The Mechanics of the Explosive Eruption of Kilauea in 1924

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Kilauea Volcano staged explosive eruptions in May, 1924, after having exhibited molten lava almost continuously for more than 100 years. The explosions occurred during a time of rapid retreat of the lava column in Halemaumau (the active vent in Kilauea caldera), of a general sinking of the mountain top, and of enlargement of Halemaumau by engulfment from a diameter of 1,500 feet to 3,000 feet. Detailed accounts of the explosions have been published in several journals (Jaggar, 1924: 30–37; Jaggar and Finch, 1924: 353).

The explosive eruptions in 1924 did not establish a precedent for Kilauea, as the surface ash deposits indicate eight or nine quite recent explosive periods (Finch, 1924: 1) and there are at least two ash beds in the walls of Kilauea caldera. The material in the surface ash beds indicates that the bulk of the ash was produced by a series of magmatic explosions (Wentworth, 1938: 101). The last explosive eruption of Kilauea prior to 1924 was about 1790. Though the material thrown out in 1790 was largely accessory, the presence of bombs had led to the assumption that all Kilauea explosions were magmatic.

In 1924 the lack of juvenile material was not especially conspicuous during the first few explosions, since a large part of the ejected blocks as well as sand and dust were red-hot when they left the Halemaumau rim. The large proportion of hot rock was not surprising, as shortly before the explosions Halemaumau had contained a lava lake 1,500 feet in diameter and the conduit was filled to an unknown depth with hot material except for a surface layer of landslide material, some of which was hot when it fell. In the beginning of the explosive period, members of the Observatory wore gas masks when making investigations, but it was soon found that none of the usual volcanic gases was present in an appreciable amount. A careful examination failed to find any juvenile material in the explosion debris. Somewhat reluctantly, then, we were forced to acknowledge that we were dealing with phreatic explosions.

Jaggar (1924: 35) has presented some of the evidence pointing to the conclusion that the 1924 explosions were due to steam and suggested that a talus plug might act as a seal in promoting a build-up of pressure. The pressure required to produce explosions of the magnitude observed was considerable —a 14-ton block landed on the Halemaumau rim over 1,300 feet above the bottom, and an 8-ton one was hurled a distance of 3,500 feet. The depth from which these blocks came and the duration of their acceleration (length of the "gun barrel") is not known. The pressure required to make an appreciable showing in the bottom of Hale-

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maumau had to exceed the pressure of the talus plug above the seat of the explosions. If the explosions took place 500 feet above sea level, that would mean that they occurred about 1,900 feet below the bottom of Halemaumau. The pressure of 1,900 feet of talus material with a specific gravity of 2.0 would be about 1,600 pounds per square inch.

To produce the explosions there must have been either a gradual build-up of pressure or a rapid generation of the same. If the pressure build-up were gradual, then an effective seal was required. A seal made up of talus blocks even with an appreciable percentage of dust would appear to be inadequate. There were no indications of fusing or cementing of the talus plug, and because the plug developed above the retreating lava column, there was no molten lava to fill in the voids between the blocks and help develop a seal. A slow build-up of pressure would necessarily limit the amount of water available for any one explosion. The pressure build-up would soon prevent the further entry of water. A rapid generation of steam pressure, as in a "flash boiler," would appear to be the most plausible explanation of the explosions. Any explanation of the explosions must consider the periods of quiet between explosion and series of explosive bursts (Jaggar, 1924: 44), often less than a minute apart.

The rapid sinking of the lava column from a depth below the Halemaumau rim of about 500 feet on May 1 to a depth exceeding 1,300 feet in the middle of the explosive period, as well as the increase in diameter of the crater from 1,500 to 3,000 feet just prior to and during the explosions, indicates a progressive rupturing of the conduit walls. A common interval between the explosions was 6 to 8 hours. Finch (1943: 1–3) has suggested that intermittent rupturing of the conduit walls and the resulting introduction of water may have been influenced by surging in the retreating lava column.

The lack of chlorides in the material ejected indicates that the steam came from fresh ground water. Stearns (1946: 44) has suggested that the explosions may have been caused by ground water trapped between dikes at relatively high levels. G. A. Macdonald of the U. S. Geological Survey has suggested (oral statement, 1943) that ground water confined between dikes may stand as much as 1,500 feet above sea level in the vicinity of Kilauea caldera. The lag in time, often 2 or 3 minutes, between the premonitory symptoms of an explosion as shown by peculiar earthquakes both recorded and felt and the appearance of the explosion cloud in Halemaumau indicates that the seat of the explosions may well have been but comparatively little above sea level—say, 500 feet. Estimates of the depth of engulfment (Jaggar, 1924: 118) make 500 feet above sea level seem a more probable seat of the explosions than 1,500 feet. The relation between the amount of material engulfed and the diameter of the conduit indicated a withdrawal to at least 300 feet below sea level. With the greater depth, more and larger trapped pockets of water might be expected. At or slightly above sea level the large body of basal ground water would be available. However, some of the first small explosions may have been due to water trapped about as high as Macdonald suggests. The retreat of the lava column and progressive engulfment indicate the possibility of a considerable vertical range in the seat of the explosions.

Collapsing in Halemaumau and harmonic tremor (Finch, 1943: 1–2) indicated that there was a retreat of the live lava column both before and during the explosions. A retreat of the lava column would leave the conduit walls and much of the material within at a temperature of about 1700° F.

Jaggar (1924: 59) suggested that shattering during engulfment may have allowed ground water to gain access to red-hot intrusive bodies and have caused some of the explosions.

The withdrawal of the lava and sudden rupturing of the conduit walls provided a means whereby water could suddenly gain access to the hot volcano system and set up a "flash boiler" mechanism. Next comes the question as to the possibility of suddenly injecting a sufficient quantity of water to produce the explosions. The Olaa well (Duncan, 1942) with a drawdown of 8 feet by continuous pumping showed an inflow of 80 gallons a second. If a void with the same capacity as that of the sump below the water surface were suddenly created, the amount of water rushing in during the first half second, say, might well be several times that of any half second after pumping had been in progress for some time. Likewise the discharge from water trapped in a dike compartment, when the wall separating it from a volcano conduit is suddenly ruptured, might greatly exceed that of the next half second. A considerable vertical range in the shattered conduit would speed up the inflow of water, for the velocity of inflow varies roughly as the square root of the depth below the surface of the water table.

The potency of volcanic heat in producing steam blasts, when the conditions that keep water out of the system are upset or disturbed, is easily understandable. A cubic foot of water at a pressure of 1 atmosphere and a temperature of 1700° F. would yield over 5,000 cu. ft. of steam, or with a constant volume would produce a pressure of 80,000 lb. per sq. in. It should be noted, however, that only a small part of the heat of the rock would be available for any one explosion. The available heat in a "flash boiler" system would be limited to a surface layer about 1/8 inch thick.

With the temperature of the rock known (about 1700° F.), by assuming some surface area it is easy to compute the available heat and then calculate the amount of water that could suddenly be converted to high-pressure steam. Suppose that an explosion were initiated by the formation of a crack where the hot portion of the wall separating the conduit from trapped ground water was 30 ft. thick. The surface of the hot rock in the walls of such a crack if 5 to 10 ft. wide and 70 ft. high, together with fragmental material within the crack, could easily exceed 6,000 sq. ft. This surface area and a thickness of 1/8 inch would give a volume of 62.5 cu. ft. With a specific gravity of 2.5, such a volume of rock would weigh about 10,000 lb. The number of available B.T.U. above 212° F. in 10,000 lb. of basalt with an initial temperature of 1700° F., if we assume the specific heat is 0.30, is 4,470,000. Taking the final temperature of the boiler system as 900° F.—on several occasions the dust of the explosion was observed to glow as it cleared the crater rim—the pressure generated could exceed 40,000 lb. per sq. in. This is many times the minimum requirement mentioned above. The temperature of the steam as it was produced may have been above 900° F., with a resulting greater pressure.

After the explosion pressure had dissipated in the case outlined above, another injection of water could produce another explosion in the same place. Progressive shattering of the conduit wall in either a vertical or horizontal direction could account for the series of explosion bursts that were noted on several occasions. The rocks of each explosion were largely confined to one sector of the ground around Halemaumau. All sectors were eventually covered with explosion debris. This fact would indicate that the shattering was more or less piecemeal, first on one side of the pit, then on another. The amount of condensation of water vapor in the explosion clouds was never striking. The explosions must have been produced by relatively small amounts of steam.

The explosions would cease with the cessation of rupturing of the conduit walls. The cessation in 1924 may have been due to the lava column's becoming stationary. There is also the possibility that the conduit walls become structurally stronger at the level of the Ghyben-Herzberg ground-water lens, which is assumed to be about 32 feet above sea level in the vicinity of Kilauea.

The above calculations are not intended to indicate actual dimensions and volumes, but rather to show that a small rock surface and a small volume of water would suffice to account for any of the 1924 explosions.

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