Technical papers

The search for Western Australia's geothermal resources

by KAR Ghori

Introduction

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 (Fig. 1) — that from hydrothermal systems (hot geofluids) and from hot rocks (hot dry rocks). Low-temperature hydrothermal resources (~50°C) are already in use in Perth at Challenge Stadium and the Melville Aquatic Centre, and in Canberra at the Geoscience Australia building, using shallow hydrothermal resources. Medium-temperature hydrothermal resources (50–100°C) are in use in many places in the world, including Birdsville in Queensland. These hydrothermal resources are in use for both direct heating and cooling, as well as some electricity production. High-temperature hot rock resources are being tested 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. A 40 MW power plant is planned for development by the end of 2010, which could gradually be expanded to 500 MW by the end of 2015 (Fig. 2), if initial testing is successful.

For electricity generation, suitable temperatures for hot water and steam range from 120 to 370°C. In contrast, shallower reservoirs of lower temperature (21–149°C) can be used directly in health spas, greenhouses, fish farms and other industries, and in space-heating systems for homes, schools, and offices. Most sedimentary basins have low-temperature geothermal water for these direct uses.

Australia is tectonically stable and does not have geologically active areas characterized by volcanism, crustal rifting, and recent mountain building that typically host high-temperature hydrothermal provinces. However, there is potential for geothermal energy from known high heat-producing granites, usually referred to as hot dry rock (HDR) sources. Since 1970 research has been undertaken worldwide aimed at commercial utilization of the Earth's heat from hot rocks, using technology referred to as EGS (enhanced geothermal systems) that is applied to HDR sources so that energy can be extracted. Geothermal energy from hot rocks differs from the conventional hydrothermal energy process that produces power commercially in geologically active areas. To utilize hot dry rocks, EGS technology is used to pump water down an injection well to

Abstract

Australia is currently tectonically stable and lacks geologically active areas characterized by volcanism, crustal rifting, and recent mountain building that can host hydrothermal provinces attractive for geothermal energy. However, Australia has significant potential for geothermal energy from known high heat-producing granites, and is at the forefront of developing the technology to extract heat from hot rocks as an energy source, such as at the Habanero project in the Cooper Basin, South Australia.

In Western Australia, geothermal studies indicate the potential for geothermal resources from both hydrothermal and hot dry rock. Low-temperature reservoirs (65–85°C) at depths between 2000 and 3500 m are potential hydrothermal energy sources, with the best economic potential in the Perth Basin. Currently hot-rock resources are economic where the depth to 200°C is less than five kilometres. Petroleum wells in parts of the Canning, Carnarvon, and Perth Basins indicate this condition can be met, with high gradients measured in the greatest number of wells in the Carnarvon Basin. The extent and economic feasibility of these geothermal resources are presently unknown as previous studies were qualitative, rather than quantitative, and based on limited datasets. The search for geothermal energy in Western Australia is thus in its initial stages and a quantitative assessment requires systematic geological, hydrogeological, geophysical, and geochemical evaluation to further delineate these resources.

KEYWORDS: geothermal resources, energy, hydrothermal, hot rock, Western Australia, Canning Basin, Carnarvon Basin, Perth Basin

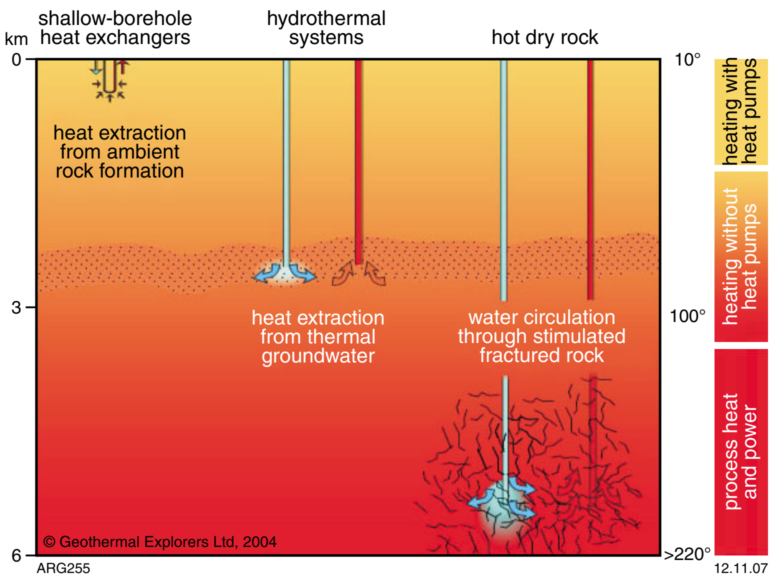

Figure 1. Types of geothermal resources from Earth's heat. Courtesy of Geothermal Explorers Ltd

hot basement rocks that may be insulated by a thick cover of sedimentary rocks. A connection is established between injection and withdrawal wells by means of hydraulic fracturing to develop a closed water-circulation system for extracting and transferring heat from hot rocks at depth to the surface. The available heat cannot be increased, but the permeability and water content can be enhanced. The extracted hot fluids are used at the surface for generating electricity (Fig. 2). Australia is at the forefront of testing the commercial viability of extracting heat energy by EGS — at the Habanero project in the Cooper Basin.

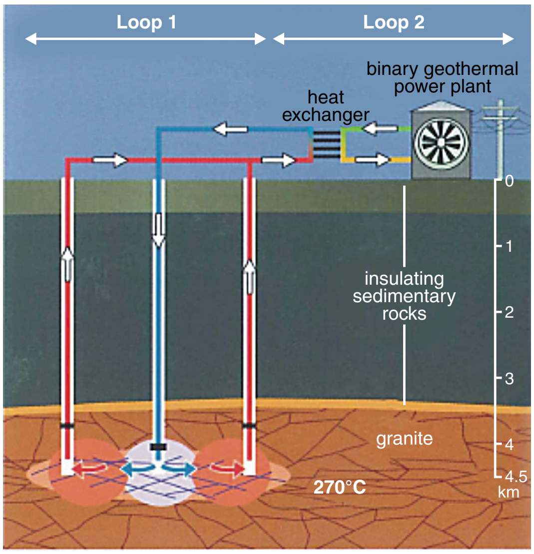

Figure 2. Concept for electricity generation from hot rock at Geodynamics Ltd's Habanero project, Cooper Basin, South Australia. Loop 1 includes injection and production wells to circulate water for extraction and transfer of heat from hot rocks at depth to the surface. Loop 2 includes a surface heat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

At present, the only geothermal energy being used for electricity generation in Australia is from a 120 kW geothermal energy plant located in Birdsville, Queensland. In the last few years, investment into exploration for geothermal energy sources and into technologies for producing geothermal energy from hot rocks and young (about 4000–5000 years old) hot hydrothermal water has increased dramatically, partially stimulated by a Commonwealth Government subsidy scheme.

Australia's most significant geothermal resources suitable for electricity generation appear to be from hot rocks, with the highest potential in the Cooper Basin followed by the McArthur, Otway, Carnarvon, Murray, Perth, Canning, East Queensland, and Sydney Basins (Somerville et al., 1994).

Conversion of geothermal energy into power is economically feasible only when three factors can be satisfied:

- the resource is located at shallow depths, usually less than 3 km, but possibly as deep as 7 km;
- porosity and fracture permeability are sufficient to produce large quantities of thermal water, either naturally or by enhanced geothermal system technologies; and
- 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 data are used to locate potential geothermal resources for exploratory drilling. Exploration for geothermal energy has some similarities to petroleum exploration, but with certain key differences (Narayan et al., 1998a) such as high-temperature logging and reservoir stimulation.

Western Australia

The Petroleum Amendment Bill 2007, recently passed by the Western Australian Parliament, amends the Western Australian Petroleum Act 1967 to provide for licensing of commercial geothermal exploration and development in Western Australia. Enactment of this bill will initiate calls for licence applications in the first quarter of 2008.

Areas of high heat flow in Australia, recognized by unusually high geothermal gradients recorded in petroleum exploration wells, were identified by Chopra and Holgate (2005). Other relevant publications on Australian geothermal energy that include Western Australia are: Sass (1964), Sass et al. (1976), Cull (1977, 1979, 1982), Cull and Denham (1978), Narayan et al. (1998b), and Chopra (2005).

GSWA has undertaken two specific studies in the search for geothermal energy in Western Australia, utilizing hydrothermal (Bestow, 1982) and hot rock (Chopra and Holgate, 2007) systems. Bestow (1982) mainly focused on low-temperature geothermal reservoirs up to 100°C, applying the available data on heatflow, geothermal gradient, and hydrogeology to the geological framework of the Yilgarn Craton, and the Eucla, Officer, Canning, Carnarvon, and Perth Basins. The study was 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 study commissioned by GSWA (Chopra and Holgate, 2007) was on high-temperature geothermal reservoirs up to 200°C. The aim of the study 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 rocks. Further, this study developed a reliable dataset (Fig. 3) of subsurface temperatures, basement depths, and rock types, and in situ stress conditions for future studies. The number of wells included in Chopra and Holgate's (2007) study, and wells currently under study or yet to be evaluated, are summarized in Figure 4.

The Chopra and Holgate (2007) study has evaluated the quality and quantity of available subsurface temperature data from 273 petroleum exploration wells in the Canning (100), Carnarvon (93), and Perth Basins (80), and extracted temperature data from more than 580 wells yet to be evaluated (Fig. 4). The purpose was to calculate reliable true formation temperatures to estimate the equilibrium geothermal gradient for each well. Higher than normal geothermal gradients recorded in many wells provided the first indication of high heat flow (Fig. 5). In Australian basins, the highest crustal temperatures are usually associated with local high-heat production under rocks of low thermal conductivity. At present, detailed geochemical information on the basement in the studied wells is not available. 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 (Fig. 6).

As well, the study evaluated the quality and quantity of stress data available from engineering measurements (e.g. hydraulic fracture and over-coring), earthquake focal mechanisms, borehole breakout, and drilling-induced tensile fractures (DITF), as well as recent geological indicators (e.g. fault slip). These data are available from the Australian Stress Map, which is the most recent compilation of Australian stress data and is a major source of regional stress data for the current World Stress Map (Hillis and Reynolds, 2000; Reinecker et al., 2005).

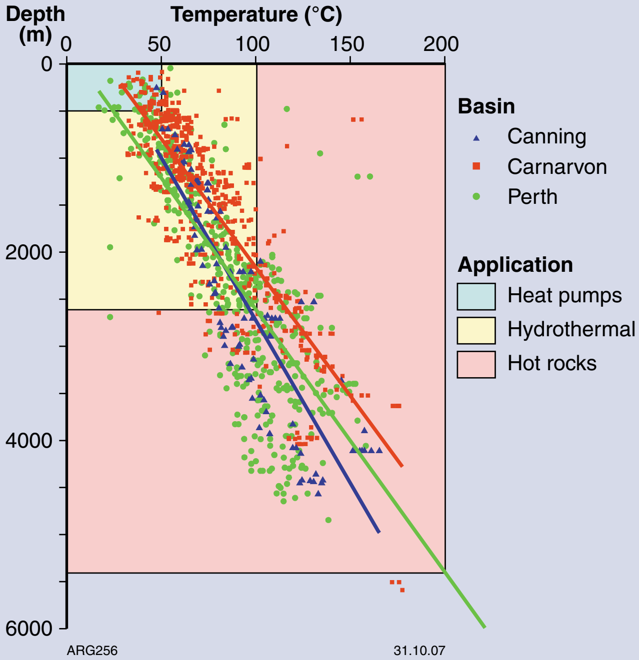

Figure 3. Plot of subsurface temperature versus depth from selected wells in the Canning, Carnarvon, and Perth Basins, showing temperature increase with depth, and temperature range for possible application of geothermal energy

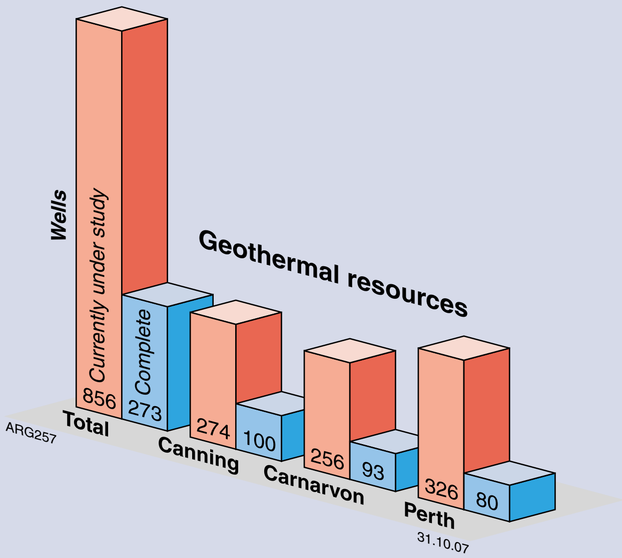

Figure 4. Wells completed (blue) by Chopra and Holgate (2007) and the wells currently under study (orange) for the evaluation of geothermal resources from hot rocks

Table 1. Wells in the Canning, Carnarvon, and Perth Basins showing total depth, estimated gradient, basement depth, and wells 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)	Estimated basement depth (m)	Estimated depth to 200°C
Canning	Canopus 1	1 779	4.74	2 000	4 937
	Nuytsia 1	1 350	4.20	3 000	4 778
	Philydrum 1	1 608	3.61	6 000	4 827
	Sundown 1	2 736	3.24	2 500	5 546
	Sundown 2	1 965	3.28	2 500	4 896
	Sundown 3	1 645	3.53	2 500	4 137
	Whitewell 1	1 754	4.11	2 500	4 960
	Wood Hills 1	1 978	3.97	2 500	4 793
Carnarvon	Airey Hill 1	1 037	3.43	5 300	4 904
	Bullara 1	1 300	4.52	7 600	3 825
	Chinty 1	1 673	4.42	5 000	4 255
	Hope Island 1	1 426	3.87	7 000	4 353
	Lefroy Hill 1	1 512	3.78	6 500	4 011
	Ningaloo 1	1 228	3.54	7 500	3 729
	Parrot Hill 1	1 287	5.56	8 300	3 273
	Roberts Hill 1	1 265	4.70	8 300	3 871
	Rough Range 11	1 168	4.78	8 300	3 341
	Sandalwood 1	1 350	4.10	7 500	4 594
	Sandy Point 2	1 678	3.35	7 500	4 372
	Talandji 1	1 488	4.40	5 000	4 249
	Trealla 1/1A	1 496	4.11	8 000	3 422
	Wingette 1	1 439	4.70	8 000	4 184
Perth	Depot Hill 1	2 473	4.40	3 000	4 505
	North Yardanogo 1	2 387	3.20	3 000	4 871
	Warradong 1	3 717	3.10	4 000	4 691
	Woodada 02	2 460	4.00	3 500	4 279
	Woodada 05	2 808	3.60	3 500	4 878
SOURCE:	Chopra and Holgate (2007)				

For the Perth region as a whole, stress data collected in situ are available from 43 locations at different depths and from different sources, but for the Perth Basin portion, the data are exclusively from borehole breakouts recorded in 20 petroleum exploration wells. The recorded maximum horizontal stress orientations are E–W across the Perth region (Reynolds and Hillis, 2000); these observations are highly relevant for assessing the HDR prospectivity of the basin, because maximum horizontal stress is favourable.

The majority of available stress data (119 locations) collected in situ for the Carnarvon Basin are from offshore petroleum wells, and are derived from borehole breakouts. No information on stress magnitudes is currently available, so the stress regime remains unconstrained. Relatively few in-situ stress data are available for the Canning Basin, totalling only 13 onshore and one offshore data points. The suitability for HDR development in the Carnarvon and Canning Basins requires further study.

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 (Table 1, Figs 5, 6).

Geochemical analyses of basement rocks are required to assess the heat-generation capacity of rocks, as small differences in the concentrations of

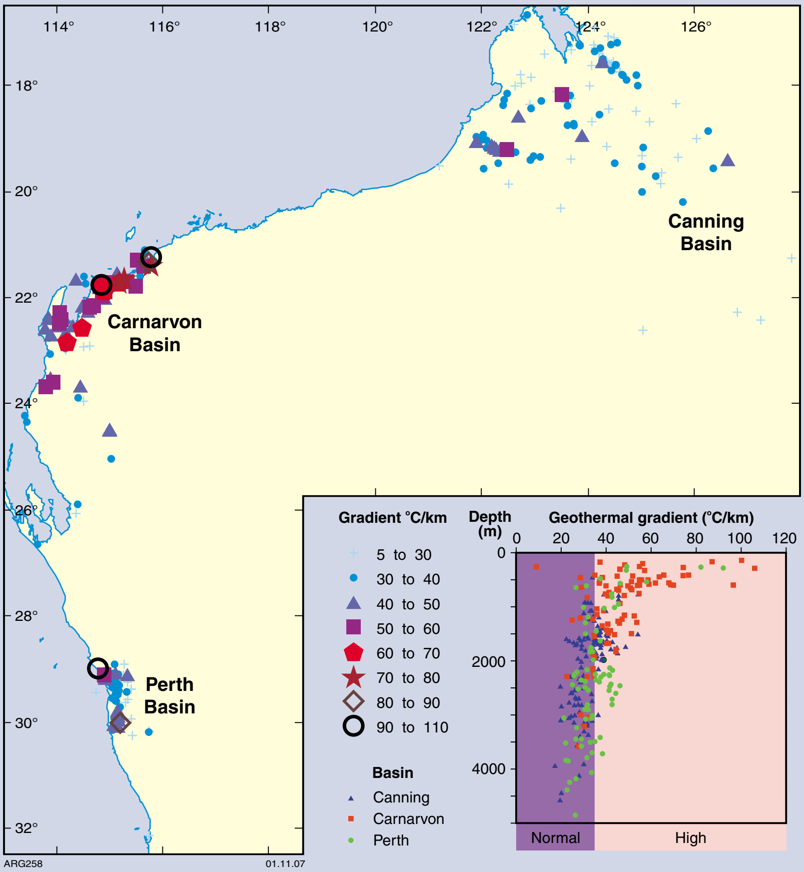

Figure 5. Present-day geothermal gradients of selected petroleum exploration wells in the Canning, Carnarvon, and Perth Basins

thorium and uranium can have quite significant impacts on heat-generation capacity, whereas large variations in potassium concentration have only a second order effect on the heat-generation capacity.

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. Given that this stress orientation is compatible with both strike-slip and overthrust failure, an understanding of relative stress magnitudes is also required for assessing the uncertainty in the application of EGS technology.

Conclusions

Western Australia is poised at the beginning of a major expansion in exploration for hot dry rock geothermal resources. Amendments to the Petroleum Act 1967 to grant rights for geothermal energy exploration and development will facilitate growth of a new industry in Western Australia — one having the potential to broaden the State's energy base.

Pre-competitive geoscience information relevant to geothermal exploration largely comes from petroleum exploration wells. These are generally in clusters, sparsely distributed at basin scale. Whereas temperature measurements from petroleum well logs are reasonably reliable, in-situ stress measurements, required for applicable EGS technology, are uncertain in the three basinal areas so far examined. Much more reliable geoscience information is required to assist private sector exploration for geothermal resources in Western Australia, most of which will be focused near energy-demand centres or near existing major power-transmission routes.

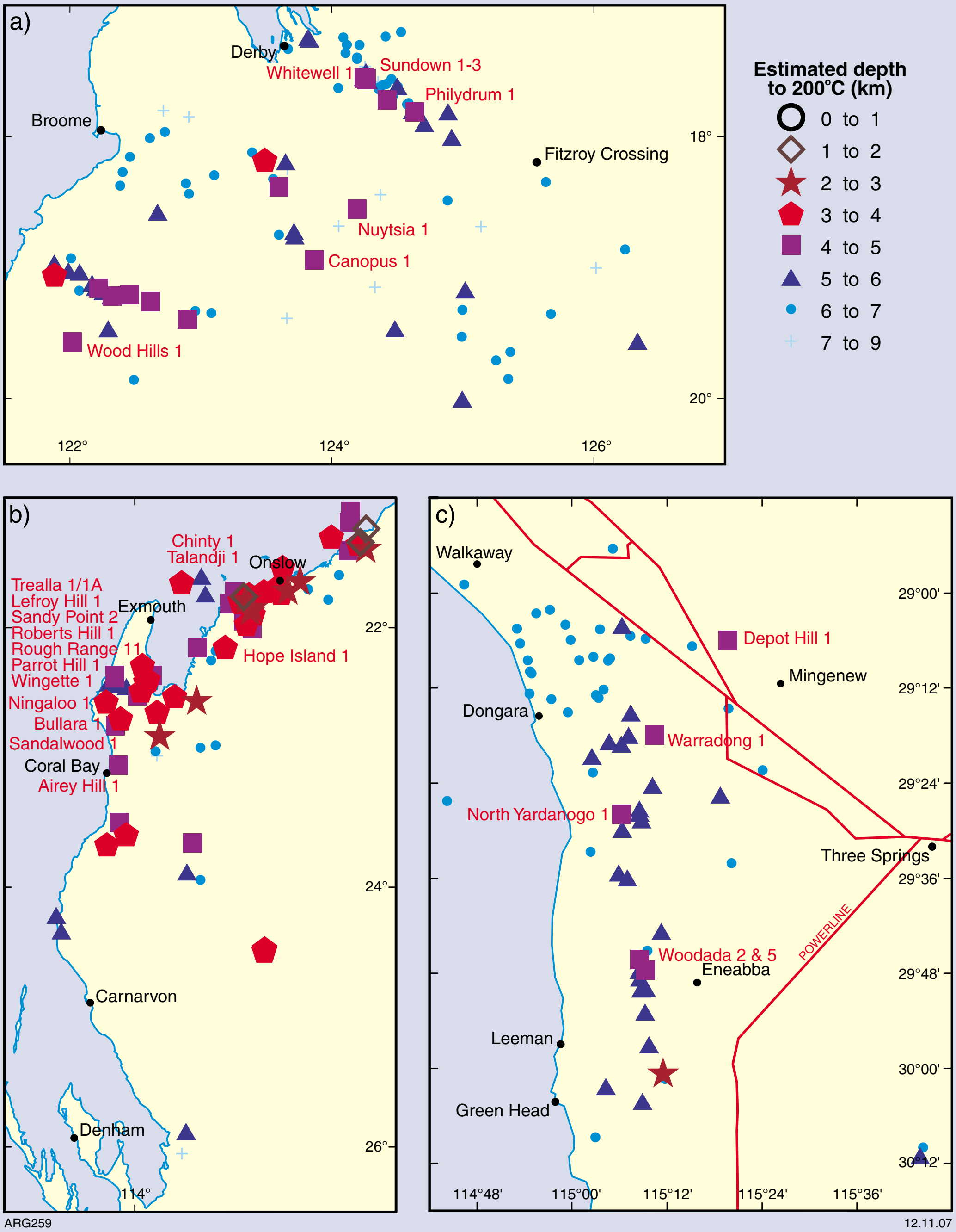

Figure 6. Wells with estimated depth to 200°C shallower than 5 km: a) Canning Basin; b) Carnarvon Basin; c) Perth Basin

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