VOLCANOLOGY

Volcanoes With Bad Hearts Are Tumbling Down All Over

Volcanologists used to think that as long as a volcano wasn't rumbling, belching ash, or spurting lava it was innocuous. But don't try telling that to Paul Segall of Stanford University and his colleagues, who have been using satellite measurements to monitor the behavior of Kilauea volcano on the southeast coast of the island of Hawaii. On the mountain's south flank, they find, more than 5000 cubic kilometers of rock are moving toward the coast at geologically breakneck speeds of up to 25 centimeters per year. "It's the biggest thing on Earth that's moving like this," says volcanologist Richard Fiske of the National Museum of Natural History. "Ultimately, there's going to be some sort of failure, though we don't know when." Should Kilauea give way, the result will be far more destructive than any of the volcano's recent gurglings.

And Kilauea's situation is far from unique, geologists are finding. The largest recent eruption in the United States, that of Mount St. Helens in 1980, began when one side of the mountain collapsed; Sicily's Mount Etna, a landmark since classical times, is also slowly spreading. Now volcanologists are homing in on the structural shortcomings that underlie these collapses, and they're finding that even when magma pressures aren't actively tearing volcanoes apart, the mountains can fall victim to weak foundations or to the pull of gravity on dense rock buried within them.

Geologists awoke to this frailty after Mount St. Helens unleashed the largest landslide in recorded history—2.8 cubic kilometers of debris—and then erupted in 1980 (*Science*, 20 April 1984, p. 275). Using that landslide deposit as a guide, geologists soon recognized more than 100 deposits left by avalanches of volcanic debris measuring up to 20 cubic kilometers in volume.

Even more striking evidence was waiting at sea, off the coast of the Hawaiian Islands. As early as 1964, geologist James Moore of the U.S. Geological Survey (USGS) in Menlo Park thought he saw signs on the ocean floor that great chunks of islands had once slid into the sea. But no one took Moore too seriously until after Mount St. Helens and the arrival in the 1980s of new technology for sonar imaging of the sea floor. By now, such imaging has revealed about 70 major landslides, some extending more than 200 kilometers and containing as much as 10% to 20% of the parent volcano (see Perspectives, *Science*, 1 April, p. 46). The waves from one swept blocks of coral 325 meters up a mountainside on the island of Lanai.

Kilauea's turn may be coming too, and studies of it are yielding insight into the forces that tear volcanoes apart. Besides the pressure from pulses of magma rising into a magma chamber just below the summit, an additional, steadier push may be contributing to the volcano's downfall. In 1988 Michael Ryan of the USGS in Reston, Virginia, suggested that magma rising from deep in the crust was pooling in an additional chamber, 6 to 10 kilometers below the summit. That deeper reservoir, said Ryan, would deliver a push above and beyond any magma pressure as dense crystals of olivine settled out of the cooling magma and collected in the lower reservoir. The resulting dense mush of olivine crystals and magma liquid would flow outward under the pull of gravity, Ryan said, and drive a wedge of the south flank almost 10 kilometers thick toward the sea.

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A slippery slope? The south flank of Kilauea volcano is slumping, but when it might fail is unknown.

Volcanologists David Clague and Roger Denlinger of the Hawaiian Volcano Observatory now believe that they have confirmed the presence of the deep olivine mass—although their picture of how it behaves differs from Ryan's. Kilauea lavas, especially those from the deeper parts of the volcano, are often rich in olivine crystals. But when Clague, the group's petrologist, compared the amount of olivine erupted in the lavas with the amount assumed to be in the parent magma feeding Kilauea, he found that a considerable amount still had to remain in the mountain.

That's just what Ryan's scenario requires. But kinks in some of the olivine delivered up by the lavas suggested to Clague that the crystals had formed a solid rock called dunite, not just a mush, and been deformed before being swept to the surface. And dunite could tear a mountain apart just as readily as mush, says Denlinger, the mineral physicist. When he read Clague's write-up on Kilauea olivine, he rushed into Clague's office to announce that dunite, because it is so weak, "will flow like mad; there's no stopping it." Under the high temperatures of Kilauea's interior, the dunite would flow like a glacier, pushing the south flank ahead of it. Ryan is pleased at the support for mountain-destroying olivine, but he thinks his geophysical probes of the volcano still require liquid as well as crystals in the lower magma chamber.

Whether mushy or just soft, the cores of other large volcanoes around the world, including Mount Etna, may be tearing the mountains apart much as Kilauea's core is, says volcanologist Andrea Borgia of the National Institute of Geophysics in Rome. His studies of smaller volcanoes, meanwhile, suggest that even before a volcano grows big enough to develop a massive core, it is vulnerable to other ills—poor footing, for example. Borgia points out that unlike ordinary mountains, which have sturdy foundations because they are the eroded remains of large blocks of crust, volcanoes form wherever magma reaches the surface—often in the worst places to build mountains. Borgia has found, for example, that the Concepción volcano in Nicaragua is collapsing under its own weight, apparently because it formed on a slippery layer of clay-rich sediments.

As volcanologists tease apart volcanoes' structural shortcomings, their ultimate goal is to predict collapse. That won't be easy, because weak volcanoes don't always suffer catastrophic failure. Etna has been spreading at an average of 0.2 centimeter per year for 300,000 years without falling apart, Borgia and his colleagues estimate from fracturing and folding there. In fact, he notes, this gradual spreading may even have stabilized Etna by reducing the steepness of its sides. But based on the recent research, no one can safely assume that Kilauea—and its human neighbors—will be as lucky.

–Richard A. Kerr

Additional Reading

Abstracts from the session on "Spreading of Volcanic Constructs," 1993 Fall Meeting, American Geophysical Union, *Eos*, 26 October 1993, p. 646.