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Deformation experiments on serpentinite at high PT conditions with implications for the mechanisms of slow earthquakes

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To understand the spatial and temporal distribution of earthquakes and deformation in subduction zones, it is important to constrain the rheological properties of metamorphic rocks (i.e., altered mantle, oceanic crust and sediments), and how they evolve during metamorphic reactions following hydration, carbonation and dehydration of the down-going slab. Especially, antigorite (the high-temperature serpentine polytype) serpentinite, the dominant metamorphic phase in hydrated mantle material at the condition of mantle wedge, is the key metamorphic rock to understand the generation mechanism of slow earthquakes and slab-mantle coupling at the plate interface in subduction zones.

Deformation experiments on antigorite serpentinite were conducted within and above the thermal stability field of antigorite using a gas pressure-medium apparatus and a solid pressure-medium apparatus to understand how dehydration reactions influence the mechanical behavior of antigorite serpentinite. At 400 ℃, within the stability field of antigorite, antigorite serpentinite shows stable sliding and a positive velocity dependence of shear stress (i.e., friction coefficient). Shear stress increased with increasing confining pressure, while the friction coefficient decreases from 0.55 to 0.37 with increasing confining pressure from 200 MPa to 1500 MPa. These results indicate that antigorite serpentinite deforms by brittle and semi-brittle processes in subduction zones.

During the experiments using a gas pressure-medium apparatus at a confining pressure of 200 MPa and temperatures close to the dehydration temperature of antigorite (450-550 ℃), antigorite serpentinite shows a slow stick-slip behaviour, which is characterised by relatively long durations and small stress drops during slip, while this type of behaviour was not observed at higher temperatures when the antigorite becomes completely dehydrated. Stick-slip in this temperature range is consistent with the temperature range where slow earthquakes occur at the corner of the mantle wedge in southwest Japan and Cascadia. The scaling law of slow stick-slip in the antigorite serpentinite gouge is distinct from that of regular earthquakes and a theoretical duration estimated from the apparatus stiffness, but similar to that of slow earthquakes.

We also conducted deformation experiments in which temperature was increased above the thermal stability of antigorite to simulate a prograde metamorphism in subduction zones, similar to the experiments by Chernak and Hirth (2011) but with a general-shear geometry. With increasing temperature from 400 ℃ to 700 ℃ during deformation, differential stress decreased and reached 120 MPa. Recovered sample suggest that the strain localizes within shear fractures and limited dehydration occurred during the experiments.

These results suggest that the dehydration of antigorite can form weak zones within the mantle wedge along the plate interface in subduction zones, even if the extent of the dehydration reaction is limited. In addition, slow instabilities of the slip interface can be caused by the dehydration of antigorite within the weak zone in the antigorite serpentinite layer, which can result slow earthquakes.

Keywords: antigorite, serpentinite, semi-brittle flow, slow earthquakes, dehydration, hydrothermal condition