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THE RHEOLOGICAL SIGNIFICANCE OF SERPENTINITE ON SUBDUCTION ZONE DYNAMICS

Serpentinite is formed by the hydration of mantle rocks and, because of its distinctive rheological properties, has a significant influence on subduction zone dynamics. These properties include a low coefficient of friction and recovery, a weak creep strength, and slow slip behavior. In this short note, I discuss the role of these unique characteristics of serpentinite on the dynamics of subduction zones, as illustrated in Figure 1.

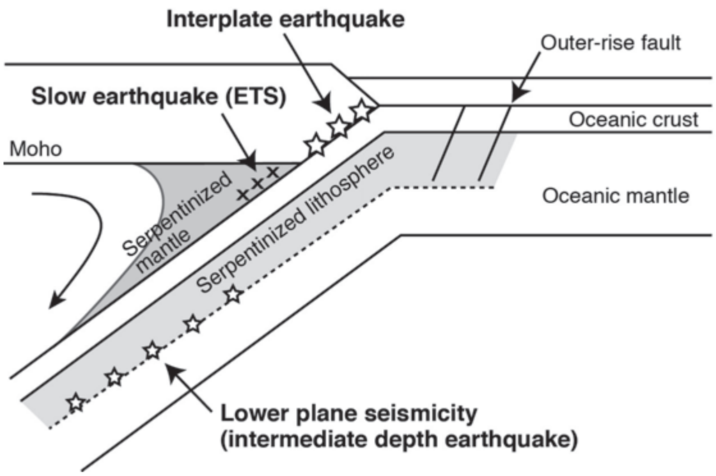

FIGURE 1 Schematic cross-section showing possible serpentinite distribution and its relation to subduction zone earthquakes

Interplate coupling along the subducting plate interface results in the great earthquakes that occur in subduction zones. However, if serpentinite is present at the subducting plate interface, the markedly low coefficient of friction and frictional recovery of serpentinite leads to a weak plate coupling (e.g. Katayama et al. 2013). Moreover, the weak plastic strength of serpentinite will enhance any ductile deformation and may result in the inhibition of subduction thrust earthquakes (e.g. Hirauchi et al. 2010). This could explain the aseismic behavior of serpentinized forearc mantle in the relatively cold subduction zones of Alaska and Chile, where the down-dip limit of interplate earthquakes coincides with the depth of the Moho. The weak plastic strength of serpentinite also influences the patterns of convection in mantle wedges, where the large contrast in plastic strength between serpentine and olivine results in a strongly decoupled plate interface, and hence a cold and stagnant forearc mantle wedge.

Although the presence of serpentinite along the subducting plate interface tends to inhibit the development of large thrust earthquakes, the occurrence of slow earthquakes, including deep low-frequency tremors and episodic slow slips, can be related to the rheological behavior of serpentinite. Aqueous fluids appear to play a critical role in the generation of slow earthquakes by elevating the pore pressure; however, the slowness of these events, compared to regular earthquakes, points to additional factors. The slow stick–slip behavior exhibited by serpentinite under hydrothermal conditions may explain the long duration and small stress release of slow earthquakes (Okazaki and Katayama 2015). This means that the generation of slow earthquakes requires not only pore-fluid pressure but also the presence and deformation of serpentinite. Such environments may be limited to relatively warm and young subduction zones, such as those of southwest Japan and Cascadia.

In the deeper parts of subduction zones, high pressures and temperatures are expected to inhibit brittle behavior. However, earthquakes are known to occur even at depths as great as 670 km. Within a subducting slab, a double seismic zone has been observed at intermediate depths of 50–200 km in several subduction zones, and the lower planes of seismicity are located within the oceanic mantle. Because serpentinite shows dehydration-related instability (Raleigh and Paterson 1965), such earthquakes might be related to the embrittlement triggered by dehydration. This "dehydration embrittlement" is attributed to increasing pore pressure as a result of a positive volume change during the dehydration reaction. However, this mechanism may disappear at depths greater than 60 km because of a negative volume change during the dehydration. Laboratory experiments have tested this phenomenon, but the results are complicated and the implications are still being debated. Another challenge for the dehydration embrittlement hypothesis is whether it can explain how oceanic mantle is hydrated at depths of several tens of kilometers. Outer-rise fault zones near the trench form one possible location at which mantle hydration occurs. Here, seawater may infiltrate along the fault planes and result in the formation of serpentinite in the oceanic mantle.

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