Proceedings Australian Geothermal Energy Conferences 2013
Brisbane, Australia, 14-15 November 2013

Potential for Geothermal Energy in the Vasse Region, Perth Basin, Western Australia

Mike F. Middleton and Mark K. Stevens

Department of Mines and Petroleum, 100 Plain Street, East Perth, WA, 6004.

E-mail address, mike.middleton@dmp.wa.gov.au

Keywords: Heat generation, hot sedimentary aquifer, Vasse region Western Australia, low temperature geothermal systems

ABSTRACT

This paper shows new data related to the geothermal potential of the Vasse region in the south west of Western Australia. Heat generation data were acquired by measuring U, Th and K concentrations in outcropping sedimentary and granitic rocks in the region, using a calibrated gamma-ray spectrometer. Heat generation values derived from the U, Th and K measurements varied between 3.8 and 40.1 μWm^{-3}. A modelling exercise examined the possibilities for low temperature geothermal energy sources in the region. Temperatures of up to 60 °C were modelled for depths of less than 1500m. Low temperature geothermal enterprises can be designed on the basis of such a temperature regime, however, depths of over 3000 m would be needed for small scale electricity generation.

1. INTRODUCTION

Implementation of geothermal energy in the environmentally sensitive Vasse region of the southern Perth Basin presents a unique, but not insurmountable challenge. Geothermal energy is one of the few clean energy sources that promise to provide a substantial supplement to base-load electrical power. It been shown in Birdsville, Queensland, that hot sedimentary aquifers can successfully supply geothermal-based electricity to small townships. Further, geothermal energy is currently used for space heating (e.g.. swimming pools) in a number of successful applications in the Perth region, and major projects are underway to apply geothermal energy to generate electricity in the Mid-west region. Geothermal energy is being successfully used the Mornington Peninsular in Victoria for the Peninsula Hot Springs tourist resort (Davidson, 2012).

Most of these projects draw geothermal energy from hot water of temperatures between 45°C and 100°C in sedimentary rocks buried between 600 and 2,000 metres beneath the Earth's surface. Such applications are considered as low temperature geothermal projects, compared to those in volcanic regions elsewhere in the world. Little is known of the geothermal potential of the South-west region of Western Australia, and this study reports a preliminary investigation of the Vasse region for low temperature geothermal energy applications.

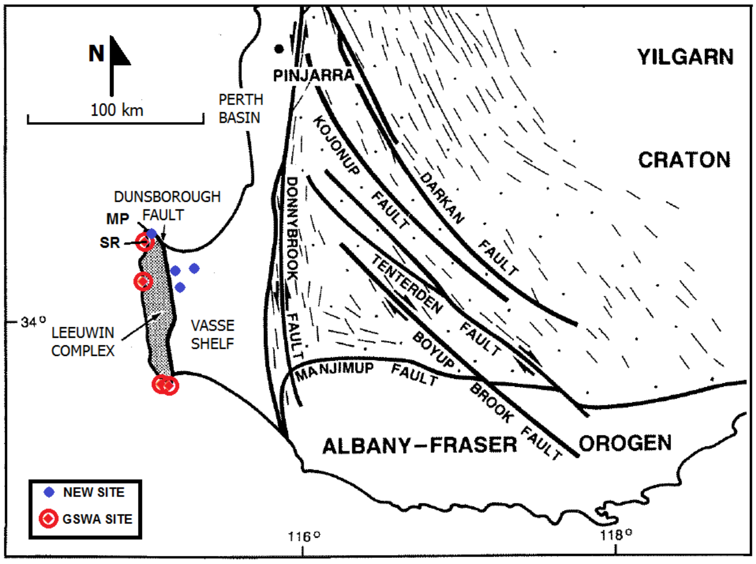

Figure 1: Location diagram showing the Vasse Shelf, Leeuwin Complex, and Yilgarn Craton, and the measurement/sample locations for this study. The localities SR and MP relate to the Sugarloaf Rock locality and the Meelup Park locality, respectively, which are discussed in the text. The localities of previous measurements in the database of the Geological Survey of Western Australia are shown in red.

It is commonly recognised that granitic "basement" rocks, informally referred to as granites herein, with a high content of the radiogenic elements Uranium (U), Thorium (Th) and Potassium (K), also referred to as "hot or radiogenic granites", provide a dominant component to the heat flow in the Earth. Two geothermal regimes are recognised in Australia, are the Hot Dry Rock (HDR and the hot sedimentary Aquifer (HSA) regimes. In HDR regimes, hot granites reside beneath a thermal blanket comprised of between three to five kilometres of sedimentary rocks, and water is injected into fractured hot granites to provide a source of hot water for geothermal energy. In HSA regimes, likewise hot granites reside beneath a sedimentary cover, but the natural hot water in the sediments is extracted for geothermal energy use.

Heat generation in the granites of the Leeuwin Complex, which crops out immediately to the west of the Perth Basin in the Vasse Vasse region, may have relevance for generation of “hot spots” in the adjacent Perth Basin (Figure 1). The aim of this paper is to present preliminary results of the heat generation study of outcrops in the Vasse region, and to estimate possible temperatures at depth from these measurements. Based on these results, some suggestions for geothermal developments in the region are proposed.

2. GEOLOGY AND GEOPHYSICS OF THE VASSE REGION

Two major geological provinces occur in the Vasse region, the Leeuwin Complex and the Perth Basin (Figure 1). The field geology of the Leeuwin Complex has been described by Janssen et al. (2003). The Leeuwin Complex lies to the west of the Perth Basin sediments, and is believed to have formed between 1300 and 1000 million years ago (Myers, 1990). However, the region underwent a major metamorphic event, involving magmatism and granulite-facies metamorphism, between 550 and 500 million years ago (Janssen et al., 2003). Subsequent substantial uplift and erosion occurred between the Cambrian (ca. 550 million years ago) and Early Permian. Sediments of the southern Perth Basin commenced to be deposited in the Early Permian, but probably earlier further to the north. The Perth Basin developed as a proto-rift system from the Permian until continental breakup between Australia and Greater India in the Cretaceous (Mory and Haines, 2013).

Iasky (1990) has shown from seismic interpretation that sediment thicknesses in the Perth Basin in this region may be up to 3000 m. Geological and hydrological studies, which entailed drilling from between 500 and 1500 m, were reported by Wharton (1982) and Appleyard (1989). These studies have also shown that the temperature is about 35°C at a depth of 500 m close to the Dunsborough Fault, which separates the Leeuwin Complex from the Perth Basin (see Figure 1). This suggests a geothermal gradient of between 50 to 55 °C/km in the Perth Basin immediately to the east of the Leeuwin Complex.

New generation aeromagnetic and radiometric mapping of the Vasse region was carried out in 2011 and is available through Geological Survey of Western Australia (2013). The aeromagnetic map of the northern part of study area is shown in Figure 2. The Leeuwin Complex shows the intense magnetic signature in the west of the image in Figure 2, and the Perth Basin exhibits the milder signature in the east of the image; the province boundaries also have a clear geophysical signature and definition. The figure also shows a significant thorium anomaly, form the same survey, superimposed on the aeromagnetics. The correlation suggests that magnetic low regions may be associated with radiometric highs, and could be applicable in mapping geothermal prospectivity. However, this is a preliminary observation.

Previously, Jaeger (1970) and Sass et al. (9976) investigated heat flow in Western Australia, but did this study did not extend to the Leeuwin Complex. From these earlier studies, the geothermal regime of the Yilgarn Craton is known to some degree, however, the relationship to the Leeuwin Complex is largely unknown. Janssen et al. (2003) have proposed some concepts for thermal origin of the Complex, but a full regional thermotectonic model is not extant.

In a geothermal context, especially in terms of heat generation (Kappelmeyer and Haenel, 1974), one needs to consider the concentrations of uranium (U), thorium (Th) and potassium (K) in the granites within the Leeuwin Complex, and those interpreted through geophysics, to underlie the Perth Basin to the east. Limited previous geochemical work on U, Th and K concentrations in granites within the Leeuwin Complex have been carried out by the Geological Survey of Western Australia (GSWA), and these locations are shown in Figure 1. These previous measurements from the GSWA database show a range for the elements: $-2 < U(ppm) < 6$ and $12 < Th(ppm) < 92$. No potassium concentrations were available, or apparently measured.

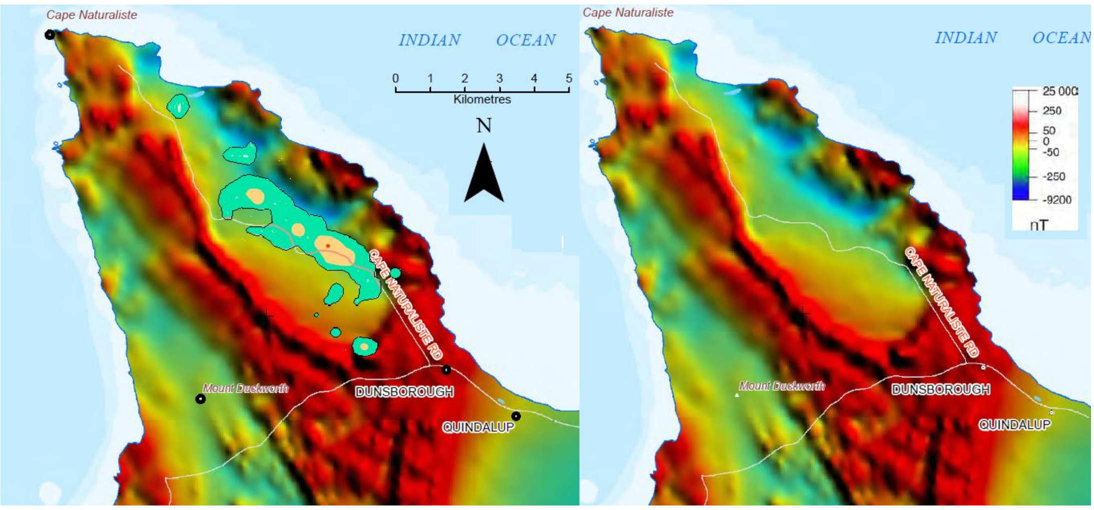

Figure 2: Map showing the aeromagnetics in the vicinity of Dunsborough (Geological Survey of Western Australia, 2013) with the location of Th anomalies superimposed on the left-hand-side (LHS) image. The right-hand-side image shows the aeromagnetics with colour scale of magnetic intensity in units of nanoTesla (nT). The magnitude of the Th anomalies

(outlined in black on LHS) is represented as green indicating 50 to 100 ppm, orange indicating 100 to 150 ppm, and red indicating 150 to 200 ppm. Ground measurements for Th concentrations were in the order of 280 ppm in the orange regions.

The radiometric survey of 2011 (Geological Survey of Western Australia, 2013) challenged these measurements. From data derived from the areal survey over these areas within the Leeuwin Complex, uranium concentrations of over 30 ppm and thorium concentrations over 150 ppm were found for a number of localities. Our understanding of the geochemistry of the granites in the Leeuwin Complex needed further work. This, especially, if a deeper understanding of the geothermal potential of the region is to be attained.

3. FIELD MEASUREMENTS

Field measurements of concentration of naturally occurring radiogenic isotopes of U, Th and K at eight sites in the Vasse region were carried out. These sites were selected for field measurement based on radiogenic anomalies found in the Geological Survey of Western Australia (2013) survey. At each site, measurement of U, Th and K concentrations were carried out with an RS-125 spectrometer. Middleton (2013) has discussed the previous use of the RS-125 spectrometer for estimations of heat generation.

URANIUM (ppm)	THORIUM (ppm)	POTASSIUM (%)	HEAT GENERATION (μWm^{-3})	COMMENT
6.0	108.4	7.4	9.9	Sugarloaf Rock (SR); Leeuwin Complex; previous GSWA site
2.1	37.9	5.7	3.8	Leeuwin Complex; previous GSWA site
2.8	37.8	5.6	3.9	Leeuwin Complex; previous GSWA site
3.3	46.8	6.2	4.8	Leeuwin Complex; previous GSWA site
10	125	0.4	11.4	Vasse Shelf sediments
9.9	42.1	0.1	5.5	Vasse Shelf sediments
18.7	147.2	0.4	15.2	Vasse Shelf sediments
75.8	275	11.7	40.1	Meelup Park (MP); Leeuwin Complex

Table 1: Mean U, Th and K concentrations measured at the eight localities in this study, with the derived heat generation.

The observed concentration values were in many cases much higher than previously observed values. Heat generation for the various localities investigated was determined (see Table 1) from a commonly used equation to convert U, Th and K concentrations into heat generation (Kappelmeyer and Haenel, 1974; Middleton, 2013). It is of note that the unusually high 40.1 μWm^{-3} heat generation at the Meelup Park locality is repeatable. The locality is within sediments overlying a Leeuwin granite-gneiss location. The thickness of sediments is unknown at present, and may contain high radioactivity Cainozoic beach sands, which are mined to the north. However, concentration of underlying radioactive minerals in granites at this location may also be a cause of the unusually high radioactivity at this locality. It is also significant to note that the U and Th concentrations measured by the RS-125 spectrometer were very similar to those measured previously by the GSWA (which were U = 4 ppm and Th = 93 ppm).

4. MODELLING

Temperature models can be derived from the heat generation data found in this study. The process to build these models is shown in Middleton (2013), and is based upon the observed heat generation data for underlying granites and assumptions about the regional geology and geophysics. Table 2 shows the assumed parameters for the modeling of the temperature versus depth profiles, and these are adapted from Schön (1976).

A simple 1D model (Carslaw and Jaeger, 1959, p. 79) is used to determine the temperature at depth in sediments, which are underlain by a granitic body with uniform heat generation and limited depth extent. The main unknown parameters in this modelling exercise are heat generation within the layer of hot granite (A_o) and its thickness (L). The other parameters, such as thermal conductivity (K), heat flow at the base of the crust (Q_b) and surface temperature (T_s) are relatively well known (Schön, 1996; Jaeger, 1970), and commonly observed values have been assumed (see Table 2). The heat generation is derived from the observations in Table 1. The maximum value of heat generation (A_o) of 20 μWm^{-3} is derived from half the maximum value observed in the field studies (see Table 1). This value has not been observed for any granite observed in the region, and caution needs to be exercised in assuming this value. Further, little is known of depth extent (i.e. L) in any granites in this region. The methodology of the modeling is explained in Middleton (2013).

PARAMETER	VALUE						
	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6	CASE 7
A_o (μWm^{-3})	4	10	20	4	10	20	8
K ($Wm^{-1}K^{-1}$)	3	3	3	3	3	3	3
L (km)	2	2	2	6	6	6	3.5
Q_b (mWm^{-2})	26.3	26.3	26.3	26.3	26.3	26.3	26.3
T_s (°C)	20	20	20	20	20	20	20

Table 2. Parameters assumed for seven cases, where the temperature profile versus depth is shown in Figure 3.

The models, therefore, represent an optimistic view of the geothermal potential of the region. However, it is significant to note that Wharton (1982) reports that the temperature in the Perth Basin immediately to the east of the Leeuwin Complex is about 40 °C, which is quite consistent with the modeling in this paper.

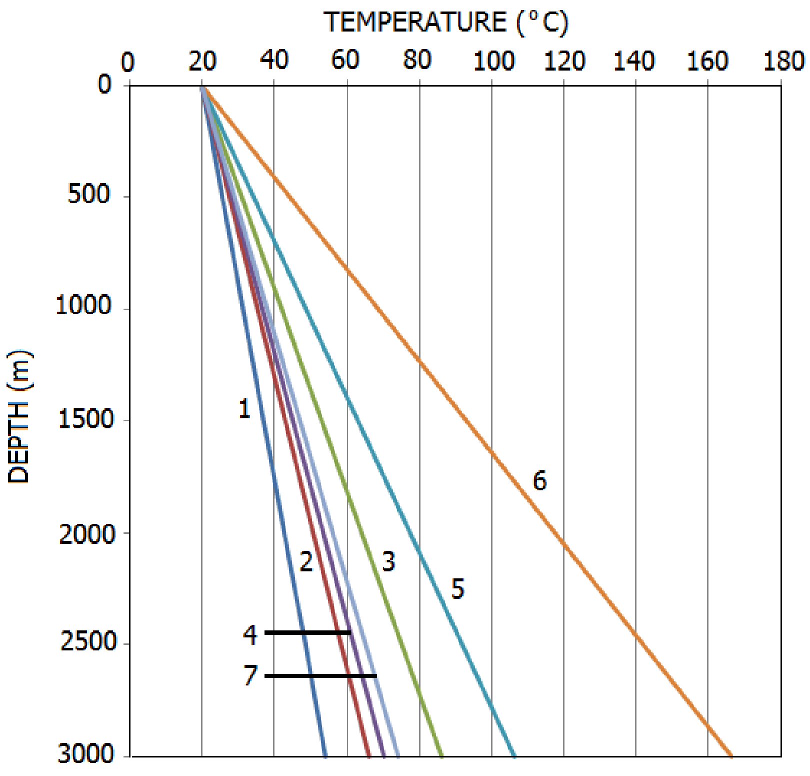

Figure 3. Temperature versus depth for the seven cases proposed in Table 2. The number on each curve identifies the corresponding case in Table 2. Wharton (1982) indicates that the temperature at 1000 m depth is approximately 40 °C. Cases 2, 3, 4 and 7 most closely satisfy this observation.

5. CONCLUSIONS

This study suggests that realistic temperatures between depths of 500 m and 1500 m, which are realistically drillable depths, in the Vasse region may vary between 30°C and 45°C. This temperature range is confirmed by hydrogeological drilling. If a hot granite is particularly thick (thickness about 6 km) then a temperature of about 60°C may occur at 1500 m. The observed data and modelling clearly indicates that the Vasse region is a low temperature geothermal regime. Unless wells are drilled to depths of greater than 3000 m, electricity generation is not an option.

Shallow wells or boreholes can replicate the hot springs scenario of the Peninsular Hot Springs resort in Victoria, and this is not an insignificant industry when in a high tourist destination. Similarly, the geothermal regime is similar to the Perth metropolitan area, where heated swimming pools are an active enterprise.

Geothermal-electricity generation, albeit on a small community scale like (Birdsville in Queensland or Margaret River in Western Australia), will require deeper drilling. The modelling suggests that wells of 1700 m to 2700 m can fulfil the requirement of the 100 °C groundwater that supplies the Birdsville geothermal plant. The answer that is not currently known is how many, and what volume of, granites residing deep in the Vasse region possess the necessary high heat generation of 10 to 20 μWm^{-3}; this level of natural heat generation is required to provide geothermal heat to sustain the region's energy. The 100 °C maximum temperature range is also sufficient to permit electricity generation with organic rankine cycle (ORC) or variable phase cycle (VPC) turbines (Welch and Boyle, 2009).

ACKNOWKEDGEMENTS

This paper is published with the permission of the Director of the Petroleum Division, Department of Mines and Petroleum, Western Australia.

REFERENCES

Appleyard, S.J. 1989. The geology and hydrology of the Cowaramup boreline, Perth Basin, Western Australia. Hydrology Report 1989/34, Western Australia Geological Survey Report 30, Professional Papers.

Carslaw, H.S. and Jaeger, J.C. 1959. Conduction of heat in solids, Oxford University Press.

Davidson, C. 2012. Geothermal beyond power – Opportunities for geothermal resources development, in Middleton, M.F. and Gessner, K. (eds.) West Australian Geothermal Energy Symposium Abstracts v. 2: 4.

Geological Survey of Western Australia. 2013. 40m magnetic merged grid of Western Australia.

Iasky, R.P. 1990. A Geophysical Synthesis of the Southern Perth Basin, Master of Science Thesis, Curtin University of Technology (unpublished).

Jaeger, J.C. 1970. Heat flow and radioactivity in Australia, Earth and Planetary Science Letters, 8, 285-292.

Janssen, D.P., Collins, A.S. and Fitzsimons, I.C.W. 2003. Structure and tectonics of the Leeuwin Complex and Darling Fault Zone, southern Pinjarra Orogen, Western Australia – a field guide: Western Australia Geological Survey, Record 2003/15, 33p.

Kappelmeyer, O. and Haenel, R. 1974. Geothermics with special reference to Application, Bebrüder Borntraeger.

Middleton, M.F. 2013. Radiogenic heat generation in the Darling Range, Western Australia, Exploration Geophysics, 44, 206-214.

Mory, A.J, and Haines, P.W. 2013. A Palaeozic perspective of Western Australia, in Keep, M. and Moss, S.J. (Eds), 2013, The Sedimentary Basins of Western Australia IV; Proceedings of the Petroleum Exploration Society of Australia Symposium, Perth, WA, 2013.

Sass, J.H., Jaeger, J.C. and Munroe, R.J. 1976. Heat flow and near-surface radioactivity in the Australian continental crust, United States Department of the Interior, Geological Survey, Open-File Report 76-250.

Schön, J.H. 1996. Physical properties of Rocks: Fundamentals and principles of petrophysics, Pergamon.

Welch, P. and Boyle, P. 2009. New turbines to enable efficient geothermal power plants, Geothermal Resources Council (GRC) Transactions, GRC 2010 Annual Meeting October 2010, Vol. 334, 765-772.

Wharton, P.H. 1982. The geology and hydrogeology of the Quindalup boreline, southern Perth Basin, Western Australia, Geological Survey of Western Australia, Record 1982/2.