PERSPECTIVES: GEOPHYSICS

Peeling Back the Layers in Earth's Mantle

John E. Vidale

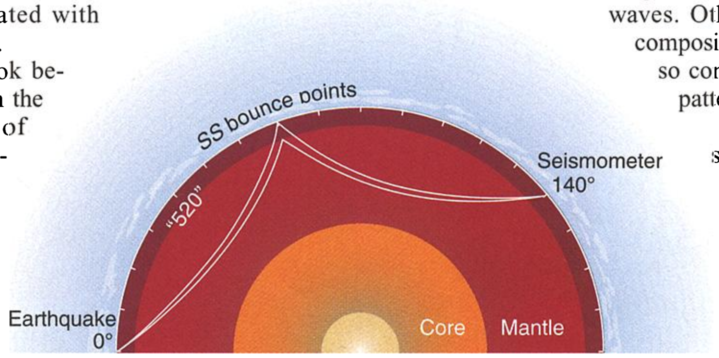
The structure of Earth's crust and mantle is gradually coming into focus, thanks to relentless seismologists. On page 354 of this issue, Deuss and Woodhouse (*1*) show an unexpected complication, adding new information to the puzzle.

Mantle and crust are composed of dramatically different rock with very different seismic properties. The 6- to 80-km-thick crust floats atop the mantle. The depth of the crust-mantle boundary, or "Moho," is related to surface topography and ongoing tectonic deformation. Converging plates create thick crust and high mountains, whereas their rifting is associated with thin crust and surface depression.

A current challenge is to look beneath the crust, at the layering in the mantle, to deduce the pattern of flow and chemistry there. Boundaries near depths of 410 and 660 km are now widely attributed to phase transitions rather than compositional changes. Topographic maps constructed from the timing of reflected seismic waves show that both boundaries undulate by 20 km or more in depth. Lateral temperature variations, estimated from the topography of the phase transition boundaries (*2*), have indicated that the "660" is deeper and the "410" more shallow near subduction (*3*), as expected given the way rocks respond to temperature and pressure in laboratory studies. This trend is consistent with the presence of cooler mantle near subducting downwellings, although the correlation is low and remains a subject of debate.

Deuss and Woodhouse (*1*) now take a close look at the seismic contrast near 520-km depth, where another weaker boundary has been identified (*4, 5*). Like its big brothers, the "520" has been attributed to a phase transition, but that explanation will need a facelift if the new observations are correct.

Deuss and Woodhouse looked at the precursors of *SS* waves, which are shear (*S*) waves that initially travel downward away from an earthquake, then turn back up, and are reflected at the surface like an echo of a voice off a wall (see the figure). Some precursors of *SS* carry information about the "520." The authors only considered seismograms written at distances of 100° to 160° from earthquakes. At closer distances, the waves travel horizontally near the "410" and "660," distorting and complicating the *S* waves. At greater distances, the waves graze the core-mantle boundary, also complicating the interpretation. By reflecting from the "520," the precursors have about 1000 km less to travel than the surface reflection and so arrive 200 s sooner. The "520" reflection is flanked by "410" and "660" reflections with about double its amplitude.



Ray paths of the seismic shear wave *SS* and its precursor. The latter bounces off the underside of the "520" boundary, providing information about the topography and complexity of this weak boundary.

CREDIT: ADAPTED FROM (12)

This experiment is an elaboration of the method of Shearer (*4*). Deuss and Woodhouse have tripled the number of seismograms and concentrated on searching for lateral differences in the "520" reflections.

There are lingering doubts that lateral structural variations may cause artifacts in analyses like this one that assume locally radial structure (*6*). The "520" is a more slippery target than its bigger siblings, not only because of its smaller amplitude but also because it does not reflect shorter period energy (*7*). It is therefore probably a boundary spread over at least 10 km in depth. It also does not reliably appear in refraction studies, suggesting that it is more of a rock density increase than a seismic velocity increase (*8*). *S* wave reflections, which have long periods and are sensitive to density changes, have therefore been the main tool to probe the "520."

Deuss and Woodhouse find that in some places, the "520" appears as a single reflector, whereas in others it appears as a pair of weaker reflections at depths of 500 and 560 km. This result neatly sidesteps the previous puzzle that the "520" seemed absent in some places. Previous work apparently averaged over regions with disparate structure, whose signals canceled when summed.

Twin reflectors with variable spacing are most easily explained by two phase changes with different properties. There are two primary candidates for these phase changes: the β-γ transition in the olivine component and the garnet-perovskite transition in the nonolivine component of the rock (*9*). It is not clear, however, that the latter would be concentrated in a depth range small enough to efficiently reflect *S* waves. Other factors, such as rheology, composition, and water content, may also contribute to the observed seismic pattern.

The new results help to constrain the temperature and composition in a difficult-to-study depth range—below or near the bottom of the keels of continents (*10*) and just above the depth where slabs might be piling up before punching into the lower mantle (*11*). The pattern that Deuss and Woodhouse find does not correlate well with the location of old continental crust, which should overlie the coldest keels, nor with tomographic maps of seismic velocity, another probable proxy for the temperature of the mantle. This independence is both confusing and exciting. It offers the possibility of a new window into the study of the nearly invisible internal affairs of the mantle.

The author is in the Department of Earth and Space Sciences, University of California, Los Angeles, CA 90095, USA. E-mail: vidale@moho.ess.ucla.edu

References

1. A. Deuss, J. Woodhouse, *Science* **294**, 354 (2001).
2. L. Stixrude, *J. Geophys. Res.* **102**, 14835 (1997).
3. J. E. Vidale, H. M. Benz, *Nature* **356**, 678 (1992).
4. P. M. Shearer, *Nature* **344**, 121 (1990).
5. J. Revenaugh, T. H. Jordan, *J. Geophys. Res.* **96**, 19763 (1991).
6. E. Chaljub, A. Tarantola, *Geophys. Res. Lett.* **24**, 2613 (1997).
7. H. M. Benz, J. E. Vidale, *Nature* **365**, 147 (1993).
8. L. E. Jones, J. Mori, D. V. Helmberger, *J. Geophys. Res.* **97**, 8765 (1992).
9. J. Ita, L. Stixrude, *J. Geophys. Res.* **97**, 6849 (1992).
10. T. H. Jordan, *J. Petrol.* **1988**, 11 (1988).
11. P. J. Tackley, D. J. Stevenson, G. A. Glatzmaier, G. Schubert, *Nature* **361**, 699 (1993).
12. M. P. Flanagan, P. M. Shearer, *J. Geophys. Res.* **103**, 2673 (1998).