Australian Government
Geoscience Australia

Induced Seismicity and Geothermal Power Development in Australia

Hot Rock geothermal power production utilises buried hot rocks to heat water and generate electricity. Australia is thought to have a large geothermal resource, with the potential to provide low-emission, cost-competitive energy for centuries to come. To make potential Hot Rock (HR) resources viable for power production, artificial fracture enhancement (hydrofracturing) may be required. One possible hazard associated with enhancing these fractures is induced seismicity.

Induced seismicity

'Induced seismicity' is the term used to describe earthquakes generated by human activities. Induced earthquakes are associated with the movement of material into or out of the earth, for example during water reservoir filling, underground mining and development of HR reservoirs. Exploration for geothermal energy in Australia has rapidly increased over the last five years, and exploration leases have been taken out around Melbourne, Adelaide, Hobart and Geelong. If shown to have viable geothermal resources, geological enhancement of these areas for HR power production may induce seismicity. Experience in Australia and elsewhere in the world to date suggests that the risks associated with hydrofracturing-induced seismicity are low compared to that of natural earthquakes, and can be reduced by careful management and monitoring.

Geothermal power production in Australia

To develop a Hot Rock resource, the three basic components of a geothermal system must be present:

- a heat source;
- a reservoir (permeable rock); and
- fluid to extract heat and move it to surface.

The heat source is the only component that has to exist naturally, as reservoirs can be artificially created and fluids can be introduced via boreholes or 'wells'. Heat sources in Australia include high-heat-producing granites, which often have low natural permeability or fluid content. Permeability is increased by injecting water under pressure into the rock to reopen existing fractures and create void space. This process is known as 'hydrofracturing'. Depending on the orientation of stresses in the earth, fractures can be horizontal, vertical, or at an angle. A horizontal fracture network is considered optimal, as it reduces water loss to the surrounding rock and increases the efficiency of the system. The hydrofracturing process can last for several weeks depending on the degree of fracturing required and the type of rock being fractured. Once the three basic elements are in place, the geothermal resource can be used to generate electricity (see Electricity Generation Factsheet at www.ga.gov.au for more detail).

Geothermal hydrofracturing projects in Australia to date

In the last few years companies have begun to explore HR resources in Australia. As of June 2008, Geodynamics Ltd have the most advanced project, with three geothermal wells drilled in the Cooper Basin, South Australia (Habanero 1, 2 and 3), and a 4th well currently underway (Jolokia 1). In 2003 and 2005, hydrofracturing tests conducted in Habanero 1 (4421 m deep) successfully created a sub-horizontal fracture network and the first induced seismicity dataset from an Australian geothermal development.

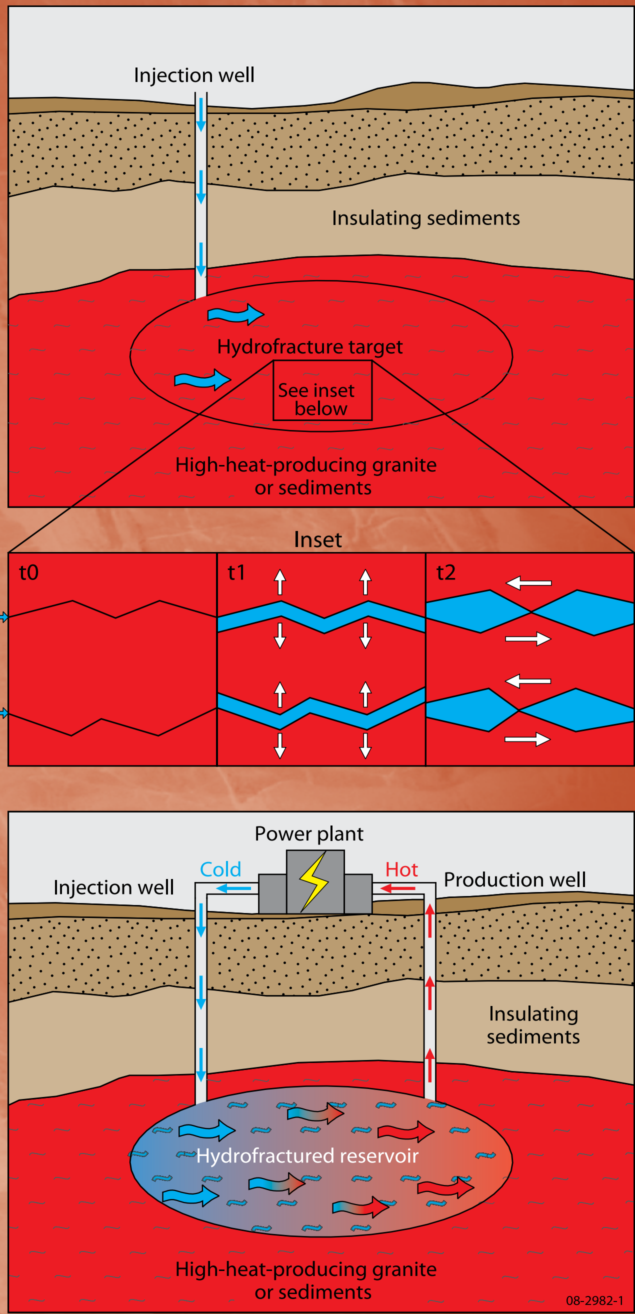

Figure 1: Reservoir enhancement by hydrofracturing, and subsequent geothermal power production.

Top: a natural hot rock reservoir ready for enhancement. Inset: the progressive expansion of small pre-existing fractures in the granite as water is injected. At t0 water is injected, at t1 fractures expand vertically under increased fluid pressure, at t2 horizontal movement props fractures open permanently, increasing rock permeability.

Bottom: a closed loop geothermal power production scenario. Fluid is pumped down the injection well throu and returned to the surface via the production well(s). In the power plant the hot fluid transfers its heat to a secondary fluid, or working fluid, before being recirculated through the underground system.

GEOCAT #66220

Hydrofracturing-induced seismicity

Induced seismicity is caused by hydrofracturing during geothermal resource development. The energy released during hydrofracturing generates earthquakes, most of which are only detectable by sensitive seismological instruments. Earthquakes are reported using the Moment Magnitude Scale; each increase in magnitude represents a ten-fold increase in the amplitude of seismic waves. The Modified Mercalli Intensity Scale (MMI) quantifies the intensity of ground motion felt at the surface and describes the physical effects of earthquakes.

During the 2003 hydrofracturing experiments, Geodynamics Ltd recorded over 27 000 small induced earthquakes over a few weeks; of these, only three were over Magnitude (M) 3.0. As the induced earthquakes were small and occurred at depth, they were not usually felt at the surface. After the hydrofracturing process ceased, the fluid pressure in the rock fractures decreased and the incidence of induced earthquakes dropped off dramatically.

Associated risks

Earthquake magnitude is proportional to rupture length. During hydrofracturing, the length of rupture is largely controlled by the amount and rate of water injected (Baisch et al., 2006). Provided care is taken not to overpressure the system either too much or too quickly, induced earthquake rupture lengths and hence magnitudes should remain small. The hydrofracturing experiments in the Cooper Basin produced small ruptures and correspondingly small induced earthquakes. The rare larger induced earthquakes were only weakly felt over a small radius. Usually, a M 3.0 earthquake can only be felt within a 3-4 km radius of the source (Wald et al., 2006). The Geodynamics Ltd induced earthquakes occurred in a very localised area: 2.0 x 1.5 km horizontally and within a 150 - 200 m vertical range at a depth of 4.25 km (Baisch et al., 2006). This suggests that even if a M 3.0 earthquake occurred on the outer edge of the hydrofractured zone, it would only be felt within a very localised area, around 5-6 km radius of the injection well. In addition, preliminary research on hydrofracturing-induced seismicity in Australia suggests that induced earthquakes release less energy, and hence will be felt over smaller radii, than naturally occurring earthquakes of a similar size.

In order to produce infrastructure damage, earthquakes generated at ~ 5 km depth would need to be at least M 5.0 for a significant amount of energy to reach the surface (Wald et al., 2006). Infrastructure type, age, configuration, size, construction materials, site conditions, and proximity to neighbouring infrastructure can all affect how much damage an earthquake is likely to cause. Risks associated with hydrofracturing-induced seismicity appear to be low, as the earthquakes produced are small. To date, in Australia (Cooper Basin), induced earthquakes have produced minor ground tremors and no infrastructure damage.

Mitigation and management of induced seismicity

The likelihood that hydrofracturing will generate earthquakes that are felt at the surface can be minimised by:

- Careful surveying prior to the development of a geothermal reservoir to identify any large existing faults (these should be avoided to reduce the risk of larger earthquakes);
- Controlling water injection rate – reduced injection rate produces fewer earthquakes (Baisch et al., 2006);
- Controlling fracturing depth – the deeper it is the less likely small earthquakes will be felt at the surface;
- Producing fracture networks of smaller vertical extent, which may result in smaller earthquakes (as observed by Green Rock Energy Ltd and Geodynamics Ltd);

In summary, current evidence suggests that there are very low risks associated with hydrofracturing-induced seismicity. With appropriate management, induced seismicity should not be regarded as an impediment to further development of the Hot Rock geothermal energy resource.

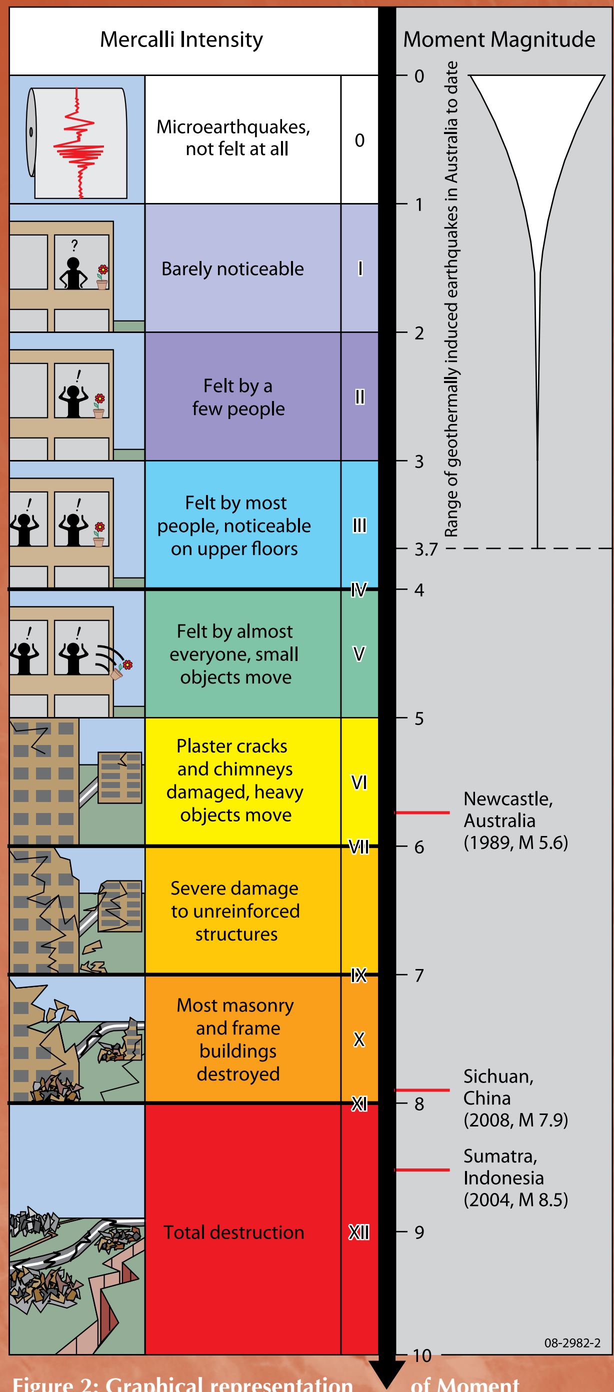

Figure 2: Graphical representation of Moment Magnitude and Modified Mercalli Intensity (MMI) scales, comparing the range of known induced earthquakes in Australia to examples of well known earthquakes in the Asia-Pacific region. The wedge shape illustrates the distribution of induced events with respect to magnitude, and the width is proportional to number of events. Most induced events occur between M 0 and M 1.0 and very few events occur above M 3.0. MMI scale based on Wood and Neumann, 1931.

References

Wald, D.J.; Worden, B.C.; Quitoriano, V.; and Pankow, K.L. (2006). Shake Map Manual: Technical Manual, Users Guide, and Software Guide. http://pubs.usgs.gov/fs.

Baisch, S.; Weidler, R.; Voros, R.; Wyborn,D.; and de Graaf, L. (2006). Induced Seismicity during the Stimulation of a Geothermal HFR Reservoir in the Cooper Basin, Australia. Bulletin of the Seismological Society of America, 96, 2242-2256.

Wood, H.O. and Neumann, F. (1931). Modified Mercalli Intensity Scale of 1931. Bulletin of the Seismological Society of America, 21, 277-283.

www.ga.gov.au/minerals/research/national/geothermal/

08-2983