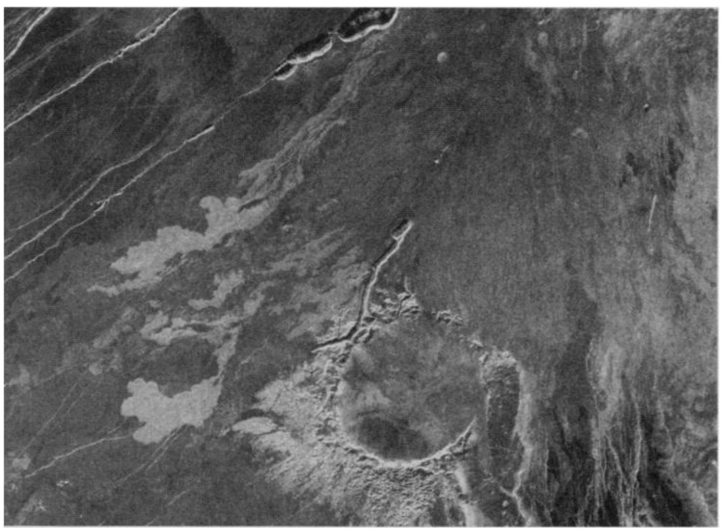
Volcanoes: Old, New, and—Perhaps—Yet To Be

Volcanoes on Venus, volcanoes beneath the sea, signs of a possible volcanic eruption in California's Long Valley. No one subject could dominate a meeting with 40 or 50 different sessions a day, but volcanoes—the topic—were erupting in session after session at the American Geophysical Union's annual meeting held in San Francisco on 3 to 7 December.

A New Wrinkle for the Face of Venus

No one, it seems, can stave off the ravages of time, and Venus is no exception. Just 2 months ago, planetary scientists were struck by the pristine appearance of the impact craters on the Venusian surface, revealed by the radar images beamed back from the Magellan spacecraft. There were few signs that they were being degraded by forces such as volcanic activity or tectonic disruption that normally age impact craters, even though other evidence showed that there had been plenty of time for such forces to act (*Science*, 16 November, p. 912). But surface remodeling is going on after all, Magellan scientists told a large crowd at the AGU meeting. More recent images show the ravages of time, but in a fashion that leaves few aged craters.

The earlier images, taken when Magellan was a few weeks into its mission and had mapped just 5% of the Venusian surface, found only one impact crater being obliterated by the customary aging processes. Since then the spacecraft has perused an additional 10% of the planet. The expanded view reveals four nearly continent-size areas, ranging from a few million to 5 million square kilometers, that have no impact craters at all. According to Magellan team member Roger Phillips of Southern Methodist University in Dallas, the absence of impact craters—despite a steady rain of asteroids and comets onto the Venusian surface—means that in the recent geologic past the craters were wiped out either by lava flooding across these areas or by tectonic faulting, stretching, and compression.



JPL/NASA

A rare find. *Magellan caught this 65-kilometer impact crater partially flooded by almost 500 meters of lava.*

The volcanic activity required to resurface the crater-free regions would be impressive by any standards, Phillips says. For example, it took at least a million cubic kilometers of lava, released over a few million years, to produce the 66-million-year-old Deccan Traps of India. This is a lava sheet that covers an area of 1.5 million square kilometers. Perhaps two or three such flood basalts form in 100 million years on Earth. But the lava-covered areas already uncovered on a small part of Venus by Magellan must have all formed within the past few tens of millions of years to have escaped being marked by impact craters.

So Magellan scientists are still left with an enigma. On the one hand, Venusian craters, despite their advancing age, look newly minted. Even after searching the newly mapped portions of Venus, which brings the total so far to 70 million square kilometers, they can find at most only a few impact craters that are being blotted out by encroaching lava or tectonic disruption. On the other hand, the discovery of the crater-free areas makes it clear that, at least in some regions, there is plenty of recent geologic activity of the sort that should be making impact craters look old.

Before the discovery of the crater-free areas, Magellan scientists were toying with the idea that volcanic activity on the planet had shut down completely after first resurfacing the entire planet with a huge outpouring of lava about 400 million years ago. That would have allowed fresh-looking impact craters to accumulate on a moribund planet.

But the existence of the crater-free areas shows that Venus is not moribund. So the current thinking, Phillips says, is that the Venusian surface could consist mainly of long-dormant areas interspersed with crater-free areas that were resurfaced so rapidly—in geologic terms a few tens of millions of years is rapid—that Magellan caught few craters in the act of being filled in.

Despite the considerable lava flows needed to accomplish the spot resurfacings of Venus, the rate of volcanic activity averaged over the whole planet appears to be on the feeble side, Phillips says. From the cratering data he estimates that Venus churns out a minimum of about 0.3 cubic kilometers of new crust every year, which would resurface the planet every 800 million years. That would make Venus more active than Mercury or Mars, but far less active than Earth, which produces about 20 cubic kilometers of new crust annually.

Magellan scientists plan to give the crater-free areas special attention when the spacecraft comes around next year for a second look at this part of Venus. By comparing Magellan's first and second passes, team members hope to catch Venus in the act of creating new crust.

Volcano Watchers Await Long Valley's Signal

Thanks to two recent successes, volcanologists have a bit more confidence in the delicate art of predicting volcanic eruptions—a development that may have come none too soon for researchers monitoring the Long Valley area, which is in California, just east of Yosemite National Park. The valley was formed by a gigantic eruption 700,000 years ago, and over the past year and a half volcano watchers have seen several signs of magma stirring under it once again. But restless magma is one thing and eruptions another.

Now, though, volcanologists have a new sign of an impending eruption to look for—a swarm of distinctive earthquakes that produce seismic waves with periods that are predominately longer than those of the seismic waves generated by ordinary earthquakes. In July of 1989, Japanese volcanologists detected just such a swarm of long-period earthquakes near Ito, a large resort city on the Izu Peninsula southwest of Tokyo. Buttressed by other signs, they warned of an imminent eruption. Three days after the long-period swarm began, a modest offshore eruption broke the sea surface off Ito. Then toward the end of 1989, similar earthquake swarms helped Alaskan volcanologists accurately predict several eruptions of Redoubt volcano, which is located southwest of Anchorage.

So, the relationship between these quakes and eruptions has been strengthened, but what are the quakes exactly? Seismologists believe that the long-period quakes occur when magma gases or vaporized ground water pressurizes the rock and opens cavities that can reverberate at long periods. Apparently such pressurization can be the last step before an eruption. "The more we look with good instrumentation," says seismologist David Hill of the U.S. Geological Survey in Menlo Park, "the more common these [long-period earthquakes] seem to be before eruptions," especially where magma must force its way through some obstruction.

Those are just the conditions in Long Valley. Although there have been no eruptions there for 40,000 years, it is currently a year and a half into its second episode of volcanic unrest in the past decade. The first episode, which spanned the first half of the 1980s, included four magnitude 6 earthquakes in May 1980, powerful swarms of earthquakes on the southern edge of the valley, and a 25-centimeter bulging in its center. Each of these could be taken as a sign of deep magma pressing toward the surface—but there's been no eruption.

The seismic activity of the latest episode has been less energetic, but it is nonetheless disquieting. Hill told AGU attendees that it began in May 1989 with a swarm of small earthquakes beneath Mammoth Mountain on the southwest edge of the valley, the site of the eruption that took place 40,000 years ago. That activity died out during the year, but by the end of the year stretching of the crust across the central valley surged and then earthquake activity on the southern edge escalated. This, too, trailed off during 1990. But, Hill says, the way the rock broke beneath Mammoth Mountain strongly suggests that magma was injected into a narrow vertical zone 5 to 9 kilometers beneath the mountain. And John Langbein of the USGS in Menlo Park likewise told the meeting that the measured crustal stretching implied the injection of fresh magma about 7 kilometers beneath the valley.

So with all this magma moving upward beneath Long Valley, researchers are looking for anything that can help them predict when it will reach the surface. Of course, that may never happen. The historical record of the behavior of calderas like Long Valley shows that the vast majority of episodes of unrest end without an eruption (*Science*, 21 July 1989, p. 255). But if there is trouble, Hill is counting on last year's Japanese and Alaskan experiences to improve his prospects for predicting a Long Valley eruption. In many ways the area off the Izu Peninsula is quite similar to Long Valley. Both are marked by multiple volcanic vents that have produced lavas of uniform composition, both have had sizable earthquakes, and both have experienced periods of sustained but not extraordinary crustal uplift.

But then there's a critical difference between Long Valley and the Izu Peninsula. Both have had intense earthquake swarms, but only in Japan did a swarm become laden with the characteristic long-period shocks. The 900 year-round residents of Mammoth Lakes, the ski resort hard by Mammoth Mountain, no doubt think that's just as well. Ruining the deep powder would be the least of an eruption's effects. A moderate eruption Could place the town at the center of a 20-kilometer oval subject to hot falling ash, lava flows, and mudflows.

Surging Plate Tectonics Erupts Beneath the Sea

Marine geologists have long known that lava erupting from sub-sea volcanoes is constantly forming new crust along Earth's 60,000 kilometers of mid-ocean ridges. But they have never been able to watch the creation of crust as it was happening in the remoteness of the deep sea. Now they have apparently come very close to their goal. Oceanographers have stumbled upon strong evidence that lava pouring from a mid-ocean ridge off the Oregon coast has created new ocean crust within the past few years, probably sometime between 1981 and 1987. This spot becomes the prime focus for efforts to catch the next eruption.

Such an undersea eruption in the 1980s may well have been related to the two "megaplumes" of warm, mineral-laden water that were discovered in 1986 and 1987 over the 45-kilometer segment of ridge where the new lava appeared. Researchers can't prove it, but it appears that the ridge split open and spilled out the hot water at the same time the lava erupted, all in a catastrophic version of the sea floor spreading that adds new crust to the edges of tectonic plates, says oceanographer Edward Baker of the National Oceanic and Atmospheric Administration in Seattle.

The discovery was made serendipitously by Baker's NOAA colleagues Robert Embley, William Chadwick, and Christopher Fox, who work at Oregon State University's Hatfield Marine Science Center in Newport, Oregon. While poring over sea floor surveys performed in 1989 at the southern end of the Juan de Fuca Ridge, which is 525 kilometers west of the Oregon coast, they noted something peculiar. They happened to compare their latest map with 3-dimensional maps of the sea floor in that area that had been made in 1981 by an instrument called Sea Beam—and found that they did not completely agree. Comparison of a second Sea Beam survey, made in 1987, with the 1981 survey confirmed that something indeed had changed.


Robert Embley

New sea floor. *This lava mound appeared when oceanographers weren't looking.*

By taking the difference between the sea floor shape determined in 1981 and that found in 1987, the NOAA researchers found a string of new mounds 17 kilometers long lying on a fracture that runs between the sites of the two megaplumes. In one case, a depression had been turned into a mound by the addition of 25 meters of rock. The 1989 survey also included camera pictures, and they showed that the new mounds are piles of lava as fresh-looking as it gets on the sea floor. The total volume of the new mounds is 50 million cubic meters, equalling the volume of the lava released by the 1977 eruption of Hawaii's Kilauea.

As massive an outpouring of lava as the mounds might seem to be, they probably did not themselves create the two megaplumes that Baker and his colleagues discovered. Instead, the mounds and plumes were probably independently formed by the same ridge spreading event. Baker's calculations indicate that it probably took 100 million cubic meters of 350°C water gushing from several kilometers of sea floor fault in a few hours or days to produce the larger plume. To get that much hot water that quickly, Baker says, the sea floor must have split open as spreading and the lava eruption occurred, releasing hot "ground water" held beneath the surface. With that kind of production, megaplumes may be significant players in the control of seawater chemistry, he adds.

Now that they have a spot on which to focus their efforts, NOAA researchers are making plans to monitor the area for any new signs of a sudden spreading event. This time they want to catch plate tectonics in the act.

■ Richard A. Kerr