

Seismic characterisation of hydraulic stimulation tests at the Coso geothermal area, California

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We studied microearthquakes before, during and after fluid injection tests at the Coso geothermal area, California, to map the fractures formed, determine the mode and sense of failure, and characterize the stress cycle associated with injection. Our approach is based on joint interpretation of high-resolution relative earthquake relocations and full earthquake moment tensors. We developed advanced computer programs for this work, which include combining waveform cross-correlation with relative relocation methods, and rigorously assessing the confidence regions for moment tensors derived using linear-programming methods. Using a high-quality permanent network of three-component digital borehole seismometers operated by the US Navy, supplemented by 14 portable three-component digital instruments installed at the surface, we analysed several months of data spanning injection experiments in well 34A-9 in 2004, well 34-9RD2 in 2005, and pre-injection earthquakes near well 46A-19RD. In the case of injection into well 34A-9, the co-injection earthquakes were more numerous, smaller, more explosive and had more horizontal motion, compared with the background earthquakes. Injection modulated the stress orientation in the activated volume for at least two months after injection ceased. In the case of well 34-9RD2, the injection produced spatially coherent seismicity different from the scattered background activity that occurs continuously there. The relocated hypocenters reveal the dimensions and orientation of a well-defined planar structure, 700 m long, 600 m high in the depth range 0.8 to 1.4 km below sea level, striking N 20 degrees E and dipping 75 degrees to the WNW. The moment tensors show that it represented a mode I (opening) crack. The seismicity rate and stress state of the rock volume in the neighborhood of the bottom of the well did not return to its background state for at least two months following the injection.