GEODYNAMICS

A Lively or Stagnant Lowermost Mantle?

Geophysicists are debating whether the deep Earth shapes the surface like a quiescent lava lamp on low or like one churning up abundant blobs

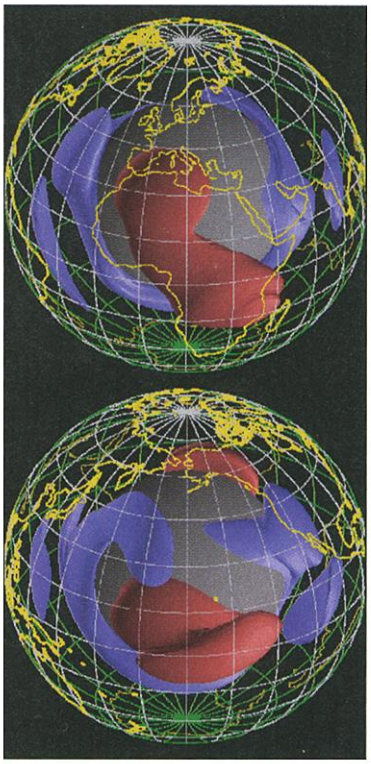
Lava lamps are back—and not just among retro hipsters lounging on shag rugs and waterbeds. Lecturers in the physics of the deep Earth are using them, figuratively or literally, to illustrate how Earth's heat engine might drive geology. The mantle—the nearly 3000 kilometers of incredibly viscous rock between the molten core and the crust—might work like a lava lamp running on low, its dense lower layer (analogous to the lamp's colored goop) remaining in place as heat trickles upward to drive plate tectonics. Or the mantle's lamp could be running at full tilt, deep material rising in great plumes that pinch off as blobs, loft high into the mantle, and carry the heat that helps drive plate tectonics. Recently, one group of geophysicists thought they saw signs of a stagnant lowermost mantle—a lava lamp on low. Now, another group instead sees signs of a fired-up lava lamp.

In this week's issue of *Nature*, two geophysicists offer evidence that two great hot plumes rise from opposite sides of the core as cooled rock sinks back, lava lamp–like, in between (*Science*, 9 July 1999, p. 187). "I think that's a reasonable model," says seismologist Barbara Romanowicz of the University of California (UC), Berkeley. Still, "there are too many unknowns in the physics" of the new analysis to be convincing yet, says geodynamicist Michael Gurnis of the California Institute of Technology in Pasadena.

The same geophysical observations motivated development of both the stagnant and churning lava lamps. In the mid-1990s, seismologists imaging the mantle with seismic waves—the way radiologists use x-rays to CT-scan the human body—had found that the bottom 1000 kilometers of the mantle stands out. Unlike the overlying mantle, where the pattern of varying seismic wave velocities paints a detailed picture of descending slabs of ocean plate, the lowermost mantle largely dissolves into an unrecognizable blur of broad, hemispheric-scale variations.

A different composition probably makes the lowermost mantle different looking, reasoned a trio of researchers, mantle modeler Louise Kellogg of UC Davis and geophysicist Bradford Hager and seismologist Rob van der Hilst of the Massachusetts Institute of Technology. Seismic probing had found large portions of the lower mantle that change the velocity of some types of seismic waves more than others. A composition different from that of the overlying mantle —a greater proportion of iron, say—could account for the waves' behavior, but a different temperature could not. More iron would mean greater density and a greater tendency for the lowermost 1000 kilometers of mantle to stay right where it is.

As a test, Kellogg and her colleagues simulated the fate of a heavy lowermost mantle in a computer model (*Science*, 19 March 1999, p. 1826). Weighted down with a few percent extra iron, the model's bottom layer warmed from the heat of the core and its own radioactivity and undulated in great waves as descending slabs kneaded it over the eons. Still, it remained intact.



Earth as lava lamp. Hotter (red) mantle rises and cooler (blue) sinks above the core (gray).

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This sluggish lava lamp model stimulated much interest, not all of it supportive. Many researchers, for example, have pointed out that such a bottom layer might be stable today, but Earth's greater internal heat in the past would not have allowed a stagnant lowermost mantle. Rather than look for a model mantle that could keep its lowermost reaches in check, geophysicists Alessandro Forte of the University of Western Ontario in London and Jerry X. Mitrovica of the University of Toronto decided to calculate how the mantle should behave given what has been inferred about its properties. "We threw all the data we know of—everything but the kitchen sink—at it," says Mitrovica. From seismic data, they calculated how temperature-driven variations in density within the mantle—warmer regions are lighter and rise, colder ones are heavier and sink—would drive flow over the eons. Flow would also depend on how much the rock resists, so these geophysicists gauged varying mantle stiffness from how the mantle's churnings affect both plate speeds and the shape of the liquid core. And finally, composition would also affect density and thus flow. So they used the competing effects of temperature and composition on different kinds of seismic waves to estimate how composition might vary through the mantle.

In the end, the two seismically distinct masses—one beneath Africa and the other under the Pacific—appear to be lighter than average despite being enriched in heavy elements. "They do contain sufficient heat to move up like hot-air balloons" high into the mantle, says Forte. "These aren't passive; they're erupting upwards." Adds Mitrovica: "This is a high-energy lava lamp."

"Forte and Mitrovica have taken a bold step forward," says Hager, but "they're going pretty far out on a limb." They've shown that two rising plumes fit the observations, he says, but not that that's the only way to fit the data. And Forte and Mitrovica ignored a nongeophysical constraint on mantle behavior, Hager notes. In order to explain the odd mix of isotopes that leaks to the surface in a few places, geochemists have long argued that substantial parts of the mantle remain isolated for billions of years. Forte and Mitrovica have the mantle flowing up or down so fast that it would tend to mix itself like a stockpot on a roiling boil, notes geophysical modeler Michael Manga of UC Berkeley. A way out is offered by the mantle's tendency to become especially viscous around a depth of 2000 kilometers, he says. If this high viscosity, which was identified in Forte and Mitrovica's analysis, is concentrated inside the two rising plumes, it would give them blobby shapes with hard cores. In that case, they might resist the stirring around them long enough to satisfy the geochemists, says Manga.

"Ours is a snapshot," notes Mitrovica. "Whether these plumes remain blobs over long periods of time or not, we don't know." Researchers will have to take a closer look at their lava lamps to divine the difference between an undulating layer, plumes, and blobs.

—RICHARD A. KERR