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Update of Development of the Geothermal Field in the Granite at Innamincka, South Australia.

Doone Wyborn

Geodynamics Limited; PO Box 2046, Milton, Qld, 4064, Australia

doone.wyborn@geodynamics.com.au

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ABSTRACT

Geodynamics Limited is developing a geothermal field in unusual geological conditions using the principles of stimulation and circulation currently advocated for Enhanced Geothermal Systems (EGS). A granitic body of about 1000 km^2 is located beneath sedimentary rocks 3.5 to 4 km thick. High heat flow and high temperature gradients in the sedimentary rocks have long been established over the granite. The granite is elongated meridionally and is about 50 km by 20 km. To date three areas within the central part of the granite have been explored each about 10km apart. These three areas have been named the Habanero, Jolokia and Savina geothermal developments.

Each of the developments is characterised by the presence of natural fractures within the granite with high fluid overpressures manifesting in the five wells drilled so far at surface with a value around 34 MPa. The cause, extent and significance of this regionally extensive overpressure will be discussed. The fracture networks discovered and enhanced by stimulation will be described and a general crustal model of fracture development proposed.

The overall aim is to build geothermal power stations as modules spread throughout the area with one station every 4 km^2. Each power station will likely be based on nine wells, 5 production wells and 4 injection wells, with a down-hole well spacing of about 1 km. The wells for each module could be drilled from the one drill pad located beside the power station. The potential to build several hundred power stations of this module size exists, however an initial commercial project is expected to provide around 50 MWe net based on projected flow rates of 70-100 kg/sec and wellhead temperatures of 240-270ºC at each production well. At full development this would amount to around 12,500 MWe potential for the granite with extraction of stored heat down to a depth of 5 km.

1. INTRODUCTION

Geodynamics recently completed its 'Proof of Concept' EGS program, with the completion of a closed loop test at the Habanero 1 and 3 wells. The wells were drilled 560 m apart into granitic basement beneath the Cooper Basin in northern South Australia south of the town of Innamincka. From these wells a stimulated reservoir was created at a depth of 4,250 m where the rock temperature is 247°C. The closed loop test confirmed the previously established large size of the Habanero stimulated reservoir. In achieving Proof of Concept the company demonstrated a number of key elements including:

- Resource definition
- Ability to drill and complete wells
- Ability to hydraulically stimulate fractures
- Ability to develop a substantial reservoir volume
- Confirming fluid circulation between production and injection wells
- Forecasting resource degradation

These achievements do not imply economic viability at this time. The closed loop test was the culmination of 6 years of work by the company.

Commercial demonstration will focus on improving drilling performance and well costs and demonstrate the ability to stimulate and circulate through multiple zones in the granite to enhance well productivity and injectivity and increase the recoverable resource base.

1.1. Tenements

The Geodynamics exploration licenses are shown in Figure 1. The tenements cover an area of 1,968 km^2 and include Geothermal Exploration Licenses (GEL's) and Geothermal Retention Licenses (GRL's), with most of the field work having been carried out at the Habanero site.

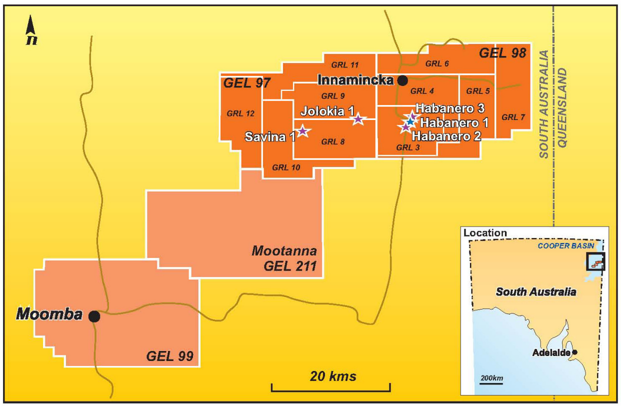


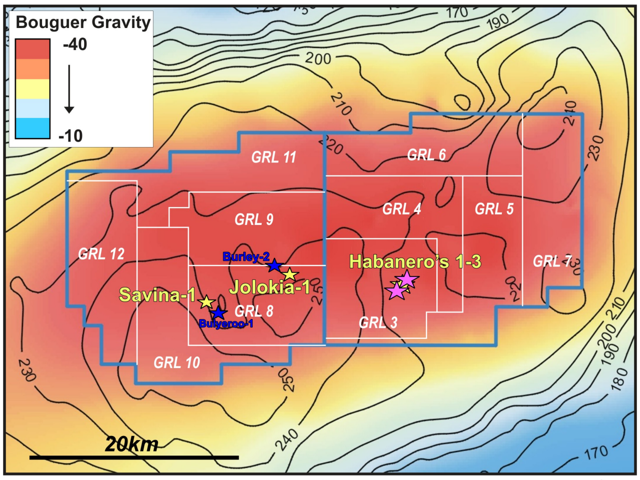
Figure 1 Geodynamics' South Australian Tenements contained in Geothermal Exploration Licenses (GEL's) and Geothermal Retention Licenses (GRL's). These licenses are held in joint venture relationship with Origin Energy Resources Limited (30%).

1.2. Geology

The Innamincka project is targeting EGS reservoirs to be developed in massive granite that have been known since petroleum exploration drilling intersected the basement in 1983.

The sub-surface distribution of the granite was determined primarily from gravity lows and temperature data from deep petroleum wells and confirmed with deep drilling for EGS. The aggregate shape of Geothermal

Retention Licenses (GRL's) 3 to 12 was constrained to the inferred granite extent (refer figure 2).



Contours: Extrapolated basement (+/- 3.7 to 4km) temperature contours °C

Figure 2. Main area of bouguer gravity anomaly as an indication of granite basement. Temperature contours are estimates of the temperature at the top of the basement. Yellow stars are wells drilled by Geodynamics. Blue stars(Bulyeroo 1 and Burley 2) drilled for petroleum exploration. Geodynamics Geothermal Retention Licenses also shown.

The granite basement is at a depth of 3,500 m to 4,500 m over the broader area as indicated by wells and seismic surveys. The geothermal field is not related to any volcanic activity. It is based on the fortuitous confluence of a number of geological conditions. These are:

1/ The presence of a large granitic body with relatively high abundances of radiogenic elements (potassium, thorium and uranium) giving a heat productivity in the range 7-10 μwatts/m^3. The age of the granite is Carboniferous (320 million years, Gatehouse et al., 1995).

2/ Gravity modelling indicates the granite is at least 10 km thick (Meixner et al, 1999) and extends over more than 1000 km^2. This thickness is in broad agreement with the heat flow (>100 mwatts/m^2, Beardsmore, 2005) that would be attributed to a body of granite with heat generation of 10 μwatts/m^3.

3/ The granite is overlain by insulating sediments composed predominantly of shales and coal measures (Cooper Basin and Eromanga Basin). The Cooper Basin contains the largest on-shore accumulations of oil and gas in Australia.

4/ The thickness of overlying sediments is in the range 3.5 to 4.5 km. These sediments have been drilled many hundreds of times since 1960 so that drilling conditions are well known and drilling to the granite is relatively simple.

5/ The granite has been buried at that depth for about 90 million years, since the youngest formation of the Eromanga Basin, the Winton Formation is Upper Cretaceous or about 90 million years old.

6/ The top of the granite has reached an equilibrium temperature of at least 220°C and has been that way for 90 million years. The temperature gradient in the overlying sediments is around 60°C/km.

7/ The temperature of sediments immediately overlying the granite has remained above 200°C for 90 million years resulting in sediment recrystallisation, grain overgrowth and almost nil porosity.

8/ The stress conditions for the last 5-15 million years have been overthrust (minimum stress vertical).

2. RESERVOIR CONDITIONS AND DEVELOPMENT STRATEGY

2.1 Stimulation

The process of fracture stimulation, using water only, is one that has been well established for EGS development since the Los Alamos hot dry rock project in the 1970's. More than 20,000 cubic metres of water was pumped into Habanero 1 in the period November-December 2003 at pressures up to 9,800 psi. The first acoustic emissions emanated from near the main exit point of the well, at a depth of 4,254 m. During the pumping period the micro-seismicity spread laterally in every direction to a maximum distance of 1.5 km from the well and finally covered a plan area of 2.5 km^2. The vertical distribution of micro-seismicity was about 100 m which is only slightly larger than the locational uncertainty.

In August 2005 stimulation was carried out from Habanero 2 targeting fractures above the main flow zone. This stimulation was quite successful as a second layer above the main zone was clearly defined by the acoustic emissions. This zone was behind casing in Habanero 1 and high sensitivity pressure monitoring of Habanero 1 showed that the zone was poorly connected through the rock to the main zone despite it being only 150 m above. This showed that independent sub-horizontal fracture zones could be stimulated independently in the stress conditions applying in this region.

A September 2005 re-stimulation of Habanero 1 was also very instructive after the initial stimulation in 2003. Essentially the stimulation commenced where it had left off 20 months earlier. Acoustic emissions were uncommon in the already stimulated reservoir but strong activity grew outwards from its boundary. The total outward growth extended the reservoir by a further 50% during the 2005 stimulation so that the total area is now almost 4 km^2. This indicates that hydro-geo-mechanical effect does not degrade with time. The Habanero 1 stimulations of 2003 and 2005 are shown in Figure 3.

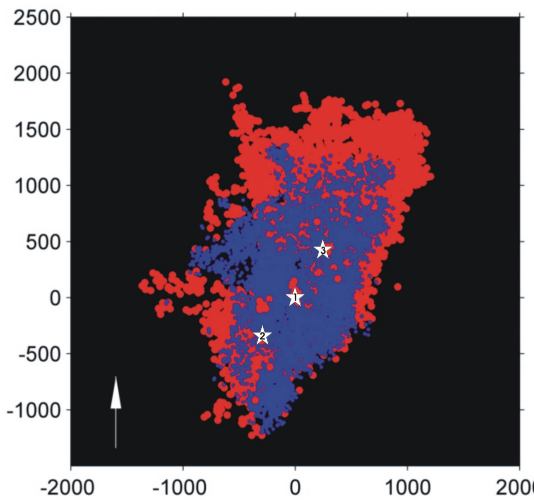


Figure 3. Habanero 1 stimulations in 2003 (blue) and 2005 (red) with the wells Habanero 1, 2, and 3 shown as white stars

In January 2008 Geodynamics completed a third well in the Habanero reservoir. The location of Habanero 3 is 550m NNE of Habanero 1, so directly opposite from Habanero 2 (Figure 3). A short stimulation locally around the well was successful and resulted in better connection of the well to the fracture system.

2.2 Fractures

The reservoir development strategy being pursued by Geodynamics assumes that there are natural fractures that are amenable to stimulation to affect the required permeability so that thermal energy can be economically extracted.

The drilling has proved the existence of these natural fractures in the granite. The fractures have been detected by a variety of methods: during drilling, image logs, flow and temperature logs and other less reliable logs such as spectral gamma and neutron logs. The fractures identified are shown in Figure 4.

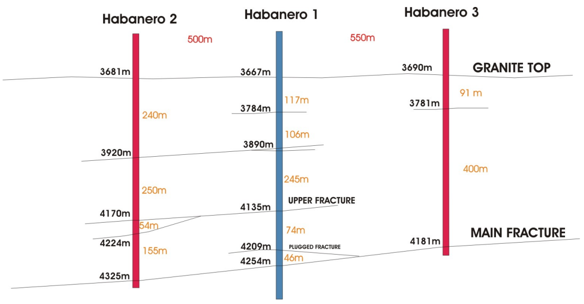


Figure 4. Location of existing natural fractures located by drilling and logging. The main fracture was stimulated from Habanero 1 in 2003 and 2005, and from Habanero 3 in 2008. The upper fracture was stimulated from Habanero 2 in 2005

An important preliminary conclusion concerning the fracture distribution is that detectable fractures may be relatively uncommon and may be spaced about 100 m apart. Some major fractures appear to have multiple branches. The dominant orientation of stimulated fractures was sub-horizontal as indicated by image logs and micro-seismic responses to stimulation. Pressure and flow responses during drilling and well testing clearly showed that some fracture zones were hydraulically connecting different wells. On the other hand, certain fracture zones could not be associated with multiple wells (e.g. the fracture at 3,920 m in Habanero 2 with the fracture at 3,890 m in Habanero 1, figure 4). The observed shallow fracture dips are consistent with the vertical orientation of the minimum principle stress in the Cooper Basin granite.

2.3. Contemporary Stress Conditions and Fluid Pressures

The natural pressure of the brine within the fracture system at Habanero is abnormally high, measuring around 34 MPa at the surface with a well full of water at a temperature in equilibrium with that of the adjacent rock. These high over-pressures are an advantage when hydraulically stimulating opening of the fractures but are a disadvantage during drilling. Similar pressures have been encountered in granite fractures at the Jolokia and Savina wells 10 km and 20 km west of Habanero respectively (Figure 2) indicating that the overpressured condition persists over most, if not the entire granite.

The origin of these over-pressures is currently speculative. During analysis of the drill cuttings across fractures it has been established that the fractures show little evidence of movement attributable to major faulting. The granite type across a fracture does not change, the degree of granite alteration does not increase adjacent to a fracture and the quartz grains from near a fracture show no more evidence of deformation than elsewhere in the rock. A good working hypothesis is that the fractures are relatively recent in age though they may have been remobilized from older structures.

It is instructive to consider these fractures in relation to the recent stress history. Currently the Australian continent is in a general overthrust stress state, a condition that has been recognized for some time (Denham & Windsor, 1991). The granite at Innamincka is in a similar condition with high horizontal stresses and the maximum stress oriented approximately E-W. However there is abundant evidence and a tectonic history (e.g. Sandiford et al, 2003) that these conditions are a relatively recent phenomena associated with crustal collision of Australia with New Guinea (Hillis et al, 2008). A hypothesis that leads to the understanding of the overpressures can be related to this recent stress history.

Prior to the Australia-New Guinea collision the horizontal stresses were rather low in Australia as Australia drifted northwards following its separation from Antarctica about 80 million years ago (Müller et al., 2000). In this case the stress conditions were probably normal or strike slip in the granite at Innamincka and overall mean stress was low. The temperature of the granite had been hot and stable for 80 million years as it was buried to its current depth at the end of Eromanga Basin deposition (Senior et al., 1978). During that period the sediments immediately above the granite recrystallised and most of their porosity destroyed. These sediments formed a pressure barrier above the granite. Petroleum industry explorers have been aware of the low porosity of these sediments despite them being gas saturated.

At the time of the collision (5-15 million years ago, a complex history; Müller et al., 2000) the high horizontal stresses propagated back from the collision across the continent and rose towards, or even surpassed the current high values. The effect of this large increase in mean stress would have been to increase the fluid pressure in rocks generally across the continent. However the pressure increases would generally be short lived and would leak off because of the natural permeability of most rocks. Only in areas where permeability barriers had been established would it take time for any overpressures to dissipate. This appears to be the case in the granite at Innamincka, and it can be attributed to recrystallisation associated with high temperatures (200-230°C) in the overlying sediments for the previous 80 million years.

The observable recent geomorphic history of the Innamincka area supports the premise that recent tectonic activity is important. The sediments of the Tertiary Lake Eyre Basin (Wopfner et al., 1974, Callen et al, 1986) were uplifted by almost 200m into a structure known as the Innamincka dome. Cooper Creek, the source of these sediments has since cut into the Innamincka dome to form a valley within its own deposits. This uplift is likely to correspond to the time when the stress conditions changed for normal to overthrust.

3. FUTURE EGS DEVELOPMENT

The granite at Innamincka extends over an area of 1,000 km^2. Current concepts of heat extraction rest on the capacity to drill wells into granite to a depth of 5 km, however drilling deeper has the potential to increase geothermal reserves. Field tests indicate that fractured reservoirs can be created to flow geothermal fluid across a well spacing of at least one kilometer. EGS designs involve nine wells being drilled directionally from a single platform or drill pad located near the power plant to reduce surface infrastructure. The well layout may involve a vertical central well and directionally drilled wells with all wells separated (down-hole) by 1 km or possibly more. The directional drilling may take place in the upper cooler sediments so that drilling in the granite is vertical or near-vertical.

The 50 MWe EGS modules are notionally designed with nine wells, including five production wells and four injection wells. These modules are based on a production temperature of 240-270°C and a production flow of 70-100 kg/sec per well. Each module is effectively a 'geothermal island' that will extract heat from the granite from an area of ~4 km^2. In order to extract heat economically for a period of at least 20 years from, say, 4.5 to 5 km below ground, multiple flowing fractures are required. Flow rates from individual fractures will also need to be sufficiently large so as to deliver a total of 70-100 kg/sec per well. To date a sustained flow rate of 30 kg/sec from a single fracture has been achieved.

For a total area of 1,000 km^2, and a 'geothermal island' every 4 km^2, it is conceivable that up to 250 power stations of 50 MWe capacity could be supported by the geothermal resource. This equates to an output of 12,500 MWe over 20+ years.

4. CONCLUSIONS

The Geodynamics EGS project has been completed to "Proof of Concept" and demonstrated extraction of heat from a reservoir developed by stimulation of natural fractures in granite at a depth of 4,250 m. The rock temperature at this depth is 247°C. The in situ rock temperatures, very high for a non-volcanic region, have developed as a result of high heat flow from a ~10-km-thick layer of radiogenic granite and thermal insulation provided by 4 km of overlying sediments. The high temperatures have been maintained for about 90 million years.

Fractures conducive to stimulation are sub-horizontal and have so far been detected with spacing of 100 m or more of vertical drill hole as indicated by drilling experience and logging. The fractures contain brine naturally over-pressured to about 34 MPa, and this overpressure seems to be uniform over a large area as delineated by Habanero 1 and Savina 1 wells (i.e. 20 km apart). The fractures and the overpressures are ascribed to recent tectonics which led to an increase in horizontal stress, an increase in mean stress, and an increase in pore fluid pressure. The overpressures are maintained by low-porosity sediments immediately above the granite (sediment porosity was destroyed during 90 million years of elevated temperature).

The fractures that have been detected during drilling and logging appear to be geologically recent. They have gained their current properties because of the increase in rock stress over the last 5-15 million years, and do not show signs of large fault displacements. Geomorphic features at surface also correspond to the stress changes that have taken place at depth.

EGS installed in the granite at Innamincka has the potential to generate up to 12,500 MWe for over 20+ years assuming that drilling 4.5 to 5 km below ground is the preferred technical option.

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