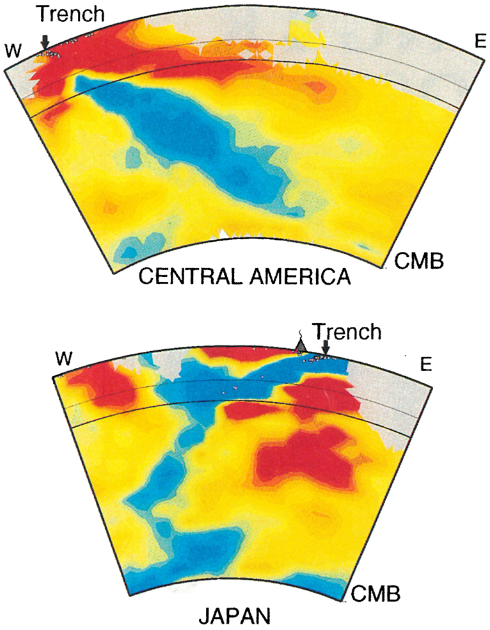
crystal structures of the minerals in the mantle. Wherever the mantle rock melts, such elements readily escape into the melt and are carried with it to the surface. Geochemists then expect that the upper mantle, where melts are more likely to develop, is more depleted in these incompatible elements than the lower mantle. Indeed, basalts from mid-ocean ridges, which are assumed to well up from the upper mantle, contain smaller percentages of the incompatible elements than either the continental crust or some ocean island basalts, which are thought to stem from plumes from the lower mantle. Mixing between upper and lower mantles, so the reasoning goes, would not allow such heterogeneities.

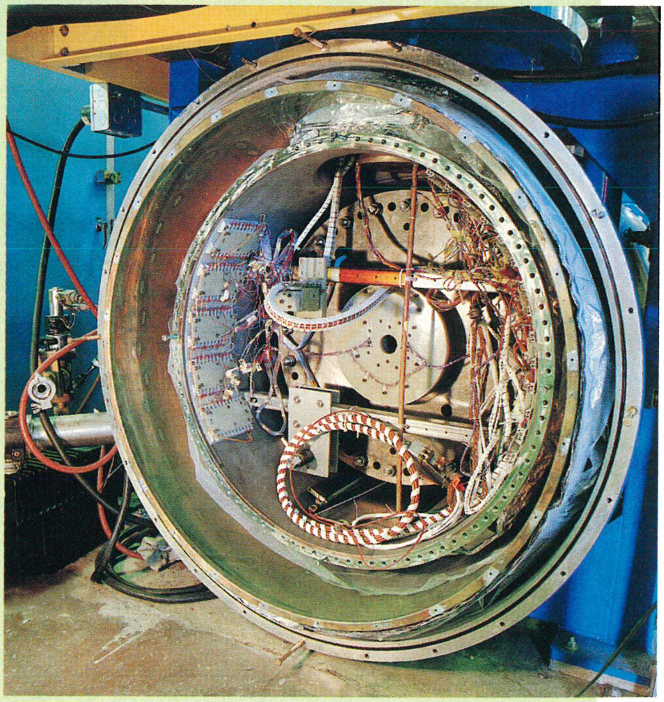
By measuring the concentration of an incompatible element in the continental crust, one can estimate the amount by which the mantle must have been depleted. In the case of neodymium, estimates of the depleted volume of the mantle range from 25–50% of



A VERTICAL SLICE through Earth's crust indicates colder material (blue), suggesting tectonic plates that have descended continuously through the mantle for perhaps 40–50 million years. Figures show the cross section of P-wave anomalies through two regions of the world, with blue coding regions where seismic waves travel anomalously fast. CMB is the core–mantle boundary. (Figure courtesy of Rob van der Hilst, MIT.)

Accelerator Magnet with Brittle Superconductor Sets a Record

At the Lawrence Berkeley National Laboratory, Ron Scanlan and colleagues are investigating the use of brittle superconducting cable to create accelerator bending magnets significantly stronger than those designed for the abandoned Superconducting Super Collider (SSC) and CERN's much-anticipated Large Hadron Collider (LHC). With the 1-meter-long prototype dipole magnet shown here end-on, the group recently achieved a record bending field of 13.5 tesla in the 5 cm beam aperture visible at the center.



The coil that creates this unprecedented dipole field is made of Nb_3Sn, an intermetallic compound whose great virtue is that the critical magnetic field at which it loses its superconductivity is considerably higher than that of the Nb–Ti alloy of the SSC and LHC magnet designs. A Nb–Ti wire cannot support any supercurrent in a field exceeding 11 T. But at least it is a malleable, ductile metal that can be extruded and wound into magnet coils.

Nb_3Sn, by contrast, is a ceramic-like compound as brittle as glass. Therefore the LBNL group had to extrude and wind the cable before the ultrathin niobium filaments were made to react chemically with the tin in the surrounding matrix by baking the wound coil at 650°C for ten days. When subsequently cooled to liquid-helium temperatures, the intermetallic compound becomes a high-current superconductor. The successive cryogenic walls seen in the photo are for an outer liquid-nitrogen shield and then the inner liquid-helium vessel.

After a series of 40 "training quenches," the record 13.5 T dipole field was achieved at 1.8 K, a temperature at which the helium is superfluid. So far, the enormous Lorentz-force stresses on the coils do not appear to have degraded the current-carrying capacity of the Nb_3Sn.

The LHC magnets, which will also be bathed in superfluid helium, are expected to operate at a field strength of only 8.4 T, limited as they are by the critical field of Nb–Ti. The energy of the protons that can be stored in an accelerator ring is proportional to the bending-magnet field strength times the ring's circumference. Therefore if one could, some day, fill the 27 km LHC ring with 13.5 T Nb_3Sn bending magnets, one could increase the collider's beam energy from 7 TeV, the present design goal, to 11 TeV. Conversely, one could fit a 7 TeV beam into a ring only 17 km in circumference. Prototype SSC magnets, designed to operate at 6.6 T in liquid helium at 4.4 K, did in fact reach 10 T when tested at 1.8 K.

Manufacturing thousands of full-length Nb_3Sn bending magnets for a next-generation proton collider is still very much in the future. Making these ceramic superconducting coils is, as yet, very expensive and time consuming. But they are also of great interest to those who are thinking about the next generation of magnetic-confinement fusion devices.

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