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Improved Methods for Mapping Permeability and Heat sources in Geothermal Areas using Microearthquake Data

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Geothermal microearthquakes, and the seismic waves they generate, provide a rich source of information about physical processes associated with Enhanced Geothermal Systems (EGS) experiments and other geothermal operations. With support from the Dept. of Energy, we are developing two software packages to enhance the utility of microearthquake data in geothermal operations and EGS experiments:

1. Relative hypocenter location techniques produce three-dimensional images showing in fine detail the geometry of microearthquake clusters, and thus failure zones. These images are valuable for diagnosing failure mechanisms and for identifying promising drilling targets, but they suffer from a fundamental weakness: they are relatively insensitive to absolute locations and generally yield cluster locations with excellent structural detail but poorly located as a whole. We are refining the hypocenter-location program **hypocc** to use both absolute and differential arrival times, in order to constrain the absolute, as well as relative, locations of clusters. This program can use three-dimensional ray tracing to take full advantage of detailed information about local structure when it is available, and can also use simpler (*e.g.*, one-dimensional) models for less well-constrained cases.

2. Local-earthquake tomography produces three-dimensional images of the seismic wave-speed structure that can delineate geothermal reservoirs and detect and measure temporal changes caused by geothermal operations. But because waves from local earthquakes travel upward to surface or shallow-borehole seismometers, they provide no information about the deeper portions of geothermal reservoirs or the regions below them. An additional problem is that some geothermal areas are only weakly seismogenic, and provide few data useful for tomographic inversion. We are extending the local-earthquake tomography program **tomo4d** to use data from regional earthquakes (out to distances of a few hundred kilometers) as well as from local earthquakes. Waves from regional earthquakes pass beneath geothermal areas, and using them can provide more accurate and complete models, including the deeper portions of reservoirs and the underlying heat sources.

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