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Constraints on earthquake dynamics from observations in the near-source region

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Near-source observations of earthquakes within seismically active crustal rocks in deep boreholes and mines have opened a new window for the study of the earthquake source. Advances in both sensors and high-temperature electronics enable recording of seismic waves over a very broad frequency spectrum (D.C. to several KHz) and amplitude spectrum (Earth noise floor to several g acceleration) in these challenging underground environments. By reducing the distance between source and receiver to a few hundred meters or less, it becomes possible to observe dynamic processes on space and time scales that approach those of laboratory experiments. Key questions that can be addressed in the near-source region include scaling of apparent stress and static stress drop, the minimum size of earthquakes, and the time, length and displacement scales of frictional evolution during nucleation. Using deep borehole seismometers in the main hole of the San Andreas Fault Observatory at Depth (SAFOD we routinely observed earthquakes with Mw < -1 with high signal-to-noise ratio. Events were recorded at three different sampling rates (1000, 2000, and 4000 sps) depending on observation period (2005 – 2010). Here, we focus on earthquakes with *S-P* time differences shorter than 0.5s, corresponding to hypocentral distance less than 3 km. Earthquake source parameters determined using the Multi-Window Spectral Ratio method indicate that there is no breakdown in apparent stress or stress drop scaling for Mw > -1. The smallest events have source dimensions ~ 1 m, indicating that if there is a minimum earthquake dimension it must lie near this or smaller spatial scale. Mean displacements in the smallest events are on the order of 100 microns, suggesting that the displacement weakening distance is comparable or smaller still. The rate of fault weakening can be studied using the earliest part of the P-wave arrival. We apply Kostrov's 1964 model for self-similar crack growth to determine the dynamic stress drop. For earthquake sources at distances of less than 1 km, we find no evidence for a slow initiation process. Instead, these earthquakes begin abruptly with the dynamic stress drop typically reaching 5 MPa within the first few milliseconds of rupture. Again, pointing to a very small displacement weakening distance, comparable to values measured in the laboratory.