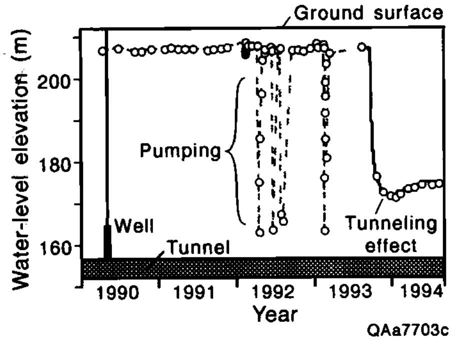

Fig. 4. Hydrograph of water-level fluctuation at SSC Laboratory monitoring well BE3 measured by electrical sonde (circles) and pressure transducer (solid black line). Also marked are elevations of SSC tunnel and the BE3 well screen. BE3 lies approximately 10 m from the tunnel edge. Water level in BE3 abruptly fell when the tunnel was mined past the well.

duced rapid drainage is responsible for the effects on hydraulic head.

Creating the tunnel opening can be viewed as a purposeful perturbation of the underground rock mass. All of the excavation effects, if properly identified, should serve to characterize the medium. Thus one important objective is to predict the mechanical and hydraulic response to the excavation.

Geomechanical Issues

During or after construction, large-scale underground works often encounter unanticipated difficulties, such as higher than expected seepage or spalling, which lead to additional construction expense or litigation, typically 5–100% of the original contract cost. But major cost savings can be achieved by minimizing overengineering and unanticipated difficulties through more accurate characterization of the upper 100 m of the subsurface.

The SSC site is a case in point. The most up-to-date contracting methods were utilized and the tunneling was generally considered to be a success. Yet, there were internal questions, such as how much will the shale floor heave over 30 years? And how much additional roof support is needed near shaft N-35, where significant spalling has occurred in the roof due to a shale seam? Uncertainties due to the current state of knowledge could have had long-term cost impact on the collider project had it gone to completion.

Given the present program of closure as mandated by Congress, a more relevant question is, how long will it take for the tunnel to fill with groundwater and will the roof collapse eventually? Therefore a long-term study of the stress distribution, deformation, and fluid flow within the tunnel will serve both as a postaudit of SSC construction and as a predictive guide to SSC closure.

A major issue for the research program is to determine how much disturbance of the initial condition was produced by the excavation itself. A series of experiments, such as successive overcoring and hydraulic fracturing experiments at scales up to a tunnel diameter in both the chalk and shale in different segments of the tunnel can definitively answer this question. A second major issue is to validate surface and borehole geophysical techniques for characterization of a fractured rock mass. An extensive list of topics and related experiments include determining scale effects on shale rheology, constitutive modeling of weak rocks, and determining stress history and joint formation through geologic time.

It is hoped that a facility at the SSC will encourage other researchers interested in the problems described to consider utilizing it for their own specific experiments. The large diameter shafts permit easy access for most machinery and experimental equipment.

Acknowledgment

We thank Charles Daugherty, George Kolstad, Bill Luth, and all the workshop participants, whose ideas are in this report. The workshop and project definition study are supported by the Office of Energy Research of the U.S. Department of Energy (contract DE-AC03-76SF00098 to Lawrence Berkeley Laboratory).

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Hot Action at the Core-Mantle Boundary

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Recent discoveries about the Earth's most prominent internal feature, the core-mantle boundary, were revealed at a workshop just held at the University of California at Berkeley. The latest seismological evidence points to the interface between the mantle and core being among the most dynamically active regions of the planetary interior.

Though distant, at 2890 km depth, the core-mantle boundary is significant: the contrasts in properties across this interface exceed even those between air and rock at the Earth's surface. Processes at the core's boundary influence the rotation and magnetic field of our planet and play an important role in the cycle of mantle convection that drives plate tectonics. In the interest of reviewing recent findings and coordinating future research, a workshop on Structure of the Core-Mantle Boundary and D" Region was held from September 10 to 11. Such workshops are among the activities sponsored by the new Cooperative Studies of the Earth's Deep Interior (CSEDI) initiative at the National Science Foundation.

As increasing amounts of seismological data are analyzed, it is becoming evident that the lowermost mantle is even more anomalous than previously recognized. New tomographic studies by A. Dziewonski and colleagues at Harvard reveal unexpectedly large heterogeneity in shear wave velocity near the base of the mantle, amounting to ±3% on a global scale and at 1000-km resolution. Anomalies in both *P* and *S* wave velocities are strongest near the core, but extend 500 km or more up into the mantle. Also, they exhibit a remarkable bipolar (degree 2) symmetry, with a ring of relatively fast velocities surrounding slower velocities in the lowermost mantle beneath the Pacific Ocean and Africa.

The magnitude of seismic heterogeneity appears to be even greater at higher resolution, as independently suggested by detailed examinations of specific patches on the core-mantle boundary. E. Garnero, P. Shearer, and J. Vidale, summarizing their work and that of others, described how large variations in shear wave velocity appear to be correlated both with compressional wave heterogeneity ($\delta V_S/V_S \sim 4\delta V_P/V_P$) and with the height to a refracting interface ~100–400 km above the core-mantle boundary. The origin of the refracting/reflecting interface is currently uncertain, but it may represent the top of a heterogeneous layer that scatters seismic waves in the lowermost mantle.

B. Romanowicz showed strong evidence for velocity anisotropy just above the core, in regions of low velocity according to the tomographic models. The horizontally polarized shear waves travel faster than vertically polarized waves in a manner suggesting a laminated structure. All of the researchers present noted the rapidity with which the heterogeneity in seismic velocities increases in the lowermost 300 km of the mantle, and considered the as-yet unexplained predominant degree-2 pattern of anomalies.

An important change in perspective, summarized by J. Bloxham, is that ±5–6 km topography on the core-mantle boundary, as suggested by early tomographic results, is quite compatible with existing observations. Indeed, such large topography is suggested by recent analyses of the geomagnetic field. However, he and others were surprised at the seismological evidence indicating that as much as a 1% drop in V_P may be observed across the outermost 50-100 km of the core. D. Stevenson (Caltech) proposed that a multiphase slurry might explain this seismological structure, while avoiding the geomagnetic complications implied by the presence of an unmixed layer at the top of the fluid core.

There is good reason to expect that a zone of enhanced temperature gradient is present at the bottom of the mantle, due to heat loss from the core. R. O'Connell and N. Sleep explored the fate of hot plumes originating from this thermal boundary layer and taking part in the convection of the overlying mantle. Still, the conclusion that seems to emerge from the workshop is that the seismic anomalies—heterogeneity, scattering, anisotropy and their distribution—cannot be entirely explained by solid state thermal effects in the lowermost mantle. Instead, it appears that partial melting or chemical reactions between the core and mantle (or both) must play a significant role in modifying the properties of the lowermost mantle.

R. Jeanloz and E. Knittle summarized experiments from several groups around the world showing that mantle and core materials do react extensively when put in contact with each other at deep-Earth conditions. B. Buffett then described how the out-of-phase annual nutation of the Earth can be explained by just such a patchy reaction zone being present at the core-mantle boundary. Finally, L. Kellogg outlined the manner in which mantle convection might stir up the reaction products of the lowermost mantle, sweeping them upward to produce the seismologically observed anomalies. Although the occurrence of intense chemical reaction between mantle and core may ultimately explain the various geophysical observations, the underlying mechanisms are poorly understood. While suggesting that reaction-infiltration processes may play a role, D. Stevenson emphasized the need for further experimental and theoretical work on this problem.

Clearly, it is not so much theory or experiment as the recent availability of large amounts of observational data, especially in seismology, that is motivating current studies of the Earth's deep interior. One of the significant outcomes of the workshop was the initiation of means by which researchers around the world could have electronic access to the new data—both travel time anomalies and corresponding waveforms—either to add new observations or to carry out their own analyses of the data. The latest studies of these observations are revealing a more dynamic picture of the planetary interior than ever before imagined.—

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FALL MEETING

Research Cruise Yields New Details of Macquarie Ridge Complex

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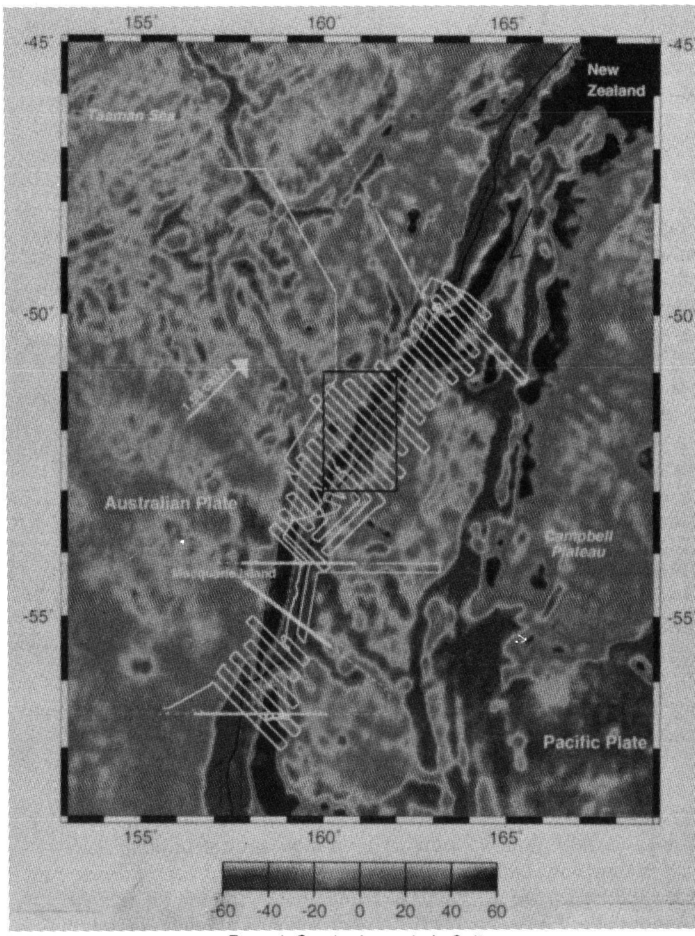
During a 44-day expedition on board the Australian vessel *Rig Seismic*, scientists collected new information on the morphology of the Macquarie Ridge Complex (MRC), located at the boundary between the Pacific and Australian plates. In the joint venture, funded by the U.S. National Science Foundation and Australian Geological Survey Organization (AGSO), investigators from the two countries studied deformation in the area along the MRC, which includes the site of the largest earthquake of the 1980s (May 23, 1989, $M_w = 8.2$).

The researchers acquired ~160,000 km^2 of HAWAII MR1 (HIG acoustic wide-angle imaging instrument, mapping researcher 1) side-scan sonar/bathymetry images and ~7000 km of 8-channel seismic reflection data (Figure 1). In addition, three ~400-km gravity transects of the MRC were completed



Free-air Gravity Anomaly (mGal)

*Fig. 1. R/V Rig Seismic track over the Macquarie Ridge Complex (MRC) south of New Zealand, superimposed on the free-air gravity field [*Sandwell and Smith, *1994]. Medium white lines indicate HAWAII MR1 side-scan and swath bathymetry, 8-channel seismic reflection, gravity, and magnetic control; heavy white lines depict 96-channel seismic reflection, bathymetry, gravity, and magnetic data; light white lines show bathymetry, gravity, and magnetic data. The boundary (black line) between the Pacific and Australian plates had been thought to follow trenches axes. Arrow on Australian plate indicates its motion relative to Pacific plate; length of arrow corresponds to 10 m.y. of motion at the rate indicated. Image prepared by L. Gahagan, UTIG. Original color figure appears at the back of this volume.*