tasks with two gyroscopes (four of six are currently operating), although high-resolution data gathering would not be possible without the stability of at least four.

"We've only lost two [gyroscopes] in the past 4 years," says Weiler. "There's a damn good chance that we could make it to 2006 doing science." But the delay in the next mission also increases the chance that Hubble could lose all its gyroscopes in the intervening period, forcing a suspension of all research operations.

It's not hard to see why Weiler would resist an additional servicing mission. He must devise a plan to keep Hubble from crashing to Earth, because NASA's new rules for operating the shuttles won't permit it to retrieve the heavy payload. Finding an alternative—possibly a space tug that would nudge it into a safe path of destruction in Earth's atmosphere—could cost $300 million. In the meantime, maintaining a Hubble servicing operations center at Goddard Space Flight Center in Greenbelt, Maryland, costs NASA $8 million to $9 million a month.

But any mission might not even be feasible. Because Hubble flies in a different orbit than the space station does, the shuttle would have no safe haven in case it developed a problem such as the tile damage suffered by Columbia at launch. That's a problem in NASA's post-Columbia world.

For all those reasons, Weiler believes "there is no rush" for an additional Hubble flight: "My goal is a servicing mission by 2006." For now, most of the space science community shares that near-term vision.

–ANDREW LAWLER

MANTLE DYNAMICS

Mantle Plumes Both Tall and Short?

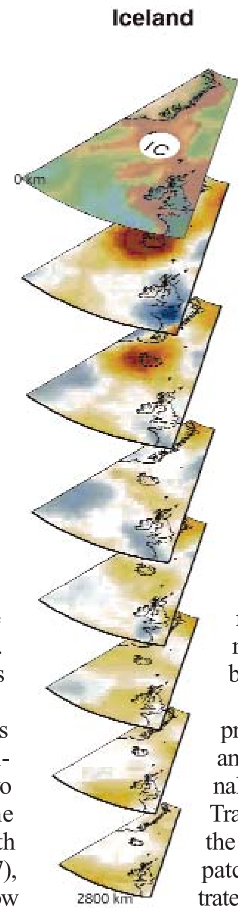
For 3 decades, researchers have been debating whether plumes of hot rock rise through Earth's mantle. Geologists and geochemists have inferred deep plumes from traces left at volcanic hot spots such as Iceland and Hawaii. And some seismologists have suggested that they could glimpse a plume or two in their seismic "CT scans" of the mantle. Even so, plumes have stubbornly remained an appealing if unproven concept. Now, as reported online this week by *Science* (www.sciencemag.org/cgi/content/abstract/1092485), a group of seismologists offers evidence of not one or two plumes but 32. Some of them span the mantle 2900 kilometers from core to crust; others hint of a surprisingly shallow origin less than 1000 kilometers down.

These seismologists are confident that they've made a breakthrough in plume studies. "This is the first work that really confirms what [plume originator] Jason Morgan said," says seismologist Raffaella Montelli of Princeton University, first of six authors of the paper. "We are providing visual proof plumes exist." Other seismologists are more cautious. "I think it is fair to at least suspect that they are overinterpreting their data set," says seismologist Barbara Romanowicz of the University of California, Berkeley. Until several technical questions are resolved, she says, "I think it is a leap of faith to claim a discovery" of dozens of plumes.

The Princeton report is getting a circumspect reception not just because of the startling number of plumes it claims. It is also introducing a new way of analyzing the seismic waves that are combined to form an image of Earth's interior. In conventional seismic tomography, seismic waves arcing through the mantle from earthquake to seismometer are considered to follow curved lines called ray paths. Where numerous ray paths traverse hotter than normal rock, the waves are slowed and an anomalously warm spot appears in the image.

But thin, warm structures—such as the supposed plumes—would be particularly difficult to image in the conventional manner. So Montelli and her colleagues—especially Anthony Dahlen and Guust Nolet of Princeton—developed an analysis that let them take into account how seismic waves actually travel, spread across a wave front rather than along a single line, or ray path (*Science*, 3 January, p. 35). By taking into account wave-front energy radiating into a ray path and washing out a slow signal, this "finite frequency" technique boosted the strength of signals from plumelike structures by 30% to 60% and more. They also combined the usual short-period waves with long-period waves, which sense temperature variations farther off their ray paths. That increased sensitivity to plumes missed by short-period waves.

The Princeton technique shows plumes beneath most classic volcanic hot spots. In addition to the two broad superplumes that everyone sees, beneath Africa and the South Pacific (*Science*, 9 July 1999, p. 187), the new method also shows narrow plumes rising off them, sometimes splitting before reaching the surface. Elsewhere, it shows lone plumes stretching from near the core-mantle boundary to the surface. But other plumes appear to rise from about 660 kilometers deep, the traditional boundary between the upper and lower mantle. A few hot spots, including Yellowstone, seem to lack plumes. And in a major surprise, the plumes beneath two of the most classic of hot spots, Iceland and Galápagos, begin at about 660 kilometers rather than at the bottom of the mantle as they had appeared to (*Science*, 14 May 1999, p. 1095).



A short one. The plume (red-brown) seismically imaged beneath Iceland begins at 660 kilometers.

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This two-tiered plume population suggests to Montelli and her colleagues that rising plumes recognize some sort of mantle division about 660 kilometers down. A long-standing view of mantle workings had an impenetrable barrier at 660 kilometers, but seismic tomography has lately called that division into question by showing that at least some descending slabs of oceanic plates sink below that depth. If plumes originate at 660 kilometers, there may be enough of a barrier there—perhaps a large, sharp change in the stiffness of mantle rock—to block most mantle material and seriously impede all but the densest slabs.

Redividing the mantle may be premature, say other seismologists. "I am very skeptical this will be the final answer," says seismologist Jeannot Trampert of the University of Utrecht, the Netherlands. Seismic data are so patchy—the earthquakes are concentrated in a few belts, and the seismometers are few and far between across oceans—that "telling what is down there using tomography is very hard," says Trampert. "There are many solutions possible with a given data set." They've done the best job anyone can do, he says, but plumes depend to some extent on the choice of adjustable parameters; others might get different results with their choices. And the tests used to check on what the method can and cannot see "don't tell you if plumes exist in the real Earth," says Trampert. "The true Earth may have something the data don't see." Better data and more analyses, he says, are needed.

–RICHARD A. KERR