Frictional properties of mafic metamorphic gouges: Implication for slow earthquakes along the Nankai Trough

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Both megathrust earthquakes and slow slip events have occurred at similar depth of ~30 km along the Nankai Trough, near southwest Japan. A convergent subduction boundary consists of kinds of materials such as sediments constituting an accretionary prism and mafic/ultra-mafic rock constituting crust and upper mantle. In order to understand the mechanisms relevant to subduction zone earthquakes, and to discuss the effect of physical conditions such as temperatures (T) and pore pressure ratio (λ), we need to know the mechanical properties of these rocks. In this study, we investigate frictional properties of mafic rocks constituting the oceanic crust. Note that the mafic rocks have been gradually and partially transformed to metamorphic rocks by metamorphism. The oceanic crust at the uppermost part of the Philippine Sea plate subducting along the Nankai Trough, might have been transformed by metamorphisms into prehnite-pumpellyite (PP), prehnite-actinolite (PA) and greenschist (GS) facies (~10-20 km depth) rocks, and epidote-blueschit (eBS), epidote-amphibolite (eAM) and GS facies (~20-30 km depth) rocks, based on the metamorphic facies diagram from Hacker *et al.* (2003) and the temperature-depth profile calculated by Yoshioka *et al.* (2013). Observation of natural deformation texture of GS and BS rocks shows that fined-grained actinolite (Act) and chlorite (Chl) mixture fills up a space between relatively coarse-grained amphibole, epidote, clinopyroxene and opaque minerals. These fined-grained aggregates are deformed to a large strain accommodated by coupled micro-fracturing and pressure solution. Other dominant minerals (e.g. epidote), however, seem to be little deformed, and behave as rigid bodies.
Based on the observation, mentioned above, we performed hydrothermal ring shear experiments using a mixture of actinolite (Act, ~85%) and chlorite (Chl, ~15%) at effective normal stresses (σ_n^{eff}) of 50-200 MPa, pore fluid pressures (P_f) of 50-200 MPa, T of 22.5-600°C, and sliding velocities (V) of 0.0003-0.1 mm/s. Our results show that the rate- and state-dependent friction parameter *(a-b)* is affected by both σ_n^{eff} and P_f at T = 200-400°C. At low velocity-step (e.g. 0.0003-0.001 mm/s), *(a-b)* shows negative at this temperature range, whereas it increases to positive with increasing V.
To extrapolate the results of the mechanical behaviors outside the experimental conditions, we quantify the effects of σ_n^{eff} and P_f on *(a-b)* in the lowest velocity-step from 0.0003 to 0.001 mm/s, using a multiple regression analysis. By applying the results of these empirical fits to the *P-T* conditions of the Nankai Trough, we demonstrate that a high $\lambda(P_f\ /\ (\sigma_n^{eff} + P_f)$, pore pressure ratio) above ~0.92-0.95 is needed for unstable, velocity-weakening behavior on Act + Chl gouge. However, since *(a-b)* increases with increasing V, unstable slip nucleating in a mixture of Act + Chl, can transition to stable sliding with increasing V, and stop without developing a huge rupture event. Act + Chl gouges therefore might have slipped at low velocity, resulting in slow earthquakes concentrating stress in adjacent undeformed bodies (i.e. asperities) of different assemblages and texture.

Keywords: metamorphic rock, oceanic crust, frictional behavior, Nankai Trough, amphibole, pore pressure ratio

