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Geothermal Prospectivity of the Mountain Bridge Area, North Perth Basin, Australia

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ABSTRACT

Regional review of the geothermal potential in the North Perth Basin indicates the presence of all the necessary ingredients for a working geothermal system (Ballesteros & Oppermann, 2013; Ballesteros, et al, 2012; Larking, et al., 2011, Larking, 2010; HDRPL, 2008). The key risk identified is locating zones with sufficient permeability to provide commercially viable flow rates of formation water. Permeability associated with natural fracture systems is considered to have the best chance of providing a viable geothermal reservoir and therefore recent efforts have focused on identifying natural fracture systems.

Exploration to date has focused on areas with 3D seismic data coverage, which provides superior ability to identify and evaluate natural fracture systems. However, a recent review of the geothermal prospectivity outside the areas with existing 3D seismic data coverage has revealed an outstanding geothermal prospect. The potential is highlighted by the results of the petroleum exploration well Mountain Bridge-1, which flowed 146°C water from the interval 3185-3235m at approximately 4 l/s. Available data from the well indicates the water came from natural fractures within the Permian High Cliff Sandstone.

A 3D seismic survey is currently scheduled for acquisition in late 2014 as part of the petroleum exploration efforts in the area. This data set will facilitate the evaluation of the geothermal potential of the area when it becomes available, and will hopefully provide a means of identifying and assessing the faulting and associated fracture systems that could provide an extensive and effective geothermal reservoir.

INTRODUCTION

The North Perth Basin (NPB) in Western Australia offers one of the most attractive areas for geothermal exploration in Australia. Key geological ingredients for a working geothermal system include a heat source and a heat trap in the form of thermally insulating rocks such as coals or low thermal conductivity shales with underlying naturally permeable, cavernous or fractured reservoir rocks (Cooper and Beardsmore, 2008). Previous studies (e.g. Ballesteros & Oppermann, 2013; Ballesteros, et al, 2012; Larking, et al., 2011, Larking, 2010; HDRPL, 2008) suggest that the NPB has all of these attributes and is also located close to a market with increasing demand for energy.

The key risk is locating zones with sufficient permeability to provide commercially viable flow rates of formation water. Permeability associated with natural fracture systems is considered to have the best chance of providing a viable geothermal reservoir and therefore recent efforts have focused on identifying natural fracture systems, with particular attention to areas with 3D seismic coverage. As a result, an attractive area associated with the Allanooka Fault (Figure 1) was identified as the preferred site for the first geothermal well in the area.

Unfortunately, non-technical issues associated with the Allanooka area were subsequently recognized that might delay drilling a geothermal exploration well in the preferred location. As a result, a review was undertaken to identify alternative locations with good geothermal prospectivity, including those outside the areas with existing 3D seismic coverage. These efforts revealed an outstanding geothermal prospect in the area around the Mountain Bridge-1 well.

REGIONAL SETTING

The Mountain Bridge area is located at the northern end of the Perth Basin, a N-S trending 1,000 km-long rift basin which formed during the Permian to Early Cretaceous when India split from the west coast of Australia during the breakup of Gondwana (Mory & Iasky, 1996; Veevers, 1982) (Fig. 1). This rifting produced a series of deep, N-S trending sub-basins along the western margin of the Yilgarn Craton that are filled in places with up to 15 km of sediments, predominantly Cretaceous to Permian in age.

The onshore Perth Basin is essentially a half graben that thickens to the east, but underwent a complex history of fracturing and faulting, resulting in the development of extensive fault and fracture networks (Larking et al., 2010, 2011).

The Mountain Bridge prospect is associated with the N-S trending Beagle Fault, a major regional feature that separates the Beagle Ridge to the west from the Cadda Terrace in the east (Figure 1). The area is also transected by the Abrolhos Transfer Zone, a regional tectonic feature where the orientation of faults relative to the current stress field should favour the retention of open permeable faults and fracture sets (Ballesteros & Oppermann, 2013). In the prospect area the Beagle fault has approximately 1400m of throw, with granitic basement encountered at 2000m on the Beagle Ridge, dropping down to about 3400m on the west side of the fault.

An assessment of the geothermal potential of the NPB conducted by HDRPL (2008) identified high heat flows and porous and/or fractured sediments that are sufficiently thick and deep enough to host geothermal fluids at temperatures over 150°C. Importantly, these temperatures are reached at depths shallower than 4,000 m, below which drilling costs increase significantly.

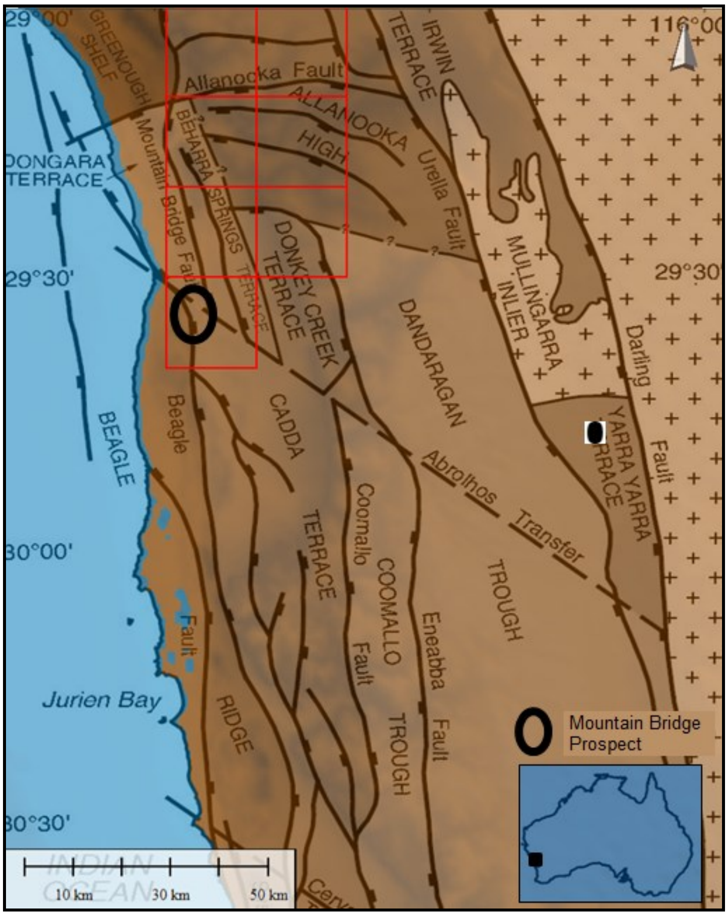

Figure 1. North Perth Basin regional tectonic elements. (modified after Mory & Iasky, 1996)

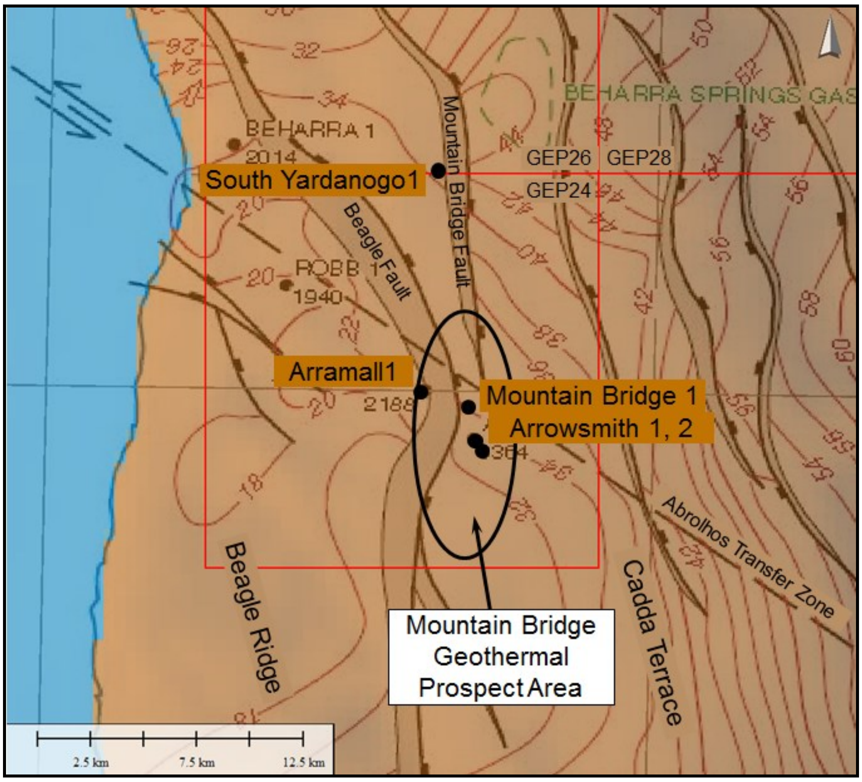

Figure 2. Depth to basement showing the structural setting of the Mountain Bridge prospect and key petroleum wells. Contours in 100s of metres. (modified after Mory & Iasky, 1996)

AVAILABLE DATA

Green Rock Energy holds Geothermal Exploration Permits GEP23, 24, 25, 26, 27, 28 and 41 located about 350km north of Perth in the North Perth basin near the town of Dongara in Western Australia (Figure 1). The Mountain Bridge area discussed here is situated in GEP24. The Arrowsmith and Mountain Bridge wells are located within EP413.

The primary source of geological and thermal information about the sedimentary sequences in the Perth Basin comes from petroleum wells and from shallower water bores. Over 250 wells have been drilled in the NPB, reaching depths up to 4,850 m and resulting in the discovery of more than 13 oil and gas fields, including the Dongara, Hovea, Eremia, Jingemia, Mt. Horner and Beharra Springs oil and gas fields (Fig. 3). Most of these discoveries are located in and around the project area and as a result this region has the highest density of petroleum wells and seismic data in the basin.

Seven petroleum wells have been drilled within GEP24, including Beharra-2 (1967), Robb-1 (1985), Beharra Springs South (2001), Arramall-1 (1988), Mountain Bridge-1 (1993), Arrowsmith-1 (1965) and Arrowsmith-2 (2013). The last four of these are of immediate relevance to defining the Mountain Bridge geothermal prospect (Figure 3).

Approximately 24,000 km of 2D seismic and over 3,000 km^2 of 3D seismic have been acquired to date and provide invaluable assistance in understanding the details of the structure and stratigraphy in the area (Figure 3).

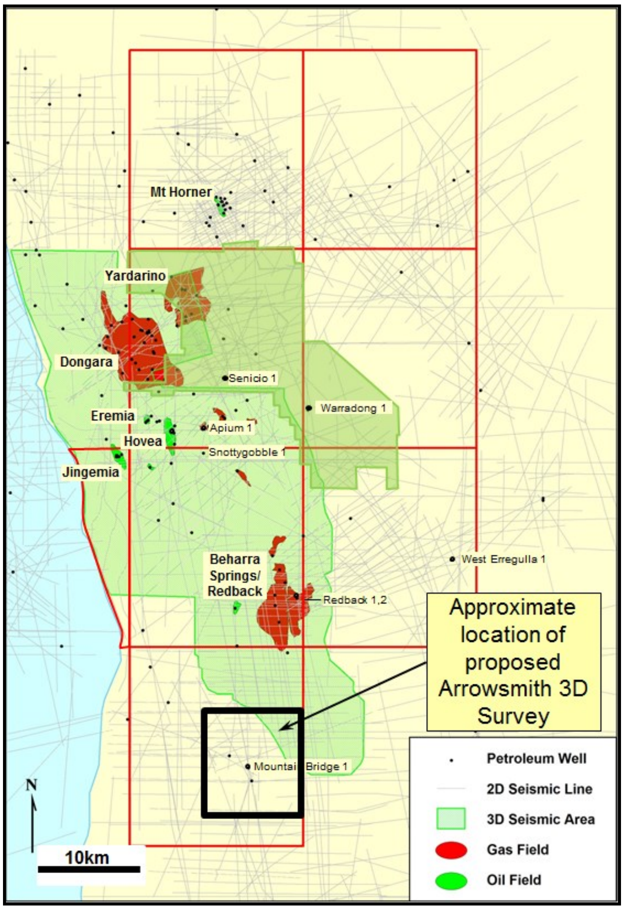

Figure 3. Location of petroleum fields and wells and seismic surveys. (modified after Ballesteros & Oppermann, 2013).

The regional evaluation of the area incorporated over 130 wells and over 1,000 km^2 of 3D data (Ballesteros, et al., 2012). Substantial 2D seismic data coverage is also available, but efforts to date have been focused on areas with 3D data coverage due to the superior imaging of faults and fracture zones that comprise the geothermal reservoir target. The Mountain Bridge area currently does not have any 3D seismic data coverage, and this is the primary reason it has not received more attention previously. However, the area covered by petroleum exploration permit EP413 is coincident with GEP 24, and the EP413 Joint Venture is currently planning to acquire a 3D Seismic Survey in late 2014. This survey should provide 3D data coverage over the critical portions of the Mountain Bridge geothermal prospect. Although the new survey data will remain confidential to the EP413 Joint Venture, it will be released into the public domain two years after it is acquired and will therefore be available for geothermal exploration at that time unless other arrangements are made prior.

HEAT FLOW AND TEMPERATURE

The target temperature for a commercially viable HSA project is about 150^{o}C and the depth at which this temperature is reached, which is closely linked to drilling costs. Modelled surface heat flows in the onshore Perth Basin range from 58–140 mW/m^2, with a median value of 95 mW/m^2 for all wells in the northern Perth Basin. This compares to a median value of around 76 mW/m^2 for the entire Perth Basin and 64.5 mW/m^2 for Australia as a whole (Ballesteros & Oppermann, 2013).

Well	Heat Flow (mw/m2)	150^{o}C Isotherm Depth (m)
Arramall-1	115	3200
Arrowsmith-2	95	3350
Mountain Bridge-1	107	3270
South Yardanogo-1	115	3340

Table 1. Modelled surface heat flow and estimated depth to 150oC isotherm for key wells in the Mountain Bridge area. Well locations shown in Figure 2.

Modelled surface heat flows have been calculated using corrected BHTs and DST temperatures where available for several wells in the Mountain Bridge prospect area. Table 1 shows the heat flow values from Arrowsmith-2, Mountain Bridge-1 and Arramall-1 and South Yardanogo-1, which are above average for the area. Also shown in Table 1 are the estimated depths to reach the target temperatures of 150^{o}C based on these heat flows, available data on the stratigraphy and estimated thermal conductivities. These figures show that the target isotherm should occur above 3300m in the prospect area. Direct validation of the calculated temperature in the Mountain Bridge-1 well is provided by the results of DST 2a in the Mountain Bridge-1, which flowed 146^{o}C water from 3185-3235m.

RESERVOIR POTENTIAL

The reservoir objective for the Mid West Geothermal Project is permeable zones associated with open natural fractures and faults. Substantial work has been undertaken to evaluate the nature and distribution of fractures in the general area using image log data from a number of wells in the area in conjunction with 3D seismic, including Automated Fracture Extraction (AFE)(Ballesteros & Oppermann, 2013; Ballesteros, et al., 2012).

Regional geomechanical studies in the NPB indicate the maximum horizontal stress direction (S_{hmax}) trends approximately E-W, varying from N78^{o}E and N84^{o}E, and a present day stress regime that is transitional strike-slip to reverse (Bailey, et al., 2012; King et al., 2008; King, et al., 2011) However, detailed geomechanical studies undertaken on data from Arrowsmith-2 indicate that S_{hmax} has rotated slightly to N110^{o}E and the present day stress regime is extensional – something that is unique in the area (Castillo, 2012). In addition, Castillo (2012) reports that a significant number of natural fractures encountered the Arrowsmith-2 well are critically stressed and therefore have a higher potential to be permeable.

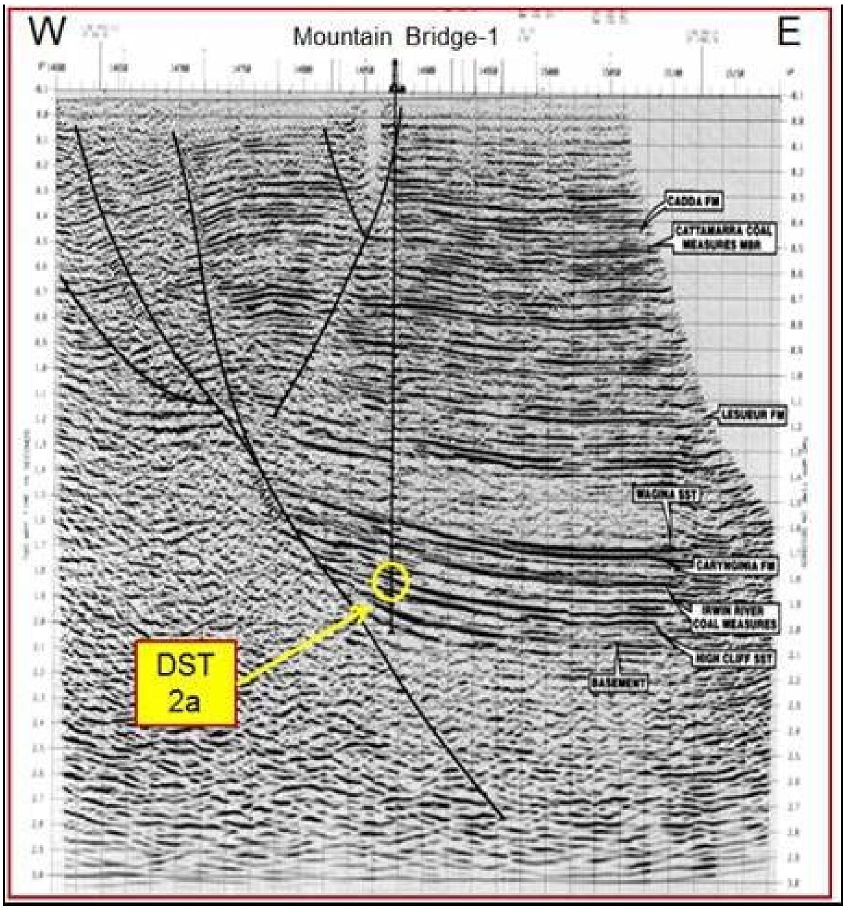

Figure 4. Seismic line through the Mountain Bridge-1 well location. DST-2a in the High Cliff Sandstone flowed 146oC water at 2000-3000 bpd from natural fractures. (modified after Sagasco, 1993)

The results of Mountain Bridge-1 provide substantial encouragement for the presence of a viable geothermal reservoir associated with natural fractures, particularly when viewed in the context of the Arrowsmith-2 geomechanical results. The well was drilled in 1993 to a total depth of 3416m. It penetrated 738m of Permian sediments prior to encountering granitic basement at 3385m. The results indicated very poor to nil matrix porosities in the lithologies penetrated below 2600m, with the exception of the Early Permian High Cliff Sandstone.

Analysis of a conventional core cut through the High Cliff Sandstone (3211.3-3228.8m) showed poor intergranular porosity (1-8%) with negligible permeability (average 0.01 mD) but the development of intersecting conjugate open fractures and a brecciated zone at 3224.4m that resulted in good fracture porosity and permeability (Sagasco, 1993). Importantly, an open hole drill stem test (DST 2a) run over the interval 3185m-3235m flowed gas-cut water at an estimated rate of 2000-3000 bpd with 200-250 Mcfd of gas, thus confirming the presence of significant permeability associated with the fracture system. Equally importantly, the temperature of the recovered water was 146°C, which is in the required temperature range for a viable geothermal project.

Unfortunately, no image logs were recorded in the well so the orientation of the fractures in unknown and it is unclear how pervasive the fractured are outside of the cored interval. No obvious indication of faulting at the well location is apparent on the available 2D seismic data (Figure 4). It is important to note that the well was not located optimally to test the fracture system associated with the Beagle Fault – a geothermal well would certainly be designed to drill through the fault plane itself, which Mountain Bridge-1 does not appear to have done (Figure 4). Likewise, no attempt was made to stimulate the well in order to assess the potential of the fracture system. These factors suggest that there may be opportunities to locate a substantial network of fracture permeability if additional data were available and the well was planned to target and evaluate potential fracture permeability.

FUTURE STUDIES

Recent results from other geothermal projects in Australia have clearly shown that identifying zones with sufficient permeability to sustain commercially viable flow rates is the biggest risk in geothermal exploration (eg. Badalyan et al., 2013). Efforts to date have utilised image log data from the wells and AFE from 3D seismic data in conjunction with regional geomechanical models to identify areas with relatively high densities of faults that are favourably oriented to be critically stressed and therefore permeable. The results of Mountain Bridge-1 demonstrate the existence of a permeable fracture zone, however the available 2D seismic data is only sufficient to allow major faults to be identified and correlation of these faults from one seismic line to the next is uncertain. The proposed Arrowsmith 3D seismic survey planned for acquisition late in 2014 should provide a good tool for generating a significantly improved interpretation of the fault systems in the area and thus significantly reduce the risk of encountering a viable geothermal reservoir - when the data becomes publically available.

Nevertheless, despite the improved imaging of faulting on the 3D seismic data, the analysis undertaken thus far has only been able to identify the discontinuities associated with faults - not whether these faults have associated permeability. No techniques have been available that allow direct identification of permeable faults and fractures in the subsurface and thereby provide a means for significant additional risk mitigation.

A new technique called Tomographic Fracture Imaging (TFI) uses passive seismic recording that they are to detect hydraulically transmissive fracture systems (Lacazette, et al., 2013). To date, this work has been aimed primarily at oil and gas exploration (mainly unconventional) but clearly has potential applications for geothermal exploration. Discussions have been undertaken with the EP413 Joint Venture to highlight the potential applications for evaluating the petroleum potential in the area. The impending acquisition of the Arrowsmith 3D Survey would provide an excellent opportunity to obtain TFI data, and if this survey is acquired it would provide an exciting opportunity to incorporate in the geothermal exploration workflow.

SUMMARY AND CONCLUSIONS

Available data indicates that the Mountain Bridge area offers very good potential as a geothermal target. It has high heat flows that have been verified by multiple wells and has successfully flowed 146°C water from fracture-related permeability, thus demonstrating the validity of the reservoir model in this area.

The primary concern about this area in the past was the lack of 3D seismic data. This issue will be addressed by the impending acquisition of the Arrowsmith 3D survey. Incorporating the results from this survey should significantly the risks associated with defining the prospect. Furthermore, the Arrowsmith survey could provide a unique opportunity to acquire passive seismic data for use in TFI processing. Should such a data set become available, it could result in not only a successful geothermal project, but a workflow that can be used to effectively mitigate exploration risks that have proved one of the greatest challenges for geothermal explorers.

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