Mantle stratification: constraints from mineral physics, seismological and phase equilibrium data

B.J. Wood
G. Helffrich
Department of Geology, University of Bristol, Bristol BS8 1RJ, UK.

Despite a great body of experimental and seismological data the presence or absence of chemical layering in the mantle is an unresolved issue. What can probably be stated uncontroversially is :- a) The seismic discontinuities at 410 and 670 km depth correspond to the pressures at which major phase transitions would be observed in peridotitic bulk compositions. b) The magnitudes of the discontinuities in p- and s-wave velocities are approximately those expected for peridotite c) The transformation of spinel to perovskite + magnesiowüstite has a negative P-T slope which would hinder convection through the 670 km discontinuity. Most of the controversy comes from the use of mineral physics data to model elastic wave speeds in the mantle. The latter are governed by thermodynamic properties of minerals which are incompletely known at the high pressures and temperatures of the transition zone and lower mantle. Depending on how the data are extrapolated one can argue for or against chemical discontinuities in addition to phase transformations at the 410 and 670 discontinuties or even somewhere clse in the lower mantle. Recent seismic data strongly support the phase change explanation at 410 and 670 km. The observation that the depths to the discontinuities are inversely correlated (Revenaugh and Jordan, 1989) is in accord with positive and negative P-T slopes of the olivine to b-spinel and spinel to perovskite + magnesiowüstite transformations respectively. Such anticorrelation is only consistent with the phase-change explanation.

Another recently resolved question is that of slab penetration into the lower mantle. Tomographic studies of Northwestern Pacific subduction zones (e.g. van der Hilst *et al.*, 1991) indicate that in some places fast material, presumably a cool slab, extends through the 670 discontinuity whereas in other regions it does not. A strict separation of mantle convective regimes into isolated upper and lower mantle flow patterns is therefore no longer tenable; there must be mass transfer between upper and lower mantles. Further support for the tomographic results from specific subduction zones may be found in whole-earth tomographic models (Dziewonski and Woodhouse, 1987). Comparison of mantle models derived from tomography with those obtained from convective flow calculations (Woodward *et al.*, 1994) suggests that whole mantle circulation is dominant but that localised layering below 670 also exists. The results are consistent with the kind of convection expected for a phase change with negative slope.

As discussed above, the major problem comes in trying to reconcile mineral physics data with a mantle of approximately constant bulk composition. Bina and Silver (1990) compared the observed bulk sound velocity profiles for the lower mantle with properties calculated for $(Mg,Fe)SiO_3$ perovskite and (Mg,Fe)O magnesiowüstite. They found that, using the best available properties of these phases, a lower mantle enrichment in silica and iron relative to peridotite gives the best fit to the observations. Within the uncertainties, however, a peridotitic mantle would also fit the data. Further high P and T measurements of perovskite volumes by Stixrude *et al.* (1992) suggested that thermal expansivity is actually greater than that used in Bina and Silver's (1990) analysis. This would reinforce the suggestion of Fe enrichment in the lower mantle. The boundary between Fe-rieh and Fe-poor layers could not, however be the 670 km discontinuity because the seismically observed deflection near subducting slabs is not compatible with it being a compositional boundary. Thus another, deeper layer, not yet seismically observed, must be postulated if the mineral physics data are accepted uncritically. We note, however, that the pressure dependence of thermal expansivity is still subject to debate and that alternative interpretations of the same data can still lead to results consistent with a peridotitic lower mantle (Chopelas and Boehler, 1992).

In summary, a peridotitic mantle explains all the data down at least to 670 Km depth. It is possible that the lower mantle is, on average, slightly richer in Fe and Si than the upper mantle.

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