EARTH SCIENCE

Minerals in Rock Mass Hold Clues to 400-Kilometer Ascent

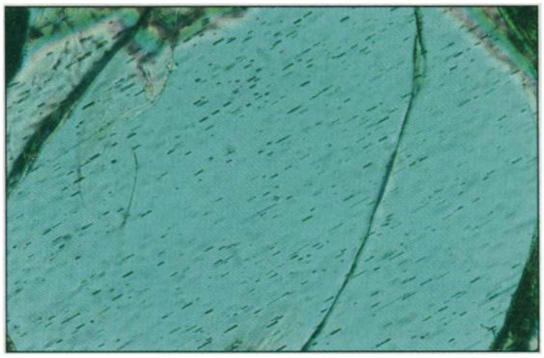
Rocks, as a rule, know their place. In the planet's layered structure, the lightest rocks float on top as a crust; below are denser mantle rocks, and at the very bottom is the weighty iron core. Here and there a slab of ocean crust cools and becomes dense enough to sink into the mantle, but otherwise rocks don't seem to have great vertical mobility. That's why a group of mineralogists was so shocked recently to find evidence that a chunk of rock in the Swiss Alps had once been 400 kilometers or more down in the mantle.

On page 1841 of this issue, Larissa Dobrzhinetskaya, Harry Green, and Su Wang of the University of California, Riverside, report that rock from the Alpe Arami massif, an 800-by-500-meter mass embedded in the mountains of southern Switzerland, contains minerals that must have formed as the mass rose to the surface from deep in the mantle. The researchers can think of only one way of transporting such a large chunk of rock from such great depths: as a passenger in a larger region of lighter crustal rock that buoyed it to the surface, like a life preserver. But that picture only raises a new puzzle: What was the relatively light sedimentary rock of the continental crust doing that far down in the mantle?

"This is indeed a wake-up call," says mineralogist Stephen Haggerty of the University of Massachusetts. "It's very exciting." It's not the first hint that crustal rocks can sojourn at mantle depths, but the depths inferred for the Alpe Arami massif are so great that Haggerty says, "There is something going on geodynamically that we don't fully understand." Whatever it is, it seems to have something to do with continental collisions like the one now taking place between India and Asia, says Haggerty. Somehow the head-to-head butting of continents—the process that uplifted the Alps about 50 million years ago—can jam light crustal rock deep into the mantle until it escapes and bobs back to the surface.

That's a very different geological elevator from the one that carried up the only other rocks known to have arrived from the deep mantle, the bits of mantle rock that bear diamonds (*Science*, 10 September 1993, p. 1391). They were blasted up from depths of hundreds of kilometers through narrow volcanic conduits called kimberlite pipes. Still, it was the microscopic appearance of rock spit up in a kimberlite pipe that first clued Green into Alpe Arami's deep source.

"In 1994 I was sitting in an ultrahigh-pressure metamorphism session at the AGU [American Geophysical Union] meeting in Baltimore," Green recalls. Haggerty was showing slides of an arrangement of green and violet minerals from a South African kimberlite pipe that implied that the rocks containing them had originated at great depth. "Suddenly, images of rocks from Alpe Arami that I had seen 20 years ago came flooding into my brain," says Green. He had visited the massif in 1973, been struck by the same odd juxtaposition of minerals, collected lots of rocks, and then never got around to looking at them under a microscope.



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Pointers to the deep mantle. Mineral rods (20 micrometers long) formed hundreds of kilometers down.

After the AGU epiphany, Dobrzhinetskaya, Green, and Wang sliced open Green's rocks and analyzed the composition and crystal structure of the minerals. Scattered through the rock's abundant olivine, a greenish, magnesium-rich mineral, were microscopic rods of iron-titanium oxide, called ilmenite in its usual crystal form. Their presence suggested that the rock had come from some depth in the mantle, probably below 100 kilometers. The inclusions must have sweated out of the olivine as the rock rose to the surface, easing the high pressures that would have kept the iron and titanium in solution in the olivine's crystal structure.

That wasn't the whole story, because the inclusions contained more titanium than anyone imagines olivine can hold, even at high pressures. Olivine "is very persnickety as to what it accepts into" its crystal structure, says Green. Pressure helps, according to preliminary experiments by the Riverside group, but, says Green, "my intuition tells me that there probably are no conditions under which olivine is stable and can dissolve that much titanium." But at a depth of 400 kilometers, pressure transforms olivine into the mineral wadsleyite, which should hold much more titanium. That implies that the Alpe Arami massif started off at least that far down.

Also pointing to extraordinary depth were variations in the crystal structure of the rods. Only some of them had the ilmenite crystal structure; the rest had one of three other structures, all previously unknown, that presumably formed at higher pressures and temperatures. The Riverside group thinks all four sets of rods are relics of a single, higher pressure phase, now vanished. That would explain the persistence of the rod shape in spite of the variations in crystal structure, Green says. From the rod shape and clues in the crystal structures, the Riverside group concludes that the mineral that first precipitated in the olivine had a so-called perovskite structure, which high-pressure lab experiments have shown can exist only at the pressures found below 300 kilometers.

"I think their data are very impressive," says Gary Ernst of Stanford University. "There's a good probability they're right. It's at least quite provocative." As provocative as their estimate of the rock's original depth is the mechanism the group favors for getting it to the surface: having more buoyant crustal rocks lift it. To explain how these crustal rocks could have reached depths of hundreds of kilometers in the first place, Green invokes "the Ivory Soap principle," a mechanism proposed by Friedhelm von Blanckenburg of the University of Oxford and Huw Davies of the University of Liverpool. Buoyant crust, like Ivory Soap, won't sink on its own, notes Green. But a collision between two continents, as in the Alps, might sandwich a "soap bar" of continental crust between two slabs of the dense mantle that underlies continents. The assemblage might then sink to mantle depths until it warms and weakens enough for the soap bar to slip out and bob back to the surface, sometimes stealing a bit of the mantle as it goes.

Ernst finds that scenario a little hard to swallow for Alpe Arami. The soap bar idea, he says, might explain the signs of deep travels in rocks at four other sites, in the western Alps, Norway, China, and Kazakhstan. The crust at those sites contains microdiamonds, which could only have formed if the rock had sunk to depths of 100 kilometers or more. But the depths required to explain the Alpe Arami massif are "almost incredible," he says.

Then again, Ernst says, geodynamicists may have to swallow hard and accept a topsy-turvy world. Green now plans to search the rock around Alpe Arami for microdiamonds to see if it too has visited great depths, as the Ivory Soap scenario requires. Says Ernst, "We'll have to see where the mineralogy takes us and let the chips fall where they may."

–Richard A. Kerr