The Environment of Episodic Tremor and Slip:
Temperature, Rock Composition, and Water

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In this study we examined the special conditions associated with episodic slip and tremor (ETS): temperature and rock composition where ETS occurs, and the probable role of water driven upward from the dehydrating subducting plate. Detailed numerical thermal models constrained by heat flow and other temperature indicators are now available for many subduction zones. For hot subduction zones like Cascadia and SW Japan the downdip limit of great earthquake rupture is at about 350C with a transition to stable sliding at about 450C. ETS slow slip occurs downdip from this limit extending until just landward of where the thrust meets the aseismic forearc mantle, i.e, 450-550C, at a depth range of 30-50 km. For these temperatures, laboratory data indicate velocity strengthening (stable sliding) for quartzofelspathic rocks, so a special mechanism is required for slip events. Increasing pore pressure on the thrust from rising fluids, that is released episodically is one possible mechanism.

The subducting oceanic crust and entrained sediments carry large amounts of water (e.g., 5-10% avg. porosity) that are initially incorporated in low temperature hydrated minerals. With downward increasing P-T there is progressive dehydration and water production from various metamorphic minerals. The reactions of the basalt-eclogite transformation are especially important for water expulsion. For Cascadia and SW Japan this transformation occurs mainly in the depth range of the ETS slip, i.e., ~500C, and overlying tremor zone in the forearc crust (although the depth range is still debated). Upward fluid production peaks in this region.

Landward of the ETS zone, the upward moving water hydrates the forearc mantle to serpentinite (antigorite) which laboratory data shows to be aseismic stable sliding. For Cascadia ~30% serpentinite is evident in seismic tomography data (high Poisson's Ratio). Little rising water is inferred to get through to the overlying forearc crust from this point landward. The landward termination of ETS tremor in the forearc crust at this point gives one indication that upward expelled water plays a role in ETS tremor. For cold subduction zones, most of the upward fluid expulsion is further landward beneath the forearc mantle where it is consumed in serpentinization. Fluid-related tremor is then not expected.

That substantial water is rising in the Cascadia ETS region is indicated by tomography evidence for silica concentrations in the lower forearc crust in this region (very low Poisson's Ratio). The fluids rising from the subducted slab are concluded to be silica saturated and the silica solubility decreases rapidly with upward decreasing temperature and pressure, so silica is precipitated in the lower forearc crust in the region of ETS tremor. The inferred amount of silica (quartz) approximately equals that estimated to be removed from the rising fluid in the 40 m.y. most recent phase of subduction. This quartz may represent 30% of the lower crust and is a substantial volume addition. Two possible sources for tremor in the lower to mid-forearc crust associated with this fluid are: (1) local discrete events of incremental rising percolating fluid, i.e., "mobile hydrofractures", (2) local deformation events associated with the added volume of silica deposition from the rising fluids.

The structure of exhumed deep quartz veins has been well studied (because of gold association), and a number of authors have described evidence for past earthquake rupture processes (for example the "fault valve" model of earthquakes; Sibson and others). Most outcrop sections studied represent lower temperatures, but some studies have shown evidence for "episodic hydraulic fracturing and the formation of breccias at fast strain rates" for temperature of 500-700C. Do these described processes represent the ETS tremor sources?