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Microseismicity illuminates open fractures in the shallow crust

Rebecca Lunn (1), Stella Pytharouli (1), Zoe Shipton (1), James Kirkpatrick (2), and Aderson Farias do Nascimento (3)

(1) University of Strathclyde, Department of Civil Engineering, Glasgow, United Kingdom (rebecca.lunn@strath.ac.uk), (2) Earth and Marine Sciences Department, University of California Santa Cruz, Santa Cruz, CA, United States, (3) Departamento de Geofisica, Universidade Federal do Rio Grande do Norte, Natal, Brazil

Geological carbon storage and radioactive waste disposal require proof of robust geosphere containment over thousands to millions of years. Such containment relies on long-term integrity of the surrounding rocks to inhibit upward migration of liquids and gases from a storage site/repository. Field evidence shows that fractures have the potential to act as focused pathways for rapid fluid movement to the Earth's surface and that the hydraulic properties of fractured rock may vary substantially over the timescales required for containment. Here we show that detailed microseismic monitoring can be used to image, and hydraulically characterize, the three-dimensional structure of open fractures up to 2.5 km depth. Using reservoir-induced seismicity from beneath Açu Reservoir in North East Brazil, we locate 185 micro-seismic events, the majority of which have a location error in all three dimensions of less than 10m. We use waveform cross-correlation techniques to identify clusters of events with statistically similar waveforms. For clusters containing more than 4 earthquakes, we define best-fit planes to identify the location and orientation of the fractures on which events are occurring. This results in the identification of eleven fracture planes for which the residuals (the perpendicular distances of the hypocenters from the fitted plane) are less than the earthquake
location errors. The individual fracture planes are then validated by independently derived composite focal mechanisms that are entirely consistent with the present day stress field. Our results are supported by local field observations of open fractures with lengths and orientations that match the seismically-derived fracture planes. Analysis of the temporal evolution of seismicity within individual fractures allows us to estimate both depth averaged shear fracture permeability and the heterogeneous within-plane permeability distribution. This research demonstrates the potential for using detailed microseismic monitoring to characterise flowing fractures, as a key part of site investigation at carbon dioxide and radioactive waste storage/disposal sites.