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Seismic Monitoring of a Hydrofracture Experiment in an Indonesian Geothermal Field

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We applied multiple data-processing techniques to 237 earthquakes in order to study the effect of a water injection experiment in a geothermal field in Indonesia. We obtained an optimal a-priori one-dimensional crustal model by inverting the entire set of P- and S-wave arrival time measurements. The relocated earthquakes clustered close to the bottom of the injection well, and these locations provide the best estimate of absolute location of the cluster.

We computed relative hypocenter locations from arrival-time differences using the program hypocc, which gave a spectacular improvement in the clustering of the locations. A planar structure was imaged, striking N 50˚ E and dipping 70˚ to the NW. It was ~ 400 m long (along strike) and ~ 400 m high (down dip).

We obtained moment tensors for 38 earthquakes by inverting body-wave amplitude ratios. Most had large explosive components and fit a model of combined tensile crack opening and shear. Most were consistent with both components responding to the same stress field, but a significant number, including some of the larger earthquakes, required different orientations for the stress fields, corresponding to the opening and shear components. An additional component of fluid inflow into the newly formed crack at the moment of rupture is also required to fit the data.

Jointly interpreting all the results yields a detailed picture of the effect of water injection into the well. We conclude that the water flowed into a pre-existing fault zone, part of which was activated seismically with a tiny foreshock followed immediately by a large M 3.3 earthquake. This large earthquake affected some tens of metres of the fault, causing opening at the millimetre level, combined with shear slip. Failure in this mode then propagated out over a ~ 400 x 400-m plane via many more smaller earthquakes. The activated plane may represent part of a more extensive fault zone.