Volcanic Hazard Alert Issued for California

Deep-seated magma near Yosemite shows signs of movement that have researchers wondering if an eruption is imminent

The ski resort of Mammoth Lakes, nestled against the east front of the Sierra Nevada just east of Yosemite National Park, knows about natural hazards. It is still being shaken by an unusual sequence of earthquakes that started in 1978 and included four earthquakes of magnitude 6 within 48 hours of each other in May of 1980. An earthquake hazard watch is still in effect.

Now, the U.S. Geological Survey (USGS) has issued a notice of potential volcanic hazard for the area that warns that "the outbreak of volcanic activity is a possibility but by no means a certainty." Nothing may happen, but the possible hazards being discussed range from moderate steam explosions to a cataclysm that could dump more than 15 centimeters of ash downwind as far east as Salt Lake City.

> "We had been treating it strictly as an earthquake hazard. There's really good evidence now that there's magma moving around at depth and it could reach the surface."

"It was only [in early May] that it dawned on us just what might be happening," says Roy Bailey of the USGS in Reston, Virginia. Bailey is coordinator of the USGS's volcanic hazards program. "We had been treating it strictly as an earthquake hazard. There's really good evidence now that there's magma moving around at depth and it could reach the surface." If it did, the result would be an eruption.

The realization that there is a potential volcanic hazard came at an unrelated Department of Energy meeting in early May that was called to discuss a possible deep-drilling project in the Mono Craters area. Mammoth Lakes, just to the south, was simply a convenient place to meet. The volcanologists present, some of whom had come down from Mount St. Helens, took particular interest in a talk by Alan Ryall, a seismologist from the University of Nevada. Most of Ryall's listeners, including Bailey, were hearing for the first time that intense swarms of earthquakes, accompanied by spasmodic tremors, had not been scattered broadly over the area since their appearance in 1980, as most had assumed. Instead, the earthquakes and the tremors were concentrated at a site 3 kilometers down the road from the meeting room. Volcanologists generally consider spasmodic tremor to be the result of rock fracturing associated with the movement of magma or magmatic gases.

Ryall's listeners became even more attentive when they learned that the quakes at the nearby site had risen from a depth of about 9 kilometers in 1980 to about 5 kilometers in July of 1981, when a particularly strong swarm hit. "That got us excited," Bailey recalls. At the time of the July quakes, Ryall and his colleagues were a bit concerned that the tremor was so intense, but the episode ended with no apparent effect. So, they did not determine the depth of the quakes until the data came up for analysis some months later. After listening to the seismic rumblings of Mount St. Helens for 2 years, the volcanologists could not take the data quite so matter-of-factly.

The excitement was not over. A few volcanologists remaining after the meeting felt a series of small earthquakes shake the Mammoth Lakes area. Ryall had returned to Nevada by then, but he called to pass on the latest observations—the earthquakes, and supposedly the magma, had ascended to within 2 kilometers of the surface. "That really got us excited," Bailey says. A second call to say that a better depth estimate was 3.5 kilometers did little to calm the group. Something should be done, the volcanologists agreed.

The result of these revelations was the issuance on 26 May of a notice of potential volcanic hazard, the lowest of three levels of official concern. In addition to the localized, ascending spasmodic tremor, it noted other evidence suggesting that magma could be moving toward the surface. Seismic studies in 1976 by Don Steeples and H. M. Iyer of the USGS in Menlo Park, California, and in 1980 by Ryall and Floriana Ryall of the University of Nevada had detected a magma chamber near Mammoth Lakes. It is 10 kilometers across and extends from a depth of 8 kilometers to 15 kilometers or more, according to Bailey. It appears to be the residuum of a magma body that rose near the surface 700,000 years ago and released about 600 cubic kilometers of ash. Mount St. Helens probably did not manage 1 cubic kilometer.

The expulsion of that much ash caused the magma chamber roof to collapse, forming the Long Valley Caldera. The caldera is a 32- by 17-kilometer elliptical depression that includes near its southwest edge both the town of Mammoth Lakes and the site of spasmodic tremors. The chamber has regularly leaked magma in eruptions about every 200,000 years. But the next major volcanic activity would not be expected for another 100,000 years if the pattern were to hold.

Recently, researchers decided that the magma chamber might not be as quiet as had been thought. In October 1980, a precise releveling survey across part of the caldera, prompted by the May 1980 earthquakes, found a bulge in the ground over the magma chamber that is 25 centimeters high and 30 kilometers wide. James Savage and Malcolm Clark of the USGS in Menlo Park believe that about 0.15 cubic kilometer of magma entered the chamber sometime between July 1979 and October 1980 and raised the bulge.

Whether the stress resulting from the magma injection triggered the four earthquakes of May 1980 or the earthquakes induced the magma movement is unclear. In a similar situation on the Izu Peninsula near Tokyo, Japanese researchers found that uplifts over a magma chamber definitely precede nearby earthquakes. Savage and Wayne Thatcher of the USGS in Menlo Park have calculated that an expanding magma chamber at a depth of 11 kilometers

0036-8075/82/0618-1302$01.00/0 Copyright © 1982 AAAS

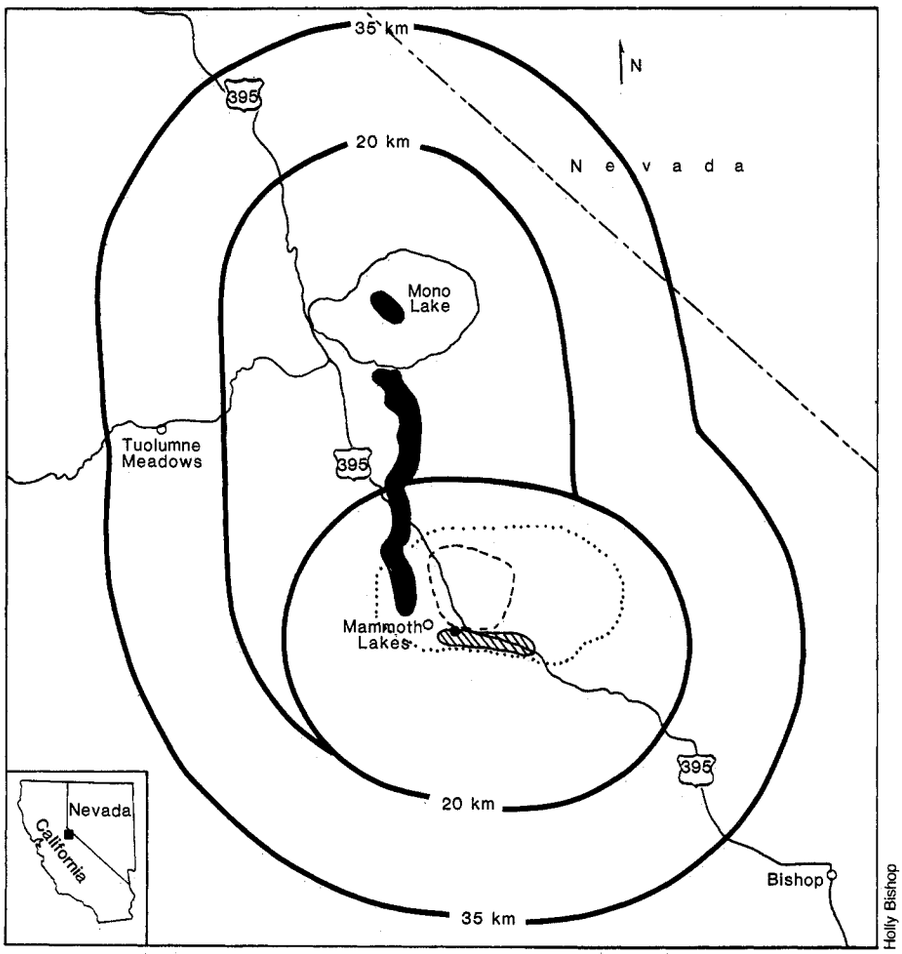
would have produced the proper stresses to trigger the observed Japanese earthquakes. In any case, most researchers now assume that the appearance of spasmodic tremor in mid-1980 and the creation this January of new steam vents 3.5 kilometers east of the tremor site means that magma from some deep source began moving in the form of an ascending tongue.

Although the activity near Mammoth Lakes has now alerted volcanologists to the possibility of magma reaching the surface, they face unusually difficult problems in forecasting future developments, if any. At Mount St. Helens, they had a single main vent to watch and reasonably detailed studies of its past behavior to go by. The Mammoth Lakes region, on the other hand, has many vents from past eruptions and a complex volcanic history. In addition, the geologic record of volcanic activity in Long Valley Caldera is older and harder to read. None of the caldera eruptions appear to be less than 50,000 years old, which means that much of the geologic detail required to formulate hazard forecasts is likely to have been eroded away or buried by nonvolcanic material (*Science*, 12 June 1981, p. 1259). The odds of a repetition of the ancient caldera-forming eruption are impossible to calculate, but even after a pause of 700,000 years the possibility cannot be excluded, says C. Dan Miller of the USGS in Denver. At Yellowstone, for instance, cataclysmic eruptions have created three overlapping calderas at intervals of 600,000 years, he notes.

To further complicate matters, volcanologists believe that another major magma body is making itself known in the area by forming a chain of highly active craters called the Mono and Inyo craters. They form a chain that runs 30 kilometers in a north-south direction and juts into the far western end of the Long Valley Caldera. While it builds up internal gas pressures for its own caldera-forming eruption in the distant future, this deep chamber is erupting ash and lava every few hundred years. No one would be surprised if one of these craters near Mammoth Lakes erupted soon; some of the eruptions of the past 1000 years have been within the caldera itself. The spasmodic tremors are about 5 kilometers to the southeast of the craters active in the past 10,000 years, which bothers volcanologists because the caldera seismic activity could conceivably reactivate the young volcanic area to the west.

In light of the obvious uncertainties, the official USGS report* on potential hazards discusses the full range of possibilities. Nothing may happen—the apparent tongue of magma might stop and freeze in place. Or the magma's heat, combined with ground water, might produce a phreatic eruption whose effects could extend 10 kilometers farther downwind. A moderate explosive eruption about the size of Mount St. Helens, could send ash flows out to a distance of 20 kilometers and drop airborne ash 5 centimeters deep 85 kilometers downwind. Depending on the wind direction, that could be Yosemite Village, the edge of the Great Valley, or well into Nevada. Another caldera-forming eruption, spewing ash from several hundred cubic kilometers of magma, could dump a meter or more of ash on a zone of "severe to total devastation" that would be 240 kilometers across, the report says. Five hundred kilometers downwind (most likely western Utah), 15 centimeters of ash would cover the ground. Apparently, little ash from the caldera has ever reached the California coast.

Historically, smaller, less violent eruptions are much more likely than cataclysmic ones. But Mount St. Helens surpassed all of its known eruptions when it blew apart in 1980. With that and their limited understanding of what is happening near Mammoth Lakes in mind, volcanologists are taking the situation quite seriously.—RICHARD A. KERR



Volcanic hazard zones near Mammoth Lakes

U.S. Geological Survey scientists have delineated preliminary volcanic hazard zones in much the same way as they did for Mount St. Helens. One set of zones is centered about a line of active volcanism of the past 10,000 years that is marked by the dark, north-south band. These are the Mono and Inyo craters. The other center is the hachured band running toward the east away from Mammoth Lakes. Recent seismic tremors (solid dot) and increased steam vent activity prompted the designation of this zone, which runs along the edge of the caldera (dotted line) just south of the area of recent uplift (dashed line). An eruption the size of Mount St. Helens within either of these zones might produce ash-flow deposits to a distance of 20 kilometers. Twenty centimeters of airborne ash could accumulate out to a distance of 35 kilometers. Ash-fall depths would depend on wind direction, which is predominantly toward the east. [*Adapted from* USGS Open-File Report 82-583]

**USGS Open-File Report 82-583*, "Preliminary assessment of potential volcanic hazards in the Long Valley–Mono Lake area," by C. Dan Miller *et al.* (1982). (Order from the Open-File Services Section, USGS, Box 25425, Federal Center, Denver, Colorado 80225.)