GEOPHYSICS

Mapping the Core-Mantle Boundary

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The boundary between Earth's core and mantle is a fundamental discontinuity where silicate minerals come into contact with molten iron alloys. Because it is so remote, nearly 2900 km below the surface, it can only be studied from afar. New studies are allowing a glimpse of the lowermost part of the mantle and raising new questions about this region. A very thin layer in which seismic velocities drop by 10% or more (*1*, *2*) may indicate melting at the base of the mantle (*3*). The lower mantle may be anisotropic, perhaps as a consequence of fine-scale compositional variations (see figure). Moreover, seismic studies have also revealed several hundred meters of small-scale topography on the core-mantle boundary (*4*).

The wide-ranging recent work provides a clearer picture of fine-scale structure in the region known as D″, encompassing about 200 km of the lowermost mantle (and ending at the core-mantle boundary). In the 1980s seismic studies uncovered a discontinuous increase in the velocities of shear and compressional seismic waves in this layer. More recently, the D″ region has been shown to vary laterally in both thickness and in seismic velocity gradient. For instance, a study of the southwestern Pacific (*5*) found that the layer varied in thickness by about 100 km over a short distance, whereas in other locations the discontinuity has not been observed at all. A variety of mechanisms have been proposed to account (alone or in combination) for the structure of D″. As the core cools, a thermal boundary layer develops at the core-mantle boundary; this layer likely becomes unstable from time to time, releasing upwelling plumes of hot material. Subducted slabs, or perhaps only the component that was once part of the oceanic crust, may languish at the base of the mantle. A residue of core formation, too heavy to rise under the influence of the heat from the cooling core, may pile up under mantle upwellings. A phase change is also a possibility. Or the boundary may be chemically active, with molten core iron altering the composition of nearby minerals. The variability of velocity gradients and thicknesses suggests that more than one of these mechanisms may be at work.

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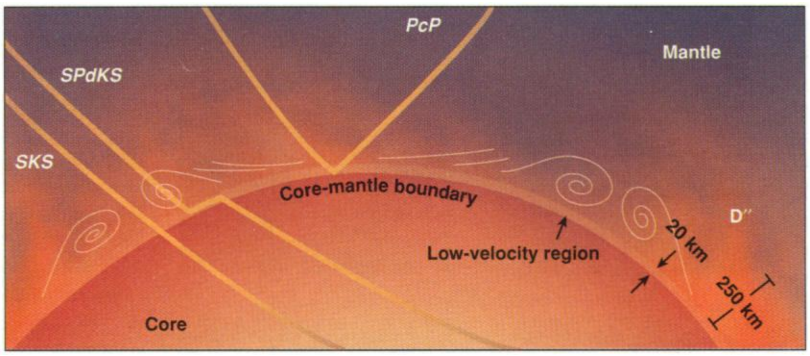
A recent approach has been to use seismic waves that are diffracted along the mantle side of the boundary to examine details of the structure. The very small signal means that multiple data from large arrays must be stacked. Within a thin (less than 20-km) layer at the base of the mantle, *P* wave velocities (v_P) are reduced by about 10% (*2*). This interpretation can vary, to some extent, with a tradeoff between layer thickness and the velocity reduction; thinner layers with a greater velocity reduction can also satisfy the data in some locations.



Recently proposed structures and characteristics of the lowermost mantle, along with schematic paths of the seismic waves used by (*2*) (*PcP*) and (*1*) to map the thin region of ultra-low seismic velocity.

What could cause such a severe drop in velocities over such a small region? Williams and Garnero (*3*) proposed that the lowermost mantle is partially molten. One consequence would be a reduction in shear-wave velocities (v_S); they predicted that v_S should drop three times as much as v_P within the layer (*3*). In their study of the core-mantle boundary beneath Tonga, Japan, and South America, Revenaugh and Meyer (*2*) conclude that just such a drop is required, supporting the partial melt hypothesis. They also note that the layer may vary in thickness from place to place, possibly because of interaction with mantle downwellings and upwellings. Whatever is happening at the core-mantle boundary, structures there are likely heavily influenced by the pattern of convection in the lower mantle.

Another constraint on the nature of the core-mantle boundary comes from studies of anisotropy of seismic velocities. In the upper mantle, anisotropy depends on mineral orientation and can indicate mantle flow direction. In the lowermost mantle, where the mineralogy is different, other mechanisms may be required, but anisotropy may still provide information about local flow patterns. One possible mechanism for producing anisotropy is compositional layering; if the deep mantle contains material of varied composition, convective flow may induce fine lamellae that would result in an orientation for the maximum and minimum v_S. Some of the strongest evidence for anisotropy has been found under Alaska and the Central Pacific (*7*), but to date only a few regions of the lower mantle have been examined.

These new approaches provide substantial insight, but they open up more questions, such as whether the thin, low-velocity layer at the base of the mantle is found around the world, and whether the observations show partial melting. If so, melting in the lowermost mantle could have significant consequences for the compositional evolution of the D″ layer and the thermal structure of upwelling plumes. Perhaps more complete maps of anisotropy along with the new estimates of small-scale topography (*4*) will indicate what the flow patterns are and how any compositional variations interact with the dynamic lower mantle.

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