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Geophysical and mineralogical constraints on the post-spinel transformation: A case study for the Tonga slab

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We investigate the precise depth of the 660 km discontinuity for the Tonga slab, with the aim of determining the Clapeylon slope of the post-spinel transformation. We analyze waveform data from short period seismic networks at western United States and Japan for about 100 deep (h> 500 km) and intermediate-depth (h>200km) earthquakes within a small (nearly 200 km by 200 km) area near 20S. We investigate later phases in a time window from 3 s to 20 s after direct P waves and search for S-to-P converted waves at the 660 km discontinuity, which would represent the post-spinel transformation. We find that immediately below the foci of the deepest earthquakes the discontinuity is depressed down to the depths of 685+-5 km on average. We also observe that the discontinuity dips toward WNW by 10+-3 km within about 70 km laterally. We attempt to constrain the thermal structure near the S to P conversion points based on an assumption that the deepest earthquakes occur around the coldest core of the Tonga slab. The distribution of the hypocenters relocated in this study and previously published tomographic images of the same region indicate that the Tonga slab bends upward when it approaches the 660 km discontinuity and transiently stagnates around the discontinuity, before it ultimately impinges on the lower mantle. By using these observations as the constraints, we numerically model the thermal structure of the Tonga slab. We find that the S-to-P conversion points are located inside and near the bottom of the Tonga slab. We also estimate the temperature around the conversion points as 1200 +- 100 degrees C, which is 300+-100 K colder than the surrounding mantle. As the average depression of the discontinuity (down to 685+-5 km) corresponds to an pressure excess over the global average (660 km) by 1.0+-0.2 GPa, the assumption of equilibrium post-spinel transformation gives an estimate of the Clapeyron slope (C1) of -3.3(+1.3 -2.7) MPa/K. On the other hand the observation of the dip of the discontinuity and the computed temperature variation (by about 200 K) leads to another independent estimate of the Clapeyron slope (C2) of -2.0(+-1.0) MPa/K. The discrepancy between C1 and C2 is marginally significant and can be diminished by considering that the slab materials at the conversion points are currently descending across the phase boundary fast enough and thus the depth of the post-spinel transformation is controlled by nucleation kinetics as well as by the temperature. The nucleation overpressure may be on the order of 0.5 GPa for the post-spinel transformation.

Keywords: post-spinel transformation, 660km discontinuity, Tonga slab, Clapeylon slope, kinetics, seismic array