Kilauea in action: April 4, 1983

Earth Fire

As Kilauea builds the island of Hawaii, scientists are gleaning information about the workings of the world's most active volcano

E Pele e!
Ke akua o ka pohaku enaena,
Eli eli kau mai!

E Pele e!
O goddess of the burning stones,
Let awe possess me!

Ancient Hawaiian prayer

By CHERYL SIMON

Hawaii's Kilauea volcano and the Mammoth Lakes area of California provide a striking contrast between two physically dynamic spots. Earth Sciences Editor Cheryl Simon recently visited both sites and reports, this week and next, on scientists' efforts to understand and predict the actions of the complex, at times mysterious, volcanic systems.

KILAUEA, HAWAII — As glowing lava crept down the southeast flank of Kilauea volcano here last January, a young woman walked to the edge of the flow and tenderly placed a lei in the path of the molten rock. In the tradition of Hawaiians for thousands of years, she sacrificed the fragrant necklace of blossoms to Pele, the goddess of volcanoes. According to ancient island lore the goddess resides in Halemaumau, the "fire pit" in Kilauea's summit.

The geologist who recounted this ritual says Pele likes gin, too, and that sometimes island residents place sacrificial bottles in lava flows to please her. If one of the scientists at the Hawaiian Volcanoes Observatory found such an offering, "no one here would touch it," says the scientist, who asked not to be named. "After a while the superstition rubs off, and you begin to think, 'Why interfere?'"

The observatory, run by the United States Geological Survey, is an isolated outpost perched on the edge of Kilauea's summit caldera, or sunken crater, in Hawaii Volcanoes National Park on the island of Hawaii. The staff of a dozen or so scientists is probing the secrets of the volcano, the world's most heavily instrumented, in an effort to understand how it works.

While it is popular to view superstition and science as incompatible, the lenience here is understandable. A picture window at the observatory allows a panoramic view of the caldera's changing face. A thick fog can form instantly, obscuring the brown and gray landscape and cloaking the observatory in cloud. Then just as quickly the mist rises and the caldera reappears. It stretches for miles, its floor made of thousands of dried lava flows broken only by the asphalt ribbon of Crater Rim Road. Steam, laden with acrid sulfur fumes, pours from hundreds of vents throughout the caldera.

The most recent eruption at Kilauea (SN: 1/15/83, p. 39) began in January and continued intermittently through the time of this writing. The volcano was quiet during May but seismographs — instruments that monitor earthquake activity— showed a persistent low-level tremor, and the scientists detected subtle expansion of less than a millimeter per day along the fissure in the East Rift Zone, where the eruption occurred. These signs warned that magma was still on the move. Thus, no one was surprised when in June and July lava again spurted forth, covering flows extruded only months ago.

In the 71 years since the observatory was founded by Massachusetts Institute of Technology professor Thomas A. Jaggar, its administration has shifted from the United States Weather Bureau, to USGS, to the National Park Service and, in 1948, back to USGS. Throughout these changes the original purpose of the station has endured — to acquire basic scientific information about the subsurface structure of the volcanoes, about the behavior, sources and properties of magma, and practical information leading to improved prediction of eruptions.

This year's eruption is the most powerful at Kilauea since 1977, but it is only one episode in the long history of the world's

Kilauea's relatively gentle eruptions allow researchers close access.

most active volcano. It does not necessarily erupt annually, but it sometimes is active several times in the space of a single year. As scientists here and around the world learn more about well-recognized companions of volcanism, such as seismicity and the breath-like stretching and shrinking of the volcanic cone, they are expanding their program to incorporate less obvious studies. Researchers now also are scrutinizing Kilauea's electromagnetic field, gas fluctuations and submarine expanses.

Since the observatory's early days, scientists have extended their knowledge to the point where they can predict an eruption with impressive accuracy 24 hours in advance, as well as where on the volcano the eruption will break out. For up to 18 months before an eruption, the summit inflates as magma rises from a source in the mantle believed to lie 60 kilometers or more beneath the surface. The inflation is caused by molten rock rising through the volcano's intricate plumbing system to a chamber where magma is stored at depths of 3 to 6 kilometers. As the magma rises through passages called dikes, breaking rock and leaving a wake of seismic waves, thousands of rapid, small earthquakes (less than Richter magnitude 3.0) shiver through the volcano.

The paths of such earthquake swarms chart the motion of the fluid rock. Magma may erupt directly from the summit, or from rifts in the flanks, some distance away. When an eruption begins at any location on the volcano, the summit caldera subsides rapidly; within five days after the January eruption began, the bulging caldera had subsided as much as 800 millimeters, says John Dvorak, who works on the deformation studies at the observatory. In their measurements of the swelling and deflation of the volcano, the scientists use sensitive instruments that gauge the distance between points on opposite sides of the summit, elevation with respect to sea level and the slope angles on the summit's flank.

Twenty-two hours before Kilauea erupted Jan. 3, a swarm of small quakes began along the East Rift Zone about 16 kilometers from the observatory. At 4 a.m. staff photographer Jim Griggs was flown to the site in a military helicopter from which he snapped still shots as the first jets of liquid rock vaulted into the sky. Since Griggs arrived at the observatory five years ago, the scientists have gained new appreciation for the utility of photographs in volcano studies.

Photos used to be a haphazard affair, taken by scientists during moments stolen from more immediate tasks such as measuring temperature or sampling gas. Now, once an eruption begins, Griggs sets up a video system that captures the progression of the eruption in real time. The camera follows the lava curtains that line the opening fissures until they stabilize at one location with gushing fountains. Meanwhile he continues to take hundreds of photos, each marked with the minute and day the image was recorded.

The photographs are of special interest to staff geologist Ed Wolfe, who is compiling a new map of the ever-changing volcano. Aerial photos of fresh lava flows can be used to compute the area of the volcano and the volume of new material added to its mass.

The timing of the January eruption was fortunate for both the photographer and for anyone who delighted in the spectacular photos and movies of the event. Usually the East Rift Zone is draped in cloud. This time, however, the eruption coincided with a drought caused by the El Niño, an ocean-atmosphere disturbance then underway in the central Pacific (SN: 2/26/83, p. 135; 4/9/83, p. 228). A spectacle that stirred the senses and the imagination, streams of lava roared from fissures, fell back to earth and headed for the coast. By the time the eruption subsided in April, the lava had consumed eight homes and had flowed nearly 8 km before it stopped 4 km from the sea, Pele's wrath assuaged.

The forces of nature are in unrelenting conflict at Kilauea, nearby Mauna Loa, and their volcanic predecessors in the Hawaiian chain. No sooner has an eruption subsided than rain and wind begin to erode the freshly laid flows. Along the coast the sea gnaws at the twisted lava, and eventually reduces it to "black sand." Over tens of thousands of years, the sea cuts deep valleys into the mountains, as it is doing to Mauna Kea, a dormant volcano on the island's north shore. At the northwest end of the Hawaiian chain, the extinct volcanoes that comprise Kauai have been slashed into jagged mountain faces and exquisite canyons in the 5.6 million years since the island formed.

Despite the barren visage of Kilauea's summit caldera, life has a tenacious grip on the volcano. By now bacterial communities no doubt are established in the open environment presented by the fresh lavas extruded this spring. Soon the ferns seen all over the Hawaiian islands will move in. In time these will be followed by fire-resistant ohia trees, scraggly plants whose red blossoms often provide the only relief from the near-monochrome of the summit. A short distance from the observatory, older flows are covered by lush rain forest, a legacy of the 254 cm (100 inches) of rain that douses parts of the park (and its 2.5 million visitors) each year.

Any movement of molten rock, in the earth's interior or at the surface, is considered a volcanic event. The most obvious is an eruption, but the intrusion of magma into one of the two major rifts, or crack systems, in Kilauea's flank or into the summit caldera also indicates volcanic action. In fact, the amount of lava extruded at the surface is only part of the material that builds the volcano.

USGS photos by J. D. Griggs

Left: Lava spurts from a vent. Center: Pahoehoe, or ropy lava, advances through the night. Right: Charred trees.

Many intrusions never reach the surface. Instead they cool and solidify in the volcano's interior as the magma's crystal structure changes, or differentiates. By the time of the next eruption, the magma that has not hardened will be the first to go. The chemistry of lavas erupted since January shows that so far, no unaltered material from the deeper magma chamber has made its way to the surface. Scientists estimate that about 50 million cubic meters of lava have flowed from the volcano this year, pushed out by as much as 80 million cubic meters of magma that have been supplied from the deeper magma chamber. Whether the balance of 30 million cubic meters will rest in the volcano or erupt is anyone's guess.

As Kilauea grows, so does the island of Hawaii, the "Big Island" newest to the Hawaiian chain. The adolescent volcano is buttressed by Mauna Loa, the island's other still-active volcano, a real behemoth. From its base on the seafloor, Mauna Loa rises 9,144 m to its summit 4,169 m above sea level, making it the largest mountain in the world. Like Kilauea, Mauna Loa follows in an ancient tradition of volcanoes that form a near-linear chain in the mid-Pacific. Scientists believe that these seamounts and islands are punched up sequentially as the crust moves over a fixed, or relatively fixed, hot-spot in the earth's mantle (SN: 9/22/79, p. 202).

Its proximity to Mauna Loa has important consequences for Kilauea. With the massive, older volcano to the north and west, there is only one way for Kilauea to grow — toward the sea, on its free southeastern face. While most minor earthquakes on Kilauea are related to movement of magma, sometimes major quakes not caused directly by magma intrusions occur in the volcano's south flank. Wolfe says that these deep quakes, focused at a depth of 8 or 9 km below the top of the volcano, may occur on the nearly flat seafloor on which the island is built. As numerous intrusions of magma penetrate into the dikes in the volcano's flank, pressure builds. Finally a major earthquake like the magnitude 7.2 quake that struck in 1975 rumbles through the side of the volcano, and a huge slab of mountain is shoved toward the sea. In this way the area of the volcano increases and new storage space for magma is created. Such major quakes may be followed by eruptions of magma, but more often several years elapse until pressure builds up to the next episode.

While much has been learned of the history of volcanic action at Kilauea, little can be taken for granted. For instance, Wolfe says, when Mauna Loa is active, Kilauea usually is quiet, "but you can't count on it." The volcanoes derive their energy from the same hot source in the mantle, but apparently have separate plumbing systems and tap slightly different sources for their magma supplies. Their lavas look identical but elaborate chemical analyses show subtle variations in their compositions.

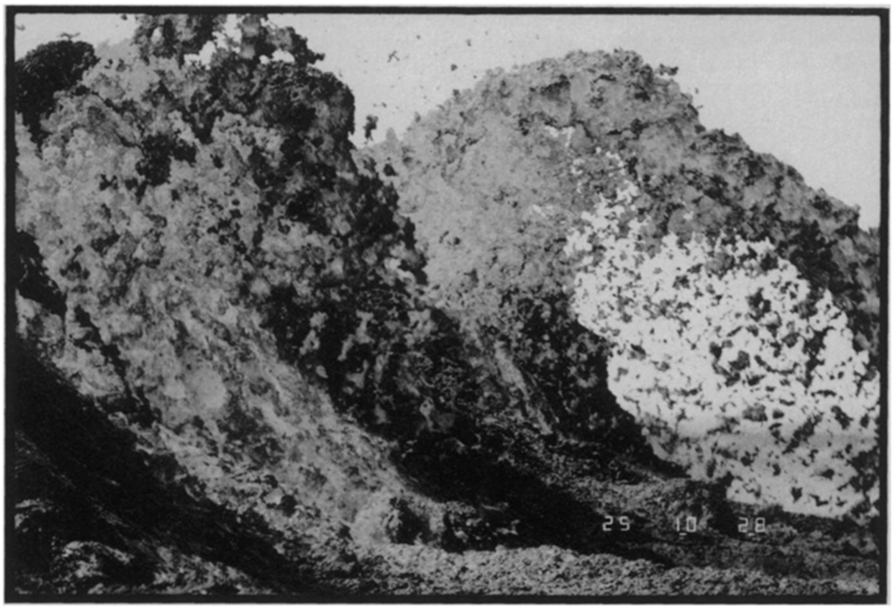
Both Kilauea and Mauna Loa are called shield volcanoes and have gently sloping sides formed by highly fluid lava flows. At no point, for instance, is the slope of Mauna Loa greater than 12 degrees. Mauna Loa is in its intermediate stage, and erupts less frequently than it probably did when it was more directly over the hot-spot. Recently the summit has inflated slightly, but the mountain has not erupted since 1975. From 1950 to 1974, no eruptions occurred, the longest quiet period in the volcano's recorded history. Mauna Loa's grand form glimpsed across the valley presages the future of the younger Kilauea; similarly, Mauna Kea, a late-stage shield volcano, sports a steep and bumpy summit like the one that lies ahead for Mauna Loa. The different stages stem from the composition of the magmas erupted, which go through a cycle during the volcano's lifetime.

The outstanding feature of eruptions in Hawaii is their gentleness. Scientists rush toward the site of a surface eruption to jab temperature probes and other sampling instruments into the advancing, fiery stream. Temperatures of the lavas are about 1,100°C to 1,180°C. The melt is notably low in silica, a constituent of lava that with temperature and gas content governs how viscous the lava is, or how easily it flows. (The more viscous lava is, the less fluid.) In general these three qualities ensure that the Hawaii eruptions, the recent one included, are not explosive like those at volcanoes such as Mt. St. Helens, which occur at the margins of the earth's crustal plates. The silica-rich magmas of explosive volcanoes are much more viscous than those of Hawaiian volcanoes, and gas remains compressed, building to high pressure before it smashes through rock, sending tons of debris and ash high into the atmosphere.

Dangerous eruptions do occur sometimes at Kilauea when water circulating through the volcano's hydraulic system touches magma. This meeting can result in a phreatic explosion, in which steam propels rock and gas with violent force. This is very much a volcanic event even though no magma necessarily reaches the surface.

Earthquake studies form the cornerstone of operations at the observatory. As seismologist Robert Koyanagi strolls through the barracks-like field station, he explains the five seismographic systems that provide the scientists with copious data. The instruments range from antiquated smoke drum recordings, in which glassine paper is rotated over a kerosene flame and placed under the jittery needles of old but reliable seismographs, to modern computers, unfortunately housed in a leaky former garage. Magnetic tapes record seismic data from 47 stations scattered around the island.

The seismic readings are correlated with measurements of summit swelling and deflation. In the past few years the observatory has embarked on studies to learn whether changes in the local electromagnetic field and in gas measured at the surface are related to movement of molten rock. The studies, both in early stages, ultimately may enhance the scientists' ability to predict eruptions.

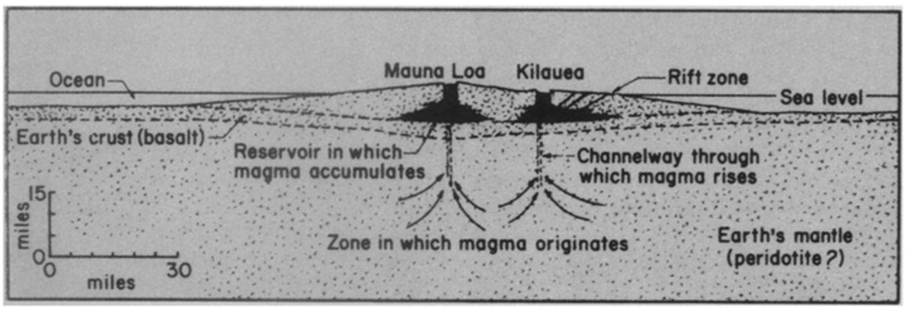


USGS photo by J. D. Griggs

Lava streamed from this fountain for more than 24 hours.

Several times each week, gas geochemist Paul Greenland gathers samples from 25 steam vents on Kilauea and measures how much of 13 gases each sample contains. The idea is that gas levels may fluctuate in response to any change in the physical or chemical state of the magma, and may indicate magma movement. As molten rock moves toward the earth's surface, the confining pressure drops and gas is expelled. The gas also may reveal physical responses such as the moving magma's interaction with rocks in its path.

Greenland cautiously suggests that fluctuations in gas concentrations precede some eruptions and intrusions, but so far, he perceives no pattern in the changes. For instance, he says, prior to the last eruption some steam vents only a meter



Mauna Loa and Kilauea share a deep magma source, but have separate plumbing systems.

From Volcanoes of the National Parks of Hawaii, Hawaii Natural History Assn. Ltd.

from the East Rift showed "no change whatsoever."

An initial finding of these fledgling studies is that gas changes have been observed at the same time as changes in the electrical field at Kilauea. The electromagnetic field responds to movement of magma because the hot fluid conducts electrical and magnetic signals better than rock does. Greenland and Dallas Jackson, who is working on the electromagnetism project, have found that changes in both gas and the electric field may occur before the effects of an intrusion are noted through the seismic readings or deformation. This may mean that magma can move without generating seismic waves.

"My interpretation is that the cracks are already open, and that the magma simply moves in," Jackson says. This is the first time that gas and electromagnetism studies have been done on an active volcano and where other properties are so well understood. Eventually, the researchers hope, their findings will enhance prediction efforts.

One puzzling aspect of the electrical studies, which detect changes as small as .001 volt, is that there is no evidence of the shallow magma chamber that almost certainly exists beneath the summit caldera. Deformation models and seismic readings generally indicate a chamber 2.5 to 5.0 km below the surface. There *is* evidence for a "conductor" starting about 5.0 km deep, but based solely on electromagnetic studies, it may or may not be magma, Jackson says. "It's an enigma," he adds. "Maybe someday we'll work it out."

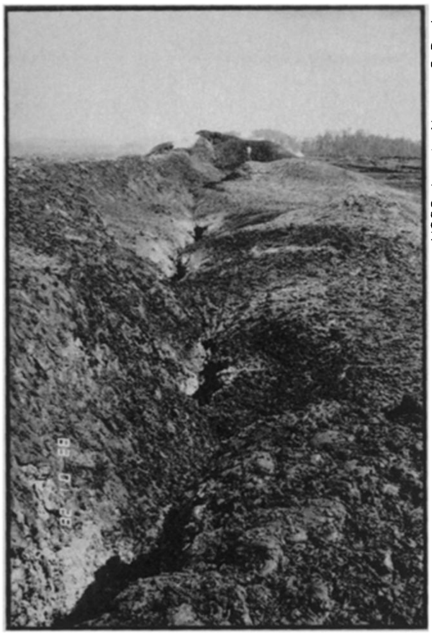
The azure waters lapping at the island's shores conceal the greater, submerged portion of Kilauea. A team of scientists from the University of Hawaii in Honolulu is looking for life on the volcano's undersea expanses. There they hope to find hydrothermal systems similar to those discovered along the East Pacific Rise. The known vents occur along a ridge where new seafloor is created, and support exotic communities of marine animals that rely on chemotrophic bacteria. These organisms digest hydrogen sulfide and use it as their main energy source (SN: 4/7/79, p. 231; 6/19/82, p. 416). The project, called "Project Pele," is the first concerted attempt to learn if vents occur in a volcanic area in the middle of an oceanic plate.

The scientists conduct their studies with the help of the university's two-person submarine, *Makalíi*. So far Project Pele has not revealed any hydrothermal vents on the submarine portion of the East Rift Zone. Geophysicist David Epp explains that this is probably because the volcano is so porous. Superheated water diffuses through the system of cracks in the rift zone instead of streaming out through the chimney-like "smokers" that characterize vent areas.

So far project scientists Epp, microbiologist David Karl and geochemist Gary McMurtry have not obtained water containing chemotrophic bacteria from the rift zone, but geothermal wells drilled on the island of Hawaii yet may provide the laboratory they seek. The temperature of water in one well, drilled in 1974 to a depth of 1,829 m, is about 350°C. This is the same temperature as water coming out of black smokers, the hottest known deep-sea vents.

When Karl viewed the well water samples through a microscope he saw the same chemotrophic, sulfur-oxidizing bacteria as "the ones we presume are driving the system at the hydrothermal vents," he says. As expected for organisms with such an abundant food supply, their population densities are greater than those of organisms found in ordinary seawater.

There is a long history of maps of the land portion of Kilauea, but little attention has been paid to its undersea stretches. In addition to looking for hydrothermal vents, the scientists are studying the form and structure of the submerged part of Kilauea, and plan to draw a detailed map. They find that this part of the volcano is "much more rugged" than they had expected, with deep valleys and steep cliffs — a nightmare for the submarine pilot whose job is complicated by the treacherous terrain.



USGS photo by Norman G. Banks

Kilauea's East Rift Zone

Their undersea survey will be combined with observations made at the geothermal wells, and should lead to a broader understanding of the volcano's hydrology. "We know that rain water comes in, and we know that a lot of it must flow out along the coastline, but we really don't know where it goes in between," Epp says. The hydrology is pertinent to continued development of geothermal energy in Hawaii, to disposal of geothermal residue which is high in silica and hydrogen sulfide, and to the functioning of the volcano, which is cooled and lubricated by the circulating water.

Researchers also are eyeing a new shield volcano forming about 30 km from Kilauea (SN: 12/19/81, p. 388). The volume of the infant mountain, named Loihi, is only about two percent that of Mauna Loa, but in time it may become the next Hawaiian island. Or, its flows may overlap those of Kilauea, making the Big Island even bigger. Epp and Koyanagi both commented that Loihi's location to the south of Kilauea suggests that the direction in which the line of islands is forming may be shifting as it did 43 million years ago at the southern end of the chain of Emperor seamounts. These volcanoes preceded the Hawaiian islands in their journey over the hot-spot. But the shift is speculative, and the answer may not be apparent for millions of years.

In the meantime, the heat goes on. □

Round pillow lavas (left) form when flowing lava meets cold seawater.

Gold coral (bottom left) growing offshore of Kilauea.

Underwater fault (below) in the East Rift Zone.

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