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Direct imaging of the metastable olivine wedge for a deep dry cold slab beneath southwest Japan

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Oceanic plates subducted at trenches penetrate into the deep mantle, and encounter a structural boundary at a depth of 410km where olivine, the dominant element of mantle rocks, transforms into a higher density form wadsleyite. This transformation may be delayed within the coldest core of subducting plates (slabs) due to kinetic effects, and it has been suggested that metastable olivine may persist deeper than 410km. Using high density seismic array data in Japan, we show the direct image of the structure corresponding to this metastable olivine wedge (MOW) beneath southwest Japan. Numerical simulation of a subducting slab, including the kinetic effect of water (H2O) on the olivine-wadsleyite transformation, indicates that the presence of the imaged MOW requires an insignificant amount of water (less than 100wt. ppm) be present in the slab mantle, thus a deep dry cold slab. We infer that the transportation of water into the deep mantle occurs along the top surface of the subducting slab, but not significant amount within the slab itself.

To image the subducting Pacific plate better, we have extended the conventional CCP stacking method by introducing a "vectorial receiver function" method (Kawakatsu, 2008, JpGU, AGU), in which images parallel or sub-parallel to the dipping Pacific slab are sought. A signature indicating a low-velocity channel atop of the slab, that may correspond to the continuation of the pathway of water into the deep mantle (Kawakatsu and Watada, 2007, Science), can be traced as deep as $\sim$350km. Below 350km right beneath central/southwestern Japan, there also exist signatures inside of the slab which we attribute to those originated from the postulated meta-stable olivine wedge (MOW; Iidaka and Suetsugu, 1992, Nature). We observe both velocity decrease (from shallow to deep) and increase corresponding respectively to the upper and lower edge of the MOW which is expected to have several percent slower seismic velocity relative to the surrounding normal slab mantle and to be seismically quite visible (Kaneshima et al., 2007, EPSL; Bina and Kawakatsu, 2010, PEPI).

Recent studies of high P-T experiments indicate that metastable olivine might persist in a cold core of a slab due to the low rate of reaction associated with the olivine to wadsleyite phase transformation, and that the reaction is expected to be accelerated or decelerated depending on the amount of water present in the slab mantle (Kubo et al., 2002, PEPI). The existence of the MOW, therefore, can be used to constrain the water content within the subducting slab mantle. To consider a problem of such non-equilibrium phase transformations, we developed a 2D Cartesian numerical code which incorporates the effect of kinetics of phase transformations into the conventional model of thermal convection which solves the momentum and energy equations simultaneously (Yoshioka et al., 2008, SSJ). The results suggest that the water content in the deep part of the slab mantle cannot exceed 100wt. ppm; otherwise, the metastable olivine does not survive deep enough. In addition, our numerical simulation, which fully incorporates the kinetic effects of the phase transitions not only for 410km but also 660km discontinuities, is capable of modeling observed seismic features (MOW, and a deep depression of the 660km discontinuity) associated with the phase transformations for the deep dry cold slab (with a gentle Clapeyron slope associated with the dissociation of ringwoodite to Pv+Mwbeneath) southwest Japan in a self-consistent manner.