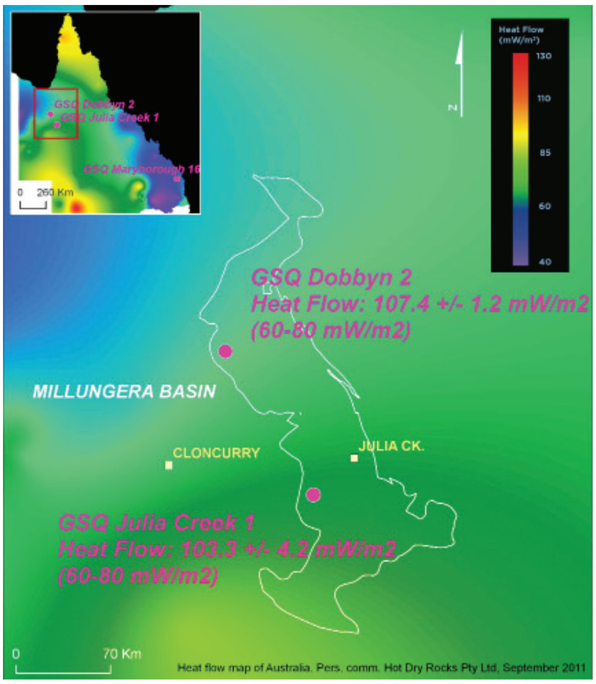


Figure 5: GSQ Dobbyn 2 and GSQ Julia Creek 1 heat flow compared to existing Millungera Basin heat flow estimates (courtesy of Hot Dry Rocks)

High heat producing Proterozoic granites which form basement to the Millungera Basin also outcrop to the west (Mount Isa Inlier) and east (Georgetown Inlier and Croydon Province) (Korsch & others, 2011). The heat production values of the Williams and Naraku Batholiths are greater than 5µW/m^3 and could form a considerable heat source at depth. Hot aquifers within the Eromanga and Carpentaria Basins such as the Hooray Sandstone (intersected in GSQ Julia Creek 1) and Gilbert River Formation (not intersected in Dobbyn 2) are also a highly prospective heat source with geothermal gradients in the area greater than 60°C/km (Korsch & others, 2011).

Preliminary data collected by the CGEI program supports the existence of geothermal potential within the Millungera Basin. The proximity of the basin to Mount Isa mining communities improves the economic viability of any development in the future.

Maryborough Basin

Heat flow extrapolations based on previous datasets inferred the heat flow present in the southern Maryborough Basin was between 50–60 mW/m^2 (Figure 6), which is considerably lower than 74.3±2.5mW/m^2 modelled for GSQ Maryborough 16. From this heat flow result, a temperature of 202±15°C was estimated at 5km.

The excellent insulating capacity of the southern Maryborough Basin is highlighted from the low thermal conductivity values measured from the interbedded sandstones, mudstones and coal units intersected in GSQ Maryborough 16.

Basin insulation capacity increases towards the north due a thickening of the stratigraphy from approximately 1400m in the south to 7000m in the north and

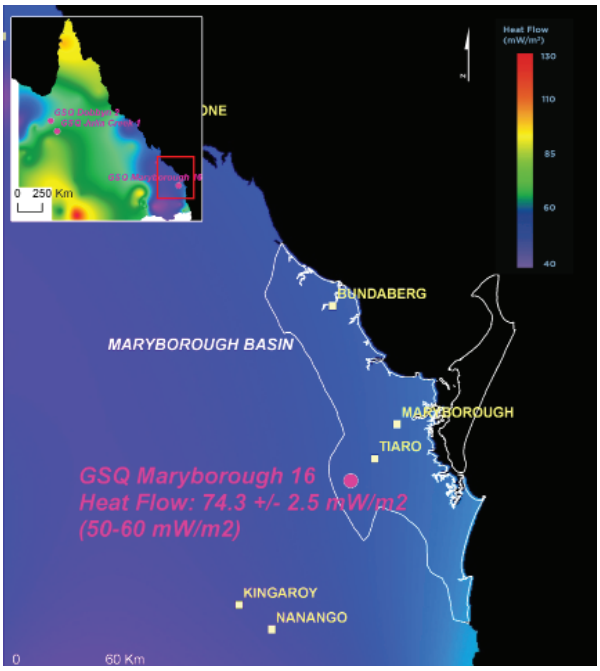


Figure 6: GSQ Maryborough 16 heat flow compared to existing Maryborough Basin heat flow estimates (courtesy of Hot Dry Rocks, 2011)

secondly, the inclusion of additional coal measures up to 3000m thick (Day & others, 1983).

The potential heat sources in the area are the Late Triassic and Late Jurassic – Early Cretaceous intrusives of the Gympie Block. There are no heat production values available for these intrusives, but recent seismicity could be indicative that a residual heat source remains in the area.

Heat flow modelling was undertaken by GA on a site 33km north-east of GSQ Maryborough 16 (Weber & others, 2011). The heat flow modelled over 204 to 310.7m was 68+4/-10mW/m^2. Expanding population and infrastructure demands on the south-east corner of Queensland may enable these heat flow values to form the basis of viable geothermal exploration targets.

CGEI DELIVERABLES

A detailed well completion report will be prepared for each CGEI drill hole after all the data for the hole has been received, assessed and interpreted. A final report will also be released, which aims to tie results gathered through the drilling program to a larger basin by basin preliminary prospectivity review.

Other outcomes from the CGEI drilling program includes:

- HyLogger scanning of all CGEI drill core
- vitrinite reflectance values from selected samples
- gas analysis of Toolebuc Formation samples
- age dating of the upper Millungera Basin units
- HQ3 cored stratigraphic reference holes for Maryborough, Tarong, Surat, Galillee, Styx, Hillsborough and Millungera Basins, and Georgetown Inlier and Hodgkinson Province.

FUTURE WORK

Further funding for the program could result in:

- drilling of phase 2 and 3 (22 sites ~320m across Queensland)
- deeper drilling (2km) within high heat flow areas delineated by Phase 1
- targeted geophysical surveying of areas with high geothermal potential.

CONCLUSIONS

Phase 1 of the CGEI drilling program is due for completion at the end of the year with further analysis and reporting to follow in 2012. Heat flow modelled for GSQ Dobbyn 2, GSQ Julia Creek 1 and GSQ Maryborough 16 are well above the global crustal heat flow of 60mW/m^2 and temperature extrapolations to 5km depth for all three sites are above 200°C.

The preliminary heat flow results and temperature extrapolations gathered for this project don't consider complexities which arise with modelling geothermal systems at depth (such as the effect of stress regimes and loss of permeability at depth) but do highlight areas where geothermal exploration opportunities, closer to population and power consumption areas, exist.

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PEEKING UNDER THE COVERS — THE NEW 'GEOLOGY OF THE THOMSON OROGEN' PROJECT

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Geological Survey of Queensland

INTRODUCTION

The vast region lying between (in both time and space) Proterozoic cratonic rocks in the west/north of Queensland and the relatively young New England Orogen in the east is geologically complex, rich in mineralisation, and partly co-incident with a major high heat flow anomaly. For simplicity we consider basement rocks in this region to belong to a 'greater' Thomson Orogen and this is the focus of a new project for the Geological Survey of Queensland. The Thomson Orogen is interpreted to occupy approximately half of Queensland but outcrop is limited to a discontinuous, relatively narrow strip between Greenvale (north) and Emerald (south), and very small and isolated exposures around Eulo near the border with New South Wales. The remainder of this immense region (>900 000km^2) is concealed by extensive sedimentary basins and remains somewhat mysterious.

BACKGROUND

The Thomson Orogen is the most poorly understood element of eastern Australian geology. Even the geographical distribution of the Thomson Orogen is subject to debate. The eastern margin is generally interpreted as concealed beneath the Bowen Basin but interpretations of the western margin vary substantially (see Direen & Crawford, 2003; Glen, 2005), even since the proliferation of modern regional geophysical surveys. Additionally, interpretations of which outcropping terrains belong to the Thomson Orogen have also varied through time (see Draper, 2006). Our current understanding of the 'greater' Thomson Orogen in Queensland (Figure 1) has a western margin defined by broadly co-incident gravity and magnetic lineaments, and outcropping geology (Table 1, Figure 2) that comprises Neoproterozoic to Cambrian metamasediments and (dominantly mafic) metavolcanics, Cambrian to Ordovician metasediments and metavolcanics, and Ordovician to Devonian intrusive suites. Neoproterozoic to Cambrian units exhibit multiple deformations, greenschist to amphibolite metamorphic grade, detrital zircon age spectra with a distinct 1000–1300Ma population (Fergusson & others, 2007), and were deformed and metamorphosed during the Dalamerian Orogeny. Cambrian to Ordovician units exhibit a range of metamorphism from unmetamorphosed to greenschist facies but lack the multiple deformations observed in the older suite. The Ordovician to Devonian intrusive suites are batholithic in scale and form basement to overlying Devonian and younger basins (e.g. Drummond Basin, Burdekin Basin, Galilee Basin).

These outcropping areas have been the focus of recent research (e.g. Withnall & others, 1995; Bain & Draper, 1997; Fergusson & others, 2001; 2007; 2009;

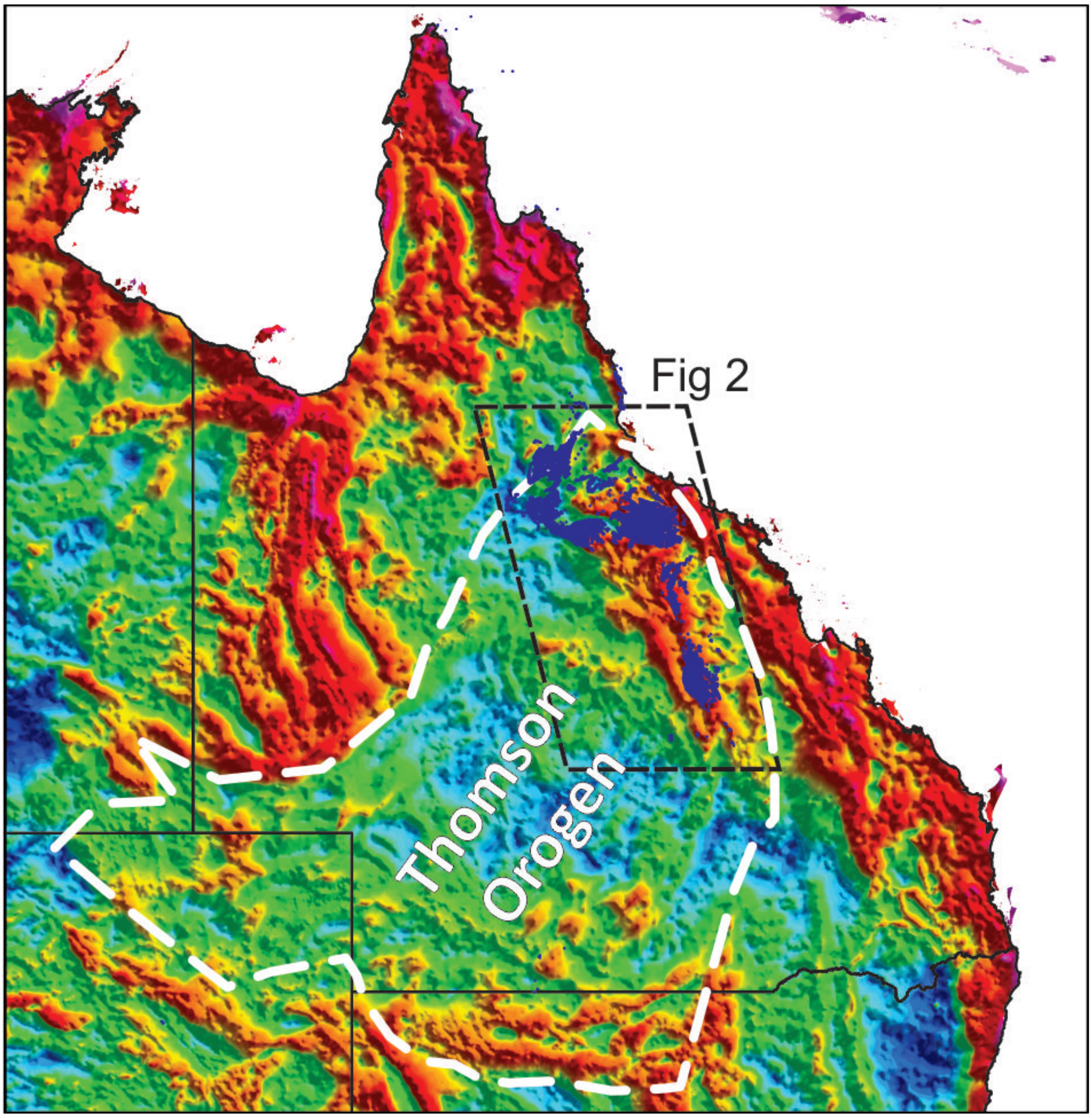

Figure 1: Distribution of the Thomson Orogen (Draper, 2006) relative to gravity image (from GA). Dark blue polygons in north-east are outcropping Thomson Orogen units.

Henderson, 2011) and are well studied. The undercover area however, is relatively unknown. The only significant studies are based around parts of a deep seismic line (see Finlayson, 1990), limited modern geochronology (Draper, 2006), and an investigation of cores from deep petroleum drill holes (Murray, 1994; 1997) which we intend to expand upon. Much information can still be retrieved from the covered area. How much is correlateable with the Neoproterozic to Cambrian metamorphic units versus the Cambrian to Ordovician units? Are there large-scale provinces of a different age or affinity? Can subsurface deposits be correlated with the Warburton Basin, the Timbury Hills Formation (Roma Shelf), or elements of the Lachlan Orogen to the south? What is the distribution, age and setting of intrusive rocks? and can we define batholiths in the subsurface?

On a broader scale, the lack of understanding of the Thomson Orogen limits the quality of post-Rodinia breakup tectonic models for Eastern Australia. Current models and individual tectonic events (e.g. Delamarian Orogeny, Benambran Orogeny)

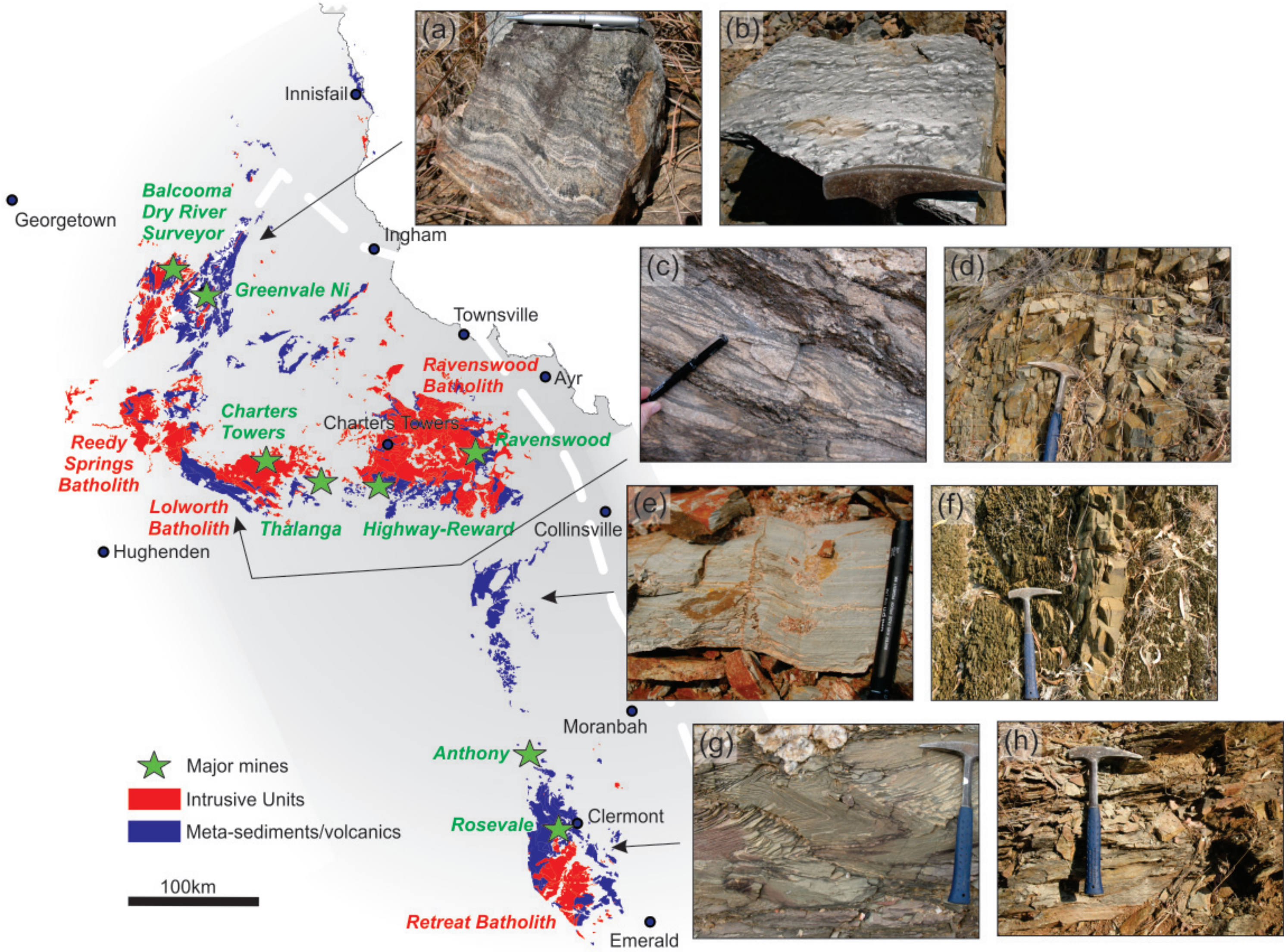

Figure 2: Outcropping geology of the Thomson Orogen in Queensland showing major mines, intrusive and metasedimentary/metavolcanic units. Photos show Neoproterozoic–Cambrian and Cambrian–Ordovician pairs of units throughout the outcropping extent.
a) Oasis Metamorphics, and
b) Balcooma Metavolcanics;
c) Cape River Metamorphics, and
d) Mount Windsor Volcanics;
e) Undivided Anakie Metamorphic Group, and f) Les Jumelles beds;
g) Scurvy Creek Meta-arenite, and
h) Fork Lagoons Beds.

Table 1: Geology of the outcropping Thomson Orogen in Queensland

Age Range	Lithologies	Units
Neoproterozoic to Cambrian	Metasediments and dominantly mafic metavolcanics	Anakie Metamorphic Group, Charters Towers Metamorphics, Cape River Metamorphics, Oasis Metamorphics, Lugano Metamorphics, Lynwater Complex, Boiler Gully Complex, Halls Reward Metamorphics, Argentine Metamorphics, Running River Metamorpics
Cambrian to Ordovician	Metasediments and felsic to intermediate metavolcanics	Fork Lagoons beds, Les Jumelles beds, Seventy Mile Range Group, Balcooma Metavolcanic Group, Eland Metavolcanics, Paddys Creek Phyllite, Gray Creek Complex, Judea Formation, Carriers Well Formation, Everetts Creek Volcanics
Ordovician to Devonian	Gabbro to granite	Ravenswood Batholith, Lolworth Batholith, Dido Batholith, Reedy Springs Batholith, Retreat Batholith, Eulo Ridge Granites

are largely based on regions in southern Australia (e.g. Adelaide Rift Complex, Koonenberry belt, Lachlan Orogen), with the narrow band of outcropping Thomson Orogen in Queensland providing minor constraints. For the Thomson Orogen, current models invoke deposition of sediments on extended Proterozoic crust in a passive margin at ~600Ma followed by deformation associated with an active margin (Murray, 1997; Fergusson & others, 2007; 2009; Glen, 2005). During the late Cambrian to Ordovician, volcanics and sediments were deposited in a back arc environment (Henderson, 1986; Fergusson & others, 2007). Extension terminated in the Late Ordovician/Early Silurian during the Benambran Orogeny with accretion of the Macquarie Arc (island arc) in south-eastern Australia (Glen & others, 2007). Similarly, recent work (Henderson & others, 2011) has suggested that parts of the Broken River Province represent elements of an island arc that developed proximal to the continental margin in the Early Ordovician and accreted in the Early Silurian. Following this, the Thomson Orogen remained in a relative back arc region.

Some obvious questions arise from these tectonic models. For example, if outcropping Thomson Orogen rocks were deposited in a passive margin and subsequent back arc environment, what is the origin of igneous rocks observed in deep petroleum basement cores several hundreds of kilometres inland from the postulated margin? Does any of the covered area share an accretionary component with the outcropping Thomson and Lachlan Orogens? How can we explain the unusual geometry of the area interpreted as Thomson Orogen? What is the source of the sediments? Are there any rocks that record initial breakup of Rodinia (~800Ma; Li & others, 2008)? What is the age and nature of the crust which underlies the Thomson Orogen? When did magmatism, deformation, metamorphism and uplift occur and how does this compare to adjacent terrains?

Despite the limited outcropping extent, the greater Thomson Orogen hosts significant gold and base metal deposits (Figure 2). Historically most gold has been extracted from orogenic deposits associated with the Ordovician–Silurian Ravenswood Batholith, most notably at Charters Towers and Ravenswood (Figure 2). At Charters Towers gold occurs in high-grade quartz-sulphide veins. Alteration phases associated with mineralisation are dated at ~417Ma (Perkins & Kennedy, 1998) and post-date the host rocks. In contrast, mineralisation at Ravenswood is younger (330–310Ma, Perkins & Kennedy, 1998), low-grade bulk tonnage, and hosted in shear zones. Gold has also been produced historically from the Clermont area, associated with basal conglomerates of Permian basins developed on the Anakie Inlier, or with quartz sulphide veining within schists.

Gold mineralisation is also present in the far south of the Thomson Orogen at Granite Springs and continues southward to the Tibooburra Goldfields in northern New South Wales. Tibooburra is described as an orogenic gold province and mineralisation occurs in syn-D1 quartz veins (~440Ma) hosed by late Cambrian, greenschist facies metasediments, and also within basal lag deposits of overlying (Cretaceous) basins (Greenfield & Reid, 2006; Brown & others, 2006). This continuity of gold mineralisation throughout the Thomson Orogen is significant for the prospectivity of the undercover regions.

Significant amounts of copper, lead, zinc, gold and silver has been produced from VHMS deposits within the Thalanga province in the northern Thomson Orogen. VHMS deposits are exclusively hosted by Cambro-Ordivician sequences (i.e. Seventy Mile Range Group and equivalents) and are classified as Kuroko-type deposits primarily due to interpretation of an extensional back arc setting (see Hutton, 2007). Significant research during the late 1990s and 2000s (emanating primarily from CODES) shows that deposits hosted within the Seventy Mile Range Group have different morphologies (e.g. stratiform/sheetlike/tabular — Thalanga and Waterloo; pipelike — Highway-Reward) but all are associated with small, rhyolite-dacite volcanic centres in moderately deep to deep marine environments (i.e. below storm wave base) (Paulick & others, 2001; Paulick & McPhie, 1999; Monecke & others, 2006; Doyle & McPhie, 2000). Further north, the Balcooma Metavolcanics are considered equivalent to parts of the Seventy Mile Range Group and also host VHMS deposits at Balcooma, Surveyor 1 and Dry River. These deposits have similar characteristics to those further south (Morrison & Beams, 1995) and highlight the prospectivity of Cambro-Ordivician back-arc deposits in the Thomson Orogen.

The Thomson Orogen also hosts copper and molybdenum mineralisation in porphyry systems. Recent discoveries include the Anthony molybdenum deposit and the Rosevale porphyry corridor. These are associated with small, multiphase intrusions of possible Devonian (Retreat Batholith) age that intrude the Anakie Metamorphic Group near Clermont.

Another mineralisation style within the Thomson Orogen is represented by the lateric Greenvale Nickel deposit. This is developed on the Cambro-Ordovician ultramafic Sandalwood Serpentinite and produced 436 430 tons of nickel metal and 36 350 tons of cobalt between 1974 and 1995.

In addition to the clear metalliferous economic potential, parts of the Thomson Orogen also have potential for large-scale geothermal energy resources. Maps of interpreted temperature at 5km depth produced by Geoscience Australia (http://www.

ga.gov.au/energy/projects/geothermal-energy.html) indicate a major thermal anomaly that is coincident with the south-western Thomson Orogen and the region of deepest cover. Interpreted temperatures in this area are well constrained due to the abundance of deep drill holes and indicate temperatures of >235°C.

APPROACH

The vast extent of relatively unknown geology within the Thomson Orogen, coupled with encouragingly rich mineralisation in the limited outcropping areas, a drive for exploration of undercover terrains, and the potential for geothermal energy resources is justification for a thorough investigation. We therefore propose a project aimed broadly at enhancing our understanding of the geology, economic potential and tectonic evolution of the Thomson Orogen. Some key questions and our approach are listed below.

1) ***What is the geology of the undercover Thomson Orogen?*** The area interpreted as Thomson Orogen under cover is immense and comprises >900 000km^2. To investigate the geology of this area, we aim to:

- Characterise the *outcropping* Thomson Orogen geology by compilation of existing geochronology (magmatic and detrital spectra) and metamorphic/deformation history. Where gaps exist, the geochronology database will be expanded.
- Construct a comprehensive database of material in ~800 deep, basement-intersecting petroleum drill holes (Figure 3) including lithology, petrographic characteristics, age, and geochemistry. Some of this will derive from existing well completion reports but a large component will be new data.
- Complete an interpretation of new gravity and magnetic data (available early 2012) over areas of shallow cover in the southern Thomson region (Figure 3). This new data will be used in conjunction with recent interpretations by the GSNSW, the drill hole database (above) and existing seismic data to compile regional-scale interpreted basement geological maps.

2) ***What is the economic potential of the Thomson Orogen?*** The relatively limited outcropping parts of the Thomson Orogen are rich in mineral deposits. Several different styles of mineralisation are observed and exploration activities are ongoing. Additionally, significant geothermal energy resources may be associated with the south-western Thomson Orogen where a temperature anomaly occurs. To investigate aspects of the economic potential of the Thomson Orogen, we aim to:

- Complete a thorough review of known mineralisation and current exploration trends.
- Provide geochronology and other detailed investigations of new and/or poorly constrained deposits.
- Generate a depth to basement (depth to Thomson Orogen) surface using validated depths from well completion reports, seismic data, modelling of geophysics, and (locally) groundwater drill hole data. We envisage a detailed surface over shallower areas in the southern Thomson Orogen, and a more generalised surface covering the entire Thomson Orogen. Initial results

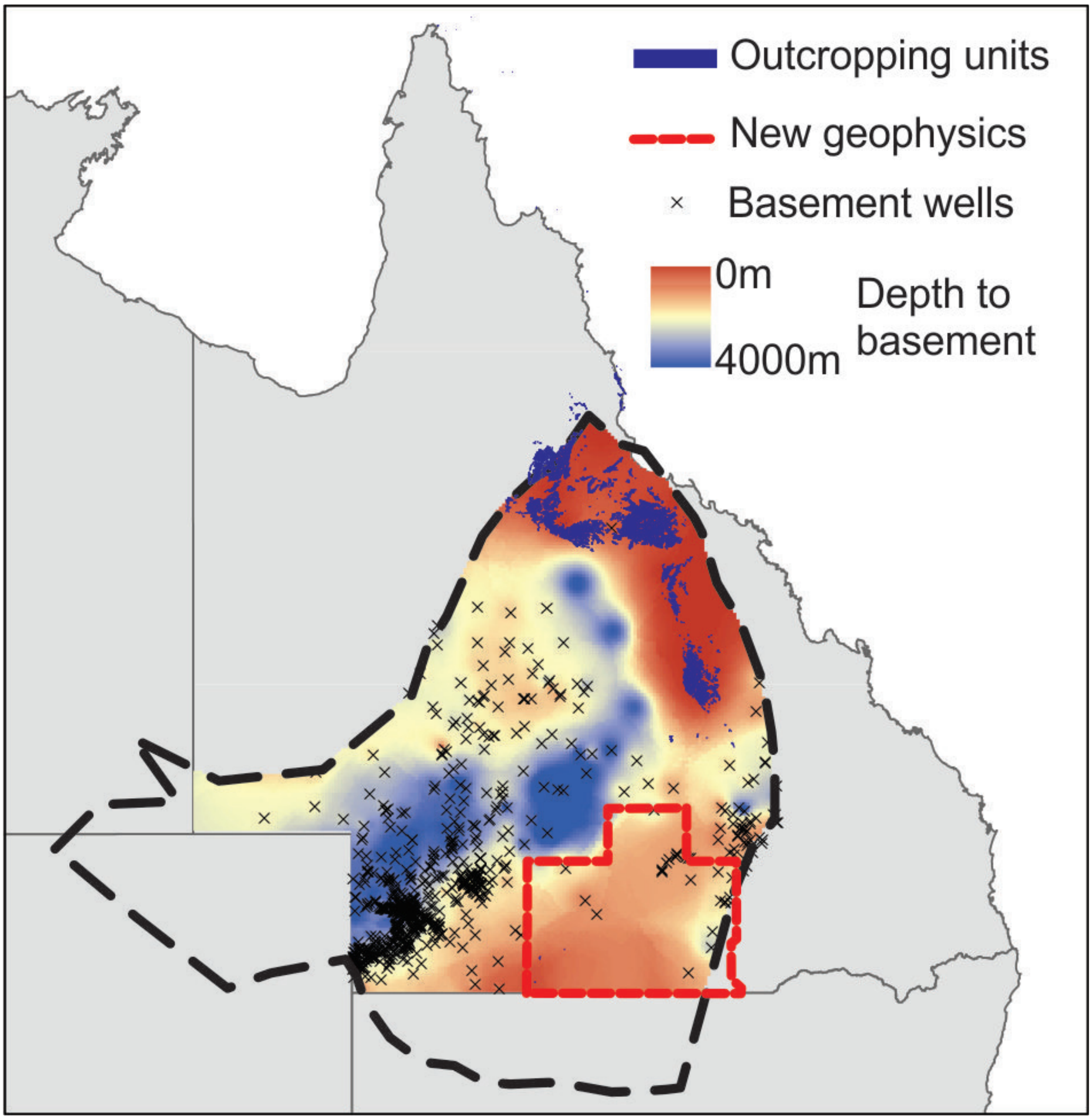

Figure 3: Outline of new geophysics and preliminary depth to basement surface. Note the high relief and strong north-east trends in southern parts of the Thomson Orogen basement surface.

(Figure 3) reveal a very high relief surface dominated by broad north-east trending features.

- Characterise the intrusive rocks in covered areas (retrieved from drill cores). These may represent the heat source associated with a thermal anomaly in south-west Queensland. Via collaboration with the Queensland University of Technology, this is already underway and involves compilation of existing and new geochronology and geochemistry, as well as more general characterisation of the intrusive rocks (distribution, mineralogy, alteration, type, tectonic affinity, comparison with outcropping batholiths etc.).

3) ***What can we learn about the tectonic development of this region?*** The tectonic development during and after the breakup of Rodinia are poorly constrained. For the Queensland part of the Thomson Orogen, events are based on either outcropping units which have a limited age range and spatial extent, or extrapolated from south-eastern Australia. Our work will add new constraints and detail to current tectonic models through:

- Investigations and mapping of the undercover geology as described above
- Compilation of a thorough thermal history for a spatially and temporally representative suite of outcropping and undercover Thomson Orogen rocks. This will include SHRIMP U/Pb dates of zircons (>900°C) augmented by lower temperature methods such as $^{40}Ar/^{39}Ar$ dates of micas (muscovite 300–350°C; biotite 350–400°C), (U-Th)/He dates of zircon (160–200°C) or apatite (55–80°C), and fission track dating of apatite (90–120°C).
- Development of a detailed time-space relationship for magmatism, deformation and metamorphism in the Queensland Thomson Orogen for comparison with adjacent tectonic elements.

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NEW QUEENSLAND ELDORADOS? RESULTS OF THE NATIONAL GEOCHEMICAL SURVEY OF AUSTRALIA PROJECT

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Geological Survey of Queensland

The Commonwealth Government through Geoscience Australia funded the National Geochemistry Survey of Australia (NGSA) program to create a nationwide, internally consistent geochemical database. A total of 311 catchments were sampled in Queensland at an average sampling density of approximately 1 site per 5500km^2, and catchments smaller than 1000km^2 (mostly coastal) and islands were excluded from the survey. The Queensland geochemical survey program has concluded with the release of the Queensland Mineral Prospectivity Atlas and associated data (Tang & Brown, 2011), the national database (Caritat & Cooper, 2011), and field data (Cooper & others, 2010).

The Queensland Mineral Prospectivity Atlas is a statistical appraisal of selected geochemistry from the recently collected NGSA data. The Atlas is designed specifically to highlight catchments with anomalous elemental concentrations and to be used as an exploration tool in Queensland. State-wide data was treated as one population and analysed statistically based on catchment-cell instead of individual data points, and the catchments were ranked by statistical breaks to highlight their mineral potential. The four statistical breaks are at 50, 75 and 90 percentiles and the interpreted anomalous population (mean plus two standard deviations). Sixty-eight (68) elements are included in this atlas.

The integration of high precision geochemistry with appropriate geologic understanding, geochemical interpretations and mineral occurrence data was adopted to identify potential mineral targets and deposit styles. Such catchment-size modelling has generated new greenfield targets that have not been previously considered prospective.

SAMPLING METHODOLOGIES

The NGSA fieldwork in Queensland was carried out by staff of the Geological Survey of Queensland. Catchments were sampled near their outlet or at their lowest point within the catchment based on digital elevation modelling. The sampling took advantage of the natural mixing of materials derived from various source rocks within catchments and the subsequent deposition in low-energy environments near their outlets. Ideally, the chemistry of outlet sediments (similar to floodplain or overbank sediments) can represent the average, background geochemical composition of such large catchments. Sediments were sampled at two depth intervals from 0–10cm from the surface for the top outlet sediment (TOS) and 60–90cm below the surface for the bottom outlet sediment (BOS).

At each sample locality, the GPS coordinates, a detailed site description, lithologic observations, field pH, and dry (if possible) and moist Munsell® soil colours were recorded and photographs of the sample site were taken. The field information was recorded either digitally or in hardcopy and subsequently uploaded into databases.

SAMPLE PREPARATION AND ANALYSIS

All samples collected in Queensland were sent to the Palaeontology and Sedimentology Laboratory group of the Petroleum and Marine Division of Geoscience Australia in Canberra for processing. The bulk sample was dried for 48 hours at 40°C and sieved through a 3.35mm mesh to remove coarse vegetative or foreign material. Each outlet sediment sample was sieved to a coarse (<2mm) and a fine (<75micron) fraction or subsample. The subsamples were analysed for 68 elements and associated physical parameters using five state-of-the-art analytical techniques, and included the mobile metal ion multi-element extraction (MMI ME) for <2000μm TOS sample only. Each target site generated 4 subsamples and 541 analyses. The 5 analytical methods are:

1. Total multiple elements content by X-ray fluorescence (XRF) and inductively coupled plasma-mass spectrometry (ICP-MS). Fifty-seven elements were determined using the combination of XRF and collision cell ICP-MS. The ICP-MS analyses were carried out on total digestion ($HF+HNO_3$) of fragments of the XRF beads.

2. Soluble multiple elements content including low-level gold (Au) by aqua regia (AR) digestion and analysed by ICP-MS. Sixty elements were determined by the AR ICP-MS method.

3. Soluble selenium (Se) content by AR digestion and analysed by ICP-MS

4. Platinum group elements or PGEs (Pd and Pt) and gold (Au) analysis using fire assay, and analysed by ICP-MS

5. Fluoride (F) content after alkaline fusion and analysed by ion specific electrode (ISE).

RESULTS AND DISCUSSIONS

Geochemical analysis showed that all catchments have broadly similar upper crustal signatures and individual catchments yield unique and consistent chemical signatures for respective subsamples. Within each catchment, geochemistry analysed using the same method varies slightly between horizon and size fractions. The BOS sample generally has higher overall geochemical concentrations and the <75μm fraction is more sensitive to both major and trace element variations.

The Queensland Mineral Prospectivity Atlas (Tang & Brown, 2011) highlights anomalous catchments for 68 elements in Queensland, defining potential new mineral discoveries. By rigorously interrogating the data and applying inter-element correlations using known mineral occurrence models, the atlas has the capability to predict catchment-scale mineralisation model. Such predictive approach is very useful for greenfield and brownfield exploration in Queensland.

Gold anomalies

Gold anomalies are relatively widespread in Queensland (Figure 1) with numerous anomalies matching known gold provinces in Queensland such as the Gympie Province (Mary River), Charters Towers Goldfields (Burdekin – Logan – Clarke Rivers), Mount Morgan area (Fitzroy River) and Etheridge Province (Einasleigh River). New anomalies were identified in and around the Mount Isa Block along the O'Shannassy River and Gunpowder Creek, which is to the north of the town of Mount Isa. Several intense gold anomalies were interpreted in the Eromanga Basin along the Thomson and Diamantina – Western Rivers, and in the Eyre Creek catchment within the Simpson Desert. The intensity of these newly identified anomalies matches the million-plus-ounce occurrences of Gympie, Mount Morgan and Charters Towers, suggesting potential Eldorados/giant deposits from greenfield regions.

The gold anomalies in the Fitzroy and Isaac River are associated with Zr, Ti, Si, Sm and Hf anomalies that point either to detrital or residual deposit signatures from the accumulation of resistant minerals. The Isaac River anomaly is associated with Al, Ga, Fe and Sc and a weak association with Ag and As. In totality, this geochemical association strongly suggests a lateritic source region for the gold with distal relations to igneous activities. The major gold mine in the Fitzroy– Isaac catchment system is the Mount Morgan mine, which was first discovered as a lateritic gold deposit. The presence of a known lateritic gold association supported inferences from the geochemical interpretation.

The Burdekin River Au anomaly is supported by adjacent catchments such as Logan and Cape River. Gold in the Burdekin system is strongly associated with K, Na, Ca and Sn, and moderately associated with Rb, Be, Mg, V, Al, Pb and Hg. The strong association with Sn and light ion lithophiles (LIL) suggested that the mineralising system was driven by high temperature hydrothermal cell(s) evident by the strong LIL association and mobilisation of elements such as Na, K, Ca, Mg and Rb. The strong presence of Sn suggested vein-styled deposit, pegmatite or oxidised magmatic system that controlled of mineralisation. Moderate association with Hg, Be, V and Pb could suggest geochemical variations of vein, source or temperature of deposition.

The Einasleigh and Clark Rivers of the Etheridge Province have strong Au anomalies. Einasleigh River has strong association between Au and K, Na, La, Rb, Be, F and Ni, and moderate association with Ca, Ce, Ga, Na, Nd, Ni, Pr, Sm, Sr, Th and Tl. The strong association of lithophilic elements with gold supports hydrothermal deposits related to late magmatic fractionation such as vein or pegmatitic style deposits. The Clark River does not have strong elemental association but has weak

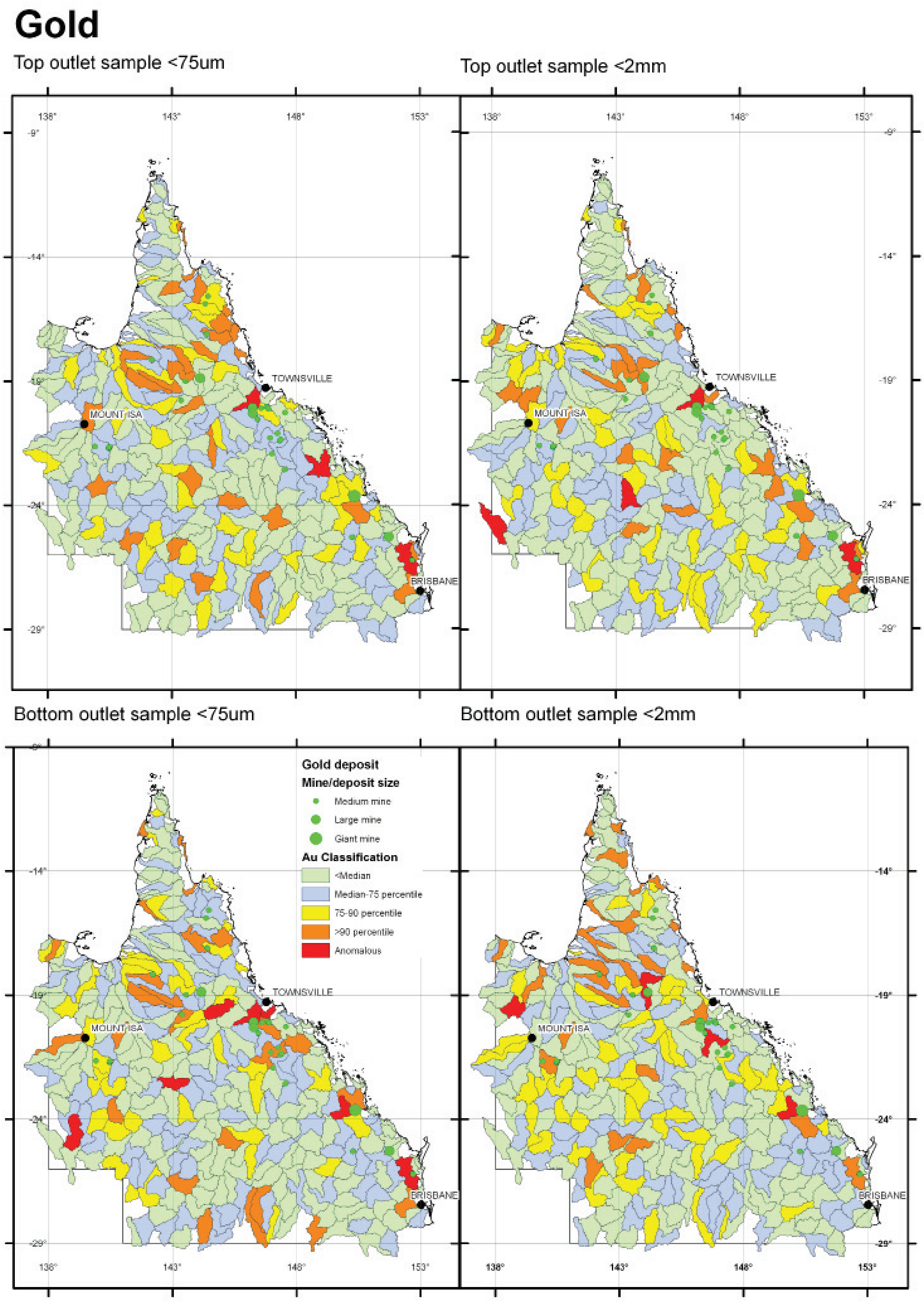

Figure 1: Gold anomalies

association between Au and Ce, Cr, Dy, Er, Eu, Gd, Ho, K, La, Na, Nb, Mo, Pr, Sb, Sm, Tb, Th, Ti, Y and Yb, which is typical of geochemical signatures associated with detrital deposits. The Clark River gold anomaly is most likely related to placer type deposition with mineral sand.

The O'Shannassy River gold anomaly to the west of Mount Isa is associated with Ca, F, Mg, Pb, Gd, P, Sb, and U. The complex association may result from either lithologic (limestone and phosphatic rocks) or mineralisation influences. The presence of Ca-F-P indicates possible presence of apatite and fluorite in the catchment and the likelihood of a fluoroapatite vein association.

The gold anomaly within the Mary River catchment is associated with As, Hg, Cr and Ni, and moderately associated with Ag, Mg, Mn, P, Sb, S and Se. The Hg and As association is interpreted as a high level or low temperature environment related to igneous sources (Se-Sb association), and the association with Cr, Ni, Mg, Mn is interpreted as a lithologic influence from mafic volcanogenic country rocks.

The Thomson and adjoining Western River have respective gold anomalies in their catchments that are not associated with any known gold occurrences. The anomalies are inconsistent and not supported by subsamples from different depth or size fractions, possibly due to poor homogenisation of sediments within the catchment. Gold is associated with Sr, Cl, Ba, Mn, S, Re and Zn in the Western River and the association of mobile elements is likely linked to ground water, which can precipitate soluble gold in the sediments. This greenfield gold anomaly will require further geochemical follow-up to ascertain the validity and/or cause of the anomaly.

Gold anomalies are identified in two catchments of the Eyre Creek with no prior gold discoveries in the vicinity. As with the Thomson and Western Rivers, the anomalies are inconsistent and not supported by subsamples. The gold anomaly is associated with B and Re, and weakly associated with Cd, In and Mo. The Au-Re-Mo elemental signature is similar to the Merlin, Mount Dore and Kalman deposit (south-east of Mount Isa) which was interpreted as an "Iron Oxide Copper Gold" deposit that evolved from a deep-seated magma.

Copper anomalies

Copper anomalies are confined mainly to the New England Orogen along the coastal margin of Queensland and in and around the Mount Isa Block. Anomalies were identified around the Texas–Silverwood Block (Condamine River catchment), along the Don River (90km south-west of Rockhampton), in the Boyne River catchment (40km south of Gladstone) and in the Funnel Creek and Pioneer River catchments near Mackay. In the Mount Isa area, copper anomalies are interpreted along the Leichhardt and Cloncurry Rivers and Gunpowder Creek. Most of the copper anomalies occur in areas of known copper occurrences with small to giant deposits. A new copper anomaly was identified in the Westmoreland region along Settlement Creek.

REE anomalies

REE anomalies occur in three distinct regions in Queensland — in Cape York Peninsula, around the Texas–Silverwood Blocks, and within the Comet River catchment north of Rolleston (Figure 2). The anomaly in Cape York is extensive and covers regions from the Georgetown Block to areas north of Weipa. Most of the REE-U anomalies in Cape York are not associated with known uranium or REE occurrences and the elemental association suggested that these anomalies are most likely associated with mineral sand deposits. A strong REE anomaly occurs around the Texas–Silverwood Blocks within the Condamine and Moonie Rivers, and Commoron and Warrill Creeks.

A distinct REE anomaly occurs within the Comet River catchment, and the anomaly is primarily for heavy REE associated with Co, Fe, Ni, Sc, Ti, V, Ga, In, Nb and Ta. Appraisal of their elemental association postulates the likely origin for REE in the Comet River as a peralkaline intrusion and further investigation is warranted.

SUMMARY

The NGSA data is a collection of high quality and internally consistent multi-element soil geochemistry. Scientifically vigorous interpretation of the data has the ability to give a state-wide snapshot of the tremendous untapped mineral potential of Queensland.

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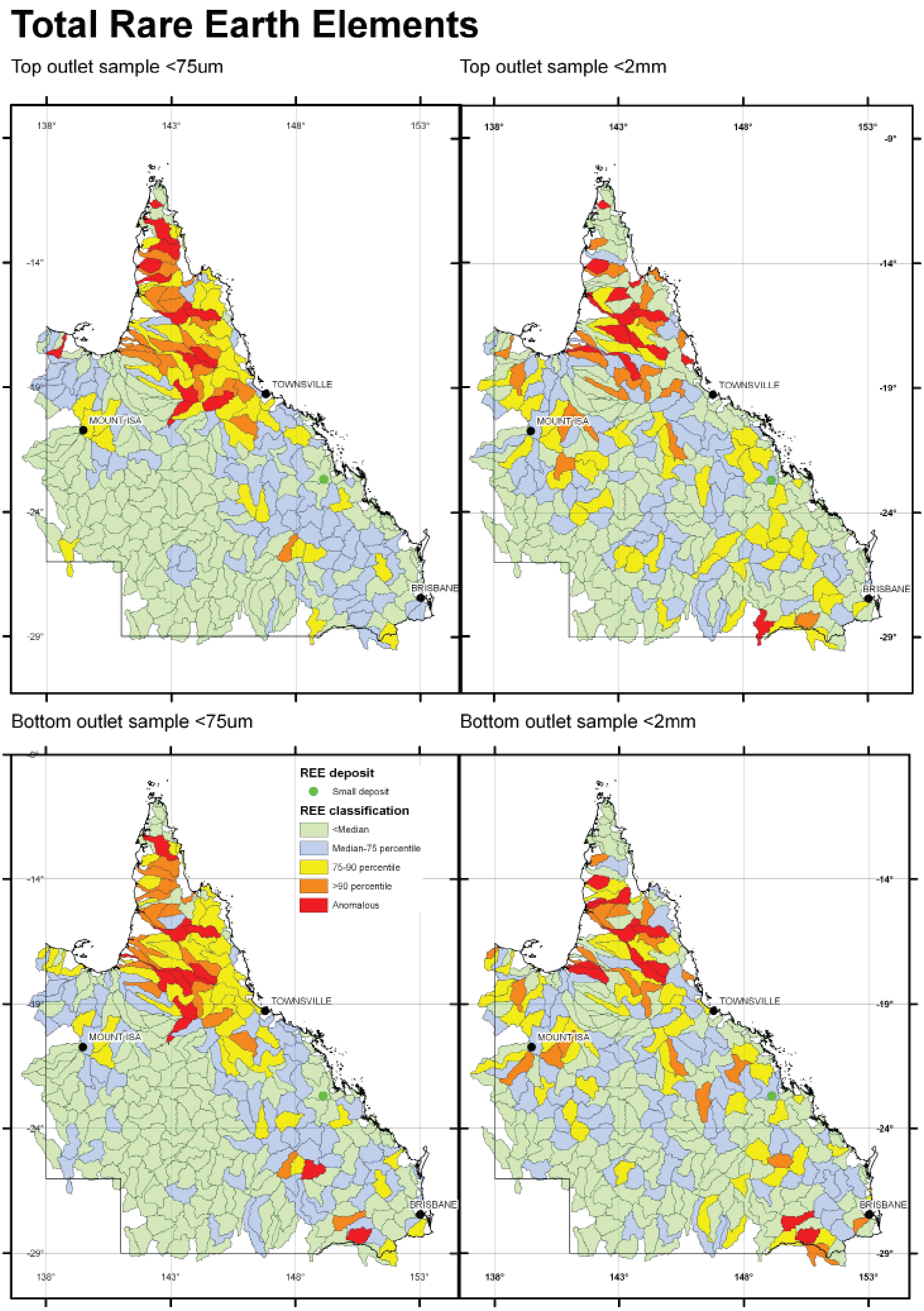

Figure 2: REE anomalies

THE LAWN HILL PROJECT

Ben Jupp

Geological Survey of Queensland

The Lawn Hill project area lies within the northern Mount Isa Inlier and extends from the Fiery Creek Fault to the Murphy Inlier to the north and covers approximately 30 000km^2 (Figure 1). The Lawn Hill Platform is of high exploration interest with significant mineral resources occurring within Proterozoic sequences hosting Cu and major Pb-Zn stratiform mineralisation such as the world class Century Mine deposit. Resources within the Lawn Hill Platform are not limited to minerals, with significant oil and gas potential hosted within the marine black shales of the Upper McNamara Group.

The Lawn Hill project is primarily focussed on resource assessment and is being carried out as part of the Greenfields 2020 Initiative. The key aims of the Lawn Hill study are as follows:

- Investigate the geological and structural architecture of the Lawn Hill Platform and develop geologically and geophysically consistent interpretations of the subsurface utilising all currently available data and literature.
- Develop a geophysically and geologically valid 3D model (Common Earth Model) using GOCAD and VPmg/UBC.

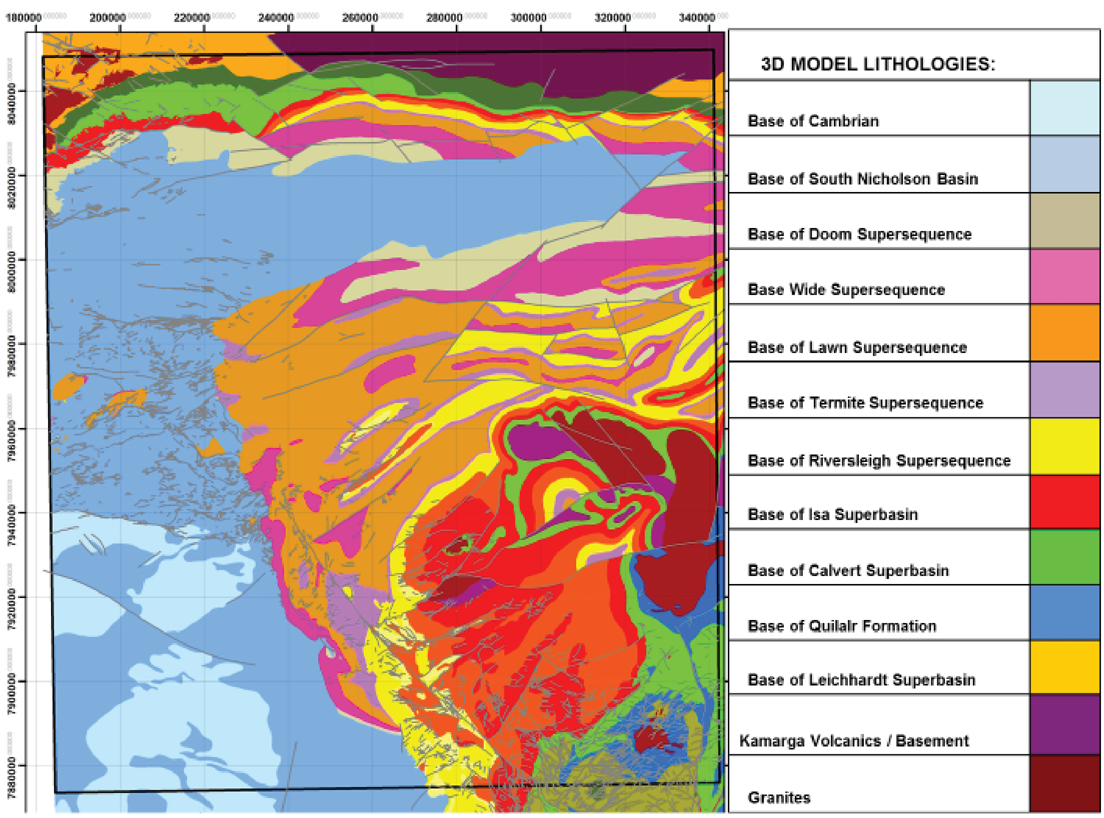

Figure 1: Simplified solid geology map of the Lawn Hill Platform

- Explore the mineral potential of the Lawn Hill region using a data driven (WofE) approach and develop 3D prospectivity maps for Pb-Zn and Cu mineralisation.

Previous work

A number of previous studies have been undertaken within the project area. The most significant recent work has been carried out by the *predictive mineral discovery**CRC (*pmd**CRC, 2007; 2008) and by the Queensland Geological Survey (NWQMEP study, Geological Survey of Queensland, 2011), and form the foundations for this study.

GEOLOGICAL MODELLING

A 3D model of the Lawn Hill Platform has been created to better understand the structural and stratigraphic architecture of the region using a standardised modelling workflow which was adopted from the *pmd**CRC. These steps are briefly discussed below.

Solid geology

Lithostratigrahic units within the Lawn Hill model have been defined based on the sequence stratigraphic approach of Southgate & others (2000). Correlations have been further updated based on recently revised 1:100000 GSQ surface and solid geology mapping (Geological Survey of Queensland, 2011). Due to the complexity of the regional geology an overall simplification of the lithostratigraphy was required. As a result units to be modelled were subdivided into superbasins. Due to the importance of the Isa Superbasin for economic potential a further subdivision into supersequences of the upper Isa Superbasin was made. Modelled units are illustrated in Figure 1.

Fault architecture

The Lawn Hill fault architecture was defined based on a review of the solid geology interpretations, literature and current geophysical datasets (Figure 2). Major fault boundaries have been interpreted based on updated regional mapping, potential field datasets and seismic datasets where available. Faults of greatest strike length were included in the model, as these have been interpreted to have greatest crustal penetration tapping into mineralising fluid reservoirs at depth. An interconnected fault network was defined for simplicity in model creation. Faults to be modelled were chosen by overall strike length, geological importance and where geological boundaries were required.

Field mapping and sampling

Field investigations were undertaken in the Lawn Hill region during May of 2011. This work was carried out in order to better define unit relationships, fault orientations

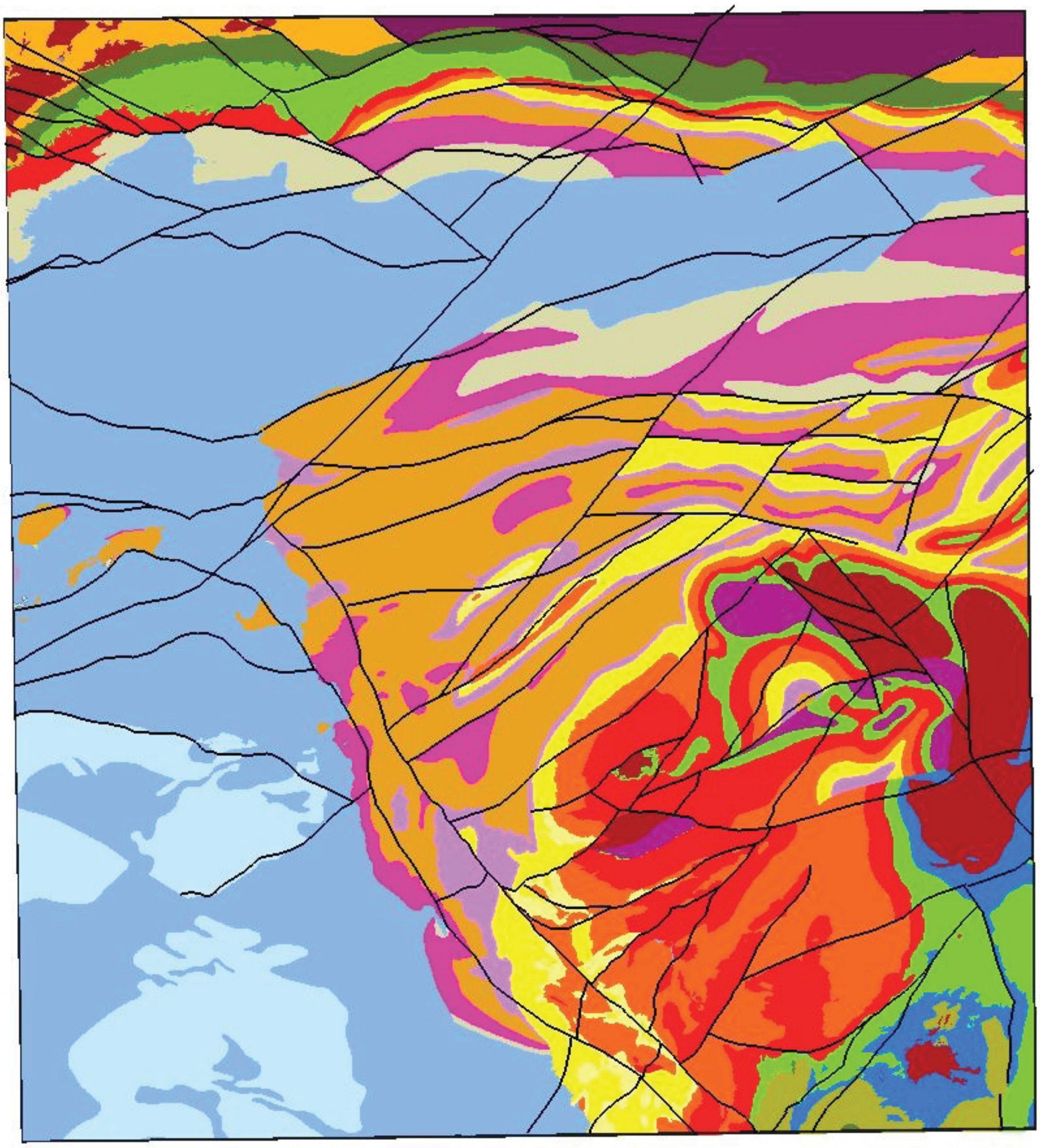

Figure 2: Solid geology map illustrating simplified modelled fault network.

and obtain representative rock property samples across the region. Magnetic susceptibility readings were obtained from representative outcrops and fresh samples were collected for further density measurements.

Cross-sections

Ten cross-sections at 1:250 000 scale were interpreted across the Lawn Hill region to define the major subsurface architecture (Figure 3). Cross sections were drawn on a semi-regular intersecting grid to a depth of 20 kilometres. Subsurface geometries were interpreted from surface mapping, seismic, magnetotelluric profiles, potential field datasets (including worms), limited drill hole information and available literature.

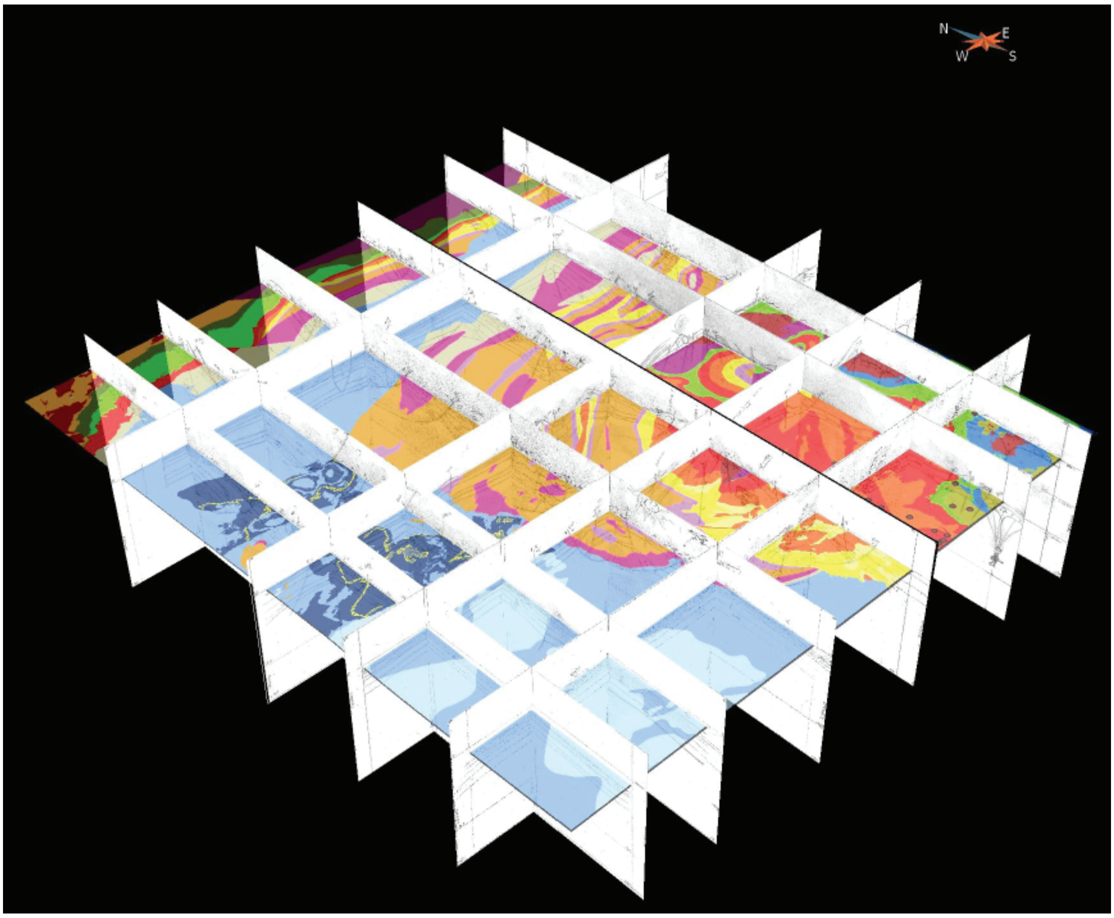

Figure 3: Cross sections registered in 3D, view from the south-west.

Forward models

Four intersecting gravity profiles were modelled along four key cross-sections in order to better constrain the interpreted geometries and lithological distributions (Figure 4). Rock property values and interpreted geometries were optimised to provide a better fit to the geophysical profiles. Consistent ranges of rock property values were used for each unit across the gravity profiles. Some minor misfit was observed with respect to the depths of some units between profiles at intersection points. This has been assumed to reflect far field influences offline from the 2D profiles or larger variations in rock properties that have been unaccounted for. These inconsistencies will be explored during the 3D geophysical inversion process.

Depth to basement

Depth to basement modelling was carried out across the Lawn Hill project area in order to better estimate depth to prospective Proterozoic units under shallow cover (Figure 5). Depths have been constrained using mineral exploration holes, water bores and more extensively magnetic depth to source modelling which was carried out during the NWQMEP study (Geological Survey of Queensland. 2011). Geological and geophysical constraints were sparse within this region. This coupled with the smoothing process (DSI) used within the GOCAD software compounds the uncertainty of results. As a result caution should be used in using this surface for true depth to basement estimates.

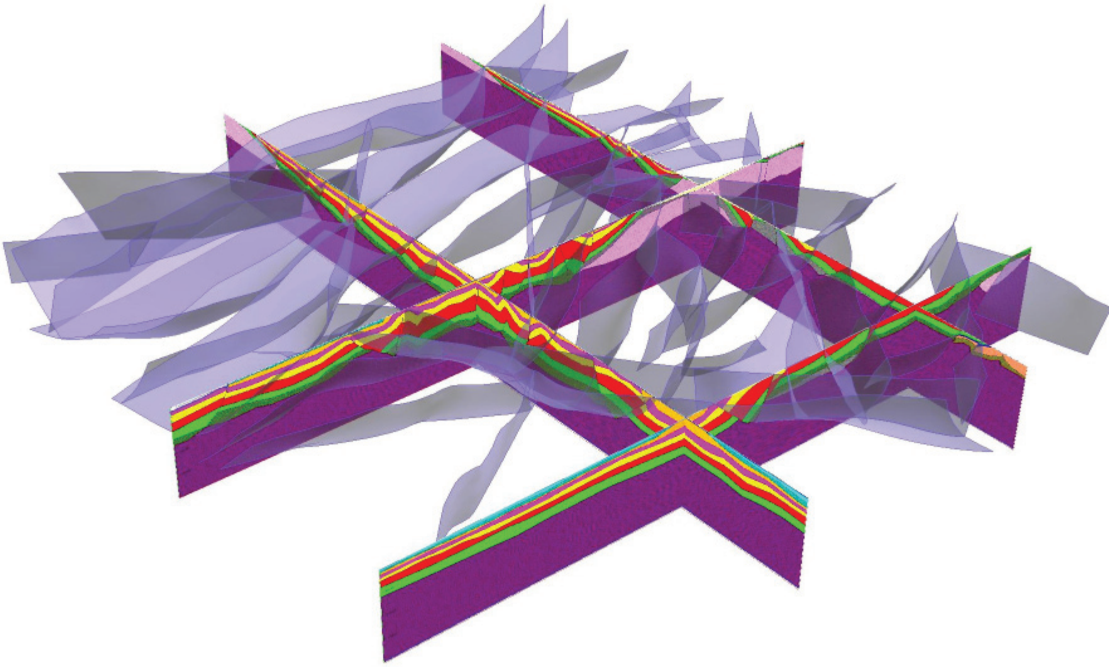

Figure 4: Forward models registered in 3D with blue fault surfaces.

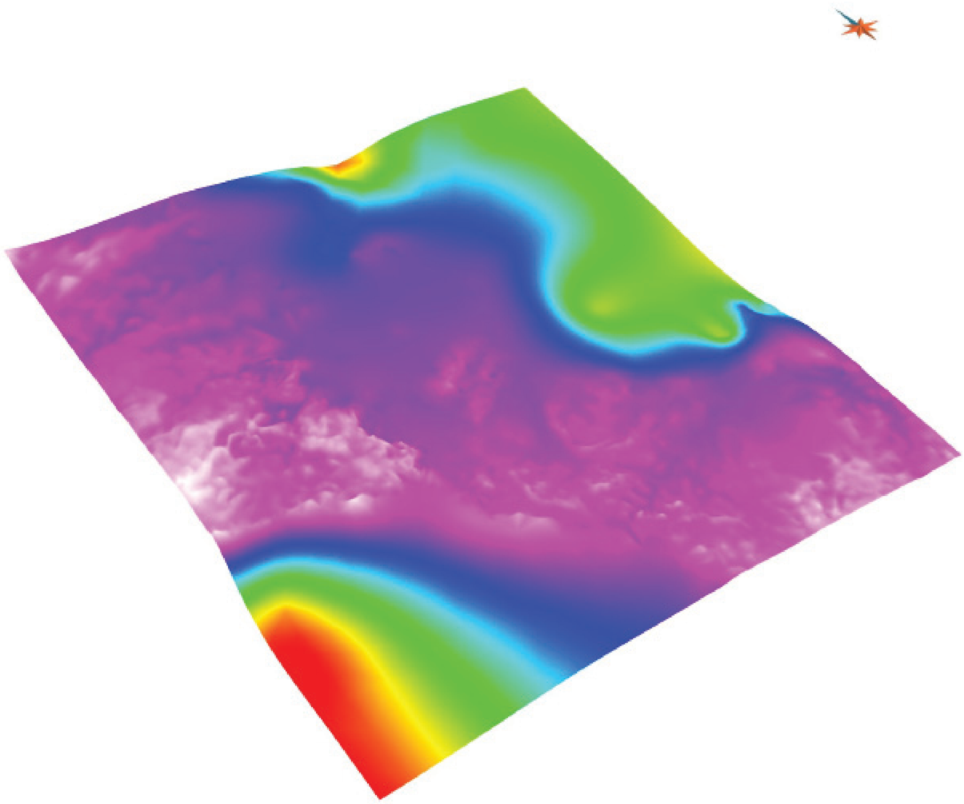

Figure 5: Depth to Basement Model. Warm colours indicate increasing depth. N.B. 10 x vertical exaggeration

Surface modelling — GOCAD and SKUA

A 3D architectural model of the Lawn Hill Platform has been constructed using the GOCAD and GOCAD-SKUA 3D modelling packages (Figure 6). In total fifty faults, twelve major units and two intrusive suites were constructed across the region by interpolating between the ten cross-sections.

Within the outcropping section of the model, units were constrained to a digital terrane model (DTM), which has been down sampled from 3-second data to limit the overall size of the 3D surface. In undercover areas, surfaces were constrained to the depth to basement surface. An overall layer cake style distribution of lithologies has been generally assumed throughout the model except where mapping and seismic data indicated otherwise.

COMMON EARTH MODELLING

Rock Properties

A compilation of petrophysical rock properties prepared from company datasets, company reports, field observations and published literature has been developed for use within the inversion and forward modelling stage of this project. Statistical analyses of the properties of each unit were carried out to constrain suitable ranges to represent each lithological package within the model.

3D Inversions

An ongoing phase of geophysical inversion modelling is currently underway. The final aim of this process is to create a Common Earth Model (CEM) that is quantitatively consistent with all geological information and potential field datasets. During the inversion process the initial values of properties within the geological domains (magnetic susceptibility and density) are adjusted within set property ranges in order to calculate a geophysical response that better matches the observed potential fields of that region while still maintaining the set geological bounds of the model.

Based on the architectural starting model a 3D grid model (voxet) was created (Figure 7). This process divides the space of the model into regular cells that represent each defined unit contained within the modelled region. Due to computational limitations a grid resolution of 500m(X) x 500m(Y) x 50m(Z) cells was chosen. Within the model each cell is assigned to a rock unit and populated with rock properties specific to those formations (i.e. magnetic susceptibility and density).

The inversion process will entail several phases utilising both VPmg and the UBC-GIF (MAG3D and GRAV 3D) inversion software packages. Initial full crustal scale magnetic and gravity inversions to 20 kilometres will be carried out using VPmg. Further detailed inversions of the upper 2.5 kilometres of the crust will be carried out in order to target shorter wavelength potential field responses which are suspected to be shallower in origin.

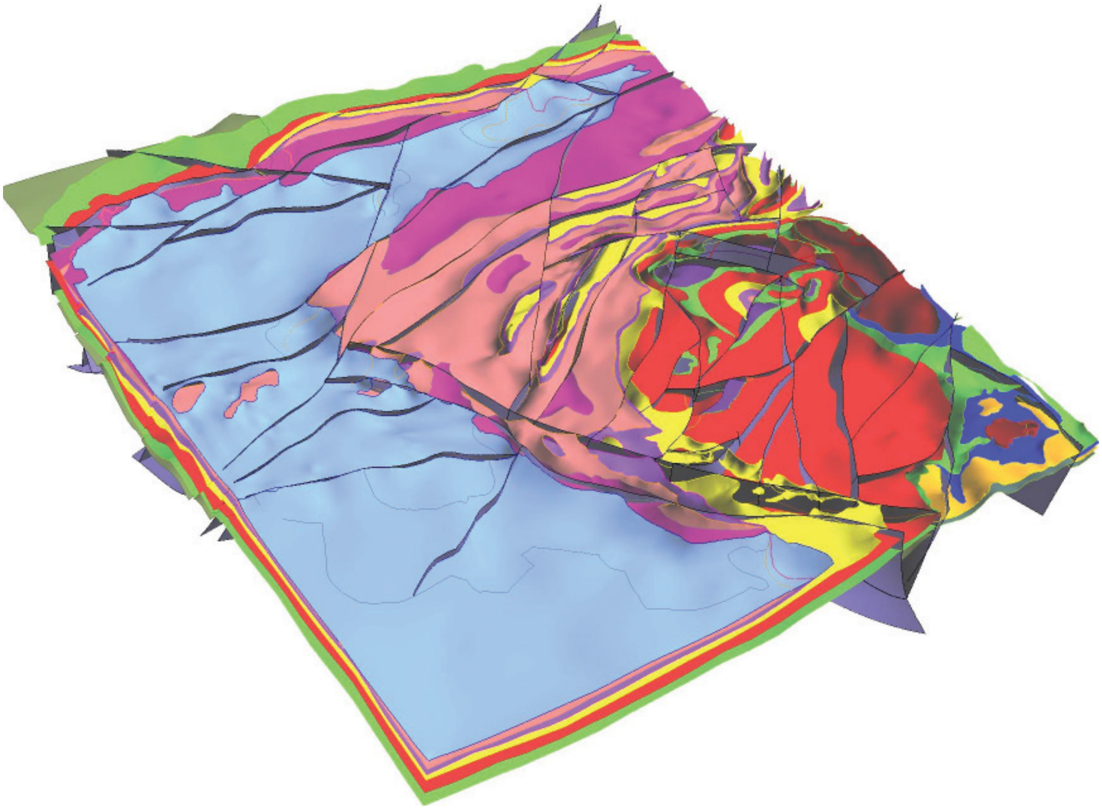

Figure 6A: The Lawn Hill 3D model. N.B. 2x vertical exaggeration

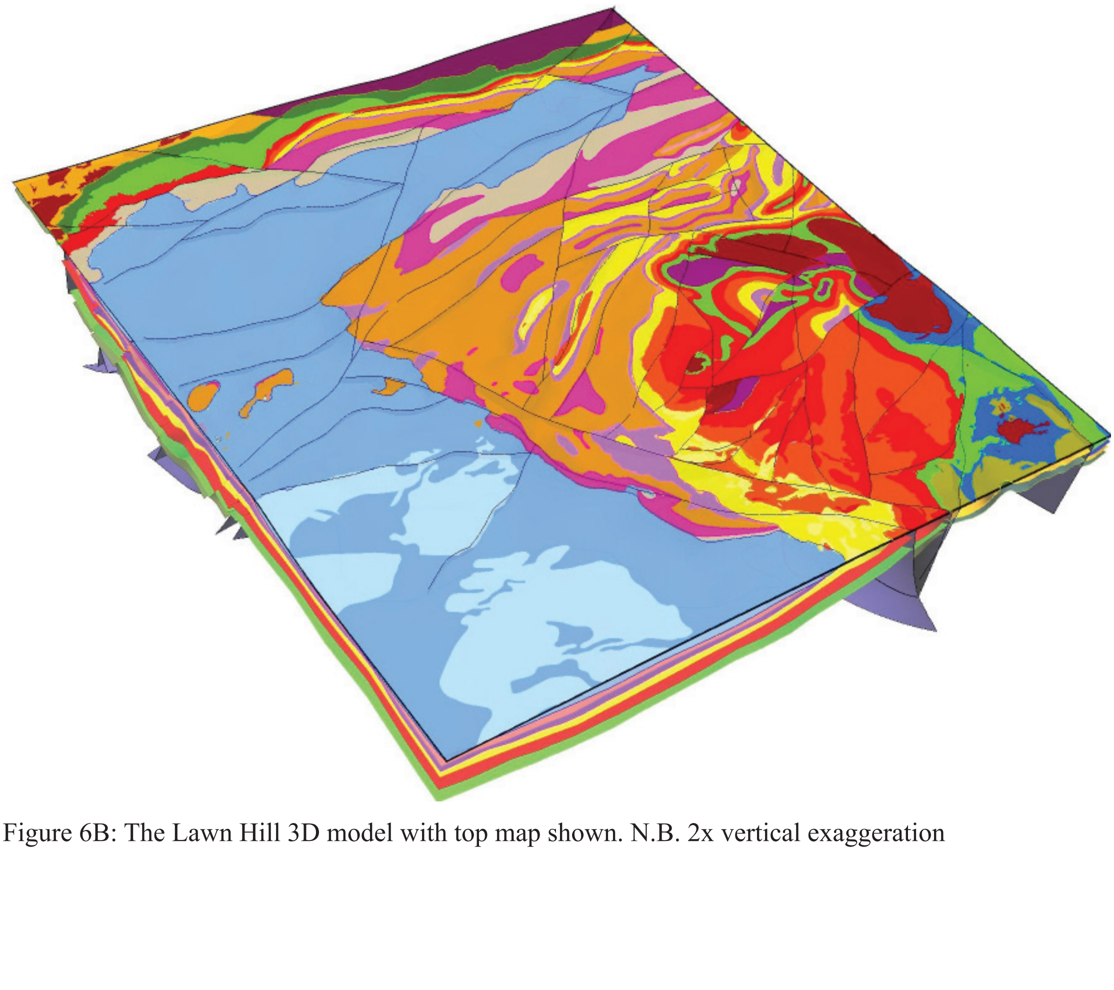

Figure 6B: The Lawn Hill 3D model with top map shown. N.B. 2x vertical exaggeration

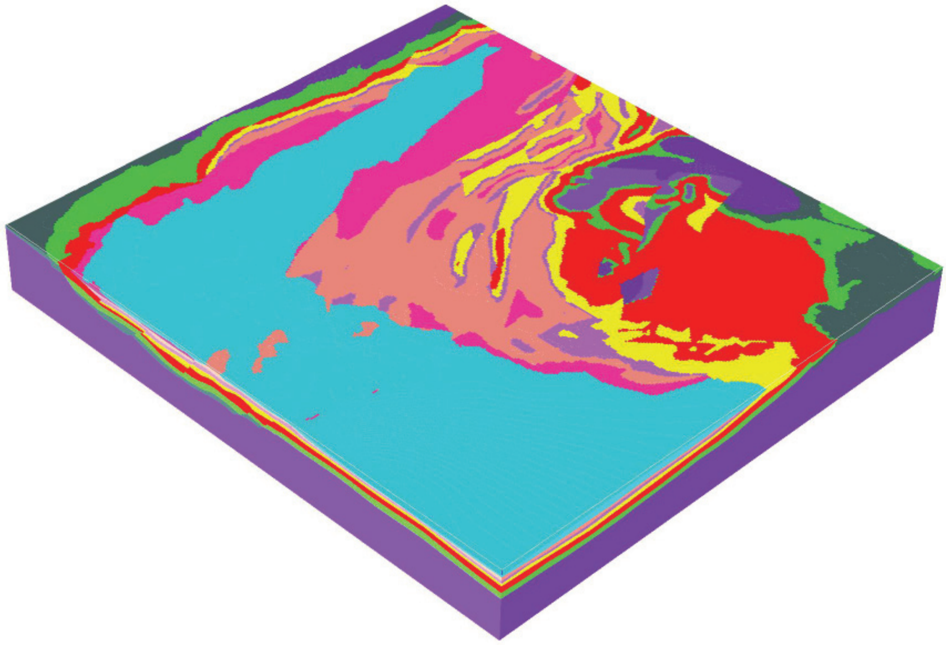

Figure 7: 3D Voxet model with grid resolution 500m(X) x 500m(Y) x 50m(Z)

PREDICTIVE MODELLING

Upon completion of the CEM prospectivity studies will be carried out in 3D using a data driven Weights of Evidence (WofE) approach. This process will evaluate spatial relationships between known occurrences of both Pb-Zn and Cu mineral deposits and multiple exploration criteria which are indicative of these mineral occurrences in Lawn Hill. Exploration criteria have been defined based on literature and the mineral systems analysis carried out during the NWQMEP study. Examples of targeting criteria to be used, although not limited to, include: proximity to faults, fault intersections, fault orientations, geological complexity and corresponding high magnetic susceptibility and density.

The evaluation method to be used is based on the 2D mineral exploration work carried out by Bonham-Carter and others in the 1990s, although this study will be carried out in the full 3D space of the model. This process will be carried out through the Targeting Workflow plugin to the GOCAD software. Using this workflow the weights of each discriminating property in relation to the training data (known mineral occurrences) will be calculated to quantitatively assess the relationship between the defined exploration criteria and actual mineral occurrences. Computed weights can be used as a tool to discriminate between areas of high or low exploration potential based on calculated weights; increasing predictive capabilities by increasing the understanding of specific district controls on the ore-forming systems. A final result from this analysis will be a complete quantitative Mineral Potential Index which represents the relative chance of each individual cell within the model to host the specific mineralisation.

CONCLUSION

The Lawn Hill project remains a work in progress but aims to be completed before June, 2012. Whilst significant uncertainties remain within the model, important advancements are being made in obtaining a better understanding of the geology of the Lawn Hill region. Through the process of geological modelling coupled with geophysical inversion techniques, a robust integrated 3D model of the subsurface can be derived. Statistical analysis of the integrated model using a quantitative WofE approach will improve our understanding of mineralising processes in the Lawn Hill region and provide significant targeting refinement for explorers.

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CU-AU-MO-RE-(U) MINERAL SYSTEMS – NEW INSIGHTS FROM KALMAN

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[1] Geological Survey of Queensland, [2] CSIRO, [3] Colorado State University, [4] Cerro Resources

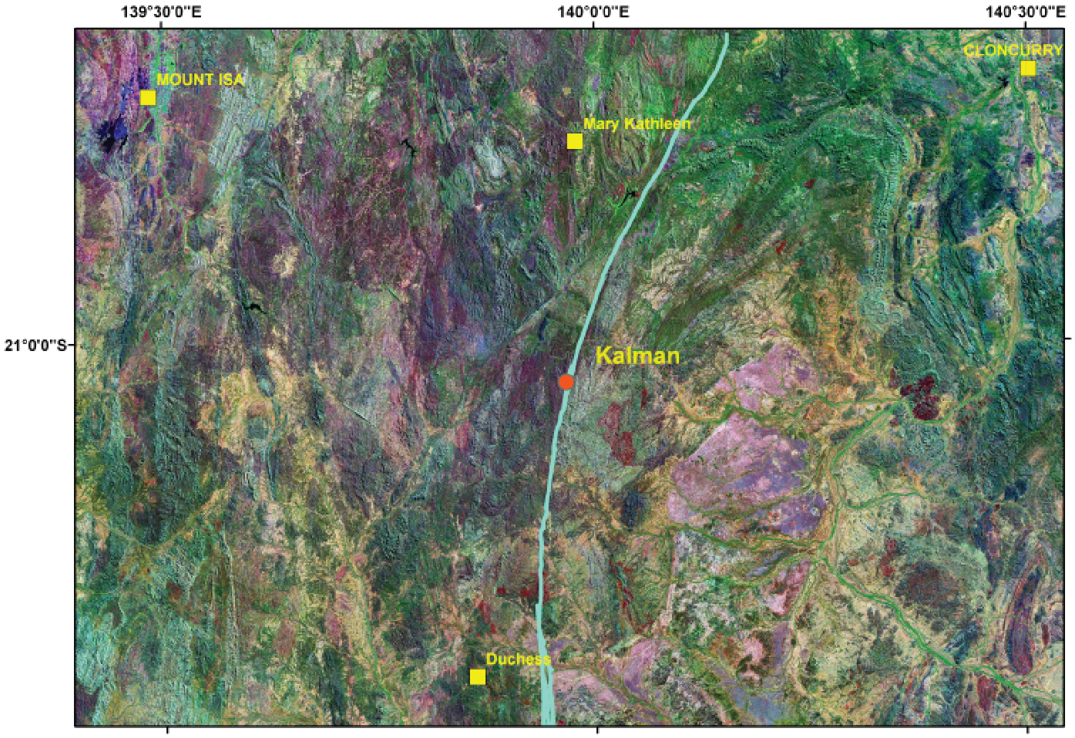

Figure 1: Landsat false colour image of the Mount Isa region showing the location of Kalman on the Pilgrim Fault (pale blue line)

ABSTRACT

Kalman is a Cu-Au-Mo-Re-(U) prospect between Cloncurry and Mount Isa. The area is being explored by Cerro Resources in association with Syndicated Metals, and an initial resource of 60.8Mt at 0.32% Cu, 0.05% Mo, 1.19g/t Re and 0.15g/t Au (Leahey & others, 2010) has been established. In 2010, the exploration company provided ten core holes (total depth approximately 3300m) for scanning by HyLogger™ in Brisbane. The data support a case study applying HyLogger to the investigation of a mineral prospect.

HyLogger is an automated visible to short wavelength infrared (SWIR) scanner used to measure drill core and identify the SWIR-active mineralogy. The instrument provided a key dataset for mapping the down-hole mineralogy and also recorded mineral textures through high resolution digital imagery. Other datasets were also linked to the study to better understand the mineral systems which generated the deposits. These included company assay data, portable XRF data, and airborne hyperspectral coverage.

Figure 2: View south at Kalman shows the prominent milky quartz vein that extends for tens of kilometres along the Pilgrim Fault (~1675Ma), and continues below surface through the mineralised zone.

In the prospect area, the Pilgrim Fault zone extends approximately North–South along the eastern margin of the Corella Formation, which is the host rock for mineralisation. The Corella Formation comprises calc silicates, meta-volcanics, breccias, and carbonaceous shale. The mineralisation is believed to be intrusion-related, possibly associated with the Overlander Granite that outcrops nearby to the north-west.

Assay results from 1m composite samples show that anomalous Cu can extend over drill intersections of up to 200m. The upper and lower boundaries of the Cu zone(s) are typically sharply defined against barren adjacent rocks. Spectral data from these boundary areas were examined to identify zones of alteration that may have accompanied mineralisation, and that could also be used to infer near-miss intersections. Chlorite-epidote, and white mica (both abundance and composition) provide indications of the extent of alteration associated with mineralisation.

The Kalman deposit has several similarities to the Merlin deposit 85km to the south-east. Re-Os dating at Merlin and nearby deposits in the Selwyn area, has determined an intrusion-related episode of mineralisation at about 1487–1515Ma (Duncan & others, 2011). New Re-Os dates from samples from Kalman will establish whether the Mo-Re mineralisation occurred at a similar time, or was an earlier or later analogue. The Kalman dates are in the final stage of analysis and will be discussed at Digging Deeper 2011.

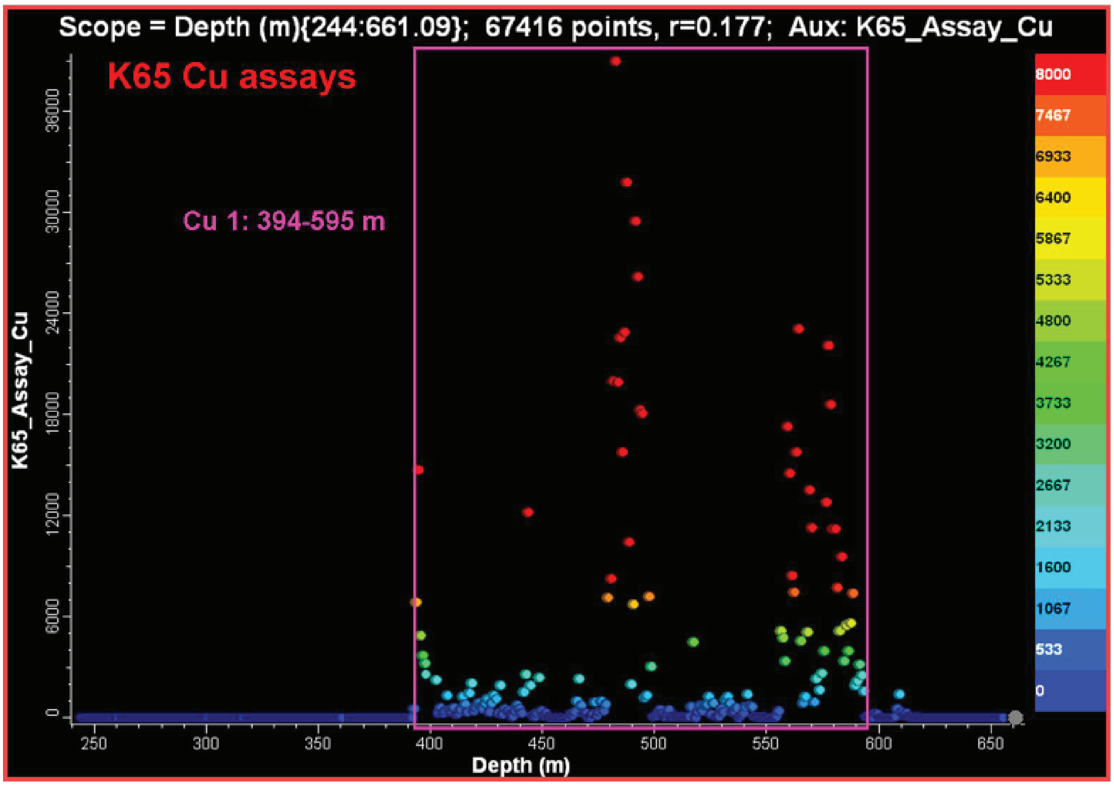

Figure 3: The mineralised zone has sharp boundaries in drill hole K65 (Cu assays).

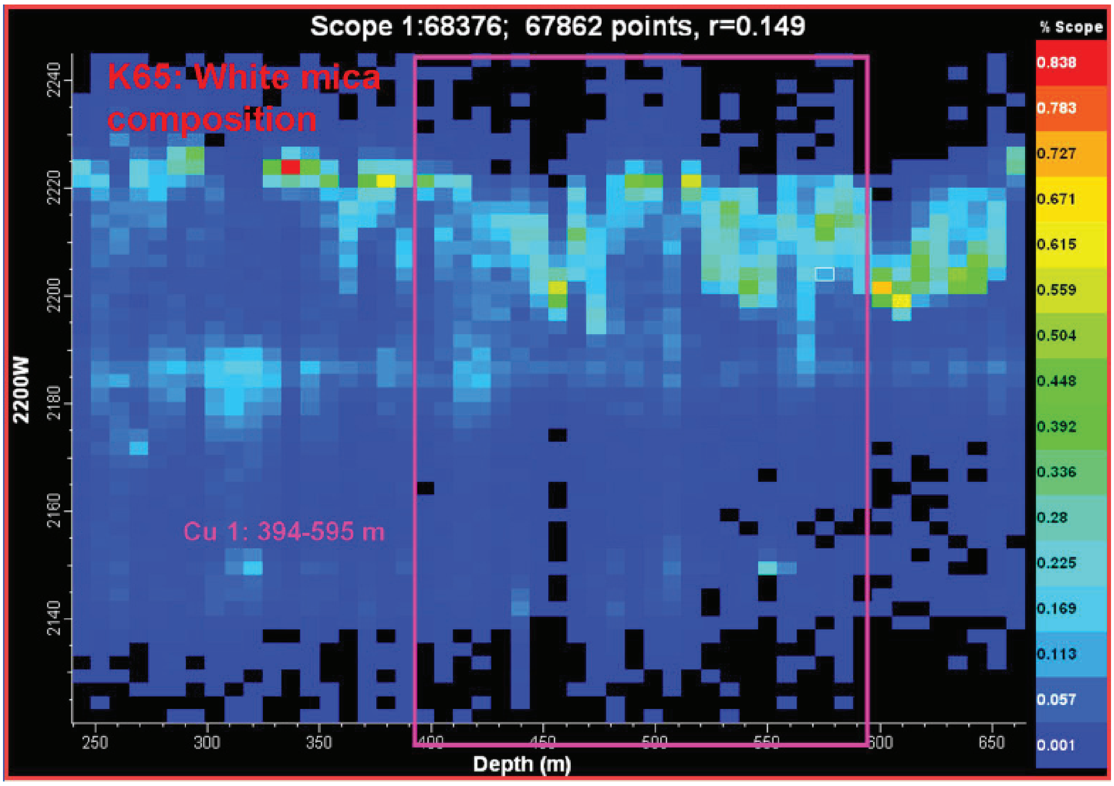

Figure 4: Trends in down-hole white mica composition are shown by the variation in centroids between 2200 and 2220nm (2200W). In K65, there is little contrast across the upper Cu boundary, whereas the lower boundary shows a change to short wavelength white mica in the barren host rocks immediately below.

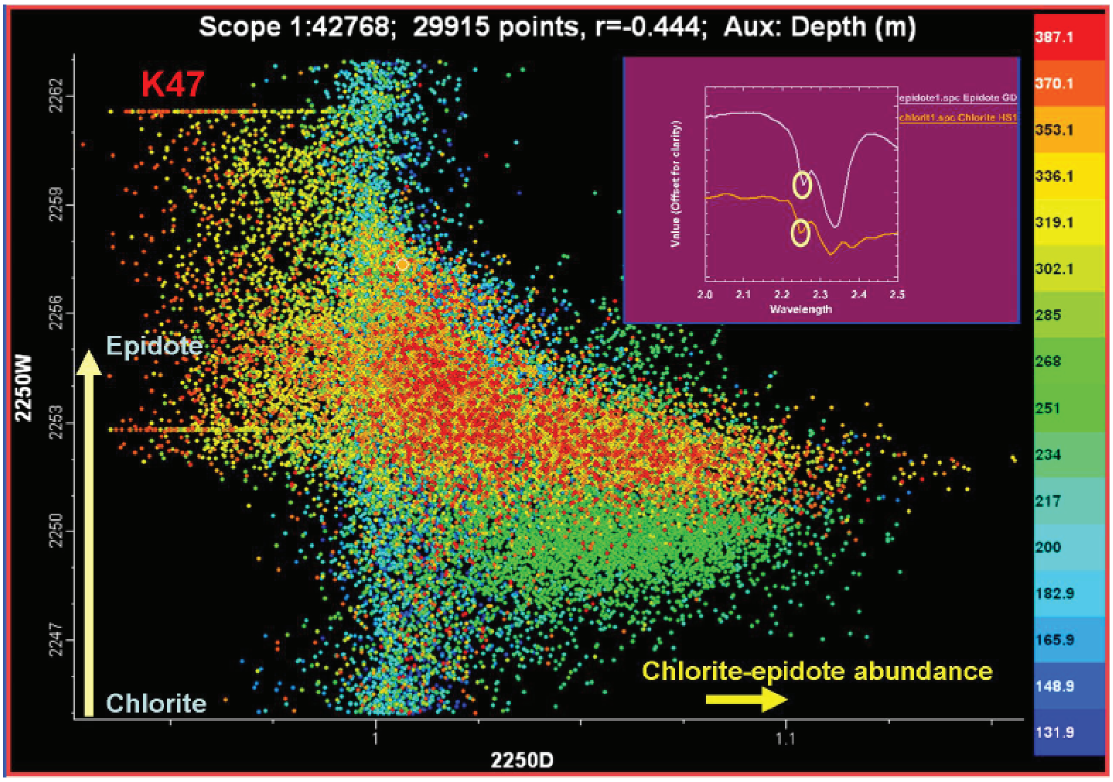

Figure 5: Scatterplot shows down-hole trends in abundance and composition of Chlorite-epidote in drill hole K47. The compositional variation is tracked by the shift in 2250nm wavelength between chlorite (short wavelength) and epidote (long wavelength). Data points are coloured by depth, suggesting a relatively high abundance of epidote towards the base of the hole (red).

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THE QUAMBY PROJECT AREA

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Geological Survey of Queensland

The Quamby project area covers an area 95km long by 80km wide extending east from the Mount Rose Bee Fault and north from Cloncurry. The Quamby project area is located within the 2010 NWQMEPS (North-West Queensland Mineral and Energy Province Study) lying immediately north of the Mount Dore project area (Figure 1). Proterozoic outcrop in the area varies from good to poor in the west to completely concealed in the east. Mesozoic sediments cover >50% of the area (with most cover depths interpreted to be less than 200m). Consequently, much of the area has been under-explored.

The Quamby project area includes the major operating Ernest Henry Cu-Au mine as well as significant Cu-Au projects such as E1 Camp, Rocklands and Roseby, and the Dugald River Ag-Pb-Zn deposit. The Quamby study is centred on the Canobie geological domain but the project area contains regions of the Mary Kathleen, Tommy Creek, Mitakoodi and Soldier's Cap domains (Figure 1). Across these domains the Quamby area is prospective for multiple styles of mineralisation including Cu±Au±iron oxide deposits, stratabound sediment-hosted Cu deposits, sediment-hosted Ag-Pb-Zn deposits, Au and Cu veins, Cu skarns, roll-front uranium in

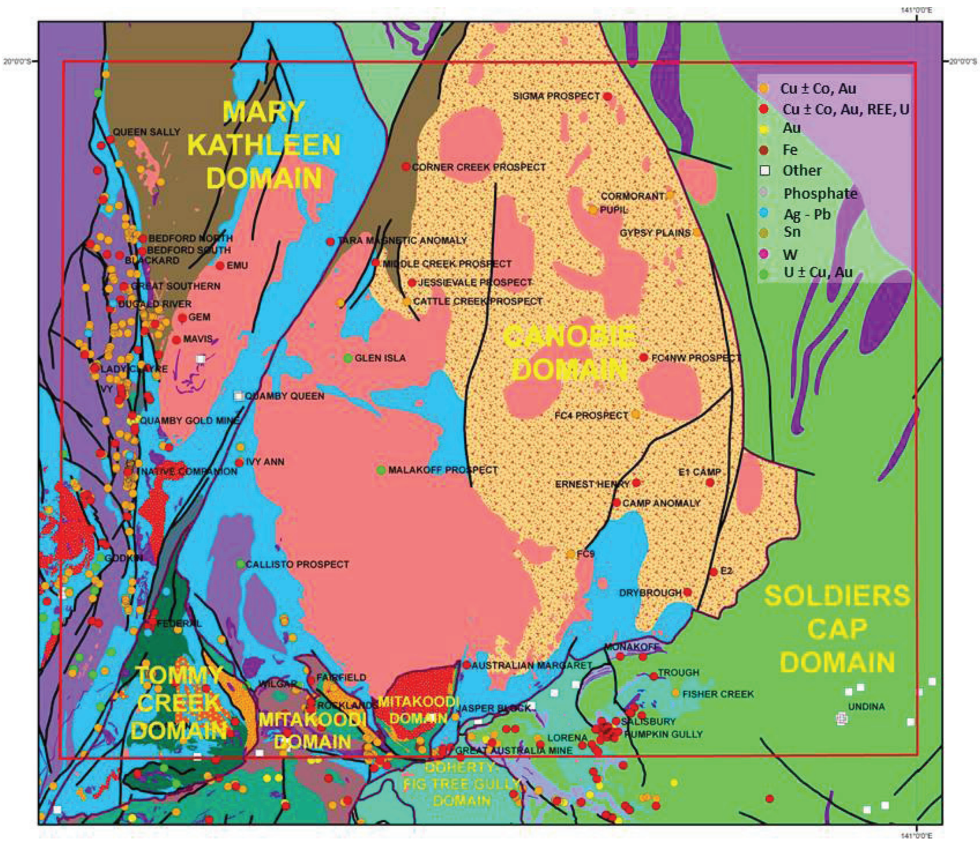

Figure 1: Location of Quamby Project area with NWQMEP study geological domains, and known sites and styles of mineralisation.

Mesozoic sediments, and magnetite-hematite in Cu±Au±iron oxide deposits, ironstone lenses and banded ironstones.

The purpose of the study was to investigate the geological, structural, geophysical and geochemical characteristics of the mineralisation and use this data as an input into a regional Common Earth Model to create 3D mineral potential models of Quamby area targeting specific mineralisation styles. The 3D mineral potential model represents the relative probability of each individual cell within the model hosting the chosen style of mineralisation and can be used to aid targeting for further mineralisation, particularly under cover, within the Quamby area.

MODELLING

The initial component of the Quamby project involved creating a 3D model of the region using GOCAD and SKUA. The current geodynamic and mineralisation models and the solid geology interpretation were compared with the 3D architectural models of the NWQMEPS. As the modelling requires a simplification of the true geology the NWQMEPS solid geology interpretation was used to identify the major 3D lithostratigraphic units. Fifteen major lithostratigraphic intervals (not including intrusive bodies) were identified as important for modelling (Figure 2). Major fault boundaries were also revised to fit updated interpretations from the NWQMEPS and available geophysical datasets including seismic data, magnetics and gravity data and magnetic and gravity worms (multi-scale edge analysis).

Cross-sections across the whole region were constructed to a depth of 20km to better conceptualise the major 3D subsurface architecture of the faults and stratigraphy. Key datasets used for the regional interpretation included deep crustal seismic and

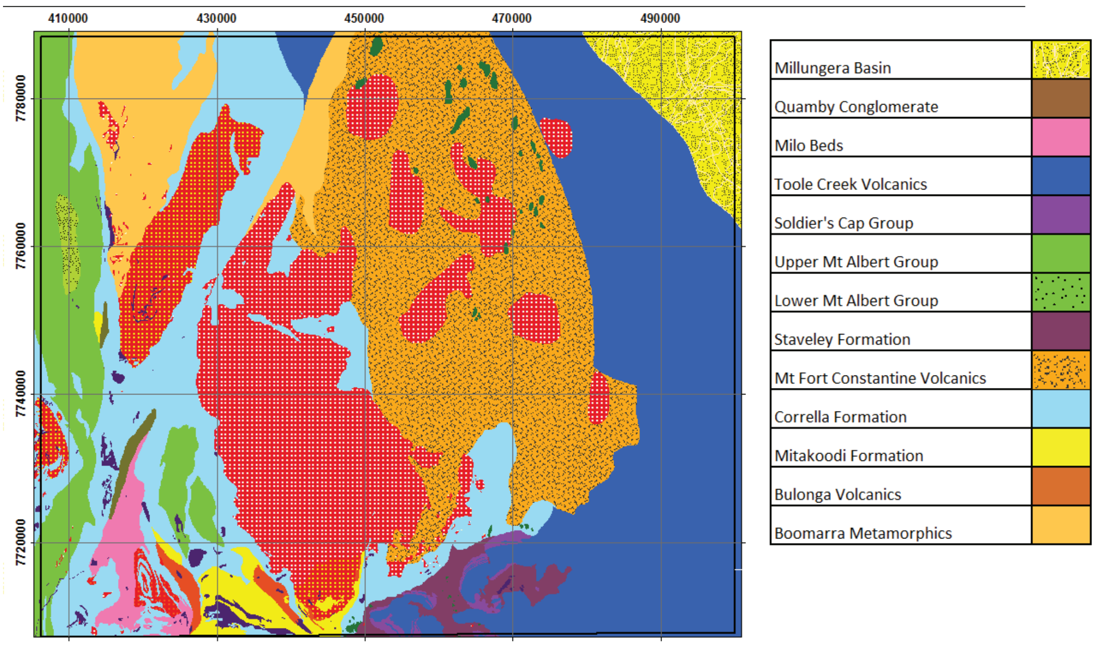

Figure 2: Solid Geology of the Quamby project area with 13 of the 15 major lithostratigraphic sequences used for modelling (Argylla and Leichardt Superbasin sequences appear in model but do not outcrop within area).

company seismic datasets, magnetotellurics, potential field datasets, solid geology and drill holes where available. Depth to basement modelling was undertaken across the project area to define the depths to prospective Proterozoic units from numerous datasets including mineral exploration holes, waterbores and depth to source modelling.

Fieldwork in the Quamby area was undertaken by GSQ staff in June 2011. This work assisted with defining unit and structural relationships as well as surface fault orientations and their relationship with inferred subsurface geometries. A database of magnetic susceptibility readings was obtained from representative outcrops and fresh samples were collected for further density measurements. These physical rock properties are critical for the 3D modelling and inversion components of the project.

Initially a 3D fault model based on regional interpretations (cross sections, seismic and fieldwork) was created using GOCAD and SKUA to test the viability of the interpreted fault architecture. Once a feasible fault architecture had been built, the stratigraphic units were incorporated into the model to ultimately build a complete 3D surface model of the Quamby project area (Figure 3).

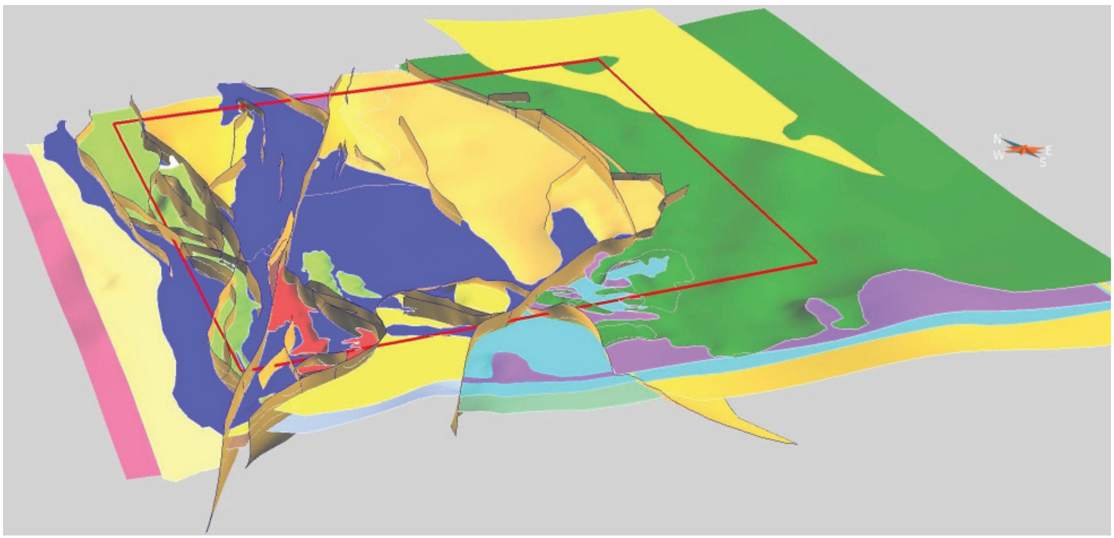

Figure 3: 3D surface model of the Quamby project area viewed from south-west

INVERSION

A regional voxet model (500 metre lateral resolution and 100 metre vertical resolution) was constructed from the GOCAD horizon model with each geological domain populated with corresponding physical properties (density and magnetic susceptibility) based on an assessment of collected rock property information (Figure 4). Initial potential field inversions of the gravity and magnetic data were undertaken using VPmg to refine and optimise the initial voxet model for regional potential field inversions.

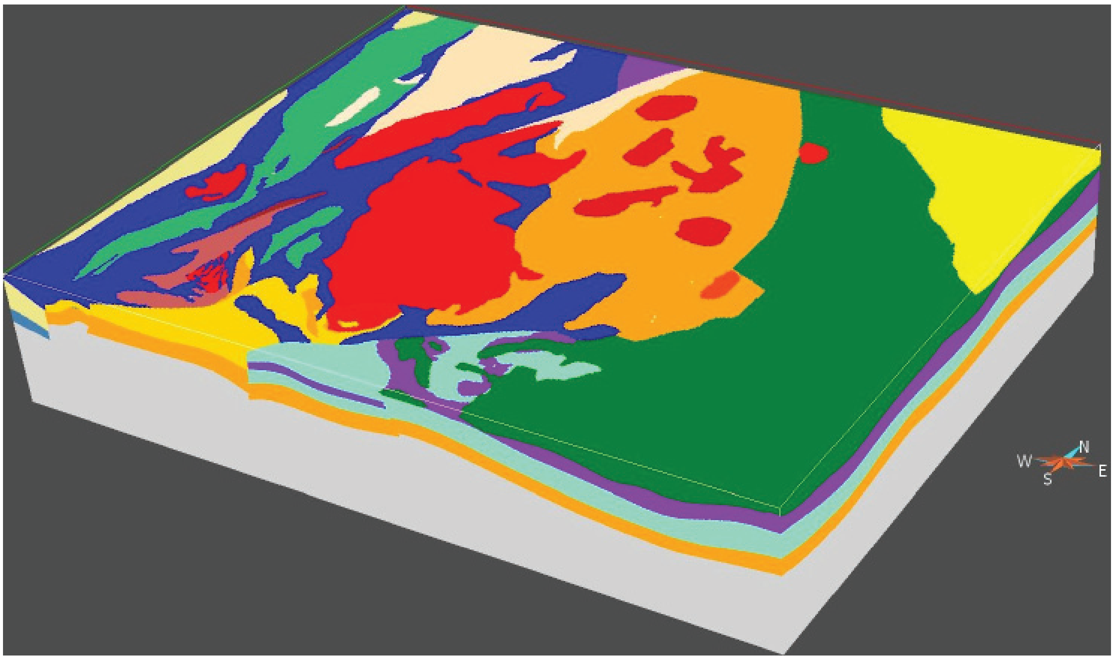

Figure 4: 3D voxet model of the Quamby project area viewed from south-east

A series of constrained potential field inversions of the magnetic and gravity data of the entire Quamby project area will be conducted VPmg, initially involving homogenous property inversions to optimise the properties assigned to each geological domain and achieve a better fit to the observed data. Following this a second inversion stage will be implemented using the optimised densities and susceptibilities as inputs for heterogeneous unit inversions

Heterogeneous unit inversions of the gravity and magnetic data allow the density or magnetic susceptibility of each cell to vary within the range of the constraints set by the initial modelled lithology to best fit the observed response. This stage of inversion highlights anomalous regions within the geological domains of the 3D density model and magnetic susceptibility model. These regional inversion results will then interpolated into a high-resolution model of the upper, prospective region of the model with a smaller cell size. A second high-resolution magnetic susceptibility inversion will be performed with the MAG3D UBCGIF inversion program to resolve magnetic anomalies in the near-surface not accounted for by the regional VPmg inversion.

EXPLORATION TARGETING

The results of the magnetic and gravity inversion will be incorporated into a Common Earth Model (CEM) along with the lithology data. Some of the key outputs from the CEM will be a pseudo-lithology model and a 3D weights-of-evidence mineral potential model.

The pseudo-lithology model analyses the property distributions across the model, creating pseudo-lithology domains within the statistical multi-variable ‘parameter space’ classifying each of the modelled cells into these domains based on their properties. The pseudo-lithology property is compared to the modelled lithology and regions of difference or misfit can be interpreted as zones of additional geological complexity, alteration or metamorphism.

The second key output to be created from the CEM will be a full 3D Weights-of-Evidence (WoE) model to assess the potential for further economic mineralisation using the existing location of known mineralisation as training data. The WoE approach is a quantitative method for assessing evidence in support of a hypothesis, exploration or targeting criteria can be statistically analysed with sites of known mineralisation to assess the effectiveness of exploration criteria.

Key targeting or exploration criteria, selected in consultation with GSQ staff, published and unpublished literature (including the mineral systems analysis undertaken as part of NWQMEP study) will be tested to in an attempt to ascertain controls on different styles of mineralisation in the Quamby area. A final 3D mineral potential model will be constructed by combining weights of the statically significant exploration criteria. This mineral potential model will highlight regions of high discovery potential in the model — areas which contain multiple favourable exploration criteria.

NEW GREENFIELDS PROJECTS UNDERWAY TO UNLOCK MINERAL POTENTIAL IN NORTHERN QUEENSLAND – NORTH QUEENSLAND GOLD AND STRATEGIC METALS PROJECT AND MOUNT ANNABLE PROJECT

Terry Denaro

Geological Survey of Queensland

NORTH QUEENSLAND GOLD AND STRATEGIC METALS PROJECT

The North Queensland Gold and Strategic Metals Project covers the region north from the southern Drummond Basin to Cooktown and from Croydon east to the coast (Figure 1). It has been selected recognising that levels of exploration for gold have declined from a high of 30% of total exploration expenditure in 1994 through 12% in early 2001 to around 5% in September 2010. This is in spite of current historical high gold prices and the acknowledged prospectivity of the region, with potential for intrusion-related (veins, porphyry, breccia, skarn, epithermal) and orogenic lode gold deposits, as well as volcanogenic massive sulphides, hydrothermal nickel, tin and tungsten veins and greisens, porphyry Mo-Cu and Mississippi Valley type Zn-Pb .

A secondary focus on strategic elements (beryllium, bismuth, cadmium, gallium, germanium, indium, lithium, molybdenum, rhenium, rare earth elements, yttrium, scandium, tantalum, niobium, tin and tungsten) reflects the growing demand for these metals for specialty alloys, electronic and communications devices, fibre optics and green energy (batteries and solar cells). Although occurrences and deposits of these metals are known within the study area, there is no current production from this part of Queensland. The study area is considered to be highly prospective for these strategic elements, particularly in polymetallic deposits associated with fractionated intrusives of Permo-Carboniferous age.

The lack of exploration momentum and discoveries since 2000 is a result of several factors including geological barriers such as:

- aerial extent and depth of cover units
- geological complexity
- patchy understanding of the tectonic framework
- limited geochemical data
- restricted predictive capability of exploration models due to insufficient understanding of mineral systems and structural controls and variances between different domains/provinces
- absence of catalyst research to stimulate exploration for new deposit types and to revitalise exploration thinking that is applied to this region.

In order to address these limitations and to stimulate exploration within the region, the Greenfields Prospectivity Unit has commenced the North Queensland Gold and

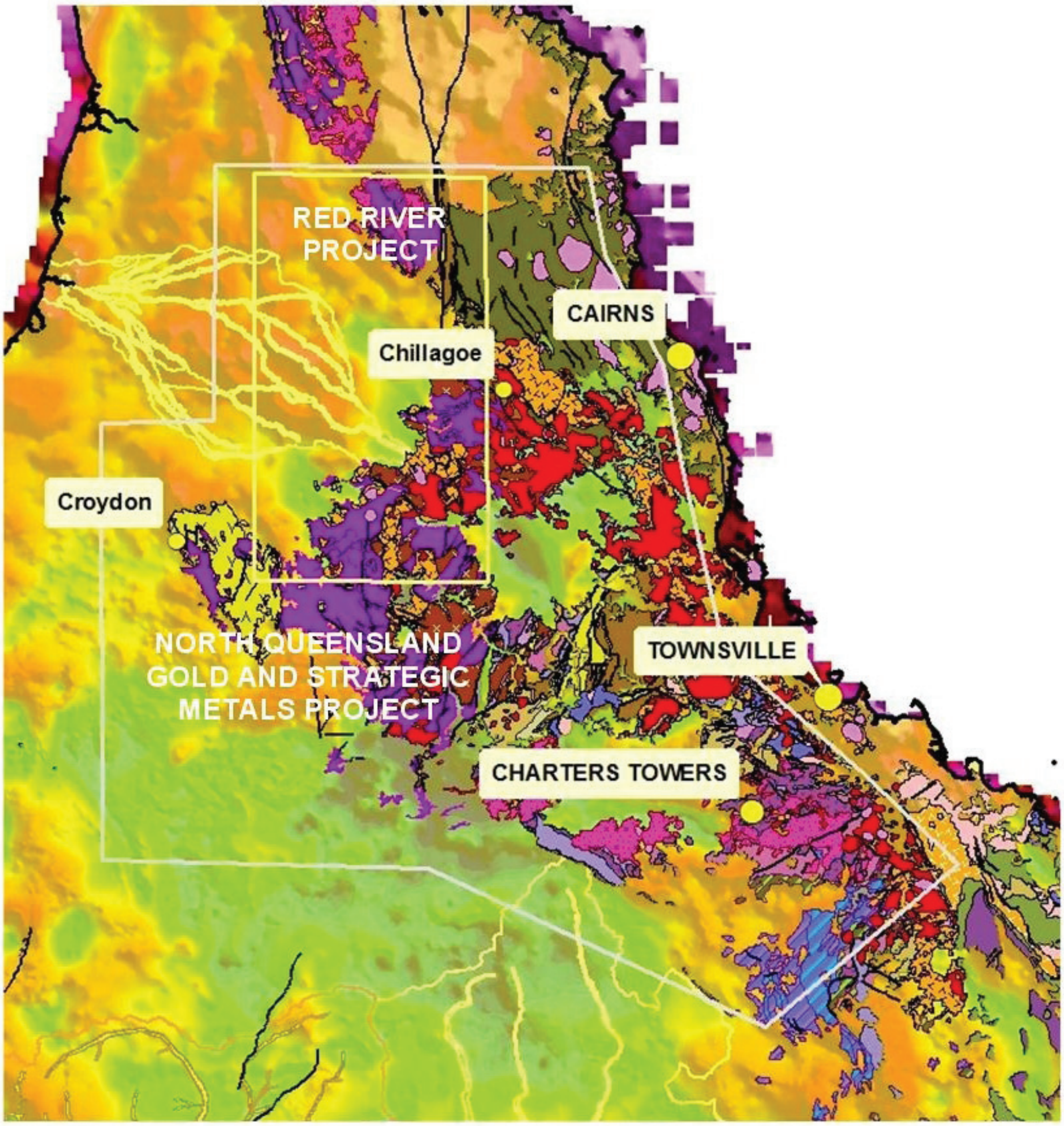

Figure 1: Location of North Queensland Gold and Strategic Metals Project and Red River Project

Strategic Metals Project, which has a three year format and consists of five integrated phases:

(1) Synthesis of current tectonic understanding for this region to provide a framework for discovery

This will involve a literature review of papers dealing with the structural/tectonic and stratigraphic evolution of the North Queensland region to provide a synthesis of the tectonic evolution of the region from the Proterozoic to Recent. A time-space chart correlating major stratigraphic groupings, igneous episodes and deformation events will also be produced.

This component of the project commenced in October 2011 and is expected to be completed in May 2012.

(2) Literature review of the regional and district controls on known gold and strategic metal systems

This work will focus on porphyry and intrusion-related gold and polymetallic mineral styles of the Drummond (Pajingo, Yandan, Wirralie, Mount Coolon), Charters Towers -Thalanga (Charters Towers and Ravenswood Goldfields, Mount Leyshon, Mount Wright), Etheridge (Etheridge Goldfield, Kidston) and Cairns (Hodgkinson Goldfield, Herberton Mineral Field, Red Dome-Mungana) regions. It will also consider potential for intrusive-related strategic metals based on examples from deposits world-wide.

An important aspect of this review will be a compilation of whole rock geochemical data to identify granite types and fractionation trends, and to highlight intrusives with potential to generate gold and/or strategic metals. The results of the National Geochemical Survey of Australia will be reviewed to highlight catchment areas requiring further analysis.

(3) Regional 3D modelling

The development of a regional 3D model will focus on reconciling and visualising the internal structure and relationships between the geological elements within the region.

(4) Targeted studies

Targeted studies will be carried out to address gaps identified in the earlier review stages in terms of mapping, geochronology, geochemistry, stratigraphic interpretation and mineral systems studies.

(5) Assessment of the resource potential for gold and strategic metals in the region

This stage will involve mineral systems analyses to develop regional and district scale criteria for exploration targeting and mineral potential assessment. Mineral systems associated with Permo-Carboniferous magmatism are of particular interest. The Red River project area (Figure 1) has been selected for detailed analysis using the 3D mineral prospectivity modelling methodologies previously developed by the Geological Survey for detailed studies in north-west Queensland. This area covers a range of geological environments and mineralisation styles and has both outcropping and undercover areas with good potential for future discoveries.

The following products are planned:

- A comprehensive bibliography of relevant papers for the region
- A report summarising a chronological framework of deformation and metamorphic events affecting the region extending from the Proterozoic to

the Palaeozoic. The report will also highlight key areas/structures to focus subsequent data acquisition/analysis phases.

- A report summarising regional and district controls on known/potential gold and strategic metal systems. The report will also highlight key areas/techniques to focus subsequent data acquisition/analysis phases.
- New geological interpretations including:
  - a series of structural thematic maps at 1:500 000 scale outlining the distribution, ambient stress field, and major structures (folds and faults) associated with each of the major deformation events in the context of the deformation event framework.
  - new geoscientific data (mapping/logging, geochronological, geochemical) aimed at developing an improved understanding of the region in terms of the potential for new gold and strategic metal resources.
  - regional and district scale 3D models
- Quantitative resource assessment and prospectivity studies.

MOUNT ANNABLE PROJECT

Following on from GSQ's successful Mount Dore district-scale 3D prospectivity modelling study, which was included in the North-West Queensland Mineral and Energy Province Report, the Greenfields Prospectivity Unit has been working on similar studies in the Quamby and Lawn Hill areas. These studies have already been described in presentations given today.

An additional study of this type is planned for the Mount Annable region (Figure 2), which covers an area about 200km long by 70km wide extending south from the Mount Isa mine. Proterozoic outcrop varies from good to poor in the north to concealed in the west and south. Cover rocks include Mesozoic sediments and the Cambrian Georgina Basin, with interpreted cover depths of >500m in the south and west. Consequently, much of the area has been poorly explored.

Geologically, the region comprises five geological/geophysical domains — the Ardmore – May Downs Domain in the west, the Mount Oxide and Sybella Domains in the north, and the Leichhardt River and Kalkadoon–Leichhardt Domains in the east. The major Mount Isa – Mount Annable – Rufus Fault Zone extends south to south-south-west down the centre of the project area. This major crustal penetrating fault system is viewed by many explorers as highly important for the transport of mineralising fluids and deposition of significant mineralisation.

The project area contains the same rock packages that host the world-class Mount Isa Ag-Pb-Zn and Cu deposits. It is viewed as prospective for sediment-hosted Ag-Pb-Zn, breccia-hosted Cu and metasomatic U and may be prospective for iron-oxide Cu-Au deposits. As well, the Sybella Granite has known minor cassiterite, beryl, monazite, tantalite-columbite, ilmenite, rutile, bismuth, fluorite, topaz and mica mineralisation. This mineralogy indicates a potential to host deposits of strategic elements such as Ta, Be, Li and REEs.

Interpretation of the Ardmore – May Downs Domain as the eastward continuation of the Arunta and Tennant Creek Provinces indicates potential for Tennant Creek style gold mineralisation.

The Cambrian rocks of the Georgina Basin in the Ardmore area host significant phosphate rock deposits and are also prospective for rare earth elements and sedimentary uranium deposits.

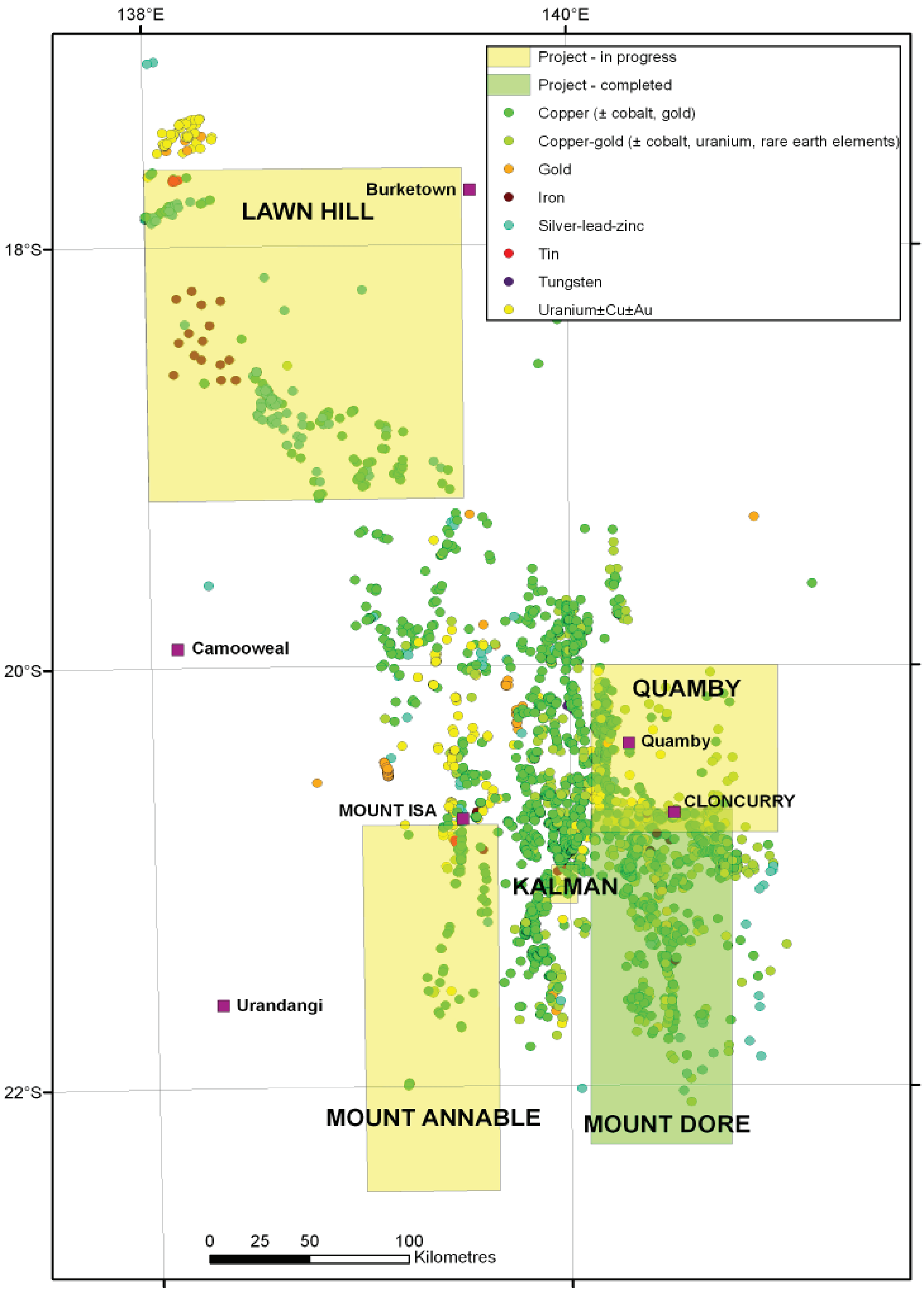

Figure 2: Location of Mount Annable Project