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All the way up and deep down: new insights on the seismogenic portion of subduction megathrusts from recent giant earthquakes and thermal modeling

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Until less than 10 years ago, there was a fairly broad consensus that seismogenic rupture could only occur between the forearc basement and the downgoing oceanic plate. This conceptual model considered that the mantle wedge was serpentinized and weak and likewise that the shallowest portion of the forearc, typically the accretionary wedge, was composed of high-porosity overpressured sediments, and that neither of these domains were capable of storing and releasing elastic stress and thus contribute to seismogenic rupture. This paradigm has been challenged by the detailed observations following the series of great megathrust earthquakes starting with the M9.1 Sumatra-Andaman Dec. 2004 earthquake and ending with the most recent M9.0 Tohoku Mar. 2011 earthquake. Deep crustal seismic surveys as well as aftershock distribution and focal mechanism studies now provide compelling evidence that seismogenic rupture commonly extends beneath the entire accretionary wedge and right up to the deep-sea trench, with low-angle thrust type focal mechanisms throughout this zone. Conversely, the down-dip limit of the seismogenic zone for both NW Sumatra and NE Japan clearly extends to well below the tip of the mantle wedge. Numerical modeling of forearc thermal structure for these two zones, considering the 100-150°C and 350-450°C isotherms as proxies for the up-dip and down-dip limits, respectively, successfully predicts the very wide extent (200 km downdip width) of the NW Sumatra seismogenic zone. For NE Japan, the thermal model successfully predicts the downdip limit, but the updip limit near the trench is more problematical. Using the same low values of interplate shear stress for both Sumatra and Japan, thermal modeling predicts a position of about 80km inboard from the trench for the 100°C isotherm along the subduction megathrust. However, both the distribution of thrust type aftershocks and published slip models indicate that the Tohoku earthquake ruptured up to the trench (where preliminary thermal models predict a temperature of only about 10°C at the decollement). We propose the hypothesis that a much higher degree of effective friction and strong shear heating along the oceanic basement - forearc basement contact could provide an explanation for this apparent paradox. Indeed, the Japan forearc has very little sediment at the trench (typically about 0.5 km) and is considered a non-accretionary (erosive) margin and thus has very different rheological properties than the NW Sumatra forearc. The hypothesis of higher effective friction and elevated shear heating for this margin configuration will be explored in greater detail in future work.