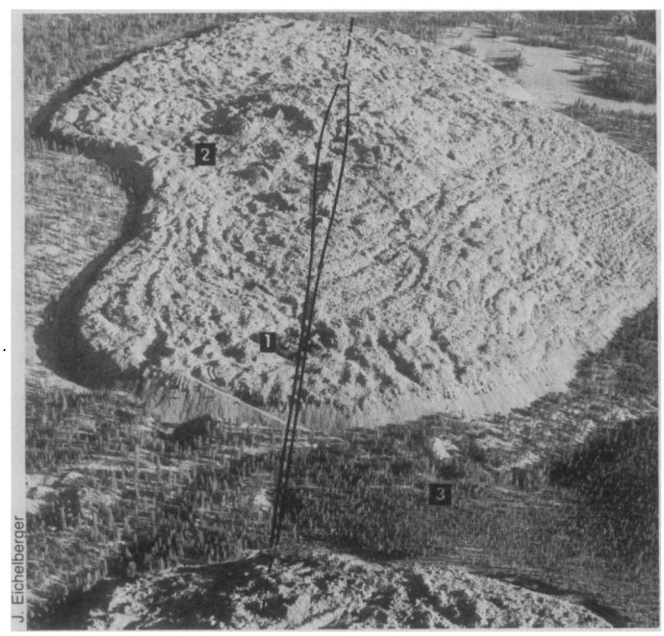
Inyo Domes Drilling Hits Pay Dirt

A modest project at the volcanic Inyo Domes of east-central California is showing what continental drilling can do for geology

It was as close to a laboratory experiment as a field geologist is likely to come. As part of the Inyo Domes Project, geologists were testing the hypothesis that a single, magma-filled crack called a dike fed the string of lava domes and craters of the Inyo chain. If their drilling hit an intrusion of solidified magma beneath the Inyo chain, it would confirm the dike hypothesis and would support the contention—based on the geologic story told by lava and ash on the surface—that the entire chain erupted more or less simultaneously 600 years ago. On the other hand, the failure to find an intrusion would support the contention of some that individual conduits rising from great depth fed each dome.



Massive cowpies of the Inyo chain

These two mounds of lava formed during eruptions just east of Yosemite Park about 600 years ago. Drilling at three sites [through a dome margin (1), through a dome supply conduit (2), and between two domes (3)] has shown that an underlying vertical crack or dike (vertical lines) supplied the magma for the eruptions centered at the domes. For scale, note road to drill site 1.

Seizing one of those rare opportunities to resolve a geological debate without controversy or hand-waving, the drillers last fall hit their target, a dike. The drilling, the first to catch a magmatic intrusion before it had a chance to cool entirely, also brought to light intriguing evidence of how magma behaves before it reaches the surface. The effort could have immediate practical application—a similar dike may be forcing its way toward the surface on the southern edge of nearby Long Valley caldera (*Science*, 1 June 1984, p. 975).

To the drilling consortium*, the Inyo volcanic chain seemed an ideal target for drilling. Running north-south along the eastern edge of the Sierra Nevada just east of Yosemite National Park, the string of explosion pits and "massive cowpies"—flat-topped domes formed where thick lava had oozed to the surface—seemed just the spot at which to study how fluid rock makes its way through the brittle upper crust and either quietly flows out or is explosively shattered into ash and strewn across the landscape.

C. Dan Miller of the U.S. Geological Survey (USGS) in Denver had concluded from his field studies of lava and ash deposits that the Inyo chain had experienced both quiet and explosive eruptions during the past 6000 years. The most recent activity occurred about 600 years ago when three vents spewed about half as much ash as Mount St. Helens did on 18 May 1980. The Inyo ash traveled at least 200 kilometers downwind. Lava having more than twice the mass of the ash then formed domes.

Relying on surface geology and some theoretical understanding, Miller and also Jonathan Fink of Arizona State University and David Pollard of Stanford University concluded that a narrow, vertical sheet of magma had fed what appeared to be simultaneous or nearly simultaneous eruptions at the three vents. But not everyone was so certain of finding a dike beneath the Inyo chain. The magma had had the consistency of thick tar rather than the corn syrup–like fluidity that leads to "curtain of fire" eruptions along the entire length of Hawaiian fissures. To some, such thick magma would be lucky to push its way to the surface through individual conduits—a continuous sheet of magma at least 11 kilometers long immediately beneath the Inyo chain seemed the less likely alternative.

The only definitive test of the dike hypothesis would be to drill a hole, which the Inyo Domes Project did last fall just east of the north-south line formed by Obsidian Dome and the Glass Creek Flow. To the surprise of dike believers and nonbelievers alike, the drill bit hit the dike at a depth of 650 meters precisely beneath the trend of the chain, demonstrating that at least above that depth the dike rises vertically to the surface. Its 8-meter width also closely matches the 10- to 15-meter width predicted by Pollard on the basis of exposed dikes elsewhere and local conditions. Below the center of Obsidian Dome, which had been slant-drilled to a depth of about 600 meters just before the dike drilling, explosive eruptions preceding dome formation had reamed out the dike to a width of 55 meters.

Another surprise was the difficulty encountered in drilling to the dike. Despite the reassuringly solid granite that outcrops near the hole, the only intact, unfractured rock encountered by the drill bit was the dike itself, the surrounding granite having been reduced to rubble in places. In this mess, the drill stem twisted off and the hole collapsed. That necessitated lining the hole with casing. Thus a number of postdrilling experiments requiring bare rock in the hole were dropped.

It appears to some consortium workers that the drilling problems were not due solely to volcanic fracturing of the granite. The nearby Hartley Springs Fault may encompass a much wider zone of breakage than expected, they say. Still, especially in light of the dike's strictly vertical ascent, they tend to believe that the fault had little to do with

*Leadership of the Inyo Drilling Program is shared by John Eichelberger and Peter Lysne, both of Sandia National Laboratories, C. Dan Miller of the USGS, and Lee Younker of Lawrence Livermore National Laboratory. In addition to these participants, the consortium currently includes researchers from two other national laboratories, four universities, and the Canadian Geological Survey.

directing the magma's flow. Rather, the broad east-west tension that is stretching the region's crust probably allowed the magma to force its way up a north-south fracture.

Magma may have forced its way to the surface where predicted, but at least beneath Obsidian Dome it did not do it in the expected manner. According to the conventional view, a lava enriched in silica (less mafic) would be extruded first, it having risen to the top of the underlying magma chamber as it separated from denser, more-mafic magma. But Obsidian Dome was unconventional. A 152-meter hole drilled straight through the dome near its outer edge, the first hole in the Inyo drilling series, showed less-mafic lava piled on top of more-mafic rock, the reverse of the expected order. The later hole slanted through the dome's conduit also showed that more-mafic magma rose first and coated the conduit before less-mafic material filled the center of the conduit. How that order of appearance came about remains unclear.

Another curiosity is the way the lava of Obsidian Dome ridded itself of excess water, one of the gases that can drive explosive eruptions. John Eichelberger of Sandia National Laboratories and the consortium and Henry Westrich of Sandia found that the lava dome's water content diminishes with increasing distance from the conduit. This trend suggests that the flow of lava on the surface contributes to degassing. But, once again running counter to conventional thinking, the abundance of bubbles also decreases with distance. It had been supposed that dense, nearly bubble-free obsidian rises from the conduit and then develops bubbles as the pressure holding the gases in solution decreases. In addition, rock deep within the dome has been degassed as if it had a direct connection with the atmosphere, according to the drilling results.

To explain these observations, Eichelberger proposed that obsidian is the product, not the starting material, of the degassing process. According to his model, magma rises from the conduit as a wet foam and ends up as dense, dry obsidian. The gases escape rapidly by passing from bubble to bubble as decompression and expansion of the magmatic foam connect the bubbles to form open pathways. After the gas escapes, the flowing of the magma smears out the bubbles and eventually destroys them entirely, according to this still controversial model.

The first penetration of a young magmatic intrusion also allowed the first measurements of the warmth lingering after magmatic intrusion. The narrow dike probably solidified in a matter of months and is now no warmer than the surrounding rock (15°C), but the dome conduit is still 82°C. That suggests conduction alone removed the heat without the aid of convection-driven ground water.

Because over 90 percent of the drilling returned core samples, the comparison of surface volcanic rock and pristine intruded rock will continue for some time. Geophysicists will also be able to calibrate their remote-sensing tools against a known intrusion. Consortium members hope to continue their drilling with a slant hole into the same dike but inside the Long Valley caldera, where the different geological setting may have modified the intrusion process.

The Inyo Domes drilling may not be as ambitious as the proposed 10-kilometer hole planned for the southern Appalachians (*Science*, 29 June 1984, p. 1418); that superdeep hole would cost several hundred times more than an Inyo hole. But, as Eichelberger has noted, "Science is not to be measured in terms of the depth of the hole. In thermal regimes, the frontier is just a few hundred meters deep."—**RICHARD A. KERR**

Additional Reading

1. J. C. Eichelberger *et al.*, *Eos* **65**, 723 (1984).
2. C. D. Miller, *Geology*, in press.

Squarks at CERN?

As physicists sift through the data from their latest run on the proton-antiproton collider at the European Laboratory for Particle Physics (CERN), they are becoming more and more confident that the anomalous events first noticed in a previous run are (i) real and (ii) a sign that something new and unexpected is happening.

Specifically, the events might be the first evidence for supersymmetry, a much-discussed theoretical principle that relates every existing particle to a "superpartner" with different spin (*Science*, 29 April 1983, p. 491). Alternatively, the events might signal the long-sought Higgs boson, or some other kind of exotica. "The exciting thing," says theorist Lawrence J. Hall of Harvard University, "is that all the ideas people dream up involve new physics."

The events in question were found in the collider's UA1 detector, which is run by a large team of physicists headed by recent Nobel laureate Carlo Rubbia. What happens is that a proton and an antiproton meet head-on, annihilate, and produce one or more highly collomated "jets" of particles directed off to the side. Such jets are abundant in high-energy collisions, but they are ordinarily produced back to back in pairs. The anomalous jets are either not back to back or else consist of only one jet. In either case, an uncharged and therefore undetected particle appears to be carrying off some of the momentum.

The two types of anomalies are called "bi-jets" and "mono-jets," respectively, and only a handful were known before the CERN collider began its most recent run in October 1984. But that run produced three times as much data as before. And with only half of these data analyzed, the CERN researchers already have some 20 clear-cut events.

"The easiest thing is to say what these events aren't," says James Rohlf, head of the Harvard team at UA1. He and his colleagues have been able to rule out detector malfunction; the decay of a Z-boson into two new particles; the decay of a new heavy particle into a Z and a quark; the decay of a W-boson into a tau lepton; and a number of other possibilities.

One process that is still consistent with the data is the production of a "squark" and an "antisquark"—supersymmetric partners to ordinary quarks. Each squark then decays to an ordinary quark and a photino, the superpartner of the photon. Finally, the photinos leave the detector unseen, and the two quarks decay into two jets of hadrons. This explains the bi-jet events; the mono-jet events correspond to situations in which one of the quarks ends up going too slowly to make an observable jet.

Of course, a number of other processes are still in the running also. The CERN physicists are careful to point out that nothing has yet been proved. But the physics community is awaiting further word with interest.

—**M. MITCHELL WALDROP**