Others blame the science media—including news articles in *Science*—for celebrating the races and lavishing recognition on teams that are the first, perhaps by only a few weeks or months, to complete a molecule, instead of mentioning subtler accomplishments, such as developing a more elegant and concise way to make a medically important compound. "If someone comes up with a truly superior synthesis, it would probably not be given as much credit as it should because the summit had already been achieved," says Burke. Adds Nicolaou, "You don't get much credit for rediscovering the wheel."

"I believe these races are minimizing our opportunity to make fundamental discoveries," says Schreiber. "I feel it's not a healthy development in our field." It may also be jeopardizing the field's future, some chemists say. Because of the competition, the handful of big groups that can put the most grad students and postdocs on a project tend to dominate the field. "If you're a young organic chemist, you can't compete with these teams," says one researcher. As a result, promising students may be looking elsewhere. "I think that the best people aren't going into this area," says one synthetic chemist from the Midwest who is not involved with total synthesis. Instead, other areas where synthesis is used as a tool to make materials or drugs, rather than as an end in itself, are siphoning off much of the talent. "Straight synthesis has a lot of competition it didn't use to have," adds the chemist.

But even if total synthesis is facing a period of soul-searching, it will continue to be valued as a way to test cutting-edge chemical techniques and as a robust training ground for the pharmaceutical industry. Companies gobble up graduates from total synthesis labs as fast as they can be minted, putting them to work on crafting potential drug molecules. The targeted, goal-oriented, problem-solving training that students get in total synthesis labs "is very important for what we do," says Paul Anderson, vice president for chemical and physical sciences at the DuPont Pharmaceutical Co. in Wilmington, Delaware.

Synthesis experts also argue that by no means does every total synthesis wind up in a race. And they say they are far from exhausting the veins of new science to be mined. "As long as you are facing new structural types, you will learn new chemistry" in order to make them, says Nicolaou. Harvard synthesis pioneer E. J. Corey adds that the total synthesis field is still assimilating the recent discovery of novel asymmetric catalytic reactions, which have had an enormous impact on how complex molecules are made. "The way people do syntheses now is totally different than [it was] 15 years ago," he says.

But leaders of big and small groups alike say it's time for the field to move on to new goals, such as developing techniques to make exotic compounds with just a few steps, so that the synthesis is commercially practical, or making natural products and their kin in large quantities so biologists can study their effects. Whether the field embraces these aims or continues to be gripped by the lure of racing for unclimbed summits could determine how it fares in its period of greatest uncertainty.

–ROBERT F. SERVICE

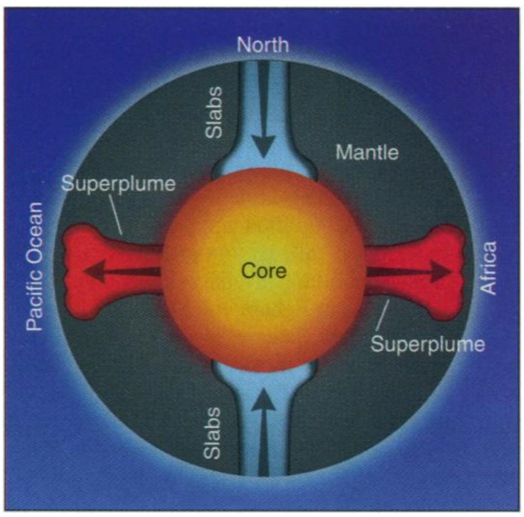
GEOPHYSICS

The Great African Plume Emerges as a Tectonic Player

A massive upwelling of hot rock beneath southern Africa may be shaping the continent as it cools Earth's core, in the flip side of plate tectonics

Plate tectonics gets all the glory. We humans ride the plates across the planet at their stately (and now measurable) pace and marvel at the natural wonders they produce—the soaring Himalayas, the deep-sea trenches, the earthquakes, the volcanoes. All this geologic hubbub happens because, through plate tectonics, Earth's mantle is cooling itself. Hot new ocean crust forms at midocean ridges, cools, and sinks back into the mantle, shedding heat and driving the plates. But geophysicists have long suspected that Earth might have another, less obvious way of chilling out. Almost 3000 kilometers down at the bottom of the mantle, they figured, heat from the molten iron core may churn up towering plumes of hot rock that slowly rise to the surface to spew volcanic outpourings. A narrow plume has recently been spied beneath Iceland (*Science*, 14 May, p. 1095), and another may fuel Hawaii's volcanoes—small potatoes in Earth's cooling system. But geophysicists are now accumulating increasing evidence of two huge "superplumes" cooling the core.

Deep beneath southern Africa, the "Great African Plume" is shaping up as the clearest example of a superplume. At the spring meeting of the American Geophysical Union (AGU) in Boston and in recent publications, geophysicists report signs that a blob of hot rock several thousand kilometers wide at its base, long known to lurk beneath southern Africa, extends toward the surface, spanning the mantle from the core to the volcanic hotspot of northeastern Africa. Its ascent could be pushing up much of southern Africa, and it could be feeding a dozen or more volcanic hotspots across the continent.



Blowing hot and cold. Superplumes loft heat from Earth's core, while cold slabs sink inward.

SOURCE: A. FORTE/U. WESTERN ONTARIO; ILLUSTRATION: L. CARROLL

Another likely superplume seethes beneath the southwest Pacific. Together, the plumes are a major force in the 80% of the planet that is the mantle, says geophysicist Alessandro Forte of the University of Western Ontario in London, who sees them forming half of "the dominant large-scale structure of the deep mantle." They might even shape climate.

Earth scientists have only just convinced themselves and most of their colleagues that narrower structures span the mantle from top to bottom. By using earthquake waves crisscrossing the mantle as a global version of the x-ray CT scans in medicine, seismologists have seen slabs of cold, dense ocean plate sinking below a depth of 670 kilometers into the lower mantle—in places, apparently, all the way to the bottom (*Science*, 31 January 1997, p. 613). A curtain of slabs descends around the Pacific Rim of Fire, while others plunge under the Mediterranean Sea and India.

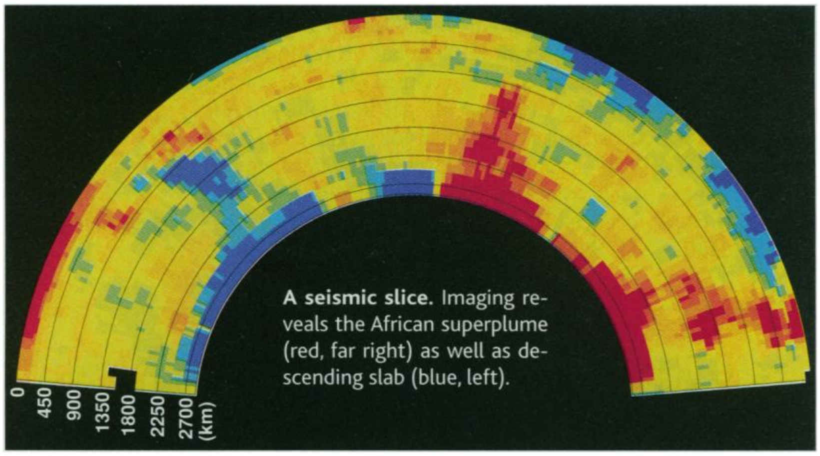
The slabs show up on seismic images because colder rock speeds up seismic waves. Hot, seismically slow features are tougher to pin down. Two great blobs of seismically slow mantle, one beneath the southern tip of Africa and the other beneath French Polynesia in the southwest Pacific, stood out in even the first fuzzy seismic images of the mantle made in the 1980s. Later images hinted that the African blob in particular might extend toward the surface, but the fuzziness was never quite dispelled.

With more earthquakes, more and better seismographs recording quakes, and more comprehensive compilations of seismic data, seismologists are sharpening their view of the African plume. At the AGU meeting, seismologists Jeroen Ritsema and Hendrik van Heijst of the California Institute of Technology presented a new mantle image based on three types of seismic observations—surface waves, which travel through only the 670 kilometers of the upper mantle; waves that rumble throughout the mantle, although less frequently through its upper reaches; and quake-triggered oscillations of the whole planet, which are particularly sensitive to velocity variations in the mid and lowermost mantle.

The resulting image portrays the African plume reaching continuously from the core-mantle boundary to the surface. "The dataset we use to assess this feature is pretty diverse," says Ritsema. "I believe [the plume] is continuous." The image shows a great blob of seismically slow rock appearing in the lower mantle beneath the southern tip of Africa, narrowing in the upper mantle, and bending northeastward to rise beneath the Afar Triangle, where the Red Sea, the Gulf of Aden, and the East African Rift mark volcanic rupturings of the plate.

"It's a very intriguing structure," says seismologist Andrew Nyblade of Pennsylvania State University in University Park, who agrees that the previously suspected continuity seems to be real. Seismic data from the Pacific are still sparse, but the chemistry of lavas erupted onto the sea floor also suggest a plume has risen there, too.

And both plumes seem to be on the move. Some recent seismic studies have suggested that the hot rock in the lowermost portion of the African plume might have a different chemical composition than its surroundings. If it were something heavy like iron that made the difference, the plume—which would otherwise be rising through the surrounding, cooler rock like a hot-air balloon—might be stagnant or even sinking. But at the AGU meeting, Forte presented calculations made with Jerry X. Mitrovica of the University of Toronto suggesting that the two superplumes are indeed rising.



A seismic slice. Imaging reveals the African superplume (red, far right) as well as descending slab (blue, left).

In a sense, they used Earth's core to weigh the mantle's two superplumes. Positioned on opposite sides of the core in the plane of the equator, the superplumes would tend to squash the core if they were heavier and sinking. But if they were lighter and rising, they would pull the core into a flattened egg shape lying in the plane of the equator. Forte and Mitrovica calculate that without two buoyant plumes rising on opposite sides of the core, it would still be flattened, by about 150 meters, simply due to the squeeze of slabs sinking to the north and south. If the plumes are rising as fast as their seismically inferred temperatures suggest they should be, the calculated flattening is 500 meters. And that is just the amount geophysicists have inferred from subtle wobblings in Earth's rotation.

"I couldn't come anywhere close to the observed flattening if I assumed these megaplumes were stagnant," says Forte. Seismologist Thorne Lay of the University of California, Santa Cruz, tends to agree: "The idea I prefer at the moment is that [the African plume] is a large upwelling or a set of upwellings."

A massive plume rising from near the core could help explain how Africa looks at the surface: uplifted and pocked with volcanoes. Last fall, tectonophysicists Cynthia Ebinger of the University of London, Royal Holloway, in Egham and Stanford University's Norman Sleep explained a host of surface features by proposing that a single plume hit the African plate beneath Ethiopia 45 million years ago, then spread across at least 5000 kilometers of the underside of the plate, channeled by preexisting "inverted ruts" in the plate.

In addition to spewing voluminous lavas across Ethiopia 30 million years ago, the still-buoyant spreading plume would have raised East Africa as it spread and fired up volcanic hotspots from Cameroon on the west coast to the Comoro Islands off Madagascar in the east. "I thought it was nuts at first," says geophysicist Bradford Hager of the Massachusetts Institute of Technology, but after doing some modeling of his own, he thinks the one-plume-serves-all idea "is probably a neat idea, though I wouldn't bet the farm on it yet."

To the south, the deeper part of the African plume may be making itself felt as well. Most of southern Africa and the surrounding sea floor is half a kilometer or more higher than it ought to be, as Nyblade and Scott Robinson of Penn State have pointed out. Tectonophysicist Carolina Lithgow-Bertelloni of the University of Michigan in Ann Arbor and seismologist Paul Silver of the Carnegie Institution of Washington's Department of Terrestrial Magnetism recently suggested that this African "superswell" gets its boost not from thicker crust, as others had suggested, but from the plume. They calculate that the plume's buoyancy, as inferred by seismic imaging, is just enough to produce a bulge in the overlying surface that matches the superswell in size and height.

On a global scale, the African plume seems to be a sizable part of the grand heat engine that shapes the surface while slowly draining the life from the planet. The two superplumes rise like opposing pistons on opposite sides of the world, while descending slabs form a ragged north-south curtain between them. Slabs have been sinking in much the same places for the past couple of hundred million years, notes Hager, so their failure to cool the mantle beneath the Pacific and Africa probably led to overheating and superplume formation.

If so, then plume tectonics could join plate tectonics as a prime mover in a range of terrestrial phenomena. Marine geophysicist Roger Larson of the University of Rhode Island in Kingston has proposed that the Pacific plume and its superswell may be just the remnants of a superplume that burst to the surface about 120 million years ago, gushing lava onto the sea floor and jerking Pacific plate tectonics into high gear (*Science*, 15 February 1991, p. 746). From a chain of speculative links, Larson invokes volcanic gases that stoked a greenhouse warming, oceans that spilled onto the continents to form inland seas, and a plume-chilled core that shut down the flip-flopping of its magnetic field. Now that, if true, would garner some glory for plume tectonics.

–RICHARD A. KERR

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