Exploring the Continent by Drilling: A New Proposal

More than 2 million holes have been drilled in the United States in the search for oil and minerals, but few have been instrumented for research and many areas of geological interest have never been drilled at all. By contrast, a nearly complete synoptic picture of the ocean basins has emerged from the drilling activities of the *Glomar Challenger*. With these disparities in mind, a group of earth scientists from industry, government, and academia has proposed a program of drilling to depths as great as 10 kilometers to explore crustal processes and the nature and evolution of continental rock.

Drilling deep into the earth's crust has been a favorite vision of geologists and geophysicists for years, and proposals for such an effort date back to the ill-fated Mohole project of the mid-1960's. What is unique about the present proposal is its emphasis on practical problems such as earthquake control, development of geothermal energy, and mineral discovery, together with the claim, which appears justified, that the research will be directly applicable to these problems.

Deep drill-holes into an active section of the San Andreas fault in California would constitute one high-priority item in the proposed program. Since earthquakes on the fault are typically centered at depths of about 6 kilometers, holes drilled vertically and then slanted (with a wedge technique called whipstocking) across the fault zone at depths of 3, 6, and 9 kilometers would permit study of rock undergoing both brittle fracturing behavior and the more plastic behavior believed to occur below the quake region. An initial goal would be to determine the mechanisms of fracturing and fault creep by in situ and laboratory measurements of permeability and other material properties, fluid pressures, stress and deformation, and seismic waves. Then experiments aimed at controlling quakes by manipulating fluid pressures with water injected into the fault zone—a technique successfully tested on a small fault near Rangely, Colorado—could be undertaken. A sparsely populated site in Bear Valley (about one-quarter of the way from San Francisco to Los Angeles) that is already heavily instrumented on the surface is proposed as the prime target, but other possible locations include the area near Anza (northeast of San Diego on the San Jacinto fault, a southern extension of the San Andreas) that is thought by some geophysicists to be a prime candidate for the next magnitude 6 quake in California.

Even more ambitious is a second major focus of the program—drilling into active geothermal systems and eventually into an active magma chamber itself. These bodies of molten rock, thought to lie from 3 to 6 kilometers beneath the earth's surface at at least 15 locations in the United States, are not only the source of heat for geothermal fields but also the source, directly or indirectly, of mineral deposits—copper, lead, zinc, molybdenum, and possibly others.

As noted in a report outlining the proposal,* production of geothermal energy is today limited to areas of hot springs and geysers just as oil production was once limited to areas beneath oil seeps. Not all magma bodies have surface manifestations, however, and by drilling into the deep hydrothermal zone (above the magma chamber but below the depth penetrated by commercial geothermal wells) it should be possible to determine the physics of geothermal systems and the geologic conditions in which they occur, thus facilitating exploration, estimates of potential resources, and development of power-producing wells. A key question is whether the hydrothermal fluids believed to circulate around a magma chamber come from the molten rock itself or from groundwater.

These fluids are also of interest because they may contain ore-forming constituents. Still more information on the origin and deposition of minerals—and on volcanism, crystallization of magma, and other basic igneous processes—could come from drilling up to the edge of or even into a magma chamber, if the technology to cope with the temperatures of nearly molten rock can be developed. Thermal balances, chemical gradients, and unique petrological data from the magma-rock interface would provide an improved basis for ore exploration and for a host of fundamental geological investigations. Physical experiments within the magma chamber, involving probes whose motion could be acoustically tracked or other tracers of convection, are also proposed.

The third major emphasis in the drilling program would be on understanding the extent and regional structure of the crystalline "basement" rocks that underlie the United States. These rocks constitute the basic material from which continents are made and are thought to contain the bulk of U.S. mineral resources. It is proposed to drill holes into the uranium-rich rocks of the Colorado Plateau, the Minnesota River valley, which contains the oldest known rocks on the North American continent, newly formed continental crust in Puerto Rico or the Virgin Islands, and other sites.

A few holes as deep as 9 kilometers have been drilled into sedimentary rock. Penetrating this deep in crystalline rock is also thought to be feasible with existing technology, although at a cost of \$4 million to \$10 million per hole and drilling times of about 1000 days. Conventional rotary drilling systems are limited to rock temperatures of 250°C, however, and even with high-temperature materials (not now available) will be restricted to less than 450°C. Thus novel hole-making techniques will have to be developed before a magma chamber could be tapped. High temperatures pose even harder problems for down-hole scientific equipment—present electrical cables are limited to about 250°C, and the solid state electronics that are the core of modern instruments cannot be used at temperatures above 150°C. Thermal insulation, refrigeration, "old" vacuum tube electronics, and efforts to develop high-temperature instrumentation are suggested as possible ways around the bottleneck.

Continental drilling on the imaginative scale now proposed will not come cheap—about \$100 million over a 10-year period is the estimate given in the report. Nonetheless, the program has caught the interest of many prominent earth scientists; some geologists believe that inadvertent discoveries of mineral deposits alone will more than pay for the drilling costs. In Poland, for example, drillers unexpectedly found a major deposit of high-grade copper ore that has turned that country into an exporter of the metal; other countries, notably the Soviet Union, are also reported to have systematic drilling programs. Among other advantages, a visible research program may well encourage oil and mineral companies to donate drilling cores and to allow research efforts to "piggyback" on commercial drilling efforts to a greater extent than at present. In any case, the feeling among supporters of the proposal is that the time has come both scientifically and in terms of national energy and mineral needs for exploring the continental mass we live on.—ALLEN L. HAMMOND

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