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Explosive eruption of Kilauea in 1924 sends huge column of ash and steam upward from Halemaumau Crater. Such eruptions are rare events at Kilauea, and are presumed to be caused by sea water somehow gaining access to the plumbing system of the volcano.

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ROGERS C. B. MORTON, SECRETARY

GEOLOGICAL SURVEY
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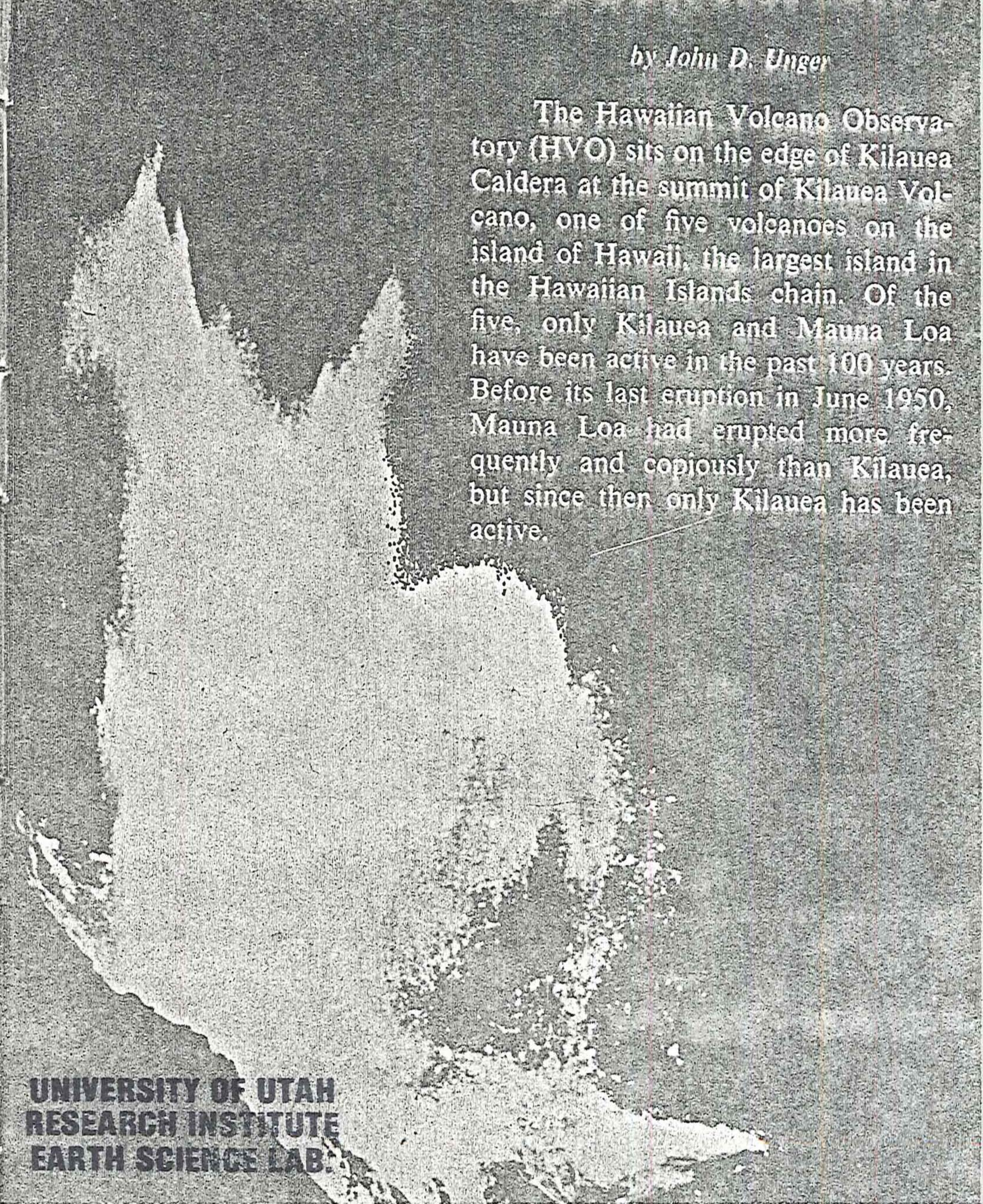
SCIENTISTS PROBE EARTH'S SECRETS at the HAWAIIAN VOLCANO OBSERVATORY

by John D. Unger



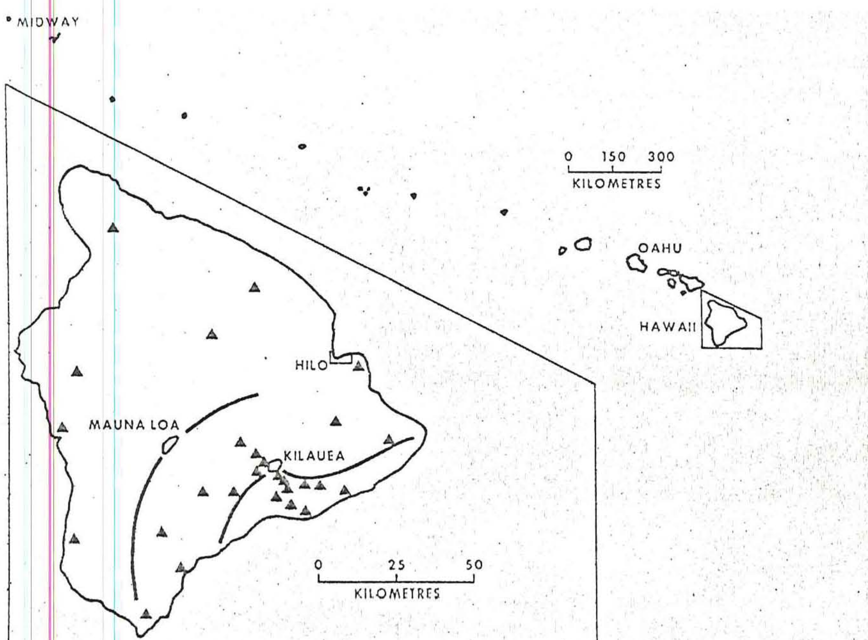
The Hawaiian Volcano Observatory (HVO) sits on the edge of Kilauea Caldera at the summit of Kilauea Volcano, one of five volcanoes on the island of Hawaii, the largest island in the Hawaiian Islands chain. Of the five, only Kilauea and Mauna Loa have been active in the past 100 years. Before its last eruption in June 1950, Mauna Loa had erupted more frequently and copiously than Kilauea, but since then only Kilauea has been active.

The island of Hawaii (or the "big island" as it is known locally) is the southernmost member of a chain of volcanic islands that stretch for 2,400 km to Midway Island at the northwest end. The islands become progressively older as one goes up the chain from Hawaii. Hawaii is thought to be less than 1 million years old; whereas the island of Oahu, 300 km to the northwest, is between 2.5 and 3.0 million years old. This systematic change in age has fostered many theories for the formation of the island chain. Scientists are still searching for an explanation that fits all of the facts as we understand them today.

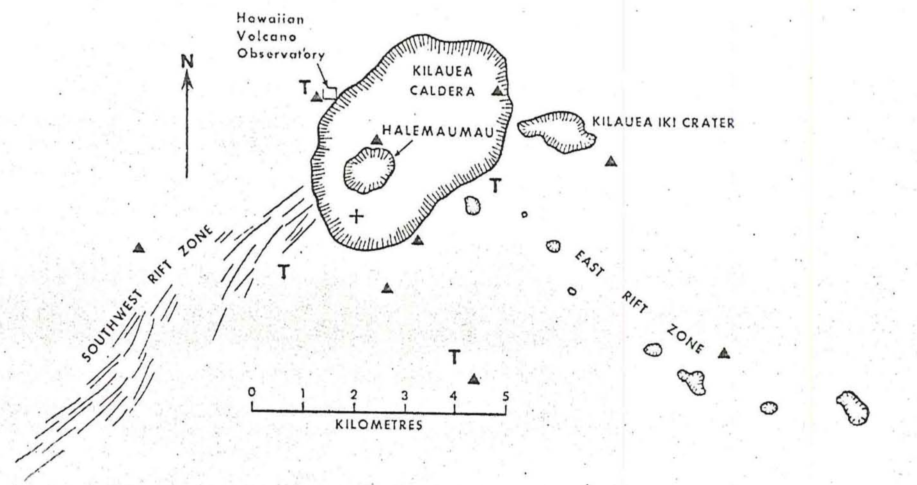
Virtually all of Kilauea Volcano and the summit region of Mauna Loa Volcano are inside the boundaries of Hawaii Volcanoes National Park. Kilauea Caldera is a crater formed by subsidence of the summit of the volcano and is about 5 km long in a northeasterly direction, 3 km wide, and approximately 150 m deep at the north end. The general outline of the caldera has not changed much since it was first described by Rev. William Ellis in 1823, but its depth and internal structure have changed greatly as a result of eruptions and repeated episodes of subsidence within it. It is one of the centers of eruption on Kilauea Volcano and has been the site of five major eruptions in the last 3 years. Two rift zones radiate from the caldera, one to the southwest and the other to the east. Along with the caldera, these two rift zones are the loci of virtually all of the eruptions on Kilauea Volcano.

OBSERVATORY FOUNDED IN 1912

The Hawaiian Volcano Observatory was started in 1912 by Thomas A. Jaggar, who was then the chairman of the Geology Department at Massachusetts Institute of Technology. Money for the new Observatory came from business leaders in Honolulu and from a research grant from M.I.T. The volcano Research Association was formed in Honolulu to raise local money to augment these funds. In 1912, Jaggar left M.I.T. to take up permanent residence at the new observatory on Kilauea. Before the observatory was finally brought into the U.S. Geological Survey in 1948, it was successively sponsored by M.I.T., the U.S. Weather Bureau, the Geological Survey, and the National Park Service. The observatory's early years were devoted to making detailed studies of the active lava lake in Halemaumau, the principal eruptive vent in the caldera, and on developing new techniques and equipment for studying the volcano. As financial support increased in response to the scientific successes of the early 1920's, the seismic studies were expanded and sophisticated surveys of Kilauea and Mauna Loa were begun. In 1933, with the country in a depression, the budget for the observatory was drastically cut, and the staff was absorbed by Hawaii National Park. During the lean years that followed, a small net of seismograph stations was maintained and records of ground tilt were kept. In 1948, when the USGS took over the observatory, the slow process of reviving volcano research began in earnest. Since then, the scope of the research has continually expanded. Scientists from all over the world visit the observatory either to learn about the work, or to carry out some special project that involves an active volcano.



Geographic setting of Kilauea Volcano and HVO. The inset map is an enlargement of the island of Hawaii showing Mauna Loa and Kilauea Volcanoes, and Kilauea's two active rift zones. The HVO seismograph stations are indicated by the triangle symbols (▲).



Kilauea summit region. The upper part of the east rift zone is delineated by a series of pit craters; the southwest rift zone by parallel, en echelon ground cracks. The cross symbol (+) shows the location of the 1,270 m deep hole drilled in 1973 and it also marks the approximate center of the upper magma reservoir. Seismograph stations around the summit region are indicated by solid triangle (▲), and the locations of continuously recording tiltmeters are shown by the letter T.

MANY ROUTINE AND SPECIAL STUDIES

The research staff at HVO is involved with many continuing and short-term projects. Many of the routine activities are associated with monitoring changes in the size and shape of the summit region of Kilauea Volcano as the internal magma pressure changes. Every 3 months approximately 35 km of continuous first-order leveling is run; 60 horizontal distances up to lengths of 20 km are measured using a laser geodimeter, and 25 tilt sites are surveyed. These tasks take 1 or 2 weeks to complete depending upon the unpredictable weather. When an eruption is occurring, much time is spent collecting samples for chemical and mineral analysis, mapping the extent of the vents and flows, and simply keeping tab on the eruptive site for any changes. After an eruption has occurred, the rocks and minerals are carefully analyzed to determine how they compare with those from previous recent eruptions.

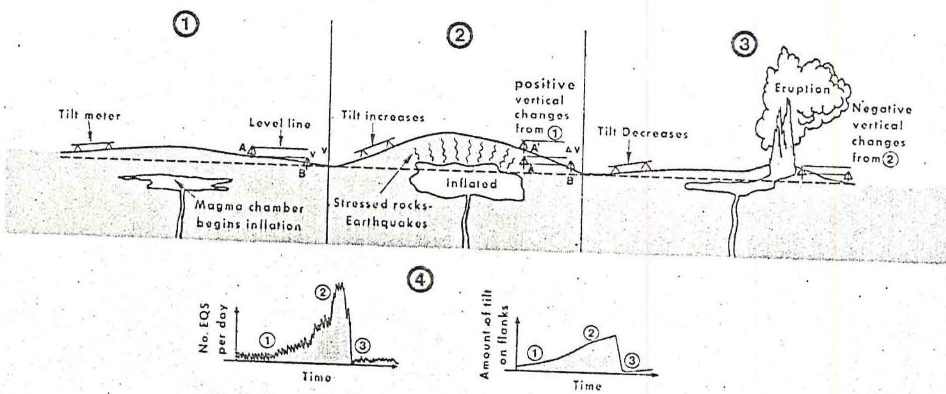
During certain long-lived eruptions, interesting and baffling features are created by the flowing lava. One of these is the formation of lava tubes. This phenomena is being intensely studied by geologists at HVO because much of the mass transfer of lava in large flows (those longer than about 1 km) appears to be by subsurface lava conduits or tubes. The roofs of active tubes can be as thin as a few centimetres or as thick as a few metres. Another puzzling feature of active lava flows is their tendency to sometimes change from a smooth, fluid type flow (called pahoehoe) to a rougher textured, clinkery type flow (called aa). This change most likely is related to the increase in viscosity of the flowing lava due to changes in temperature, gas content, and degree of crystallization, but the details are complicated.

An important instrument for the study of lava flows is a specially designed temperature probe used to measure the temperature of lava in flows and in tubes; these temperatures usually range between 1000°C and 1100°C. Electrical geophysical methods are also being applied to the study of lava flows. Very low frequency (VLF) radio signals are used to detect the lava-filled tubes beneath the ground surface. Using this method, not only the location but also the size and depth of the lava tube can be estimated. Another method involves the measurement of minute electrical currents in the ground. Although scientists do not know precisely the primary cause of these currents, they appear to delineate "hot" regions around the volcano that possibly overlie shallow intrusions or conduits of magma.

MONITORING GROUND TILT AND EARTHQUAKES

Of all the ongoing projects at the observatory, the two that have provided the most information about the internal workings of the volcano are direct measurement of ground deformation and tilt, and seismic studies. The ground deformation studies consist of monitoring vertical ground changes by precise leveling, of detecting horizontal changes by measurements with the laser geodimeter that can measure distance accurately to within about one part in one million (1 mm for 1 km of distance), and of continuously recording the amount of ground tilt using tiltmeters that are sensitive to tilts as small as 0.1 second of arc. The seismograph network on the island presently consists of 35 short period instruments. The data from these seismic stations are telemetered to the observatory by either VHF radios for the more distant stations or by cables for the stations closer to the observatory. Twenty-four of the seismographs are located on or close to Kilauea Volcano.

Interpretation of the data collected from these instruments has given rise to a crude model of volcanic activity that explains many of the observations made at HVO over the years. Briefly, the model calls for a continuous movement of magma from its source, which is probably 60 to 80 km beneath Kilauea, upwards into a shallow reservoir complex centered 3 to 6 km under the southern part of Kilauea Caldera. If no eruptions are occurring, the continuous supply of magma from the mantle causes the upper reservoir, or chamber, to swell, and the ground surface responds by forming a gentle uplift. The vertical ground movement can be measured by precise leveling and by tiltmeters placed along the flanks of the "bulge" which will show tilting outwards from the center of the uplift. Such swelling creates stresses in the cap rock over the reservoir. As many as a few thousand small earthquakes per day are sometimes recorded on nearby seismographs when the swelling is increasing. The pressure in the summit reservoir is relieved suddenly when an eruption occurs and the magma moves from the reservoir and is extruded as lava either in the summit region or along the rift zones. The "deflation" of the reservoir causes the ground surface, which has been bulged upwards, to return rapidly to normal. This sudden change is shown by inward tilting on the tiltmeters during

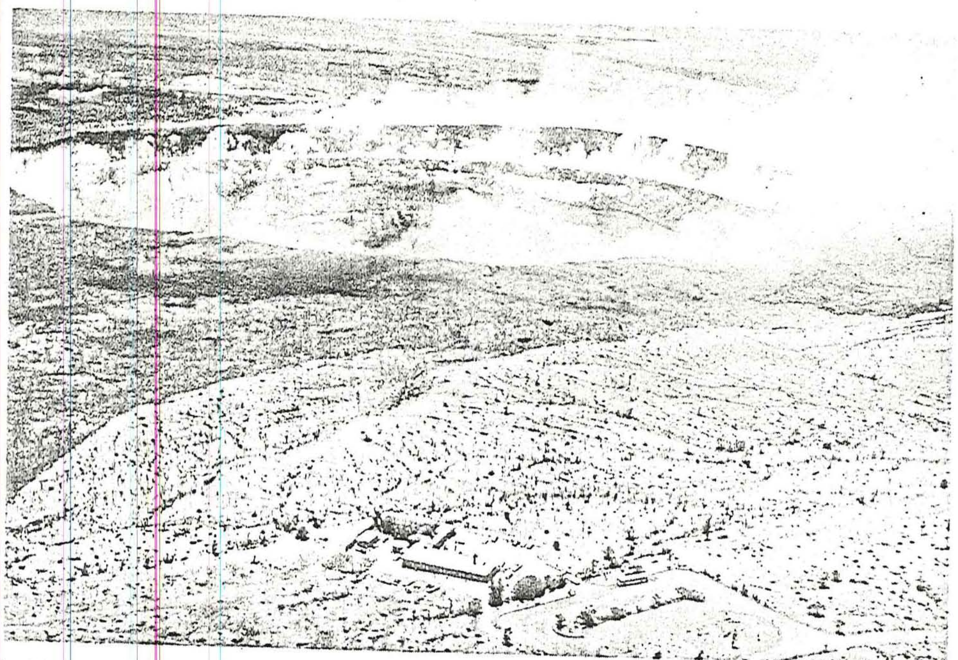


Schematic diagram of three stages in an idealized eruptive episode on Kilauea Volcano. (1) The episode is started when magma from depth feeds into the upper reservoir. (2) The inflow of magma has distended and swollen the reservoir which in turn has deformed the ground surface over it. The tiltmeters on the flanks of this "bulge" tilt outward from the center; the vertical distance beween points A & B has increased; and the rock above the reservoir is highly stressed, causing many small earthquakes. (3) Finally, the magma pressure becomes too great, and an eruption breaks out at a weak point. The pressure in the reservoir is released very suddenly, and the ground surface over the reservoir moves downward as evidenced by the tiltmeters and a decrease in the distance between points A & B. Also, because the stress in the overlying rock is relieved, the frequency of earthquakes rapidly diminishes. (4) Idealized graphs of earthquake frequency over the reservoir and surface tilt on the side of the reservoir as a function of time. Part (1), (2), and (3) are indicated on each graph.

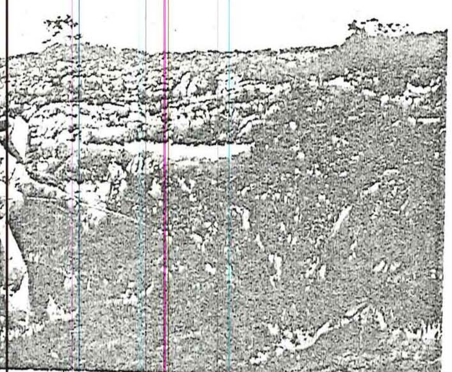
the eruption and by downward vertical changes over the reservoir when leveling is done after the eruption. As one might expect, the above sequence is somewhat idealized, and some eruptions do not exactly follow this pattern. However, the general processes occur within the framework of this model.

DRILL BURIED BY LAVA

In 1958, a very spectacular eruption occurred in Kilauea Iki Crater that filled the bottom 100 m of the crater with a lava lake. When solid crust rapidly formed on the lake, observatory scientists began to plan a series of unique experiments to drill through the crust and into the molten rock below. These experiments were successfully completed and much new information was collected on the cooling rate of the lava in the lake and on the type of minerals that formed at the bottom of the crust as it gradually thickened. A few years later, similar drilling experiments were successfully completed on smaller lava lakes formed in Alae and Malaopuhi Craters in 1963 and 1965 on Kilauea's east rift zone. However, in 1969, a drilling program in a freshly formed lake in Alae was abruptly terminated



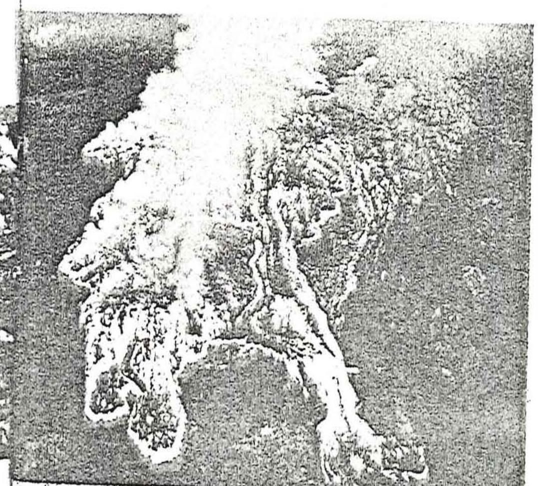
Aerial view of the Hawaiian Volcano Observatory with Halemaumau Crater in the background. Photo taken in 1971.



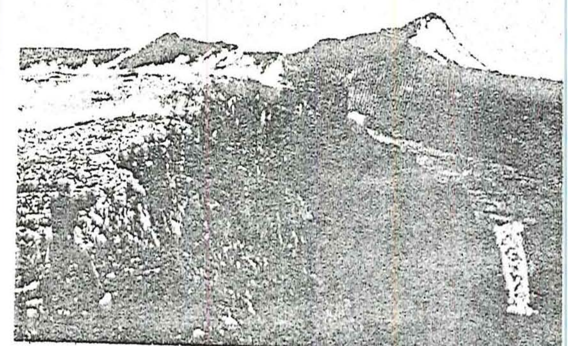
eat reflective suit protects a scientist placing a ampling rod into front of advancing lava flow om Kilauea.

A scientist advances cautiously to margin of lava flowing from Mauna Ulu.

Lava flow entering the sea during the 1950 eruption of Mauna Loa. At that time, three flows traveled rapidly from the southwest rift of the volcano and advanced downslope into the sea.



Lava flow pouring down the side of Mauna Loa toward the sea during the 1950 eruption.

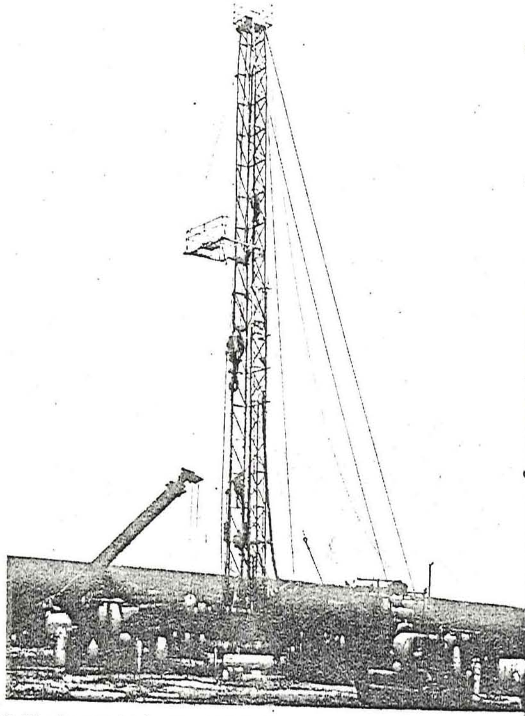


Summit craters of Mauna Ulu on the upper east rift of Kilauea during the eruption of 1972. Lava from one creater is cascading into an adjacent crater.

when lava from a new eruption buried the drill rig completely! In a few months a new drilling program is to begin on the Kilauea Iki lava lake. Previous calculations estimate that the drill will have to penetrate about 40 to 50 m of crust before breaking into the still-molten portion of the lake.

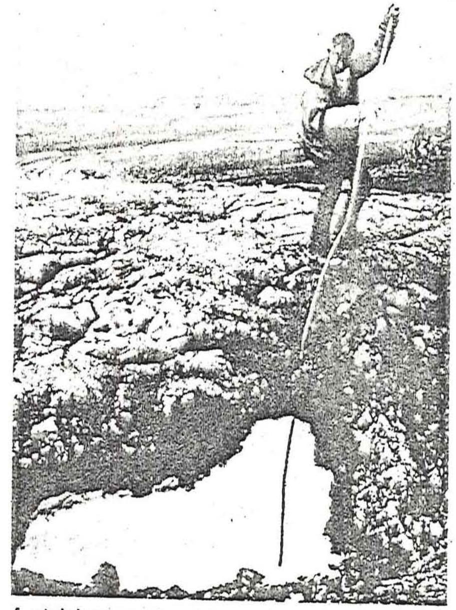
SEARCH FOR GEOTHERMAL ENERGY

Recently, much time and effort has been spent searching for usable geothermal energy in Hawaii. Discovery and utilization of such a resource would be especially valuable in the Hawaiian Islands because all of the electric power now generated comes from imported fuel oil, and, consequently, the cost of electricity is high and is expected to increase. As one might expect, locating a source of heat on Hawaii is not as difficult as in the continental United States. The problem is the extremely high porosity and permeability of the basalt flows that comprise the island make it difficult to locate a self-sustaining geothermal "system" that would directly yield usable steam. In order to test some of the theories postulated for the shape and size of the shallow magma chamber beneath Kilauea and also to look for a possible closed geothermal system that might directly form high pressure steam, a 1,270 m deep hole was drilled on Kilauea Caldera early in 1973. Although the temperature at bottom was about 140° C. and was rising with increasing depth, no steam or magma was encountered during the drilling. Because commercial development of any geothermal resource is not allowed within the bounds of Hawaii Volcanoes National Park, current exploration is centered on the portions of Kilauea's east and southwest rift zones that lie outside the park and also on the southwest rift zone of Mauna Loa.

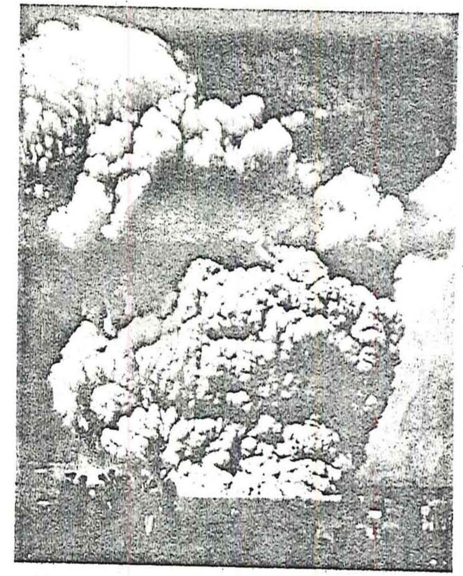


Drill rig used to drill 4,100 foot research hole financed b the National Science Foundation. Hole drilled near summi of Kilauea, about 1 mile south of Halemaumau.

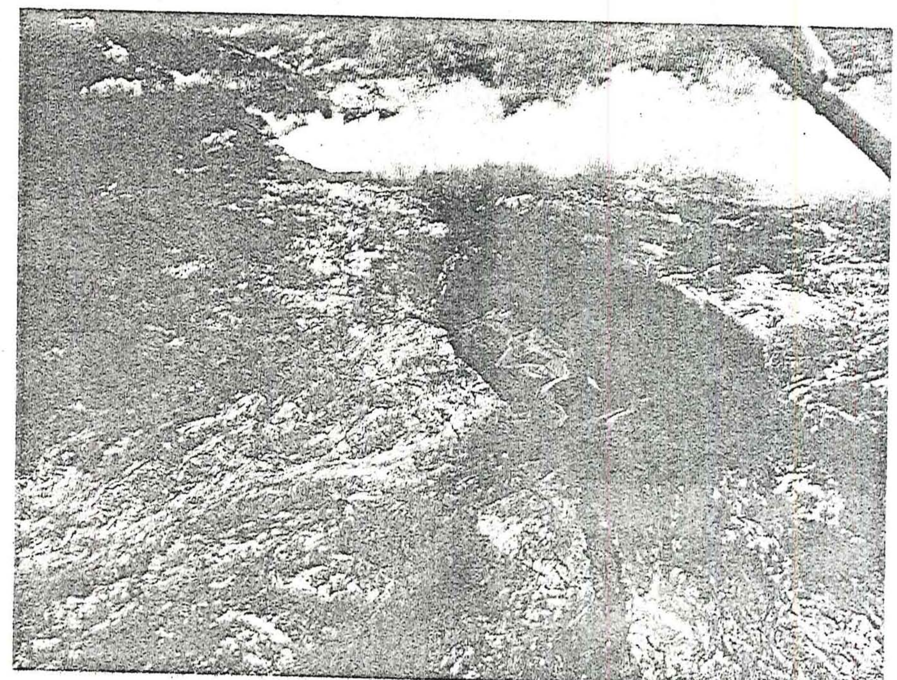
Collecting samples of volcanic gas immediately after the 19 eruption of Kilauea Iki.



A stainless steel rod is pushed through the roof of a lava tube and into the actively flowing lava river below. This is done to determine the depth of the lava river.



Explosive eruption of Kilauea in 1924 sends huge column of ash and steam upward from Halemaumau Crater. Such eruptions are rare events at Kilauea, and are presumed to be caused by sea water somehow gaining access to the plumbing system of the volcano.



Aerial view of the summit craters of Mauna Ulu in 1971. The Mauna Ulu eruption persisted from 1969 to 1974.