How the Thermal State and Surface Roughness of the Subducting Plate Control the Seismogenic Behaviour of the Megathrust

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The tectonic history of the subducting oceanic plate and the materials carried into the subduction zone by the plate provide primary control on the seismogenic behaviour of the megathrust. Here we synthesize recent modelling studies and observations on the roles of the thermal state and surface roughness of the subducting plate.

The thermal state is determined mainly by the age of the plate, but in some situations it can be modified by hydrothermal circulation within the subducting crust. In warm-slab subduction zones Nankai, Cascadia, and Mexico, the seismogenic zone is confined to a depth much shallower than the forearc Moho, due to thermally controlled shallow transition from the frictional to viscous rheology. Around the mantle wedge corner (MWC), and spatially separated from the seismogenic zone, there is abundant occurrence of Episodic Tremor and Slip (ETS) that can be explained by petrologic processes of the MWC associated with shallow dehydration of warm slabs. In other subduction zones where the slab is colder, the seismogenic zone typically extends beyond the Moho and often to a depth of ~50 km, with no ETS around the MWC.

The surface roughness is determined by the presence of bathymetric features such as seamounts and aseismic ridges, but it is commonly modified by sediment deposition or accretion and by slab faulting. For very rough slabs such as at Kyushu and northern Hikurangi, the megathrust exhibits “strong creep” –primarily cataclastic shear of a broad fault zone against strong resistance, including numerous small and medium seismic and aseismic events. The extreme structural and stress heterogeneity makes it difficult for large areas of the fault to stay locked or to rupture coherently. Very smooth faults associated with a featureless subducting seafloor and/or with the subduction of large amounts of sediments, such as in south-central Chile, Cascadia, Nankai, Alaska, and northern Sumatra, produce great earthquakes. Between these end members, low-amplitude roughness associated with horst-graben structure or small seamounts, such as along much of the Japan Trench and Costa Rica, gives rise to a mixture of large earthquakes and various slow slip events throughout the seismogenic depth range.

The thermal state and roughness work together and affect each other. A particularly notable example is northern Hikurangi, where the subducting plate is very old yet very rough. Strong creep associated with the roughness dissipates much frictional heat, resulting in a warm megathrust despite the cold slab. Tremor around the MWC (representing ETS) is observed here, like in warm-slab subduction zones.

Keywords: subduction zone, megathrust earthquakes, seismogenic zone, thermal structure of subduction zones, morphology of subducting plate, slow slip events