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Olivine-Wadsleyite Transformation within the Subducting Pacific Slab in Kuril

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At the top of the mantle transition zone, it is commonly accepted that olivine (α) transforms to wadsleyite (β) at about 410 km depth under equilibrium conditions, i.e., a pressure of ~ 14 GPa and a temperature of ~ 1350 °C. The subsequent wave speed increase upon the α-β phase transition leads to the discovery of the 410-km discontinuity as a global feature seismologically. However, the complex topography of the “410-km discontinuity” is unclear within cold subducted oceanic lithospheres sinking into the lower mantle, partly due to the sparsity of seismic waves sampling the pertaining complex 3-D structures.

This study uses triplicated P waves (~ 2 seconds), most sensitive to the 410-km discontinuity, to invert for the characteristic parameters of its depth and radial wave speed gradients near the discontinuity. Six distinct wave propagation directions are investigated for a carefully chosen earthquake. These directions are sub-parallel to the slab depth contours in the Kuril subduction zone to guarantee a simplified layered earth modeling. Our results show azimuthal variations of the discontinuity depth either above or within the slab.

For example, the 410-km discontinuity is uplifted by 5-10 km at a depth of about 100 km above the slab upper interface. The uplift increases up to 15-20 km when the 410-km discontinuity is closer to, i.e., only 50 km above, the cold slab. This observation is consistent with the expected phase transition in equilibrium with temperatures greater than 1000°C. In contrast, within the cold slab (< 1000°C), the α-β transition exhibits drastic variations of P-wave speed. Our non-gradient-based inversion results show optimal models that place the following unique seismic constraints: 1) a significant P-wave speed increase within the slab (+5.5 ±1.5 %) compared to the ambient mantle; 2) a zone of extremely low wave speed (LVZ) within the slab with a P-wave speed reduction of -14 ±4 %. The observed LVZ is located near a depth of 350 km with an apparent thickness of 15-30 km, which can be much thinner in the direction normal to the slab upper interface.

These observations indicate a layer of destabilized olivine (LVZ) exists inside the slab. The α-β transition involves atomic diffusion highly dependent on temperature. Once olivine becomes unstable within a cold wedge, it cannot directly transform into wadsleyite. The drastic P-wave speed reduction is likely caused by the sudden grain-size reduction induced by the phase

transition, and possibly also by the transient (meta)stability of an intermediate phase, the ω-olivine, under substantial shear stress during the transformation within the cold wedge of the sinking slab.