Inner Space

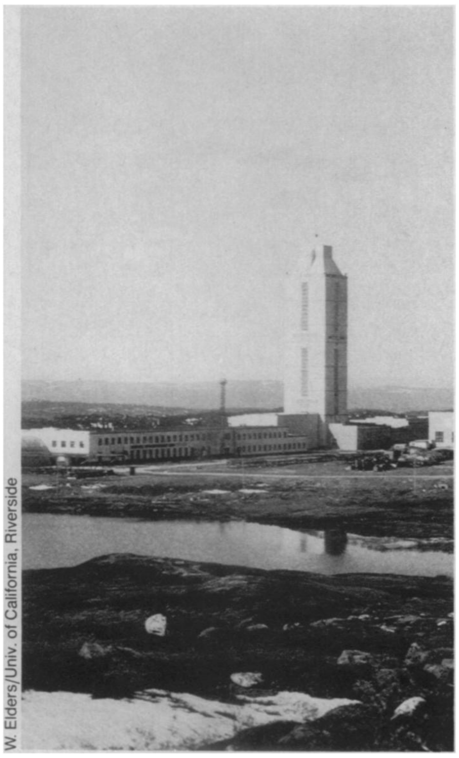
The Soviet Union and West Germany delve into Earth's deep secrets as the United States looks on

By RICHARD MONASTERSKY

Captain Kirk of the starship *Enterprise* proclaimed outer space the final frontier. But according to a small corps of scientists, no one needs to fly billions of miles to find vast unexplored realms. The last frontier, they say, lies underfoot.

Nobody knows what really sits a few miles under the skin of our own planet. For centuries, geologists have roamed Earth's surface, trying to imagine what internal heavings raise mountains, drive earthquakes and feed volcanoes. Since the early 1900s, scientists have probed beneath the ground using such techniques as sound waves, magnetic surveys and gravity measurements. But these offer indirect glimpses – almost like pressing an ear against a wall to catch the muffled conversation of unknown speakers in another room. Only within the last few decades have researchers tried drilling directly into the deeper layers of the crust to discover its secrets.

Many countries regularly drill scientific holes down to a modest kilometer or two. Now the Soviet Union and West Germany are spending billions of dollars to reach much deeper. At last July's meeting of the International Geological Congress in Washington, D.C., scientists from several nations discussed their deep-drilling programs, often to the envy of U.S. researchers who have watched as tightening purse strings in fiscal year 1989 halted all purely scientific continental drilling in the United States.



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While buried rocks might seem unimportant to society at large, those involved with the Soviet and West German deep-drilling projects say their research is gathering information that addresses some of the more pressing issues of the day. Several deep drillholes may aid in the search for hidden oil and gas reserves, and at least one has already revealed valuable mineral deposits. Others should provide answers about the origins of earthquakes and the ramifications of dumping radioactive wastes into deeply buried vaults.

Drilling proponents think of the deep holes as telescopes into the Earth, offering a unprecedented chance to see what lies inside the planet's crust. "We know more about the moon or the ocean floor than we know about the continental crust," says Robert S. Andrews, president of DOSECC, a Washington, D.C., nonprofit consortium that manages land-based scientific drilling for the National Science Foundation.

In the world of deep drilling, the Soviet Union stands far ahead of all other nations. Its current program features 11 deep-hole projects, including the deepest drillhole in the world. Located on the Kola peninsula near Scandinavia, this granddaddy hole is 19 years old and presently reaches a depth of 12.066 kilometers. The Soviets will soon resume drilling at Kola, aiming for a depth of 14 to 15 km, says Yevgeny A. Kozlovsky, who served for 12 years as Minister of Geology in Moscow.

On the Kola peninsula, north of the Arctic Circle, the Soviet Union has drilled the world's deepest hole. A 30-story building houses the drilling derrick.

With several holes targeted for a 15-km depth, the Soviets have evolved a vocabulary to describe the different varieties of boreholes. While others around the world have adopted slightly different categories, most drilling experts would define "deep" holes as those reaching a depth of 4 to 7 km, while "superdeep" or "ultradeep" holes go beyond 7 km.

All of the Soviet holes address practical concerns as well as basic research questions, and Soviet scientists list several reasons for drilling at Kola. The region is geologically stable and quiet, making it a good location for the flagship hole that must test new drilling equipment and techniques. At Kola, the engineers have not had to deal with high crustal temperatures, corrosive fluids or other factors that complicate and hinder drilling in many other areas.

The search for minerals also drives the Kola project. This region holds the richest copper and nickel deposits known in the USSR, and the Soviets wanted to see if additional deposits lay hidden at lower depths, says Vadim I. Kazansky of the Institute of Geology of Ore Deposits, Petrography, Mineralogy and Geochemistry in Moscow.

In that search, the Soviets succeeded. Their drill bits cut through a layer of previously undiscovered nickel and copper ores at 1.6 km, or roughly a mile deep – a reachable depth for mining. "This discovery enlarged by many times the [region's] ore potential," Kazansky says.

While he calls that find a "predicted" discovery, Kazansky says the hole also led to several unexpected finds, such as the appearance of copper, nickel and lead deposits at depths between 6 and 11 km.

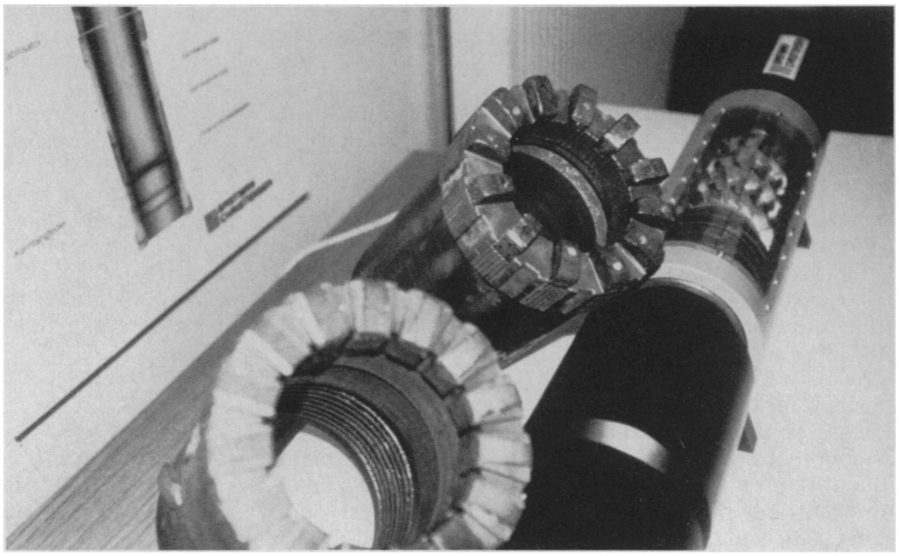
These deposits belong to a type that develops from hot fluids flowing through cracks and pores in hard crystalline rock. The underground solutions leach out minerals as they circulate, and their load precipitates in a small area – a process that concentrates the minerals.

On the basis of laboratory work and theories, scientists have regarded this type of mineralization as a shallow phenomenon, happening no deeper than 3 to 5 km, says Kazansky. In crystalline rocks below this depth, the weight of overlying rock should close off all cracks and pores, according to traditional thinking.

The deep mineral finds in the Kola well have poked a hole in that theory. Erosion over the last half-billion years has stripped off several kilometers of crust. Thus the minerals must have formed at greater depths than their present location, says Lev Vernik of Stanford University, who formerly worked on the Kola project.

Even more startling, the Soviets report evidence of fluids still flowing in fractured and porous rock at depths of up to 9 km. Since the researchers have provided few details, however, the reports have raised skeptical inquiries by Western scientists. During drilling, crews must pump fluids down the hole to lubricate the bit, and it is often difficult to prove certain fluids come from the rock rather than from the drilling process.

The deep mineral deposits at Kola lie well beyond the reach of present-day mining practices, but their discovery is far from useless. If mineral deposits form that deep, geologists can search for places where eons of erosion have brought ores closer to the surface, where they can be mined. "There may be economic deposits that formed at 8 km depth and are now shallower that we don't know anything about," says Stanford's Mark D. Zoback, chief scientist of the Cajon Pass drilling project (SN: 3/26/88, p.199). The deepest scientific drillhole in the United States, the Cajon Pass project is investigating the ground stress near Los Angeles along the San Andreas fault.


G. Barber

Drill bits for West German "superdeep" hole contain little pieces of diamond. As they descend, the bits collect cores of rock for later analysis by scientists.

Physicians use X-rays and ultrasound to look inside a patient without cutting flesh. Geophysicists have their own noninvasive tricks for probing the planet's subsurface. In one widely used technique, scientists set off a line of explosives along the ground, then record the seismic waves that travel through the crust and bounce off buried rock layers.

After computer processing, the profiles of a seismic-reflection survey resemble static on a TV with a few horizontal or diagonal lines running across the image. Seismologists call these lines reflectors, and according to theory, they represent a transition between two rock types with different densities and sound-carrying characteristics. But without drilling, scientists can only guess what actually causes the reflectors.

Kola revealed how far from truth scientific theory can roam. Before drilling, the Soviet scientists performed seismic profiles and found several clear reflectors. One of the strongest sets fell at a depth between 7.5 and 8.5 km, where there was a sharp contrast in the seismic velocity of the rocks above and below the reflectors. This contrast, found on all continents, is called the Conrad discontinuity, and it supposedly represents the boundary between the middle and lower portions of the crust.

According to theory, the crust resembles a layer cake, with sedimentary rock layers on top, acidic granite-type rocks in the middle and thick sheets of basaltic rocks on the bottom. Since no one had ever drilled through the Conrad discontinuity to test this idea, the Soviet scientists relished the possibility of piercing the deep basalt region.

Yet when the drill actually reached a depth of 7.5 km, the scientists did not find basaltic rock. Even at the present depth of 12 km, the drill has not crossed into the region of layered basaltic rock. The Soviets now believe that if the basalt layers exist, they must lie much deeper.

That leaves open a question: What do the strong 7.5-km-deep reflectors represent? Although theories abound, nobody quite knows, according to Vernik. Drilling showed that the reflectors don't represent any physical structure, such as a fault or a boundary.

Some scientists now think these reflectors represent subtle changes in the rock. More than a billion years ago, tectonic forces squeezed and heated the Kola region, cooking the original rock until mineral grains melted and realigned – a process called metamorphism. Because the changes depend on temperature and pressure, shallow rocks go through metamorphic transformations that differ from those of deeper rocks. It may be that the transition between slightly different metamorphic fabrics can generate a seismic reflector.

Others say the reflectors could represent areas of fractured rock or fluid-saturated regions.

"This is something with worldwide significance," Zoback says. Usually, when scientists see a line on a seismic profile, they interpret it as a junction between two rock types. This interpretation comes from drilling by oil and gas companies, which use seismic surveys to probe sedimentary layers for buried reserves. But geophysicists are often interested in studying the hard crystalline rocks that form the foundations of all continents. The Kola hole has warned scientists that they have much to learn about interpreting seismic surveys of crystalline rock.

While the Soviets have 11 drillholes in the works, the West Germans are sinking all their Deutschemarks into one spot. They plan to drill a 10- to 12-km-deep hole in the Oberpfalz region of northeast Bavaria for basic scientific research, at a cost of about $300 million.

The target area marks the collision zone between two continental blocks that smashed together some 350 million years ago when all Earth's land masses were collecting into one supercontinent called Pangaea. One purpose of the hole is to illuminate how the blocks actually broke up as they crashed. Seismic profiles show several nearly horizontal reflectors, and scientists think these may indicate where layers of one block slid up on top of the other.

The West Germans are aiming to reach the ductile zone – the crustal region where high temperatures cause rocks to bend and warp instead of breaking as they do at shallower depths. Calculations suggest the subsurface rocks in the Oberpfalz area start to become ductile at about 300°C, so the West Germans plan to drill to that temperature. Because hot rock taxes drilling equipment, the high temperatures will add a major complication to an already ambitious superdeep drilling project.

In part, researchers chose Oberpfalz rather than a rival site because information from shallow holes indicated a cooler crust at Oberpfalz, which would make drilling easier. According to the original plans, the crew could drill to 15 km there before reaching the 300°C mark.

But a recently completed pilot hole down to 4 km showed the scientists how little they actually know about the rock underground. The bottom temperature in the 4 km hole was 118°C rather than the predicted 80°C. "That is really a big difference," admits Rolf Emmermann of the University of Giessen. "What we got was a very wrong result for a depth of only 4 km."

Imagine, then, how wrong the results would be for 15 km. The West Germans have made those calculations and concluded they cannot meet that original target depth. Now they believe they may reach 300°C at 10 km, and they are planning to drill to that mark with an option to continue to 12 km. They say the well's limited depth will not prove a huge setback. Heinrich Rischmüller, chairman and managing director of engineering and technology for the German program, says the 10-km hole can address most of the original scientific objectives.

Starting next summer, the West Germans plan to drill the main hole about 200 meters away from the pilot hole site. The project will rely mainly on a time-consuming and expensive process called coring. This technique uses a rotating diamond-impregnated drill bit with a hollow center. As the bit descends, a cylindrical core of rock is saved within the hollow drill pipe. The crew periodically stops drilling to pull up the core, which scientists later analyze.

Having already obtained core samples down to 4 km from the pilot hole, the West Germans can use a much quicker drilling method on the second hole until they reach that depth. Many U.S. experts commend the decision to drill two wells instead of one, noting that it will allow the crew to forgo shallow coring and instead concentrate on keeping the main hole straight from the start – a critically important point in drilling deep holes.

Why drill so deep? Rischmüller says temperature and stress measurements in the 10-km hole should have important implications for earthquake research. Quakes occur when stress builds to the point where rocks break. Scientists believe the brittle/ductile transition zone plays an important role in setting stress levels in the crust.

The West Germans also want to look at the fluids circulating through the crust. Though the pilot hole descended mostly through dry rock, the bottom of the hole pierced the top portion of a hydrothermal system. There, flowing through open cracks, the researchers found 100°C water containing up to 10 percent dissolved salts. To improve their understanding of how ore deposits grow, they now want to see what kinds of fluids circulate at deeper levels.

While the Soviets and West Germans continue to set new records in scientific drilling, the deepest purely scientific hole in the United States bottoms out at 3.5 km. The nation has no plans to start any superdeep holes in the near future.

Why not? Money, say most people involved in U.S. scientific drilling.

Though inexpensive when measured against such multibillion-dollar projects as the space station or the Superconducting Super Collider, scientific drilling costs more than most other types of geoscience research. And the expense increases exponentially with depth, so a superdeep project may be 100 times more costly than a shallow drillhole.

The National Science Foundation (NSF), which provides funds for most U.S. scientific drilling, has suffered budgetary woes over the past three years, and funding for its earth sciences division has barely kept pace with inflation. With individual earth scientists scrambling to find money for their own projects, researchers in this field have not thrown their collective weight behind plans for a superdeep drillhole.

"My perception is that the health of earth sciences support is not such that they can afford the luxury of an expensive drilling program," says DOSECC President Andrews.

In fiscal year 1989, the NSF could barely afford even a cheap drilling program. After spending $4.5 million on continental scientific drilling in 1988, it allotted only $1.5 million for 1989. That money supports scientific investigations at holes drilled in previous years, including the one at Cajon Pass.

With this kind of budget, a superdeep hole remains only a wish. The NSF earth sciences division advisory committee recommended last year that by 1995, "support for continental scientific drilling should reach $50 million, with half of that amount budgeted for ultradeep drilling."

Says James F. Hays, director of the division, "People are always telling us how to spend money we don't have." For fiscal year 1989, Hays had $55 million to dole out to all the earth sciences, ranging from dinosaur studies clear through to earthquake research. To support the kind of drilling program envisioned by the advisory board, his budget would have to grow more than fivefold over the next seven years, he notes. That places U.S. deep and superdeep scientific drilling on the back burner for now.

"What I would like to see is a stable progression of drilling at shallow and moderate depths and seeing what kind of projects and science come out of that," Hays says. If these projects, achievable with existing technology, reap important scientific benefits, then the United States might tackle a deep scientific hole in a decade or so, he says.

Logically, a superdeep hole would be next on the drilling list. At this point, though, even those researchers who see great value in scientific drilling express uncertainties about superdeep projects. While they won't criticize the Soviet and West German programs publicly, a few U.S. scientists have told SCIENCE NEWS they don't think the scientific benefits of such superdeep holes are worth the expense. Rather than spending hundreds of millions on a single 12-km hole, these scientists say they would rather see NSF fund a few 5- to 7-km holes that address interesting questions.

Right now the United States *is* drilling holes in that range. Both the Department of Energy and the U.S. Geological Survey fund drilling projects, but they drill for reasons other than basic science. This summer, the Energy Department started a 6-km-deep borehole into California's Long Valley volcanic caldera to explore the potential for geothermal energy (SN: 8/12/89, p.101). While not dedicated to basic science, these types of holes offer the opportunity for pure research, and the government does provide some funds for such research.

Nonetheless, says G. Arthur Barber, past president of DOSECC and now a consultant in Denver, the sad state of U.S. continental scientific drilling should concern its scientists and citizens. "There's a need for the United States to recognize that we've fallen behind very rapidly in understanding the crust of the Earth. . . . We talk about leadership in the sciences. We don't have to worry about that with respect to continental scientific drilling because we're not even close to that. Right now we're one of the poor boys on the block, and it's unfortunate."

Drilling enthusiasts contend the United States should explore the inner Earth to better understand our own planet rather than spend billions of dollars on a space station and similar otherworldly matters. But they say they are working against the mystique of space. Many people seem to equate space with heaven, while the realm underground connotes an opposing image.

"When you can send a rocketship to heaven," Barber asks wryly, "who wants to drill a hole down to hell?" □