Geothermal studies in Western Australia

by

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Geothermal energy includes thermal or electrical power produced from the heat contained in the Earth. The Earth's heat is stored in both rocks and geofluids. Geofluid heat is from water-dominated hydrothermal resources, oil- and gas-associated hydro-geothermal resources, and methane-dominated high-pressure geothermal resources. These resources have potential to be commercially used to produce electricity and for direct applications. The hot rock resources are also referred to as petrothermal, hot dry rock, or hot fractured rock, which are widely distributed and the most abundant source of geothermal energy. Low-temperature or low-enthalpy resources are suitable for direct heat use (≤100°C), whereas medium-enthalpy (100°C to 200°C), and high-enthalpy (≥200°C) are suitable for both electricity generation and direct-heat use.

A new phase in the search for energy from geothermal resources in Western Australia started in January 2008, with the amendment of the *Petroleum Act 1967* to *Petroleum and Geothermal Energy Resources Act 1967*. The first geothermal acreage was released in the Perth Basin (Fig. 1), and the second within the Carnarvon Basin*. Petroleum data (mostly from onshore wells) generated from petroleum exploration since the 1950s are the basis for geothermal studies by the Geological Survey of Western Australia (Fig. 1). The first study was done in the 1980s (Bestow, 1982) with a long gap until 2006 when studies for potential hot-rock resources commenced (Chopra and Holgate, 2007; Hot Dry Rock Pty Ltd, 2008).

The geothermal systems in Western Australia are classified as low-enthalpy hydro-geothermal and petrothermal systems related to regional heat flow. The temperature of the reservoirs ranges from 65°C to 85°C at depths between 2 km and 3.5 km (Bestow, 1982), and the water is heated by a more or less normal geothermal gradient. Bestow (1982) concluded that geothermal and hydrogeological conditions for developing a geothermal resource for both direct use and electricity generation are present.

Since 2006, the focus has been on high-enthalpy petro-thermal resources that are currently economic, where the depth to 200°C is less than 5 km with favourable local stress conditions. Such conditions are potentially indicated by the study of 443 petroleum wells in parts of the Canning (100 wells), Carnarvon (90 wells), and Perth Basins (253 wells). The Carnarvon Basin has the greatest number of wells with a high present-day geothermal gradient (estimated depth to 200°C is less than 5 km), followed by the Canning and Perth Basins (Chopra and Holgate, 2007). Heat-flow modelling of 170 Perth Basin wells is constrained by 30 new measured thermal conductivities and indicates a surface heat flow from 30–140 mW/m^2, with a median interpretative value of 76.5 mW/m^2. This is higher than the Australian median value of 64.5 mW/m^2. The heat flow increases, and depth to 200°C decreases, from south to north, with highest heat flow and shallowest depth to 200°C around the Eneabba area (Hot Dry Rocks Pty Ltd, 2008). All Phanerozoic basins have minimal associated igneous activity, with the youngest volcanic activity primarily associated with breakup of Gondwana in the early Cretaceous.

Present-day stress is an important geological control on the development of artificially created heat reservoirs, exchangers, or engineered water pathways in petrothermal systems using enhanced geothermal system (EGS) technology. Available stress data are mostly from the northern Perth Basin, followed by 13 locations in the Canning Basin, and only offshore wells in the Carnarvon Basin (Chopra and Holgate, 2007; Heidbach et al., 2008). The Perth Basin is characterized by an east–west maximum horizontal stress orientation, and the Carnarvon Basin also has maximum horizontal stress oriented broadly east–west, but the orientation rotates northeast–southwest in the Canning and Bonaparte Basins (Hillis and Reynolds, 2000; King et al., 2008; Heidbach et al., 2008).

The Northern Carnarvon is the main oil and gas producing basin in Western Australia, with more than 984 petroleum wells to a maximum depth of 9 km. In the Southern Carnarvon Basin subsurface data are limited to 258 wells, mostly onshore. Within the Northern Carnarvon Basin, the highest present-day surface heat flow (90 mW/m^2) is near Barrow Island and the lowest (17 mW/m^2) over the Exmouth Plateau Arch (Swift et al., 1988). No such studies have been undertaken for the Southern Carnarvon Basin. The average recorded geothermal gradient is 35°C/km in the Exmouth Sub-basin, 32°C/km in the Merlinleigh Sub-basin, and 31°C/km over the Peedamullah Shelf. This shows a general increase of geothermal gradient from the

* For ease of reference, Carnarvon Basin in this paper refers to the Southern Carnarvon and the inner Northern Carnarvon Basins

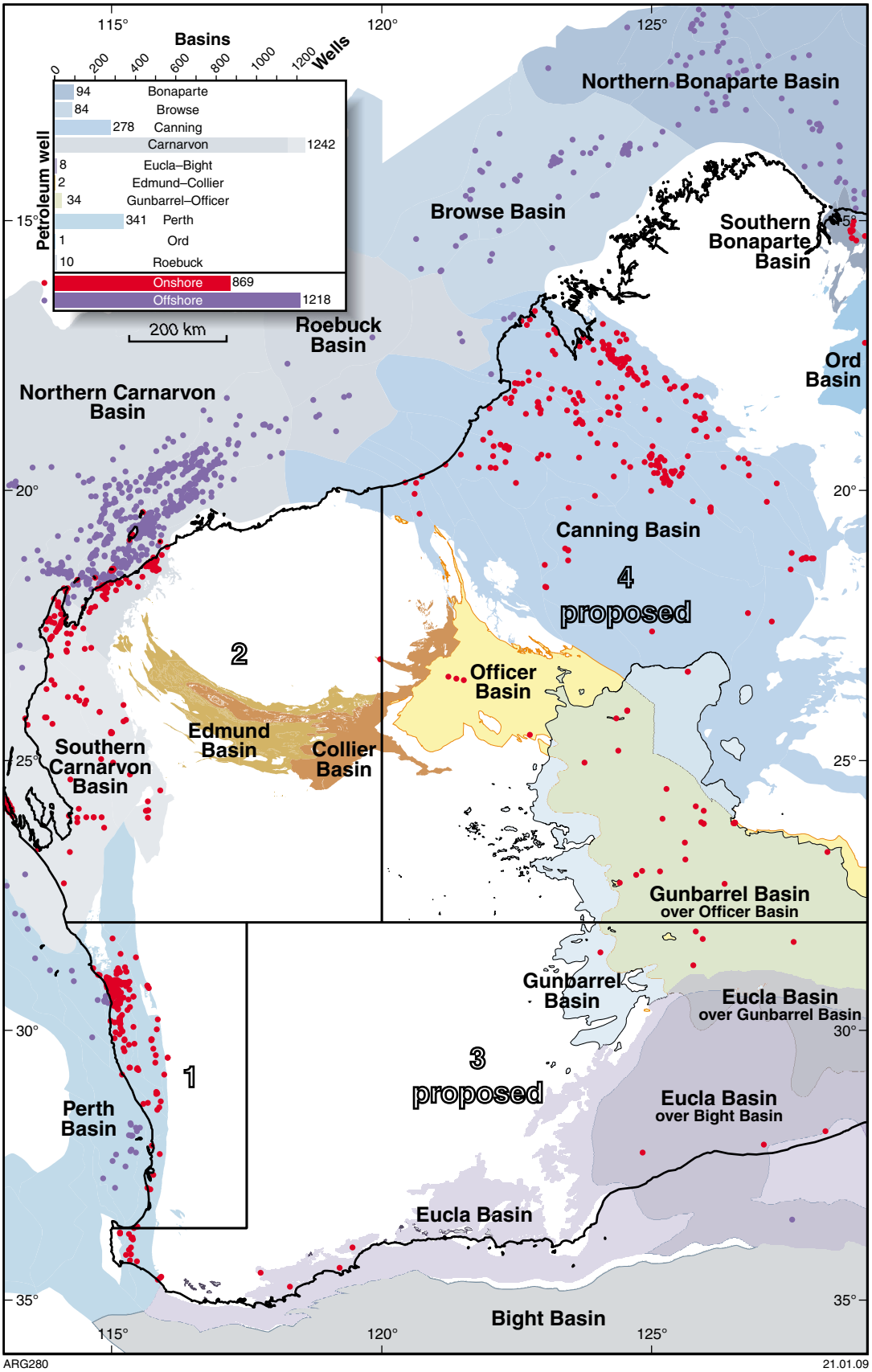

Figure 1. Map showing geothermal acreage areas (released and proposed, 1–4), sedimentary basins, and data available from wells for geothermal energy exploration in Western Australia

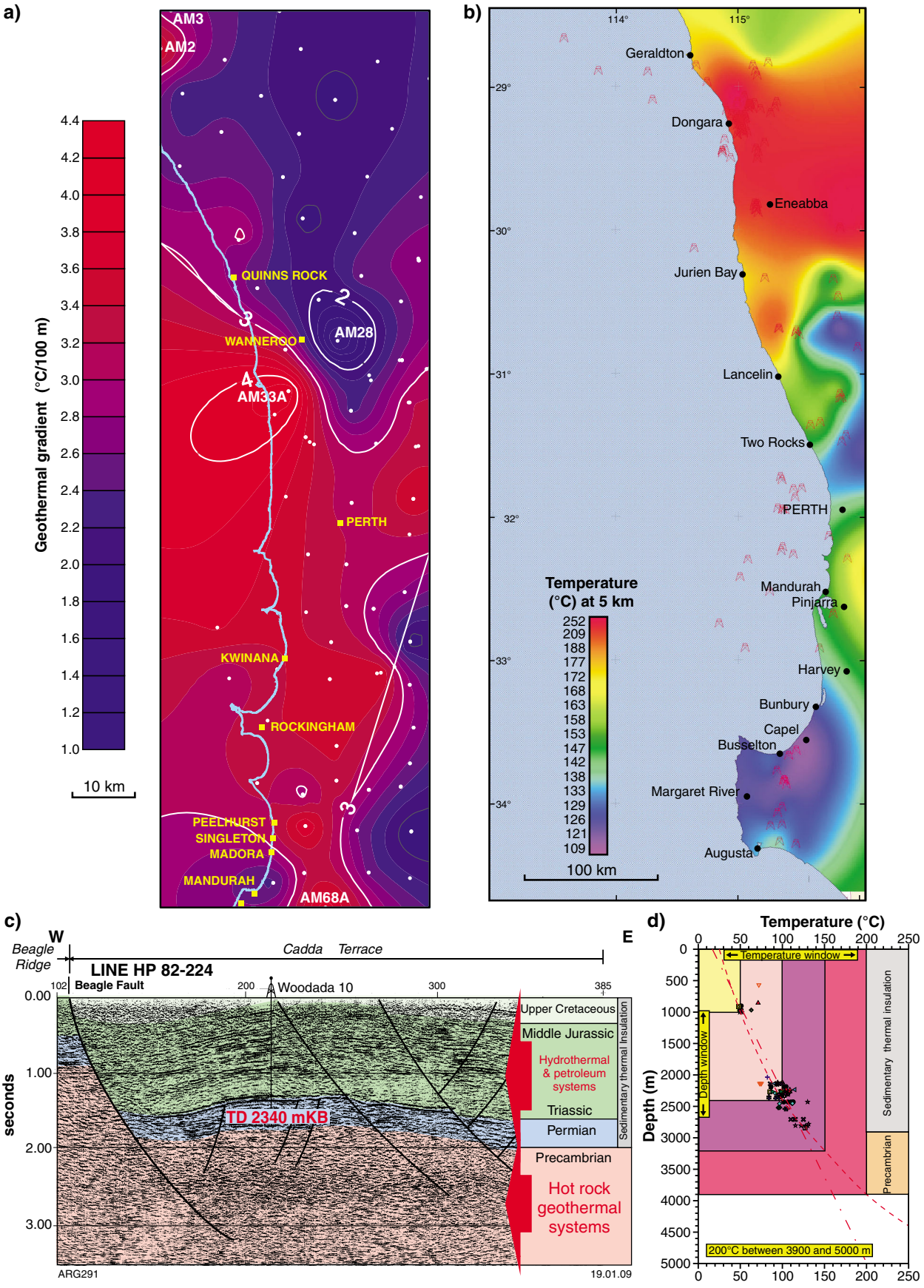

Figure 2. Subsurface data for potential geothermal resources of the Perth Basin: a) geothermal gradient from recorded temperatures in 47 artesian monitoring water bores; b) estimated temperature at 5 km depth in the Perth Basin, based on petroleum wells (wells marked with oil-rig symbol); c) conceptual model for hydrothermal, petroleum, and hot rock resources at Woodada Gas Field; d) recorded subsurface temperatures in 17 wells in the Woodada Gas Field

predominantly Paleozoic onshore Southern Carnarvon Basin to predominantly Mesozoic–Cenozoic offshore Northern Carnarvon Basin (Ghori et al., 2005).

The Canning Basin is the largest Western Australian basin, covering an area of 530 000 km^2 onshore. There has been limited exploration and petroleum production, and infrastructure is necessary for major geothermal resource development. The basin is west-northwesterly trending, with thick, mostly Paleozoic, sedimentary rocks ranging from Ordovician to Cretaceous in age. Subsurface temperature data are available for 233 of the 274 wells drilled for petroleum exploration. The recorded geothermal gradients in many petroleum wells are higher than 4°C/km and the maximum stress orientation is northeast–southwest.

The Perth Basin is a north–south elongated trough along the southwestern margin of Western Australia, containing a Permian to Lower Cretaceous succession under a thin cover of Cenozoic rocks. The Jurassic Yarragadee Formation is a major confined multi-layer groundwater aquifer that underlies the entire Perth region and extends northwards and southwards through most of the Perth Basin. The formation is more than 2 km thick, and the maximum depth to the base of the aquifer is about 3 km, with temperatures up to 90°C (Davidson 1995; Bestow, 1982). The recorded temperature in 47 artesian monitoring bores indicates low-temperature resources up to 50°C at a depth of less than 1 km (Ghori, 2008). The Perth Basin has comparable hydro-geothermal resources to those exploited in the Paris Basin of France, the Pannonian Basin of Hungary, the Williston Basin in the USA, and many Chinese basins (Eggle and Sametinger, 2008).

The Northern and Southern Carnarvon, Canning, and Perth Basins are huge, deep basins within which there might be extensive geothermal systems that are not associated with volcanic activity (Eggle and Sametinger, 2008). The northern Perth Basin shows the most favourable conditions for developing both hydro-geothermal and petrothermal resources from commercial, infrastructure, and geological points of view (Fig. 2), followed by the Northern and Southern Carnarvon and Canning Basins.

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