Temperature and heat flow information for geothermal energy exploration in Western Australia

K. Ameed R. Ghori

K. Ameed R. Ghori

Department of Mines and Petroleum, Perth, Western Australia
Email: Ameed.GHORI@dmp.wa.gov.au

The Geological Survey of Western Australia (GSWA) is continuing its studies in subsurface temperatures and heat-flow modelling to assess prospective areas and encourage geothermal energy exploration in Western Australia. Estimated temperatures and heat-flow modelling identified high temperatures on the Broome Platform and in areas north of Onslow within the Canning and Carnarvon basins, respectively. In the Perth Basin, 3D modelling calculated temperatures above 150°C at 4 km below sea level within the Bookara Shelf, Coomallo and Beermullah troughs. These areas have temperatures up to 100°C within a depth of 3 km for hot sedimentary aquifer (HSA) resources, and up to 200°C within a depth of 5 km for hot rock (HR) resources. The northern Perth Basin is the most attractive target for geothermal energy development, with its favourable temperatures, geology, well-developed infrastructure and commercial markets.

Keywords: geothermal gradients, heat flow, modelling geothermal energy, Western Australia.

Introduction

Exploration for geothermal energy in Western Australia was formalized in January 2008, with the first geothermal acreage released in the Perth Basin. Presently, seven companies are exploring for geothermal energy in 41 Geothermal Exploration Permits (GEPs) in the State. The University of Western Australia (UWA) and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) are developing new technologies for geothermal energy exploration, exploitation, and utilization.

The Geological Survey of Western Australia (GSWA) is continuing its studies in subsurface temperatures and heat-flow modelling to identify prospective areas for geothermal energy exploration in Western Australia. Nine specific geothermal reports can be downloaded free of charge from http://www.dmp.wa.gov.au/801.aspx; http://geodocs.doir.wa.gov.au/document/documentSearch.do.

New data include estimated equilibrium temperatures in 579 wells, measured thermal conductivity on 302 cores, one-dimensional (1D) heat-flow modelling in 329 wells, and three-dimensional (3D) geological and heat-flow modelling of the northern Perth Basin, and available stress and basement heat generating data for the study areas. These data include all available temperatures recorded in onshore petroleum wells, drilled within the Bonaparte, Carnarvon, Canning, Officer, and Perth basins, including two offshore Browse Basin wells.

The aim is to identify areas with temperatures up to 100°C within a depth of 3 km for hot sedimentary aquifer (HSA) resources, and up to 200°C within a depth of 5 km for hot rock (HR) resources, which can be developed using Enhanced Geothermal System (EGS).

Bonaparte and Browse Basins

The larger part of the Bonaparte Basin lies offshore whereas the Browse Basin is entirely offshore. Thermal conductivities were measured in 13 cores from four wells, Bonaparte 1A, Bonaparte 2, Laminaria East 1, and Turtle 1, within the Bonaparte Basin. The lowest measured conductivity is 1.24 W/m°C for the Jurassic Frigate Shale in Laminaria East 1, and the highest is 5.09 W/m°C for the Devonian Cockatoo Group in Bonaparte 1A (Hot Dry Rocks Pty Ltd, 2010a). Within the Browse Basin, conductivities were measured in four cores from Brecknock 2 and Calliance 1, with minimum values of 2.29 W/m°C for the Triassic Nome Formation, and maximum values of 4.51 W/m°C for the Jurassic Plover Formation (Hot Dry Rocks Pty Ltd, 2010b).

Based on 1D heat flow modelling of nine wells (Hot Dry Rocks Pty Ltd, 2010a) the apparent surface heat flow ranges 60–103 mW/m² with a median value of 76 mW/m² for the Bonaparte Basin. Within the Browse Basin, the modelled heat flow values for the Adele Island 1 and Browse Island 1 sites are 30 mW/m² and 51 mW/m², respectively (Hot Dry Rocks Pty Ltd, 2010b).

Presently, these basins are not suitable for geothermal energy development and no company has applied for Geothermal Exploration Permits.

Canning Basin

The Canning Basin is the largest basin of Western Australia. Estimated equilibrium temperatures in 274 wells, measured thermal conductivity on 50 core samples from 22 wells, and 1D heat flow modelling in 101 wells identified regions of high temperature (up to 200°C) at depths of less than 5 km, which is presently considered economic for development of hot rock resources using EGS.

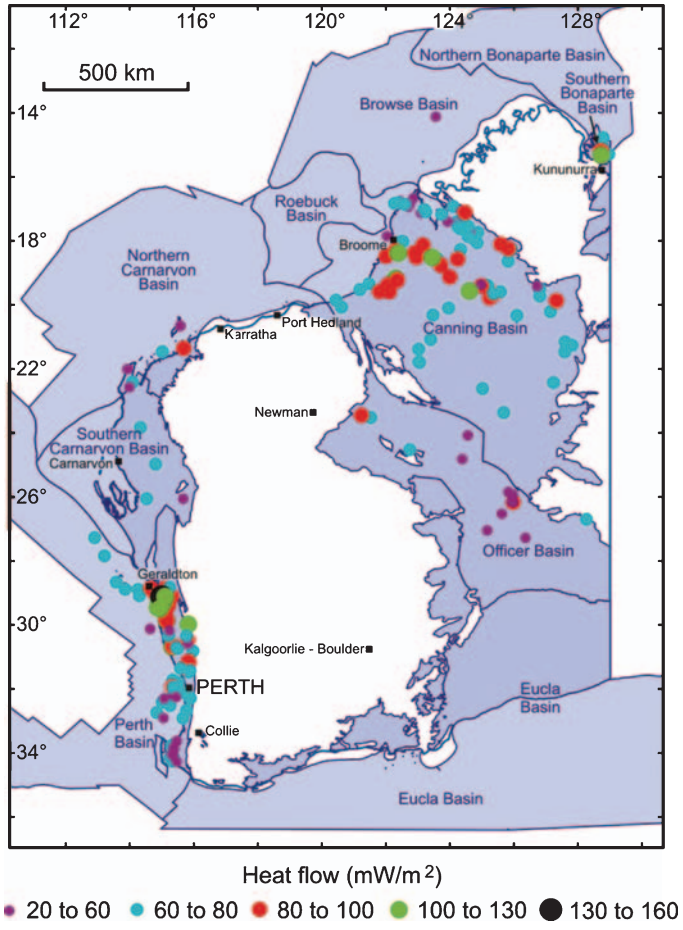

Fig. 1. *1D heat-flow values modelled in wells of Western Australian basins.*

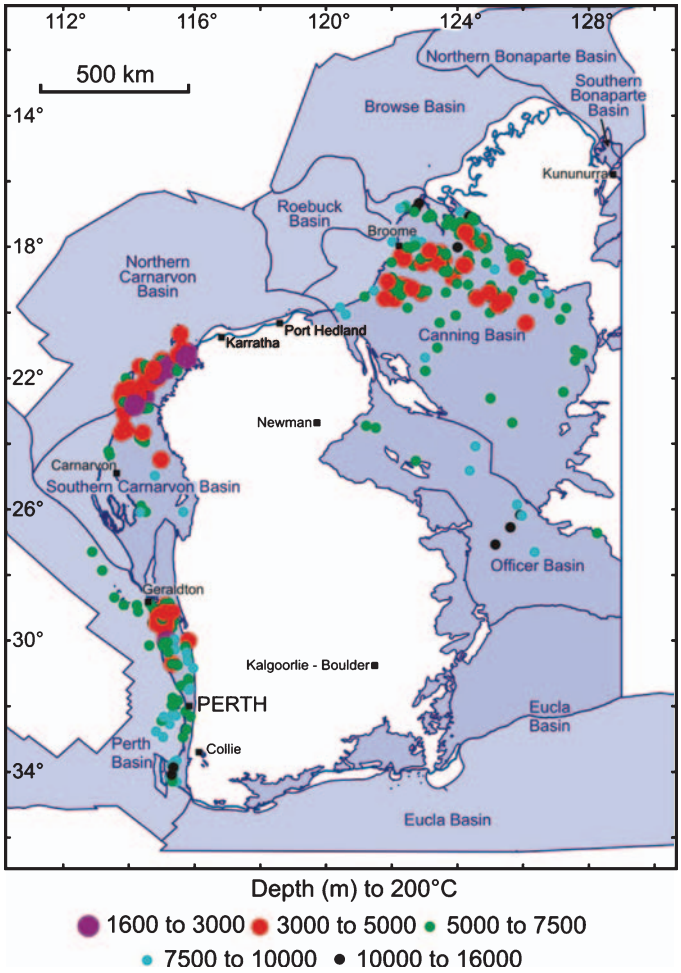

Fig. 2. *Calculated depth (m) to 200°C in wells of Western Australian basins.*

Measured thermal conductivity ranges from 1.06 to 5.83 W/m°C and modelled surface heat flow ranges 20–160 mW/m². The lowest measured thermal conductivity (1.06 ± 0.28 W/m°C) is within the Ordovician Goldwyer Formation, and the highest values (5.83 ± 0.22 W/m°C) were detected within the Upper Carboniferous Reeves Formation (Driscoll *et al*., 2009).

Estimated heat flow values are lower (less than 65 mW/m²) in locations where thick sedimentary deposits are present such as the Fitzroy Trough, Lennard Shelf, and Kidson Sub-basin. The heat flow values increase to over 80 mW/m² on the Broome Platform and Jurgurra, Mowla and Barbwire Terraces. Higher heat flow values have been modelled for Goodenia 1, Lovells Pocket 1, Kanak 1, Cudalgarra North 1, and Cudalgarra 1, where heat flow values exceed 100 mW/m² (Figure 1). These new data indicate that the Broome Platform has the highest temperatures (Figure 2). Given its shallow basement the Broome Platform has a high potential for geothermal energy development, provided other factors are also found favourable for developing HR and HSA (Chopra and Holgate, 2007; Driscoll *et al*., 2009; Ghori, 2009; Ghori, 2010).

Geothermal energy exploration in the Canning Basin began with an acreage release in September 2009, and applications for GEPs are under consideration.

Carnarvon Basin

The Northern Carnarvon Basin is the main oil and gas producing basin of Western Australia, with over 984 petroleum wells providing a huge amount of subsurface data up to a drilled depth of 9 km. Subsurface data for the Southern Carnarvon Basin is limited to 258 wells, mostly onshore.

Estimated equilibrium subsurface temperatures in 138 onshore petroleum wells, measured thermal conductivity on 61 core samples from 10 wells, and 1D heat-flow modelling of 21 wells identified regions of high temperature (up to 200°C) at depths of less than 5 km (Chopra and Holgate, 2007; Ghori, 2008; Hot Dry Rocks Pty Ltd, 2010c).

The measured thermal conductivity ranges, from 0.64 to 4.97 W/m°C and modelled surface heat flow ranges from 24 to 95 mW/m². The lowest measured thermal conductivity (0.646 W/m°C) is within the Devonian Gneudna Formation, and the highest values (4.97 ± 0.24 W/m°C) are within the Carboniferous Quail Formation (Hot Dry Rocks Pty Ltd, 2010c).

Estimated heat flow values increase from south to north within the onshore parts of the Carnarvon Basin. Values are lowest (<60 mW/m²) in the Barrow and Exmouth sub-basins and increase to up to 95 mW/m² toward the onshore Peedamullah Shelf (Figure 1). Although these observations are based on a limited number of wells it indicates that the area north of Onslow has the highest temperatures (Figure 2). Given its shallow high-temperature areas the Carnarvon Basin has a high potential for geothermal energy development, provided other factors are also found favourable for developing HR and HSA

(Chopra and Holgate, 2007; Driscoll *et al*., 2009; Ghori, 2009; Ghori, 2010).

Presently, two companies are investigating geothermal resources in eight GEPs, awarded in February 2010 (Middleton and Bruce, 2010).

Officer Basin

The Officer Basin contains over 8 km of Neoproterozoic strata and has been explored sporadically for petroleum since the late 1960s. Yowalga 3 is the deepest (4197 m) of 16 wells within the basin.

Estimated equilibrium temperatures in 16 petroleum wells, measured thermal conductivity on 40 core samples from six wells, and 1D heat-flow modelling in 14 wells indicate regions of low temperature (up to 150°C) at depths of greater than 5 km (Hot Dry Rocks Pty Ltd, 2010d).

The measured thermal conductivity ranges from 1.25–5.54 W/m°C and modelled surface heat flow values from 33 to 95 mW/m². The lowest measured thermal conductivity is within the Cretaceous Samuel Formation (1.25 ± 0.03 W/m°C) from BMR Browne 1, and the highest values are within the Neoproterozoic Hussar Formation (5.54 ± 0.11 W/m°C) in GSWA Empress 1A (Hot Dry Rocks Pty Ltd, 2010d).

Generally the estimated heat flow values increase from the deep basin centre to the basin margins. The lowest value (<60 mW/m²) is observed in the eastern Gibson, Yowalga, and northern Lennis areas (Figure 1). These data indicate that in most of these locations temperatures are lower, i.e. 150°C at depths greater than 5 km (Figure 2; Hot Dry Rocks Pty Ltd, 2010d).

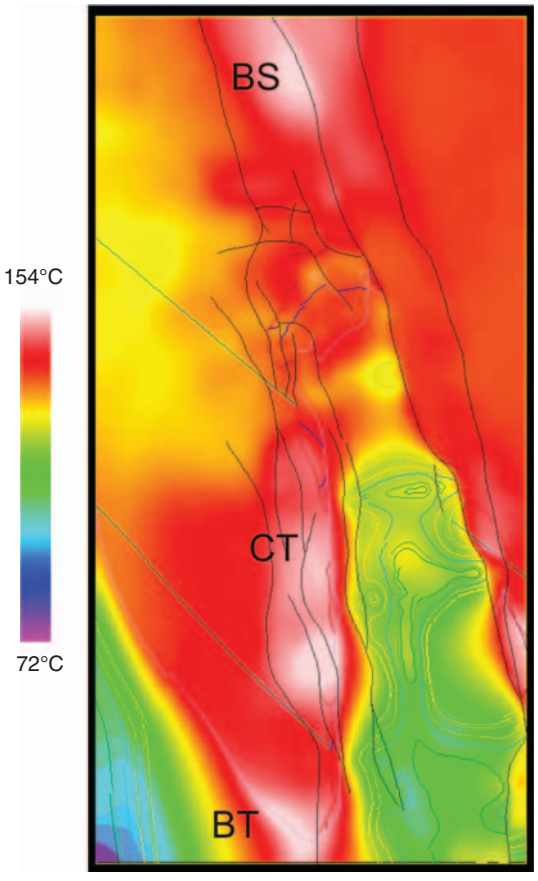

Fig. 3. *Temperatures at 4 km below sea level, computed from 3D heat-flow modelling. Highest temperatures are computed in the vicinity of BS (Bookara Shelf), CT (Coomallo Trough), and BT (Beermullah Trough), after Gibson* et al. *(2010).*

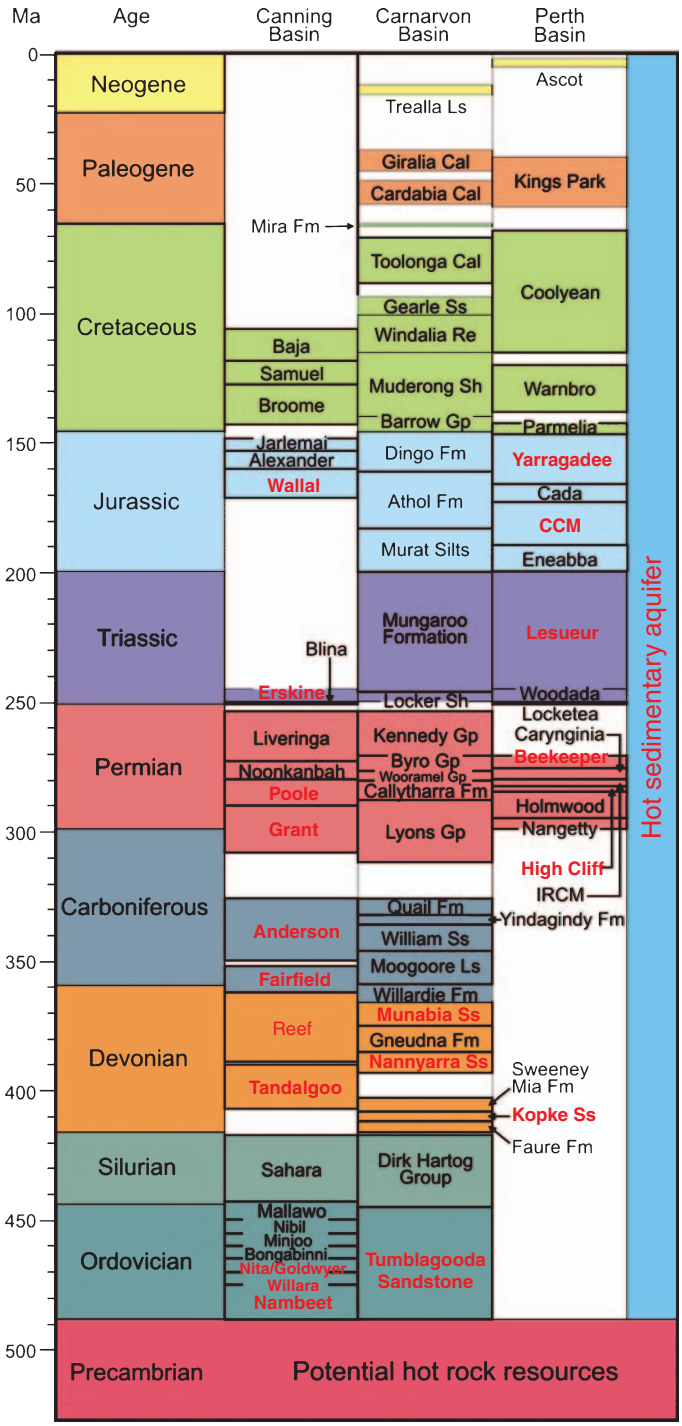

Fig. 4. *Generalised time-stratigraphy of the Carnarvon, Canning, and Perth basins, and potential geothermal resources (after Ghori, 2009).*

Perth Basin

GSWA initiated the search for geothermal energy in the early 1980s and recognised the potential of low temperature hydrothermal resources of up to 85°C at depths of less than 2 km

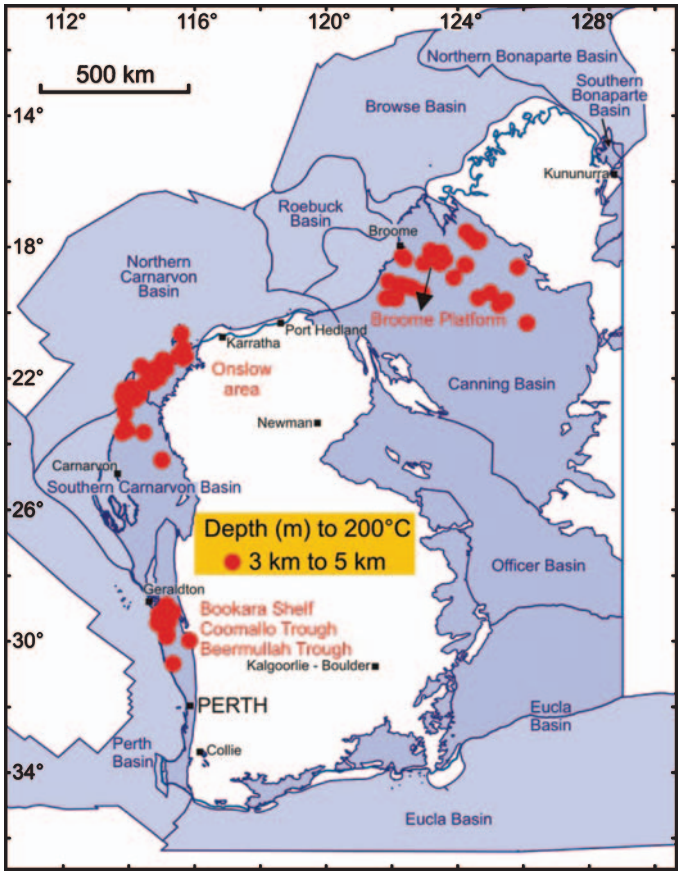

Fig. 5. *Location of wells with 200°C within depths between 3 km and 5 km, within the Carnarvon, Canning, and Perth basins.*

(Bestow, 1982). Geothermal exploration and exploitation was formalized in 2008, after a two-decade long break (Ghori, 2009). Presently, the Perth Basin is the most attractive target for geothermal energy research, exploration and development with six companies and two research institutions exploring in 31 GEPs (Middleton and Bruce, 2010).

Estimated equilibrium temperatures in 289 petroleum wells, measured thermal conductivity on 36 core samples from 14 wells, 1D heat flow modelling of 162 wells, and 3D geological and heat flow modelling of the northern Perth Basin identified regions of high temperature (>150°C) at depths of less than 4 km (Chopra and Holgate, 2007; Hot Dry Rocks Pty Ltd, 2008; Ghori, 2008; Gibson *et al.*, 2010).

The measured thermal conductivity ranges from 1.33 to 7.01 W/m°C and modelled surface heat-flow ranges from 30 to 140 mW/m². The lowest measured thermal conductivity (1.30 ± 0.11 W/m°C) is within the Permian Rosa Brook Coal Measures in Sue 1 and the highest values are within the Jurassic Cadda Formation (4.55 ± 0.86 W/m°C) in Gingin 1 (Hot Dry Rocks Pty Ltd, 2008).

The estimated heat flow values are lower in the south (Bunbury Trough) and increase up to 90 mW/m² north of Eneabba. The highest heat flow values have been modelled at Dongara 26 (116 mW/m²), and lowest (30 mW/m²) at Narkarino 1 (Figure 1). Calculated high temperatures from 3D heat-flow modelling are recognised at the vicinity of Coomallo and Beermullah troughs, Bookara Shelf, and north of Moora (Figure 3).

New temperature and heat flow data indicate that northern parts of the Perth Basin have the highest temperatures and shallow basement, within 5 km depth (Figure 2 and 3), provided other factors are also found favourable for developing HR and HSA (Hot Dry Rocks Pty Ltd, 2008; Ghori, 2008; Gibson *et al.*, 2010).

Stratigraphy and potential geothermal resources of the Carnarvon, Canning, and Perth Basins are summarised in Figure 4, and location of wells where depth to 200°C is between 3 km and 5 km in Figure 5.

Conclusions

The Coomallo and Beermullah troughs, Bookara Shelf, and the area north of Moora in the Perth Basin; the Broome Platform in the Canning Basin, and areas north of Onslow in the Carnarvon Basin have favourable temperatures with shallow basement for geothermal exploration. The estimated temperatures in many wells of the Canning, Carnarvon, and Perth basins are up to 100°C within a depth of 3 km for hot sedimentary aquifers (HSA) resources and up to 200°C within a depth of 5 km for hot rock (HR) resources. The Perth Basin is the most attractive target with its well-developed infrastructure and commercial markets.

Acknowledgments

This paper is published with the permission of the Director, Geological Survey of Western Australia.

References

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

Chopra, P. N., and Holgate, F., 2007, Geothermal energy potential in selected areas of Western Australia, a consultancy report by Earthinsite.com Pty Ltd, Western Australian Geological Survey, Statutory petroleum exploration report, G31888 A1, unpublished.

Driscoll, J. P., Mortimer, L., Waining, B., Cordon, E., and Beardsmore, G. R., 2009, Geothermal energy potential in selected areas of Western Australia (Canning Basin), Hot Dry Rocks Pty Ltd report prepared for the Department of Mines and Petroleum, Western Australia, Western Australian Geological Survey, Statutory petroleum exploration report, G31888 A3, unpublished.

Ghori, K. A. R., 2008, Perth Basin's geothermal resources: in *Proceedings of the Sir Mark Oliphant International Frontier of Science and Technology Australian Geothermal Energy Conference*, edited by Hal Gurgenci and Anthony Budd, Geoscience Australian, Record 2008/18, p. 55–61.

Ghori, K. A. R., 2009, Petroleum data: leading the search for geothermal resources in Western Australia: *Australian Petroleum Production and Exploration Association Ltd. Journal* **2009**, 365–379.

Ghori, K. A. R., 2010, New heat flow data aids exploration in the Canning Basin: *Australian Petroleum Production and Exploration Association Ltd. Journal* **2010**, 411–424.

Gibson, H., Bonet, C., Seikel, R., and Hore, S., 2010, 3D geological model building, and 3D temperature and heat flow calculation of the northern Perth Basin: Geological Survey of Western Australia, Record 2011/16, 76 pp.

Hot Dry Rocks Pty Ltd, 2008, Geothermal energy potential in selected areas of WA (Perth Basin), a report prepared for the Department of Industry and Resources, Western Australia, Geological Survey of Western Australia, Statutory petroleum exploration report G31888 A2, unpublished.

Hot Dry Rocks Pty Ltd, 2010a, Geothermal energy potential in selected areas of Western Australia (Bonaparte Basin), Western Australian Geological Survey, Record 2010/24, 27 pp.

Hot Dry Rocks Pty Ltd, 2010b, Geothermal energy potential in selected areas of Western Australia (Browse Basin), Western Australian Geological Survey, Record 2010/23, 24 pp.

Hot Dry Rocks Pty Ltd, 2010c, Geothermal energy potential in selected areas of Western Australia (Carnarvon Basin), Western Australian Geological Survey, Record 2010/25, 65 pp.

Hot Dry Rocks Pty Ltd, 2010d, Geothermal energy potential in selected areas of Western Australia (Officer Basin), Western Australian Geological Survey, Record 2010/22, 65 pp.

Middleton, M., and Bruce, R., 2010, State awards of Geothermal Exploration Permits: *Petroleum in Western Australia, Department of Mines and Petroleum, Digest,* September 2010, 30–33.