GEOPHYSICS MEETING

# Scientists Ponder Deep Slabs, Small Comets, Hidden Oceans

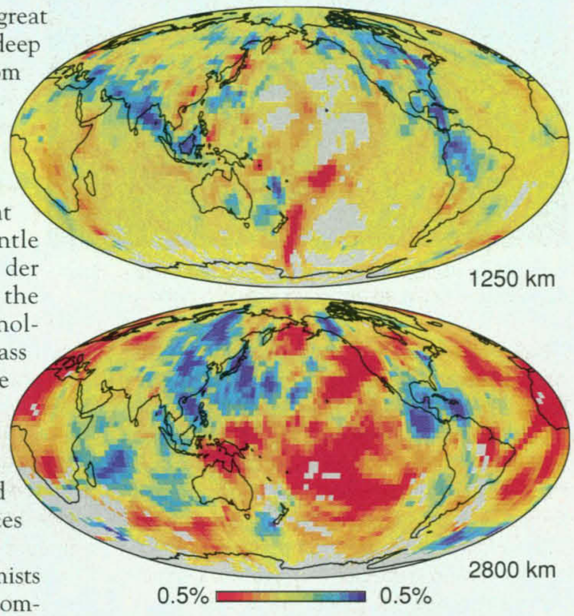
**BOSTON**—More than 3500 geophysicists gathered here from 26 to 29 May for the annual spring meeting of the American Geophysical Union (AGU), a record for this meeting. The claim that tiny comets rain down on Earth got plenty of critical attention, but oceans within satellites of Jupiter and the churning of Earth's rocky mantle drew notice too.

## A Stagnant Deep Mantle?

Middle ground may be emerging in the deep Earth. One faction of earth scientists, trying to explain the mix of elements in surface rocks, has long insisted that rock from the deep mantle must be sealed off from shallower rock by a barrier 660 kilometers down. Another faction has argued that the viscous rock of the mantle mixes from top to bottom—and last year this group seemed to gain the upper hand: Images derived from seismic waves showed that great slabs of surface rock dive into the deep Earth and stir the whole mantle from top to bottom (*Science*, 31 January 1997, p. 613).

Now both factions may have to get used to a partly mixed mantle. By refining the images that last year pointed to whole-mantle mixing, seismologists Rob van der Hilst and Hrafnkell Kárason of the Massachusetts Institute of Technology (MIT) suggest that slabs pass through a distinct layer in the deepest mantle, leaving it largely unmixed. "Whole-mantle [stirring] may be too simplistic," says mineral physicist Carl Agee of Harvard University. "There may be places that are not very well mixed."

That's certainly what geochemists have long believed. They have compared the amounts of various isotopes of helium, potassium, lead, and argon measured at the surface with what planetary theorists believe the newborn Earth must have contained. To explain the disparity, geochemists inferred that the deep mantle must hold isolated reservoirs of pristine material, which only mix to the surface over billions of years.




SOURCE: VAN DER HILST AND KÁRASON / MIT

**Slabs take the plunge.** Seismic imaging shows slabs sinking through the midmantle (*top*, blue) and piled on the mantle floor (*bottom*), but in between they break up, perhaps as they punch through a layer of isolated rock.

Last year's seismic images seemed to leave little room for such reservoirs, however. Van der Hilst and his colleagues had compiled data on millions of seismic waves that had crisscrossed the mantle. Because the waves' travel time from earthquake to seismograph depends on the rock's temperature—the hotter the rock, the slower the speed—and composition, they could turn the seismic data into images showing the slabs of cooler surface rock that plunge into the mantle at deep-sea trenches. The images showed the slabs going right through the 660-kilometer "barrier." But the lowermost mantle still looked fuzzy and indistinct. For a clearer view, Van der Hilst and Kárason have now added more waves that probe the lowermost mantle, including those that bounce off the underside of the surface, those that skim the top of the molten outer core at the base of the mantle, and those that pass through the outer core.

The sharper seismic view confirms that two great slab sheets, one hanging beneath the Americas and the other beneath southern Eurasia, plunge deep into the mantle, reaching depths of at least 1600 kilometers. And as in the earlier images, the bottom 300 kilometers of the mantle seems to hold slab material that has accumulated in broad piles on the mantle floor. In both the old and new images, the slabs seem to vanish between these two layers. Some researchers blamed the disappearance on poor resolution in the earlier images. But the new images suggest that the massive slabs do disrupt about 1800 to 2000 kilometers, says Van der Hilst, melting away into smaller scale features, only to reappear near the mantle floor. "Something funny does happen" about 2000 kilometers down, says seismologist Kenneth Creager of the University of Washington, Seattle. "It's suggesting some new phenomenon."

To many researchers, a likely possibility is that the lowermost 1000 kilometers of the mantle is the geochemists' long-sought storehouse of ancient, pristine rock. It "seems an obvious place to put geochemical reservoirs," says geophysicist Bradford Hager of MIT. Under the right conditions, a dense, viscous layer below 2000 kilometers could resist mixing, according to modeling work by Hager and geophysical modeler Louise Kellogg of the University of California, Davis. In their model, slabs could plow through to the bottom of the mantle and plumes of hot rock could rise from near the core toward the surface. Because of the high viscosity of the layer, this traffic wouldn't unduly disturb it—or disrupt the delicate compromise between geophysicists and geochemists.

## "Atmospheric Holes" Rejected

A year ago at the AGU meeting, space physicist Louis Frank of the University of Iowa in Iowa City started something of a snowball fight. He revived his decade-old theory that small comets—house-sized balls of fluffy ice—strike Earth 25,000 times a day, and he argued that dark spots seen in new satellite images of the upper atmosphere are watery traces of these snowball impacts. Some researchers agreed that the spots, or "atmospheric holes," might well be real, but almost no one took small comets seriously as the cause. Frank and his critics have been lobbing arguments back and forth all year. Now, after a comet shower of criticism at this year's meeting, the dark spots themselves may be vanishing into oblivion.

"The small-comet business is a very dead horse," says planetary scientist Thomas Donahue of the University of Michigan, Ann Arbor, who last year was impressed by the evidence for the spots. Now, he says "the case for [spots] gets weaker and weaker as time goes on."

The images on which Frank based his claims last year (*Science*, 30 May 1997, p. 1333) came from two cameras aboard the Polar satellite, his own and one operated by space physicist George Parks of the University of Washington, Seattle. Parks has already concluded that the dark spots are simply instrumental noise (*Science*, 14 November 1997, p. 1217). And at the meeting, two independent teams—one led by Parks and another by space physicist Forrest Mozer of the University of California, Berkeley—presented new analyses that underscore that conclusion.

If the dark spots are truly blobs of water vapor 1000 kilometers or so above Earth, both groups reasoned, their images as seen by Polar should swell and shrink by a factor of 100 as the satellite swings close to Earth and then away again on its highly elliptical orbit. But if the spots are noise generated within the cameras, their apparent size should not change.

Neither Parks nor Mozer could find any hint that the spots changed size with the satellite's altitude. That finding "is robust and devastating," says Mozer. "The data are completely consistent with an internal source" within the camera. Indeed, the spots could all be accounted for as noise produced by a camera's image intensifier, which can brighten an image erratically, according to modeling work by Mozer and space physicist James McFadden, also of Berkeley.

But Frank is holding fast to his ideas. At the crowded session on small comets, he argued that Mozer's and Parks's analyses are flawed. The speed at which the holes cross the camera's field of view would also vary with spacecraft altitude, he said. That would sometimes make the holes hard to detect and so skew analyses like Parks's and Mozer's. Using his method of measuring holes, he showed that they get somewhat larger when viewed from lower altitudes. But Mozer countered that the size change was too small for the spots to be real.

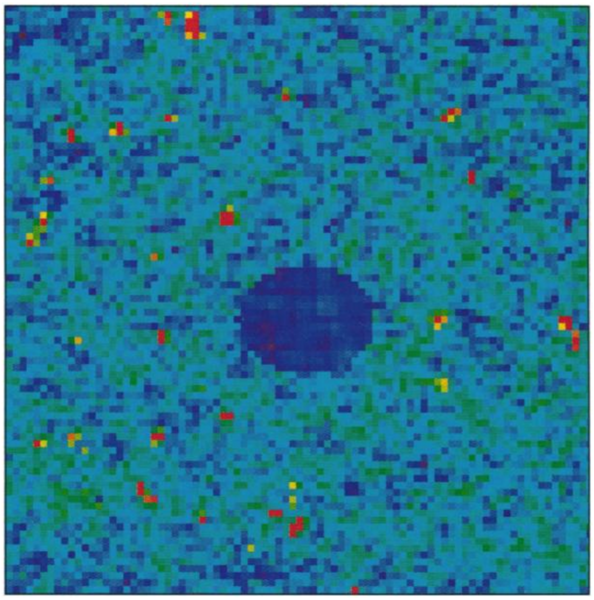
Undaunted, Frank continued, citing what he called supporting evidence. For example, he said that the spots are most abundant in images taken of the leading side of Earth, where Earth's orbital motion concentrates meteor impacts the way a moving car drives bugs onto the windshield. But others challenged that idea in a heated exchange during the question period. Unlike meteors, small comets are supposedly in orbits similar to Earth's and therefore overtaking Earth from behind. Their impacts should therefore peak on the trailing side, said longtime small-comet critic Alexander Dessler of the University of Arizona, Tucson. Frank countered that Earth would gravitationally focus the comets back to the leading side.

"I don't agree," chimed in planetary scientist Alan Harris of the Jet Propulsion Laboratory in Pasadena, California, as he projected a diagram of the orbital situation on the screen.

"These cartoons are meaningless," retorted Frank.

"I have a Ph.D. in orbital mechanics," Harris snapped back, in a jab at Frank's Ph.D. in the physics of auroras and magnetospheres. "I think I can speak authoritatively."

The acrimony suggests that the skeptics have taken over once more. "The ball's back in Lou's court," says Donahue, who says Frank should detail his analysis in print. Further analysis of Polar data by others is not likely soon, says Donahue: "Most of the community regards it as a waste of time."



SOURCE: L. FRANK / UNIV. OF IOWA MODIFIED BY F. MOZER ET AL.

**Now you see them ...** One analysis suggests that actual traces of small comets should be as large as this computer-generated spot, and that the small "atmospheric holes" are just noise.

## An Ocean for Old Callisto

Callisto has been the odd moon out of Jupiter's four large satellites. The other three—Io, Ganymede, and Europa—have revealed clear signs of geologic activity: erupting volcanoes on Io, a magnetic field generated by a churning molten core on Ganymede, and, most exciting of all, a tortured, icy surface and likely subterranean ocean on Europa. In contrast, Callisto looked utterly inert, inactive inside and out for billions of years. But now, it seems, Callisto has a magnetic field—and even an ocean—of its own.

At the meeting, researchers analyzing data from the Galileo spacecraft reported strong evidence of a magnetic field induced in an ocean beneath Callisto's icy surface by Jupiter's own powerful field. "This is an astonishing result," says planetary physicist David Stevenson of the California Institute of Technology in Pasadena, because "Callisto looks dead."

Finding geophysical stirrings and liquid water beneath an ancient, unchanging surface required a bit of inference. Galileo team members led by Margaret Kivelson of the University of California, Los Angeles, had already suspected that magnetic signatures picked up during passes near both Europa and Callisto (*Science*, 2 January, p. 30) might have been induced in hidden oceans by Jupiter's massive magnetic field. That tilted field wobbles like a tipsy top as the planet rotates. In a salty ocean—which is a good conductor—the moving field would induce electrical currents, which in turn would create a magnetic field oriented roughly opposite to Jupiter's. Galileo seemed to have found such fields on its first passes by the two moons in 1996 and 1997. That was no great surprise for Europa, whose jumbled, icy surface shows signs of liquid water not far beneath, but the implications for stable Callisto were shocking. Kivelson herself remained cautious about an ocean, as did her colleagues.

Now those doubts are falling away. "We think a subsurface ocean is likely" on Callisto, Kivelson said. During the latest Galileo flyby of Europa on 29 March, Europa continued to behave as an ocean-bearing moon should, reinforcing the argument for Callisto. And researchers such as space physicist Frances Bagenal of the University of Colorado, Boulder, are now particularly impressed by data collected late last year. When Galileo caught the moon in the opposite hemisphere of Jupiter's magnetic field, Callisto's field had flipped, just as an induced field should. The case for a subsurface ocean is "clear-cut," says Bagenal.

Europa's ocean has made it a tantalizing candidate for life, and planetary scientists are now beginning to wonder about the implications of an ocean for Callisto. Presumably, internal heat from radioactive decay is responsible for melting some of Callisto's ice to water, a key ingredient for life. Exactly where the ocean lies remains uncertain. Kivelson is putting it near the surface, far from the moon's inner fires, while Stevenson expects it to be at least 100 kilometers down. Geologists are also wondering how a subterranean ocean might have shaped surface geology during the past 4 billion years. Clearly, Callisto is the odd moon out no longer.

**–Richard A. Kerr**