EXPLANATIONS OF LOW VELOCITY ZONES

Summary

The usual explanation of LVAs is some combination of volatile enhanced melting and high temperatures. Our explanation combines both, along with dynamic melting. The LVAs which occur sporadically near 400 and 700 km depth[26,27] may have similar explanations [2,23] (Weidner; Ricard) and do not require recycling of water and crustal components to the base of the mantle and back through a water filter. Most geochemical and geodynamic models assume whole mantle convection at the outset, and ignore the effects of dynamic melting and CO_2 when interpreting LVAs[25,27].

The causes of low velocities, high attenuation and anisotropy in the Earth's upper mantle have recently become controversial. The plate tectonic paradigm for intraplate volcanism, which involves stress release of indigenous melts in the LVZ, has been challenged with arguments that assert that melts do not occur in the LVZ or that if they do they drain out quickly or that even if they don't drain out the effect is too small to explain the seismic observations [15-17]. The theory used, however, does not explain the laboratory data on partially molten materials that motivated the idea in the first place [1,21]. This apparent paradox is due to the neglect of the pertinent physics. Models that claim to rule out upper mantle melts assume that a melt phase is an unreactive component [3,5] that can be accounted for by volume averaging and conclude that small amounts of melt do not have a large effect on seismic velocities[15,16] and that they drain away quickly anyway. These studies ignore experiments and theory that show the ability of small amounts of melt to dramatically modify physical properties, including permeability, through chemical effects. The interaction between seismic waves and melt, and of migrating melts with the matrix, are significant. The effects of fluids are also not entirely microscopic; the presence of large lamellae and sills are consistent with observed seismic anisotropy in the LVZ[10,24].

Taken as a whole, the seismic structure of the LVZ, including attenuation, sharp boundaries, and anisotropy are best explained using a dynamic melting model. The implication is that the LVZ contains melt and that it is not only a plausible source but it is the most likely source for mid-plate and large igneous province volcanism [6,62,63]. Sources deeper than ~300 km may be too cold[24,29,41], to explain the hottest Hawaiian basalts [49].

The Transition Zone water filter model & dehydration melting

In addition to the low-velocity zone at the top of the mantle, others have been detected at depths of roughly 350-370, 400-410 and 600-700 km [21,23-27]. These have been explained by CO_2 and the accumulation of eclogite. In the water filter model[23] it is assumed that broad upwelling currents dehydrate and melt as they pass through the 410-km discontinuity, leaving water, melt and impuritities behind. Lower mantle LVZs are attributed to diffuse downwellings that dehydrate as they sink below 650 km[27], whole mantle convection being assumed. Transition zone properties, however, are consistent with cold mantle accumulating above, depressing the 650-km discontinuity, displacing older warmer mantle upwards, elevating the 410; they are not consistent with whole mantle convection with throughgoing slabs and hot plumes[28]. Alternative explanations of deep LVAs are CO_2, segregated basalt, metastability, underplating and interaction of the seismic waves with phase changes. None of these require whole mantle convection, deep slab penetration or transport of water into the lower mantle and then back again to 410 km [13,14].

Low-velocity anomalies (LVAs) are often simply attributed to excess temperature or water content, small grain size or decompression and dehydration melting, but the actual situation is much more complex and requires mechanisms for causing these phenomena. A horizontal LVZ can be due to the effects of CO_2, ponding under a permeability barrier or a negative Clapyron slope boundary, shearing, metastable phases or the dynamic effects discussed in this paper. LVAs can be formed at solid-solid phase boundaries and do not even require the presence of melt [2,3].

The transition-zone water filter and hydrous melting models [23,27] assume that water is the main 'impurity' that lowers melting points and that the transition zone is the major water reservoir in the mantle. Melts and impurities accumulate above and below the transition zone but not in the shallow LVZ [12]. In these models, the global mantle flow pattern is dominated by slab-related localized downwelling currents and diffuse upwelling flow. This is the precise opposite of the mantle plume model, which assumes narrow focused upwellings (plumes) and diffuse downflow. Alternatively, ancient ambient depleted mantle at the base of the TZ is forced up by the downward flux of subducting slabs and becomes the passive depleted upwellings that fuel midocean ridges and near-ridge hotspots. Those that rise midplate interact with the surface boundary layer and pick up the impurities and chemical components that define midplate basalts[14]. Volatiles and impurities are sheared into the surface boundary layer and this, not the regions above the TZ or the core, is the source of Hawaii, Samoa, Yellowstone and other intraplate volcanoes.

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