SUPPORTING AUSTRALIA'S EMERGING GEOTHERMAL INDUSTRY: GEOSCIENCE AUSTRALIA'S ROLE

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SUMMARY Australia's emergent geothermal energy industry is growing rapidly, with 29 geothermal companies currently prospecting for Hot Rock and hydrothermal resources. The Hot Rock model in the Australian context comprises a thick sequence (>3km) of low-thermal conductivity sediments overlying deeper high-heat-producing granites. Until now, the key datasets available to industry to guide their geothermal exploration have been a map of crustal temperature at 5km depth, and heat-flow data. Both datasets suffer from regions of low data density and heterogeneous data distribution. The Australian Government has provided Geoscience Australia with funding for an Onshore Energy Security Program (OESP). Established as part of the OESP, a new Geothermal Project will generate precompetitive geoscientific information for geothermal explorers through two major activities: mapping heat across Australia, and developing a geothermal information system. The Australian Government has also awarded several renewable energy and start-up grants to the geothermal industry since 2000, and is currently funding the preparation of a Geothermal Industry Development Framework (GIDF). The GIDF aims to support the industry by developing strategies to ensure that technical, economic and regulatory obstacles are tackled in a coordinated way.

1. INTRODUCTION

Australia is uniquely endowed with internationally-significant Hot Rock geothermal resources, and its geothermal industry is developing rapidly. At present, 29 companies have applied for geothermal exploration licenses, and of these, five companies have commenced drilling. Hot Rock feasibility studies in Australia began over a decade ago (Somerville *et al.*, 1994), however the prospect of climate change and the associated need for clean energy sources for the future provided the impetus needed to jump-start the industry, with the first geothermal company listing on the Australian Stock Exchange (ASX) in 2002. Geothermal energy is an attractive energy source given that is it low emission, renewable, and has the potential to contribute to Australia's baseload electricity needs at low cost. In addition, direct-use of geothermal energy for heating applications conserves high-grade fuels such as natural gas, and reduces reliance on fossil-fuel generated electricity which also offsets greenhouse gas emissions. As a fledgling energy sector, the geothermal industry faces a number of challenges as projects progress through exploration (research), proof-of-concept (appraisal) and demonstration (development) stages on the path to commercialisation.

In the initial exploration stages, limited spatial coverage of key geoscience datasets across Australia presents a significant impediment to geothermal companies, increasing exploration and investment risk. Unlike the traditional hydrothermal geothermal resources that are used for electricity generation elsewhere, Australia's geothermal potential is principally contained in Hot Rocks – high-heat-producing basement rocks that are buried at depths >3km by insulating sediments. Hot Rock geothermal resources have minimal surface expression, and exploration for this type of resource typically relies on measurements of temperature and heat-flow down boreholes. However, the two existing datasets used to map temperature and heat-flow in Australia both suffer from insufficient data-points and poor data distribution, and in the case of heat-flow, questionable data quality. In addition, no information system exists for easy access to this geothermal geoscience data.

In the later stages of geothermal development, regulatory and technical aspects, price-competitiveness, and project financing are likely to also become impediments to geothermal commercialisation. Although government grants and capital-raising through the ASX have enabled geothermal companies to begin exploration and proof-of-concept, raising significant capital in the later stages of project demonstration and ultimately commercialisation will present a significant impediment to many geothermal companies. An important factor contributing to this is the absence of a formal geothermal resource/reserve definition scheme, which currently makes it difficult for geothermal companies to obtain venture capital as is common in the petroleum and minerals industries. In addition, generation of electricity from Hot Rock systems on a commercial scale has not yet been

demonstrated anywhere in the world, and as such it is potentially viewed as a risky investment.

Recognising that the Australian geothermal industry faces these impediments, the Australian Government has awarded $32 million in grants to the geothermal industry since 2000, and has several projects in progress that aim to engender a successful commercial geothermal industry. These are the Geothermal Project in Geoscience Australia's Onshore Energy Security Program, and a Geothermal Industry Development Framework (managed by the Department of Industry, Tourism and Resources). These projects are described in more detail in the following sections.

2. GEOSCIENCE AUSTRALIA'S ONSHORE ENERGY SECURITY PROGRAM (OESP)

The Prime Minister announced an Energy Security Initiative in August 2006, part of which provides Geoscience Australia with $58.9 million in funding over 5 years for an Onshore Energy Security Program (OESP). The OESP aims to better understand Australia's geological potential for onshore energy resources such as petroleum, uranium and geothermal, and includes the acquisition of new seismic, radiometric, heat-flow, magneto-telluric, gravity, magnetic, geochemical and drillhole data. Following extensive consultation with State and Territory Geological Surveys, a Geothermal Project was established as part of the OESP, which aims to address the geoscience-related impediments facing the industry. The key activities in the Geothermal Project include mapping heat, 3D Hot Rock source and trap modelling, creating a geothermal information system, and contributing to the development of a reserves/resource definition scheme. The outputs of these activities will reduce geothermal exploration & investment risk for Australian geothermal companies, and are discussed in more detail in the following section.

2.1 Mapping Heat

Currently, drilling technology limits the economic development of geothermal extraction systems to about 5km depth, and this is the depth to which geothermal resources are considered. Temperatures of >200°C are required at such depths to make the generation of electricity commercially feasible. The AUSTHERM07 database stores 5722 measurements of temperature and geothermal gradient that have been collected from drillholes around Australia (Chopra & Holgate, 2005). These data are vertically extrapolated to 5km depth and horizontally interpolated between the drillholes to produce a gridded map of crustal temperature at 5km depth across the entire continent (Figure 1B). There are many areas where limited temperature measurements have been made (see Figure 1A), and the interpolation is performed across vast areas. The 5km temperature map is thus not reliable in all zones. Geoscience Australia intends to update the AUSTHERM07 database by incorporating new temperature measurements made by the petroleum and minerals industries. In addition, improvements are being made to the 5km temperature map by considering other geological factors when extrapolating temperature to 5km depth. Examples of these include: using OZ SEEBASE™ (FrOG Tech, 2006) sediment thickness data to better constrain the depths at which geothermal gradients changes from those typical of sedimentary basins to the lower gradients typical of crystalline basement rocks; and, dividing the continent into areas of distinct basement temperature gradient based on recognised heat-flow provinces (Sass and Lachenbruch, 1979).

2.2 Crustal Contained Energy

The AUSTHERM07 database can be used to estimate the geothermal energy contained within the Australian crust. Simply, the 5km economic drilling depth was used as a lower depth extent (in the USA a similar estimate used a 10km depth limit (MIT, 2006)), and the calculated depth of the 150°C isotherm was used as the upper depth limit. Using 5km × 5km grid size, the average temperature, volume and an estimate of the contained heat was calculated for each cell. An estimate of 1.9×10^{25} Joules was derived for the energy contained in the upper 5km of Australia's crust (Figure 1C).

This is equivalent to approximately 2.6 million years energy supply at 2004-2005 consumption levels (2004-2005 gross energy consumption equalled 7258.1 PetaJoules (Cuevas-Cubria and Riwoe, 2006)). Even if only 1% of this energy could be extracted, it would equate to 26,000 years of energy supply for Australia. This figure is conservative, given that future drilling and extraction technologies will undoubtedly allow extraction of heat at depths greater than 5km, and the renewable nature of geothermal energy is also not considered.

2.3 Heat-flow Measurements

There are less than 200 published heat-flow measurements for Australia (see Figure 2A). Heat-flow values are variable, ranging from 15 to 160 mW/m^2. The high values are generally found in a linear belt extending from Tasmania through to Queensland and the Northern Territory (Figure 2B). Geoscience Australia is purchasing a thermal conductivity meter and downhole logging equipment for the acquisition of new heat-flow measurements that will improve the definition of

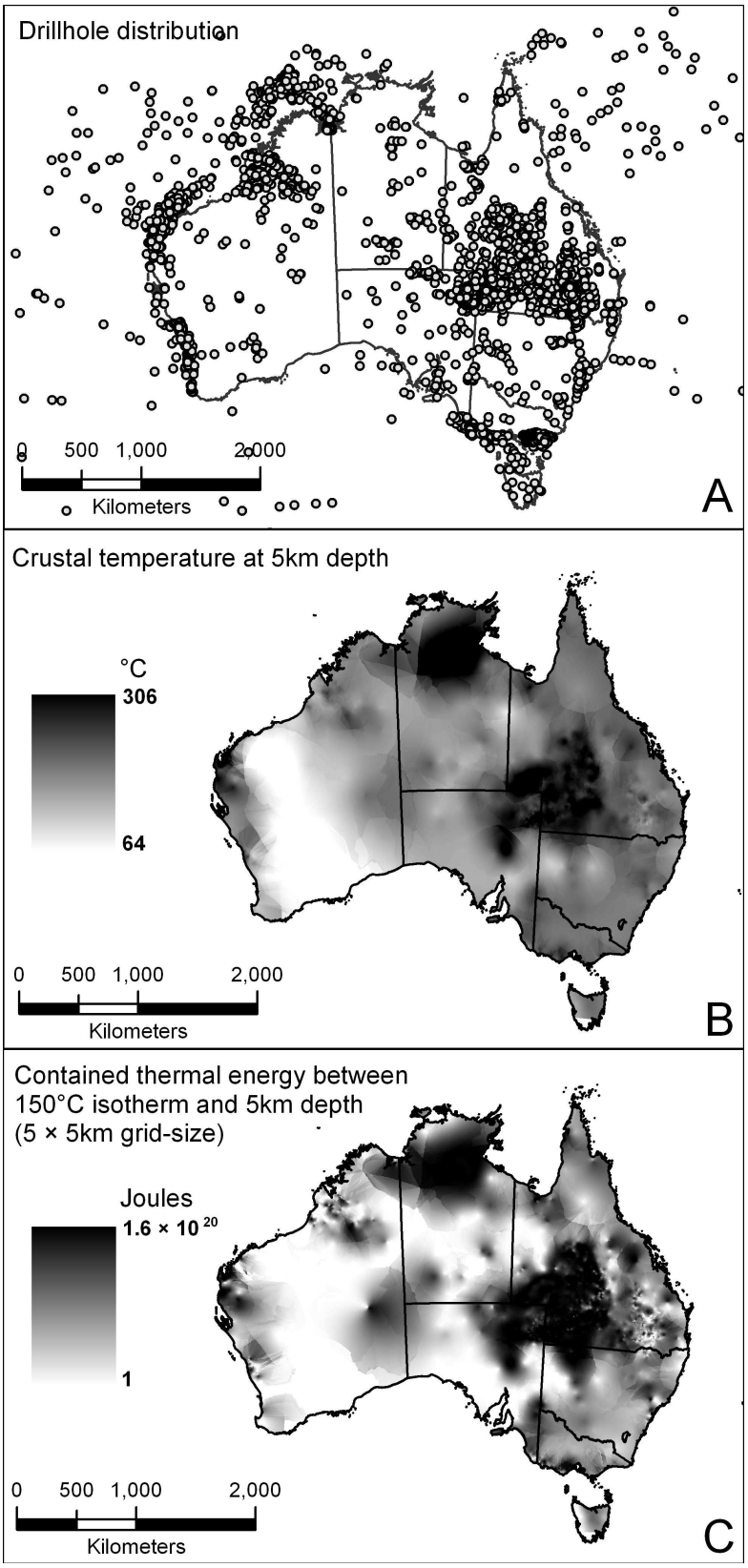

Figure 1 Australian geothermal temperature data. (A) Distribution of drillholes from which temperature measurements have been entered into the AUSTHERM07 database. (B) Map of crustal temperature at 5km depth, clipped to the Australian coastline. (C) Thermal energy contained in the upper crust between the 150°C isotherm and 5km depth contour. These maps have been derived from proprietary information owned by Earth Energy Pty Ltd ACN 078 964 735.

heat-flow across the Australian continent (Heat-flow = Thermal Conductivity × Thermal Gradient). Geothermal gradients will be measured in selected drillholes across the continent that have been prioritised using spatial (proximity) and crustal-element criteria. In conjunction, thermal conductivity measurements will be made on drill-core samples collected from these same prioritised drillholes (samples stored in the State and Territory core libraries). Once the equipment has been purchased, Geoscience Australia will also be working with State and Northern Territory geological surveys to measure heat-flow in new petroleum and mineral drillholes.

2.4 Geothermal for Cities

Current knowledge of Australia's geothermal resource distribution is focused almost exclusively on the high temperature (>150°C) Hot Rock resources, which given appropriate geological conditions and technological expertise, can be used to generate electricity. To date, far less attention has been given to mapping the distribution of lower temperature (<100°C) geothermal resources, which have significant potential for direct-use applications when located near populated areas. In the Geothermal for Cities sub-project, the geothermal resources beneath

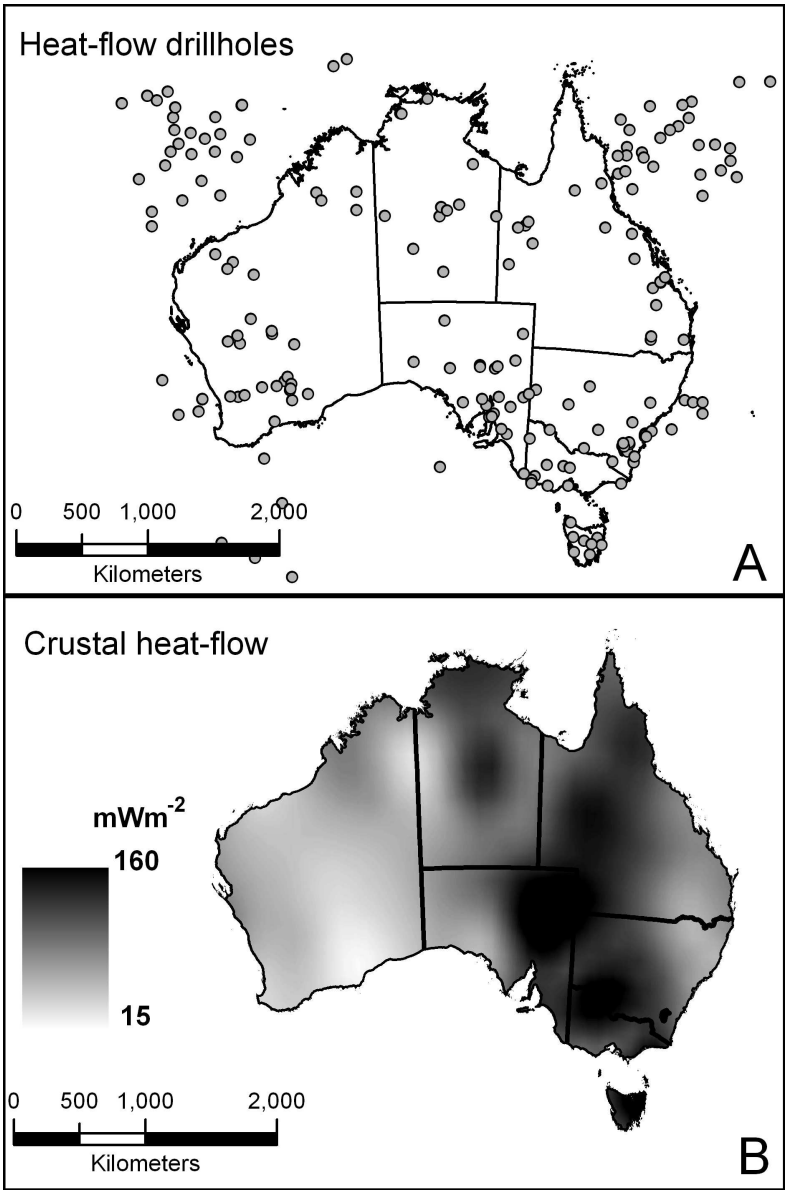

Figure 2 Heat-flow data for the Australian crust. (A) Location of Australian heat-flow measurements used to derive the gridded map. (B) Heat-flow across the Australian continent (clipped to the coastline). Map modified with permission from Barton (1999).

selected capital cities and/or major population or industrial centres across Australia will be assessed and quantified. These resources are likely to be low-temperature (<100°C), hydrothermal-type geothermal resources. In the first instance, we hope to locate temperature and/or heat-flow anomalies near population centres, after which hydrogeology will be assessed to see if suitable groundwater systems are co-located to form a potential hydrothermal resource.

2.5 Granite Source-Trap Modelling

The key geological ingredients of the Hot Rock geothermal model are high-heat-producing granites overlain by thick accumulations of low-thermal-conductivity sediments. The decay of low concentrations of radioactive elements (predominantly uranium, thorium and potassium) over millions of years produces heat. This heat may be trapped at depth within the crust by the sedimentary cover, which acts like a thermal blanket above the granite. By mapping out deeply buried granites and having knowledge of both their chemistry and the thermal conductivity of any overlying sediment, it will be possible to make predictions about crustal temperature and geothermal prospectivity.

Granite chemistry data that are currently available are predominantly for surface samples rather than buried granites. Geoscience Australia is thus collaborating with the State and Territory Geological Surveys to obtain granite samples collected from drill core for geochemical analysis. Buried granites can be located using geophysical methods such as gravity and magnetics. By mapping granite outcrops it is possible to make predictions of the composition of buried granites as they trend from outcrop areas to beneath sediments. In this way the heat production beneath sedimentary basins may be estimated. With information about the thicknesses and thermal conductivity of the overlying sedimentary strata, the heat production of the buried granites, and estimation of heat-flow upwards from the mantle, local temperature profiles of the crust in a given location may be estimated.

Initial stages of this work have included the compilation of information about outcropping granites and their chemistry. The heat production of the granites has been calculated, and combined in a Geographic Information System (GIS) with maps of basin thickness. This provides a first-pass map of prospective areas, but also highlights where more granite geochemical data are needed. This map will be updated as new data are collected.

2.6 Geothermal Information System

Geoscience Australia has developed an Information Management Plan for the capture, storage, manipulation and delivery of geothermal-related geoscience data. The first stage of this plan is to develop a heat-flow database, which will be populated with new data acquired by the Geothermal Project, as well as legacy data compiled from the literature and contributions from geothermal companies, State and Territory Geological Surveys, and universities. In addition to complete heat-flow measurements, this database will have stand-alone fields for temperature and thermal conductivity. Other data layers that will be captured in either a relational database system or GIS include the 5km depth temperature grid, granite geochemistry, drillhole locations and attributes, Bouger gravity, magnetic and radiometric coverages, topographic information, gamma logs, geology layers, seismic lines, DEM, mean annual surface temperature, thermal infra-red, and hydrogeological data.

2.7 Reserves and Resource Definition Scheme

The Australian Geothermal Energy Group (AGEG) has a broad membership including key geothermal stakeholders from academia, industry and government. AGEG's Terms of Reference centre on reducing critical shared uncertainties at minimum cost and maximum pace to foster the commercialisation of Australia's geothermal energy resources. Geoscience Australia is contributing to a Technical Interest Group that aims to develop a geothermal reserves/resource definition scheme. Work has commenced on a draft public reporting scheme and guidelines for geothermal resource and reserve definitions. This will be directly analogous to the Joint Ore Reserves Committee (JORC) Code for Mineral Resources and the SPE/WPC/AAPG Petroleum Resources Classification and Definitions. The geothermal scheme is being developed in collaboration with both local and international stakeholders.

3. GEOTHERMAL INDUSTRY DEVELOPMENT FRAMEWORK

The Australian Government is assisting the geothermal industry by developing a Geothermal Industry Development Framework and a Geothermal Technology Roadmap.

On 27 March 2007, the Federal Industry Minister and the Federal Environment Minister jointly hosted a Geothermal Industry Roundtable at Parliament House in Canberra. The meeting was attended by geothermal companies, industry associations and researchers working on geothermal energy. Participants agreed to work together to prepare a Geothermal Industry Development Framework that would provide a strategy for the long term development of this emerging energy sector. In April 2007, the Council of Australian Governments (COAG)

agreed to develop four energy technology roadmaps, including one for geothermal technology. The Australian Government offered to fund the preparation of this roadmap as part of the Geothermal Industry Development Framework.

Following these events, consultation with stakeholders identified a number of issues that should be included in the Geothermal Industry Development Framework. These are:

- the Geothermal Technology Roadmap;
- an assessment of the research, training and skills development infrastructure of the geothermal sector;
- an assessment of the legislative and regulatory framework governing the geothermal sector;
- an analysis of private sector and government financing structures supporting the geothermal sector; and
- an analysis of work undertaken on geothermal resource assessment and definitions.

Furthermore, it was agreed that the Geothermal Industry Development Framework should identify components of a communication strategy for the geothermal industry and develop a Geothermal Industry Map that would illustrate the linkages of the industry with other sectors and the position of the industry within the larger economy.

Overall, the Geothermal Industry Development Framework aims to support the growth of Australia's geothermal industry through strategies agreed by stakeholders from government, industry and the research community. This will be achieved through strategic analysis of the industry, identifying opportunities for and impediments to its growth, and developing a set of coordinated actions that will contribute to a self-supporting, sustainable and internationally competitive industry.

The Australian Government, through the Department of Industry, Tourism and Resources, has hired a consulting company, Sinclair Knight Merz (SKM), to undertake further analysis of the geothermal industry sector and conduct a series of workshops that will address the above issues. These workshops will be held between November 2007 and March 2008. It is planned that the Geothermal Industry Development Framework and the Geothermal Technology Roadmap will be completed in April 2008.

4. CONCLUSIONS

Through Geoscience Australia's Geothermal Project, the Geothermal Industry Development Framework, and renewable energy grant schemes, the Australian Government is helping to address the impediments facing Australia's developing geothermal industry. Geoscience Australia will provide pre-competitive geoscience data to the industry, reducing both exploration and investment risk. The Geothermal Industry Development Framework and Geothermal Technology Roadmap will identify long-term strategies to deal with the technical, regulatory and financing impediments the industry will face on the road to commercialisation.

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