Seismic Evidence for Water Transport Out of the Mantle Transition Zone Beneath the European Alps

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The mantle transition zone has been considered a major water reservoir in the deep Earth. Mass transfer across the transition-zone boundaries may transport water-rich minerals from the transition zone into the water-poor upper or lower mantle. Water release in the mantle surrounding the transition zone could cause dehydration melting and produce seismic low-velocity anomalies if some conditions are met. Therefore, seismic observations of low-velocity layers surrounding the transition zone could provide clues of water circulation at mid-mantle depths. Below the Alpine orogen, a depressed 660-km discontinuity has been imaged clearly using seismic tomography and receiver functions, suggesting downwellings of materials from the transition zone. Multitaper-correlation receiver functions show prominent ~0.5-1.5% velocity reductions at ~750-800-km depths, possibly caused by partial melting in the upper part of lower mantle. The gap between the depressed 660-km discontinuity and the low-velocity layers is consistent with metallic iron as a minor phase in the topmost lower mantle reported by laboratory studies. Velocity drops atop the 410-km discontinuity are observed surrounding the Alpine orogeny, suggesting upwelling of water-rich rock from the transition zone in response to the downwelled materials below the orogeny. Our results provide evidence that convective penetration of the mantle transition zone pushes hydrated minerals both upward and downward to add hydrogen to the surrounding mantle.

Our knowledge about the density of relevant melt compositions is currently poor at deep-mantle conditions. First-principles molecular-dynamics simulations of Fe-bearing MgSiO$_3$ liquids, considering different valence and spin states of iron over the full range of mantle pressures, predict the high-spin to low-spin transition in both ferrous and ferric iron in the silicate liquid to occur gradually at pressures around 100 GPa. The calculated iron-induced changes in the melt density (about 8% increase for 25% iron content) are primarily due to the difference in atomic mass between Mg and Fe, with smaller contributions (< 2%) from the valence and spin states. A comparison of the predicted density of mixtures of (Mg,Fe)(Si,Fe)O$_3$ and (Mg,Fe)O liquids with the mantle density indicates that the density contrast between the melt and residual-solid depends strongly on pressure (depth). In the shallow lower mantle (depths < 1000 km), the melt is lighter than the solids. Therefore we expect that partial melt generated by water release at ~50-150 km below the 660-km phase discontinuity will be less dense than residual lower-mantle rock, and therefore will likely return to the mantle transition zone.

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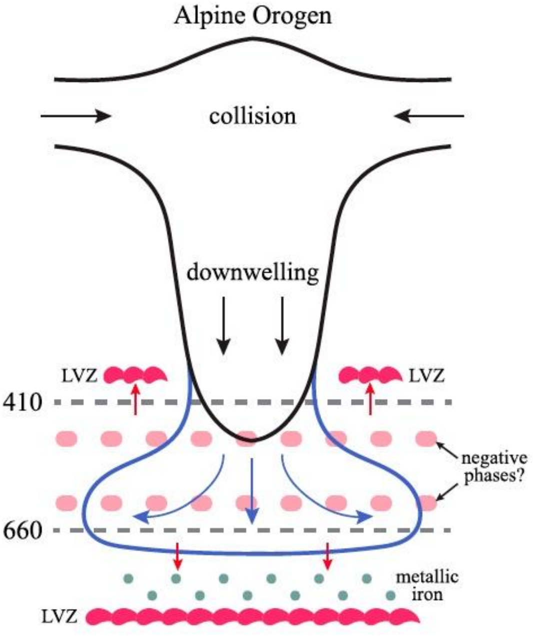

Figure: Illustrations of partial melts (red layers) associated with convective mantle flows (arrows) below the Alpine orogeny. The 660-km discontinuity and the 410-km discontinuity are indicated by two broken lines. Blue arrows indicate the flattening of downwelled lithosphere at the base of the 660-km discontinuity. Light-red patches between the 410-discontinuity and the 660-discontinuity indicate the observed negative RF-phases within the MTZ. The red arrows denote the water transport across the MTZ-boundaries. Grey dots below the 660-km discontinuity denote metallic Fe that prevents partial melting.