THE BORINGS AT KILAUEA VOLCANO

By T. A. JAGGAR, Volcanologist

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The scientific value of making borings on a live volcano has been discussed among geologists for many years. It has been discussed by business men, also, in Hawaii, with the notion that endless power resides in that boiling lava. The use of steam for generating electricity at Larderello in Italy has been much quoted as comparable to what should be done in Hawaii. The late Mr. John Brooks Henderson, of Washington, D. C., in 1920 furnished some money to start boring experiments at Kilauea and other money was raised by the writer through the Hawaiian Volcano Research Association to supplement the Henderson gift. Some of this was furnished by the Whitney endowment of the Massachusetts Institute of Technology.

The plan discussed was referred to Dr. H. S. Washington, of the Geophysical Laboratory of the Carnegie Institution, to several experienced engineers and firms making boring apparatus and to practical drillers. The big problems confronting the work were the lack of natural water, the effects of the hot porous hard lava on drill tools, and the lack of roads for transporting machinery across the rough lava fields.

The information expected from borings is fourfold at a lava crater: First. How does the temperature increase as one goes down? Second. How does the undeground temperature change across country for the same depth? Third. What are the mineral changes underground? Fourth. What are the gas changes undeground? From the six holes that were bored in 1922–23 a reconnaissance survey has been made of these four questions, experimental tests have been made of churn, hammer, and shot drilling, and a small laboratory has been erected over the hottest steam holes for experiments with engines and condensers.

Diamond drilling in Hawaii appeared too costly owing to the lack of any drillers there. Shot and churn drills were available. Binding or seizing of bits in the hot dry rocks was expected and encountered and bits were lost. Such experiences with diamond bits would have been disastrous. Therefore churn drills and shot drills were used first.

The drillers were baffled from the start by the unexpected hardness of the Kilauea basalts. An experienced drill boss thought the lava would be brittle and easily invaded by a churn drill several feet an hour; instead he advanced only 2 or 3 feet per day. Three holes were bored by this method, respectively 23, 50, and 79 feet deep, the first two at the hot, steaming sulphur banks near the hotel and the deepest one at the east floor of big Kilauea Crater.

The sulphur banks revealed iron and copper sulphides just beneath the upper oxidized rocks, the gas there was everywhere 96 per cent steam at 204°, and this is the theoretical boiling point of water for the elevation, about 3,945 feet above sea level. The sulphur of the banks was shown to be superficial, veins coated with zeolites were found, analysis revealed tiny amounts of free sulphur and sulphur dioxide in the gas, but most of the 4 per cent other than water vapor was air and carbon dioxide.

The steam is practically at atmospheric pressure, as all that confines it is a porous rock and a 6-foot overburden of volcanic ash, and red clay derived from the ash by the chemical action of the sulphurous steam. It seems nearly certain from the boring samples that the steam comes from profound depths along vein cracks that here constitute a zone of fracture at the edge of an ancient part of the crateral lava fill. These cracks are deeper than other large chasms near by, to judge from their sulphurous emissions, or else the subterranean lava under them rises near to the surface, bringing up its heat and its dissolved sulphur gases.

The constant temperature for 50 feet of depth was striking, and the coincidence of this temperature with the boiling point for the elevation suggested the teakettle effect. That is, the rain water somewhere underground was boiling like a teakettle. There is plenty of rain, a hundred inches a year, more or less, at the observatory near by, but there are no springs, or brooks, or ponds, for the lava is so porous all the rain soaks down right away. This water may maintain a seepage which is brought to boiling at the hot lava level. But that level might be a thousand feet down or more, in which case the boiling temperature should be higher. Indeed the absence of springs on the active volcanoes everywhere except at sea level makes it probable the ground-water level under Kilauea is very low. If the borings could be pushed down a thousand feet at the sulphur banks some very interesting discoveries might be made. The 50-foot hole without any change of temperature merely whets the scientific appetite!

The hole 79 feet deep out on the lava of 1894 in the big crater took six weeks to drill and three weeks to prepare for. All these holes in the thin-bedded flows tended to wear away the churn bits, to jam the bits with fallen fragments, to soak up all the water fed down and so defeat the "sand bucket" for bringing up specimens, and to break the treadle or gears occasionally by producing a sudden sticking of the string of tools.

The heat in this hole was much less than at the sulphur banks, although the place is a mile nearer the central fire pit and the rocks are more recent lava flows. For 45 feet of depth the temperature rose about 2° F. for each foot, but there the increase of heat stopped, and at some depths below, the temperature went down a few degrees. At the bottom 79 feet down the hole measured only 155° F. Nothing came up but warm air. At about the 70-foot level there was a caving bed of soft sandy or gravelly deposit. To get by this the hole had to be cased with iron pipe. Even in this short sinking of 79 feet the hole had to be diminished in size three times from 10 inches to 4 inches diameter to prevent sticking of tools. Nothing was discovered here in interesting minerals.

The next experiment lasted over two months and a hole 60 feet was bored 5 inches in diameter with a shot drill. Chilled steel shot make the abrasive and this is washed down a rotary tube so as to grind the rock and let a 4-inch core come up the middle. Such a tool will cut granite easily, but again the vesicular lava made trouble with its cracks, its holes and its easily broken thin layers. The water pumped down would refuse to rise up the outside of the drill rods. It went off into pores and cracks and took the abrasive with it. Broken pieces of rock got under the drill and rolled around for hours. Shoulders of hard lava, with a cavern beneath, would catch the top of the tool, bump it until the core had dropped down the hole, and delay progress lamentably.

This hole was in the observatory grounds among the warm vapor cracks of the upper edge of Kilauea Crater, not far from the sulphur banks. But it was not hot at all, only about 100° F. at the hottest, and the hottest place was only 20 feet down, while below it was cooler! Its minerals and its gases were lava and air. Its temperature changes were neither gradual nor consistent. Presumably it was cooled or warmed locally by inclined cracks bringing up air or vapor.

The rest of the boring was done with the shot drill at the sulphur banks, extending the 50-foot hole to 70 feet, losing two bits in its hot depths and sinking two more shallow holes on each side of it for tapping the steam zone. By casing the deeper hole with cement (for convenience of drilling) it was learned that less steam rises from below the 50-foot level than from the 15-foot level. Therefore the two side holes were lowered only 15 feet, and the battery of three holes was piped to the adjacent steam laboratory for physical and chemical tests dealing with power, condensation of water, and corrosive action of this vapor on metals. No new temperature data were revealed by this last spell of drilling at the sulphur banks. Throughout all the holes at this place the temperature was 204° F.

The discovery that more steam lies just below the ash beds than at 70 feet down seems to imply that the steam-bearing veins outcrop on an inclined zone crossed by the drilling in the upper levels of the wells. At the lower levels the drilling had penetrated the footwall, and here there was less sulphide as well as less steam.

Thus have these preliminary borings at Kilauea Volcano thrown light on differences of subsurface temperatures and subsurface minerals and gases, but they have also explored the possibilities of method. Hammer drilling with compressed air or electricity for holes not more than 25 feet deep at many places would be illuminating. Air hammers cut the lava rapidly in 3-inch holes at Hilo quarries and use very little water. They bore 25 feet in two hours easily. It is necessary to have large and powerful compressors and air tanks. It remains to be proved whether any system of hammer drilling can be made sufficiently portable to run a line of holes across Kilauea Crater in several directions for measuring subsurface temperatures under uniform conditions.

In the work on Kilauea floor much was learned about hauling water and drill rigs over lava topography without roads. A Ford automobile was rigged with six gears and double tires on rear wheels. This did most of the work. Other kinds of tractors and trucks proved less serviceable. A way was searched out, marked with stones, beaten down and filled slightly, and then the rig was divided into appropriate loads and hauled to its destination.

As to deep drilling, the diamond is probably the proper tool and the center of the greater crater would be the ideal place for trying it. It would be necessary to accumulate water in large tanks in advance and to be prepared for losses of valuable bits. Fifty thousand dollars might bore a hole there from one to two thousand feet deep and reveal intensely interesting facts bearing on gases, minerals, and temperatures.

All the holes bored have their openings cased and covered, and these become valuable assets of the volcano observatory for furture temperature measurements and physical experiments. Nothing sensational has yet been learned bearing on the utilization of Kilauea power. There is available power at the sulphur banks in small amount, but no superheated steam at high pressure such as is used at Larderello or such as may be available in Napa Springs, Calif., or in the Yellowstone Park. These places of high pressure steam are usually *not* active volcanoes.

ON THE PREDICTION OF TIDAL WAVES[1]

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By R. H. FINCH, Meteorologist

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The earthquake of February 3, 1923, that had its origin off the Aleutian Islands or the coast of Kamchatka and the resulting tidal wave that noticeably influenced all the northern half of the Pacific Ocean, brings to mind the possibility of accurately predicting such waves.

Tidal-wave predicting is not new; in fact, before the days of instrumental seismology seismic sea waves often gave the first notice that an earthquake had occurred. In 1904, Baron Kikuchi[2] made the statement that "further observations [on tsunami-tidal waves] may lead to important results, perhaps even to the prognostication of tsunami."

Warning of the possibility of a tidal wave in Hawaiian waters was given about four hours in advance on Feb. 3 at the Volcano Observatory and at Kealakakua, both on the island of Hawaii. At the latter place the Hawaiian Volcano Research Association maintains a seismograph in charge of Capt. R. V. Woods. When the instruments were inspected about 8 a. m. it was noticed that a large earthquake had occurred.

There is considerable discrepancy in the distances as given by several seismographic stations but the time at the origin was probably close to 16h. 02m. G. M. T. or 5:32 a. m. Hawaiian standard time. The velocity of the sea waves to Hilo was about 7.5 miles per minute.

It is obvious that a displacement of a considerable area on the ocean floor, the cause of practically all tidal waves, will produce several waves of different size. The velocity with which the large and small waves travel even over the same ocean stretch is different and the total duration of the seismic sea waves produced is a variable and depends, among other things, largely on the distance from the source. The velocity of the large waves is a function of the ocean depth. As the depth between any two points in most oceans is not uniform, and also islands and shoals intervene, no simple equation between velocity, gravity, and depth is satisfactory for computing the transit time of seismic sea waves, rather the problem resolves itself into integrating for several average depths. The observed velocities range from 3 to 8 miles per minute depending on the depth.[3]

The number of earthquakes followed by tidal waves is rather small, though larger than would be expected if judged by press reports. Undoubtedly many tidal waves

[1] Tidal waves as here considered as the popular term for what might more properly be called seismic sea waves. Captain Woods immediately notified all interests along the coast on his side of the island to look out for a tidal wave. A few people at Volcano House and at Hilo were notified that there was a possibility of a tidal wave about 12 o'clock. The wave reached Hilo at approximately 12:30 p. m. and Haleiwa, on northwestern Oahu, about 225 miles northwest, at 12:02 p. m. At Hilo there was one fatality. Considerable property damage was done at Hilo and at Kahalui, island of Maui.

[2] *Pub. Earthquake Inves. Comm. Foreign Languages*, No. 19, 1904.

[3] *Jour. Col. Sci. Imp. Univ. Tokyo*, vol. 24, 1908; also Davison. *Manual of Seismology* p. 98.