Rheological weakening via hydration reactions in a mantle shear zone: Implications for the initiation of oceanic plate subduction

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Plate tectonics on Earth is essential for mantle geochemistry and planetary habitability; however, its initiation remains controversial and previous geodynamic models require a preexisting zone of weakness (average stress less than 30 MPa) in the oceanic lithosphere. Although the operation of grain-sensitive creep (e.g., diffusion creep) causes a reduction in stress, fault strength near the brittle-ductile transition (BDT) remains remarkably high (1500 MPa), even when assuming olivine diffusion creep with an anomalously small grain size (1 μm) and a slow strain rate (10^{-15} s^{-1}). Although the oceanic lithosphere is considered to be dry, infiltration of seawater into a preexisting fault zone (e.g., fracture zones) will lead to the formation of hydrous phyllosilicates (e.g., amphibole, serpentine, and talc). To investigate hydration-induced rheological weakening effects on preexisting faults in intra-oceanic settings, we conducted high-pressure friction experiments on peridotite gouge under hydrothermal conditions. We find that increasing strain and reactions lead to the development of localized talc-rich shear zones, which induce an order-of-magnitude reduction in stress. The rate of reaction is strongly dependent on the degree of cataclastic deformation, rather than time.

Our laboratory experiments demonstrate that the operation of frictional-viscous flow, controlled by pressure-solution-accommodated frictional sliding on weak hydrous phyllosilicates, leads to a drastic reduction (down to 40 MPa) in the high stresses near the BDT within the oceanic lithosphere. Our results also suggest that the existence of oceans is a prerequisite for the initiation of plate tectonics on terrestrial planets (e.g., Earth); otherwise, stagnant lid convection operates in the mantle (e.g., Venus).

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