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Dynamics of melt and water circulation in the mantle transition zone

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The presence of melt above the mantle transition zone has been predicted by several groups, and its formation has been attributed – according to the "water filter model" (Bercovici & Karato 2003) – with causing whole mantle convection to appear geochemically layered. In recent years, various seismological studies (e.g., most recently Jasbinsek and Dueker, 2007) have collectively inferred an extensive low velocity region at 410km depth, suggestive of the predicted melt zone. The leading mechanism proposed for generating this melt zone is by dehydration melting, which is supported by modest transition-zone water concentrations inferred by electromagnetic sounding (Huang, Xu, Karato, 2005). In this mechanism, warm upwelling "damp" transition-zone material (wadsleyite) crosses the 410km boundary, and arrives above the solidus water limit in the upper-mantle (olivine) partial melt stability field. The fate of the subsequently produced melt is important for inferring the structure, observability and stability of this melt region. The most recent models of a wet melt layer spreading along the 410km boundary and reacting with a background mantle flow predict that the layer will be several 10s of kilometers thick, and that the melt's material will be entrained into the lower mantle well before it reaches any slabs (Leahy & Bercovici, 2010). At these pressures the melt is possibly more dense than the solid, although the density cross-over point is not likely to be far above the 410km boundary. However, unless the density cross-over actually intersects the melt zone, the melt is stable to any Rayleigh-Taylor instability (Youngs & Bercovici, 2009). Finally, continued re-hydration of the transition zone is required to supply the melt layer in the presence of background mantle flow. Slabs foundering and flowing horizontally across the transition zone provide one of the best means for transporting water across the transition zone. Slabs at the bottom of the transition zone release water but also extract heat, which causes double-diffusive instability (Richard and Bercovici, 2009); however chemical buoyancy allows brief but rapid convective release of water from the slab into the transition zone that also facilitates slab warming, and thus possibly contributes to slab positive buoyancy and prolonged transit across the transition zone. In the end, the complete cycle of water into and through a melt layer atop the 410km boundary, through slabs and back into the transition zone provides a rich small scale circulation that is potentially vital for regulating the mantle's geochemical structure and evolution.