Geothermal Simulation, Perth Basin, Western Australia

[1]Ghori, K.A.R. and [2]Gibson, H*.
Ameed.Ghori@dmp.wa.gov.au and helen@intrepid-geophysics.com
[1]Geological Survey of Western Australia, Department of Mines and Petroleum, East Perth, Western Australia.
[2]GeoIntrepid, 2/1 Male Street, Brighton, Victoria, 3186, Australia.

One-dimensional (1D) and three-dimensional (3D) thermal modelling indicates that the highest geothermal anomalies in the Perth Basin occur in the Coomallo and Beermullah Troughs, Bookara Shelf, and north of Moora township. The modelled temperatures and recorded temperatures are up to 154 and 150°C at 4 km, respectively. These are based on temperatures in 253 petroleum wells, 1D modelling of 162 wells, and temperature simulation directly from a 3D geology model centred on the Dongara to Eneabba region (which the earlier 1D modelling indicated as having the highest simulated and recorded temperatures within the Perth Basin).

Introduction

Petroleum wells and water bores drilled in the search for petroleum and groundwater resources provide first-hand information on subsurface temperatures and geology, which aids evaluation of geofluid systems of the Perth Basin's petroleum, groundwater and geothermal systems.

Exploration for geothermal energy in Western Australia was formalized in January 2008, with the first geothermal acreage released in the Perth Basin. Presently, the Perth Basin is the state's most attractive target for geothermal energy research, exploration, development and utilization. Six companies and two research institutions hold 31 Geothermal Exploration Permits (GEPs). The Perth Basin has favourable geology, well-developed infrastructure and proximity to commercial markets (Fig. 1).

Previous multi-disciplined published work includes that of: Crostella (1995), Mory and Iasky (1996), Crostella and Backhouse (2000), Owad-Jones and Ellis (2000) addressing petroleum geology; and work by Thorpe and Davidson (1991), and Davidson (1995) investigating groundwater resources. Studies addressing geothermal energy potential in the Perth Basin include those by: Bestow (1982), Chopra and Holgate (2007), Ghori (2007, 2008a, 2008b, 2009), Hot Dry Rocks Pty Ltd (2008), and Gibson et. al. (2010).

Geology

The Perth Basin is a northerly elongated rift-trough extending along the west coast of Australia (Fig. 1); the major tectonic units include the Darling Fault and Dandaragan Trough in the east and the offshore Abrolhos and Vlaming sub-basins in the west. The Dandaragan Trough is the major depocentre containing up to 12 km of sedimentary succession, predominantly Permian to Cretaceous in age, with only a veneer of younger rocks (Fig. 2).

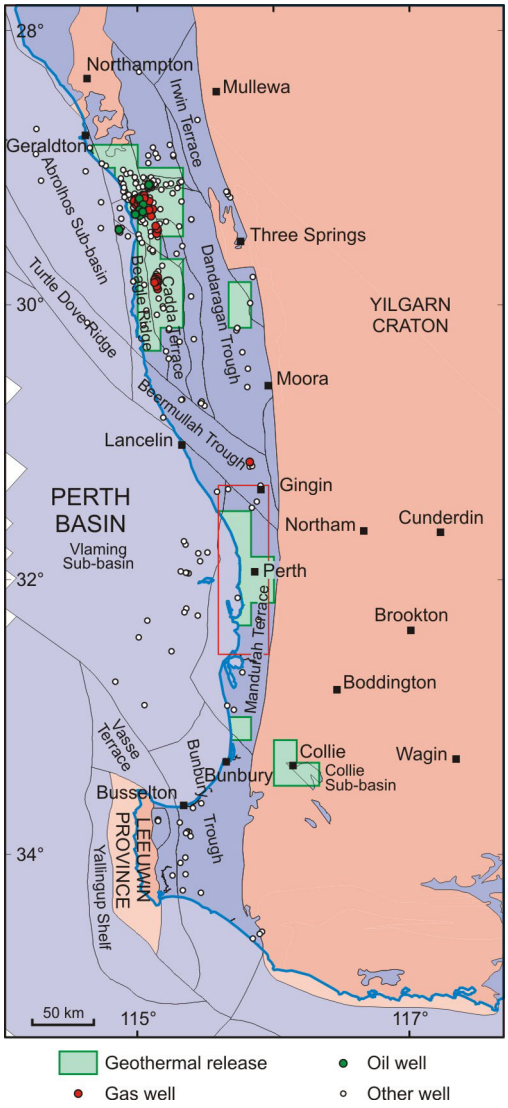

Figure 1. Perth Basin Map showing petroleum wells and Geothermal Exploration Permits.

Approach

GSWA aims to develop a reliable subsurface dataset of temperatures, basement depths, rock types and in-situ stress conditions to analyse geothermal and petroleum systems of the Perth Basin. First, raw temperature data was compiled from 253 petroleum wells and 47 artesian monitoring water-bores. Temperature gradients were then calculated and mapped, including an evaluation of data quantity and quality, ready for follow-up interpretation studies. Next, 253 wells were further assessed for data quality, and

equilibrium temperatures were calculated for the purpose of 1D heat-flow modelling of 162 selected wells (Chopra and Holgate, 2007; Hot Dry Rocks Pty Ltd, 2008). Finally, 3D geological, temperature and heat-flow modelling were undertaken by Gibson et. al. (2010) for the northern Perth Basin were the highest predicted temperatures of the basin occur.

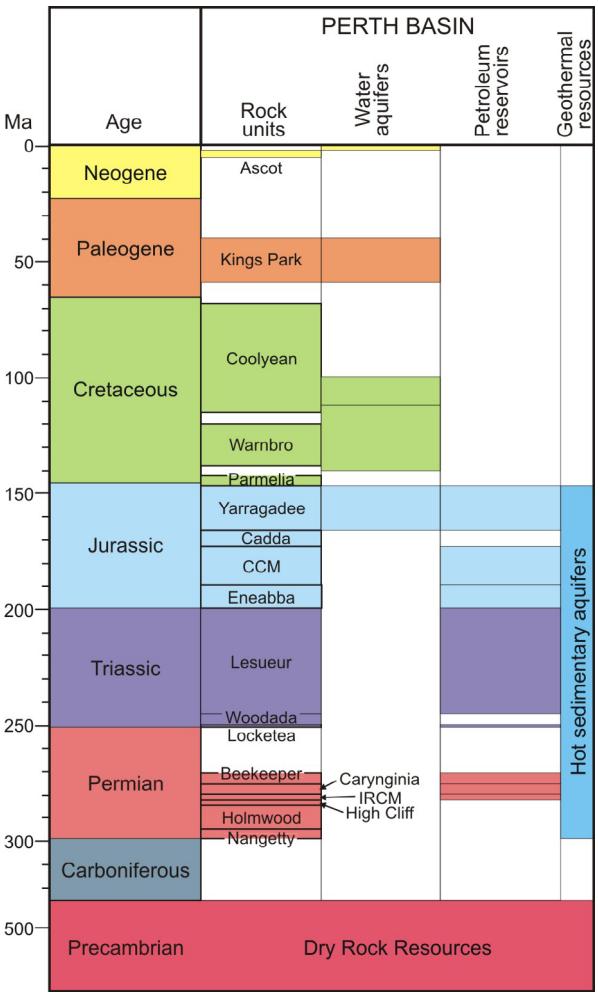

Figure 2. Generalised time-stratigraphy showing ground water and petroleum reservoirs, and potential geothermal resources.

Temperatures

Temperatures from the 253 petroleum wells are mostly from maximum bottom hole temperatures (BHTs) recorded during logging, with limited temperatures from drill stem tests (DSTs), and production tests (PTs). BHTs are lower than equilibrium temperatures and require more positive corrections compared to temperatures from DSTs and PTs. Horner and semi-log plots were used to estimate equilibrium temperatures for wells where sufficient data were available to apply these corrections. Ground surface temperatures are from the Australian Bureau of Meteorology (Chopra and Holgate, 2007; Hot Dry Rocks, 2008). The estimated equilibrium temperatures are up to 160ºC between 3.5 and 4.5 km (Fig. 3a). Normal and higher geothermal gradients are found at depths <2.8 km, due to thick sedimentary cover of low thermal conductivity rocks. Normal and lower gradients occur in deeper wells, down to 4.8 km (Fig. 3b).

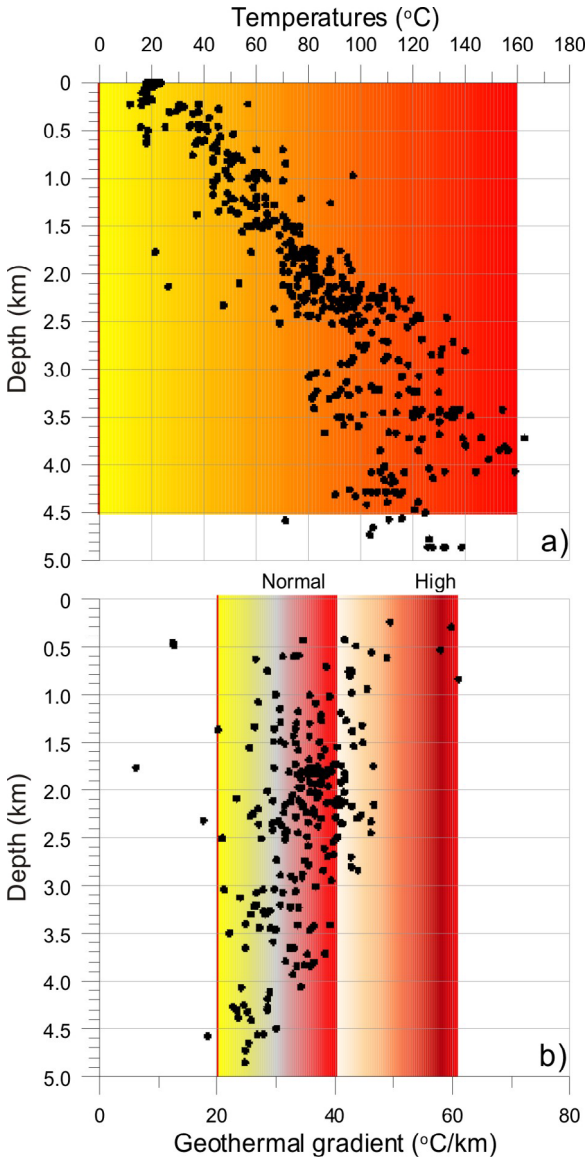

Figure 3. Recorded: a) temperatures, b) geothermal gradients versus depth.

Heat-flow modelling

1D conductive heat flow modelling was performed for 162 wells for the purpose of estimating temperatures at depth. Heat flow outcomes ranged from 30 to 140 mW/m², with values <65 mW/m² estimated in the Bunbury Trough, and values >90 mW/m² estimated towards the Eneabba and Dongara region (Hot Dry Rocks Pty Ltd, 2008). Estimated temperatures at 5 km are up to 250 ºC in the north, and as low as 110 ºC in the south (Fig. 4). This confirms the north Perth Basin, where basement is at comparatively shallow depths, has the highest heat flows and temperatures. The north Perth Basin also hosts the oil and gas fields discovered within the basin.

3D conductive heat flow modelling (Gibson el al, 2010) was performed to characterize the

geothermal anomaly in the Dongara to Eneabba region, where high temperatures occur at comparatively shallow depths.

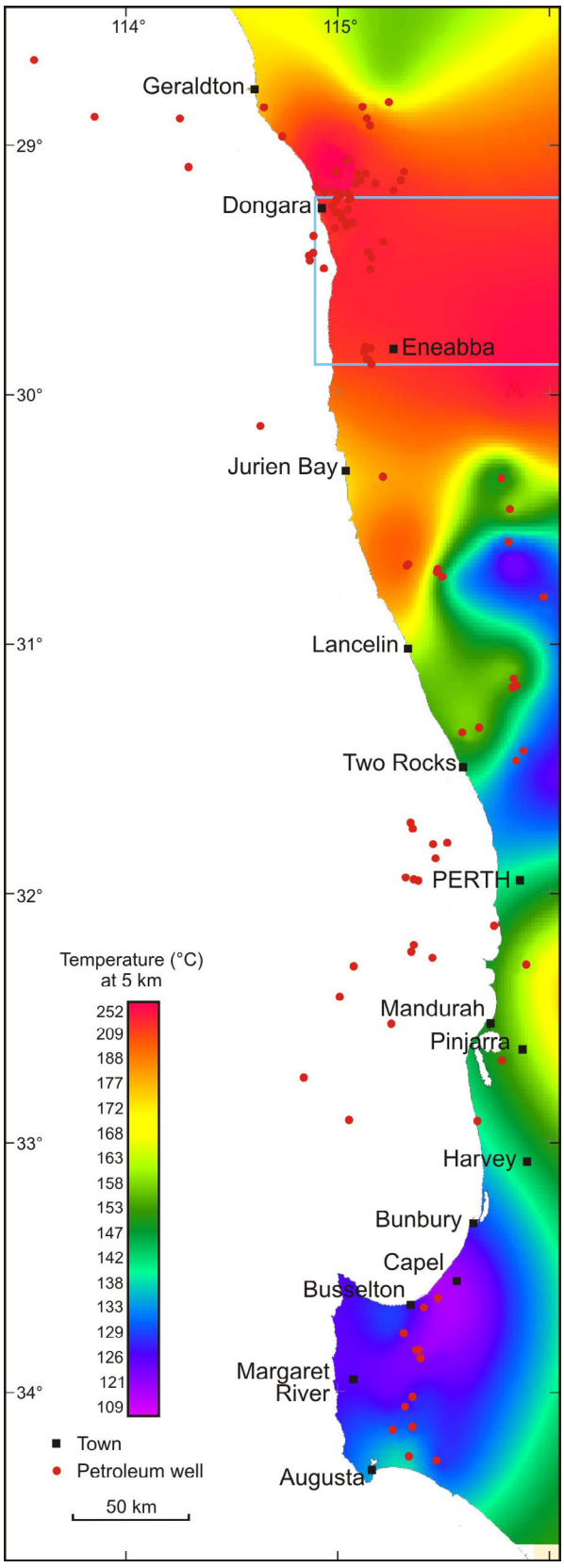

Figure 4. Shows the distribution of subsurface temperatures at 5 km, estimated from 1D heat-flow modelling (Hot Dry Rocks Pty Ltd, 2008).

3D geological, temperature and heat-flow modelling utilised constraints from previous GSWA studies by Mory and Iasky (1996), Chopra and Holgate (2007), and Hot Dry Rocks Pty Ltd (2008), including adopting formation tops and temperature data from 96 wells in the region.

First, a geological model for a 3D area about 140 km wide, 280 km long and 16 km deep was built, and later gridded to a low resolution constant cell size (X 1000; Y 1000; Z 100 m), and a high resolution cell size (X 500; Y 500; Z 50 m). These voxel models were basis on which 3D simulation of temperatures could be performed throughout a 3D grid, directly from the geology model. Following calibration in which measured BHT temperatures where validated, temperature outcomes ranged from 22 to 380 ºC, throughout the model including depths up to 15 km below SL.

3D modelling identified high-temperature anomalies on the Bookara Shelf in the north, the Coomallo Trough (central), and the Beermullah Trough in the south (Fig. 5). Across the Coomallo Trough temperatures range from ~100 to 154 ºC at 4 km (Fig. 5). Within the model depth-limits, estimated vertical heat flows range from 50 to 102 mW/m² (Fig. 6) and vertical temperature gradients range from 15 to 40 ºC/km (Fig. 7).

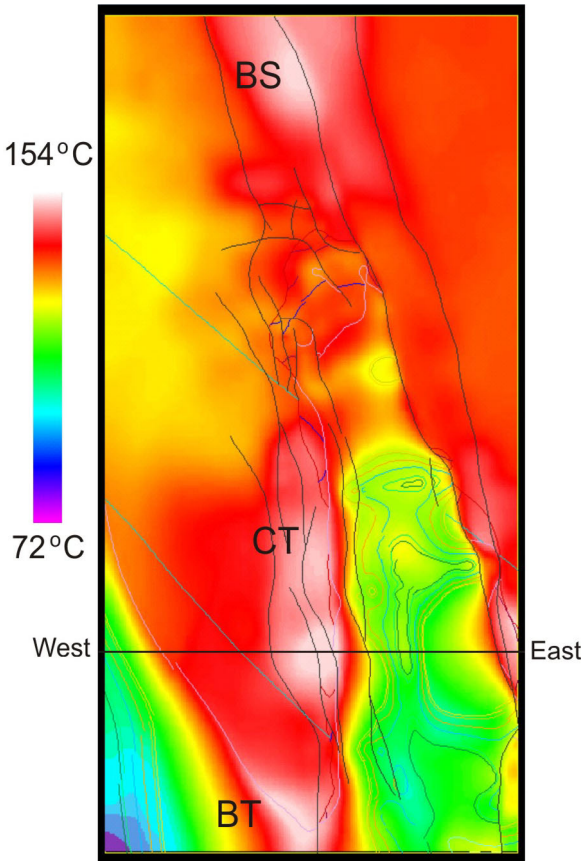

Figure 5. Estimated temperatures at 4 km below sea level derived from 3D modelling (BS = Bookara Shelf; CT = Coomallo Trough and BT = Beermullah Trough), from Gibson et. al. (2010).

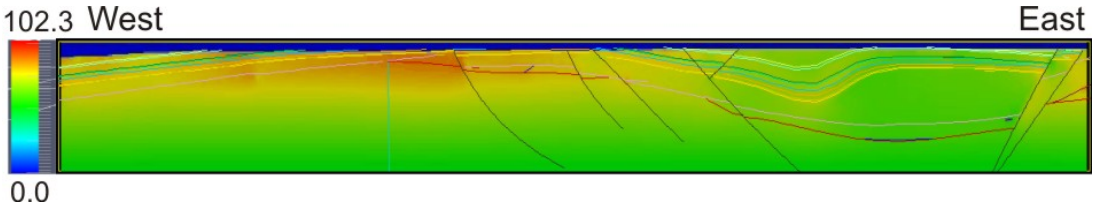

Figure 6. Modelled vertical heat flows across the Coomallo Trough range from 50 to 102 mW/m² (see fig. 5 for section location), from Gibson et al (2010).

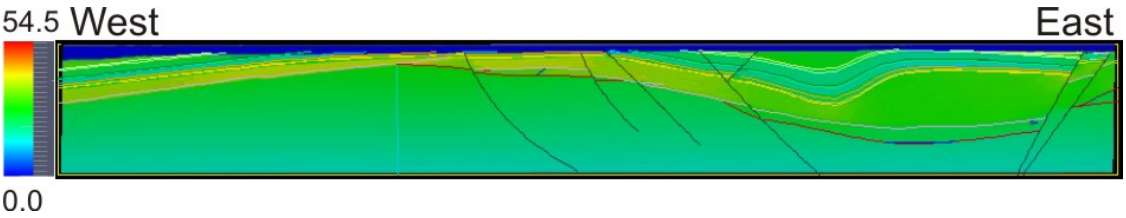

Figure 7. Modelled vertical temperature gradients across the Coomallo Trough range from 15 to 40ºC/km (see fig. 5 for section location), from Gibson et al (2010).

Conclusions

The Coomallo Trough, Beermullah Trough, Bookara Shelf, and north of Moora areas have the highest estimated temperatures within shallow locations, in the Perth Basin. The modelled 3D temperatures and the measured temperatures are up to 154 ºC and up to 150 ºC at 4 km, respectively. In conclusion, the northern Perth Basin has the best temperatures for direct and electric generation applications from its geothermal systems. It also has favourable geology, and well-developed infrastructure and commercial markets within reach.

Acknowledgments

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