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UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1952

UNITED STATES DEPARTMENT OF THE INTERIOR
Oscar L. Chapman, *Secretary*

GEOLOGICAL SURVEY
W. E. Wrather, *Director*

CONTENTS

[The letters in parentheses preceding the titles are those used to designate the papers for separate publication]

ILLUSTRATIONS

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The 1949 Summit Eruption of Mauna Loa, Hawaii

By GORDON A. MACDONALD *and* JAMES B. ORR

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THE 1949 SUMMIT ERUPTION OF MAUNA LOA, HAWAII

By Gordon A. Macdonald and James B. Orr

ABSTRACT

A new eruptive phase of Mauna Loa began on January 6, 1949. Lava broke out along a series of fissures extending part way across the summit caldera and a short distance down the southwest rift. In the early hours a flow advanced more than 6 miles down the western slope of the mountain, but within 48 hours it became inactive. Within 72 hours lava extrusion was entirely restricted to a short length of fissure at the foot of the southwest wall of the caldera. There lava fountains as much as 800 feet high built a large cone of pumice and fine cinder, with a small cone of coarse cinder and spatter in its crater. Lava flooded more than half the floor of the caldera and filled to overflowing a small pit crater adjoining the caldera on the south. A flow spilled out of the pit crater and moved 4 miles southward.

Lava fountaining ceased on February 5, but short periods of quiet lava extrusion probably occurred during the rest of February and March. During late March or early April this quiet outflow became essentially constant and continued until about the end of May, veneering the small cinder-and-spatter cone with lava, building a small lava cone, and sending flows over areas in the southern part of the caldera floor.

The lava of the 1949 eruption is basalt poor in olivine. Tests for radioactivity in the lava were negative. The total volume of extruded lava was approximately 77,000,000 cubic yards.

No definite premonitory pattern of earthquakes was recognized, although there was a great increase in the number of earthquakes during the month immediately preceding the eruption. For several days just before the outbreak magnetic disturbances, possibly connected with magma movements, were observed near Honolulu, 190 miles away.

INTRODUCTION

GENERAL FEATURES OF THE VOLCANO

Mauna Loa, on the island of Hawaii, is a broad/shield volcano rising to a height of 13,680 feet above the sea level and nearly 30,000 feet above its base at the ocean floor. At its summit is Mokuaweoweo, a caldera some 3 miles long, 1.5 miles wide, and 600 feet deep on its western side. Adjoining the caldera at the north and south ends are two pit craters, known respectively as North Bay and South Pit.

Most of the eruptions of Mauna Loa take place in the caldera or along one of two zones of fissures, known as rift zones, that extend northeastward and southwestward from the summit of the mountain (fig. 1).

The eruptions of Mauna Loa may be classified as summit or flank eruptions. The summit eruptions take place in the caldera, commonly with activity extending outward for the first few hours onto the upper-

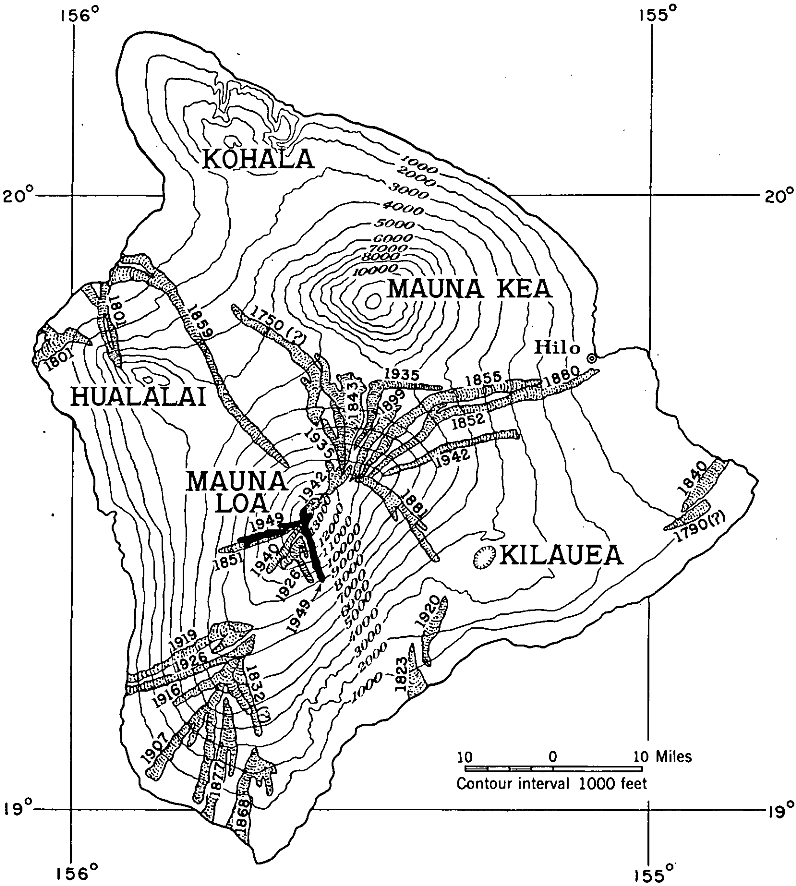

FIGURE 1.—Map of the island of Hawaii, showing the position of the 1949 lava flows (solid black) in relation to other historic flows (stippled) of Mauna Loa and Kilauea.

most slopes of the mountain. The flank eruptions occur lower on the sides of the mountain, generally along one of the rift zones. Flank eruptions nearly always begin with a few hours of activity at the summit, followed by a few hours of quiet and then by an outbreak lower on the flank. The eruption of 1949 was confined to the caldera and the uppermost part of the southwest rift zone and is therefore to be classed as a summit eruption. In its general character it closely resembled the summit eruptions of 1933 and 1940 and probably that of 1851.

SCOPE OF THE PRESENT REPORT

This paper constitutes a report on the joint investigation of the eruption by members of the Geological Survey and the National Park Service. Because of the difficulty of reaching the summit area of Mauna Loa, staff deficiencies at the Hawaiian Volcano Observatory and Hawaii National Park, and heavy blizzards at the summit during the early part of the eruption, continuous observation of the activity at the summit was impractical. The history of the 1949 eruption must be pieced together from the results of occasional close observation coupled with continuous long-range watch from Kilauea, 20 miles to the east (fig. 1). One or the other of the writers was at the summit during the periods January 7–8, January 21–24, February 5–7, April 7–9, May 6–9, June 2–4, and July 26–27. Other observers were at the summit on several additional dates, either on the ground or in planes. The piecing together of the resultant data yields a picture that is accurate in its essentials, although some minor details undoubtedly are lacking.

ACKNOWLEDGMENTS

The writers wish to thank Superintendent F. R. Oberhansley, Chief Ranger F. A. Hjort, and other members of the ranger force of Hawaii National Park for the use of riding animals, aid in transporting equipment to the summit of the mountain, and many other courtesies. They also wish to extend thanks to all the persons, too numerous to mention individually, who contributed information on the volcanic activity. Special thanks are due the following: Ercell Hart, of the Hawaiian School of Aeronautics, for repeated observations from the air during the early part of the eruption; Naturalist D. H. Hubbard and Ranger V. R. Bender for observations made from the air on January 7 and 9; Charles Hoeppel, of the Coast and Geodetic Survey, for making transit observations to locate the terminus of the southern flow; Doak C. Cox, geologist for the Hawaiian Sugar Planters Association, for operating the Geiger counter at the summit of the mountain; and Prof. Harvey E. White, of the University of California, for testing samples of the lava for radioactivity. R. H. Finch, H. A. Powers, and R. E. Wilcox, of the Geological Survey, have kindly read and criticized the manuscript of this paper, and Finch has permitted the use, in advance of publication, of his own paper on earthquakes accompanying the eruption.

HISTORY OF THE ERUPTION

JANUARY

After more than 5 years of quiet, Mauna Loa resumed eruptive activity about 16 o'clock (Hawaiian standard time) on the afternoon of January 6, 1949. Some of the earliest gas bursts were explosively violent. At the beginning of the eruption heavy rumbling sounds were plainly audible at the Hawaiian Volcano Observatory on the rim of Kilauea caldera, 20 miles east of the scene of eruption. No explosions audible at nearly so great a distance had been reported since the summit eruption of 1851 (Hitchcock, 1909, p. 85). Fragments of pumice as much as 1.5 inches across, hurled out during these early explosions, were found on the east flank of the mountain 7 miles from the lava fountains, and drifting Pele's hair was observed at Kulani camp,

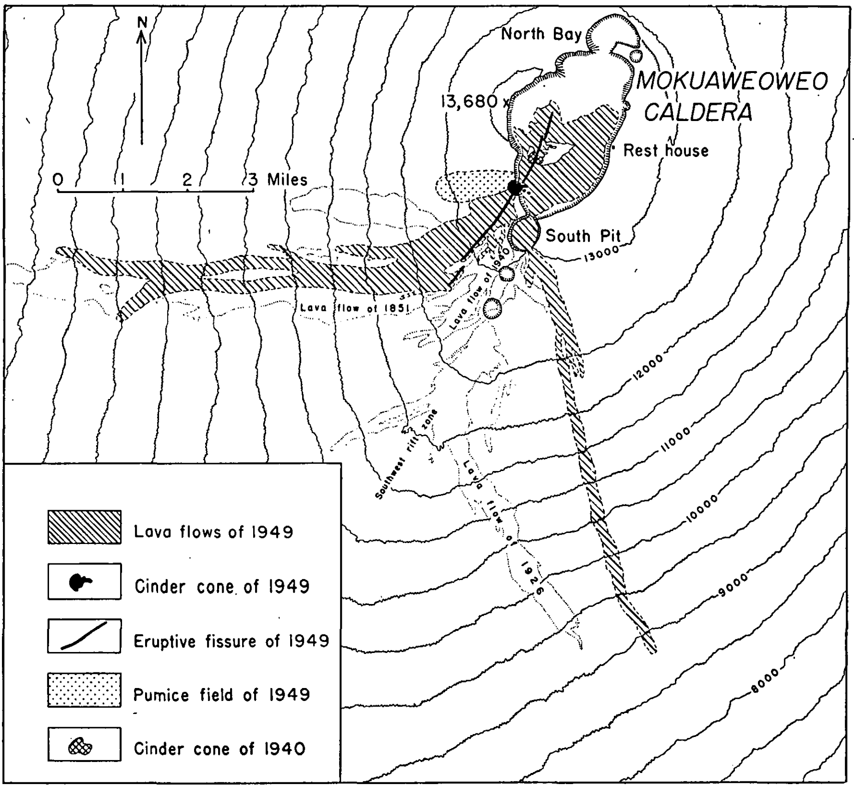

FIGURE 2.—Map showing the approximate distribution of the lavas and the location of the vents of the 1949 eruption of Mauna Loa, Hawaii.

on the east slope of Mauna Loa 20 miles from the fountains. The explosions appear to have been entirely magmatic, however, inasmuch as no accessory nor accidental rock debris could be found among the ejecta.

Lava broke out along a series of fissures that extended south-southwestward across the caldera floor, up over the wall of the caldera, and about 1.7 miles down the southwest rift zone (fig. 2). The fissure that crossed the caldera floor was not continuous, but consisted of two segments en echelon. One of these segments lay north of the 1940 cone (fig. 3). The other split the 1940 cinder cone and extended on southwestward, up over the caldera wall, and about 1.2 miles down the southwest rift (figs. 3, 4). A third segment, slightly offset from the second, continued the zone of fissuring on down the mountainside for another half-mile (fig. 5). The total length of the fissure was about 3 miles. For the first few hours of the eruption an essentially continuous chain of lava fountains, a few feet to 100 feet high, spouted from this crack, constituting the spectacle picturesquely known in Hawaii as the "curtain of fire."

During the first few hours of the eruption, lava rose in the fissure that cut the 1940 cinder cone, filling the crater of the cone to the level of the low notch in its north rim and sending out flows of gas-rich pumiceous pahoehoe from the fissure on both the north and south flanks of the cone. Abundant spattering in the crater coated the rim and upper flanks of the cone with pumiceous ejecta, which accumulated so rapidly that individual clots did not solidify, but ran together to form three small rootless flows on the southeast flank of the cone. The lava in the crater of the 1940 cone eventually drained back down into the eruptive fissure, leaving the lower walls of the crater veneered with a thin layer of new lava. By the morning of January 7 all lava effusion at the 1940 cone had ceased. The cone continued to fume heavily until mid-February, but no additional lava issued from it.

The "curtain of fire" phase of the eruption was, as usual, short-lived. By the morning of January 7 only four short stretches of the fissure were still emitting lava. The longest of these was a chain of lava fountains half a mile long, playing 50 to 150 feet in the air, near the center of Mokuaweoweo caldera (fig. 3). This fountain chain was in the same location, as nearly as can be ascertained, as the more easterly of two fuming fissures observed by Macdonald and H. A. Powers in October 1948. Two other short chains of low fountains were active along the upper part of the southwest rift outside the caldera. At the southwest wall of the caldera a small fountain played intermittently from the fissure at the base and part way up the wall, and another, larger fountain just northeast of it on the caldera floor played to heights of 150 to 300 feet (fig. 4).

The lava extruded along the upper part of the southwest rift formed a thin, fluid, rapidly moving flow that moved westward along, and just north of, the flow of 1851 (fig. 5). During the first 24 hours the flow advanced about 6 miles. Activity outside the caldera was brief, however. Within 24 hours fountaining on the rift zone had nearly ceased, and within 72 hours eruption was entirely confined to

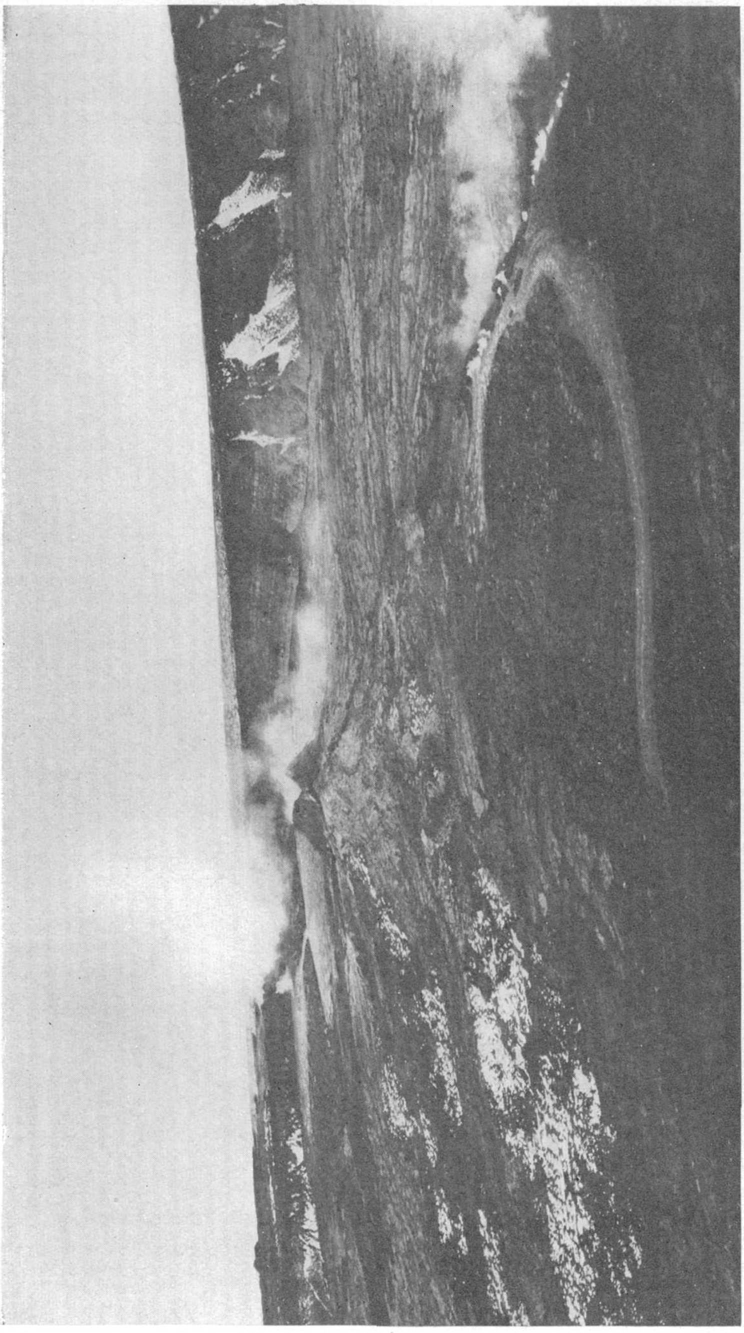

FIGURE 3.—Mokuaweoweo caldera, Mauna Loa, island of Hawaii, looking southwestward on the morning of January 7, 1949. The northern fountain chain and the lava flow leading eastward from it are in the right foreground. In the middle distance the eruptive fissure cuts through the 1940 cinder cone, which can be seen fuming strongly. Official photograph of the United States Navy.

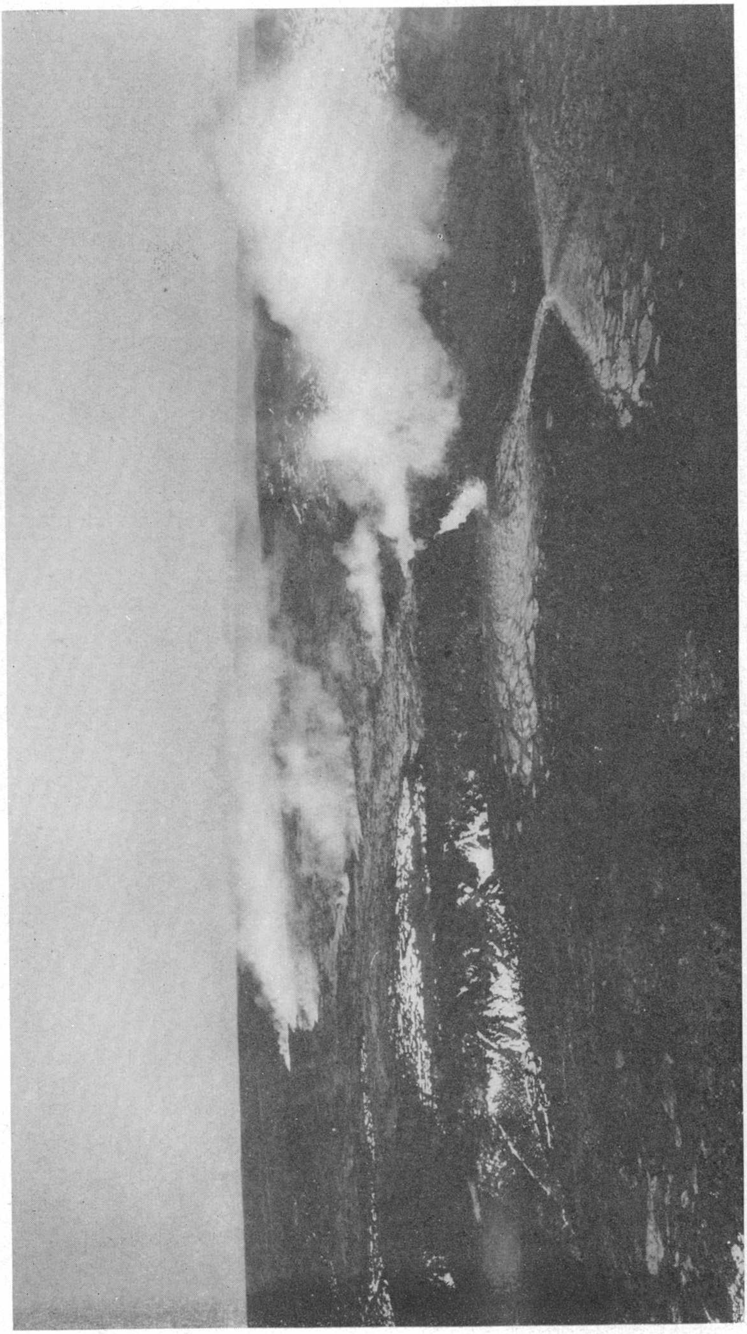

FIGURE 4.—Southwest edge of Mokuaweoweo caldera, Mauna Loa, Hawaii, on the morning of January 7, 1949, showing the eruptive fissure crossing the wall of the caldera and extending on down the outer slope of the mountain. Lava fountains are playing from the fissure at the base of the caldera wall and at several points along the fissure beyond. At the right a new lava flow is flowing northward onto the caldera floor, and at the left another lava stream is pouring into South Pit. Official photograph of the United States Navy.

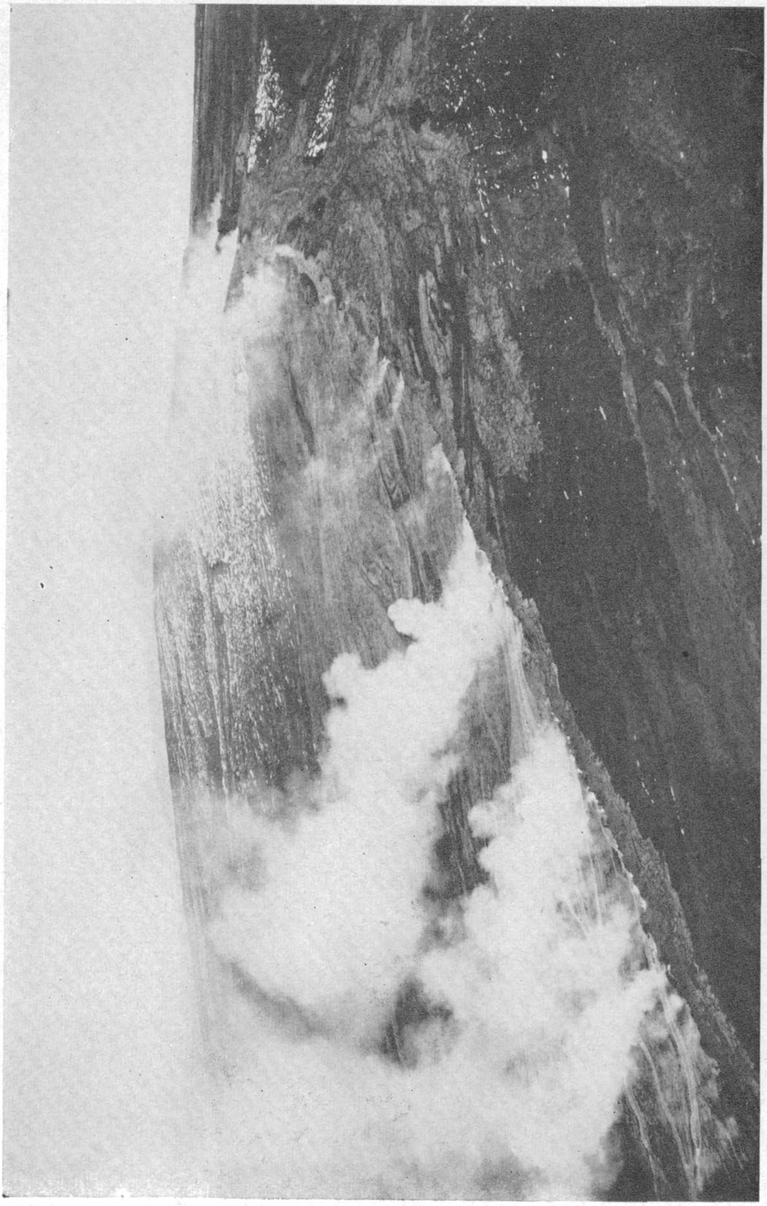

FIGURE 5.—Fuming fissure along the upper part of the southwest rift zone of Mauna Loa, Hawaii, on the morning of January 7, 1949. Spatter ramparts are visible along the fissure, and to the left the lava is moving westward down the mountain. The caldera is in the background. Official photograph of the United States Navy.

the caldera. Observations made on January 8 showed that the front of the western flow had reached an altitude of about 8,250 feet at a distance of 6.8 miles from its source, but the flow appeared to be essentially motionless.

A large stream of lava from the big fountains at the foot of the southwest wall of the caldera flowed northward and northeastward over the caldera floor, joining the flows from the northern fountain chain (fig. 4). Within 24 hours of the beginning of the eruption, more than half the caldera floor was buried beneath new floods of pahoehoe. The cinder cone and part of the lava shield of the 1940 eruption were left protruding as an island in the midst of the new lava. Another stream of lava from the southwestern fountains moved southward and spilled into South Pit. It is estimated that the volume of lava poured out during the first 24 hours of the eruption was about 50,000,000 cubic yards, or approximately two-thirds of the total volume liberated during the entire eruption.

By the afternoon of January 9 the fountaining near the center of the caldera had stopped, and lava extrusion was restricted entirely to the two fountains at the southwest edge of the caldera. These fountains remained 100 to 300 feet high for the ensuing week, but after that they gradually grew higher. On January 19 the larger fountain jet was reaching heights of 400 to 500 feet (fig. 6). On January 23 the height of the jet was estimated to be well over 500 feet, some bursts reaching 800 feet or a little more. The more northeasterly fountain (fig. 7, vent *A*) was the larger, and its lava appeared to be richer in gas than that of the smaller one. On the other hand, judging by color, the smaller fountain (fig. 7, vent *B*) appeared to be the hotter. The larger fountain produced most of the ejected pumice, although the smaller one appeared, at least part of the time, to liberate more liquid lava. The huge fountains were building a single cone (fig. 7, cone 1) of cinder and pumice against the caldera wall, and flows from the fountains were forming a broad, flat lava shield around the base of the cone. Wind blew much of the pumice westward, where it formed a blanket half a mile wide, a mile long, and as much as 20 feet thick near the edge of the cone (fig. 2). Pele's hair from the very high fountains was drifted by the wind as far as Napoopoo, on the coast 20 miles westward, and as far as the Kau Desert and Kilauea caldera, 20 miles to the southeast.

The fountain jets were inclined slightly eastward, and much of the ejecta from the larger fountain (vent *A*) fell into a pool of lava at the east edge of the cone. From this pool an open lava river led eastward for half a mile, then northeastward near the base of the caldera wall. During part of the eruption a branch of this flow diverged southward and cascaded into South Pit. Lava also moved from the fountains southeastward directly toward South Pit (fig. 7). In the early stages of the eruption these last-mentioned flows maintained open channels, but in later stages they formed covered channels or lava tubes that issued from the pool just east of the cone.

The lava draining into South Pit gradually filled it, and on the evening of January 25 the pit overflowed, spilling a stream of lava to the southeast. By the evening of January 26 the front of the flow

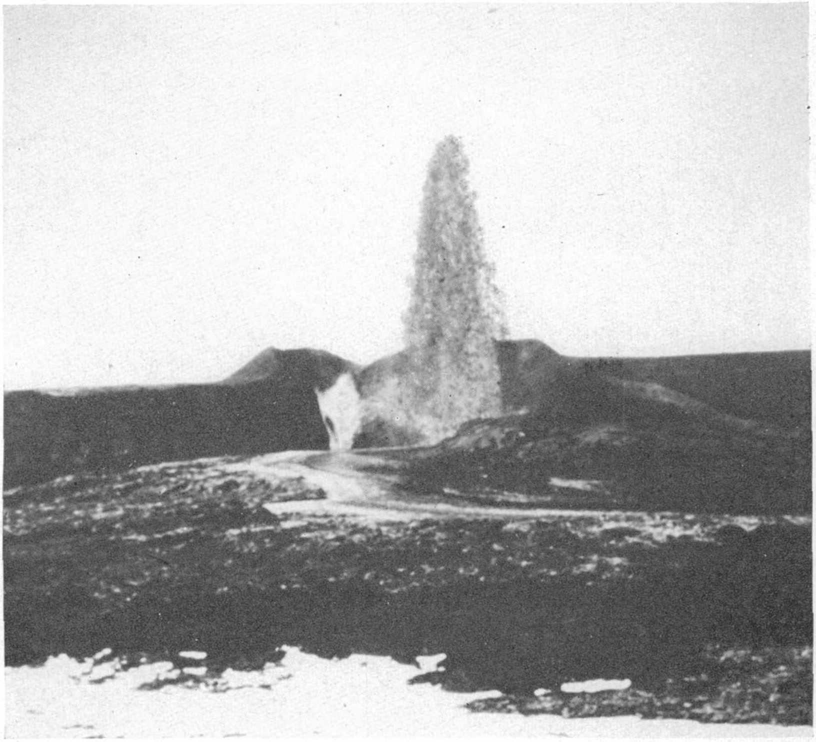

FIGURE 6.—Lava fountains at the southwest edge of Mokuaweoweo caldera, Mauna Loa, island of Hawaii, on January 21, 1949. The higher fountain is playing to a height of about 500 feet. Behind and to the left of it a smaller fountain plays from the fissure in the caldera wall. The fountains are building a large cone of cinder and pumice. A lava flow issues from the breached crater of the compound cone. Photograph by F. A. Hjort, National Park Service.

was about 3 miles from South Pit and 4 miles from its source at the fountains. On the evening of January 27 the flow front was about 4 miles from South Pit. The speed of advance had decreased greatly, however, and during the next 24 hours the front moved only about 0.5 mile. By January 31 the flow front was about 5.5 miles from South Pit, but its advance had essentially ended.

The immobilization of the front of this long southern flow appears to have resulted from the diversion of its lava supply to form a new flow that broke out laterally from the older flow near South Pit on

January 29 or 30. The new stream moved down slope just east of the older one, partly overlying it. It was much less active than the earlier flow and by February 7 had attained a length of only 2 miles.

FEBRUARY–MARCH

During the night of February 4 fountain activity was still moderately strong. However, by midmorning on February 5 it had become weak and irregular, and by the afternoon of that day it had ceased

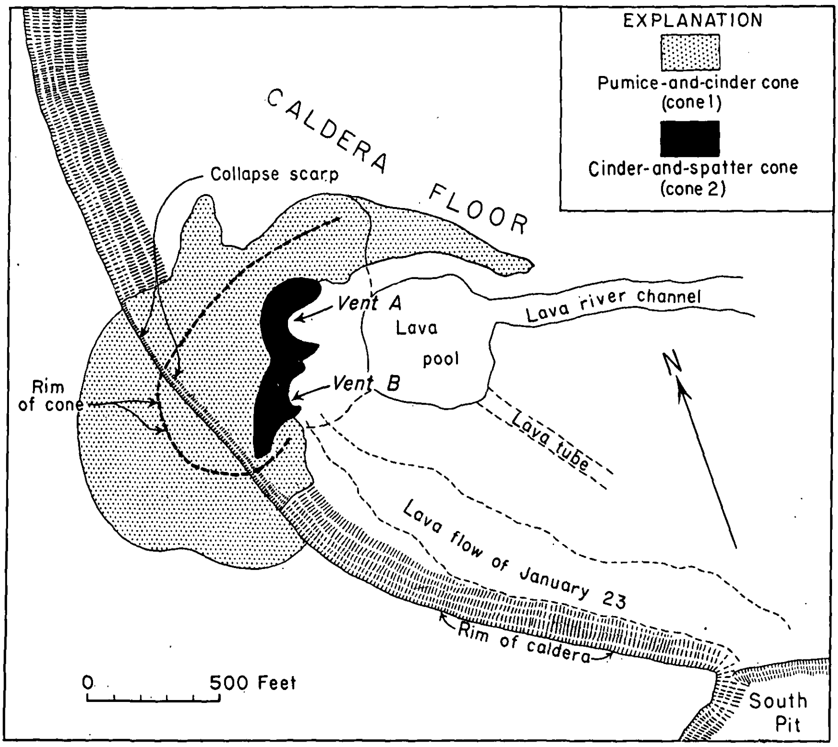

FIGURE 7.—Sketch map of the area in the vicinity of the 1949 cinder cone at the southwest edge of Mokuaweoweo caldera, Mauna Loa, Hawaii, in February, at the end of the period of large lava fountains.

entirely. When the source cone was examined at close range on February 6, no sign of lava extrusion could be detected. The lava pool and river east of the cone had collapsed, owing to the draining away of the lower, liquid portion of the lava, leaving a subcircular open basin about 35 feet deep and 400 feet across. During the last few hours before the cessation of fountaining there appears to have been a marked reduction in gas pressure. The size of the fountains decreased greatly, and the ejecta changed from predominantly highly vesicular pumice to denser spatter, resulting in the formation of a small double conelet of coarse cinder and spatter within the breached crater of the big pumice cone. (See fig. 7.)

Examination of the southern lava flows on February 7 showed that the distal ends of both flows were still moving and that movement in the newer, easterly flow was quite active. This movement appears to have resulted from the draining of still-fluid lava from the feeding tubes of the flows higher up the mountain.

During the remainder of February and March, fume frequently was observed rising from the summit of the mountain, and on several scattered nights a distinct glow on the fume cloud was visible. (See Macdonald and Finch, 1949b, for the precise dates.) The nearly constant presence of fume, whenever the mountain top was visible, appears to indicate that the magma column continued to stand high in the conduit throughout this interval, and the occasional appearance of glow indicates that some eruption of lava took place. However, the infrequency of glow and the fact that on two occasions observers looking into the caldera were unable to see any signs of activity except fuming show that the extrusion of lava was far from continuous and probably took place only during a few short intervals.

APRIL–MAY

About the first of April, lava activity in Mokuaweoweo caldera again became essentially continuous. The exact date cannot be determined. However, on March 28 the fume column was unusually conspicuous, and as seen from the Humuula saddle between Mauna Loa and Mauna Kea, its rise was distinctly pulsatory. On the evening of that day the glow was intense. During the next several days the mountain top was obscured by clouds, but on April 1 harmonic tremor, such as commonly accompanies the movement of magma in the volcanic conduit, was recorded for several minutes on the seismographs on the eastern slope of Mauna Loa and at Kilauea. March 28 appears to be the most likely date for the return of essentially continuous lava extrusion.

On April 7 the small double cinder-and-spatter cone at vent *A* (fig. 7), built in early February within the breached crater of the large pumice cone, was found to be fuming copiously, and a little fume was issuing from vent *B* against the caldera wall. At that time no lava flows had spilled over the flanks of the cinder-and-spatter cone. The principal activity was concentrated at a point about 250 feet south-southeast of vent *A* near the west edge of the former lava pool where the fountain ejecta had accumulated in late January. (See figs. 7–9.) There a steep-sided lava cone had been built, rising 80 feet above the lava platform at its southeast base. At the summit of the cone (fig. 9, cone 3), a crater 40 feet in diameter contained a seething pond of fluid lava. The level of the pond within the crater rose and fell as much as 15 feet, but at no time from April 7 to April 9 did lava over-

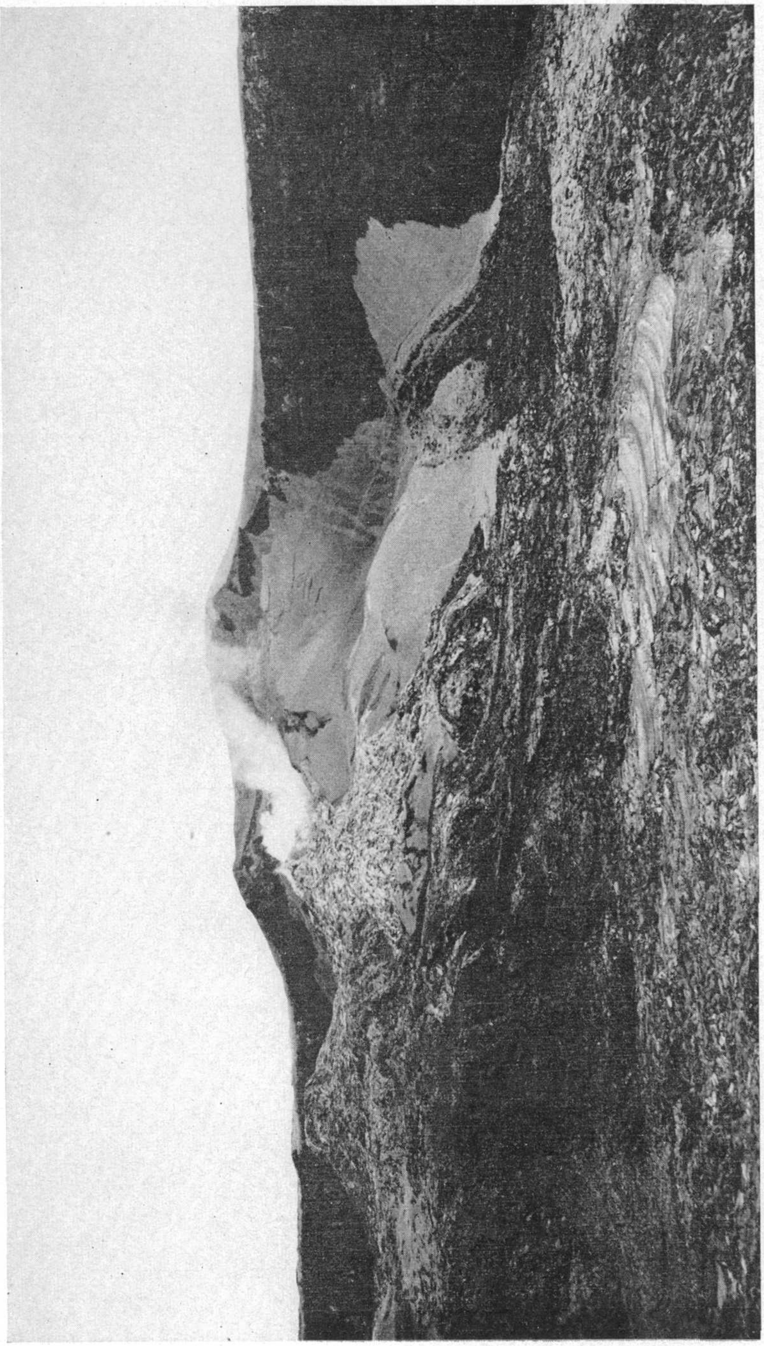

FIGURE 8.—Cone area of the 1949 eruption at the southwest edge of Mokuaweoweo caldera, Mauna Loa, Hawaii, seen from the 1940 cone on June 3, 1949. In the background the large cinder-and-pumice cone rests against and on top of the caldera wall and has partly collapsed. Within its crater the small cinder-and-spatter cone (cone 2), largely covered by lava flows, is fuming strongly. Farther to the left the lava cone (cone 3) is visible. Photograph by J. B. Orr.

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flow the rim. Obviously, however, the cone had been built up by repeated short flows from this vent. The lava forming the cone was pahoehoe (fig. 10) but was much denser than that of the earlier phases of the eruption. Lava leaving the vent area through tubes beneath

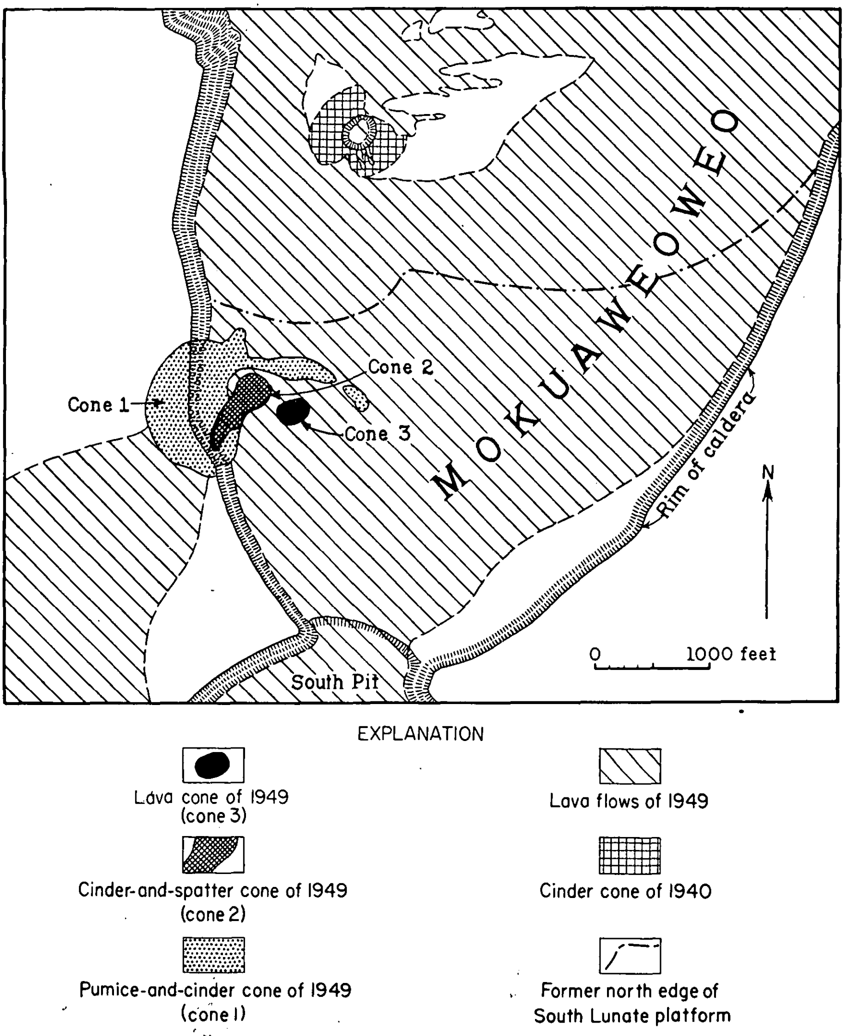

FIGURE 9.—Sketch map of the southern part of Mokuaweoweo caldera, Mauna Loa, Hawaii, on June 3, at the end of the 1949 eruption.

the surface fed two sluggish flows of aa. One of these issued from the tube about a mile northeast of the cones and spread over the eastern part of the caldera floor. The other issued from its tube about half a mile southeast of cone 3 and flowed into the northern part of South Pit.

A month later, when observed from May 6 to May 9, the lava cone (cone 3) was found to have grown about 15 feet in height (fig. 11).

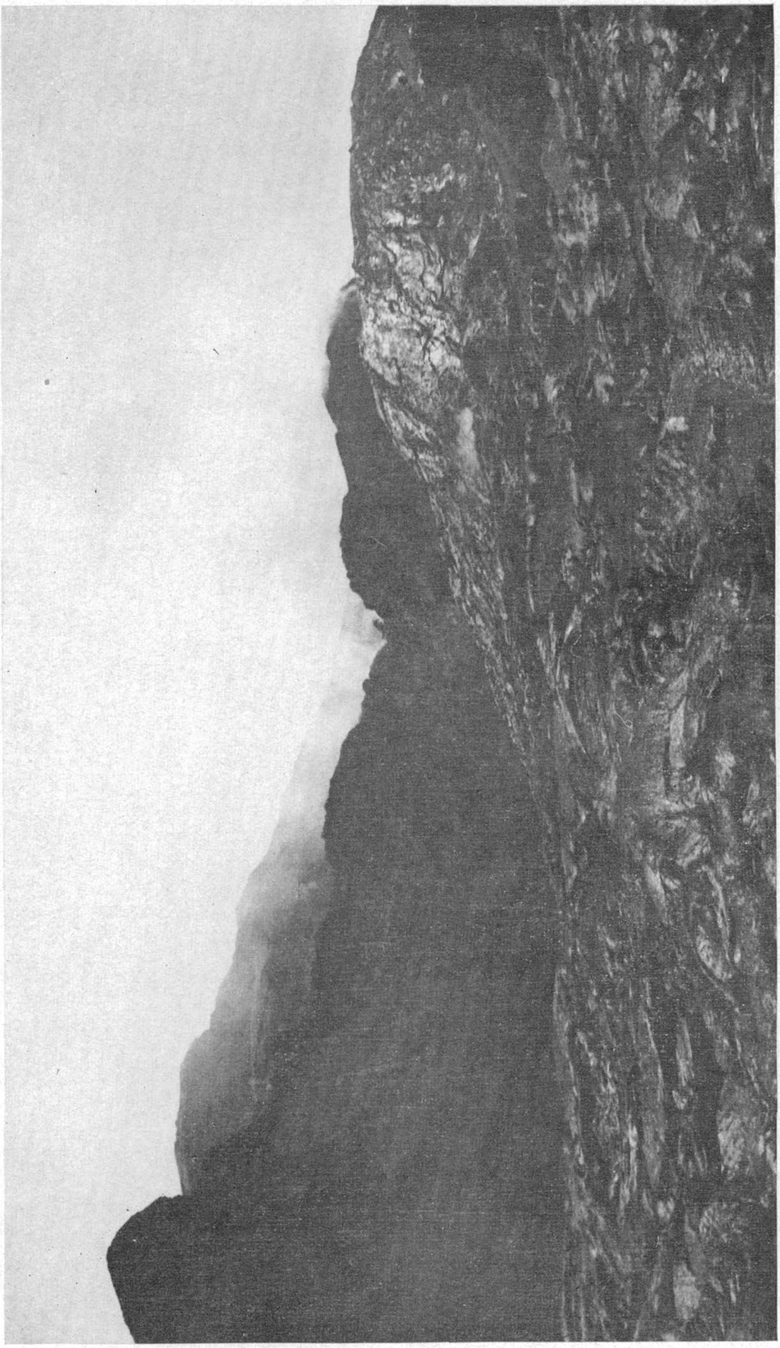

FIGURE 10.—View looking northwestward into the 1949 cone area, Mauna Loa, Hawaii, on April 8. At the right the lava cone (cone 3) can be seen in an early stage of development. The lava in the foreground is typical pahoehoe. Photograph by J. B. Orr.

Its crater still contained a pond of liquid lava, and the lavas composing the cone still were much denser than the early lavas of the eruption. In the interval since the April visit the cinder-and-spatter cone (cone 2) had liberated many short flows that partly veneered its slopes (fig. 12). These lavas were partly dense, like those of the lava cone, but partly very vesicular and shelly like the early lavas. A small,

FIGURE 11.—The 1949 lava cone (cone 3), Mauna Loa, Hawaii, seen from the top of the caldera wall to the southwest on May 7. Mokuaweoweo caldera is in the background. Photograph by John Bonsey.

slowly moving pahoehoe flow was spreading near the base of the lava cone, and from the cone fluid lava moved through tubes northeastward for about a mile across the caldera floor, where it issued to form an advancing pahoehoe front. At the tip of the flow small pahoehoe toes were continuously developing as small tongues of fluid lava squeezed up through cracks in the solidified crust. The pahoehoe of this flow resembled aa in some respects, and the fluid lava must have been close to the physical transition from pahoehoe to aa.

An interesting series of eruptive cycles, of about 3½ hours' duration, was observed by Orr at the vents on May 7. The first cycle began at approximately 14:30 o'clock (H. s. t.) with a violent hissing and rattling roar from within cone 2 at vent *A* (fig. 12), accompanied by a

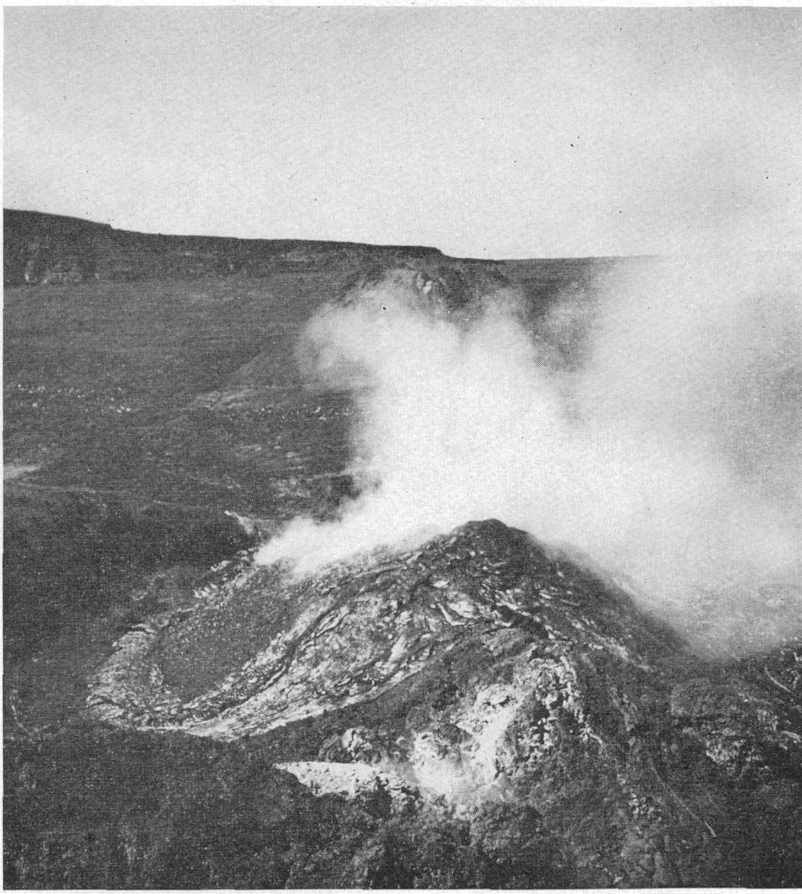

FIGURE 12.—Small cinder-and-spatter cone (cone 2), Mauna Loa, Hawaii, seen from the summit of the larger pumice-and-cinder cone to the southwest on May 7, 1949. One horn of the breached pumice cone is visible on the left. The cinder-and-spatter cone is partly veneered with lava flows. The 1940 cone is visible in the background. Photograph by John Bonsey.

voluminous liberation of pale-brown to white fume. The violent escape of gases lasted approximately 5 minutes; it then subsided quickly and was followed by a prolific outpouring of gas-rich pahoehoe accompanied by relatively little fume. The lava cascaded down the cone slopes a short distance and then separated into two flows, one moving northeastward and the other south-southwestward. Large sheets of pahoehoe crust slid down the fluid lava streams from the cone summit, wrinkling into distorted and involuted folds where they were stopped by obstructions near the base of the cone. This activity continued for about 45 minutes, the intensity of extrusion gradually decreasing until all flows ceased.

Within 5 minutes after the cessation of effusion down the flanks of the cone, the deep throaty hissing and roaring within the cone resumed and gradually increased in intensity. The escape of the gas at the top of the cone was hindered by the lava crust, and partly cooled plates of pahoehoe were tilted and lifted several feet into the air, allowing the gas to escape from under them. In some instances the plates were tilted until they stood on edge. As the gas bubbles escaped, the lava plates dropped back to their former position but continued to vibrate like so many lids on boiling pots. This continued for about 10 minutes and was accompanied by the liberation of great volumes of dark-tan fume.

During the early part of the cycle at cone 2, cone 3 had been dormant and its crater had remained empty. Immediately after the second violent escape of gas at cone 2, cone 3 began to fume heavily. At 15:30 o'clock, fluid lava entered the crater of cone 3 (fig. 11) through an opening near its base on the west-southwest side. Within 10 minutes the crater was filled to the level of overflow. Fuming almost ceased, only a wisp of white fume being present over the crater. The fluid lava rose gently into a broad, flat dome that protruded 1 or 2 feet above the rim of the crater. Then the tough pahoehoe skin ruptured, streams of lava escaped over the lip of the crater, and irregular slabs of the partially cooled pahoehoe crust broke away at the convex summit and went slithering down the flanks of the cone. The slabs slid about 15 feet, cooling as they went from a bright fiery red through dull cherry red to black. This process was repeated several times as the supply of lava to the crater was renewed.

The activity of the pond in cone 3 gradually increased, as shown by the increase in the amount of the nearly continuous spattering at the southwest edge of the crater. At no time, however, was there any evidence of convectional circulation such as characterized the true lava lakes of Halemaumau at Kilauea. The process apparently was merely a slow rise of lava into the crater and overflow at the crater lip. Three lava flows poured down the northwest, southeast, and southwest flanks of the cone during the height of the eruptive episode, reaching the base of the cone but not flowing far beyond it. This part of the cycle lasted until 16:45. Then the lava flows ceased, and the convex meniscus at the top of the cone sagged in, became concave, and within 15 minutes cracked and collapsed as the lava was withdrawn from the interior of the cone. The crater was left empty, its walls glowing cherry red. The subsidence of magma was accompanied by a marked increase in the turbulence of the surface of the pond, by the liberation of great clouds of light-tan to white fume at both cones, and by the hissing, rattling roar from the interior of the cones.

A period of quiescence lasting approximately an hour followed this cycle. Then activity again began at cone 2, and the entire cycle was repeated. The same cycle of events was observed four times, with only minor variations in the duration of its parts.

JUNE–JULY

The vent area was again visited on June 3 (fig. 8). During the period since May 9 the lava cone (cone 3) had grown about 20 feet. Cone 2 was about 15 feet higher than cone 3, and the cinder and spatter that composed most of it had been largely covered with new flows. The last lavas erupted from both cones were not dense, like those that had built most of cone 3, but highly vesicular and shelly, resembling the early lavas of the eruption. A slight glow was visible on the floor of the crater of cone 3, forty feet below the rim, during the daytime and on the flank of cone 2 at night, but lava movement had entirely ceased. A moderate amount of white fume was being liberated at cone 2 but was very largely steam, smelling only mildly of sulfur dioxide. Condensation of the fume on rocks near the summit of the cone produced little pools of water with a strongly acid taste.

On June 4 the fume cloud had decreased to a mere wisp. During the remainder of June no fume at the summit was reported. Weak fume was reported on July 4, near sunset, and on July 8 visitors to the summit observed weak fuming at the cones but no other signs of activity. On July 26 the cones were still hot in places, some sulfurous fume could be smelled, and several wispy clouds of white fume, which apparently consisted largely of steam, were rising both north and south of the 1940 cone and on the slopes of the large 1949 cinder-and-pumice cone. Pale-bluish fume rose from the crater of the 1940 cone. No glow could be detected in any of the cones or flows.

The date of the final cessation of lava extrusion is uncertain. On May 19 flows still were moving on the caldera floor. On June 1 fume still was abundant. On June 2 lava liberation had ceased and the amount of fume had decreased, but the cone still was glowing. On June 3 fume liberation had become very weak. The end of the eruption, in the sense of lava extrusion, may be placed between May 20 and June 2, probably on June 1.

ERUPTIVE PRODUCTS

CONES

Along the short-lived eruptive fissures in the center of Mokuaweoweo and on the outer slope of the mountain, low ramparts and small cones up to 20 feet high were formed of welded spatter (agglutinate). However, true cone building was restricted to the large, long-lived fountains at the southwest edge of the caldera. There the fountains gradually built a cinder cone that exceeds in size the big cone of the 1940 eruption.

The new cone (fig. 7, cone 1) is about 1,500 feet across and 250 feet high, projecting 100 feet above the former level of the caldera rim. It rests partly on the floor and wall of the caldera and partly on the outer slope of the mountain. The double fountain resulted in a single large cone breached on its east side, partly because prevailing winds blew most of the ejecta westward but also because lava flowing eastward from the fountains carried away much of the ejecta that fell to the east and prevented the building of the east wall of the cone. The huge, gas-rich fountains produced an unusually large amount of pumice, and the big cone is composed largely of pumice and fine cinder.

Toward the end of the period of lava fountaining, reduced gas pressure and the diminished size of the fountains resulted in the building of a small double conelet of coarse cinder and spatter (fig. 9, cone 2) within the eastward-projecting horns of the larger cone. Also as a result of the lessened gas content, a few relatively dense black "cow dung" and ribbon bombs were deposited on the pale-brown pumice on the outer slope of the large cone. At about the same time the hot pumice cone (cone 1) partly collapsed, forming a northeast-facing scarp 10 to 20 feet high across the top of the cone along the line of the buried caldera wall (fig. 8).

The resumption of lava extrusion about the end of March brought no return of fountain activity. The lava welled out quietly. Many of the outwellings were small in volume and accumulated immediately around the vent, veneering the small cinder-and-spatter cone (fig. 9, cone 2) and eventually covering it to a large extent (fig. 12) and building a small lava cone (cone 3) about 250 feet farther east-southeast (fig. 11). At the end of the eruption the site of cone 2 was marked by an irregularly domical heap of lava, about 80 feet high, with two small spatter conelets at its summit and another on its northwest flank.

When the summit of the mountain was visited on July 26 it was found that cone 2 had partly caved in (fig. 13). It was then seen that the cone was hollow—a condition that would account for the roaring noises heard from it during the eruption. The core of the cone was occupied by an open chamber, shaped in cross section like a gothic arch with its walls nearly vertical at the bottom but curving inward to a point at the top (fig. 14). The chamber was about 25 feet across, and its visible height was about 40 feet, but the floor was formed of loose rubble resulting from the collapse of the cone. The walls of the chamber were lined with a layer of pahoehoe 2 to 4 feet thick, showing essentially vertical flow lines parallel to the walls (fig. 14). From the apex of the chamber a dike of pahoehoe led upward

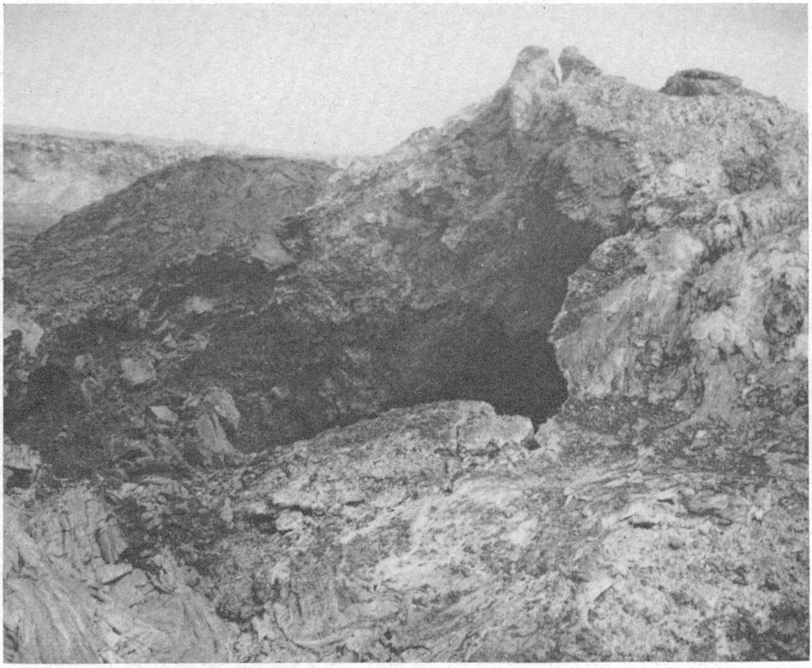

FIGURE 13.—The collapsed hollow cinder-and-spatter cone of 1949 (cone 2), Mauna Loa, Hawaii, seen from the north on July 26. The lava cone is behind it to the left. Photograph by G. A. Macdonald.

to the spatter conelets at the summit of the cone. The walls of the chamber ranged from 20 to 50 feet in thickness and consisted partly of coarse cinder and spatter and partly of a thin veneer of pahoehoe lava.

The lava cone (cone 3) is of a type unusual in Hawaii. Most Hawaiian lava cones are very flat domical shields, but the 1949 lava cone is steep-sided, with slopes averaging about 35°. (See figs. 8 and 11.) In profile it more nearly resembles a cinder cone than one of the typical lava cones of Hawaii. Its slopes are entirely covered with short imbricated flows of pahoehoe, many of them showing highly twisted and convoluted forms. At the end of the eruption the lava cone was approximately 115 feet high on its southeast side and 65 feet high on its northwest side, where its lower slope merges with that of the lava-mantled cinder-and-spatter cone.

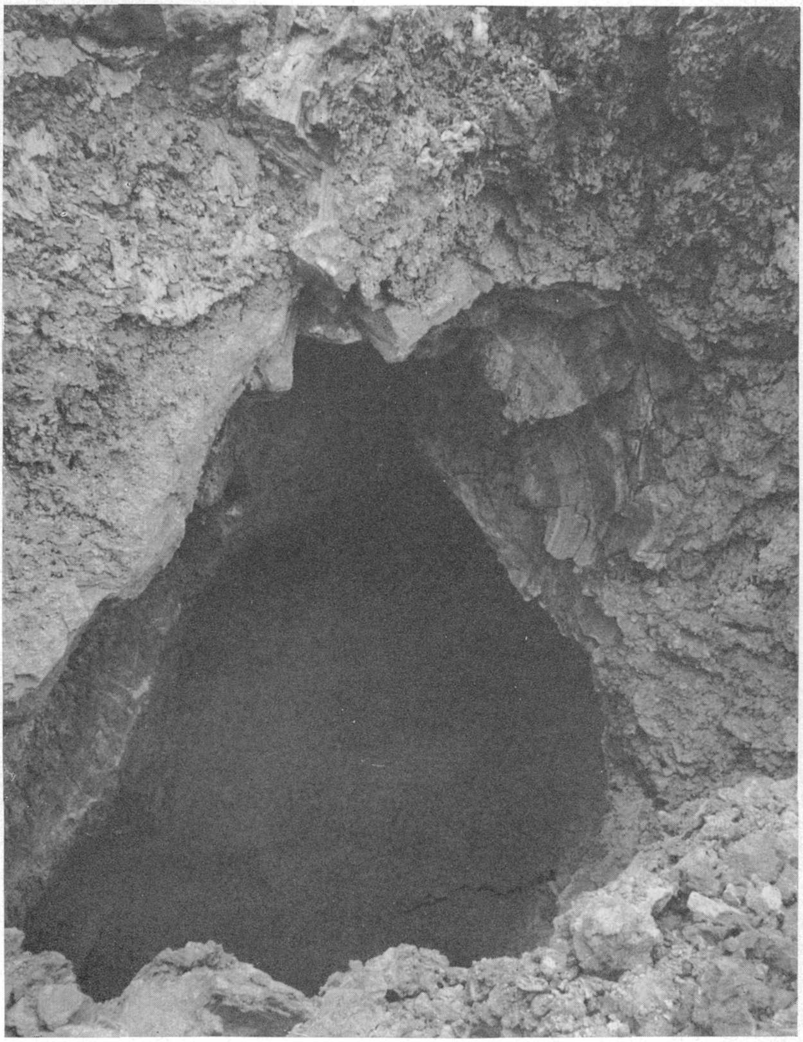

FIGURE 14.—View looking into the open chamber at the center of the 1949 cinder-and-spatter cone (cone 2), Mauna Loa, Hawaii. The flow-banded pahoehoe lining of the chamber is clearly visible, and at the top a dike extends upward through the cinder. Photograph by G. A. Macdonald.

LAVA

The lava of the 1949 eruption is basalt, containing approximately 3 percent olivine. The early lava in Mokuaweoweo and that in the proximal parts of both the western and southern flows is pahoehoe;

the later lava in Mokuaweoweo and that forming the distal parts of both major flows is very largely aa. The early flows close to the vents on the upper end of the southwest rift and in the caldera were very rich in gas and formed exceedingly shelly pahoehoe containing many empty tubes and blisters. The tubes and blisters are as much as 3 feet deep and are covered with a crust that often is less than 2 inches thick. Much of the surface of these flows is coated with a thin layer of flow pumice (Finch, Powers, and Macdonald, 1948).

The lava flows of the 1949 eruption cover an area of about 5.6 square miles. Their aggregate volume is about 77,000,000 cubic yards. The accompanying table shows the area and volume of each of the principal divisions:

Area and volume of 1949 lava from Mauna Loa

Division	Area (square miles)	Volume (cubic yards)
Mokuaweoweo caldera	1. 5	[1] 44, 000, 000
South Pit	. 2	8, 000, 000
Western (Kona) flow	3. 1	16, 000, 000
Southern (Kau) flow	[2] . 8	[2] 9, 000, 000
Total	5. 6	77, 000, 000

[1] Of this volume, about 40,000,000 cubic yards was extruded during the first and second phases of the eruption prior to Feb. 5.
[2] Figure slightly larger than that previously given by Macdonald and Finch (1949a) because of a new and better determination of the position of the terminus of the flow.

By far the greatest accumulation of lava in Mokuaweoweo was in its south end. There the flows were poured out on the surface of the old South Lunate platform, a crescentic step-fault block that formerly occupied the south end of the caldera. Pouring northward over the edge of the Lunate platform, the flows almost completed the obliteration of its north-facing scarp, which had already been partly buried in 1933 and 1940. Only at its west end, near the cones, is there still a topographic reflection of the buried scarp.

It has already been pointed out that the lavas that built cone 3 and part of those that veneered cone 2 during April and early May were much denser than the earlier lavas. This greater denseness resulted from a relative paucity of gas in the liberated fluid lava. At the time this was thought possibly to reflect the exhaustion of the gas-enriched top of the magma column as the eruption progressed. However, the trend toward greater denseness of the lavas did not continue. The last lavas to be erupted at the cones were again highly vesicular and shelly, and the extruded magma must have been nearly as rich in gas as that liberated near the beginning of the eruption. Thus the lavas extruded near the middle of the eruption were poorer in gas than those extruded both before and afterward. It appears probable that the explanation of this unusual sequence may be as follows:

The dense lavas were erupted in April and early May, directly following a quiet period of nearly 2 months during which there was very little lava extrusion but constant liberation of fume. The volume of the fume cloud was sometimes small, but at other times it was large, and the total volume of gas liberated was enormous. During this time the upper part of the magma column probably stood relatively undisturbed, as convectional stirring probably was not very effective in such highly viscous liquid in the narrow fissure conduit. In upper levels, however, the pressure was low enough to permit vesiculation, and many of the bubbles of gas slowly rose to the surface and escaped, forming the visible fume cloud. In this manner the uppermost part of the magma lost a large proportion of its gas. However, below the level at which vesiculation could occur, the magma lost only the small proportion of gas that diffused upward to regions of lower gas concentration. When eruption was resumed after the period of quiet, the first lavas to be extruded were gas-poor and dense, but as eruption continued, the gas-depleted magma in the upper part of the conduit was exhausted and the extruded lavas again contained a normal proportion of gas.

Temperature measurements were made by the senior author with an optical pyrometer, on February 5, on the glowing interior of a thick aa flow in South Pit. The hot interior of the flow was exposed in a large crack. The flow was still heaving forward a little but was nearly dead. The measurements, which indicate a temperature of 760° C., are probably accurate to within 50°.

Measurements made with a Geiger counter on the hot lava in South Pit on February 5 indicated activity about equivalent to that found on the nearby old lavas—that is, of the intensity to be expected from cosmic radiation alone (Szalay and Csonger, 1949). Tests for radioactivity made by Dr. Harvey E. White, of the University of California, on specimens of early lava from Mokuaweoweo and pumice from the fountains yielded negative results.

BOMBING OF LAVA FLOWS

The advance of the earlier of the two southern flows in late January might eventually have endangered the small communities that lay in its path, and the possibility of diverting the lava by aerial bombing was under consideration. On the upper slopes of Mauna Loa the moving liquid lava of the main feeding channel of a flow commonly is at a level higher than that of the land surface adjacent to the flow, being confined within tubes or between natural levees of its own building. The breaking down of the levees would allow the liquid lava to escape to one side and, if topographic conditions were favorable, to start a new flow, thus robbing the older flow of its supply of liquid lava and causing it to stagnate.

That the flow levees can be broken down artificially by aerial bombing was proved in 1942 (Finch, 1942, p. 4). Breaking in the top of a major tube and causing the tube to become clogged with debris also might result in an overflow of the liquid at the point of break and stagnation of the earlier flow below the break. Similarly, a breaking down of the walls of the cinder cone at the source of the flow might, if conditions were favorable, allow the liquid to escape and form new flows around the vent, robbing the earlier flow of its supply of lava. The natural breakdown of the cone wall during the 1942 eruption produced that result (Macdonald, 1943, p. 250), and the advance of the older flow, which had constituted a menace to the city of Hilo, stopped shortly afterward. In January 1949, the natural diversion of the lava near the head of the first southern flow likewise appears to have caused stagnation of the flow. Thus these two natural examples appear to point the way for artificial diversions.

Probably there is little hope of diverting flows by bombing during the great initial rush of escaping liquid, especially where they are on steep slopes, as was the western flow of January 7, 1949, or where the vent is within about 7 miles of the area to be protected. The time necessarily involved in making ready the planes and in selecting suitable targets is too long. Only lava barriers, such as those suggested by Jaggar (1945), can furnish protection from these flows. However, once the rapid early extrusion has ceased, artificial diversion of lava flows by aerial bombing appears entirely practical on Mauna Loa, where the terrain is undissected and the course of the lava flow is governed only by the general direction of slope. In regions of deeply cut stream valleys, where the course of the flow is governed by marked preexisting topographic features, its practicability would be very much less general.

PHENOMENA ACCOMPANYING THE ERUPTION

EARTHQUAKES AND GROUND TILT

Some eruptions of Mauna Loa are preceded by striking patterns of earthquakes, constituting definite indications of coming activity. Thus, in 1942, a series of earthquakes started about 2½ months before the eruption on the northeast flank of the mountain. The first of the series was a strong quake at a depth of 27 to 30 miles in the vicinity of Hilo, about 36 miles northeast of the summit, and 26 miles from the site of the coming flank eruption. The foci of the earthquakes gradually approached the surface, and the epicenters migrated up along the northeast rift zone, a swarm of earthquakes centering at an altitude of about 9,000 feet near the point where the eruption took place 2 months later (Finch, 1943a).

No such definite pattern preceded the eruption of 1949. It is notable, however, that the number of earthquakes recorded on the Mauna Loa seismograph, 13 miles east of Mokuaweoweo caldera, during the month of December 1948 greatly exceeded the number during any month in the preceding year (Finch, in preparation). Figure 15 shows the number of earthquakes recorded on the Mauna Loa seismograph during each month from January 1943 to September 1949. It should be noted that the actual number of quakes during December 1948 was not appreciably greater than the totals recorded during May and December 1946. The significant feature appears to be the marked increase in the number of quakes relative to the immediately preceding months, rather than their number alone. The great number of quakes in November 1943, representing a very large increase over the preceding months, immediately preceded and accompanied a burst of fume and reported glow at the summit of Mauna Loa that unquestionably indicated weak eruptive activity at that time. The summit eruption of 1914 also was preceded by an abnormally large number of

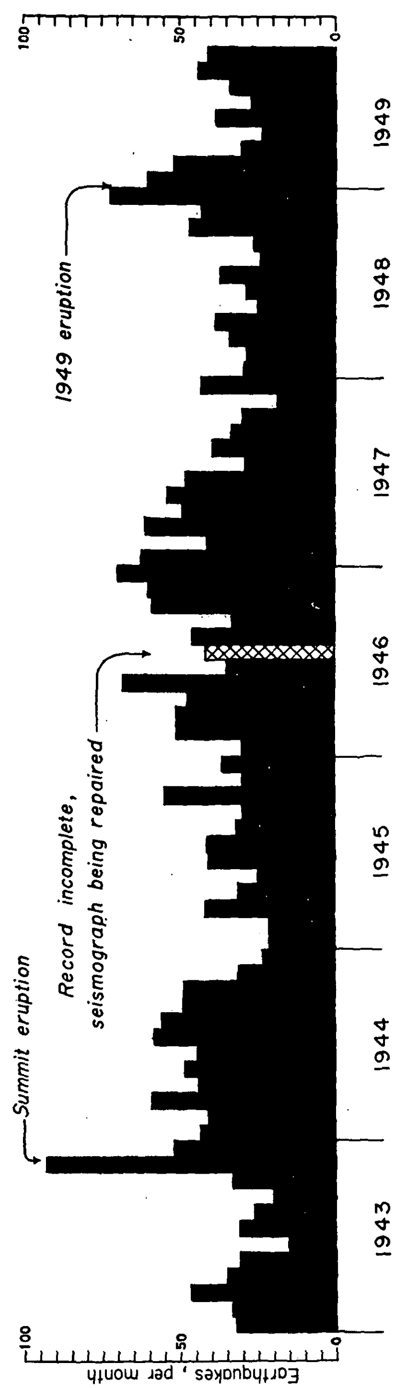

FIGURE 15.—Graph showing the number of earthquakes recorded on the Mauna Loa [Hawaii] seismograph each month from January 1943 to September 1949.

light earthquakes during the 2 months before the eruption (Wood, 1915). It is obvious from an examination of figure 15, however, that a marked increase in the number of earthquakes does not necessarily indicate impending eruption. Several increases are shown that are comparable in magnitude to that of December 1948 but were not associated with any other recognized signs of volcanic activity. Nevertheless, it appears that any marked increase in the number of earthquakes should be regarded as a sign of possible coming activity, especially if it is associated with other, similar indications such as abnormally strong ground tilting and marked magnetic disturbances.

Most of the earthquakes registered on the Mauna Loa seismograph during December 1948 were very small and apparently were of shallow origin (Finch, in preparation). Most appear to have centered along the northeast rift zone, although a few, including one moderately strong quake on December 13, originated under or near Mokuaweoweo. On January 6, the day of the outbreak, a strong earthquake occurred at 15:59 o'clock (H. s. t.), with its focus at a depth of about 5 miles, 2 miles northeast of Mokuaweoweo and about 4 miles northeast of the place where the major lava fountains later developed. It has been suggested by Finch that this earthquake accompanied the initial opening of the eruptive fissure. Harmonic tremor, believed to indicate the movement of magma in the conduit, began registering at 15:47 and continued until about 03:00 on January 7. Thirteen very small earthquakes were recorded on January 6, but all except one of these occurred after the outbreak of activity. Throughout the remainder of the eruption the number of earthquakes was not greater than that commonly recorded during periods of no volcanic activity. Most of these earthquakes originated at shallow depths along the northeast rift zone.

From October 27 to November 14 a strong eastward tilting of the ground surface took place at the seismograph vault at the northeast rim of Kilauea caldera. The easterly component of the tilt equaled approximately 5 seconds of arc. Eastward tilting in excess of the normal seasonal amount probably indicates an increase in volcanic pressure under Mauna Loa; if the strong eastward tilting had continued, it would have been regarded as a rather definite indication of coming activity on the part of Mauna Loa. However, after November 14 the rapid eastward tilting ceased and was succeeded by small amounts of alternate eastward and westward tilting, which by the day of the outbreak had resulted in a net eastward tilt of only 0.1 second of arc. For this reason, the large number of earthquakes recorded in December was not regarded as indicative of immediately impending surface activity.

MAGNETIC DISTURBANCES

It appears probable that movements of the magma underground should be accompanied by variations in the geomagnetic field in the environs of the volcano. On the basis of preliminary studies, Omer (1945) showed that a possible correlation exists between variations in horizontal intensity in the north-south field at the Honolulu Magnetic Observatory and seismicity at the Hawaiian Volcano Observatory during the years 1933–36. During that period there occurred two eruptions of Mauna Loa and one of Kilauea. Because increased seismicity commonly is associated with a rise or fall of the magma level, the correlation indicates, also, a possible relationship to eruptive activity.

Variations in the horizontal intensity of the magnetic field were observed at Honolulu just preceding and following the 1949 outbreak of Mauna Loa. In a letter to R. H. Finch, dated January 20, Laurie R. Burgess, then observer in charge of the Honolulu Magnetic Observatory of the United States Coast and Geodetic Survey, stated:

> Late on the day of 3 January 1949, the horizontal intensity variometer * * * began to show signs of a peculiar (though not uncommon) short period, small amplitude disturbance (none greater than about one gamma). This activity steadily increased so that on the 5th and 6th of the month it was very apparent, lasting throughout the entire day. It probably was greatest on the 6th. It would seem that it might be in some way related to the January volcanic eruption, although it preceded the actual eruption somewhat. These disturbances died off after the 6th and were almost completely absent on the 8th. Such disturbances are recorded practically every month. They may all be associated in some way with the volcanic activity on the island of Hawaii.

The Honolulu Magnetic Observatory is situated about 190 miles from Mauna Loa. If such disturbances are detectable at that distance and if, as appears possible, they actually are related to magma movements, it seems reasonable to expect that they would be much more marked in the immediate vicinity of the volcano. A program of magnetic studies is now being started at the Hawaiian Volcano Observatory.

PREDICTION OF COMING ACTIVITY

Jaggar (1949) has predicted that the next eruption of Mauna Loa will take place on the northeast rift, somewhere above an altitude of 10,000 feet, about December 1950. This prediction appears to be as good as any that can now be made. However, because the work of the Hawaiian Volcano Observatory is to a considerable extent directed toward the prediction of coming eruptions, it seems desirable to outline the grounds on which an attempt to predict activity is based and to point out their manifest weaknesses.

Jaggar's prediction is based largely on the general eruption pattern during the past century, plus the fact that most Mauna Loa earthquakes during recent months have originated on the northeast rift. Broadly considered, the recent history of Mauna Loa gives the impression of an alternation of summit and flank eruptions, which may indeed be the normal succession. However, detailed analysis of the eruptive history fails to give this theory any strong support. Sixty-seven percent of the summit eruptions since 1880 have been followed by flank eruptions, but if the entire period since the beginning of fairly complete records in 1843 is considered, the figure drops to only 53 percent because of the several successive summit eruptions between 1870 and 1877. If the weak summit activity of November 1943 is ignored, the percentages become 75 and 56, respectively (Finch, 1948). In other words, there is a small mathematical probability—based on historical precedent—that the 1949 summit activity will be followed by a flank eruption.

During the past century the average interval between the end of a summit eruption and the beginning of a succeeding flank eruption has been 20 months. On these grounds alone, a flank eruption of Mauna Loa might be expected about the end of 1950. However, the average interval between eruptions means little. About one-third of the recent summit eruptions have been followed by another period of summit activity, rather than by flank eruption. Even when summit eruption has been followed by flank eruption, the interval between the two has ranged from 6 to 38 months. Thus, on the basis of historical precedent, a flank eruption might be expected to take place anywhere from December 1949 to August 1952. The greater amount of earthquake activity on the northeast rift as compared with the southwest rift appears to be real, although the seismographs are better situated to record small earthquakes from the northeast rift and the apparent difference may be greater than the actual difference. On this basis it is reasonable to expect that if a flank eruption does occur, it will be on the northeast rift. However, several strong, recent earthquakes have originated beneath the western slope of the mountain and suggest the possibility that the pattern of 1870 to 1877 may be repeated, when a succession of summit eruptions was followed by an outbreak low on the west flank.

Obviously, prediction on such grounds is highly uncertain. No really sound basis for long-range prediction has been developed thus far. Measurements of ground tilting are as yet not sufficiently quantitative to be used as a basis of definite prediction and probably never will give a warning of more than a few months. The earthquake pattern that precedes some flank eruptions (Finch, 1943a) furnishes a warning of only a few weeks at most. The measurement of local magnetic variations bears some promise of being useful in the prediction of eruptive activity but is as yet only in the very early stages of trial. Other geophysical methods, such as measurements of earth potential and variations in gravitative attraction, may constitute valuable tools in the future, although it seems doubtful if any of these will ever give a warning of more than a very few months. At present the most that can be said with reasonable assurance is that Mauna Loa very probably will erupt again within the next few years and that the chances are more than equal that the activity will occur on the flank and probably along the northeast rift zone.

NOTE.—Conditions described above are those which existed when the report was prepared in October 1949. They remained essentially unchanged through April 1950. During May 1950 earthquake activity became concentrated on the southwest rift of Mauna Loa, making it probable that any eruption in the near future would take place there instead of on the northeast rift. The eruption came on June 1, 1950, on the southwest rift.

SUMMARY

Assuming the activity to have ended on June 1, the 1949 eruption of Mauna Loa lasted 147 days. This was the longest period of activity since the flank eruption of 1880–81, which lasted 275 days, and the longest summit eruption since the 560 days of essentially continuous activity in 1873–74. The length of the dormant period following the probable summit activity in 1943 was 5 years, 1½ months. The interval between the end of the last flank eruption, in May 1942, and the 1949 outbreak was 6 years, 8 months.

The three phases typical of Mauna Loa eruptions were clearly shown in the eruption of 1949. The characteristics of these phases, as illustrated by previous eruptions, have been summarized as follows (Macdonald, 1943):

> (1) A period of a few hours during which very hot fluid lava is squirted from a narrow fissure, forming a nearly continuous wall of lava jets thousands of feet in length. Lava extrusion forms extensive thin flows. Low ramparts of agglutinate are built by spatter along the fissure, but no large cones are formed.

During the 1949 eruption this phase lasted about 48 hours, from January 6 to 8.

> (2) Restriction of the lava fountains to a relatively short medial portion of the fissure, and the building of cinder and spatter cones. One or more major flows issue continuously from the cones, and numerous minor flows may occur.

This is the period of highest lava fountains and principal cone building. During the 1949 eruption it occupied the interval from January 8 to February 5.

> (3) Decline of the fountains, with cooling of the liquid lava in the vent, and decrease in the amount of liberated gas. The flow of lava may die out with the fountains, or may continue for weeks or even months after the cessation of fountain activity.

This phase was represented during the 1949 eruption by the period from February 5 to the end of May. The temperature of the lava being erupted, as compared with that during the second phase, was less markedly lower than was the case during the 1942 eruption, but the decrease in the amount of gas liberated was very marked. This and a general decrease in fluid pressure (possibly in turn related to the decrease in gas) appear to be the essential characteristics of this final phase.

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