Large-scale Unconventional Geothermal Development in an Unconventional Site in Australia

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Introduction

Geodynamics Limited, a publicly listed company on the Australian Stock Exchange (listed September 2002) has been advancing a new geothermal field since 2003 that holds potential to be by far the world's largest geothermal development. The field is located near the centre of the Australian continent remote from seismically active regions but also from markets. Development techniques know as Enhanced Geothermal Systems (EGS) are being applied to extract the heat. Only large scale development can be justified in order to build transmission to the National Electricity Grid 500km away.

Geology

The field is not associated with any volcanic activity. It is based on the fortuitous confluence of a number of geological conditions (just like a giant mineral deposit). 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 5-10 µwatts/m^3. The age of the granite is Carboniferous (320 Ma).

2/ Gravity modeling indicates the granite is at least 10 km thick and extends over more than 1000 km^2.

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 3.6 to 4km making drilling to the granite relatively simple.

5/ The granite has been buried at that depth for about 100 million years.

6/ The top of the granite has reached an equilibrium temperature of at least 220°C and has been that way for 100 million years. The temperature gradient in the overlying sediments is around 60°C/km.

7/ Sediments immediately overlying the granite have been above 200°C for 100 million years and have effectively lost all porosity by grain overgrowth.

8/ The stress conditions for the last 5-10 million years have been compressional (minimum stress vertical).

9/ Prior to the last 5-10 million years the stress conditions were probably extensional (maximum stress vertical).

10/ As a result of the recent stress change (coinciding with continental collision with Indonesia and New Guinea) net stress has risen considerably and pore pressures in the fractures have risen from being hydrostatic to be more than 5,000 psi above hydrostatic.

11/ The low porosity in the hot sediments immediately overlying the granite and the low vertical permeability in highly compressed steeply dipping fractures in the granite has resulted in low leak-off of the overpressures.

12/ The overpressures in granite fractures has resulted in natural hydraulic stimulation of sub-horizontal joints and fractures on a wide scale enhancing their permeability considerably. Steeply oriented joints and fractures are not stimulated because of the recently imposed high horizontal stresses. They have very low permeability.

Current development

Geodynamics' founders understood the geothermal potential for the area in the 1990's but the potential was recognized much earlier. In the 1980's Mr. R.D. (Bob) Koch, Assistant General Manager, Drilling, in BP's Exploration and Production Department, London, recognized the significance of the high temperature gradients in the region. Bob was born in South Australia, but spent most of his life overseas with BP which he joined in 1946. He published a pioneering paper in the Journal of the South Australian Chamber of Mines in April, 1985 (Koch, 1985), where he stated "*the Cooper Basin must be one of the most significant geothermal areas in the world*". His experience in almost every oil basin in the world indicated that temperature gradients in the Cooper Basin were much higher than elsewhere, and he ascribed this to the presence of uranium-rich granites beneath. Unfortunately, not long after the 1985 paper was published, Bob Koch died, and his dream of powering South Australia with geothermal energy was temporarily held in abeyance.

In early 2002 Geodynamics obtained the right to explore for geothermal energy over an area of 1,000 km^2 corresponding to the gravity low thought to define the buried granite. Three gas exploration wells had already been drilled into the granite to establish temperature gradients and granite heat productivity. The first well, Habanero 1, named after the world's hottest chilli pepper, was designed as an injector. It was drilled to 4,421 m by October 2003. Several permeable fractures were intersected in the granite and an overpressure of 5,000 psi was established. Difficulty in controlling the overpressures resulted in mud losses amounting to over 2,000 barrels.

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 resultant acoustic emissions were monitored in real time by a network of 8 three-component borehole sondes. As expected, acoustic emissions commenced close to the known main exit point in the well, at a depth of 4,254m. Over the pumping period they spread laterally in every direction out to a maximum distance of 1.5 km from the well and covering an area in plan view of 2.5km^2. The vertical distribution was little more than the vertical locational error of around 100m. This enhanced reservoir is considerably larger than that of any previous EGS project.

A production well, Habanero 2, was sited, based on a detailed analysis of the acoustic emissions, at a location 500m SSW of Habanero 1. The main fracture zone was targeted at a depth of 4,310 ± 50m at this location. Habanero 2 was drilled in late 2004 using a process known as Managed Pressure Drilling (MPD). The mud weight was deliberately kept slightly below balance and an automated choke system applied a back pressure to keep the well on balance, with different pressures being applied depending on the operation at the time. Fractures above the target were intersected at a depth of 4,100 to 4,150m and the MPD system was kept on-balance with these fractures. At a depth of 4,325m, within 15m of the target depth a major fracture zone was intersected and the well suffered massive losses. The well was finally completed blind after drilling another 17m with all cuttings lost into the fracture zone along with a number of pills of Lost Circulation Material (LCM).

Unfortunately further problems with the well including the breaking of the drill string (requiring a side-track) and the loss down hole of a bridge plug resulted in a sub-optimal connection with the target fracture zone. Flow testing was carried out in the period April to July 2005 using the overpressures to drive production. The flow resulted in an instantaneous pressure decline in Habanero 1 proving the connection to the injection well 500m away. The maximum flow was 25 kg/second and maximum surface temperature achieved was 210°C. However with declining production and chaotic pressure surges it was clear that the dropped bridge plug was located above the main flow zone and being packed off by debris (granite cuttings, borehole breakout and LCM). Eventually connection to the main flow zone was lost.

In August and September 2005 further stimulation was carried out in both Habanero 2 and Habanero 1. The Habanero 2 stimulation was targeted at fractures above the main flow zone that were not blocked off. This stimulation was quite successful as a second layer above the main zone was clearly defined by the acoustic emissions. This zone had been cased off 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 150m above. This showed that independent sub-horizontal fracture zones could be stimulated independently in the stress conditions applying in this region.

The September 2005 re-stimulation in 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 of Habanero 1 so that the total area is now almost 4 km^2. This essentially means that once the area has been stimulated to a certain level it remains that way. Reservoir evaluation by our consultant reservoir engineers, Q-con GmbH, indicated an enhancement of fracture permeability of at least 100 times above a permeability already enhanced by the natural overpressures. The highly-connected fluid volume was estimated at 11 million cubic metres.

Despite these successful stimulations, access to the main reservoir is blocked in the production well and access to the upper reservoir is cased off in the injection well so circulation testing could not be achieved in the classical sense. In 2006 we attempted to drill around the lost bridge plug in Habanero 2 using a snubbing unit. Under this scenario water would be used as the drilling fluid and the well would be allowed to flow. A high back-pressure would be applied at surface to minimize flow. Unfortunately this operation failed when the drill pipe became irretrievably stuck 100m short of the target. Because of the high differential stress in the rock, the lowering of fluid pressure in the hole resulted in excessive borehole breakout that lead to the stuck pipe condition.

In 2007 Geodynamics re-assessed its position on drilling and decided to purchase a rig to drill a new well known as Habanero 3. The location of Habanero 3 is 550m NNE of Habanero 1, so directly opposite from Habanero 2.

The well will be 8 ½ inch in the granite rather than 6 inch in the earlier two wells. A larger diameter drill pipe and more robust equipment will reduce risks. Habanero 3 is targeted at the main zone at a depth of 4,160m. The rig that has been purchased is manufactured by LeTourneau of Longview, Texas. It is a 3000 hp AC drive model LDW1000k. The rig is due to arrive in Australia at the end of June 2007 and we expect to spud Habanero 3 before the end of July 2007. Following the successful completion of drilling, a 6 week circulation test should be completed by the end of 2007 with formal geothermal reserves declared.

Future Directions

Geodynamics has an ambitious plan to scale-up the project with the concept of drilling deeper and drilling multi-well grids of interconnected production and re-injection wells. We intend to drill wells to a depth of 5km, but 6km is also possible where the temperature is expected to be well over 300°C. The scale-up is dependent on stimulating a number of parallel fracture zones over the depth interval 4,200m to 5,000m. On the basis of assessed characteristics of the main fracture zone as presently determined, modeling of a 41-well system consisting of 25 production wells and 16 injection wells in a square pattern can produce 250 megawatts net. Production and re-injection wells are nominally 1km apart. The model indicates that production temperatures will draw down by 12°C after 20 years and 40°C after 50 years. The life of such a system would be well in excess of 50 years.

The initial scale-up is to 40 megawatts net consisting of four production wells and three re-injection wells. Habanero 3, being of larger diameter will be the first of this 40 megawatt commercial development. This is planned to be in production by late 2010. With a continued accelerated drilling program we are planning further scale-up to 500 megawatts (85 wells) by 2015.

In principle, the whole of Geodynamics 1000 km^2 tenement area could be accessed for its heat resources. To a depth of 5km this is equivalent to 57 billion barrels of oil, or more than 20 times Australia’s current oil reserves. To a depth of 6km the potential doubles to more than 100 billion barrels of oil equivalent, or about 10% of the total worlds oil reserves. This area has the potential to provide Australia with the equivalent of all its electricity requirements at current production levels for over 100 years. As far as is known there is no other area on Earth with the heat content of Geodynamics tenement in the Cooper Basin area, and with the potential for extraction of that heat from expansive horizontally oriented reservoirs through multi-well networks.

References

Koch, R.D., 1985, Geothermal – South Australia’s future energy bonanza. Journal of South Australian Chamber of Mines (Johnny Green’s Journal), 5 (4), April 1985, 22-26.

Web sites

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