Drilling into Surprises Beneath an Inyo Crater

Volcanologists got a shock recently when they drilled through a volcano; it had not erupted the way they thought

IF surprising results characterize exciting experiments, the drilling beneath South Inyo Crater in east-central California was one exhilarating undertaking. Investigators in the project had already tested some of their ideas about the behavior of silica-rich, volatile-laden magma by drilling three holes through and between the Inyo Domes to the north. They found the solidified magma just where they predicted.

Then they drilled beneath South Inyo Crater to show why the same magma should erupt as ash and ooze onto the surface to form lava domes in the northern part of the Inyo volcanic chain while stopping short of the surface and blasting out craters in the southern part. The theory was that differences in the rock intruded by the magma would account for the contrasts. That turned out to be an incomplete explanation. Instead of a silica-rich, volatile-laden magma that rose from a shallow chamber, they hit silica-poor basaltic rock that rose from the mantle as a volatile-poor magma.

"The main moral to be drawn," says John Eichelberger of Sandia National Laboratories, project coleader with Leland Younker of Lawrence Livermore National Laboratory, "is that we don't know as much about these things as we thought we did. Neither the size nor the composition of the intrusion was what we expected. It was a lesson in humility. It does show the very close association of basaltic magmas with silicic eruptions." In fact, the Inyo drilling seems to have uncovered a clear case of basaltic magma triggering a silicic eruption.

The Inyo Drilling Program is one of the new breed of field geology studies that take the direct approach to testing hypotheses. In the past, geologists have minutely studied what an active volcano has spewed out and then inferred what was going on deep inside. Their only other guide was the guts of long-dead volcanoes exposed by erosion.

But along the north-south–trending Inyo volcanic chain just southeast of Yosemite National Park, volcanologists had a chance to form hypotheses from surface observations and compare them with the reality of subsurface samples. The eruptions along the chain are so young—about 600 years old—that traditional field studies provide a clear picture of eruptive behavior, and drilling down less than a kilometer can reveal how the magma that drove the eruption was actually behaving.

The first three holes tested the hypothesis, developed solely from field observations and theory, that the separate Inyo domes were connected by a continuous, vertical fracture about 10 meters thick that was slightly rotated from the chain's general trend and filled with silicic magma. Drilling did penetrate such a dike between two domes (*Science*, 1 February 1985, p. 504). There were some surprises, such as the way magma ridded itself of dissolved water without leaving bubbles, but all in all the drilling results vindicated the hypothesis.

For the fourth hole, the assumption was that the same silicic magma dike produced all the eruption sites along the chain—both the domes on the northern section and the craters to the south. The difference supposedly arose because the craters form the part of the chain that lies in the sediment- and lava-filled Long Valley caldera, a 3-kilometer-deep depression left after a cataclysmic eruption 700,000 years ago. Magma feeding the craters through the porous caldera fill would have encountered copious ground water that flashed to steam. The generation of that steam and the release of gases from the magma would have driven the crater-forming eruptions while tending to keep the magma from rising farther.

When the rock cores began coming up from directly beneath the crater, "It was a total shock," says Eichelberger. Instead of a silicic dike tens of meters wide, as predicted from surface studies, drilling encountered rock fragments, from millimeter chips to meter blobs in size, embedded in a 20-meter-wide zone of packed powder. As unlikely as it seemed, fragments of basalt appeared to be the remnants of the magma that drove the eruption. Other fragments were debris from the old crustal rock beneath the caldera fill and the fill itself. Despite their nearly simultaneous eruption along the chain, the magmas involved must have come from widely separated sources.

The presence of basaltic magma was a surprise, but in addition it seemed to have been emplaced quite differently than expected. If reassembled without the intervening debris, the basalt would form a dike only 3 meters wide, a tenth as wide as inferred from the surface.

Once the gas-poor basaltic magma neared the surface, its behavior naturally differed from that of a silicic magma. Rock from below a depth of 700 meters was blown from the crater, even though the basalt at 600 meters showed no signs of releasing gas to drive the eruption. Therefore, ground water heated by the basaltic magma must have provided all the driving force for the explosive eruption that dug out the crater.

A role for basaltic magma might have been deduced much earlier without drilling. The melange of rock blown from the crater would inevitably have included basalt, but, before drilling, any basalt in eruption debris was assumed to have been blown from the much older basaltic lava flows that top the caldera fill. As Eichelberger explains, no one was expecting young basalt from the craters so they did not look for it.

J. Eichelberger

Inyo craters

Drilling beneath South Inyo Crater (diameter 200 meters) in the lower left was intended to show why steam explosion craters formed here and lava domes (far upper right), formed to the north. Contrary to expectations, the magma that drove the crater eruptions encountered a second, shallow magma and forced it to form the domes.

The results from drilling beneath South Inyo Crater may have startled researchers, but having two types of rock in hand from essentially the same eruption pleases them to no end because it is a splendid example of a much discussed but poorly documented means of triggering eruptions. As Eichelberger and his colleagues see it, one portion of the mantle many tens of kilometers below the surface partially melted and sent the same basaltic magma rising beneath the entire length of the Inyo chain. To the south, the magma simply rose until it struck ground water whose steam blew bits of magma and rock onto the surface.

To the north, the magma encountered a barrier and never reached the surface. It must have oozed into the bottom of a shallow silicic magma chamber, perhaps the one whose top is thought to reach within 5 kilometers of the surface in the northwest corner of the caldera. Being heavier, the basaltic magma could not rise through the chamber. It could, however, encourage the silicic magma to push toward the surface. The added volume of magma would pressurize the chamber, the added heat would make the silicic magma more fluid and drive out its dissolved gases, and the rapid chilling of the basaltic magma would extract additional gas. All this would make for conditions favoring an eruption. Evidence that the two magmas actually came in contact with each other has been found in the form of globules of basalt in the silicic rock of the most southerly dome by Robert Varga and Gene Suemnicht of Unocal Geothermal Division and Roy Bailey of the U.S. Geological Survey in Menlo Park.

Investigations into eruption triggering and eruption style in the Inyo chain are hardly academic. The Inyo chain and the contiguous Mono Craters to the north form a volcanic trend that became active 40,000 years ago and for all practical purposes must be considered still active. The trend crosses into a caldera underlain by a magma chamber that is showing all too clear signs of life. During the past decade new magma has entered the chamber, triggering major earthquakes and bulging the caldera by as much as 50 centimeters. A cluster of earthquake activity on the southern edge of the caldera, just a few kilometers off the Mono-Inyo trend, has behaved as if a dike of magma was forcing its way toward the surface there.

A bit disconcertingly, the magma influx to the chamber seems to be continuing at a reduced rate of about 20 million cubic meters per year. At that rate, only a few years would be needed to accumulate the volume of magma produced by one of the eruptions 600 years ago. ■ RICHARD A. KERR

Gene Identity Confirmed

Last spring, Yueh-hsiu Chien, Mark Davis, and their colleagues at Stanford University School of Medicine found a new gene that appeared to encode a previously missing T cell receptor protein (*Science*, p. 1187, 5 June). Recent work by the Stanford workers and several additional groups has now confirmed the identity of the gene.

The gene in question encodes the δ chain of the T cell receptor, which is the cell surface molecule used by T cells to recognize and bind foreign antigens, thereby triggering the immune activities of the cells. A T cell receptor consists of two nonidentical, variant proteins that are associated with a third invariant protein, called T3. In most of the T cells of mature animals the nonidentical chains are of the α and β type, but in a small minority—up to 5%—they are of the γ and δ type.

By the beginning of 1987, all the genes had been cloned, except the δ gene. Immunologists wanted to track down this gene because knowing the δ chain structure would help them to clarify the function of the γδ receptor. They want to know whether it works the same way that the αβ receptor does in triggering T cell activities. In addition, there are indications that the γδ receptor may help to regulate T cell development in the thymus gland.

The finding of a candidate δ chain gene by the Chien-Davis group therefore attracted a great deal of attention, especially in view of the gene's unusual location. It is nestled among the coding sequences of the α chain gene.

Since then, Michael Brenner, Michael Krangel, and their colleagues at Harvard Medical School also identified a possible δ chain gene and showed that it is the human equivalent of the gene originally found by the Stanford researchers, which is of mouse origin.

Both the Stanford and Harvard groups, and that of James Allison at the University of California, Berkeley, have recently produced immunological evidence indicating that the gene encodes the δ protein, as proposed. They have found that antibodies that recognize a peptide specified by a portion of the δ chain gene also bind to the δ chain itself, and conversely, an antibody that is specific for the δ chain binds to a synthetic peptide made to correspond to the δ gene sequence.

In addition, Philippa Marrack and John Kappler's group at the Howard Hughes Medical Institute at the National Jewish Center for Immunology and Respiratory Medicine in Denver has shown that a partial amino acid sequence of an isolated mouse δ chain matches that of the predicted sequence of the protein encoded by the Stanford gene. "The immunological evidence is pretty convincing, but the most definitive evidence is the sequencing," Davis says.

With genes for all four T cell receptor proteins in hand, the way is open to exploring the relation between the structures of the two types of receptors and their functions in T cell activation and development. An unusual structural feature has already turned up in the δ gene.

The genes for the α, β, and γ chains, as well as the genes for other, related immunological proteins are assembled from either three or four separate segments of DNA. But Chien and Davis have found that some genes for δ chains are assembled from five DNA segments. These genes contain two D (for diversity) segments, instead of the usual one. The extra D should help to generate the structural variation that the protein products of the genes need to recognize a wide range of antigens. ■ JEAN L. MARX

ADDITIONAL READING

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