[PS]Western Australia's Geothermal Resources*

By
Ameed Ghori[1]

Search and Discovery Article #80023 (2008)
Posted August 18, 2008

*Adapted from extended abstract prepared for poster presentation at AAPG Annual Convention, San Antonio, Texas, April 20-2, 2008, together with poster presentation (in PDF format).

[1]Geological Survey of Western Australia, Department of Industry and Resources, East Perth, WA, Australia (ameed.ghori@doir.wa.gov.au)

Abstract

Western Australia is commencing a new era in the search of energy from geothermal resources. The study for a geothermal energy was initiated in the 1980s from hydrothermal resources and recognised low temperature reservoirs (65-85^{o}C) at greater depths (2-3.5 km), with the best economic potential in the Perth Basin. The high temperature hydrothermal resources that are attractive geothermal energy targets in geologically active areas of the United States, Philippines, Mexico, Indonesia, and Italy are not found in tectonically stable Western Australia.

Thus the second study for geothermal energy in 2006 targeted hot rock resources that are currently economic, where the depth to 200^{o}C is less than five km. Petroleum wells in parts of the Canning, Carnarvon, and Perth basins indicate two favourable factors for developing Enhanced Geothermal System (EGS), potentially high-heat generating granitic basements and maximum horizontal stress orientations that are favourable for developing horizontally oriented high temperature geothermal reservoirs. The Carnarvon Basin has the greatest number of wells with high temperature gradients, followed by the Perth and Canning basins.

The extent and economic feasibility of hydrothermal and hot rock geothermal resources are presently unknown because studies were qualitative, rather than quantitative, and based on limited datasets. Data gathering, validating, and interpretation of greater than 1000 wells is underway for a quantitative assessment that requires systematic geological, hydrogeological, geophysical, and geochemical evaluation to further delineate and prove these resources.

The Australian continent has significant potential for geothermal energy from known high heat-producing granites, and Geodynamic Ltd is a leader of testing the commercial viability of extracting heat energy by EGS at the Habanero project in the Cooper Basin.

WESTERN AUSTRALIA'S GEOTHERMAL RESOURCES

Department of Industry and Resources

Ameed Ghori, Geological Survey of Western Australia, Department of Industry and Resources, Perth, Australia

Geological Survey of Western Australia

New era

Western Australia

The first acreage release for geothermal exploration in the Perth Basin on January 22, 2008 commenced a new era in the search for energy in Western Australia to broaden the State's energy base (Figure 1).

The geothermal acreage release followed the amendments to the State's Petroleum Act 1967 that were approved in January 2008, now known as the Petroleum and Geothermal Energy Resources Act 1967.

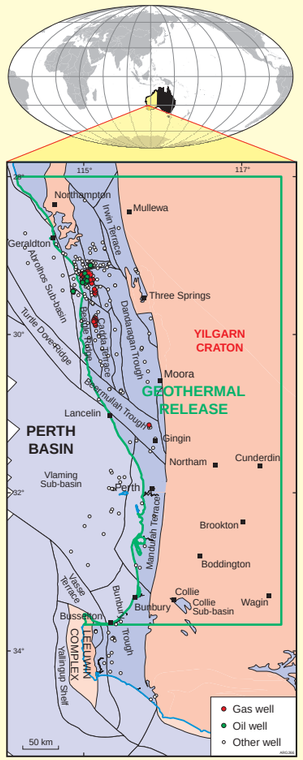


Figure 1. Map showing acreage release and petroleum wells locations in the Perth Basin.

Australia

South Australia was the first State to develop legislation for geothermal exploration and granted the first Australian Geothermal Exploration Licence (GEL) in 2001. Since then about 12 geothermal wells have been drilled in South Australia (Figure 2).

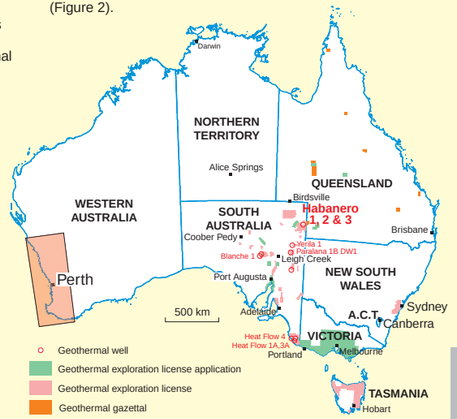


Figure 2. Map showing geothermal exploration in Australia.

There has been an exponential increase since 2002 in the interest shown by companies that is reflected by increasing investment in the exploration and development of geothermal energy resources in Australia (Figure 3).

An investment totalling $686 million has been proposed for five-year work programs by 27 companies over 166 licences.

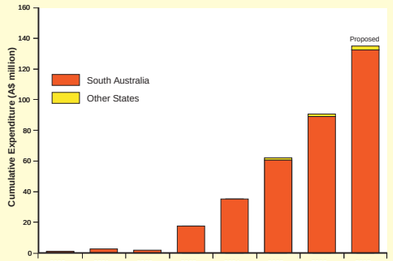


Figure 3. Australian expenditure growth in geothermal exploration from 2000 to 2007
(source: Primary Industries and Resources South Australia).

Geothermal Energy

Energy outlook

The energy outlook for this century indicates that there will be significant energy supplies from geothermal, solar, wind, and hydro-electric resources. Of these, geothermal energy from hot rocks shows the greatest potential for long-term, continuous electricity supply, and Australia is leading the way in EGS (enhanced geothermal system) technology (Figure 4).

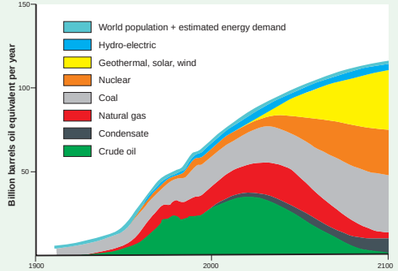


Figure 4. World's energy outlook for this century
(Courtesy of Geothermal Explorers Ltd).

The trend in EGS technological advances indicates that within decades the cost for electricity generation from EGS will be competitive with conventional energy generation from coal and natural gas, and lower than any other form of renewable energy (Figure 5).

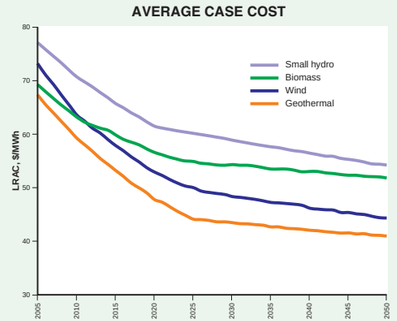


Figure 5. Outlook for electricity generation from alternative energy
(source: Renewable Energy Generators Australia Ltd).

Energy types

Geothermal Energy includes thermal or electrical power produced from the heat contained in the Earth. There are two basic types of energy that can be sourced from Earth's heat: from hydrothermal systems (hot geofluids; Figure 6) and from hot rocks (hot dry rocks, HDR; Figures 6 and 7).

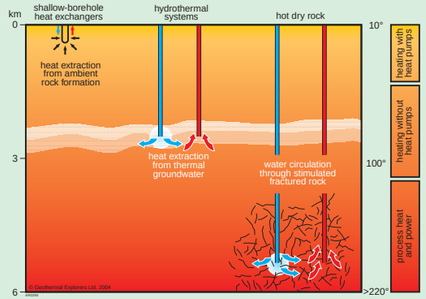


Figure 6. Type of geothermal resources from Earth's heat,
(courtesy of Geothermal Explorers Ltd).

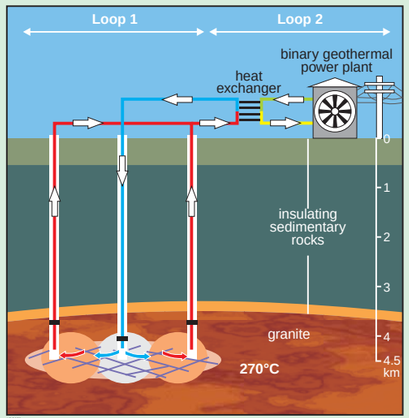


Figure 7. Concepts for electricity generation from hot rock at Geodynamics Ltd's Habanero project, Cooper Basin, South Australia. Loop 1 includes injection and production wells to circulate water for extraction and transfer of heat from hot rocks at depth to the surface. Loop 2 includes a surface heat exchanger to run a turbine for electricity generation,
(courtesy of Geodynamics Ltd.)

Australian achievements

Australia is at the forefront of testing the commercial viability of extracting heat energy by EGS at the Habanero project in the Cooper Basin, South Australia. The objective of the Habanero project is to develop Australia's first commercial-scale power plant from geothermal resources in stages. A 50 MW power plant is planned for development by mid-2011, which could gradually be expanded to 100s of MW for commercial base-load power plants. The completion of Habanero 3 at target depth of 4221 m is a significant milestone toward commercialization of the HFR (hot fractured rock) geothermal well (Figure 8).

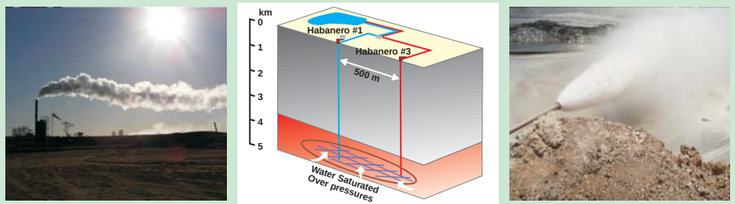


Figure 8. Left photo shows steam flowed from Habanero 1 and right photo shows Habanero 3, steam flowed, as part of the well clean up program prior to flow testing. The well flowed at approximately 23 kg/sec.

Since 1970 research has been undertaken worldwide aimed at commercial utilization of the Earth's heat using EGS technology applied to HDR (hot dry rock) sources so that energy can be extracted (Figures 9 and 10).

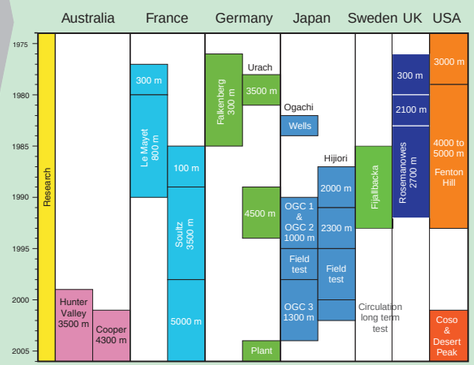


Figure 9. Major HDR and EGS projects worldwide.
(source: http://geothermal.inel.gov).

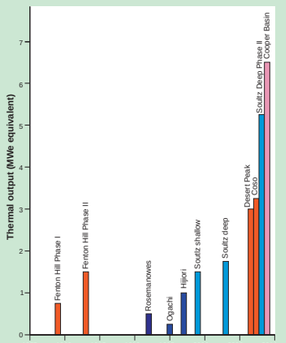


Figure 10. Estimated electrical power output per production well, with time from EGS projects.
(source: http://geothermal.inel.gov)

KEYWORDS: Geothermal resources, Hydrothermal, Hot rock, Western Australia.

Department of Industry and Resources

WESTERN AUSTRALIA

Ameed Ghori, Geological Survey of Western Australia, Department of Industry and Resources, Perth, Australia

Geological Survey of Western Australia

Data resources

Geological Survey of Western Australia (GSWA) has undertaken two specific studies in the search for geothermal energy (Figure 11).

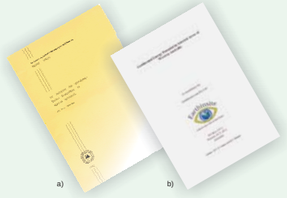
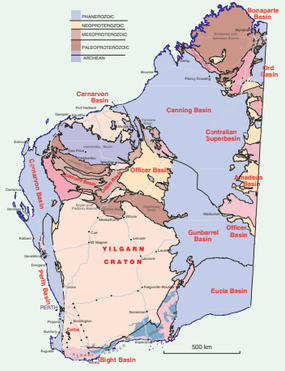


Figure 11. Publications: a) GSWA Record 1982/6 "The Potential for Geothermal Energy Development in Western Australia" by T. T. Bestow, 1982, b) Earthnote consultancy report on "Geothermal Energy Potential in Selected Areas of Western Australia" by Dr P. N. Chopra and Dr F. Holgate, 2007, (GSWA unpublished report G31888 A1).



Basin	Number of onshore wells
Bight	7
Bonaparte	10
Canning	260
Carnarvon	257
Edmund/Collier	2
Gunbarrel	1
Officer	33
Ord	1
Perth	282
Yilgarn Craton	2

Figure 12. Basins and number of petroleum wells drilled in Western Australia.

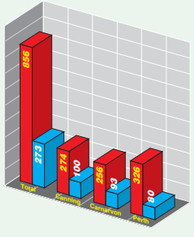


Figure 13. Wells completed (blue) by Chopra and Holgate (2007) and the wells currently under study (red) for the evaluation of geothermal resources from hot rocks.

Initial study

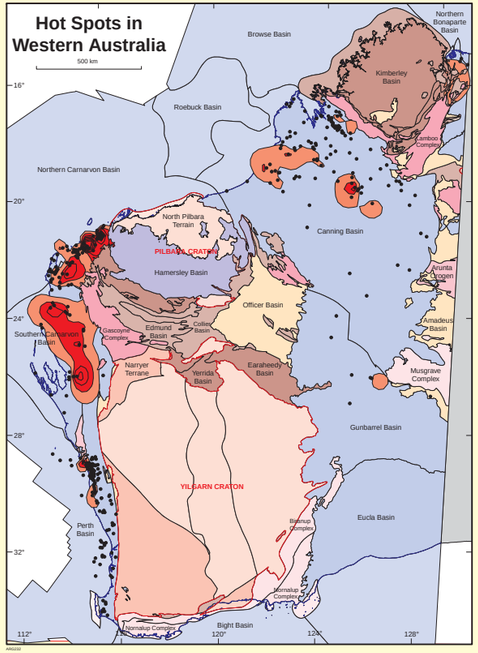


Figure 14. Map showing hot areas in Western Australia based on BHT (bottom hole temperature) recorded in petroleum wells. This map was generated initially to select the areas for further detail study to verify the quality and quantity of subsurface data available for geothermal resource evaluation.

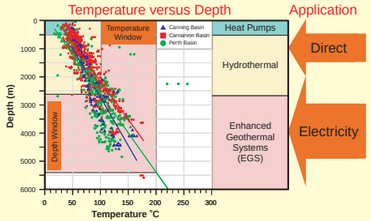


Figure 15. Temperature versus depth plot to show recorded subsurface in petroleum wells of the Canning, Carnarvon, and Perth Basins with potential applications. This plot was generated initially to select the wells for further detail study to verify the quality and quantity of subsurface data available for geothermal resource evaluation.

Potential hot rock resources

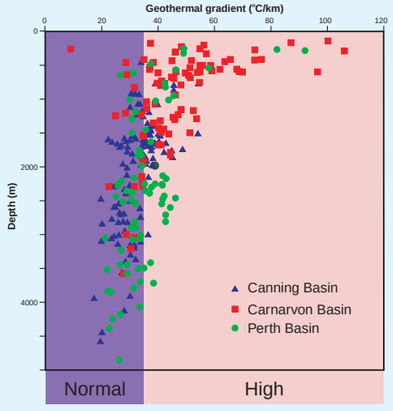


Figure 16. Geothermal gradient versus depth plot for petroleum wells studied by Chopra and Holgate (2007). This plot shows that higher than normal geothermal gradients are observed in many wells. In Australian basins, the high crustal temperatures are usually associated with local high-heat production under rocks of low thermal conductivity.

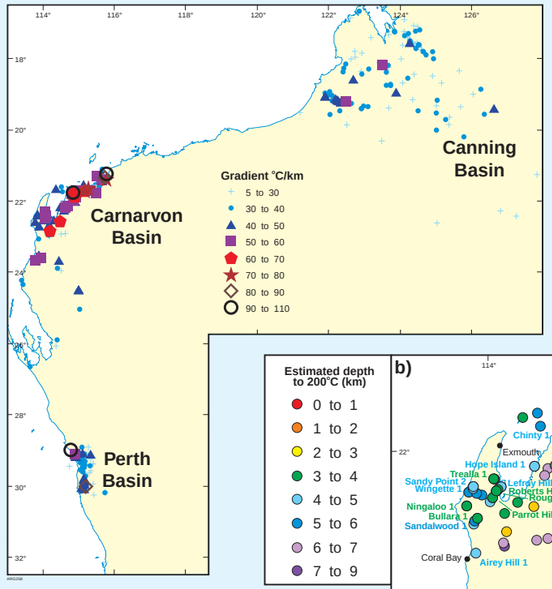


Figure 17. Map showing distribution of present-day geothermal gradients of the selected petroleum exploration wells of the Canning, Carnarvon, and Perth Basins. This map shows that the Carnarvon Basin has the greater number of wells with higher gradients, followed by the Canning and Perth basins, respectively.

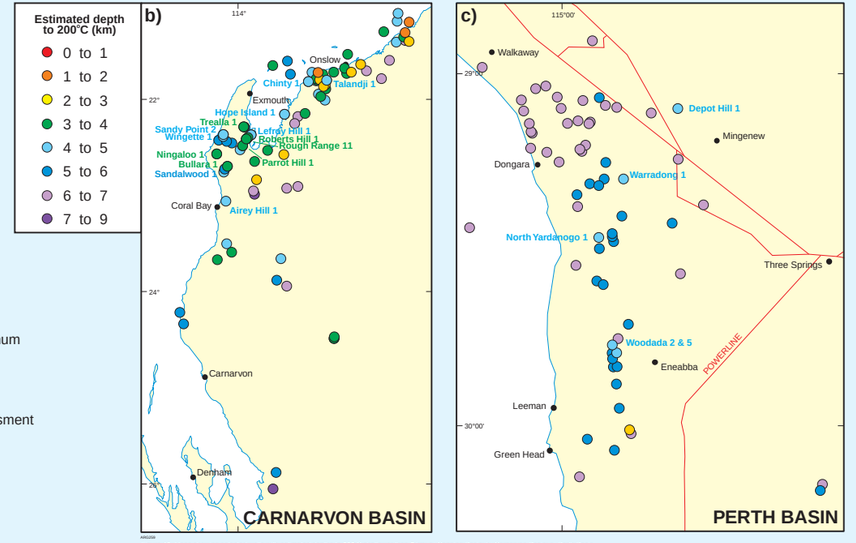


Figure 18. Maps showing selected wells with estimated depths to 200°C shallower than 5 km: a) Canning Basin; b) Carnarvon Basin; c) Perth Basin.

The most prospective basin for geothermal energy appears to be the Carnarvon Basin, followed by the Canning and Perth Basins. This is based on the present-day geothermal gradient for wells where the estimated depth to 200°C is less than 5 km (Figures 16 to 18).

The stress conditions are best known for the Perth Basin where the predominant orientation of the maximum horizontal stress is east–west, with similar conditions inferred for the Canning and Carnarvon Basins. The extent and economic feasibility of hydrothermal and hot rock geothermal resources are presently unknown because studies were qualitative, rather than quantitative, and based on limited datasets.

Data gathering, validating, and interpretation of more than 900 wells is underway for a quantitative assessment that requires systematic geological, hydrogeological, geophysical, and geochemical evaluation to further delineate and prove these resources.

The estimates of equilibrium geothermal gradient and depth to basement have been used to predict the temperature at the top of the basement and the depth at each well location required to reach the 200°C isotherm (Figure 18).

KEYWORDS: Geothermal resources, Hydrothermal, Hot rock, Western Australia.

Department of Industry and Resources

PERTH BASIN

Ameed Ghori, Geological Survey of Western Australia, Department of Industry and Resources, Perth, Australia

Geological Survey of Western Australia

Geofluid resources

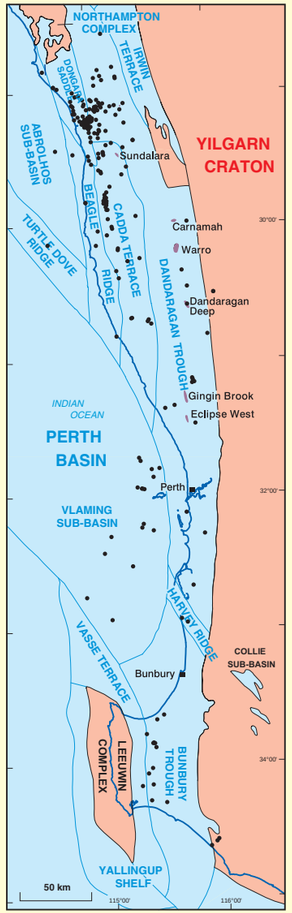


Figure 19. Perth Basin structural units and petroleum wells.

The **first Perth Basin geothermal acreage release** in Western Australia is the beginning of a major expansion in exploration for hot rock geothermal resources (Figure 1).

The **Perth Basin** is a north–south elongated trough in the southwest of Western Australia (Figure 19), contains Permian to Lower Cretaceous succession under a thin cover of Tertiary rocks. These successions are a source of groundwater and petroleum with potential for geothermal energy (Figure 20).

This evaluation is mainly based on GSWA publications :

- **Geothermal resources**
  Bestow (1982), Chopra and Holgate (2007), Ghori (2007 and 2008).
- **Hydrogeology**
  Thorpe and Davidson (1991), Davidson (1995).
- **Petroleum geology**
  Crostella (1995), Mory and Iasky (1996), Crostella and Backhouse (2000), Owad-Jones and Ellis (2000)
- Unpublished company reports submitted to GSWA.
- See also reference list below.

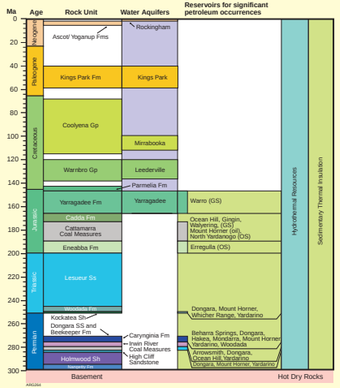


Figure 20. Generalized stratigraphy of the Perth Basin and distribution of groundwater aquifers, petroleum reservoirs and potential geothermal resources

Hydrothermal resources

Figure 21 shows the distribution of geothermal gradients and Figure 22 shows the temperature versus depth. These figures are based on data available from 145 artesian monitoring water bores. Of these, 47 recorded temperature logs that were used to calculate geothermal gradients. The recorded gradients range from 1.1°C/100 m to 4.4°C/100 m, a depth of about 1 km.

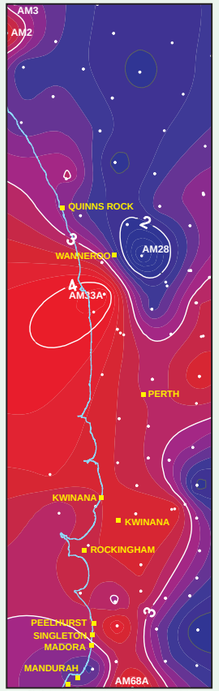


Figure 21. Distribution of subsurface geothermal gradients from water bores of the Perth region

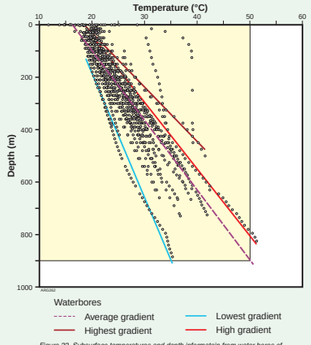


Figure 22. Subsurface temperatures and depth informatoin from water bores of the Perth region.

Figure 21 indicates that the recorded highest and lowest subsurface temperatures are around the Wanneroo area. The lowest temperatures extend towards the north of and the higher temperatures towards the south of the Wanneroo area. Figure 22 indicates low temperature resources up to 50°C at a depth less than 1 km in areas of high geothermal gradients.

The first West Australian geothermal study by Bestow (1982) recognised low temperature reservoirs (65-85°C) at greater depths (2 to 3.5 km), with the best economic potential in the Perth Basin.

Conceptual models for potential hot rock resources

Conceptual models for petroleum and geothermal resources have been developed for the Beagle Ridge (Figure 23) and the Cadda Terrace (Figure 24) in the northern part of the Perth Basin. High geothermal gradients are observed in Jurien 1 (55°C/km; Figure 25) on the Beagle Ridge and Woodada 02 (40°C/km) within the Woodada Gas Field on the Cadda Terrace (Figure 26). Jurien 1 was drilled to a total depth of 1026 m and intersected granitic basement at 967 m. The extrapolated recorded temperatures indicate that 200°C was expected to be reached between 2.5 and 3 km (Figure 25). Temperatures around 200°C at these depths have potential for the development of geothermal energy. Figure 26 shows the subsurface temperatures as a function of depth in 17 wells of the Woodada Gas Field. The extrapolated temperatures indicate that 200°C is expected to be reached between 4 and 5 km. These are potentially suitable depths for developing geothermal resources with conditions favourable for enhanced geothermal systems. The reservoir temperature of the Woodada Gas Field is 120°C at a depth range from 2125 to 2496 m (Owad-Jones and Ellis, 2000).

Figures 25 to 27 show that the recorded temperatures and depths are up to 150°C and 4.5 km. The corrected estimated equilibrium temperatures are expected to be higher (by generally 10 to 20%) than these recorded temperatures.

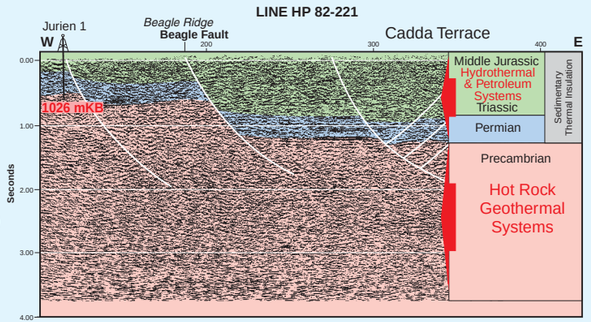


Figure 23. Conceptual model for petroleum and geothermal resources of the Beagle Ridge, Perth Basin.

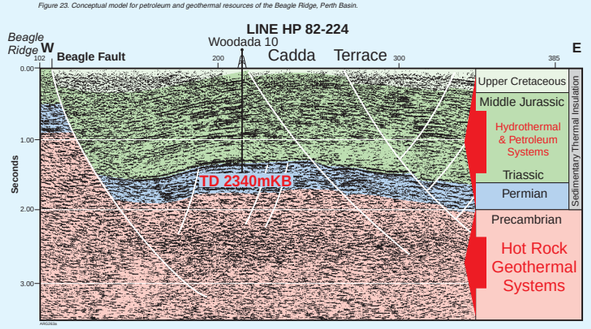


Figure 24. Conceptual model for petroleum and geothermal resources of the Cadda Terrace, Perth Basin.

Temperature information is also available from 242 petroleum wells over a larger area and a greater depth (850 m) from the Perth region water bores. Of these only 83 wells have been studied to date (Chopra and Holgate 2007; Figure 13).

For the Perth Basin, the estimated geothermal gradients in 83 wells indicate very high to normal gradients, ranging from 90 to 20°C/km (Figure 16). Gradients in wells deeper than 2 km are considered more reliable and representative for hot rock resources.

The recorded maximum horizontal stress orientations are east–west across the Perth region (Reynolds and Hillis, 2000). These observations are highly relevant for assessing the hot dry rock prospectivity of the basin because maximum horizontal stress creates the most favourable environments (Chopra and Holgate, 2007).

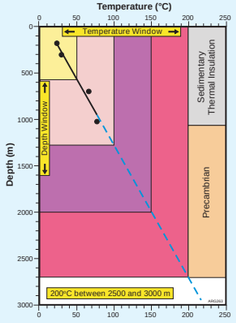


Figure 25. Subsurface temperatures as a function of depth in Jurien 1.

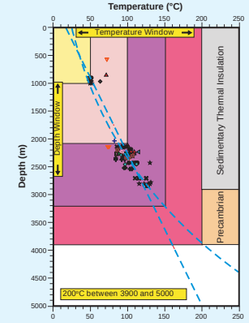


Figure 26. Subsurface temperatures as a function of depth in Woodada Gas Field wells.

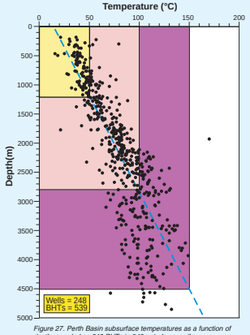


Figure 27. Perth Basin subsurface temperatures as a function of depth recorded as 540 BHTs in 242 petroleum wells.

References

Bestow, T. T, 1982. The potential for geothermal energy development in Western Australia: Geological Survey of Western Australia, 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 F. Holgate, 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 F. Holgate, 2007**, Geothermal energy potential in selected areas of Western Australia; a consultancy report by Earthinsite.com Pty Ltd for Geological Survey of Western Australia: Geological Survey of Western Australia, Statutory petroleum exploration report, 03/1888 A1 (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 BMR, Journal of Australian Geology and Geophysics, v. 4, no. 1, p. 113. **Cull, J. P, 1982.** An appraisal of Australian heat flow data: Australia BMR, Journal of Australian Geology and Geophysics, v. 7, p. 11–21. **Cull, J. P, and D. Denham, 1979.** A case for research and development on geothermal energy in Australia: Australia Bureau of Mineral Resources, Record 1978/58, p. 7. **Crostella, A., 1995.** An evaluation of the hydrocarbon potential of the onshore Perth Basin: Western Australian Geological Survey, Report 43, 67 p. **Crostella, A., and J. Backhouse**, Geology and petroleum exploration of the central and southern Perth Basin, Western Australia: Western Australian Geological Survey, Report 57, 85 p. **Davidson, W. A., 1995.** Hydrogeology and groundwater resources of the Perth Region, Western Australia: Western Australia Geological Survey, Bulletin 142, 257p. **Ghori, K. A. R., 2007**, Search for energy from geothermal resources in Western Australia: September 2007 Petroleum in Western Australia, Western Australia's Digest of Petroleum Exploration, Development and Production, Department of Industry and Resources, Perth, p. 36–39. **Ghori, K. A. R, 2008.** The search for Western Australia's geothermal resources: Geological Survey of Western Australia Annual Review 2006–07, p. 25–31. **Hillis, R. R., and S. D. Reynolds, 2000.** The Australian Stress Map: Journal of the Geological Society, London, v. 157, p. 9159–21. **Mory, A. J., and R. P. Iasky, 1996**. Stratigraphy and structure of the onshore northern Perth Basin, Western Australian Geological Survey, Report 436, 102 p. **Narayan, S. P., D. Nisseby, Z. Yang, and S. S. Rahman, 1998a**. Petroleum and hot dry rock: two of the energy sharing commonalities: APPEA Journal 1998, p. 830–847. **Narayan, S. P., D. Nisseby, Z. Yang, and S. S. Rahman, 1998b.** Creation of HDR reservoirs and fracture in-situ stress conditions, in Proceedings of Twenty-third Workshop on Geothermal Reservoir Engineering: Stanford University, Stanford, California, USA, January 1998, p. 322–329. **Owad-Jones, D., and G. Ellis, 2000.** Western Australia atlas of petroleum fields, Onshore Perth Basin, Petroleum Division, Department of Mineral and Energy Western Australia, Volume 1, 114 p. **Reinecker, J., O. Heidbach, M. Tingay, B. Sperner, and B. Müller, 2005.** The release of the 2005 World Stress Map: World Stress Map Project, Geophysical Institute, Karlsruhe University. **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., J. C. Jaeger, and R. J. Munroe, 1976.** Heat flow and near-surface radioactivity in the Australian continental crust: United States Geological Survey, Open-File Report 76–250, 91p. **Somerville, M., D. Wyborn, P. Chopra, S. Rahman, D. Estrella, and V. D. M. Theo, 1994.** Hot dry rock feasibility study, a report compiled for the Energy Research and Development Corporation: Canberra, Australia, Energy Research and Development Corporation, ERDC 94/243, 133p. **Thorpe, P. M., and W. A. Davidson, 1991**. Groundwater age and hydrodynamics of the confined aquifers, Perth, Western Australia, in Proceedings of the International Conference on Groundwater in Large Sedimentary Basins, Perth, Western Australia, 1990: Australian Water Resources Council Series, no. 20, p. 420-436.

KEYWORDS: Geothermal resources, Hydrothermal, Hot rock, Western Australia.