Proceedings World Geothermal Congress 2010
Bali, Indonesia, 25-29 April 2010

Geothermal Energy in the Perth Basin

Adrian Larking[1] and Gary Meyer[2]

PO Box 1177, West Perth, Western Australia, 6872, Australia

[1]alarking@greenrock.com.au and [2]gmeyer@greenrock.com.au

ABSTRACT

In 2008, the Government of Western Australia amended the onshore Petroleum Act to include rights to explore for and produce geothermal energy. The first geothermal exploration rights under this legislation were offered for application by tender in the Perth Basin adjacent to the coast and where most of Western Australia's population and infrastructure is located. This favourable location close to markets together with the Basin's geological potential to contain extensive geothermal resources presents the opportunity to supply energy for electricity production and direct use including air-conditioning and desalination of water.

The Perth Basin is a 1,000 kilometre long geological rift or half graben containing a thick sequence of sediments in places up to 15 kilometres deep. The rift was initiated when Australia split from India. The Basin has potential for both hydrothermal energy resources hosted in thick permeable aquifers and for enhanced geothermal systems in basement rocks. With many heat flows determined to be over 100 mW/m^2 from deep petroleum wells, the Perth Basin contains some of the highest heat flows found on the Australian continent. The source of the heat flows is uncertain but is expected to be crystalline basement rocks underlying the Basin. The EGS potential is unproven but drilling for petroleum and water has shown the sedimentary sequences have the potential to contain large volumes of geothermal water with sufficient temperature and water flow capacity at depths considered to be economic for commercial uses.

1. BACKGROUND

Recovery of geothermal energy for commercial uses requires the production of an adequate and sustainable flow of sufficiently hot geothermal water to the surface while minimising the amount of the recovered energy consumed to pump the hot water to the surface and re-inject it. Geothermal exploration for natural geothermal water therefore should be focused on discovering hot regions at economic drilling depths with high permeability. Essentially this means finding hot regions with good water flow potential. With its large thicknesses of potential sandstone reservoir rocks and high heat flows the Perth Basin is considered to have considerable potential to contain geothermal resources which can supply clean, renewable energy for commercial uses.

2. GEOLOGY OF PERTH BASIN

The Perth Basin is a major north-south trending geological pull-apart rift extending 1,000 kilometres on the south-western margin of the Australian continent between latitudes 27°00'S and 33°30'S. It contains a Silurian to Pleistocene sedimentary succession to 15 kilometres deep. In the vicinity of the city of Perth the sediments are around 10 kilometres deep.

The structure of the Perth Basin is the product of rifting during the Permian through to the Early Cretaceous. The Perth Basin is an intensely faulted half-graben comprised of a series of sub-basins, troughs, shelves and ridges containing predominantly Early Permian, Late Triassic, Early to Middle Jurassic and Early Cretaceous sedimentary sequences[1]. Its eastern boundary is the Darling Fault separating the Basin sequences from the adjacent Archaean to Proterozoic rocks of the Yilgarn Craton. To the west the rift sediments extend offshore beneath the Indian Ocean to the continental–oceanic boundary. Several structural units are recognised within the Basin representing deeper troughs or uplifted blocks. To the north, the Basin grades into the Southern Carnarvon Basin. Precambrian rocks of the Pinjarra Orogen underlie the Perth Basin and outcrop as fault bounded mid-basin ridges to the south at Leeuwin and in the north as the Northampton Complex[2].

Deposition of the sedimentary sequence of the Perth Basin commenced with extension during the Permian (~290 Ma) and continued to the Early Cretaceous (~138 Ma). This rifting produced the series of deep, north-south trending rift basins (Bunbury Trough and Dandaragan Trough) along the western margin of the Yilgarn Craton with syn-depositional growth along the Darling Fault. In the Early Cretaceous the Basin was uplifted during the final separation of Western Australia and greater India during the breakup of Gondwana. This resulted in significant deformation, strike-slip tectonics, volcanism and erosion of the formations and development of what is known as the Break-up Unconformity. Following this continental break-up, the Basin subsided and sedimentary deposition resumed upon the unconformity along a passive continental margin. A relatively thin layer of Quaternary superficial formations cover the Tertiary and Cretaceous sediments of the coastal plain.

Perth, a city of 1.7 million people with Australia's fastest growing city, is located in the central Perth Basin within the Mandurah Terrace, a structural terrace within a larger, half-graben setting that is bounded by the Darling Fault to the east, the offshore Vlaming sub-basin to the west and by the Turtle Dove and Harvey Transfer fault systems to its north and south, respectively. The onshore stratigraphy of the central Perth Basin is predominantly comprised of Permian to Jurassic sediments.

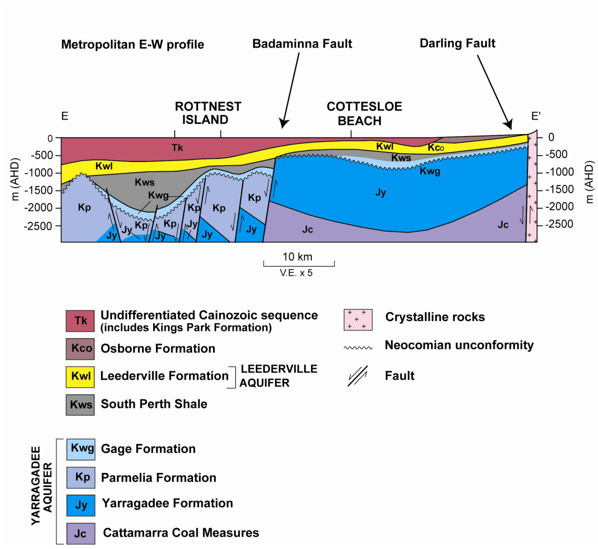

Figure 1: Sedimentary Section for the near Perth city[14]

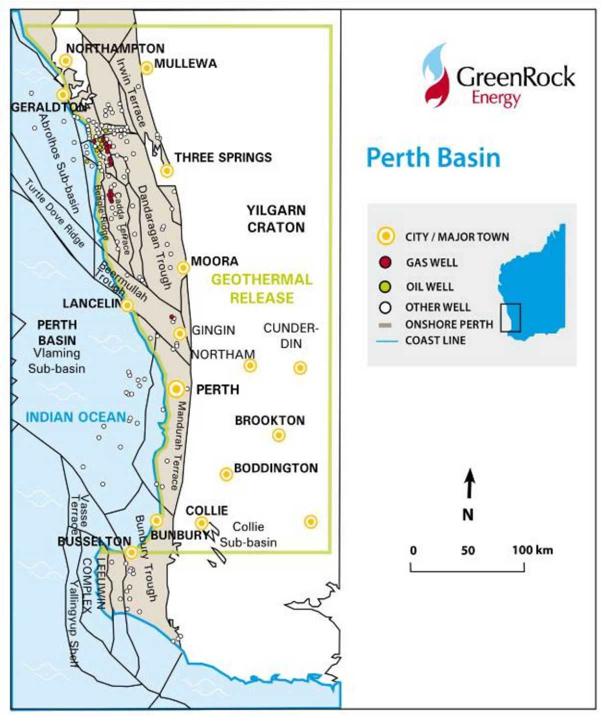

Figure 2: Perth Basin Sub-Divisions (after Hocking, R.M. 1994 Western Australia Geological Survey Record, 1994/4, 84p)

3. STRUCTURAL SETTING

Three major fault trends have been observed across the whole Basin[4]:

1. E-W (275°) striking listric normal faults and NW (320°) striking strike-slip "transfer" faults were associated with the first phase of rifting during north-south extension initiated in the Early Permian;

2. The second major phase of rifting during the break-up of Gondwana in the Early Cretaceous produced the most dominant structural trends in the Perth Basin, consisting of major N-NNW (~360°-345°) striking normal faults and related conjugate NW (~310°) and NE (~45°) striking strike-slip transfer faults and several large N-S striking anticlines;

3. East and north-northwest striking fractures are currently critically stressed and re-activated[5].

This early extensional tectonic regime is currently overprinted by an essentially compressional setting as the Australian plate migrates northwards at the relatively fast geological rate of nearly 7 cm per year. The contemporary stress regime for the Perth Basin has been interpreted to be a transitional reverse to strike-slip faulting stress regime with an approximate east-west maximum horizontal compression direction. Stress field data for the Perth Basin are derived mainly from petroleum well borehole breakouts and drilling-induced tensile fractures from 34 measurements as shown in the World Stress Map[6]. Stress measurements from the adjacent Archaean Yilgarn Craton to the east are broadly in agreement with those in the much younger Perth Basin. Formation pore pressures are expected to be normally pressured.

4. SOURCES OF GEOTHERMAL ENERGY

Geothermal heat generated within the Earth's interior is dissipated upwards by conduction and, where rock permeability and thickness permit, by groundwater convection. Geothermal energy resources or anomalous concentrations of heat occur in two natural forms, namely naturally hot water trapped underground or heat contained in hot buried rocks. In both cases water is used as the medium to transport the contained heat to the surface where it can be used.

Finding geothermal energy resources involves searching for heat anomalies or hot spots at depth. The challenge is to find these concentrations of heat at depths which are affordable to exploit. To determine the amount of geothermal energy resources or heat in place in a location requires the measurement and mapping of temperature distributions at depth. The critical requirements for sustainable commercial production of geothermal energy resources are a high enough temperature and shallow enough depth of the contained heat and the rate at which geothermal energy can be recovered from depth together with the amount of energy consumed in the operations to deliver the geothermal energy to the surface. Temperature is relatively easy to measure although reported temperature measurements from existing wells are not always reliable. Recovery of energy is considered to be the key risk and can only be properly determined by carrying out flow tests of water produced from the geothermal reservoir horizons. While energy recovery is a function of the reservoir temperature and pressure of the geothermal energy resources, the key determinant of the rate and sustainability of energy recovery depends on the permeability of the geothermal reservoir. The magnitude and character of permeability controls the rate at which geothermal water can flow in the geothermal reservoir and hence the recovery of geothermal energy.

5. GEOTHERMAL ENERGY RESOURCES

Geothermal energy has been recovered from sedimentary aquifers in the western suburbs of the metropolitan area of Perth City since at least early last century to heat public swimming baths at the edge of the Swan River. This area is within Green Rock Energy's Perth City Permit area which also houses four full sized swimming pools currently heated by geothermal energy obtained from highly permeable sandstone aquifers from a depth of about 780 metres. One of those pools is the Challenge Stadium Aquatic Centre where the World Swimming Championships have been held twice in the previous decade.

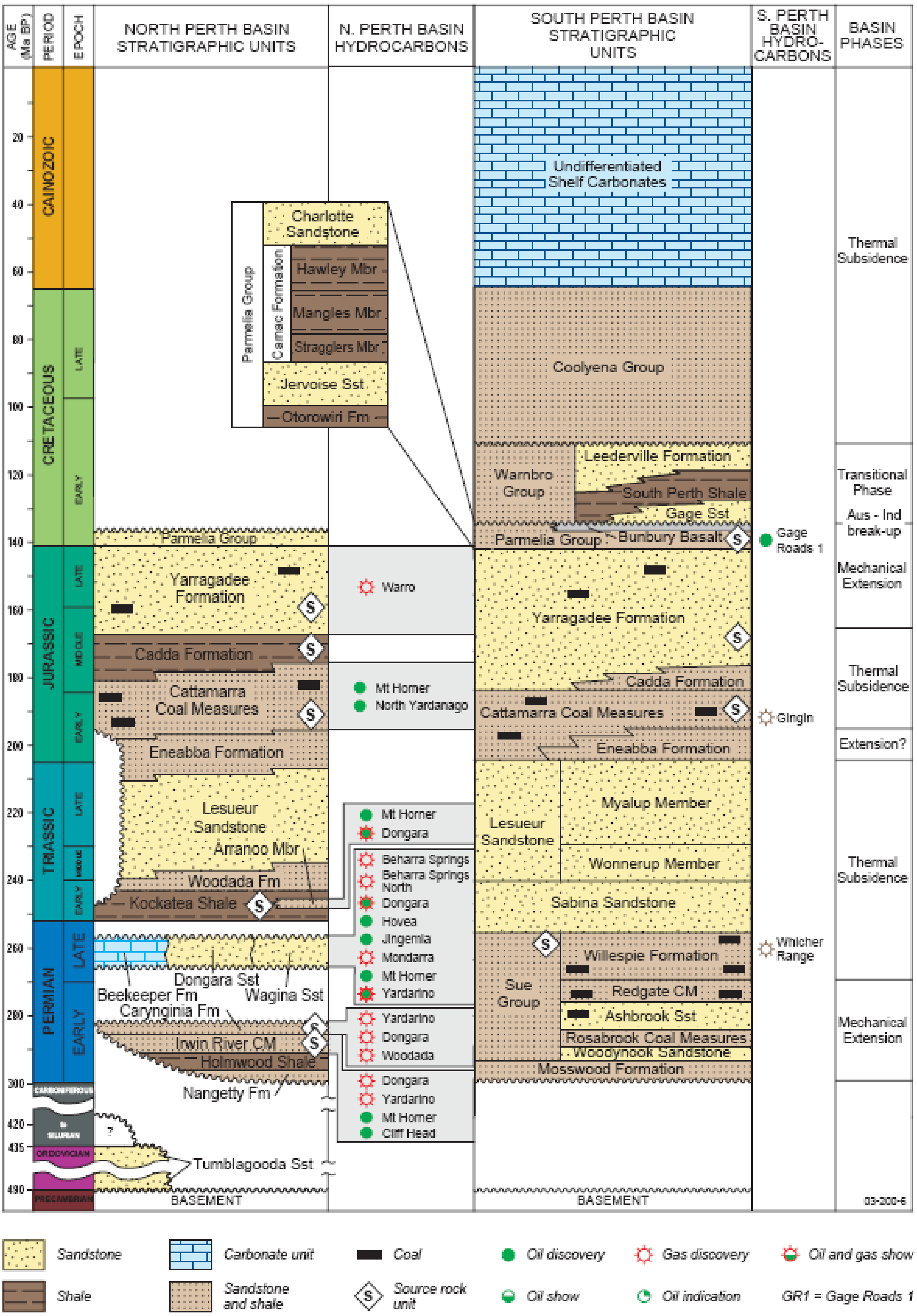

Figure 3: Generalised Stratigraphy of Perth Basin and distribution of water aquifers and potential geothermal resources (Ghori, Khwaja, 2008 Geological Survey of Western Australia, Department of Industry & Resources)

Figure 4: Perth City

Figure 5: Challenge Stadium Aquatic Centre

Key geological ingredients for areas with geothermal energy resource potential are: a heat source, naturally permeable or artificially fractured reservoir rocks to contain the heat, and an overlying heat trap in the form of thermally insulating rocks such as coals or low thermal conductivity shales. Current knowledge of the Perth Basin's geology, its geological history and the contemporary stress regime has been derived mainly from a large regional 2D seismic grid of 23985 line kilometres, and from 2838 square kilometres of 3D seismic and over 250 petroleum exploration, development and stratigraphic wells together with numerous much shallower water bores[7]. Aeromagnetic and gravity images were also used to establish the orientation of faults and provide additional insight into the structural fabric of the basin[8].

Evidence of the extent of economically recoverable geothermal energy resources at depth in the Perth Basin is patchy. Most of the temperature and permeability data at depth in the Perth Basin have been derived from petroleum drilling and from much shallower water bores. From 1961 the groundwater resources of the Perth region have been evaluated by drilling. As a result, high yielding aquifers of Neogene to Jurassic age down to a depth of 1,100 m are exploited to supplement the city's industrial and domestic water supply. The best data are from the northern Perth Basin where there is the greatest concentration of petroleum wells.

Petroleum drilling commenced in the Perth Basin in the 1950s and resulted in the discovery of more than 13 oil and gas fields9. Data derived from petroleum wells are rather sparsely distributed and focused in limited areas where petroleum fields have been discovered, mainly in the northern Perth Basin.

Information about the distribution of permeability through the Basin is available where water bores have been drilled to depths of less than 1000 metres but is typically scarce or inadequate for geothermal targeting at much greater depths. Moreover testing of permeability in petroleum wells generally has been targeted for petroleum potential and to avoid formations where there was a risk of high water flows.

To appraise the temperature potential throughout the Perth Basin a total of 250 petroleum wells were assessed by an independent consultancy for the Western Australian State regulatory agency, now known as the Department of Mines and Petroleum10. Conductive heat flows were modelled for 162 of these wells distributed throughout the Perth Basin and a further 21 wells in the Perth Basin from permit areas within and around areas applied for by Green Rock Energy6. These studies showed that the majority of the Permit areas held in the northern Perth Basin by Green Rock Energy are within areas of modelled high heat flows in the Perth Basin. Modelled surface heat flow in the Perth Basin ranged from 30–140 mW/m2, with a median value of 95 mW/m2 for all wells in the northern Perth Basin, and a median value of around 76 mW/m2 for the Basin as a whole (Fig. 6). The Australian median surface heat flow is 64.5 mW/m2 from the Australian heat flow database6. This heat analysis follows earlier independent analysis of the geothermal energy potential at depth carried out by Chopra & Holgate12.

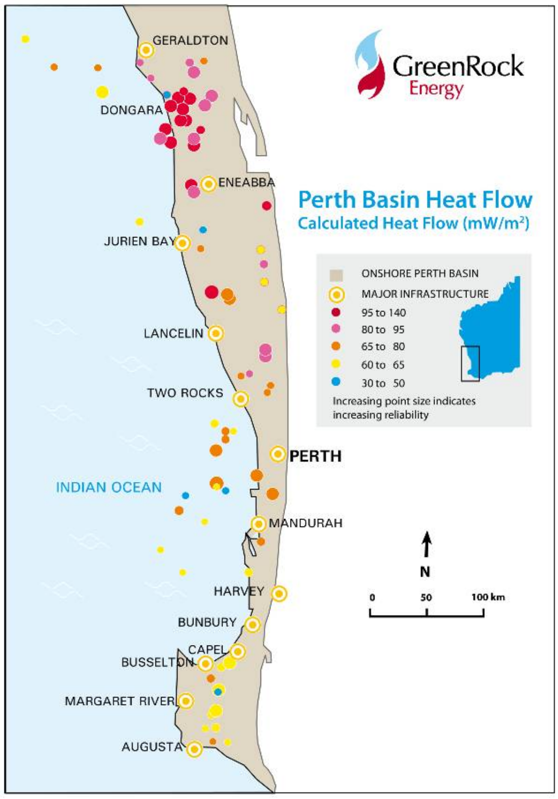

Figure 6: Perth Basin Heat Flow (after Hot Dry Rocks Pty Ltd)

In the northern Perth Basin, where the highest surface heat flows have been recorded, temperature gradients exceeding 5°C/100m have been measured near the petroleum fields. Temperatures of around 160°C are expected at depths less than 4,000m which is sufficient to generate electricity commercially near the existing high voltage power grids at this location provided that sufficient geothermal water flow rates can be achieved.

Within the Perth city area, where petroleum wells and deep seismic data are lacking, most of the useful data have come from deep water bores, the deepest of which extend to only about 1000 metres. In the 1980s a study to evaluate the geothermal energy resources for Western Australia recognised low temperature reservoirs (65-85°C) at depths of 2.0-3.5 km with the best economic potential in the Perth Basin[13]. In the Perth metropolitan area, temperature gradients of about 3 to 4°C/100m have been observed within water bores where the permeable Yarragadee Formation is overlain by the South Perth Shale[15]. Temperature gradients in the southern and central Perth Basin have been reported to be around 2°C and 2.5°C/100m[15]. These relatively low regional values could be related to the generally high thermal conductivity and thick sequences of sandstones that dominate in these regions.

6. COMMERCIAL OPPORTUNITIES

Green Rock Energy has acquired the rights to Geothermal Exploration Permits where indications from petroleum drilling are that the heat flows are the highest in the Perth Basin. Geothermal water temperatures in the northern Perth Basin are considered to be sufficient for commercial generation of electricity provided that sufficient water flow rates can be attained. Access to markets are available via high voltage power lines.

In the vicinity of the City of Perth temperatures expected at depth are likely to be insufficient for commercial generation of electricity but should be adequate for direct heat uses such as purification of water by distillation and for air-conditioning of buildings. To develop opportunities near the City of Perth, Green Rock Energy, in a joint venture with the University of Western Australia (UWA), holds an exploration Permit in metropolitan Perth. The joint venture plans to drill wells at the UWA campus to around 2 to 3 kilometres deep to recover geothermal energy from sandstone aquifers in the fluvial Yaragadee Formation and Cattamurra Coal Measures where the temperature is expected to range between 75°C and 100°C. The project is designed to replace a significant portion of the UWA's Crawley Campus' electrical powered air-conditioning with geothermal powered absorption chillers for its air-conditioning and heating needs. UWA is also a participant along with Curtin University and the CSIRO, Australia's premier science and industrial research organisation, in the Geothermal Centre of Excellence which has recently been formed and is funded by the Western Australian Government.

7. REGULATION OF GEOTHERMAL ENERGY IN WESTERN AUSTRALIA

In 2008, the Government of Western Australia amended the onshore Petroleum Act of 1967 to include rights to explore for and produce geothermal energy[16]. The Act does not extend to or regulate recovery of geothermal energy resources used only for small scale non-commercial uses or small scale heat pumps, or uses of a kind which the Government may prescribe by regulation.

Under this amended legislation the first Geothermal Exploration Permits, in the form of statutory licences to explore, were offered in 2008 for application by a work program tender in the Perth Basin adjacent to the coast and where most of Western Australia's population and infrastructure is located. This favourable location close to markets, together with the Basin's geological potential to contain extensive geothermal resources, presents the opportunity to supply energy for electricity production and direct use including air-conditioning and desalination of water. The first Permits were awarded in July 2009. Green Rock Energy was awarded the first Permit (GEP1) and another 12 Permits.

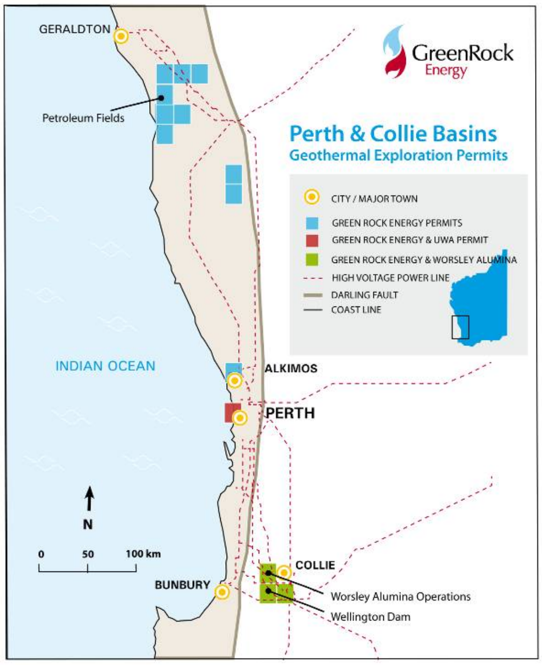

Figure 7: Green Rock Energy's Perth Basin Permits

The Petroleum Act was chosen as the legislative vehicle to regulate geothermal energy within the State of Western Australia. Possibly, this was because both petroleum and geothermal energy occur in nature in gaseous and liquid form and use similar types of drilling rigs for the deep drilling required for the recovery of petroleum and hot water. This choice enabled essentially the same administrative machinery from oil and gas legislation and regulation to be duplicated or adapted for use of geothermal energy.

Under this geothermal legislation there is no concept of private ownership of geothermal energy in the ground. In essence the legislation provides for ownership of the geothermal energy to pass from the State to the geothermal title holder when the geothermal energy is recovered at the surface. The State government has imposed a royalty on geothermal energy sales. Saleable geothermal energy produced will be subject to payment to the State of a royalty of 2.5% of the well head value as agreed between the holder and the Minister or as determined by the responsible government Minister.

Recovery of geothermal energy resources in the form of hot water does not confer ownership or property rights to the water. The use of water remains subject to regulation under the Water & Irrigation Act. This means that in addition to holding a geothermal tenement a water licence would be required to use geothermal water recovered from the tenement. This is so even though, in general, reinjection of the geothermal water will be required after the useable heat is extracted. Reinjection is not a specified requirement of the legislation or the regulations but for environmental reasons and conservation of resources it is likely that a water licence will be issued only with a condition that the water must be re-injected into the same or another suitable reservoir. From a technical viewpoint re-injection into the same reservoir or aquifer would be desirable for maintenance of reservoir pressure. For an EGS project re-injection of produced water is an essential ingredient for the circulation process to work.

Geothermal regulatory mechanisms copied or adapted from the provisions applying to petroleum include the type and term of title which can be granted, regulation of deep drilling, concepts of protection of rights of other land users and pre-existing petroleum title holders, environmental protection and health and safety. Exploration rights are applied for by a competitive tender system by submission of a work program. Geothermal Exploration Permits are awarded to the successful applicant for a six year initial term with the right for the title holder to be granted a renewal for a period of five years unless the conditions of the Permit had not been complied with during the initial term.

The holder of a Geothermal Exploration Permit or a Retention Lease has the right to apply for and be granted a Production Licence over any area in which they have discovered geothermal energy resources. Under the Act the discovery of geothermal energy resources are required to be reported to the governmental agency. Geothermal energy resources are defined in the legislation to be "subsurface rock or other subterranean substances that contain thermal energy". Geothermal energy is heat generated naturally from within the Earth. Under the legislation geothermal energy is defined to be "thermal energy that results from natural geological processes" and is contained in "geothermal energy resources".

Recovery of geothermal energy is required to follow an approved development plan in accordance with requirements set out in the regulations. At the time of writing, an amendment to change the current 21 year life of Production Licences with a right of renewal for another 21 years is before Parliament. If given effect, this change will create Production Licences with a term which matches the production life of the resource.

Within a period of two to four years after discovery of geothermal energy resources the geothermal exploration title holder may apply for a Retention Lease over the discovery area. A Retention Lease will be granted if the Minister is satisfied that recovery of geothermal energy from the geothermal lease area is not commercially viable at that time but is likely to become commercially viable within the following 15 years. A Retention Lease entitles the holder to retain title, continue exploring for geothermal energy resources in the lease area and to carry out work on a discovery and recover geothermal energy for the purpose of establishing the nature and probable extent of a discovery of geothermal energy resources until economic circumstances improve.

SUMMARY

With its thick sequences of sandstone aquifers, high heat flows and the presence of thermally insulating shales and coals, the Perth Basin offers the prospect of containing geothermal energy resources at reasonable depths of sufficient size and quality for commercial uses. The challenge is to find where the hottest sites have sufficient water flow potential to deliver geothermal energy at the sustainably high flow rates required to recover sufficient energy for commercial viability.

The northern Perth Basin has the potential to host geothermal water hot enough at reasonable depths for commercial generation of electricity. The northern region of the Perth Basin contains the highest surface heat flows in the Basin at reasonable depths. These surface heat flows determined from petroleum wells have an average value of 95mW/m² which confirms the potential for sufficient heat at reasonable depths for electricity generation.

The Perth Basin has substantial power infrastructure which could deliver this electricity to Perth's markets.

As well as using geothermal energy for emission free, base load electricity production, it can be used directly for a variety of uses such as for desalination of sea water or purification of poor quality water, for heating and air-conditioning. In and near the city of Perth geothermal energy resources are expected to be appropriate for using geothermal energy for air-conditioning.

REFERENCES

Chopra P.N. and Holgate, F. (Earthinsite Pty Ltd 2007): Geothermal Energy Potential in Selected areas of Western Australia, a Report commissioned by Western Australian Department of Industry and Resources; and also (2005) – A GIS Analysis of Temperature in the Australian Crust; Proceedings of World Geothermal Congress, Antalya, Turkey 2005, pp 7.

Davidson, W.A. 1995. Hydrogeology and groundwater resources of the Perth Region, Western Australia: Western Australia Geological Survey, Bulletin 142, 257 pp

Department of Mines and Petroleum 2009, personal communication.

Freeman, M.J., and Donaldson, M.J. 2006: Geology of the southern Perth Basin and Margaret River wine district, southwestern Western Australia – a field guide: Western Australia Geological Survey, Record 2006/20

Geoscience Australia, Australian map, 2007 compiled by Geoscience Australia from Global Heat Flow Database.

Gori, 2008, ibid.

Gori, K.A.R. 2008: Perth Basin's Geothermal Resources, Australian Geothermal Energy Conference 2008, Extended Abstract. Geological Survey, department of Industry and Resources.

Hot Dry Rocks Pty Ltd, 2008: Geothermal Energy Potential in Selected Areas of Western Australia, Perth Basin, pp 270.

Hot Dry Rocks Pty Ltd 2009: Western Perth Geothermal project, Geothermal Exploration Stage 2, pp28, Unpublished report for Green Rock Energy Limited

Mory, A.J., Haig, D.W., Mcloughlin,S., and Hocking, R.M. 2005: Geology of the northern Perth Basin, Western Australia – a field guide: Western Australia Geological Survey, Record 2005/9.

Mory, R.J, and Lasky, R.P. 1996: Stratigraphy and Structure of the Onshore Northern Perth Basin, Western Australia. Report 46, Geological Survey of Western Australia pp 126 and

Mory, R.J., and Lasky, R.P. 1996, ibid.

Petroleum and Geothermal Energy Resources Act 1967, Western Australia.

World Stress Map