AUSTRALIA'S FAVOURABLE GEOLOGICAL ENVIRONMENT FOR ECONOMIC EXTRACTION OF HDR ENERGY: AND CURRENT PROPOSALS.

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ABSTRACT

Geothermal energy has, until recently, not been regarded as a major future source of energy for Australia. However the coupling of knowledge learned from US, European and Japanese hot dry rock (HDR) programs with an understanding of the temperature and stress regimes pertaining to the Australian continental crust has dramatically changed that view. The economics of extracting large amounts of HDR energy from a large rock volume with a minimum number of drill holes of minimum depth is suggested to be highly attractive in Australia because of the unique combination of a number of independent geological conditions. These are:

1. In much of central and eastern Australia the crustal heat generating capacity is twice that of normal continental crust.
2. Much of the Australian continent is covered by sedimentary basins which contain a high proportion of coal measures and shales that have low thermal conductivities, thus providing an insulating blanket for the heat being generated beneath.
3. The sedimentary basins are in many places underlain by large untectonised granite bodies that are a major contributor to crustal heat generation. Such granite bodies are likely to be ideally suited to the establishment of HDR reservoirs because of their homogeneous character and intricately distributed joint sets.
4. The crustal shortening stress field that is found in the majority of the Australian continental crust results in a vertical minimum principal stress orientation which should result in horizontal propagation during fracture stimulation.

As a result of the new understanding plans are being put into place to attempt to exploit these energy resources.

A study of the rock properties and stress conditions in the Cooper Basin area of South Australia has begun, and will lead into a microfracture stimulation program in a gas exploration well to determine the extent and direction of fracture propagation. The project is funded by the Australian Government through the Energy Research and Development Corporation, and by a number of industry partners.

In the northern part of the Sydney Basin a geothermal anomaly discovered by the local electricity utility during a search for coal-bed methane is the focus of attention. A company with part ownership by major Australian resource and mining companies has been established to carry out a pilot two-well circulation program.

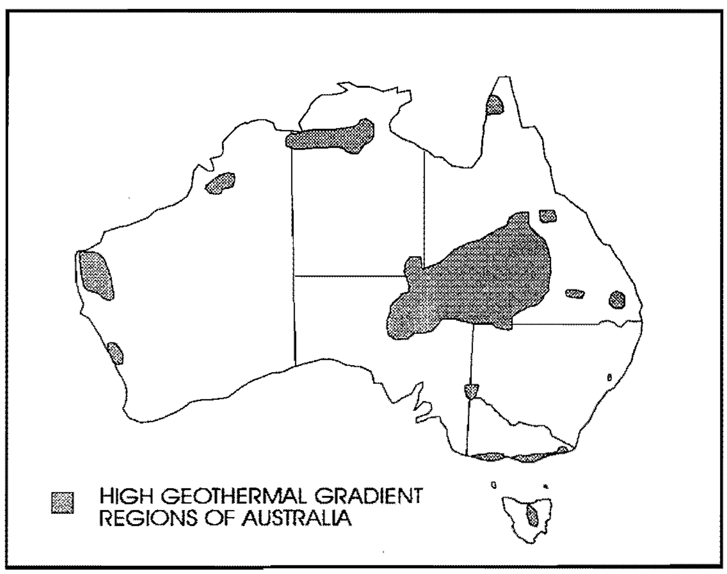

Figure 1. Distribution of high geothermal gradient areas across Australia. Most areas are coincident with basins containing low conductivity sediments.

INTRODUCTION

The extent of geothermal energy use in Australia up to the present has been limited to low temperature direct heating of public buildings in the city of Portland in western Victoria, and to small scale electricity generation (150KWe) using an organic Rankine Cycle system from 100°C water at the remote town of Birdsville in western Queensland. However, a recent report published by the Energy Research and Development Corporation (Somerville et al., 1994) documents the hot dry rock (HDR) geothermal energy potential for electricity generation. It concludes that Australia has a large high grade HDR resource at depths of less than 5km, equivalent to 7500 times the present annual energy consumption. Here high grade is defined as hot enough to generate electricity, or above 150°C. Most of this resource (80%) underlies the Great Artesian Basin in central to eastern Australia, but favourable sites are distributed across the country (Fig. 1). The high HDR potential is possibly unique in the world, in that the potential sites mostly lie beneath sedimentary basins, with the best sites corresponding to gravity lows interpreted as buried granitic bodies. The resources residing in these granitic bodies at depths shallower than 5km contain the equivalent of 830 times Australia's present annual energy consumption.

GEOLOGICAL SETTING

Australia is situated wholly in an intraplate environment in the Indian-Australian Plate. The most recent volcanic activity that could have contributed to heating of the upper crust is related to the passing of Australia over a mantle hot spot millions of years ago. The geothermal energy potential relating to this volcanism is small. However hot springs and hot artesian water is widely distributed in Australia. The Great Artesian Basin is the most well known area (Habermehl, 1980). It underlies 1.7 million square kilometres of Australia (about 22%), and is currently producing around 1 million cubic metres of water per day from 3000 wells. The high water temperatures in the basin appear to be related to high crustal heat production mainly from underlying granitic rocks, as suggested by Koch (1985). High geothermal gradients in oil and gas exploration wells from sub-basins beneath the Great Artesian Basin are closely correlated with known granitic bodies in the basement that have been intersected in drilling, or occur near gravity lows that can be interpreted as basement granites. Measurements of heat productivity in basement granites intersected in exploration wells commonly give up to 10 μwatts per cubic metre.

High geothermal gradients in other basins are also possibly correlated with high heat production granites in the basement. Two 800m wells drilled by Pacific Power 5km apart in the northern Sydney Basin have geothermal gradients twice that of other wells in the region. Subsequent gravity measurements outlined a surrounding gravity low about 10km by 15km. The basement is estimated at a depth of 3.5km in this area, with possible temperatures at that depth of 200°C. Assuming that the gravity low corresponds to a buried granite, this area is a prime target for HDR development. It lies only 15km from one of Australia's largest coal-fired power stations, and is centrally located to major industry, population centres, water supply and the national electricity grid.

STATE BREAKDOWN OF POTENTIAL SITES

1. South Australia: The Cooper Basin, a sub-basin of the Great Artesian Basin in the NE of the State, has long been known for its high geothermal gradients. Koch (1985) states that "the Cooper Basin must be one of the most significant geothermal areas in the world". The highest gradients are associated with the gravity low from the deepest central part of the basin where nine wells have intersect high heat production granites in the basement. The area of granite is estimated at 900 square kilometres, with an average temperature of 260°C between 3.5km and 5km depth (Somerville et al., 1994). This area is the highest grade HDR resource known in Australia, but it is far removed from population centres.

2. Queensland: Several gravity lows beneath the Great Artesian Basin in western Queensland are thought to be buried granites with relatively high rock temperatures. The Betoota gravity low appears the most promising. It has an area of 750 square kilometres, with an average rock temperature shallower than 5km estimated at 230°C.

Closer to population centres are a number of narrow rift basins near the central coast of Queensland containing thick shale oil deposits. High geothermal gradients are expected in these basins, and if thicknesses of several kilometres can be proven, there is the potential for relatively high temperatures at their base.

3. New South Wales: The gravity low in the northern Sydney Basin mentioned above is a prime target for HDR development. Its area of about 150 square kilometres could contain enough high grade HDR energy to provide New South Wales with all its electricity needs for the next 50 years. Other well defined gravity lows are known within the Sydney Basin, but drilling has not been sufficiently well spaced to determine if they are associated with high geothermal gradients.

4. Western Australia: In the northern Perth Basin, quite close to large population centres, relatively high temperatures are associated with rift faulting and basement granites. This area is similar to the Rhine Graben site for the European Hot Dry Rock Project at Soultz (Baria et al, 1995), in that there are already hydraulically active fracture zones known from the basement. Development of the site could potentially follow a successful program at Soultz.

5. Victoria: No high grade HDR sites are known in Victoria, but aquifers within the Gippsland and Otway Basins are bringing moderately hot water close to the surface along the Victorian coast. This water is already being used for direct heating at Portland, and could potentially be used to a much greater extent.

IMPLICATIONS FROM THE AUSTRALIAN CRUSTAL STRESS FIELD

The intraplate environment of Australia is similar to most other cratonic areas, in that the majority of the Australian crust is in a crustal shortening regime (Denham & Windsor, 1991) where fault types are overthrust and the minimum principal stress axis is close to vertical. This fundamental characteristic of the crust has been determined using earthquake focal mechanisms, hydrofracture experiments, well bore breakouts, and overcoring experiments. The implication is that HDR reservoirs will tend to have horizontal or sub-horizontal orientation rather than the vertical or sub-vertical orientation of HDR experimental sites elsewhere. A second general result of the stress observations is that there is considerable regional variation in the orientation of the maximum principal stress axis. This does not have particular implications for HDR reservoir engineering except to suggest that, while in general, crustal blocks in Australia are tending to overthrust each other, there is a tendency for horizontal wrenching in some zones, as borne out by some strike-slip and oblique-thrust focal mechanisms. In these zones, HDR reservoirs would tend to have vertical or sub-vertical orientations.

The experience of HDR experiments performed to date indicates that an injection test carried out at a representative Australian site would stimulate a horizontal or sub-horizontal reservoir zone. The zone would have maximum elongation in a direction close to the maximum principal stress axis. Fractures most readily opened would be horizontal, and shear fractures most readily activated by release of tectonic strain would be inclined at about 30° to the horizontal. The zone would have minimum extent in a vertical or sub-vertical direction.

There are several important implications of a sub-horizontal reservoir geometry. Firstly, water migrating horizontally away from the injection well would be flowing through rock at near-isothermal conditions. This is more favourable than upward migration, in which case water is flowing through cooler rock, and also more favourable than downward migration, in which case the temperature will increase but the water will tend to become inaccessible to production wells. Secondly, in a sub-horizontal reservoir, the problem of water loss, or 'leakage', would be minimised, and it should be possible to optimise production of water at temperatures prevailing at the bottom of the injection well. Thirdly, vertical geometry for injection and production wells is optimum in terms of ease of drilling and logging. Elimination of the need for directional drilling, which has been employed at some of the HDR experimental sites, is a significant advantage of the crustal shortening stress regime that is characteristic of Australia.

Sub-horizontal reservoir geometry also has important implications for multi-cell reservoir design. In a crustal shortening stress regime, it should be possible to generate a vertically-layered group of sub-horizontal reservoirs from a vertical injection well. Decisions on the siting of a production well, or wells, would be straightforward. Sub-horizontal reservoir geometry would provide scope for expanding the scale of an HDR facility virtually without limit by drilling additional vertical wells. Moreover, with sub-horizontal reservoir cells, there would be options for engineering additional cells in both vertical and horizontal directions (Figure 2).

The existence of a crustal shortening regime does however have an important consequence on the injection pressure that may be required to generate a reservoir. In crustal shortening regimes, the minimum principal stress is vertical, and equivalent in magnitude to the lithostatic pressure. In general, fluid pressures at least as high as this are required to open existing fractures in the rock. Thus, although shear failure may be induced at lower pressures, provision must be made, when planning an injection experiment, for borehole pressures at least as high as the minimum principal stress. The lithostatic pressure at the depth of a typical HDR test in granite overlain by a thermal blanket of sediments is likely to be in the order of 100mPa corresponding to a depth of 4 to 4.5km. The hydrostatic head at this depth is 40 to 45 mPa, so injection pressures of up to 60mPa are required to overcome the minimum principal stress. This pressure is higher than has been used in HDR testing to date. Such pressures are not, however, uncommon in oilfield fracturing operations, and the technology is well understood. Furthermore, while the minimum principal stress is large in crustal shortening regimes, it is at least predictably large, thereby obviating the need for hydrofracture stress measurements to determine its magnitude.

The high pressures pertaining in an HDR reservoir at 4km depth in a crustal shortening regime could be advantageous for reducing water losses during circulation. The reservoir will be surrounded by an unstimulated envelope of granite whose permeability will be lower than granite under lower confining pressures. This may help keep the water confined to the stimulated region, thus minimising water losses.

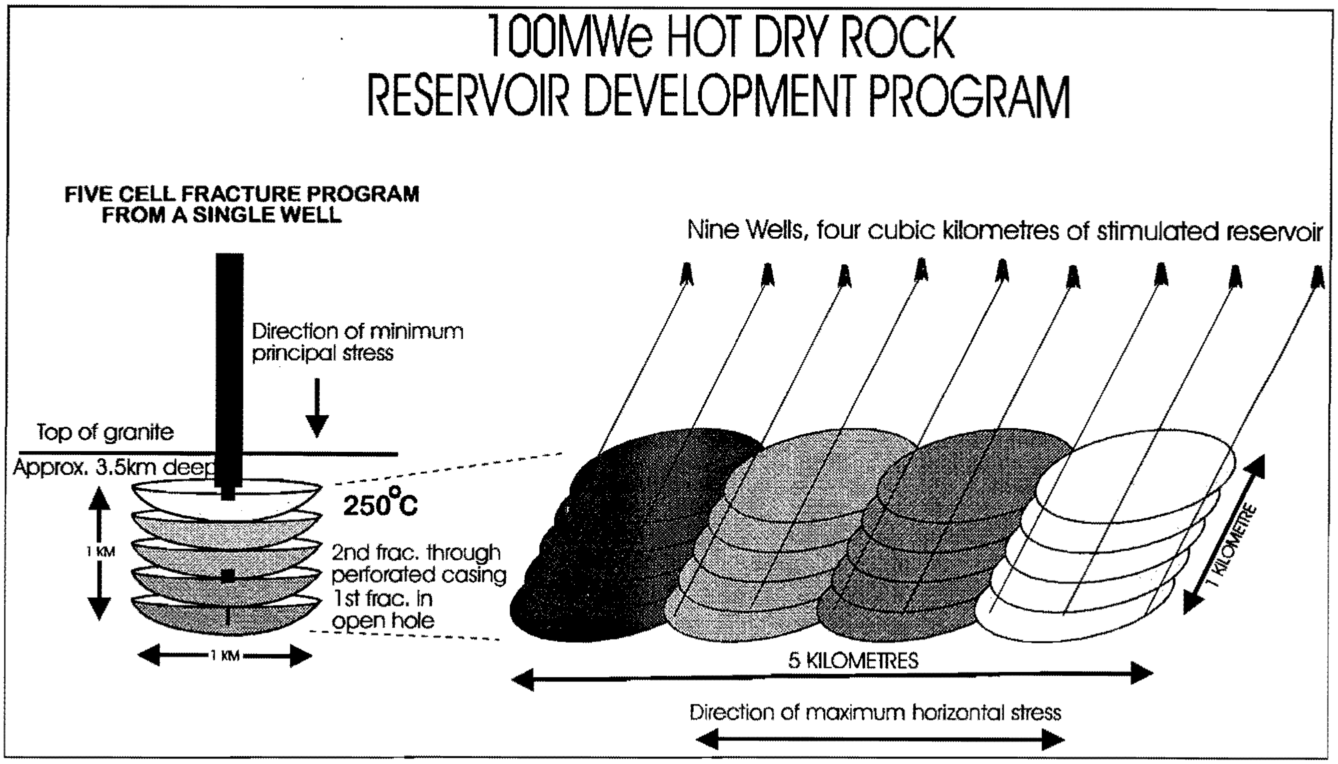

Figure 2. Hypothetical development of stacked horizontal stimulation cells producing approximately 1 cubic kilometre of HDR reservoir from one vertical well, and showing how these could be packed together to build larger systems. The system shown requires 9 wells and could produce 100MWe from 4 cubic kilometres of stimulated reservoir.

In summary, HDR reservoir engineering in a crustal shortening regime will differ from most HDR experiments to date in that higher injection pressures will be required, and the geometry of the reservoir generated by stimulation will be sub-horizontal rather than sub-vertical. Overall, a crustal shortening regime appears to be more favourable than others, despite the need for higher injection pressure, because of advantages in reservoir geometry and drilling requirements. This should considerably reduce the cost of development of multicell reservoirs, and most importantly deliver economically attractive large scale HDR multiwell systems.

CURRENT RESEARCH AND DEVELOPMENT PROPOSALS

Two projects are currently being planned. The first has secured funding from the Energy Research and Development Corporation and a number of industry partners. The project is focused on the mechanisms of fluid pressure induced fracture and sub-surface reservoir engineering in hot, low permeability, highly stressed rocks of the deep parts of the Cooper Basin in NE South Australia. It has a dual aim of enhancing natural gas recovery from this region, and proving the relationship between horizontal fracture propagation and a crustal shortening stress field. A microfracture stimulation trial is due to take place in early 1999 involving a seismic monitoring network, and pumping to a depth of 3km where the rock temperature is around 200°C. Additionally, high pressure and temperature laboratory facilities will be used to determine fracture permeability enhancement during shearing along joints in granite samples.

The second project will capitalise on the experience of the first, and is focussed on the high geothermal gradient area coincident with a gravity low in the northern Sydney Basin. The site is adjacent to the Hunter River south of the town of Muswellbrook. A group of Australian resource companies has formed a research company known as Hot Rock Energy Pty Ltd. The company plans to characterise the geothermal anomaly with further shallow drilling and seismic reflection surveys leading to the drilling of a 3km slim hole. If a buried high heat production granite is indicated, then two wells will be drilled to a depth of 4.5km. The aim is to create a series of horizontal stimulation cells stacked up the first well (Figure 2), with the extremities of the cells intersected by the second well. Success in this project could lead to the building of a demonstration power plant of about 20MWe on top, and future expansion into a multiwell system similar to that depicted in Figure 2.

CONCLUSIONS

Australia has large volumes of high grade HDR resources at depths of less than 5km. As far as is known, there are no other parts of the world where large volumes of high temperature rock (>200°C) occur close to the earth's surface in a crustal shortening stress field. It is this fact that gives Australia its unique advantage. The attempts to extract HDR energy resources from high temperature rocks in Japan, Europe and USA have all taken place in stress fields which have produced vertically extensive reservoirs, and, to date, have failed on economic grounds. In the Australian crustal shortening stress field the reservoirs should be oriented horizontally, an ideal geometry to maximise reservoir size with a minimum number wells. This fact alone makes it essential that Australia takes a new initiative on a HDR extraction research program. Two projects, one in northern South Australia and one in the northern Sydney Basin in New South Wales are about to commence to capitalise on the unique geological environment.

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