

The Hydrologic, Metamorphic, and Frictional Habitat of Shallow Slow Earthquakes

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Abstract:

Slow slip events (SSE) and very low frequency earthquakes (VLFE) in the outermost forearc of subduction zones demonstrate that unstable slip nucleates at shallower depths and nearer the trench than previously recognized. These events provide an important opportunity to unravel the physical processes governing the nature of slip on subduction megathrusts; their source regions are accessible by drilling and well-imaged by geophysical surveys, enabling investigation of the properties and state of the plate interface. Here, we describe a suite of recent drilling, modeling, and laboratory results that, collectively, advance our understanding of the habitat of these events.

Estimates of in situ pore fluid pressure obtained by combining laboratory measurements on core samples with P-wave velocities from regional geophysical surveys show that the slow earthquake source regions are highly and locally overpressured, with pore pressures ~75–90% of lithostatic. Kinetic models of smectite-illite transformation show that the reaction and peak fluid release occur mostly updip of the slow earthquake source areas. Laboratory frictional experiments on samples cored from shallow faults document primarily velocity-strengthening behavior, suggesting that nucleation of unstable slip is unlikely. However, a minimum in the friction rate dependence parameter ($a-b$), reflecting nearly velocity-neutral behavior, occurs at sliding velocities of ~1–3 $\mu\text{m/s}$. Additionally, slip-weakening trends in these materials have been noted over larger distances (several mm) than used in measurement of frictional rate dependence, and are quantitatively consistent with several characteristics of slow earthquakes.

The emerging picture is that VLFE occur in a zone of highly overpressured fluids, low stress, and transitional frictional behavior. Although illitization is largely complete updip of the events, clay dehydration may augment fluid overpressures generated by disequilibrium compaction. Elevated pore fluid pressure and low effective normal stress, coupled with a minimum in frictional rate dependence at slow slip rates, likely produces a fault zone with transitional frictional stability and reduced rigidity, favoring long rise times and slow rupture.