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Geothermal Seismology: The State of the Art

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Injecting fluid into crustal rocks for purposes such as engineering geothermal systems and sequestering CO_2 often has, as a side effect, the stimulation of seismic activity. Understanding the physical processes involved is important for controlling the maximum size of such earthquakes, and limiting the damage that they might cause. At the same time, the seismic waves from induced earthquakes provide a rich source of potentially high-resolution information about these physical processes. Many recent seismological developments, such as the moment-tensor source representation, high-resolution relative hypocenter-determination, and time-dependent seismic tomography, have greatly advanced our ability to extract this information from seismograms, particularly when different result types (*e.g.* moment tensors and relative hypocenter locations) are interpreted together. Many challenges still remain, however. Confidence assessments for derived quantities are essential components of an y scientific investigation. Methods for computing confidence regions for moment-tensor source mechanisms have not been available until recently, and are still a rapidly developing subject, especially for very small (micro-) earthquakes. Most common hypocenter-location computer programs use methods that involve highly unrealistic assumptions about the sources of errors, e.g., that the crustal velocity structure is perfectly known, and produce confidence regions that are too optimistic by an order of magnitude. In truth, hypocenter location errors are dominated by real geophysical travel-time anomalies, not seismogram-reading errors. Methods based on stochastic modeling of wave-speed variations in the Earth can greatly improve both estimated hypocenters and estimated hypocentral confidence regions. The three-dimensional seismic-wave speed structure can delineate geothermal reservoirs, and temporal changes in wave speeds can be used to monitor changes in pore-fluid pressure within them. Local microearthquakes in geothermal areas, however, are s hallow, and cannot be used to determine structure at great depth. We have extended tomographic methods to combine data from local and regional earthquakes. In cases where suitable seismicity exists, this extension will enable us to measure wave speeds, and their temporal changes, within the deep parts of reservoirs and the heat sources beneath them. This work is resulting in important steps forward in making microearthquake studies an practical industrial tool for planning, guiding, and managing industrial reservoir fluid injection.