Plumes From the Core
Lost and Found

The first clear seismic images of deep, rising magma plumes support, in part, a theory under fire

SAN FRANCISCO—For a 30-year-old unproven hypothesis, mantle plumes have shown remarkable vigor. Most geoscientists assume that the plumes, columns of hot rock rising 2900 kilometers to the surface from the very bottom of the rocky mantle, explain volcanic hot spots such as Hawaii and the great magmatic outpourings of the geologic past called flood basalts. Some have even posited the possible evolutionary effects of plumes spewing such huge eruptions.

No more the cozy comforts of ignorance. Increasingly detailed seismic probing of Earth’s interior is forcing geologists to confront some cold, hard truths about these elusive phenomena. Last month, at the fall meeting of the American Geophysical Union (AGU) in San Francisco, scientists reported that not all hot spots have plumes. Some insisted that plumes more than a few hundred kilometers in depth could not form because of the mantle’s physical properties. Yet in the face of this assault on the status quo, the meeting also featured striking new evidence of how some hot spots are fed from the deepest reaches of the mantle.

“There was a lot of plume bashing going on” at the AGU meeting, says seismologist Göran Ekström of Harvard University. Don L. Anderson of the California Institute of Technology (Caltech) in Pasadena gave three invited talks and co-authored two more presentations, none of which missed an opportunity to put down plumes. Anderson, a pillar of the geophysics community, believes that the mantle’s physical properties preclude the formation of narrow, buoyant plumes in the lower mantle and in fact seal off the mantle below about 1600 kilometers. Instead, he argues, chains of volcanoes like the one anchored at the Hawaiian hot spot could form along a crack in the plate that lets hot mantle rock a few hundred kilometers down rise to the surface and melt.

A case in point seems to be Yellowstone, one of the largest continental hot spots. Two groups of seismologists—Jason Crosswhite and Eugene Humphreys of the University of Oregon, Eugene, and Brian Zurek and Kenneth Dueker of the University of Wisconsin, Madison. Yellowstone isn’t the only place where deep-plume hunters are coming up empty-handed. Jeroen Ritsema of Caltech and Allen have applied the tomographic technique to a set of global seismic observations, paying particular attention to the mantle beneath 45 hot spots on most people’s lists. “The relation between hot spots and plumes has been implicit in many people’s minds,” says Allen, but “it seems clear there is not a plume beneath every hot spot.” They have identified only eight plumes going deeper than 200 kilometers.

So where do plumes actually span the mantle? After 4 days of widespread plume bashing at the meeting, seismologist Tony Dahlen of Princeton University delivered an hourlong invited lecture that shored up conventional wisdom on the topic. The work, which involves sharpening up global tomographic images, offers evidence of at least a dozen deep, continuous plumes rising beneath major hot spots worldwide. “People recognize the first images … that are actually convincing,” says Dahlen’s Princeton co-worker, Guust Nolet. Allen just calls it “the most exciting thing I saw at AGU by a long way.”

A key to the Princeton plume imaging was to think of a seismic wave’s behavior in terms of a hollow banana rather than just a thin line. Seismic waves actually ripple away from an earthquake in all directions, but for the purpose of analysis, seismologists traditionally consider seismic waves to be a collection of lines or “rays.” In conventional analyses, when a ray path passes through a hotter blob of rock, the full slowing of the ray is assumed to be recorded when the wave eventually reaches a seismometer. But, at least in the case of lower-frequency waves passing through skinny blobs like a plume, a ray begins to “forget” its slowing as seismic energy radiates into the ray path from adjacent parts of the wave. Nolet and Dahlen, working with former Princeton postdoc Shu-Huei Hung of the National Taiwan University in Taipei, concluded that a more useful representation would be a hollow banana: most sensitive around a curving ray path (all seismic waves are curved by the deep Earth) but insensitive at its center.

Graduate student Raffaella Montelli of
Princeton used the new technique in analyzing a relatively small but high-quality set of 87,806 seismic recordings assembled by seismologist Guy Masters of the Scripps Institution of Oceanography in La Jolla, California. In Princeton’s final global image, the features beneath the classic hot spots of Hawaii, Tahiti, and Easter Island “really are deep mantle plumes,” said Dahlen. Some hot-spot plumes, such as those rising to Réunion in the Indian Ocean and the Azores in the Atlantic, actually branch off one of the two huge “superplumes” rising into the lower mantle beneath the South Pacific and Africa (Science, 9 July 1999, p. 187).

Not every hot spot has a deep plume in the Princeton tomography, however. Yellowstone is “iffy,” says Nolet, and nothing deep feeds Europe’s shallow Eiffel plume or Africa’s Tibesti hot spot. Absent plumes might reflect patches of sparse data, says Nolet, but “there are a lot of things we call hot spots and associate with plumes that may be shallow.”

“It was very impressive,” says seismologist Yang Shen of the University of Rhode Island, Narragansett. From the Princeton presentations and his own work with Hung on Iceland data, he finds that the hollow-banana approach improves plume images substantially, up to 100% in the upper mantle beneath Iceland. Seismologist Adam Dziewonski of Harvard was more cautious after hearing the rapid-fire presentations. “I’m usually pretty skeptical when people say they get images of plumes,” he says. In the Princeton case, he wonders if they haven’t somehow smeared signals from shallow hot rock down into the lower mantle. He’s waiting for the Princeton group to complete its testing of the tomography.

Plumes spanning the mantle would have a stimulating effect on a range of earth science. They could clarify how cooling of the interior drives mantle churning. Geochemists would have a better idea of where to locate the mantle’s five compartments that store material for up to billions of years. Geologists might better understand the massive flood basalt—thought to spill from the bulbous heads of rising plumes—that dot the globe and are speculated to have overheated climate and triggered extinctions (Science, 6 December 1996, p. 1611). Plumes may even shatter supercontinents. Now that would be true vigor.

—Richard A. Kerr