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MICROEARTHQUAKE SEISMOLOGY: CINDERELLA TECHNOLOGY COMING INTO ITS OWN

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As long as people have lived near geothermal areas, it has been known that these areas generate their own small earthquakes. The earthquakes may even be graced with a special name in the local language. (They are called "hverakippir" in Icelandic.) And ever since geothermal utilization amounted to more than simply drilling shallow wells amongst the hot springs, Earth scientist have tried to use geothermal microearthquakes to help make better operations decisions.

Nevertheless, microearthquake technology has not yet matured into a primary geothermal research tool. Analyses have tended to be limited to traditional locations obtained using simple crustal models. While these have improved with the advent of better location programs, higher-quality seismic networks involving down-hole sensors, three-component instruments and careful, manual data processing, in general the improvement has been limited to moving from diffuse clouds of earthquakes to somewhat less diffuse clouds of earthquakes. There are few published case histories where microearthquake seismology has played a forefront role in major operations decisions such as where to site production wells, and how deep to drill them.

As a result of increasing anxiety over global warming, energy shortages, volatile oil prices and political control over the distribution of resources, there is currently a major upsurge in interest in geothermal resources. High-temperature water and steam reservoirs near to population centers are relatively rare, and thus there is a major focus on maturing Enhanced Geothermal Systems (EGS) technology to a point where it is commercially viable. EGS is critically dependent on the creation of new fracture networks in low-permeability formations. For this reason, microearthquake seismology will play a pivotal role because it is essentially the only method that can image fracture formation at depth and constrain the type of fracturing occurring.

Considerable work remains to be done before the full utility of microearthquake seismology is realized, however. Basic techniques exist already to extract first-order information from microearthquake data but refinements and developments are needed to deliver results of the accuracy demanded by EGS operations. Some imminent developments include:

- Improving the accuracy of relative locations of spatially close earthquakes, to improve the definition of geological structures such as planar faults. Techniques such as waveform cross-correlation need to become standard data processing tools;

- Improving the absolute location accuracy of microearthquake clusters. This is crucial if clusters are to be used to guide drilling, *e.g.* through new permeability zones created by fluid injection;

- Improving the accuracy of microearthquake moment tensors, including higher-order components. This may contribute to interpreting the still poorly understood volumetric components known to occur in geothermal earthquake mechanisms;

- Imaging the structure of geothermal heat sources beneath their seismically active production zones. The deeper heat sources of geothermal areas have very rarely been identified, limiting our understanding of the origin of geothermal energy and our ability to prospect on a large scale;

- Additional case histories are urgently needed to guide the direction of future technique developments.

These advances are all feasible and will become available in the immediate future. With full implementation of existing state-of-the-art microseismic processing tools and new advances such as those listed above, coupled with data from top-quality, optimally-designed seismic networks, microearthquake technology promises to come into its own and become the most important geophysical tool for assessing the success of EGS experiments.

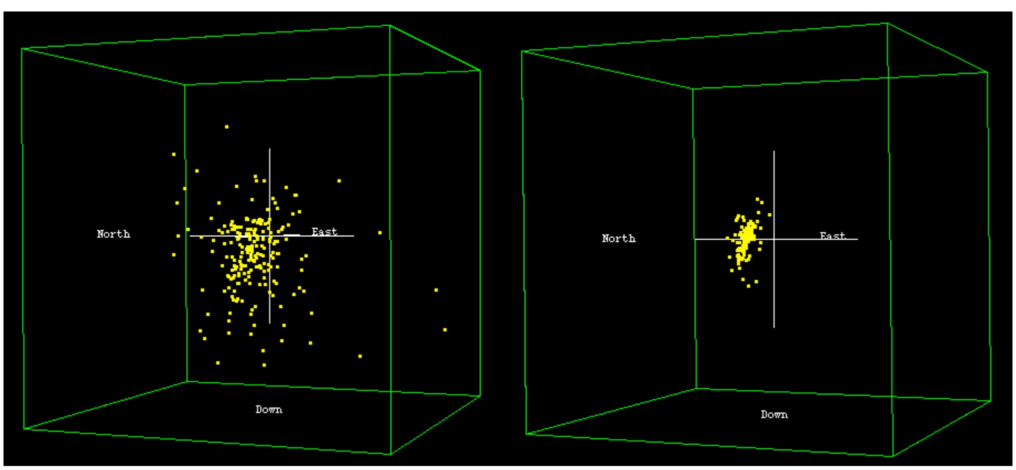

Figure 1: Before and after–locations and relative locations. But do we know the absolute location of the new fault sufficiently accurately to drill through it?