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Observation of TCDP Borehole Seismometers: Evidence of the Isotropic Hydraulic Fracturing Events, and Scaling of Microearthquakes

Abstract:

Shear failure is the dominant mode of earthquake-causing rock failure along faults. High fluid pressure can also potentially induce rock failure by opening cavities and cracks, but an active example of this process has never been directly observed in a fault zone. Using borehole array data collected along the low-stress Chelungpu fault zone, Taiwan, here we observed several small seismic events (I-type events) in a fluid-rich permeable zone directly below the impermeable slip zone of the 1999 Mw 7.6 Chi-Chi earthquake. Modeling of the events suggests an isotropic, non-shear source mechanism likely associated with natural hydraulic fractures. These seismic events may be associated with the formation of veins and other fluid features often observed in rocks surrounding fault zones and may be similar to artificially induced hydraulic fracturing.

In addition to the observation of I-type events, microearthquakes with magnitude down to 0.3 were also well detected by the Taiwan Chelungpu-fault Drilling Project Borehole Seismometers (TCDPBHS). Despite the large coseismic slip of 12m at the drill site during the 1999 Chi–Chi earthquake, our studies show very little seismicity near the TCDPBHS drill site 6 yr after the Chi–Chi main shock. The microearthquakes clustered at a depth of 9–12 km, where the Chelungpu thrust fault turns from a 30◦ dipping into the horizontal decollement of the Taiwan fold-and-thrust tectonic structure. Continuous GPS surveys did not observe post-slip deformation at the larger slip region and no seismicity was observed near the drill site. Therefore we suggest that the thrust belt above the decollement is locked during this interseismic period. We further investigated source parameters of 242 microearthquakes by fitting ω−2-shaped Brune source spectra to our observation data using a frequency-independent Q model. We find that the static stress drop increases significantly with increasing seismic moment. However, due to the intense debate on this topic of scalingrelations and the related self-similarity of earthquakes, we further improve the data analysis and correct for path and site effects using the Projected Landweber Deconvolution (PLD) method for events within some clusters. The PLD method analyses the source time functions of the larger and the smaller event by an iterative technique. As a result we received source dimensions and stress drops of larger events including path and site effect corrections. The results from the PLD method are less scattered and also show a positive relation between static stress drop and seismic moment. We find a similar positive trend for the apparent stress scaling with seismic moment."