Upper Mantle Discontinuity Topography Beneath South America from Thermal and Chemical Heterogeneity

Nicholas Schmerr[1,2] and Edward Garnero[1]

[1]School of Earth and Space Exploration, Arizona State University, Tempe, AZ, USA
[2]Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, DC, USA
nschmerr@dtm.ciw.edu garnero@asu.edu

Utilizing high resolution stacks of precursors to the seismic phase *SS*, we investigate seismic discontinuities associated with mineralogical phase changes approximately 410 and 660 kilometers deep within the Earth beneath South America and the surrounding oceans. The western margin of South America has experienced over 200 million years of convergence, a process that is currently manifest in the subduction of the Nazca plate beneath the continent. Tomographic imaging has revealed the presence of high shear and compressional velocities associated with subducting lithosphere; these anomalies extend into the mantle transition zone and into the lower mantle. In some of these images, sinking slabs appear to stall or stagnate within the transition zone before continuing into the lower mantle. The lateral variation in temperature and composition beneath a subduction zone affects the depth and stability of high-pressure phases changes in the mineral olivine, producing topography on upper mantle discontinuities. Imaging the depth of these boundaries allows us to interrogate the slab's thermochemical properties within the mantle transition zone.

To determine the depth of the 410 and 660 km discontinuities beneath South America, we utilize transversely polarized *S*-waves that reflect off the underside of seismic discontinuities approximately halfway between an earthquake and a seismometer. These underside reflections arrive several hundred seconds prior to the seismic phase *SS* as precursory seismic phases, named by the depth of interface, such as *S410S* or *S660S*. We collected a dataset of over 16,000 high quality seismograms recorded at broadband stations that densely sample the mantle transition zone beneath the subducting Nazca slab. Owing to the typically low amplitudes of *SS* precursors (1-10% of the *SS* phase), the data are stacked into geographical 'bins' of 1000 km radius to enhance the signal-to-noise ratio. We maximize precursor coherency through several methods: (1) by excluding epicentral distances with interfering seismic energy, (2) by stacking on the individual slowness of each precursor, and (3) by employing a bootstrap-resampling algorithm to assist in detecting multiple precursory arrivals at similar depths.

Detailed maps of phase boundary topography beneath South America reveal deep 410- and 660-km discontinuities in the down-dip direction of subduction, inconsistent with purely isochemical olivine phase transformation in response to lowered temperatures. Two mechanisms invoking chemical heterogeneity within the mantle transition zone are explored to explain this feature. We propose that the deep 410 km discontinuity beneath the South American continent is (1) a reflection off the base of a hydrated lens of wadsleyite that resides at the top of the transition zone (Fig. 1A), or (2) the 410 is stabilized to a greater depth by the subduction of melt-depleted, magnesium enriched mantle wedge material into the transition zone (Fig. 1B). Hydrogen transported into the transition zone by subduction will reduce the seismic wave speeds and density of the wadsleyite phase; if this material is concentrated at the top of the transition zone by trench rollback at a sufficient level of wadsleyite hydration (≥ 0.75 weight percent H_2O) and has a relatively sharp base (< 50 km gradient), it will produce a seismic discontinuity. The underside reflection is produced from the base of a lens of hydrated wadsleyite overlying anhydrous wadsleyite, rather than the olivine to wadsleyite phase transition. Alternatively, the extraction of iron in the mantle wedge by extensive melting and subsequent entrainment of the Mg-rich residue into the transition zone by subduction/trench rollback stabilizes the olivine to wadsleyite phase transition to a greater depth. An increase in Mg content of $(Mg,Fe)_2SiO_4$ of the mantle from 89% Mg (pyrolitic) to 92-94% Mg (harzburgitic) is required to form such a feature. In some regions, multiple reflections from the discontinuities are detected, consistent with strong relief on the 410 km and/or additional phase changes near 660-km depth. Thus, the origin of upper mantle heterogeneity has both chemical and thermal contributions, and is associated with deeply rooted tectonic processes.

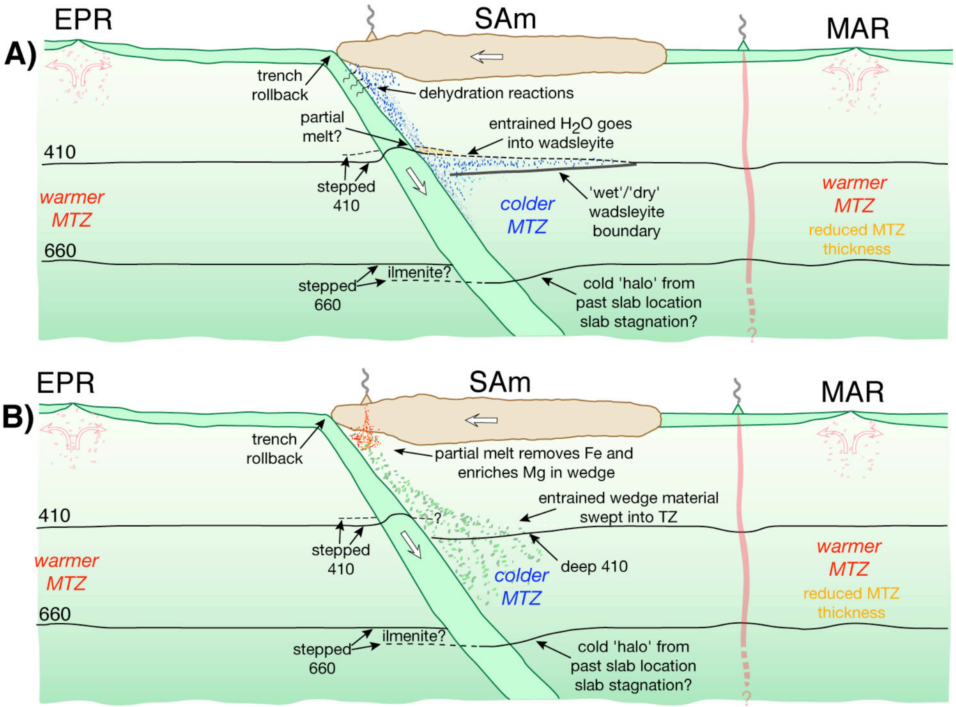

Figure 1. Two proposed hypotheses explaining the deep 410 and deep 660 km discontinuities, as well as other features imaged beneath the South American continent. The assumed trench rollback rate is ~1-3 cm/year over the past 200 Myr. Abbreviations are as follows: MTZ-mantle transition zone, EPR-East Pacific Rise, MAR-Mid-Atlantic Ridge, and SAm-South America. A) The formation of a hydrated wadsleyite lens at the top of the transition zone. B) Entrainment of Fe-depleted mantle wedge material into the transition zone.