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Frictional behaviour of exhumed subduction zone sediments from the Shimanto Belt, Japan, at in-situ P-T conditions and implications for megathrust seismogenesis

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Seismogenesis on subduction zone megathrusts is generally thought to be limited to a region between the ∼100-150°C isotherms, at ∼5-15 km depth, and the ∼350°C isotherm, typically at ∼40 km depth. This zone is bounded at its up-dip and down-dip limits by aseismic zones. However, in recent years it has been discovered that very low frequency earthquakes (VLFE) and non-destructive Slow Slip Events (SSEs) or slow earthquakes nucleate in these presumed aseismic regions. Slip on megathrusts is likely to localize in the weak subducted sediments along the plate interface, which implies that the fault material is derived at least in part from these sediments. Therefore, understanding the depth distribution of seismicity and SSEs on megathrusts requires knowledge of the frictional behaviour of metapelites. We investigated such behaviour by performing shear experiments on natural megathrust fault gouges, derived from exhumed subduction zone sediments and faults exposed in the Shimanto Belt on Shikoku Island, Japan. These gouges correspond to peak paleo-temperatures of 105°C to 280°C, representing different stages in the diagenetic and metamorphic evolution of the subducted sediments, covering the shallow aseismic zone as well as the seismogenic zone. The composition of all gouges was dominated by illite/muscovite, with smaller amounts of quartz, feldspar and chlorite. We sheared these gouges at low displacement rates (0.1-100 micron/s) to address the nucleation of megathrust earthquakes and SSEs, using either a double-direct (biaxial) shear machine or a rotary shear machine. The double-direct shear experiments were performed at room temperature, 5% relative humidity and 50 MPa normal stress. The rotary shear experiments, in turn, were conducted at the sample-specific, approximate peak in-situ P-T conditions, i.e. the P-T conditions corresponding to the maximum burial depth of these samples. At room temperature, samples from different peak paleo-temperatures showed similar frictional behaviour, with near-neutral velocity dependence, i.e. stable or aseismic behaviour. When deformed at their approximate in-situ peak P-T conditions, on the other hand, the samples showed a progressive transition from strong velocity-strengthening (stable) behaviour at 105°C (notably at 10-100 micron/s), to velocity-weakening (unstable) behaviour at 280°C. The results at elevated P-T conditions match previous results on simulated illite-quartz analogue fault gouges and imply a broad transition in the slip stability of subduction megathrusts from stable (velocity-strengthening), to unstable (velocity-weakening) with increasing depth, in agreement with seismological observations.