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Double Seismic Zones and Dehydration Reactions within the Descending Slabs

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Double seismic zones have been observed at a depth range of 50-200 km in several subduction zones. Unbending of the slab [e.g., Kawakatsu, 1986], thermoelastic stresses [e.g., Goto et al., 1985] and sagging of the subducted slab [Sleep, 1979] have been proposed as possible mechanisms for the origin of the double seismic zones. However, these are insufficient to explain the occurrence of earthquakes at depths greater than 30 km because lithostatic pressure is too high for any brittle fracture or frictional slip to take place [e.g., Kirby, 1995]. Therefore, additional mechanisms to reduce the rock strength are required for the occurrence of intermediate-depth earthquakes. Many studies emphasized the importance of dehydration embrittlement in the slab for the double seismic zone [e.g., Kirby et al., 1996; Seno and Yamanaka, 1996; Peacock, 2001]. We adopt dehydration embrittlement as a possible mechanism for inducing instability in the descending slab.

We examine the possibility whether dehydration embrittlement can explain the observed geometry of the double seismic zones in the world. We calculate reliable temperature structures of the descending slab for northern Chile [Comte et al., 1999], Cape Mendocino [Smith et al., 1993], eastern Aleutians [Hudnut and Taber, 1987], northeast Japan [Hasegawa et al., 1978; Matsuzawa et al., 1986], southwest Japan [Seno et al., 2001] and northeast Taiwan [Kao and Rau, 1999] referring to the subduction history in each area. We then compare the observed geometries of double seismic zones with the dehydration loci of metamorphosed crust and mantle on the basis of experimentally derived phase diagrams [Okamoto and Maruyama, 1999; Wunder and Schreyer, 1997; Ulmer and Trommsdorff, 1995].

The dehydration loci of crust extend to the depth of about 120 km or more. The dehydration loci of serpentine produce a double-layered structure for cold slabs, but they degenerate into a single layer for hot slabs. For northern Chile, eastern Aleutians, northeast Japan and northeast Taiwan, the upper plane of the double seismic zones is associated with the dehydration of the oceanic crust from blueschists to lowsonite-eclogite, and the lower plane is associated with the lower dehydration loci of serpentine. The deepest portion of the upper plane observed in eastern Aleutians is located at the upper dehydration loci of serpentine, but that portion observed in northeast Japan could not be explained by either the dehydration embrittlement in crust or serpentine. For Cape Mendocino and southwest Japan, the upper plane seismicity is explained by the successive dehydration of oceanic crust from greenschists to dry eclogite, and the lower plane seismicity by the degenerated dehydration loci of serpentine. We find that the upper and lower planes of double seismic zones are generally explained by the dehydration loci of crust and the lower or degenerated loci of serpentinized mantle, respectively. Therefore, existence of a double seismic zone requires hydration of the mantle rock prior to subduction at the depth corresponding to the temperature of about 600 degree for both cold and hot slabs.