MANTLE DYNAMICS

Rising Plumes in Earth's Mantle: Phantom or Real?

Seismologists probing the planet's depths are generating tantalizing images, but whereas some researchers see signs of plumes feeding volcanic hot spots, others see noise

Almost half a century after the plate tectonics revolution, geoscientists still have a hangover. By 1970, a decade or two of geophysical observation beneath the world's oceans had ushered in jostling plates and sinking slabs. But plate tectonics can't explain midplate volcanic centers such as Hawaii, and a hypothesis proposed in 1972—that hot rock rises in narrow plumes through the mantle to stoke such hot spots—still gets a mixed reception. "The existence of plumes is controversial to some and old hat to others," geophysicist Norman Sleep of Stanford University in Palo Alto, California, recently noted. "Skeptics are justified in demanding deep evidence for a deep-mantle hypothesis."

The latest evidence from the deep—pictures of the interior painted with seismic waves—is stirring up a field in which such tomographic results have often been disputed. At the same time, geological and geochemical studies are bringing some putative plumes into question (*Science*, 8 September, pp. 1394 and p. 1426). The new imaging will not calm the turmoil anytime soon, but it is forcing seismic tomography researchers to grapple with the limitations of their tools.

The hubbub in global seismic imaging started when a group of Princeton University seismologists introduced a new analytical tool to sharpen their view. The problem with plumes has been that according to theory they would be narrow, perhaps a couple of hundred kilometers across at most. A hot plume would slow the part of a seismic wave that passes through it from an earthquake to a seismometer. But the slowed segment of the wave—which in a tomographic analysis would paint a splotch of warm mantle in the image—could then "heal" before ever being recorded, much as an ocean wave can reform after passing around the piling of a pier.

So Raffaella Montelli, then a graduate student at Princeton and now at ExxonMobil in Houston, Texas; her Princeton adviser Guust Nolet; and theoretical seismologist Anthony Dahlen of Princeton developed a way of analyzing seismic data that for the first time takes account of such wave behavior. In their version of "finite-frequency" analysis, Montelli and colleagues were able to combine so-called P (for primary) seismic waves of two frequencies to form an image of the global mantle from a high-quality data set. Where others had reported nothing more than a debatable plume or two beneath Hawaii and Iceland, the Princeton group saw plumes of varying height beneath most of the classic hot spots, 32 plumes in all (*Science*, 5 December 2003, p. 1643).

With the proliferation of plumes and the introduction of a radically new technique, the plume debate only intensified, so Montelli and colleagues have gone one step further. In a paper in press in *Geochemistry Geophysics Geosystems*, they report how they formed a new global image from S (secondary) waves rather than P waves, again using their finite-frequency technique. S waves—which have a shearing or twisting action—react differently to variations in rock temperature and composition than do P waves, which are compressional, like sound waves. But almost all of the plumes they saw in the P-wave image they also found in the S-wave model. "There is remarkable agreement," says Nolet.

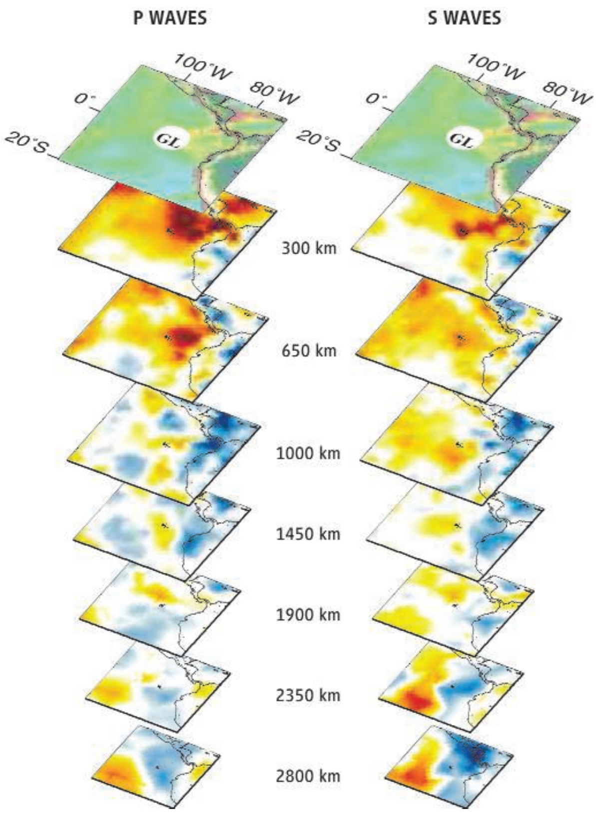
The geophysics community's reaction has been mixed. "I must say I found it striking that with both S and P they do get very similar images for some of the plumes," says theoretical seismologist Jeroen Tromp of the California Institute of Technology in Pasadena. To some others, the picture is much fuzzier. "There are similarities, but many differences too," says seismic tomographer Rob van der Hilst of the Massachusetts Institute of Technology in Cambridge. And tomographer Adam Dziewonski of Harvard University simply says that "it's difficult to argue these things are real" in either P or S renditions.

A fundamental problem, say many researchers, is a dearth of data. Everyone agrees that some finite-frequency technique is the way to go, but many argue that even it is being overwhelmed by the limited data available. Most earthquakes that seismically light up Earth's interior fall around the Pacific's Ring of Fire, whereas the seismometers recording them are limited to the continents and a few islands. So even data sets drawing on millions of quake recordings leave parts of the mantle largely in the seismic dark. As a result, "there are infinitely many [tomographic] pictures of Earth that all satisfy the data," notes Nolet.

To sort out which picture is the most likely one, the analyst must twist some knobs on the procedure to sharpen the picture while keeping things physically realistic. "This is sort of like reading tea leaves," notes Dziewonski. And methods for quantitatively gauging how well the final picture can explain the data are still severely limited by computer power. "Interpretation of tomographic models [of the mantle] is a high-risk operation," concludes Dziewonski.

To reduce the risk, researchers, predictably, call for more and better data. New seismometers are filling gaps in coverage, but it's taking longer to incorporate new kinds of data from existing seismic records. Most observers see another 5 to 10 years before they'll be able to say with confidence whether plumes exist after all.

–RICHARD A. KERR



A deep plume? Extra-hot rock (red and yellows) appears as deep as 2000 kilometers beneath the Galápagos Islands in images generated from either P seismic waves or S seismic waves.

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