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Induced Seismicity and Geothermal Energy

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Over the past year induced seismicity (*IS*) has become an important issue which Earth scientists working in the geothermal, mining, petroleum and other industries must address. We present a brief review of the history of *IS*, AltaRock's experience with the issue, and suggest possible paths forward to managing *IS*.

IS is associated with changes in stress in the Earth's crust. These can accompany withdrawal or injection of fluids during oil and gas development, enhanced oil recovery, geothermal operations, and waste disposal. *IS* is also associated with mining and the filling of reservoirs. Such industrial activities have occurred worldwide for decades, and scientific understanding of *IS* and our ability to manage it has increased in concert. Starting in the 1940's, oil and gas wells were hydraulically fractured with injected fluid to increase near-well permeability, and *IS* was not considered an issue. With higher volume injections, such as a waste disposal wells that penetrated deep into fractured bedrock below the Rocky Mountain Arsenal (RMA) near Denver, the possibility of *IS* in some geologic environments became apparent. Study of injection records and microseismicity recorded on a single seismometer near the RMA, indicated that increasing injected volume caused fluid pressure to rise above a critical value, causing seismic slip to occur on ideally oriented, pre-existing fractures, a mechanism for *IS* that is completely consistent with theory first presented by Hubbert and Rubey in 1959. Subsequently, *IS* rates and size distributions have been further related to geomechanical parameters such as changes of injection pressure, injected volume, stress drop, and critical stress state, contributing to an ongoing effort to develop a theoretical basis for understanding and managing *IS*. Current strategies include avoiding injecting fluid directly into large faults, avoiding large scale injection operations in densely populated areas with a history of seismic activity, monitoring *IS* with dedicated local networks, maintaining injection pressures below the critical pressure for shear failure during long term operation and controlling the volume injected into a single zone.

Engineered Geothermal Systems (EGS) have the potential to expand clean renewable, baseload energy beyond conventional geothermal areas. However, in 2009, an EGS project in Europe experienced troublesome *IS*. The project, near Basel in Switzerland, was associated with an M=3.4 earthquake, which caused alarm in the urban area and minor damage. The project was halted as a result. A review of the project concluded that the problem was not the EGS technology *per se*, but the geologic and cultural setting in which the project had been conducted.

In early 2009 AltaRock planned and commenced a DOE-funded, EGS project in the southeast Geysers, California, with the objective of creating a reservoir in intrusive rock below the currently producing steam reservoir. The Geysers is one of the most seismically active producing geothermal fields in the world. Currently about 1000 events with M>1.5, and ~20 event with M>3.0 occur there every year. During 50 years of production and injection, the largest seismic event has been an M~4.6 event, which occurred in the field in 1982.

Altarock complied with federal environmental regulations under NEPA through both the BLM and DOE. After meeting with the BLM and state and county regulators, AltaRock staff and contracted expert seismologists assessed the risk of hazardous *IS* and concluded that a significant change to existing seismic rates would be unlikely. To monitor seismicity around the project AltaRock installed a network of eight state-of-the-art borehole seismometers plus an additional strong ground motion seismometer.

The BLM issued a Finding of No Significant Impact (FONSI) for the project in June of2009 with protocols for monitoring and mitigating *IS* during the project. The DOE requires that any EGS projects with federal funding complies with protocols established by the International Energy Agency (IEA) that include a maximum threshold for shaking recorded on a strong motion seismometer in the nearest community. In December 2009, the DOE also issued a finding of no significant impact (FONSI) for the project. The DOE went on to fund three new EGS projects in the fall of 2009.

Unrelated to issues of *IS,* difficulties were encountered during redrilling of the planned injector as the hole, which penetrated unstable serpentine and mélange that repeatedly collapsed. At the end of 2009 AltaRock suspended the project pending a decision on a suitable substitute hole and pending DOE approval of further funding for the project. To date, no EGS-related injection has occurred in the southeast Geysers, and thus no *IS* was ever produced by this project.

As experience accumulates, suitable ways of managing *IS* are becoming clearer. Independent seismic hazard reviews of project areas are needed, and significant efforts should be made to inform local stakeholders. Ongoing and open communication with the media and the general public need to be maintained and efforts need to continue to refine protocols that emphasize the possible maximum strength of ground shaking in the nearest community.