K. Ameed R. Ghori
Senior Geologist
Geological Survey
of Western Australia

Search for energy from geothermal resources in Western Australia

Soon a new era in the search for energy will commence in Western Australia with amendments to the Western Australia *Petroleum Act 1967* to facilitate exploration for, and production of, geothermal energy. Sources of geothermal energy are heated groundwater and hot dry rocks. Hydrothermal water can be used directly for heating or, if the water is hot enough, to create electricity. Heat energy from hot dry rocks can also be used to generate electricity by pumping water into the ground and converting the extracted heat. The process is referred to as Enhanced Geothermal Systems (EGS).

The Geological Survey of Western Australia (GSWA) commenced studies of geothermal energy in the 1980s and geothermal resources were recognised from hydrothermal sources of low temperature reservoirs (65-85°C) at depths between 2000-3500 m. At the time, the economics were not favourable for geothermal energy from these hydrothermal resources and the technology for generating electricity by EGS was not developed and was still at demonstration stage.

The GSWA's recent research started in 2006 because of technological advances, awareness of global warming, a desire to use clean and renewable energy, as well as decreased costs of generating power from geothermal energy. These factors drastically increased interest in, and investment for, exploring and developing geothermal energy in Australia. The first study in the search for geothermal resources by EGS in Western Australia indicates hot spots in the Canning, Carnarvon and Perth Basins (Chopra and Holgate, 2007). These hot spots are recognised from present-day geothermal gradients recorded in petroleum wells (Fig. 1).

Geothermal Energy

Geothermal energy refers to thermal or electrical power produced from the heat contained in the Earth, which can offer a renewable and clean energy source. Geothermal reservoirs are generally classified as being either low temperature (<150°C) or high temperature (>150°C). For commercial production of electricity, the high temperature reservoirs are suitable, as they have relatively elevated crustal heat indicated by higher geothermal gradients than normal (17-30°C/km); such areas are present in Western Australia (Fig. 2). Hot springs, mud pots, geysers, or fumaroles are the surface indications of geothermal systems. Deep geothermal reservoirs, where temperatures can reach more than 350°C, are powerful sources of energy.

Applications of geothermal energy include: electricity generation, direct use, and ground-source heat pumps. Direct use includes applications such as heating buildings or greenhouses and drying foods, whereas ground-source heat pumps are used to heat and cool buildings using surface soils as the heat reservoir.

Although geothermal energy is present everywhere beneath the Earth's surface, it must be concentrated to be an effective power source. Conversion of geothermal energy into power is economically feasible only when:

1. The resource is located at shallow depths, usually less than 3 kilometres, but possibly as deep as 6 to 7 km, where other factors are favourable;
2. Porosity and fracture permeability are sufficiently high to produce large quantities of thermal waters, either naturally or engineered; and
3. The hot geothermal fluids can be efficiently transported (typically less than a few tens of kilometres) to a power generating facility.

Geological, hydrogeological, electrical, magnetic, geochemical and seismic surveys are used to locate the geothermal resources that need to be confirmed by exploration drilling and produced by development drilling. Exploration for geothermal energy is very similar to petroleum exploration but with certain differences (Narayan et al., 1998a). For generating electricity, suitable temperatures for hot water and steam are between 120-370°C. In contrast, shallower reservoirs of lower temperature 21-149°C are used directly in health spas, greenhouses, fish farms, and industry and in space heating systems for homes, schools and offices. Most sedimentary basins have low temperature geothermal water for direct use (non-power generation) to meet the developing energy needs, which is also expected to be present in Western

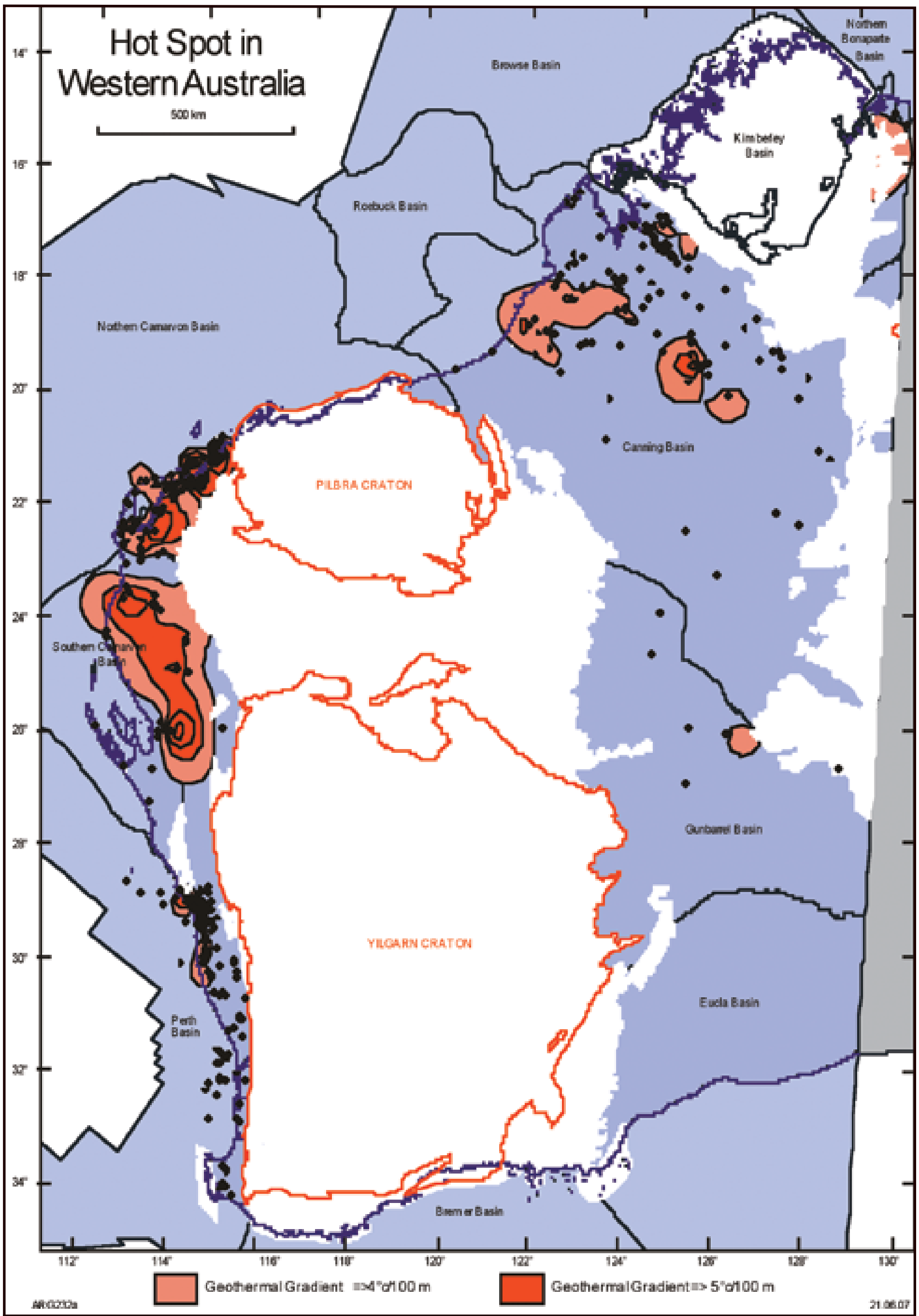

Figure 1. West Australian hot spots based on estimated present-day geothermal gradients.

Australia, as discussed in the first GSWA study (Bestow, 1982).

Since the 1970s, the geothermal industry, with the assistance of government research funding, has overcome many problems of drilling, power plant, corrosion and scaling of pipes from geothermal water. As a result, the cost of generating geothermal power has decreased by 25% over the past two decades. Enhancing the recoverability of the Earth's heat energy is an important area of ongoing research.

Australia

Australia is tectonically stable and does not have the hydrothermal provinces of geologically active areas such as volcanism, crustal rifting and recent mountain building. However, it shows a huge potential for geothermal energy from known high heat producing granites and many Australian explorers are in the forefront for testing EGS.

Commercial utilisation of the Earth's heat from hot rocks is undergoing testing to develop EGS where reservoirs are missing. In this system, communication is established between injection and withdrawal wells by means of hydraulic fracturing. The available heat cannot be increased, but the permeability and water content can be enhanced (Figs 3 and 4). It is estimated that by the year 2020, man-made geothermal reservoirs could be supplying 5 to 10% of the world's electricity.

At present, the only geothermal energy being used in Australia is from a 120 kW geothermal energy plant located in Birdsville, Queensland, which is negligible on the scale of worldwide installed capacity. In the last few years, there has been a dramatic increase in investment to explore for, and demonstrate the potential of geothermal energy from: EGS, hot wet rocks, and recent hot hydrothermal water (about 4000-5000 years old). These concepts have stimulated the search for geothermal resources in Western Australia.

Western Australia was included in many studies undertaken for Australian geothermal resources, which concluded that Australia's most significant geothermal resources suitable for electricity generation appears to be from EGS, with highest potential in the Eromanga Basin followed by the McArthur, Otway, Carnarvon, Murray, Perth, Canning, East Queensland and Sydney Basins.

The presence of high heat flow was first recognised from the high geothermal gradient data recorded in petroleum exploration wells, assembled by the Australian National University and the Bureau of Mineral Resources (Fig. 5). Publications relevant to Australian geothermal energy including Western Australia are: Sass (1964), Sass, et al. (1976), Cull (1977, 79, 82), Cull and Denham (1978), Somerville et al. (1994), Narayan et al. (1998b); Chopra (2005), Chopra and Holgate (2005).

Western Australia

The GSWA has carried out two specific studies in the search for geothermal energy in Western Australia from heated groundwater (Bestow, 1982) and EGS (Chopra and Holgate, 2007). These studies indicate the presence of geothermal resources in the Canning, Carnarvon and Perth Basins, but their extent and economic feasibility are unknown because both studies were qualitative rather than quantitative.

For quantitative assessment, systematic geological, hydrogeological, geophysical and geochemical evaluations are necessary, as with any other subsurface energy resource. These studies require the compilation of pre-existing data of over 580 wells on temperatures, depth to basement, geochemistry of basement

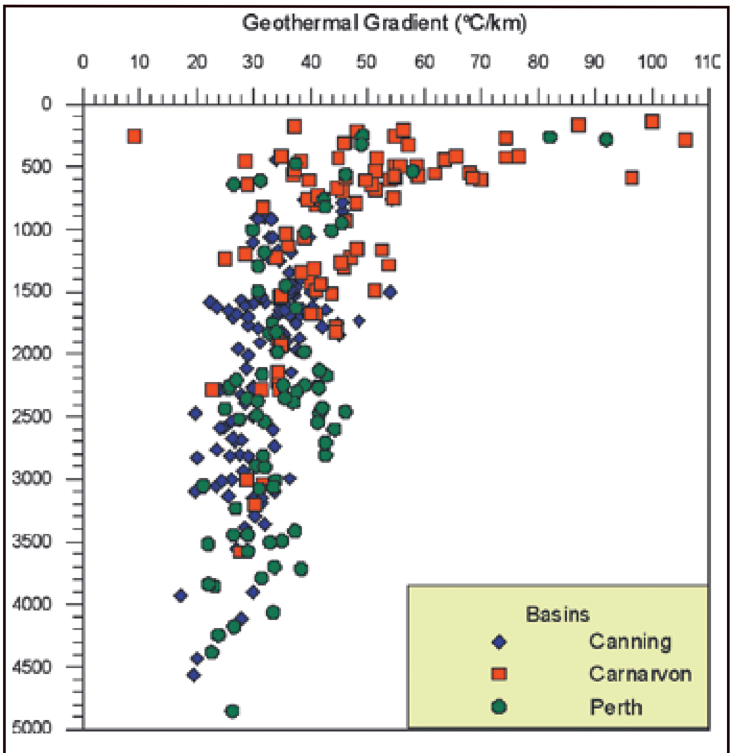

Figure 2. Estimated present-day geothermal gradients.

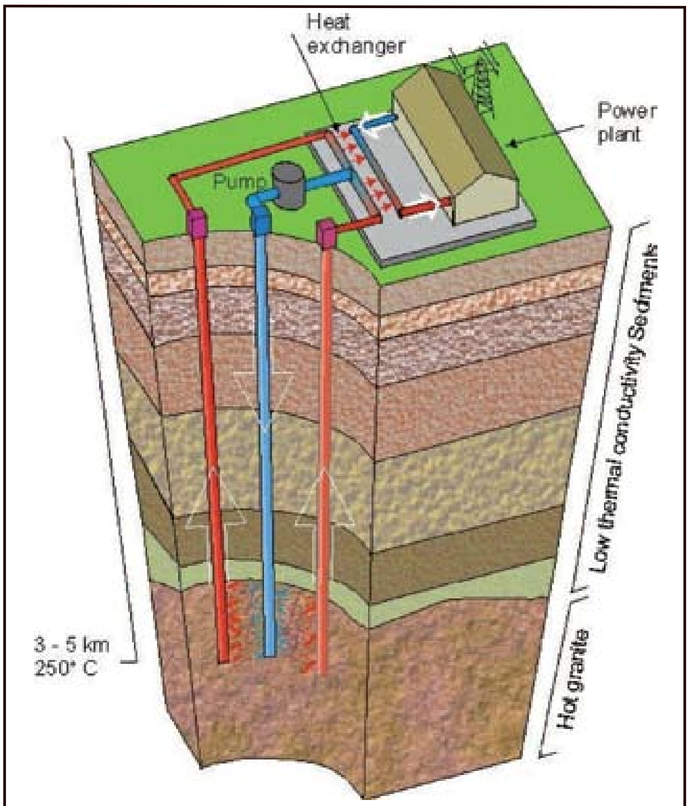

Figure 3. Schematic diagram illustrating the concept of Hot Fractured Rock geothermal energy. Cool water is pumped down the central "injection well" where it passes through the hot rock mass along natural fractures that have had their permeabilities artificially enhanced by hydraulic stimulation. The heated water is then returned to the surface power plant by the flanking "production wells".

Table 1. Well sites where the depth to 200°C is less than 5000 m (based on extrapolation of an equilibrium temperature)

Basin/Well	Total depth (m)	Gradient (°C/100 m)
Canning		
Canopus 1	1779	4.74
Nuytsia 1	1350	4.20
Philydrum 1	1608	3.61
Sundown 1	2736	3.24
Sundown 2	1965	3.28
Sundown 3	1645	3.53
Whitewell 1	1754	4.11
Woods Hills 1	1978	3.97
Carnarvon		
Airey Hill 1	1037	3.43
Bullara 1	1300	4.52
Chinty 1	1673	4.42
Hope Island 1	1426	3.87
Lefroy Hill 1	1512	3.78
Ningaloo 1	1228	3.54
Parrot Hill 1	1287	5.56
Roberts Hill 1	1265	4.70
Rough Range 11	1168	4.78
Sandalwood 1	1350	4.10
Sandy Point 2	1678	3.35
Talandji 1	1488	4.40
Trealla 1/1A	1496	4.11
Wingette 1	1439	4.70
Perth		
Depot Hill 1	2473	4.40
North Yardanogo 1	2387	3.20
Warradong 1	3717	3.10
Woodada 02	2460	4.00
Woodada 05	2808	3.60

rocks, stratigraphy and lithology of sedimentary sections.

Geophysical data, including gravity, magnetic and seismic surveys need to be reviewed. Scientific review requires the compilation of data, followed by desktop evaluation of quantity and quality of this data, synthesis and interpretation of data, integration of geology, geophysics and geochemistry of the basins to map and identify the best areas of high geothermal anomalies, as well as what and where new data are needed. Desktop studies need to be followed by field studies to obtain new data on heat flow and rock geochemistry.

The GSWA study by Bestow (1982) mainly focuses on low temperature geothermal reservoirs up to 100°C. The study applied available data on heatflow, geothermal gradient, and hydrogeology to the geological framework of Precambrian Shield, Eucla, Officer, Canning, Carnarvon, and Perth Basins. The objectives of the study were more qualitative than quantitative and concluded that geothermal and hydrogeological conditions for developing a geothermal resource for both direct use and power generation are present in Western Australia.

The main focus of the recent GSWA study (Chopra and Holgate, 2007) was on high temperature geothermal reservoirs up to 200°C. The aim was to map and identify the most suitable areas within the Canning, Carnarvon and Perth Basins that may have potential for development of geothermal energy from Hot Dry Rocks (HDR) as originally known, then Hot Fractured Rock (HFR) and now Enhanced Geothermal Systems (EGS). Secondly, this study developed a reliable dataset on subsurface temperatures and their quality, basement depths and rock types, and in-situ stress conditions for further detailed studies.

The most prospective basin for geothermal energy appears to be the Carnarvon Basin, followed by the Canning and Perth. This is based on the present-day geothermal gradient of wells where the estimated depth to 200°C is less than 5000 m (Table 1).

Geochemical analyses of basement rocks are required to assess the heat generation capacity of rocks because fairly subtle variations in the trace concentrations of thorium and uranium can have quite significant impacts on heat generation capacity, whereas quite large variations in bulk potassium concentrations tend to have only a second order effect on the heat generation capacity.

The stress conditions are best known for the Perth Basin where the in-situ stress field appears to be either of a thrust or strike-slip character. The predominant orientation of the maximum horizontal stress is E-W, which is also inferred for the Canning and Carnarvon Basins. However, the details of relative stress magnitudes are poorly known at present, thus the suitability for EGS development cannot be assessed without further study.

Conclusions

The search for geothermal energy in Western Australia is in the initial stages and a quantitative assessment requires systematic geological, hydrogeological, geophysical, and geochemical evaluation. Data compilation, followed by the synthesis, interpretation and integration of data is required to determine an areas' geothermal potential, and what new data is required for further evaluation.

Studies by the GSWA indicate the presence of geothermal resources both from hydrothermal and EGS, and that further detailed studies are warranted. Geothermal resources recognised from hydrothermal sources are from low temperature reservoirs (65-85˚C) at depths between 2000 and 3500 m.

Present technology, expanding demand for clean and renewable energy, interest and investment for exploring and developing geothermal energy in Australia provide impetus to expedite the process to explore for geothermal energy in Western Australia.

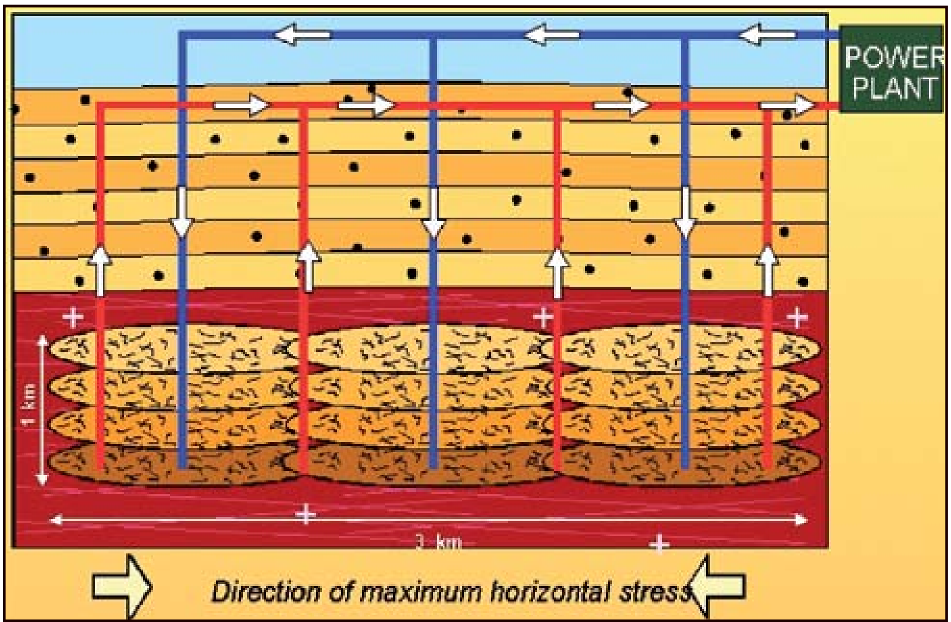

Figure 4. Conceptual model of an Australian HFR development comprising stacked heat exchangers from multiple wells. Diagram is from the Geodynamics Limited web site.

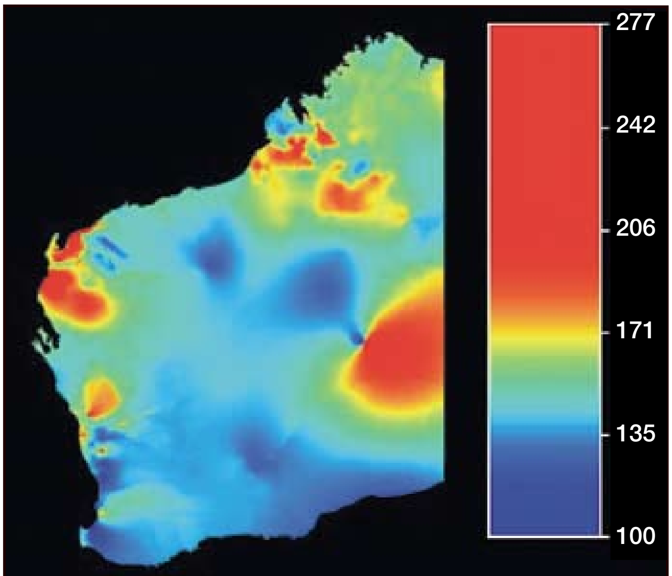

Figure 5. West Australian hot spots estimated at 5 km, temperature in degrees Celsius.

References

Bestow, T. T., 1982, The potential for geothermal energy development in Western Australia: Western Australia Geological Survey, Record 1982/6, 67p.

Chopra, P.N. 2005, Status of the geothermal industry in Australia, 2000-2005: Proceedings, World Geothermal Congress, 2005, Antalya, Turkey, 24-29 April 2005

Chopra, P. N., and Holgate, F., 2005, A GIS Analysis of temperature in the Australian Crust: Proceedings, World Geothermal Congress 2005, Antalya, Turkey, 24-29 April 2005.

Chopra, P. N., and Holgate, F., 2007, Geothermal energy potential in selected areas of Western Australia, a consultancy report by Earthinsite.com Pty Ltd for Geological Survey of Western Australia: Western Australia Geological Survey, S-series, G31888 A1, 355p. (unpublished).

Cull, J. P., 1977, Geothermal energy prospects in Australia: Search, v. 8, no. 4, p. 117-121.

Cull, J. P., 1979, Regional variations in Australian heat flow: Australia Bureau of Mineral Resources, Journal, v. 4, no. 1, p. 1-13.

Cull, J.P. 1982, An appraisal of Australian heat flow data, Bureau of Mineral Resources, Journal of Australasian Geology & Geophysics, 7, p.11-21.

Cull, J. P., and Denham, D., 1978, A case for research and development on geothermal energy in Australia: Australia Bureau of Mineral Resources, Record 78/58, p. 7.

Narayan, S. P., Naseby, D., Yang, Z., and Rahman, S. S., 1998a, Petroleum and hot dry rock: two of energy sharing commonalities: APPEA Journal 1998, p.830-847.

Narayan, S. P., Naseby, D., Yang, Z., and Rahman, S. S., 1998b, Creation of HDR reservoirs under Australian in-situ stress conditions: Proceedings, Twenty-third Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, California, January, 26-28, 1998, p.322-329.

Sass, J. H., 1964, Heat-flow values from the Precambrian of Western Australia: Journal of Geophysical Research, v. 69, no. 2, p. 299-308.

Sass, J. H., Jaeger, J. C., and Munroe, R. J., 1976, Heat flow and near-surface radioactivity in the Australian continental crust: U. S. Geological Survey, Open-File Report 76-250, 91p.

Somerville, M., Wyborn, D., Chopra, P., Rahman, S., Estrella, D., and Theo, V. D. M., 1994, Hot dry rock feasibility study, a report compiled for the Energy Research and Development Corporation, Canberra, ERDC 94/243, 133p.