

Rheological properties of mafic schists: Implications for subduction dynamics

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To understand the spatial and temporal distribution of deformation (e.g., underplating and exhumation of metamorphic rocks) and earthquakes in subduction zones, it is important to constrain the rheological properties of metamorphic rocks (i.e., altered oceanic crust and sediments), and how they evolve during metamorphic reactions following hydration, carbonation and dehydration of the down-going slab. Metamorphism of oceanic crust has stimulated hypotheses on the relationship between intra-slab earthquakes and slab-wedge coupling along plate boundaries in subduction zones. While it is well known that metamorphism has important effects on material fluxes and arc volcanisms at subduction system, it remains unclear how the formation of metamorphic minerals following fluid release influences rheology. Past experimental studies on mafic metamorphic rocks were mostly concentrated on phase equilibrium, thus there are few reports on the mechanical data for these metamorphic rocks.

We conducted triaxial deformation experiments on two mafic schists sampled from the Sambagawa metamorphic belt (Shikoku Island, Japan), using Griggs-type solid pressure- medium apparatus at Brown University. Both mafic schists are mainly composed of amphibole, albite, epidote, and chlorite with small amounts of titanite and phengitic mica. However, there are differences in the peak metamorphic condition (i.e., the maximum PT condition), amphibole composition and mineral abundance of minerals in the two schists. One, which was metamorphosed at greenschist facies (pressure of ~ 0.75 GPa and temperature of ~ 400 °C), has a relatively high chlorite content (~ 12 %) and actinolite is the dominant amphibole phase. The other, metamorphosed at the epidote-amphibolite facies (pressure of ~ 1 GPa and temperature of ~ 520 °C), has a lower chlorite content (< 2 %) and hornblende is the dominant amphibole phase. Constant strain rate experiments and strain rate stepping experiments were conducted at confining pressures (P_c) from 0.76-2GPa, temperatures (T) from 300-600 °C and strain rates from 10^{-5} - 10^{-7} 1/s.

At conditions near the peak conditions of the greenschist ($P_c = 1$ GPa, $T = 400$ °C), differential stresses were higher than 1 GPa. The greenschist samples are weaker than the epidote-amphibolite samples under all experimental conditions. Both types of samples exhibit strain rate strengthening; frictional behavior that inhibits earthquake nucleation. Differential stress increased with increasing confining pressure, while friction coefficient decreased with increasing confining pressure and temperature. At $T = 400$ °C, the nominal friction coefficient (μ) for the greenschist samples was $\mu \sim 0.34$ at $P_c = 1$ GPa and $\mu \sim 0.30$ at $P_c = 1.5$ GPa; for the epidote-amphibolite, $\mu \sim 0.48$ at $P_c = 1$ GPa and $\mu \sim 0.42$ at $P_c = 1.5$ GPa. Stress exponents (n) for the greenschist samples at $P_c = 1$ GPa were $n \sim 26$ at $T = 300$ °C, $n \sim 36$ at $T = 400$ °C and $n \sim 34$ at $T = 500$ °C; for the epidote-amphibolite, $n \sim 31$ at $T = 400$ °C and $n \sim 21$ at $T = 500$ °C. Microstructures of recovered samples showed modest buckling and several localized shear zones. These features suggest that the deformation of mafic schist is accommodated by semi-brittle deformation resulting in strain localization on faults.

We also conducted deformation experiments in which temperature was increased above the thermal stability of chlorite (~ 800 °C) to simulate a prograde metamorphism in subduction zones. With increasing temperature during deformation, differential stress decreased and reached nearly 0 MPa. This suggests that such reaction-enhanced weakening of metamorphic rocks forms weak fault zones in subducting slab, which might promote detachment of oceanic crust from the subducting slab and allow underplating to forearc crust. The strain-rate strengthening behavior of these materials suggests that such faults would be relatively aseismic.

Keywords: mafic schist, subduction zone, deformation experiment, oceanic crust, semi-brittle deformation, intermediate depth earthquake