duced by micrometeorite impacts into the regolith of the parent body. Lunar agglutinate glass contains metallic iron and sulphides, like the GEMS. Keller and McKay also observed compositional differences between the rims and centres of lunar crystals[13] which they attributed to deposition of vapour from nearby impacts. If both the mineralogy and chemical gradients of the GEMS can be produced by impact-derived regolith processing, then a preaccretional irradiation may not be required. However, Bradley indicates this mechanism will produce oxygen depletions, rather than the excesses (or Mg and Si depletions) he finds[1].

If it can be confirmed that the only plausible mechanism to produce these chemical gradients is exposure to intense radiation, then it seems these amorphous glasses are either the long-sought interstellar silicates or the earliest known nebular condensates. In either case, detailed study of these unusual IDP building blocks should improve our picture of the process of Solar System formation, and provide laboratory samples against which to compare the emission features observed in astronomical settings. □

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GEOPHYSICS

A mystery in the mantle

John E. Vidale

THE rocky mantle occupies more than 80 per cent of the volume of the solid Earth, and excludes only the 10–100-km-thick crust on the surface and the 3,000-km-radius iron core at the centre. Although the mantle is known to flow with the convective currents that release the Earth's heat to space, the simplicity of the flow pattern is a subject of debate. The question of flow in the mantle hinges on the difference between the upper and lower mantles. Some geochemical evidence suggests differing compositions for the two mantle layers, implying separate convection cells in each, whereas other evidence from seismic tomography suggests whole-mantle convection, implying a homogeneous composition. To muddy the waters still further, Kawakatsu and Niu, on page 301 of this issue[1], now throw in an observation of mantle layering at far greater depths than had been expected.

The search for the possible compositional boundary between the upper and lower mantles has tended to concentrate near 660 km depth. But we now attribute the observed changes in seismic velocities and density there to a phase transformation[2–8], despite some lingering inconsistencies[9–11]. The signature of the proposed compositional contrasts should be more subtle, and might coincide with the phase transition or might be deeper. The geophysical signs of upwellings have proved tantalizingly faint, so studies have focused on the more visible downwelling subducting slabs.

Recently, strong evidence has been presented for simple mantle downwelling beneath the west coast of the Americas that extends to the base of the mantle[12,13]. More complicated geometries have been inferred from seismic observations in the western Pacific as well as from some flow models[14–16]. It has been proposed that the phase transition near 660 km depth may hold back downwellings for millions of years, followed by episodes with much material flowing into the lower mantle. This theory of alternating accumulation and flushing of downwellings has been termed dynamic layering, but like simple whole-mantle convection would probably homogenize the compositions of the upper and lower mantles.

Kawakatsu and Niu[1] find layering beneath several subduction zones that is deeper, about 920 km down. As they discuss, structure at this depth has been previously proposed[17], but the evidence is now far more compelling. The J-array, the network of short-period seismometers that they used, is much longer than those of previous high-frequency studies of this type[4,6,8]. The 4,000-km aperture allows unprecedented resolution in unscrambling high-frequency reverberations, and the ray paths from Tonga to Japan sample parts of the mantle unreached by previous studies.

The origin and extent, and thus the implications, of the layering seen near 920 km depth are not yet clear. It may be the signal of a phase change related to the increase in pressure with depth in the mantle, such as a change in structure of perovskite or reactions involving garnet in the downwelling slab. The former would be present globally, whereas the latter would appear only near slabs. However, these effects were not necessarily expected to appear at this depth, nor would they be expected to produce a signal as large as observed.

Kawakatsu and Niu favour the suggestion that the layering is the signature of a global change in composition with depth. But this too has its difficulties. A chemical boundary would be expected to fluctuate in depth by hundreds of kilometres, even for the larger density contrasts present at the 660-km boundary[5,7], in response to the convective currents. Instead, the observations suggest a fairly constant depth for the boundary.

In addition, a global compositional boundary would coincide with a thermal boundary layer, probably with a temperature contrast of several hundred kelvin, because the transfer of heat by convection would be interrupted by the compositional change. The large gradient in temperature near a thermal boundary layer results from the relative inefficiency of conductive heat transfer. The extra temperature increase with depth would be consistent with high estimates of core temperatures[18], but should also enhance the visibility of the structure to seismic waves, whereas the 920-km-depth layering is subtle. Other iron studies indicate lower core temperatures, compatible with whole-mantle convection[19].

Another problem is that mantle downwellings that pass through this depth and would cause mixing between the layers have been observed[12,14]. And the presence of a global boundary with a several per cent contrast in velocity across a 10-km depth interval, as the authors suggest, would generate complications in grazing P waves that are not generally observed.

So the cause of Kawakatsu and Niu's structure at 920 km depth is not yet certain. What is clear is that the more carefully we look, the more structure becomes visible within the Earth. And as usual, it appears that seismic observations are ahead of the theories. □

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