Hawaiian Volcanoes During 1952

GEOLOGICAL SURVEY BULLETIN 1021-B

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By GORDON A. MACDONALD

A CONTRIBUTION TO GENERAL GEOLOGY

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A report of the Hawaiian Volcano Observatory

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By Gordon A. Macdonald

ABSTRACT

The year 1952 opened with the Hawaiian volcanoes quiet. Mauna Loa had last erupted in June 1950, for 3 weeks, and Kilauea had not erupted for nearly 18 years.

During March and April a swarm of more than 4,000 earthquakes originated beneath the ocean a few miles south of the island of Hawaii. Their epicenters were distributed along a line nearly parallel to the southern shore of the island, 10 to 15 miles offshore. The line crosses a broad domical structure that probably is a shield volcano built against the flank of the Kilauea shield. No evidences of submarine volcanic eruption accompanied the earthquakes.

Early in April a series of earthquakes commenced at foci along the east rift zone and beneath the caldera region of Kilauea volcano. These were accompanied by northward tilting of the ground at the northeast edge of the caldera, indicating swelling of the volcanic structure resulting from an increase of volcanic pressure beneath Kilauea. The volcano continued uneasy throughout May and June, although there was no recognized progression of earthquake hypocenters from depth toward the surface.

Kilauea volcano erupted on the night of June 27, 1952. At about 23^h40^m a fissure opened in a northeast-southwest direction across the floor of Halemaumau. For the next few hours a continuous line of fountains, 2,600 feet long, played along the fissure. Most of the fountains were 50 to 150 feet high, but at the southwest end of the fissure a fountain more than 800 feet high overtopped the rim of the crater at the beginning of the eruption.

Gradually the big southwest fountain subsided and activity became restricted to a smaller part of the fissure. By 04^h on June 28 only the northeastern quarter of the fissure was active, but at about 04^h30^m fountains reappeared along the southwestern part of the fissure. By that time the old floor of Halemaumau was submerged beneath a pool of liquid lava 50 feet deep. Long waves, resembling ocean ground swell, rolled across the surface of the pool from the fountains to the walls of the crater. A dark crust covered the lava pool but was broken by a network of cracks that revealed the bright golden glow of the hot liquid beneath.

The northeastern fountains continued active until July 5, building 50-foot spatter cones that were later obliterated, partly by collapse and partly by burial under new lava. The fountain at the southwest edge of the crater resumed activity on the morning of June 28 and continued for several days. During that period it alternated in activity with a sinkhole, at the same location, which received a stream of lava from the central fountains. The southwestern fountain

reached a second climax on July 3 and 4, when some bursts attained a height of 600 feet.

A chain of about 20 small fountains extended across the southwestern part of the crater floor during the first 2 weeks of the eruption. About July 11 the active length of this fissure became restricted to 400 feet, and 2 principal fountains began building a large cinder-and-spatter cone. Rivers of lava pouring out through gaps in the cone wall fed a lake of liquid lava around the cone. On August 5 this lake had an area of 34 acres.

By late August, overflow from the central cone had largely ceased. Two active vents were building small spatter cones in the crater of the larger cone. Between the conelets was a small lava lake that had an average diameter of about 100 feet. These conditions persisted essentially unchanged throughout the eruption. Flows appeared from time to time on the floor of Halemaumau crater outside the cone. Several of these issued at the foot of the crater wall, where the lava probably was squeezed up along the line of break between the old crater wall and the mass of new lava.

The eruption came to an end on November 10. The average depth of the new lava fill was 310 feet, and the volume of new lava was 64,000,000 cubic yards. The depth of the crater had decreased from about 770 feet, before the eruption, to 460 feet. The rise of the crater floor was caused partly by overflow of new lava, and partly by bodily elevation as new lava was squeezed into the still-mobile lower part of the new fill.

INTRODUCTION

This report continues the account of activity of Hawaiian volcanoes begun in earlier reports (Finch and Macdonald, 1951, 1953; Macdonald and Wentworth, 1954). The outstanding event of the year was the renewal of eruptive activity at Kilauea volcano after a quiescence of nearly 18 years, and this report deals largely with that event.

Personnel of the Hawaiian Volcano Observatory remained unchanged during the year 1952, except that Burton J. Loucks, instrument maker, returned to take over the operation of the instrument shop after more than a year's absence on active duty in the United States Navy. John C. Forbes remained on the staff as assistant instrument maker.

ACKNOWLEDGMENTS

Many persons on the island of Hawaii have aided the operations of the Hawaiian Volcano Observatory during the year by supplying information on earthquakes and volcanic activity. Chief among these are the staff of Hawaii National Park, and the several volunteer earthquake reporters in different parts of the island. Members of the staff of Hawaii National Park who supplied information based on their observations during the eruption of Kilauea include: F. R. Oberhansley, superintendent, I. J. Castro, E. K. Field, E. L. Bohlin, R. A. Apple, D. J. Tobin, B. M. Sumner, O. K. Roberts, A. J. Medeiros, G. A. Ruhle, V. R. Bender, R. E. Jeffery, and J. R. Fox.

E. K. Field, chief ranger, and E. L. Bohlin, ranger, furnished photographs of Halemaumau taken from the air during the eruption, and Bohlin furnished information and a photograph of the extent of the tsunami at Kalapana on March 17.

Those who have supplied valuable information on the effects of earthquakes in their districts are: Myrtle E. Hansen of Naalehu, Ernest Morton of Kahuku, Robert Baldwin of Hilo, A. P. Johnston of Kapapala, Eleanor Christensen, Olive Finkenbinder, and Beth Hartig of Kukuihaele, Dorothy Endicott and Mary Stetson of Pahala, Nancy R. Wallace of Kealakekua, Amy Greenwell, David Fraser, and K. Kishi of Captain Cook.

The Honolulu office of the U. S. Coast and Geodetic Survey and Doak C. Cox, of the Hawaiian Sugar Planters' Association, made available photostat prints of the tide-gage records of the tsunami of November 4. R. E. White, observer in charge of the Honolulu Magnetic Observatory, U. S. Coast and Geodetic Survey, loaned a Neumann-Labarre seismometer for experimental use during late 1951 and early 1952, and aided in the installation of the instrument.

Lt. Col. B. W. Rushton, commanding officer of Kilauea Military Camp, and Louise Fox of Hawaii National Park were the first persons to report the outbreak of Kilauea volcano on June 27, 1952. Colonel Rushton has also been of assistance in other ways.

Constance Conard, teacher, and Kazuo Ikeda, principal, of Naalehu School, permitted the operation of a portable seismograph in the basement of one of the school cottages during the earthquake swarm of late March. During the same earthquake swarm, J. F. Ramsey and Wayne Richardson permitted the similar use of the beach house of the Hawaiian Agricultural Company at Punaluu.

W. E. B. Benson spent from July 5 to 16 at Kilauea, aiding in mapping the changes in Halemaumau and keeping a record of the eruption.

Prof. John J. Naughton, of the University of Hawaii, has kindly permitted the use, in advance of publication, of his measurements of the temperature of the lava fountains on July 2 and 3.

To all of these persons the staff of the Hawaiian Volcano Observatory extends its sincrere thanks.

SEISMOGRAPHS AND TILTMETERS

For the most part the instrumental installations described in earlier reports (Finch and Macdonald, 1951, 1953; Macdonald and Wentworth, 1954) remained unchanged throughout 1952. Several minor changes were made, however. For several years the Whitney, Uwekahuna, and Mauna Loa seismograph stations operated with independent time-control clocks. The lack of a synchronized time signal at the three stations made it difficult to use absolute arrival times in locating the focal points of earthquakes. During 1952 the stations were connected with field-telephone wire, laid on the ground, and after some experimentation a satisfactory synchronized time signal at the three stations was put into operation during November. The signal is originated by the standard master clock in the Whitney Laboratory of Seismology. The clock is corrected generally twice daily to the radio time signal of the National Bureau of Standards, broadcast over station WWV.

The type of seismograph operating in the Hilo station, together with other seismographs in the process of construction, previously termed the modified Bosch-Omori seismograph (Finch and Macdonald, 1953, p. 30), has been renamed the Loucks-Omori seismograph. These instruments, designed by B. J. Loucks and built by Loucks and J. C. Forbes in the shop of the Hawaiian Volcano Observatory, differ in design and construction from the standard Bosch-Omori seismograph, and are operated at a much shorter period.

A Neumann-Labarre seismometer, loaned by the Coast and Geodetic Survey, was installed in the Uwekahuna station in September 1951, and operated on a part-time experimental basis until March 1952. Operated at a magnification of about 3,600, it proved useful in the study of local earthquakes of very slight intensity.

In June 1952 a Sprengnether series *A–R* seismograph of Wood-Anderson type was installed in the Uwekahuna station to record the horizontal component of earthquakes in the east-west azimuth. Operated at a period of 1.5 seconds, the amount of microseism recorded by the instrument proved excessive. Reduction of the period to 1 second eliminated most of the microseism from the record. Like the Sprengnether vertical seismograph, the instrument has been useful in the study of local earthquakes of slight intensity. Unfortunately, the lack of electric power at night still limits the operation of both these instruments to about 8 hours a day.

In January 1952 an Imamura three-component seismograph was installed in the main Observatory building at the west edge of Kilauea caldera. This instrument has been in continuous operation since, as a strong-motion seismograph to record local earthquakes intense enough to cause dismantling of the more sensitive instruments. Capillary ink pens were used on the recorder for a time, but have been replaced by more satisfactory smoked-paper recording. Earthquake annunciators also were installed in the observatory building and in homes of staff members, and adjusted to sound an alarm on the occurrence of earthquakes of moderate or strong intensity.

Table 1 lists the seismographs and tiltmeters in operation in the stations of the Hawaiian Volcano Observatory during 1952. The

TABLE 1.—*Seismographs and tiltmeters operated by the Hawaiian Volcano Observatory during 1952*

Station	Latitude (north)	Longitude (west)	Instrument	Period of pendulum (seconds)	Magnification (approximate)	Sensitivity to tilt (seconds of arc per mm)
Whitney Laboratory of Seismology (northeast rim of Kilauea caldera).	19°25′53″	155°15′40″	Bosch-Omori seismograph and tiltmeter.	7.7	115	0.12
Mauna Loa (altitude, 6,600 feet on east slope of Mauna Loa).	19°29′32″	155°23′29″	Hawaiian-type seismograph.	7.1	115	.14
Uwekahuna (1,000 feet west of west rim of Kilauea caldera).	19°25′26″	155°17′36″	Jaggar vertical seismograph.	.4	250	None
Do	19°25′26″	155°17′36″	Sprengnether vertical seismograph.	.5	1,750	None
Do	19°25′26″	155°17′36″	North-south and east-west horizontal pendulum tiltmeters.	20.0	7	.32
Do	19°25′26″	155°17′36″	Neumann-Labarre seismograph.	.5	3,600	----------
Do	19°25′26″	155°17′36″	Wood-Anderson seismograph.	1.0	600	----------
Volcano Observatory (west rim of Kilauea caldera).	19°25′21″	155°17′23″	Imamura seismograph	3.0	15	----------
Hilo (St. Joseph's School).	19°43′11″	155°05′20″	Loucks-Omori seismograph.	3.0	175	.48
Kona (Konawaena School, Kealakekua).	19°30′47″	155°55′07″	Hawaiian-type seismograph.	7.3	115	.13
Southeast tilt cellar (floor of Kilauea caldera southeast of Halemaumau).	19°24′20″	155°16′59″	Normal pendulum tiltmeter.	3.0	100	1.3
West tilt cellar (floor of Kilauea caldera west of Halemaumau).	19°24′32″	155°17′33″	do	3.0	100	1.3

principal constants of the instruments and the locations of the stations are given.

The stations in which tilt instruments are operated are underground vaults insulated to reduce daily temperature fluctuations. The vault at the Whitney Laboratory is kept at a temperature of about 32°C by volcanic steam beneath the floor. The daily change of air temperature of about 0.5°, but during 1952–53 the average daily temperature ranged from 28° to 38°. During the same period the temperature in the Uwekahuna vault ranged from 16° to 21°C, with a daily change of about 0.5°; and that in the Mauna Loa vault ranged from 10° to 21°C, with a daily change generally of about 1°. Seasonal variations of temperature of these magnitudes are undesirably large for the successful operation of metal horizontal pendulum tiltmeters, and experimentation with other types of tiltmeters is in progress.

Figure 1 shows the location of the Hawaiian Volcano Observatory and the Hilo and Kona seismograph stations on the island of Hawaii. The location of the Whitney, Uwekahuna, Observatory, and Mauna Loa seismograph stations are shown in figure 2.

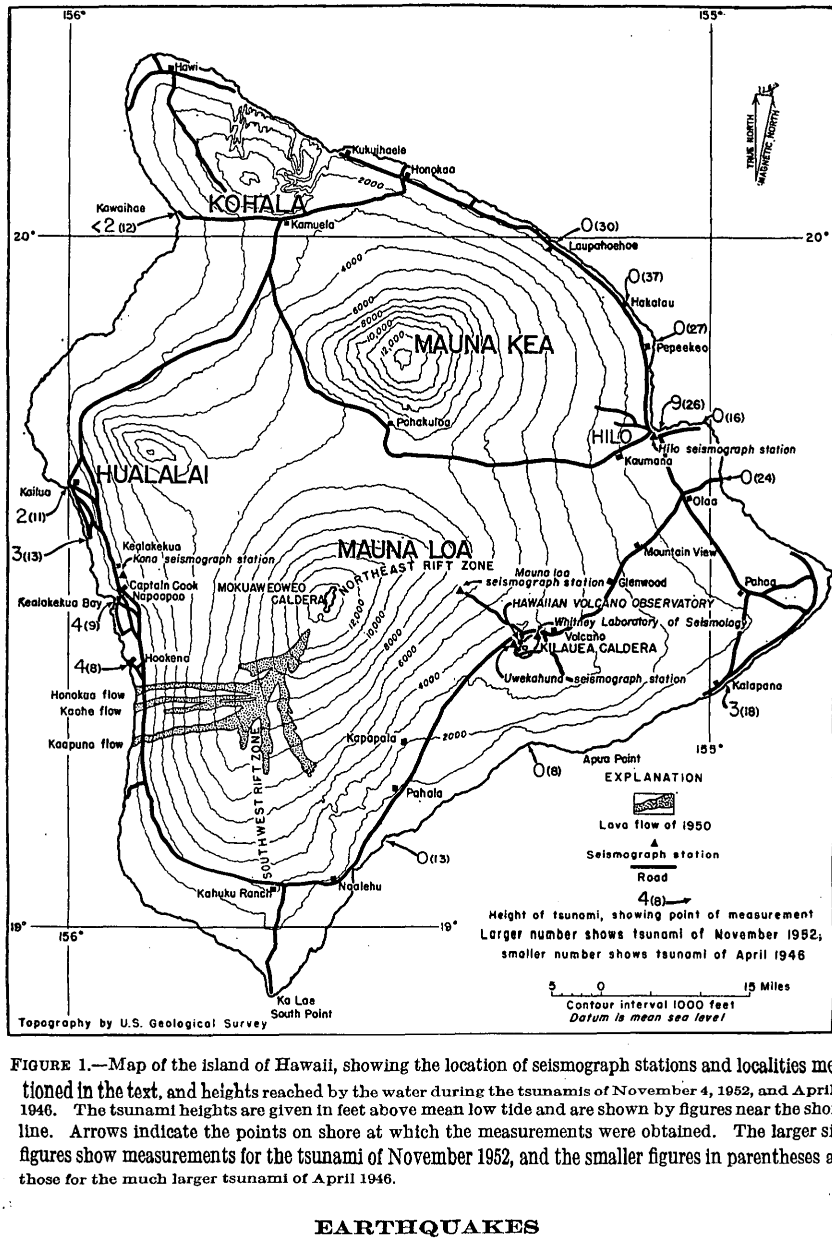


FIGURE 1.—Map of the island of Hawaii, showing the location of seismograph stations and localities mentioned in the text, and heights reached by the water during the tsunamis of November 4, 1952, and April 1, 1946. The tsunami heights are given in feet above mean low tide and are shown by figures near the shoreline. Arrows indicate the points on shore at which the measurements were obtained. The larger size figures show measurements for the tsunami of November 1952, and the smaller figures in parentheses are those for the much larger tsunami of April 1946.

EARTHQUAKES

Seismographs at Kilauea caldera recorded 5,011 earthquakes during 1952, in addition to the continuous tremor of the ground throughout nearly all the eruption of Kilauea volcano. Most of these earthquakes occurred during the great swarm that originated off the southern coast of the island in March and April, and the lesser swarm, in April, May,

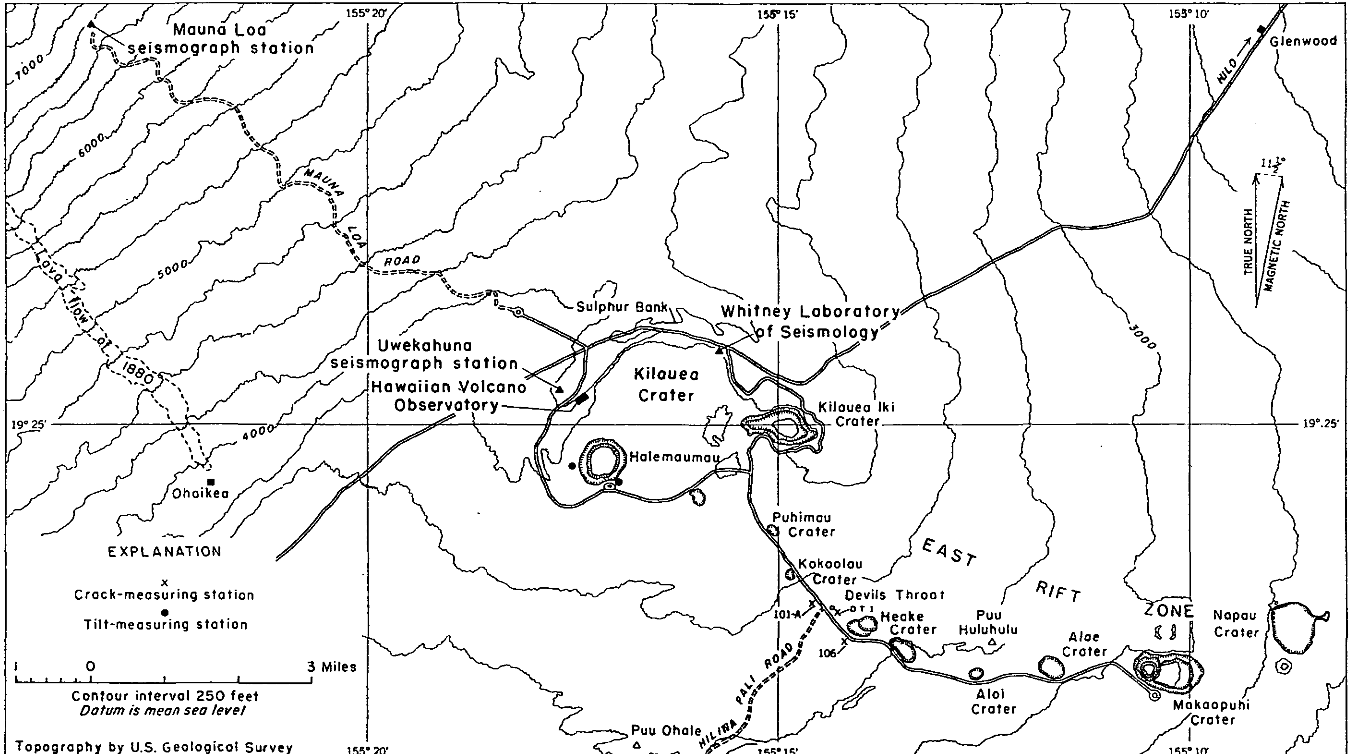


FIGURE 2.—Map of the Kilauea Crater area showing the location of seismograph, tilt-measuring, and crack-measuring stations on the east rift of Kilauea.

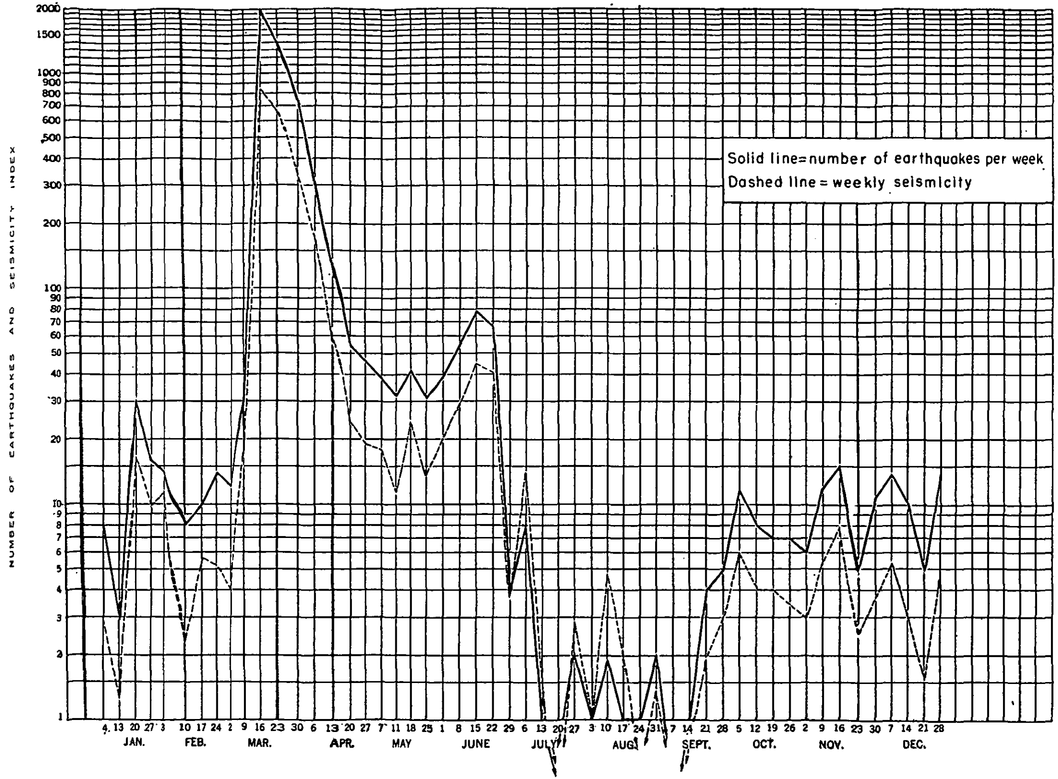


FIGURE 3.—Graph showing variations in the number of earthquakes recorded per week and weekly seismicity at the Whitney Laboratory of Seismology during 1952.

and June, that preceded the eruption of Kilauea volcano. These two earthquake swarms are discussed in a later section of the report.

The number of earthquakes recorded per week on the Bosch-Omori seismograph at the Whitney Laboratory of Seismology, on the northeastern rim of Kilauea caldera, ranged from 0 to 1,850. The weekly seismicity at the same station ranged from 0 to 859.25. The scale of seismicity in use at the Hawaiian Volcano Observatory is an arbitrary one, based on the amplitude of the record produced by the earthquake on the seismographs. Each local earthquake is assigned a seismicity value depending on its strength, as follows: Tremor, 0.25; very feeble, 0.5; feeble, 1.0; slight, 2.0; moderate, 3.0; strong, 4.0. These values are totaled to give the weekly local seismicity. Continuous volcanic tremor is ignored in the calculation. The strength assigned to the earthquake depends on the double amplitude of the maximum oscillation it causes on the Bosch-Omori seismograph, as follows: Tremor, less than 0.5 mm; very feeble, 0.5 to 4 mm; feeble, 4 to 11 mm; slight, 11 to 25 mm; moderate, 25 to 60 mm; strong, greater than 60 mm.

In figure 3 the variations in weekly seismicity and number of earthquakes are shown as curves plotted on a semilogarithmic base. The high peak of the curves during March corresponds with the great swarm of earthquakes from foci just south of the island. The lesser peak in mid-June directly preceded the eruption of Kilauea volcano.

Seismographs at Kilauea caldera recorded 109 earthquakes during January and February. Most of these originated at very shallow foci under or near the caldera, or from nearby parts of the east rift zone. During the same interval the Mauna Loa seismograph recorded only 58 earthquakes, many of which were of Kilauean origin. Seismic activity thus centered at Kilauea throughout the early part of the year, while Mauna Loa was relatively quiescent. In October, however, the Mauna Loa seismograph recorded a total of 187 earthquakes, as compared with 77 recorded at Kilauea. Most of these Mauna Loa quakes were recorded in a swarm of 165 very small quakes that originated on the northeast rift zone on October 24 and 25. The uneasiness of Mauna Loa during October did not continue into November.

DESCRIPTION OF INDIVIDUAL EARTHQUAKES

An earthquake felt in the northern part of the island at 06^h26^m (Hawaiian standard time) on January 23 originated beneath the Waimea plain about 5 miles east-southeast of Kamuela.

A strong earthquake at 01^h58^m on January 26 originated on the Hilina fault system north of Apua Point. Slight aftershocks at 02^h52^m on the same morning and 00^h57^m on January 27 originated at the same locality.

A quake at 01^{h}16^m on February 2 was felt generally in Hilo, and by some persons in nearly all parts of the island. It originated beneath the northeastern slope of Mauna Loa about 5 miles southwest of Hilo. A quake felt at Kapapala at 22^{h}40^m on February 23 had its epicenter on the southwest rift of Mauna Loa at an altitude of 8,500 feet.

At 12^{h}12^m on May 23 a strong earthquake originated on the Kealakekua fault near Napoopoo, on the west coast of Hawaii. Its focus was near that of the major earthquake of August 21, 1951 (Macdonald and Wentworth, 1954, p. 185, 209). It was felt over all the island of Hawaii, and by some persons on the island of Maui. In the central Kona area dishes were broken, groceries and bottles were jarred off shelves, pavements cracked, slides occurred in roadcuts, some water tanks were damaged, windows were broken, and tombstones overturned. The intensity near the epicenter was 6 in the modified Mercalli scale (Wood and Neumann, 1931). The breaking of dishes extended as far from the epicenter as Naalehu, where the intensity was 5.

Other earthquakes with foci in central Kona, many of them probably on the Kealakekua fault, continued throughout the year. Most were of very slight intensity, but some were strong enough to be felt near the epicenter. Several quakes, including one felt in Kona at 22^{h}14^m on November 27, originated along a line extending westward from the summit of Mauna Loa toward Kealakekua Bay. These may have been caused by movement along the same fracture zone on which occurred the eruption of 1877.

A quake felt widely over the southern part of the island at 04^{h}45^m on September 2 had its focus near Kilauea caldera. It may have been related to the conspicuous revival of eruptive activity at Kilauea in early September. A small quake felt at Naalehu at 18^{h}01^m on December 10 originated beneath the summit region of Mauna Loa. It was not, however, associated with any other signs of uneasiness of Mauna Loa.

Several of the earthquakes recorded during the year apparently originated on the Kaoiki fault system, between Mauna Loa and Kilauea. One quake recorded at 09^{h}09^m on December 12, was felt in Naalehu and in the Volcano area. A moderate earthquake at 01^{h}21^m on December 28 probably originated beneath the summit of Hualalai volcano.

Table 2 lists the local earthquakes stronger than tremors, recorded at seismograph stations of the Hawaiian Volcano Observatory during 1952. The table shows the arrival time of the preliminary phase at the Whitney Laboratory of Seismology. The time is stated to the nearest minute in Hawaiian standard time, which is 10 hours slower than Greenwich civil time. If the earthquake was more intense at one of the other stations than at the Whitney Laboratory, the intensity rating at the other station is given in the column headed "Remarks."

Table 3 lists the earthquakes of distant origin recorded on the Bosch-Omori seismograph at the Whitney Laboratory during 1952. The time given is that of the arrival of the first recognizable oscillation. The epicenters given in the table are taken from the notices of Preliminary Determinations of Epicenters published by the U. S. Coast and Geodetic Survey.

TABLE 2.—*Local earthquakes stronger than tremors recorded at Hawaiian Volcano Observatory during 1952*

Serial no.	Date	Time (Hawaiian standard) h m	Intensity at Whitney Laboratory	Epicenter	Remarks
1	Jan. 2	06 47	Very feeble		
2	8	05 40	No record		Very feeble, Kona.
3	10	00 22	Very feeble		
4	11	02 33	do		
5	12	04 23	do		
6	12	20 54	do	Kilauea caldera	
7	15	05 13	do		
8	17	07 36	do		
9	23	00 54	do		
10	23	04 10	do	Kilauea caldera	Shallow.
11	23	06 27	do	Waimea plain, about 5 miles east-southeast of Kamuela.	Felt at Kukuihaele.
12	23	07 54	Feeble	Near Kilauea Iki	
13	23	11 13	Very feeble	Kilauea	
14	23	11 54	do		
15	24	07 03	do	Kilauea	
16	24	07 14	do		
17	24	13 26	do	Kilauea caldera	
18	24	18 24	do	do	
19	25	03 04	do	do	
20	25	03 06	do		
21	25	16 53	No record	Central Kona	Feeble, Kona.
22	25	19 44	Very feeble	Kilauea caldera	
23	25	20 55	No record	Central Kona	Very feeble, Kona.
24	26	01 58	Strong	Hilina fault system, about 3 miles east of Puu Kapukapu.	
25	26	02 52	Slight	do	
26	27	00 07	do	Hilina fault system	
27	27	18 52	Tremor	Central Kona	Feeble, Kona.
28	27	18 59	Very feeble	do	Slight, Kona.
29	Feb. 1	20 30	do	do	Feeble, Kona. Felt at Captain Cook.
30	2	01 16	Moderate	Nearly under Kaumana, about 30 miles deep.	Felt over most of the island, strongly at Hilo.
31	2	03 46	Very feeble		
32	2	05 58	Tremor		Felt in Kukuihaele.
33	2	06 19	Very feeble		
34	2	13 05	do		
35	6	06 20	do		
36	6	18 42	Feeble	East rift of Kilauea near Makaopuhi Crater.	
37	6	20 52	Very feeble		
38	6	22 10	do		
39	7	04 27	Slight	East rift of Kilauea near Makaopuhi Crater.	Shallow.
40	7	21 22	Very feeble		
41	7	21 23	Feeble	East rift of Kilauea	
42	7	21 55	Strong	East rift zone of Kilauea, 1 mile east of Napau Crater.	Do.
43	8	02 02	Tremor		Very feeble, Kona.

TABLE 2.—*Local earthquakes stronger than tremors recorded at Hawaiian Volcano Observatory during 1952*—Continued

Serial no.	Date	Time (Hawaiian standard) h m	Intensity at Whitney Laboratory	Epicenter	Remarks
44	Feb. 13	20 36	Very feeble	Central Kona, probably on Kealakekua fault.	Moderate, Kona.
45	14	15 46	Tremor	Central Kona	Slight, Kona.
46	14	15 50	do	do	Do.
47	15	14 47	do		Very feeble, Kona.
48	15	23 04	do	Central Kona	Do
49	19	11 20	Very feeble	Southeast slope of Mauna Loa near Kapapala.	Felt at Kapapala.
50	19	19 26	do		
51	21	06 15	Slight	East rift of Kilauea about 2 miles east of Napau Crater.	Shallow. Felt from Volcano district to Pepeekeo.
52	22	17 10	Very feeble	Kilauea	
53	22	21 34	do		
54	23	01 47	do	Kilauea	
55	23	22 41	do	Southwest rift of Mauna Loa at an altitude of about 8,500 feet.	Felt at Kapapala.
56	24	10 20	do	North slope of Mauna Loa about 11 miles north of Mokuaweoweo.	Feeble, Mauna Loa.
57	24	11 22	do	Kilauea caldera	
58	24	11 47	do		
59	24	11 54	do		
60	25	08 28	do		
61	26	12 36	do		
62	Mar. 1	11 59	do	Kilauea caldera	
63	2	14 36	do	do	
64	6	20 44	Feeble	Hilina fault system about 2 miles northwest of Ka Lae a Puki.	Felt at Hilo and in Volcano district.
65	9	05 59	Very feeble		
66	9	07 51	do		
67	9	10 51	do		
68	9	13 57	Slight	Hilina fault system about 2.5 miles northwest of Kaena Point.	
69	9	14 01	Very feeble		
70	10	13 45	do		
71	11	10 10	do		
72	12	03 37	do		
73	12	16 28	do		
74	12	16 54	Feeble	Central Kona	Slight, Kona.
75	12	17 07	Very feeble		
76	12	17 11	do		
77	12	22 17	do		
78	13	11 38	Strong	Off south shore, at lat, 19°02′ N., long, 155°06′ W.	Felt from Volcano district to Naalehu.
79	14	17 45	Very feeble	Kilauea	
80	14	18 21	Strong	Off south shore, at 19°03′ N., 155°05′ W.	Felt from Hilo to Kapapala.
81	14	19 06	Very feeble		
82	14	19 09	do		
83	15	22 16	do	Kilauea caldera	
84–1,427	16–31		Mostly very feeble to slight.	Earthquakes mostly originating off the south shore of the island.	Moderate and strong earthquakes of this group, and earthquakes of other origin, are listed separately below.
88	16	15 53	Feeble	Kilauea caldera	Shallow. Felt in Volcano district.
95	16	22 45	Very feeble	Hilina fault system 2 miles west of Kupaahu, at 19°20′ N., 155°02′ W.	
148	17	17 58	Strong	Off south shore at 19°07′ N., 155°02′ W.	Felt at Naalehu, caused small tsunami at Kalapana.
167	18	04 50	Very feeble	Kilauea	
183	18	08 03	do	Kilauea caldera	
199	18	10 53	Moderate	Off south shore, at 19°00′ N., 155°20′ W.	Felt at Naalehu.
212	18	13 01	do	Off south shore at 19°06′ N., 155°20′ W.	
220	18	14 18	Strong	Off south shore at 19°05′ N., 155°25′ W.	

TABLE 2.—*Local earthquakes stronger than tremors recorded at Hawaiian Volcano Observatory during 1952*—Continued

Serial no.	Date	Time (Hawaiian standard)	Intensity at Whitney Laboratory	Epicenter	Remarks
		h m			
275	Mar. 19	02 55	Strong	Off south shore, at 19°06′ N., 155°02′ W.	Felt at Naalehu.
283	19	08 05	Very feeble	Kilauea	
340	19	15 51	Strong	Off south shore at 19°02′ N., 155°20′ W.	
385	20	01 22	do	Off south shore at 19°02′ N., 155°18′ W.	
414	20	09 51	do	Off south shore at 19°03′ N., 155°15′ W.	Do.
466	20	20 16	Moderate	Off south shore at 19°03′ N., 155°24′ W.	Do.
494	20	23 48	do	Off south shore at 19°02′ N., 155°24′ W.	Do.
524	21	04 35	Strong	Off south shore at 19°03′ N., 155°14′ W.	Do.
567	21	14 25	Moderate	Off south shore at 19°04′ N., 155°14′ W.	
649	22	02 05	Strong	Off south shore at 19°02′ N., 155°12′ W.	Do.
668	22	06 19	Moderate	Off south shore at 19°08′ N., 155°00′ W.	
762	22	19 20	do	Off south shore at 19°06′ N., 155°04′ W.	Do.
808	23	06 52	do	Off south shore at 19°12′ N., 154°55′ W.	Felt at Naalehu and Pahala.
842	23	15 05	do	Off south shore at 19°03′ N., 155°14′ W.	Felt at Naalehu and Kapapala.
894	24	02 02	do	Off south shore at 19°08′ N., 155°02′ W.	Felt at Naalehu.
927	24	13 29	Strong	Off south shore at 19°06′ N., 155°02′ W.	Do.
954	25	00 30	Moderate	Off south shore at 19°01′ N., 155°17′ W.	
965	25	07 04	Strong	Off south shore at 19°04′ N., 155°06′ W.	Do.
979	25	09 17	do	Off south shore at 19°05′ N., 155°05′ W.	Do.
1016	26	04 40	Moderate	Off south shore at 19°03′ N., 155°14′ W.	Do.
1083	27	04 31	do	Off south shore at 19°03′ N., 155°13′ W.	Do.
1128	27	22 44	do	Off south shore at 19°02′ N., 155°14′ W.	Felt at Naalehu and Pahala.
1166	28	11 57	do	Off south shore at 19°03′ N., 155°11′ W.	Felt at Naalehu.
1200	29	02 42	do	Off south shore	Do.
1317	30	13 53	Strong	do	
1422	31	22 00	do	Off south shore at 19°02′ N., 155°13′ W.	Do.
1428–1886	Apr. 1–May 31		Mostly very feeble to slight.	Earthquakes mostly originating off the south shore of the island.	Moderate and strong earthquakes of this group, and earthquakes of other origin, are listed separately below.
1529	Apr. 3	05 09	Feeble	Kaoiki fault near Ohaikea	
1531	3	06 23	Very feeble	Kilauea, east rift	
1532	3	06 27	do	do	
1547	4	11 09	Slight	Kilauea, east rift near Napau Crater.	
1548	4	11 19	Feeble	do	
1554	4	16 08	do	Kilauea caldera	Shallow.
1555	4	20 08	do	Hilina fault zone, about 1.8 miles N. 10° W. of Ka Lae a Puki.	Do.
1569	5	11 23	Moderate	Kilauea, east rift near Makaopuhi.	About 13 miles deep.
1571	5	14 16	do	Off south shore of Hawaii	
1587	5	21 04	do	Kilauea, east rift near Napau Crater.	
1596	6	03 44	Slight	do	
1597	6	04 06	Feeble	Kilauea, east rift about 1.5 miles west of Kalalua Crater.	
1612	6	15 10	Moderate	Off south shore of Hawaii	
1623	6	20 53	Slight	Kilauea caldera	Shallow.
1631	6	22 58	Strong	do	Shallow. Felt generally in Volcano district.

TABLE 2.—*Local earthquakes stronger than tremors recorded at Hawaiian Volcano Observatory during 1952*—Continued

Serial no.	Date	Time (Hawaiian standard)	Intensity at Whitney Laboratory	Epicenter	Remarks
		h m			
1639	Apr. 7	01 31	Feeble	Kilauea caldera	Shallow.
1640	7	01 54	do	Kilauea, east rift about 1 mile east of Makaopuhi Crater.	
1645	7	03 59	Slight	Kilauea caldera	Do.
1653	7	06 05	Moderate	Kilauea, east rift near Puu Huluhulu.	Do.
1656	7	06 44	Slight	Kilauea caldera	Do.
1668	7	12 15	Very feeble	Kilauea, east rift near Alae Crater.	
1669	7	12 53	Strong	Kilauea, east rift near Makaopuhi Crater.	Felt from Naalehu to Volcano. About 12 miles deep.
1670	7	13 00	Moderate	Off south shore of Hawaii	
1671	7	23 55	do	Kilauea, east rift near Alae Crater.	About 7 miles deep.
1701	10	16 56	do	Hilina fault zone at Poliokeawe Pali, 3.5 miles N. 45° W. of Kaena Point.	Felt at Naalehu.
1703	10	22 52	Slight	Deep (20 miles?) beneath the southwest rift of Mauna Loa near the 9,200-foot contour.	Moderate, Mauna Loa. Felt strongly from Naalehu to Volcano, moderately at Hilo, and slightly as far as Paauhau and Kukuihaele.
1705	11	07 34	Feeble	Kilauea, east rift near Makaopuhi Crater.	
1711	12	01 29	do	Kilauea, east rift about 2 miles east of Napau Crater.	Shallow.
1715	12	05 53	Strong	Kilauea, east rift 1 mile northwest of Heake Crater.	Felt at Naalehu and Kapapala. About 13 miles deep.
1716	12	06 22	Moderate	Off south shore of Hawaii	
1719	12	16 55	Very feeble	Kilauea, east rift near Puhimau Crater.	
1721	12	19 40	Slight	Kilauea, east rift near Puu Huluhulu.	Felt in Volcano district.
1726	13	12 29	Feeble	Kilauea, east rift near Puhimau Crater.	
1729	13	21 04	Very feeble	Kilauea, east rift about 2 miles east of Kalalua Crater.	Shallow.
1734	14	08 37	Slight	do	Do.
1736	14	12 25	Very feeble	Kilauea, east rift near Kalalua Crater.	
1737	14	16 56	do	do	
1739	15	07 51	Feeble	East rift of Mauna Loa	Shallow.
1745	15	17 56	Slight	Kilauea, 2 miles west-southwest of Puu Ohale.	About 6 miles deep.
1746	15	17 59	do	Kilauea, 3 miles west-southwest of Puu Ohale.	About 5 miles deep.
1750	16	00 58	Feeble	Kilauea, east rift near Makaopuhi Crater.	
1752	16	07 08	Moderate	Off south shore of Hawaii	
1780	21	17 45	do	Off south shore of Hawaii, 16 miles S. 10° W. of Apua Point.	
1813	May 3	18 16	do	Off south shore at 19°12′ N., 155°21′ W.	
1816	6	06 35	Feeble	Off south shore at 19°09′ N., 155°19′ W.	Felt at Kapapala.
1830	10	19 14	Strong	Kilauea Caldera	About 7 miles deep.
1839	13	22 50	Slight	Southeast slope of Mauna Loa.	
1842	15	04 10	Feeble	Hilina fault system at 19°18′ N., 155°10′ W.	
1849	10	01 16	Slight	Off south shore at 19°03′ N., 155°07′ W.	
1851	19	04 08	do	Southeast slope of Mauna Loa, at 19°20′ N., 155°29′ W.	
1856	21	17 13	Moderate	Southeast slope of Mauna Loa, at 19°18′ N., 155°28′ W.	

TABLE 2.—*Local earthquakes stronger than tremors recorded at Hawaiian Volcano Observatory during 1952*—Continued

Serial no.	Date	Time (Hawaiian standard)	Intensity at Whitney Laboratory	Epicenter	Remarks
		h m			
1863	May 23	12 13	Strong	Kealakekua fault, about 3.5 miles west of Napoopoo, central Kona, at 19°29′ N., 155°59′ W., about 6 miles deep.	Magnitude 6 assigned at Pasadena, Calif. Felt over all the Island of Hawaii, and on the Island of Maui. Minor damage in central Kona.
1866	24	03 32	Feeble	Kilauea caldera	Shallow.
1882	29	13 20	do	do	Do.
1883	31	05 00	Very feeble	Off south shore at 19°02′ N., 155°21′ W.	
1884	31	06 52	Feeble	Southeast slope of Mauna Loa, at 19°20′ N., 155°26′ W.	
1888	June 1	01 05	Moderate	About 4 miles north-northeast of Whitney Laboratory of Seismology.	
1895	3	21 12	Slight	About 4 miles north-northeast of Whitney Laboratory, on hypothetical extension of Kaoiki fault.	Felt in Volcano district.
1919	10	16 25	do	Summit of Mauna Loa	Shallow. Felt at Kapapala.
1920–1923	11		Very feeble	Kilauea caldera	Shallow.
1924	11	08 01	Slight	Off south shore at 19°01′ N., 155°16′ W.	
1925	11	08 12	Feeble	Kilauea caldera(?)	
1931	13	06 57	Slight	About 4 miles northeast of Whitney Laboratory.	Felt in Volcano district.
1939	14	10 44	do	Kilauea Caldera	Shallow. Felt in Volcano district.
1953	17	16 37	Very feeble	East slope of Mauna Loa	
1954	18	05 17	Slight	Off south shore at 19°02′ N., 155°20′ W.	
1955	18	05 20	Feeble	Off south shore	
1957	19	16 03	Strong	Southwest rift of Kilauea about 0.5 mile northeast of Mauna Iki.	Shallow.
1958	17	16 20	Slight	Southwest rift of Kilauea near Ponohohoa.	
1959	19	16 27	Moderate	Kilauea, southwest rift near Kamakaia Hills.	
1960–2024	19–26		Very feeble	Nearly all apparently originating in the vicinity of Kilauea caldera at very shallow depths.	
2025	26	07 53	do	Near summit of Mauna Loa	
2026	26	17 23	do	Near Kapapala, probably on Kaoiki fault.	Shallow. Felt strongly at Kapapala.
2027–2047	26–27		do	Earthquakes apparently originating in the vicinity of Kilauea caldera at very shallow depths.	Continuous volcanic tremor started at 23ʰ37ᵐ30ˢ on June 27, at about the time glow was first observed at Halemaumau, and appears to mark beginning of eruption.
2048	27	23 39	do	Kilauea caldera	
2049	27	23 49	do	do	
2050	27	23 51	do	do	
2051	27	23 58	Slight	do	
2052	28	00 20	Very feeble		
2053	28	00 31	do		
2054	28	00 47	Moderate	Kilauea caldera	
2055–2063	28–30		Very feeble and feeble.		Earthquakes accompanying the eruption of Kilauea volcano.
2064	July 1	04 16	Very feeble		
2065	3	09 05	Feeble		Slight, Mauna Loa.
2066	3	12 26	do		Do.
2067–2069	5		No record	Central Kona	Very feeble, Kona.
2070	6	15 38	Very feeble		Feeble, Hilo. Felt at Kukuihaele.

TABLE 2.—*Local earthquakes stronger than tremors recorded at Hawaiian Volcano Observatory during 1952*—Continued

Serial no.	Date	Time (Hawaiian standard) h m	Intensity at Whitney Laboratory	Epicenter	Remarks
2071	July 6	22 56	Feeble		Felt at Kukuihaele.
2072	7	04 43	Slight		Felt at Hilo and Kukuihaele.
2073	7	06 16	Very feeble		
2074	9	06 54	Slight		Felt in Volcano district.
2075–2076	9	08 10	do	Hilina fault system(?)	Twin earthquake. Felt at Hilo, Volcano, and Naalehu.
2077	12	13 53	Moderate	Central Kona	Strong, Kona. Felt from Kona to Hilo.
2078	14	16 45	Tremor		Very feeble, Mauna Loa.
2079	16	12 32	Feeble		
2080	17	17 44	Tremor		Do.
2081	17	18 14	do		Do.
2082	21	11 49	do		Do.
2083	22	02 46	No record		Very feeble, Kona.
2084	27	14 51	do		Very feeble, Mauna Loa and Hilo.
2085	29	01 30	do		Very feeble, Mauna Loa.
2086	29	10 51	do		Do.
2087	Aug. 1	12 33	Slight		
2088	2	15 17	No record		Very feeble, Kona.
2089	2	16 10	Slight		
2090	3	14 49	No record		Very feeble, Kona.
2091	3	18 08	do		Very feeble, Mauna Loa.
2092	4	04 00	do		Very feeble, Kona.
2093	5	18 21	Tremor		Very feeble, Mauna Loa.
2094	9	10 31	Feeble		Slight, Mauna Loa and Hilo.
2095	10	18 06	No record	East rift of Mauna Loa	Very feeble, Mauna Loa.
2096	11	12 21	Tremor		Do.
2097	12	20 16	do		Very feeble, Mauna Loa, Hilo, and Kona.
2098	13	00 52	do		Feeble, Mauna Loa.
2099	14	14 08	Slight	Off south shore of Hawaii	Felt at Volcano, Kapapala, and Naalehu.
2100	16	21 07	Moderate	do	
2101	18	13 59	Slight	Kaoiki fault(?)	Moderate, Mauna Loa.
2102	25	21 20	Very feeble		
2103	30	12 34	Tremor		Very feeble, Mauna Loa.
2104	31	05 39	Very feeble		
2105	Sept. 2	04 45	Feeble	Kilauea caldera	Felt at Glenwood, Volcano, Naalehu, Kona.
2106	3	12 47	Tremor		Very feeble, Mauna Loa.
2107	6	20 51	No record	Central Kona	Feeble, Kona.
2108	8	02 27	do		Very feeble, Kona.
2109	9	20 21	do		Do.
2110	10	07 50	do		Do.
2111–2112	12		do		Do.
2113	14	08 11	Very feeble		Felt at Kukuihaele.
2114	14	18 21	No record		Very feeble, Kona.
2115	17	12 41	Tremor		Feeble, Kona. Felt in Kona.
2116	18	14 15	do		Very feeble, Kona.
2117	19	15 57	No record		Do.
2118	19	20 58	do		Very feeble, Kona. Felt in Kona.
2119	20	06 53	do		Do.
2120	22	02 23	Very feeble		
2121	22	12 27	do		
2122	24	11 45	No record	Central Kona	Feeble, Kona. Felt in Kona.
2123	26	14 56	Very feeble		
2124	27	07 22	Tremor	Central Kona, probably Kealakekua fault.	Slight, Kona. Felt in Kona.
2125	27	20 36	Very feeble		
2126	30	04 10	No record		Very feeble, Kona. Felt in Kona.
2127	30	20 57	Very feeble		
2128	Oct. 2	10 04	do		
2129	3	12 12	Feeble		Slight, Mauna Loa. Felt at Naalehu and Kapapala.
2130	4	02 56	Very feeble		
2131	4	18 32	do		
2132	5	14 29	do		

TABLE 2.—*Local earthquakes stronger than tremors recorded at Hawaiian Volcano Observatory during 1952*—Continued

Serial no.	Date	Time (Hawaiian standard)	Intensity at Whitney Laboratory	Epicenter	Remarks
		h m			
2133	Oct. 5	16 14	Very feeble		
2134	7	11 40	do		
2135	7	11 54	do		
2136	8	00 04	do		
2137	8	05 20	do		
2138	8	14 40	do		Feeble, Mauna Loa.
2139	8	18 59	do		
2140	9	15 35	No record		Feeble, Hilo.
2141	9	17 46	Very feeble		
2142	10	14 14	do		
2143	11	05 14	do		
2144	11	19 42	do		
2145	12	13 42	do		
2146	13	21 53	No record		Very feeble, Mauna Loa.
2147	13	23 36	Very feeble		
2148	14	07 30	do		
2149	14	11 52	No record		Do.
2150	14	21 58	do	Central Kona	Very feeble, Kona.
2151	15	06 55	Very feeble		
2152	16	14 31	do		
2153	16	15 37	do		
2154	18	02 47	do		
2155	18	17 02	do	Kaoiki fault near Wood Valley(?).	Felt at Kapapala.
2156	18	21 17	do		
2157	20	11 25	do		
2158	21	07 23	do		
2159	22	01 45	No record		Feeble, Kona.
2160	22	10 10	Very feeble		
2161	22	16 39	Feeble	Kaoiki fault near Bird Park (?).	
2162	23	14 11	Very feeble	Kilauea	
2163	24	15 00	do		
2164	25	09 25	do	Central Kona	Slight, Kona. Felt in Kona.
2165	25	14 30	Tremor		Very feeble, Mauna Loa.
2166	25	14 44	do		Do.
2167–2175	25		Very feeble		Very feeble, Mauna Loa; at other stations tremors or no record.
2176–2184	26		do		Do.
2185–2186	27		do		Do.
2187	29	13 39	do		
2188	30	05 15	No record		Very feeble, Kona.
2189	Nov. 1	01 23	Very feeble		
2190	1	14 11	do		
2191	2	02 57	do		
2192	5	12 49	do	Southwest rift of Kilauea(?).	
2193	7	22 21	do		
2194	8	18 33	do		
2195	9	16 56	do		
2196	10	21 42	do	Central Kona	Moderate, Kona. Felt in Kona.
2197	12	08 05	do		
2198	12	10 43	do		
2199	12	17 43	do		
2200	13	12 28	Slight	Off south shore of Hawaii	
2201	13	12 54	No record	Central Kona	Feeble, Kona.
2202	13	14 57	Tremor		Very feeble, Kona.
2203	16	02 40	Very feeble		
2204	16	02 41	Slight	Off south shore of Hawaii	
2205	16	09 49	Very feeble		
2206	18	00 39	No record		Very feeble, Kona.
2207	19	03 27	Very feeble		
2208	20	10 19	do	Kilauea.	
2209	22	01 08	Slight	East rift of Kilauea near Alae Crater.	About 13 miles deep.
2210	23	18 31	Very feeble		
2211	27	16 35	do	Central Kona	Feeble, Kona. Felt in Kona.

TABLE 2.—*Local earthquakes stronger than tremors recorded at Hawaiian Volcano Observatory during 1952*—Continued

Serial no.	Date	Time (Hawaiian standard) h m	Intensity at Whitney Laboratory	Epicenter	Remarks
2212	Nov. 27	22 14	Slight	Near summit of Mauna Loa, 4 miles west of North Bay, end of Mokuaweoweo, 19° 29′ N., 155°38′ W.	Felt in Kona.
2213	Dec. 1	00 30	Very feeble		
2214	1	01 22	do	Off south shore(?).	
2215	3	01 12	Tremor	West slope of Mauna Loa	Feeble, Kona. Felt in Kona.
2216	3	09 10	No record	Central Kona	Very feeble, Kona.
2217	3	20 03	do		Very feeble, Kona. Felt in central Kona.
2218	5	17 59	Very feeble	Off south shore at 19°06′ N., 155°19′ W.	
2219	6	09 45	do	Kilauea.	
2220	7	02 26	do	West slope of Mauna Loa at about 19°28′ N., 155°43′W.	
2221	7	11 12	do		
2222	8	17 30	do		
2223	10	18 01	do	Near summit of Mauno Loa.	Felt at Naalehu.
2224	11	01 06	do		
2225	12	09 09	Feeble	Kaoiki fault, south of Ainapo.	Felt at Naalehu and Volcano district.
2226	15	18 47	Very feeble	East rift of Kilauea near Puu Huluhulu.	Shallow.
2227	15	18 57	do	Kilauea caldera, 28 miles deep(?).	
2228	15	21 11	do		
2229	17	03 00	No record		Very feeble, Kona.
2230	21	12 12	do	Central Kona	Do.
2231	22	01 18	do		Do.
2232	23	03 46	Tremor		Do.
2233	25	00 10	Very feeble		Felt in central Kona.
2234	28	01 22	do	Beneath summit of Hualalai.	Moderate, Kona. Felt in Kona.
2235	29	20 55	No record		Very feeble, Kona.
2236	31	16 00	Tremor	Central Kona	Do.

TABLE 3.—*Distant earthquakes recorded by seismographs of the Hawaiian Volcano Observatory during 1952*

[Based on Bosch-Omori seismograph in Whitney Laboratory of Seismology]

Date	Time (Hawaiian standard) h m	Strength at Whitney Laboratory	Epicenter (From Preliminary determinations of Epicenters by U. S. Coast and Geodetic Survey)
Jan. 12	10 28	Slight	Fox Islands, in Aleutian archipelago.
Mar. 3	15 33	Strong	Near the east coast of Hokkaido Island, Japan.
5	06 08	Slight	Off east coast of Hokkaido.
9	06 58	do	Near south coast of Kamchatka.
June 10	00 15	do	Fiji Islands region.
22	11 58	do	Kurile Islands.
July 21	01 59	Strong	Tehachapi, Calif.
28	22 10	Slight	Southern California(?).
Aug. 20	05 39	Moderate	Off coast of Oregon.
Sept. 9	03 29	Slight	Near coast of Costa Rica.
Nov. 4	07 07	Very strong	Near south end of Kamchatka Peninsula. Accompanied by a tsunami that did moderate damage in the Hawaiian Islands.
29	14 03	Slight	Off southern coast of Alaska Peninsula, at 56° N., 155° W.

THE TSUNAMI OF NOVEMBER 4

On November 4, 1952, a strong earthquake occurred off the southeastern coast of Kamchatka. The notice of Preliminary Determination of Epicenter issued by the U. S. Coast and Geodetic Survey gives the point of origin as latitude 52½° N., longitude 159° E., and the time of origin as $16^h58^m20^s$ Greenwich civil time ($6^h58^m20^s$ Hawaiian standard time).

The earthquake was recording on the Bosch-Omori seismograph when the record was changed at 07^h45^m. The amplitude was among the largest recorded at the Volcano Observatory. Quick inspection of the record indicated that the quake probably originated beneath the Pacific Ocean, or very near to its border, and consequently might be accompanied by a tsunami. The intensity of the earthquake suggested that the tsunami might be severe.

At about 08^h the writer notified the Hawaii Police Department in Hilo that an earthquake had occurred and suggested that they be alert for a possible "tidal-wave" warning that would be issued by the Seismic Sea Wave Warning System of the Coast and Geodetic Survey. The statement was also made that it would be at least 3 hours before the "tidal wave," if there were one, would reach Hilo.

By 09^h, further study of the local records and comparison of arrival times at mainland stations, received by wire from the Hilo Tribune-Herald, made it apparent that the quake had originated in the Kamchakta area and that, if a tsunami had been generated, it should reach Hilo about 13^h30^m. Shortly afterward the actual wave warning was issued by the Coast and Geodetic Survey, based on reports of actual observed water waves.

The tsunami reached Hilo at approximately 13^h30^m, as predicted. The record of the tide gage at Kuhio wharf shows that a rise of about 4 feet began at 13^h32^m, bringing the water level to approximately 7 feet above mean lower low tide at 13^h49^m. This was followed by a trough, bringing the water level to 1 foot below mean lower low tide at 14^h05^m. These extreme oscillations were followed by a series of diminishing oscillations, having an average period of about 17 minutes, that continued for the next several days. The dominant period of 17 minutes in these oscillations probably is approximately that of the harbor seiche.

Heights reached by the water on the island of Hawaii were much less than in the Aleutian tsunami of 1946 (fig. 1). At Hilo the greatest heights measured were at Kuhio wharf, in Reeds Bay, and on Cocoanut Island (fig. 4). Water swept over the wharf to a depth of 11.5 feet above mean lower low tide. Near the head of Reeds Bay the high-water mark ranged from 9 to 11 feet above the same datum, and on Cocoanut Island the greatest height was approximately 12 feet. Near

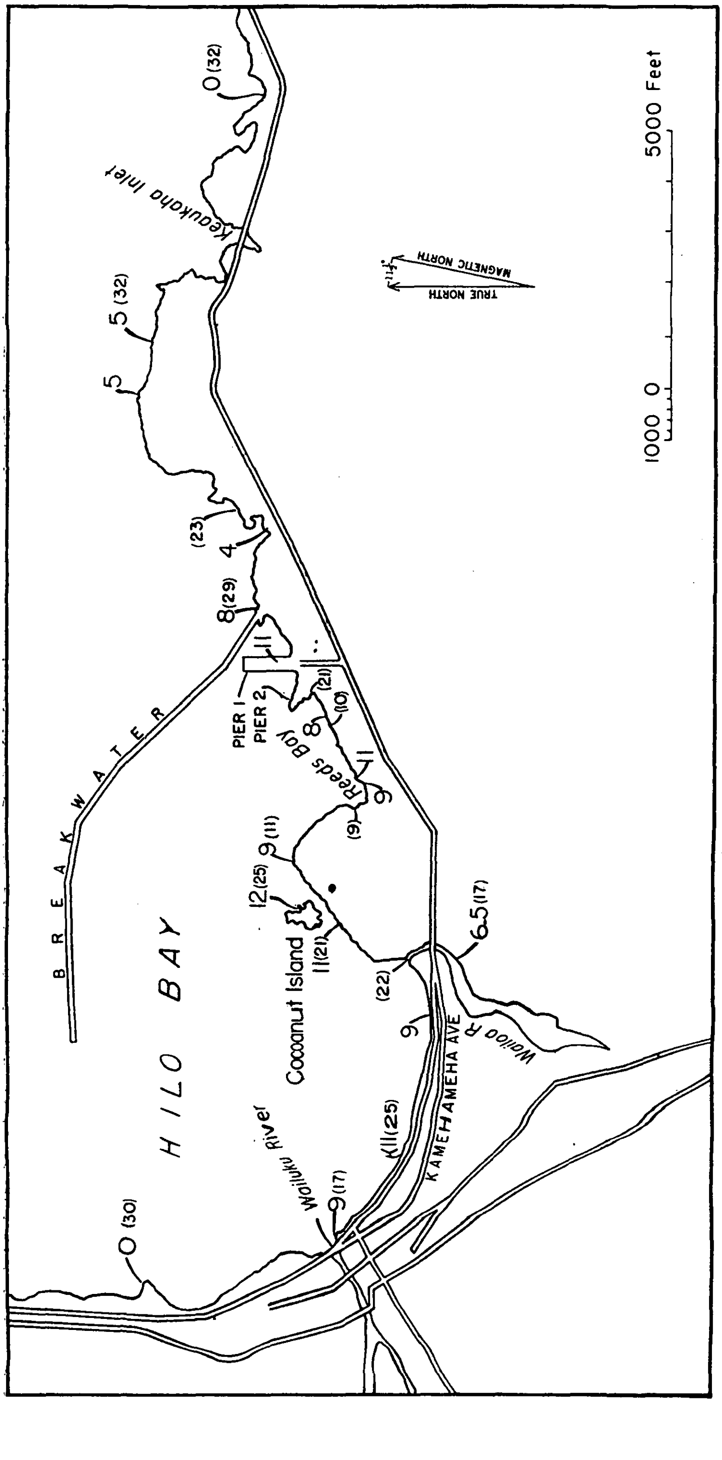


FIGURE 4.—Map of Hilo Bay, showing heights reached by the tsunamis of November 4, 1952, and April 1, 1946. The heights are given in feet above mean low tide. The larger size figures are those for the tsunami of November 1952, and the smaller ones in parentheses are those for the tsunami of April 1946.

the mouths of Wailuku and Wailoa Rivers the water reached a height of about 9 feet.

Northward and eastward from Hilo the height of the water decreased rapidly, and east of Keaukaha estuary the rise was so slight that it is not certain any occurred. The same condition prevailed along the southeastern, southern, and northeastern coast of the island. Along the western coast the rise at most places ranged from 2 to 4 feet. On Hawaii, damage was restricted to the Hilo area.

Damage at Hilo included beaching of several sampans and rolling over of another on the ways in a boat-building yard; damage to buildings on Cocoanut Island and near the head of Reeds Bay; destruction of one span of the bridge to Cocoanut Island; flood damage at the Naniloa Hotel, at the wharf, and along the shore between the wharf and Reeds Bay; and destruction of a boat landing at the wharf.

Nearly all the damage observed in Hilo probably was the result of gentle flooding. No signs were observed of violent impact, such as occurred in 1946 (Macdonald, Shepard, and Cox, 1947). No sharp crest, or "bore" front, was reported in Hilo Bay, although an 18-inch bore was reported in the Wailoa estuary.

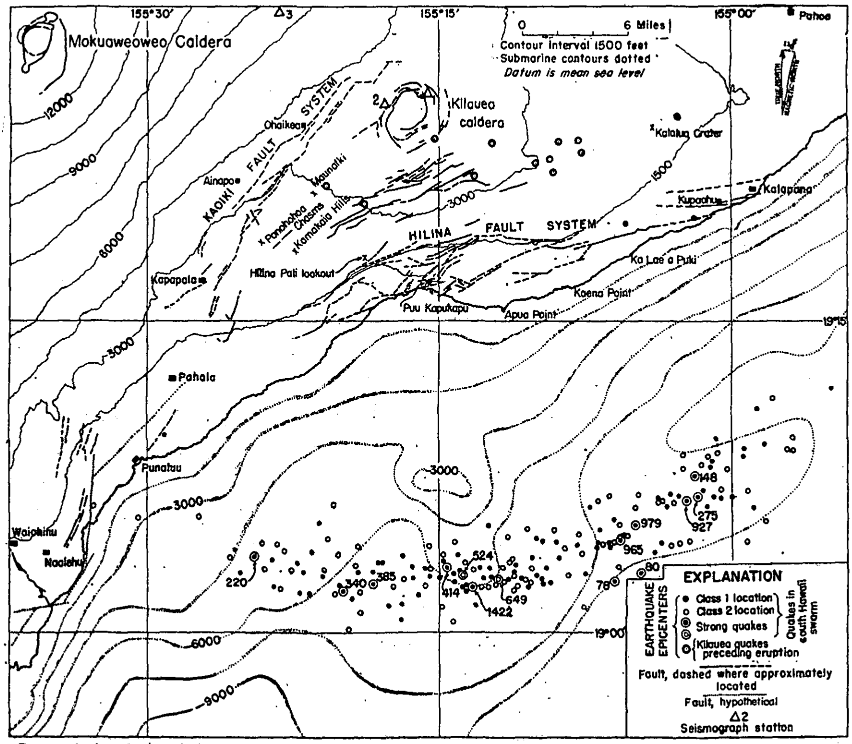
The boat landing, a house on a bar in Reeds Bay, and the span of the Cocoanut Island bridge apparently were floated from their foundations. During crests of the tsunami water poured into the bay through the channel and by flooding over the breakwater. In contrast, during troughs the water could drain out only through the channel, except for the relatively small amount that leaked through the stonework of the breakwater. As a result, water accumulated in the bay behind the breakwater and flooded that part of the shore.

Differences in pattern of the effects around the island of Hawaii between the tsunamis of 1946 and 1952 illustrate well the individuality of such waves, resulting from disturbances of different sizes, centering at different distances and directions. Such individuality makes extremely difficult prediction of the nature and size of the effects at any given locality, even when measurements are available from other areas nearer the point of origin of the waves. The generally excellent operation of the Seismic Sea Wave Warning System in November 1952 demonstrates that general prediction of the occurrence of a tsunami of distant origin is now well in hand, but many more observations, over a period of many years, will be necessary before accurate local predictions can be made.

THE SOUTH HAWAII EARTHQUAKES OF MARCH AND APRIL

At 11^h38^m Hawaiian standard time on March 13 a strong earthquake (no. 78, fig. 5 and table 2) originated beneath the ocean south of the island of Hawaii, 23 miles S. 19° W., of the coastal village of

Kalapana. The earthquake was felt over all the southern part of the island, and its intensity along the southern shore was estimated at 4 in the modified Mercalli scale. At 18^h20^m on March 14 a similar earthquake (no. 80, fig. 5) originated in the same general area. These quakes were the forerunners of a great swarm of earthquakes that began on March 16 and continued throughout April.



Topography by U.S. Geological Survey

FIGURE 5.—Map of part of the southeastern coast of Hawaii, showing the location of epicenters of earthquakes during March, April, and May, 1952, and the positions of known and hypothetical faults above sea level. The broad bulge in the submarine contours south of Kilauea caldera probably marks a submarine shield volcano with a ridge extending eastward along a rift zone. Stronger earthquakes numbered as in table 2.

On March 16 the seismographs at Kilauea caldera recorded 39 earthquakes, all probably originating in the offshore area south of the island. On the following days the number of quakes rapidly increased, reaching a peak of 395 on March 20. Figure 6 indicates the daily seismicity at the Volcano Observatory from March 16 to April 30. The daily seismicity was determined by assigning a seismicity value to each earthquake, depending on its size, and totaling the values for each day (Macdonald and Wentworth, 1954, p. 148). Each strong earthquake was assigned a seismicity value of 4.

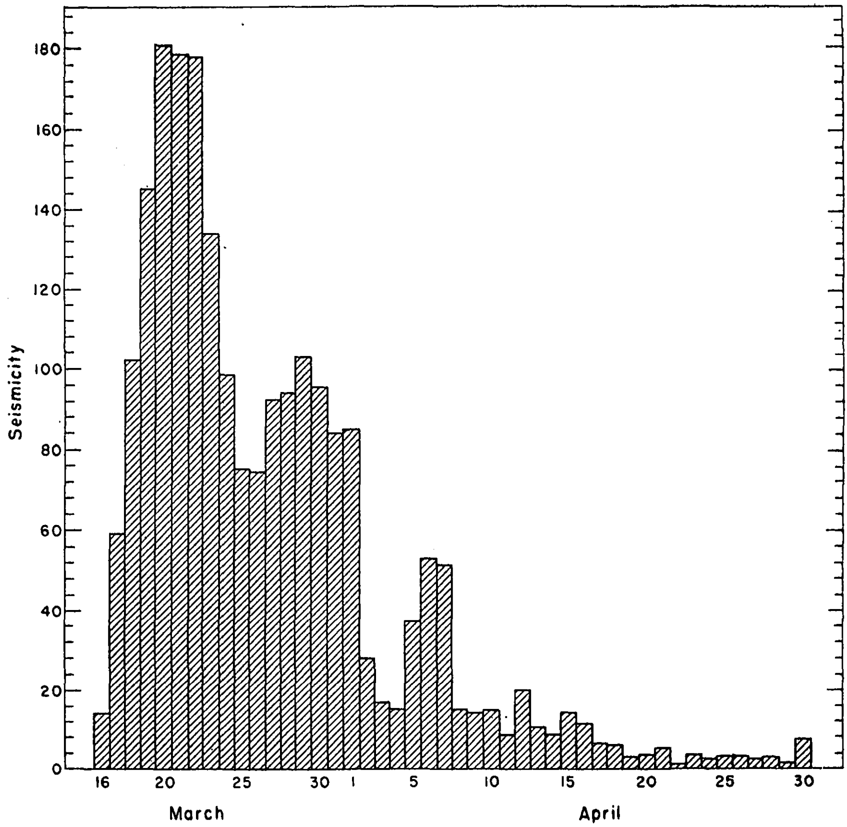


FIGURE 6.—Graph showing daily seismicity at the Whitney Laboratory of Seismology from March 16 to April 30, 1952.

Decrease in the number of quakes from foci south of the island was less rapid than the increase had been, and at a fairly regular declining rate. In figure 6, the marked hump in the curve on April 5–7 is caused by a series of earthquakes originating on the east rift zone and beneath the caldera of Kilauea volcano. This swarm of Kilauea earthquakes was essentially over by April 8, although quakes of Kilauea origin were recorded through the rest of April.

At the end of April, the total number of earthquakes recorded since March 13 was 4,553. Most of these were small and many were tremors too small to permit the recognition of phases in the seismogram. On the basis of the records from the Bosch-Omori seismograph in the Whitney Laboratory of Seismology, 31 were classed as moderate and 18 as strong. Several of the strong earthquakes were felt generally over the southern part of the island. All the strong quakes and many of the smaller ones were felt in the area from Kapapala to and beyond Naalehu (fig. 5). During the height of the activity it is estimated that 20 to 30 earthquakes a day were felt at Naalehu. Northeastward at Kapapala, residents felt fewer earthquakes than at Naalehu; and a still smaller number was felt in the Kilauea caldera area. It is noteworthy that very few of the earthquakes were felt at Kalapana, despite the proximity of that village to the epicenters of many of the quakes. The shocks were much more generally felt in the region nearly in line with the presumed submarine fault on which they originated than in areas at similar distances approximately normal to the fault.

None of the earthquakes caused much damage to property, although several of the large ones caused slight shifting or overturning of small objects on shelves. A strong quake (no. 148, fig. 5) at 17^h58^m on March 17 caused a small tsunami ("tidal wave") at Kalapana. At about 18^h waves swept inland about 600 feet, entering the yard of the Kalapana School. Storm waves at the time were not of sufficient size to account for the incursion of the water. This small tsunami produced no record on the tide gage at Hilo. No damage was done. However, the writer considered it advisable to issue a warning to all communities along the southeastern shore of the island that as long as the swarm of submarine earthquakes continued there was a possibility that a large quake of shallow origin might be accompanied by a destructive tsunami. On the basis of this warning, the Department of Public Instruction ordered the Kalapana School closed and the children were transported to school elsewhere, until the swarm of undersea earthquakes ended.

About 185 earthquakes of the swarm yielded seismograms on which the emergence of the *P* and *S* phases could be recognized with sufficient certainty at several stations to permit reasonably accurate location of the epicenter. These epicenters are indicated in figure 5. All were located by means of the distance indicated by the interval *S–P*, using at least three stations. Records from the Whitney Laboratory, Mauna Loa station, and Hilo station were used in nearly all the locations, and the locations of the strong earthquakes were checked by means of the records of the Kona station. Checks on many locations were obtained from the records of the vertical seismographs and the Imamura strong-motion seismograph at Uwekahuna. In addition, a portable seismograph was operated by J. C. Forbes at Naalehu on March 26, at Punaluu on March 28, and at the Hilina Pali lookout station on April 1.

In figure 5, two classes of epicentral locations are shown. In locations of class 1 there was good agreement of the data from all stations. In locations of class 2 the agreement was less perfect, although still close. Instances in which agreement of the data was poor were rejected, and those epicenters are not shown in figure 5. Owing to the unfavorable distribution of seismograph stations with regard to the earthquake epicenters, depth determinations were too uncertain to be useful.

Submarine contours based on the soundings shown on U. S. Coast and Geodetic Survey chart 4115 (7th ed., June 1940) show a broad dome with its apex 21 miles nearly due south of the summit of Kilauea volcano. Soundings are inadequate to give a detailed picture of this feature, and it is highly desirable that many more soundings be obtained off the island of Hawaii. Existing soundings are, however, adequate to give a rather definite generalized picture. A few old isolated soundings not accordant with adjacent new soundings, and probably erroneous in position, have been rejected in contouring.

The contours are shown by dotted lines in figure 5. The dome is probably a shield volcano, lying against the side of the Kilauea shield just as Kilauea does against the side of Mauna Loa. The broad nose projecting eastward, shown by the minus-9,000-foot contour, probably is a ridge built along an eastward-trending rift zone like that of Kilauea. It is noteworthy that this probable submarine volcano lies almost exactly on a line drawn through the summits of Hualalai and Mauna Loa volcanoes. The line coincides with a minor rift zone on the upper slopes of Mauna Loa along which eruption occurred in prehistoric times.

The distribution of epicenters in figure 5 clearly indicates that the earthquake swarm was caused by movements along a line or narrow zone nearly parallel to the southern coast of the island. The eastern part of the line lies approximately along the axis of the eastward-trending submarine ridge, and the entire line may mark a rift zone crossing south of the summit of the shield, as does the rift zone of Kilauea. If so, the movements that caused the earthquakes may have accompanied subterranean magma movement or eruption of the submarine volcano. Careful observation was made throughout the earthquake period for any signs of submarine eruption. On March 28 a cowboy employed by the Kapapala Ranch reported seeing three puffs of cloud rising from the ocean south of the island, at 14^h32^m, 14^h50^m, and 15^h10^m, respectively. These were not reported by any other observer. The ocean south of the island was under observation for the next several days from the Volcano Observatory, and on March 29 and April 1 from the Hilina Pali lookout. Both binoculars and a telescope were employed. Several times watchers at the observatory saw puffs of cloud that at first appeared to be rising from the ocean, but each time further observation showed them to be merely developing puffs of the common coastal cumulus. From Hilina Pali no clouds were observed rising from the ocean, nor was any other disturbance of the ocean surface observed.

It is entirely possible that eruption in several thousand feet of water might not produce any visible evidence at the surface. Pressure of overlying water might prevent vesiculation of sufficient degree to produce pumice or scoria light enough to float to the surface. Steam generated by contact of the hot lava with ocean water probably would be cooled and condensed as it rose through the overlying cold water, and magmatic gases might be entirely dissolved. Thus neither floating pumice nor rising gases might be visible at the surface. On the other hand, it appears unlikely that eruption could have occurred without producing some record of volcanic tremor on the seismographs. Such tremor characteristically accompanies eruptions of Mauna Loa and Kilauea, but it was totally absent from the records during March and April 1952. Furthermore, even in deep water the heating of the immediately surrounding water, and possibly the introduction of toxic gases, probably would cause the death of many fish, which would float ashore as they did when the 1950 lava flows entered the ocean. (The deep-water fish killed in 1950 are described by Gosline and others, 1954.)

A more probable interpretation is that the line indicated by the epicenters in figure 5 marks a fault, or more probably a group of faults, crossing the southern slope of the submarine shield volcano much as the Hilina fault system crosses the southern slope of Kilauea volcano above sea level, and that the earthquakes were caused by movement along this fault zone. The probability is increased by the occurrence during 1951–52 of repeated movements along the other similar fault systems on the flanks of both Kilauea and Mauna Loa. It is noteworthy that three of the located earthquakes of the March–April group originated along the Hilina fault system, probably as a result of adjustment along that system in response to movement on the faults farther south. Displacement on the faults of the Hilina system has resulted in a rise of the central part of the island in relation to the submerged part. It is probable that on the offshore faults also the predominant movement has been a rise of the island in relation to the adjacent ocean basin.

The migration of the epicenters indicates that fault movement began at about longitude 155°06′ W., shifted eastward to about longitude 154°57′, then westward as far as 155°32′ on March 19–20, then again eastward. After March 25 the located quakes mostly lay near the central part of the zone of activity, with no definite shifting indicated. The migration of earthquake activity back and forth along the fault zone is shown graphically in figure 7, in which the longitudes of the epicenters shown in figure 5 are plotted against time.

The seismicity values may be taken as a qualitative indication of the energy release by the earthquakes. During the first few days of

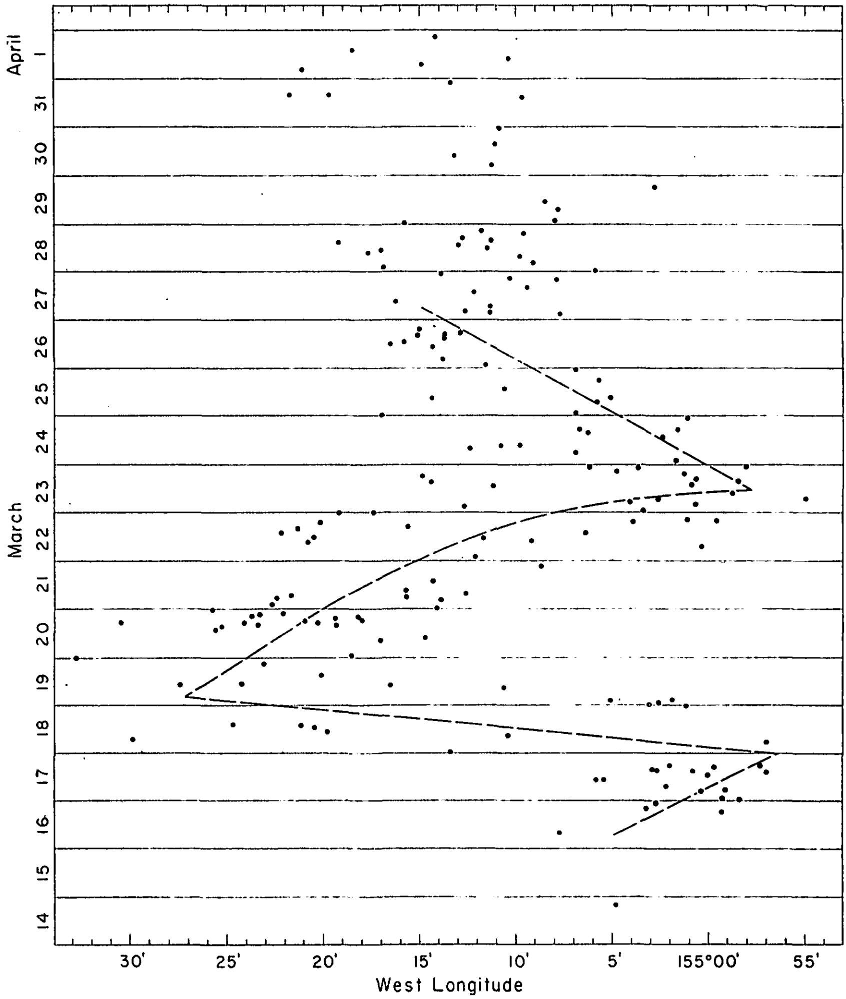


FIGURE 7.—Graph showing relationship between longitude of focus and time of occurrence of the earthquakes the epicenters of which are shown in figure 5. The dots represent the actual earthquakes, and the dashed line the approximate median curve.

the earthquake swarm the average rate of energy release apparently increased at an essentially uniform rate, suggesting a fairly uniform increase in the strain, the release of which was responsible for the earthquakes. In figure 8, the curve representing the average hourly seismicity during each 24-hour period, March 16–20, rises as a nearly straight line. After March 20 the curve flattens into a nearly horizontal plateau. In detail, however, the energy release was not uniform. The plotting of hourly seismicity in the columnar graph (fig. 8) generally indicates a succession of progressive increases of energy release, each terminated by one or more strong earthquakes, followed by a period of a few hours of relative quiet. Thus, although the

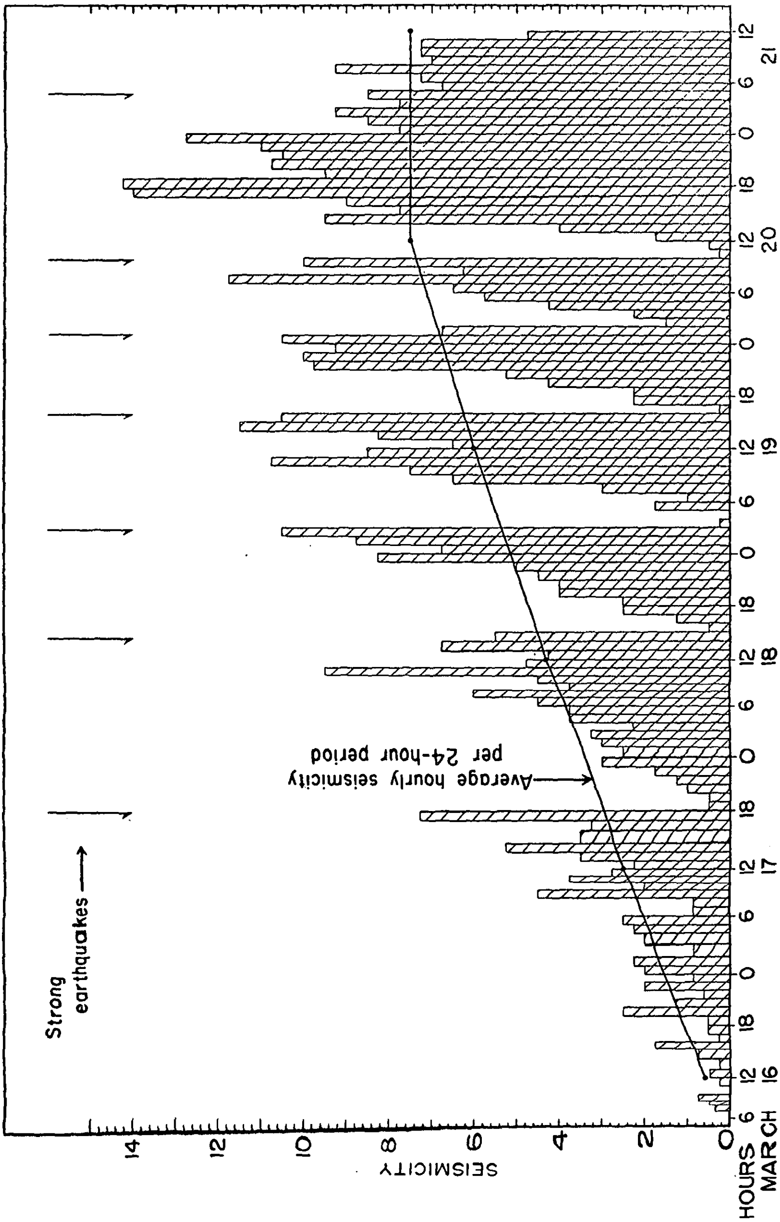


FIGURE 8.—Graph showing by means of columns the hourly seismicity at the Whitney Laboratory of Seismology from March 16 to 21, and by means of the black dots the average hourly seismicity for each day. The line connecting the dots indicates the trend of average hourly seismicity. The single-barbed arrows at the top of the figure indicate the time of occurrence of strong earthquakes.

strain on the fault system probably accumulated at a fairly regular rate, the release of the strain was not regular, but periodic. The arbitrary scale of seismicity in use at the Volcano Observatory probably does not adequately represent the greater amount of energy released in the large earthquakes, but a scale in which the greater energy release was accurately represented would merely increase the already striking character of the periodicity in the graph.

Possibly this cyclical behavior may result from a progressive elastic yielding of the fault surface or surfaces. Each face of the fault surface can be regarded as consisting of a very large number of small areas in contact with the opposing face, with widely varying frictional or interlocking resistance to displacement. As the strain gradually accumulates, in the adjacent rocks, at a more or less uniform rate, the shearing stress on the fault surface becomes sufficient to overcome the resistance to displacement at the more weakly bonded spots. These areas yield, and elastic rebound locally relieves the strain and produces small earthquakes. The over-all strain remains unrelieved, however, and the local movements actually increase the stress acting on the more firmly bonded parts of the fault surface, until these also yield, producing larger earthquakes. Stress finally becomes great enough to cause yielding of the most firmly bonded areas of the fault surface, the major earthquakes are produced, and the over-all strain is relieved, ending the cycle. A period of relative quiet ensues, until the stress on the relocked fault surface again reaches proportions great enough to cause yielding of its least firmly bonded parts and a new cycle commences.

The earthquake swarm of March and April 1952, somewhat resembled that of 1868, although on a smaller scale. During late March of 1868 residents of southern Hawaii experienced great numbers of earthquakes, reportedly reaching dozens or even hundreds a day. They were most severe in the region from Kapapala to Waiohinu. This activity was climaxed on April 2 by a violent earthquake of about intensity 10 (Wood, 1914, p. 192) that leveled nearly every building in the area. This earthquake was accompanied by a mudflow at Wood Valley, between Kapapala and Pahala, that buried a village and killed 31 persons. At the same time a great tsunami seriously damaged every coastal village along the southeastern shore of the island, destroying 108 houses and taking the lives of 47 people (Brigham, 1909, p. 118). The great earthquake was followed, a few days later, by eruption of both Kilauea and Mauna Loa volcanoes.

The location of the origin of the great earthquake of April 2, 1868, is uncertain. Movement on a fault just west of Waiohinu is reported to have horizontally offset a wagon road the width of the road (Wood, 1914, p. 199). However, the great tsunami that accompanied the earthquake suggests that part of the movement occurred offshore. It is not impossible that the violent quake of 1868, and many of its attendant smaller shocks, originated on the same fault system that caused the quakes of March 1952. It appears more probable, however, that they originated on the faults in the vicinity of Waiohinu and Naalehu, and their seaward extensions.

TILTING OF THE GROUND

Tilting of the ground surface is measured at the Whitney Laboratory of Seismology and the Uwekahuna seismograph station, on the northeast and west edges of Kilauea caldera, respectively, and at tilt stations just southeast and west of Halemaumau crater on the caldera floor (fig. 2). The relationship of ground tilting to volcanic activity

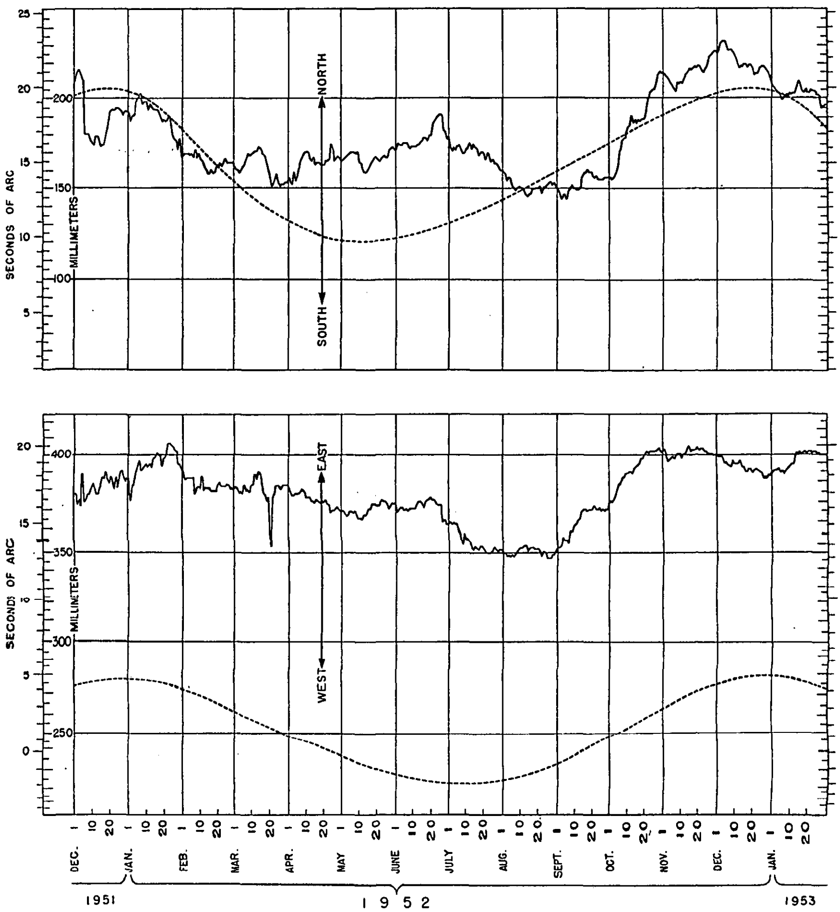


FIGURE 9.—Graph showing ground tilting at the Whitney Laboratory of Seismology, on the northeastern rim of Kilauea caldera, during 1952. The solid line shows the tilt as measured during the year. The dashed line is the approximate normal annual curve for years in which there is no volcanic disturbance

has been discussed in earlier reports (Finch and Macdonald, 1953, p. 41; Macdonald and Wentworth, 1954, p. 158).

Figure 9 is a graph showing the north-south and east-west components of the tilting of the ground surface measured at the Whitney Laboratory of Seismology by means of the Bosch-Omori seismograph. The approximate average annual tilt curves in the two components, determined for years in which there was no surficial volcanic activity, also are shown in the figure. Any marked variation of the curves of actual measured tilt from those of the average annual tilt probably is the result of variations in volcanic conditions, presumably largely subsurface magmatic pressure. An increase of pressure beneath Kilauea caldera causes a rise of the ground surface in the caldera and the immediately surrounding area, and a general outward tilting of the surface around the caldera. This results in a north-northeastward tilting at the Whitney Laboratory, and a westward tilting at Uwekahuna. Conversely, a lowering of pressure results in a sinking of the surface in the caldera area, an inward tilting of the surface around the caldera, south-southwestward tilting at the Whitney Laboratory, and eastward tilting at Uwekahuna. An increase of pressure beneath the summit area of Mauna Loa apparently causes an eastward tilting at the Kilauea stations, but because of the great distance (22 miles) of the stations from the summit of Mauna Loa, the effect is much less conspicuous than tilting caused by pressure changes beneath Kilauea.

Table 4 lists the direction and amount of the tilting of the ground surface measured at the Whitney and Uwekahuna stations during each week of 1952.

During January and February the ground surface at the Whitney Laboratory tilted southward through an angle of a little more than 4 seconds of arc. The direction and amount were approximately normal for that season of the year. Eastward tilting continued at the Whitney Laboratory until January 23, about a month later than the average date of the annual reversal from eastward to westward tilting. This suggests the possibility of some increase of volcanic pressure beneath Mauna Loa during early January. During February, however, westward tilting occurred at about the normal rate.

Through March tilting in the east-west azimuth at the Whitney Laboratory was irregular, and there was scarcely any accumulation of tilt in either direction, as compared to a normal small westward tilting. Southward tilting during March was normal for that season, but the rate was somewhat less than usual. The abnormally small amount of southward tilting, together with an absence of westward tilting, suggests some increase of volcanic pressure beneath Kilauea during March. The annual reversal from southward to northward tilting occurred about the first of April, about a month earlier than

TABLE 4.—*Ground tilting at seismograph stations on the rim of Kilauea caldera during 1952*

Week beginning	Whitney station (northeast rim)		Uwekahuna station (west rim)	
	Direction	Amount (seconds of arc)	Direction	Amount (seconds of arc)
Jan. 6	S. 18° E.	0.4	S. 6° E.	3.2
13	S. 11° W.	1.2	N. 8° E.	2.2
20	S. 45° E.	1.7	N. 14° W.	6.9
27	S. 37° W.	1.2	N. 72° W.	1.0
Feb. 3	W.	.6	S. 13° E.	4.2
10	S. 12° W.	1.1	----------	.0
17	N. 27° E.	.5	S. 5° E.	3.5
24	S.	.5	S. 27° E.	1.4
Mar. 2	N. 7° W.	1.1	S. 14° W.	1.3
9	N. 70° E.	1.0	N. 6° W.	2.9
16	S. 31° W.	2.8	N. 9° W.	4.2
23	N. 80° E.	.7	S. 19° W.	1.0
30	N. 45° W.	.7	S. 27° E.	2.1
Apr. 6	N. 12° W.	1.1	S. 25° E.	3.9
13	S. 18° W.	.4	S. 16° E.	2.3
20	N. 71° W.	.8	S. 19° E.	3.0
27	N. 45° W.	.5	N. 22° W.	1.7
May 4	S. 18° W.	.4	S. 13° E.	2.6
11	S. 11° E.	.6	N. 9° W.	5.8
18	N. 45° E.	.7	S. 64° W.	.7
25	N. 18° W.	.4	N. 9° W.	2.0
June 1	N. 63° W.	.5	N. 45° E.	.9
8	N. 68° E.	.6	N. 19° W.	3.0
15	N. 6° E.	1.3	W.	.6
22	S. 66° W.	1.5	N. 13° E.	2.9
29	S. 14° W.	1.0	S. 24° E.	2.4
July 6	N. 67° W.	.9	----------	.0
13	S. 18° W.	.7	S. 63° E.	.7
20	S. 18° W.	.7	S. 19° E.	6.8
27	S. 21° W.	1.3	S. 20° E.	3.7
Aug. 3	S. 59° E.	.7	S. 18° E.	1.0
10	S.	.5	S. 63° E.	1.4
17	N. 27° W.	.5	S. 29° E.	3.3
24	----------	.0	N. 8° W.	2.3
31	S. 31° E.	.7	N. 18° W.	1.0
Sept. 7	N. 74° E.	1.2	N. 45° W.	.4
14	N. 40° E.	.9	N. 22° E.	3.4
21	S. 45° W.	.2	N. 71° E.	1.0
28	N. 55° E.	1.5	S. 28° W.	4.7
Oct. 5	N. 22° E.	2.9	S. 34° W.	1.2
12	N. 69° E.	1.0	N. 20° W.	4.7
19	N. 13° E.	2.1	N. 34° W.	1.2
26	N. 23° W.	.9	S. 7° E.	2.6
Nov. 2	S. 27° E.	.5	N. 27° W.	1.4
9	N. 7° E.	1.0	S.	.3
16	S. 45° E.	.3	E.	.3
23	N. 18° W.	1.5	S. 18° W.	1.0
30	N. 81° W.	.7	E.	.3
Dec. 7	S. 18° E.	1.2	----------	.0
14	S. 83° W.	1.0	S. 11° E.	1.6
21	W.	.2	S. 34° E.	1.2
28	S. 16° E.	1.7	S. 27° E.	1.4

normal. Northward tilting continued throughout April, May, and June, accompanied by somewhat less than normal westward tilting, and indicated a definite increase of pressure beneath Kilauea. This increase was terminated by the eruption of Kilauea on June 27, and the outbreak was followed by a rapid southward tilting that continued until mid-August. Apparently the cracking of the volcanic structure relieved the excess of pressure beneath, and allowed the area around the active vent to subside.

Northeastward tilting somewhat exceeded the normal through September and October, possibly as the result of increase of pressure beneath Kilauea as the rate of eruption decreased. Reversal from northeastward to southwestward tilting came about a month earlier than usual, however, suggesting in turn a decrease of pressure beneath Kilauea during the end of the year.

Sharp tilting of the ground surface away from the center of Halemaumau was shown by both tilt stations on the caldera floor at the beginning of the eruption of Kilauea. It is not known how long before the outbreak this marked tilting commenced, because the two stations had been on a schedule of monthly readings and the last reading before the eruption was on June 2. Between that date and June 30 the ground surface at the southeast tilt cellar tilted 4.9 seconds S. 42° E. The pointer at the west tilt cellar was moved beyond the limits of the scale, but estimation of the approximate position of the pointer indicates that during the same interval the ground at that station tilted about the same amount S. 30° W. Thus there was a marked outward tilting of the rim of Halemaumau crater just before the eruption.

CRACK MEASUREMENTS

Measurements of crack widths were made at 14 stations on the floor of Kilauea caldera and along the east rift zone at monthly intervals throughout 1952. A fifteenth station (no. 3) was added to the group in early October. The location of the crack-measuring stations on the caldera floor are shown in figure 10, and those on the east rift zone are shown in figure 2. The measurements, including those for December 31, 1951, for comparison, are given in table 5.

TABLE 5.—*Crack measurements, in centimeters, at Kilauea during 1952*

Date	Width of cracks for indicated station—															
	Rim of Halemaumau								On floor of caldera					On east rift		
	3	5	6	7	8	9	20	27	37 N-S	37 E-W	37A	40	41	101A	106	DT 1
Dec. 31	-----	116.6	60.7	35.0	58.0	77.6	-----	64.9	49.5	45.1	64.5	33.1	33.5	130.1	101.6	36.0
Jan. 31	-----	117.4	61.0	35.0	57.9	77.6	-----	64.9	49.5	45.0	64.5	33.1	33.5	128.9	101.6	36.0
Feb. 21	-----	118.0	61.1	35.0	58.0	77.5	114.5	-----	-----	-----	-----	-----	-----	-----	-----	-----
Mar. 1	-----	118.1	61.2	35.0	58.0	77.5	115.0	64.9	49.5	45.1	64.6	33.1	33.5	129.2	101.7	36.0
20	-----	-----	-----	-----	-----	-----	121.0	-----	-----	-----	-----	-----	-----	-----	-----	-----
Apr. 1	-----	118.8	61.4	35.0	58.0	77.5	121.1	64.9	49.6	45.1	64.7	33.1	33.5	129.2	101.5	36.0
May 1	-----	119.5	61.6	35.0	57.9	77.3	121.4	65.0	49.7	45.2	64.7	33.1	33.5	129.6	101.6	36.0
23	-----	120.1	61.8	34.9	57.9	77.2	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
June 2	-----	120.3	61.8	34.9	57.9	77.1	-----	-----	49.7	45.3	64.8	33.1	33.5	129.6	101.7	36.0
July 18	-----	121.1	62.1	34.8	57.9	77.0	122.0	64.9	50.6	46.1	65.2	-----	(1)	-----	-----	-----
30	-----	-----	-----	34.8	57.9	77.0	122.2	65.0	-----	-----	-----	33.6	(1)	-----	-----	-----
Aug. 8	-----	121.7	62.5	-----	57.9	-----	-----	-----	-----	-----	-----	-----	(1)	-----	-----	-----
Sept. 5	-----	122.3	62.8	34.8	57.9	77.2	122.3	65.1	50.4	46.0	65.0	33.5	(1)	-----	-----	-----
Oct. 1	73.9	122.6	62.9	34.9	57.9	77.2	122.4	65.0	50.4	46.0	65.0	33.5	33.4	130.2	101.7	36.0
Oct. 31	-----	123.0	63.0	34.9	57.9	77.2	122.4	65.1	50.6	46.1	65.1	33.6	33.4	-----	-----	-----
Dec. 1	74.1	123.4	63.1	35.0	58.0	77.2	122.4	65.1	50.6	46.1	65.1	33.6	33.4	130.3	101.7	36.0

[1] Buried by pumice and ash from Kilauea eruption.

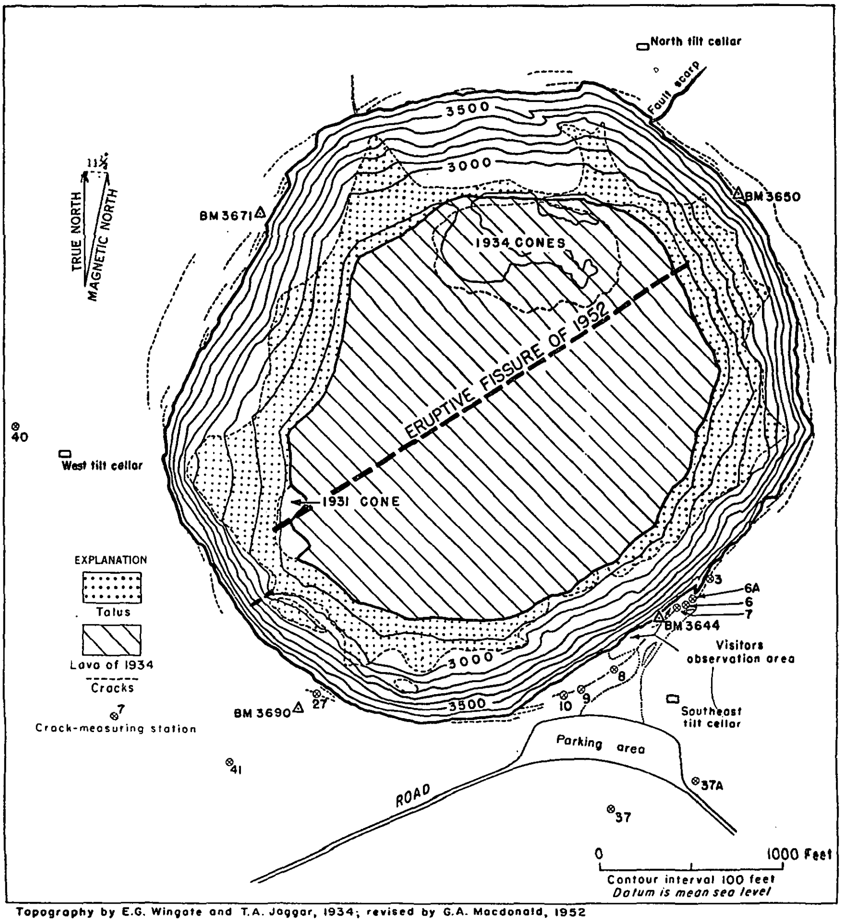


FIGURE 10.—Map showing the condition of Halemaumau crater before the 1952 eruption, and the location of crack-and tilt-measuring stations in the vicinity of the crater.

Cracks 5 and 6, at the rim of Halemaumau crater, just north of the visitors' observation area, opened consistently throughout the year. Crack 5 showed an opening of 6.8 centimeters from December 31, 1951, to December 1, 1952. Crack 6 opened 2.4 centimeters during the same interval. Stations 7 and 8, which lie along a crack parallel to the rim of Halemaumau farther south, showed no appreciable change in width. Station 9, located on the same crack 150 feet south of station 8, showed a closing of 4 millimeters. Crack 27, near the south edge of the crater, opened 2 millimeters.

Crack-measuring station 20 is situated on a crack behind a narrow sliver of rock that teeters on the edge of the crater and appears ready to fall any time. In the interval between November 1, 1951, and December 1, 1952, the crack widened 14.5 centimeters. During the eruption of Kilauea, in July and August, the block outside the crack was swaying back and forth with the pulsations of the lava fountains. Measurements indicated a rhythmic opening and closing of the crack through a width of 1 to 1.5 millimeters.

Cracks 37, 37A, and 40, on the floor of the caldera, showed a marked opening between June 2 and July 18. This undoubtedly was the result of the tumescence of the caldera floor directly preceding the eruption of Kilauea on June 27. These cracks showed no appreciable closing during the remainder of 1952 and the early 1953.

GEOMAGNETIC OBSERVATIONS

Measurements of the relative intensity of the vertical component of the earth's magnetic field at stations on Kilauea and adjacent parts of Mauna Loa were continued through 1952. The work was carried out by C. K. Wentworth. An account of the earlier work, and a map showing the location of the stations at which measurements were made, are contained in a report by Macdonald and Wentworth (1954, p. 145, 163).

Table 6 lists the readings obtained during 1952. All readings in the table are differences (in gammas) of the vertical intensity at each of the magnetometer stations from that at station 0, near the Volcano Observatory, on the same date. No obvious effect of the eruption of Kilauea volcano on the vertical intensity of the magnetic field appears in the readings.

TABLE 6.—*Difference in vertical intensity of geomagnetism (in gammas) at stations on Mauna Loa and Kilauea, compared with the intensity at station 0 during 1952*

Station no.	Jan. 29–30	Feb. 22–23	Mar. 19–20	Apr. 24–25	May 14–15	June 14–16	July 4–11	Sept. 12–13	Oct. 20	Nov. 21	Dec. 30–31
1	−843	−860	−897	−827	−864	−827	−789	−813	−795	−915	−817
2	−66	−42	−130	−83	−37	−10	−26	--------	+27	−37	−115
3	−255	−388	−458	−347	−453	−352	−328	−314	−291	−328	−392
4	−308	−398	−472	−370	−490	−356	−323	−324	−310	−550	−637
5	+133	+88	+18	+74	+51	+101	+121	+102	+157	−171	+5
6	−165	−171	−264	−162	−116	−176	−131	−153	−88	−245	−212
7	−118	−130	−490	−93	−148	−227	−88	−217	−65	−157	−184
8	−868	−850	−878	−767	−920	−740	−766	−721	−689	−882	−1,122
9	−1,005	−1,021	−994	−933	−1,035	−860	−879	−827	−790	−1,007	−887
10	−744	−809	−818	−877	−776	−818	−695	−697	−777	−910	−873
11	−180	−204	−291	−92	−240	−259	−168	−138	−176	−226	−263
12	−805	−652	−841	−517	−712	−758	−677	−688	−647	−1,039	−767
13	−474	−573	−601	−439	−572	−545	−540	−522	−504	−591	−513
14	−47	−74	−51	−26	−74	−23	−42	−4	+64	−351	−97
15	+474	+522	+448	+587	+471	+494	+461	+411	+582	+300	+402
16	+218	+194	+1,150	+153	+245	+268	+210	+203	+263	+157	+180
17	−839	−813	−374	−679	−721	−670	−686	−735	−661	−799	−744
18	−483	−504	−83	−499	−453	−397	−506	−471	−476	−536	−485
19	+304	+314	+665	+144	+365	+365	+334	+314	+355	+171	+272
20	−294	−328	−5	−208	−435	−277	−295	−287	−254	−642	−328
21	+285	−106	+1,718	+338	+319	+51	+309	+268	−47	+203	+140
22	+1,004	+965	+864	+1,040	+878	+906	+852	+868	+882	+1,483	+846
23	+1,355	+1,395	+1,330	+1,289	+1,326	+1,391	+1,540	+1,386	+1,344	+966	+1,234
24	−109	−167	−157	−171	−83	−88	−54	−148	−134	−633	−120
25	+3,032	+2,684	+2,199	+2,569	+2,495	+2,634	+2,761	+2,606	+2,568	+2,569	+2,574
26	+436	+263	+180	+310	+37	+263	+261	+296	+249	−23	+393
27	−1,000	−980	−1,007	−928	−1,040	−993	−860	−966	−957	−924	−1,072
28	−971	−1,081	−1,040	−1,035	−943	−966	−920	−1,031	−998	−1,197	−1,183

TEMPERATURE MEASUREMENTS

Measurements of the temperature of the steam escaping at Sulphur Bank (fig. 2) were continued through 1952. Measurements were made at a natural vent near the east end of the solfataric area, and at the drilled well (Finch and Macdonald, 1951, p. 116). At neither place did the temperature show any variation detectable within the limits of reading of the thermometer. The temperature of the steam issuing at the well remained 96°C throughout the year. That of the steam at the natural vent was 94.5°. The boiling temperature of water at the altitude of the vents is 95.7°.

Many measurements of the temperature of the fluid lava were made during the eruption of Kilauea. These are discussed in the section of the report dealing with the eruption.

On March 20 the Territorial Highway Department installed a recording thermometer on the Kaapuna flow (formerly known as the Ohia Lodge flow) of the 1950 eruption of Mauna Loa. The thermal element was placed in a hot crack at an altitude of 1,350 feet, just inland from the position of the old highway that was buried by the flow. The flow is about 50 feet deep at that point.

K. B. Hirashima, testing engineer for the Territorial Highway Department, states that a temporary installation with the thermal element at a depth of 18 inches yielded a temperature reading of 460°C. This initial reading agreed reasonably well with rough measurements made by the writer in September 1950 (Macdonald and Wentworth, 1954, p. 171). The permanent installation at a depth of 3 feet indicated a temperature of 515.5°C. The temperature recorded was much higher than at comparable depths over most of the flow, as was demonstrated in cuts several feet deep excavated along the course of the new highway, which crosses the flow a short distance seaward of the position of the old highway. The high temperature at the thermometer installation was caused by gases rising from the lower part of the thick flow.

TABLE 7.—*Temperature readings at a hot crack in the 1950 Kaapuna lava flow near the old highway, during 1952*

[Data supplied by K. B. Hirashima, Territorial Highway Department]

Date	Temperature (° C)	Date	Temperature (° C)	Date	Temperature (° C)	Date	Temperature (° C)
1952		*1952*—Con.		*1952*—Con.		*1953*	
Mar. 20	515	June 26	294	Oct. 2	138	Jan. 8	76
April 3	504	July 10	260	16	126	22	76
17	482	24	232	30	116	26	71
May 1	449	Aug. 7	207	Nov. 13	99		
15	410	21	188	27	90		
29	371	Sept. 4	166	Dec. 11	82		
June 12	326	18	149	25	82		

Table 7 gives readings taken from the chart of the recording thermometer at biweekly intervals during the remainder of 1952 and January 1953. Operation of the thermometer was discontinued after January 1953 because of completion of the new highway construction. The figures were supplied by Mr. Hirashima.

RAINFALL RECORDS

Daily readings of rainfall were continued at the gage near the Uwekahuna seismograph station throughout 1952. Gages at the Mauna Loa seismograph station and at an altitude of 5,500 feet on the Mauna Loa truck trail were read every 2 days. A rain gage 300 feet north of the southeast tilt cellar, on the floor of Kilauea caldera southeast of Halemaumau, was read at the end of each month. The monthly total for these gages are given in table 8.

TABLE 8.—*Rainfall during 1952, in inches*

Month	Gage			
	Halemaumau	Uwekahuna seismograph station	Mauna Loa truck trail	Mauna Loa seismograph station
January	22.27	21.22	17.64	19.67
February	4.07	3.31	3.54	3.94
March	12.22	7.85	8.00	11.40
April	.74	.64	.75	1.17
May	3.69	1.50	3.52	5.51
June	.55	.41	.00	.08
July	1.55	.95	2.00	3.39
August	.20	.08	.03	.24
September	1.15	.42	.79	1.68
October	3.05	1.75	3.55	3.51
November	6.45	3.67	6.72	6.46
December	2.07	.98	.49	.76
Total	58.01	42.78	47.03	57.81

VOLCANIC CONDITIONS DURING 1952

The principal event of the year was the eruption of Kilauea volcano that began on June 27 and continued until early November. The eruption is discussed in detail on later pages.

Both Kilauea and Mauna Loa were quiet through January and February, although earthquake activity was somewhat greater at Kilauea than usual. Early in February a large rock slide occurred on the southeastern wall of Halemaumau, south of the visitors' lookout point. The scar left by the slide was first observed on the morning of February 9, but the slide probably occurred during or immediately following a strong earthquake at 21^h 55^m on February 7. Halemaumau was not visible from the Volcano Observatory on February 8 because of rain clouds filling Kilauea caldera. The slide removed a layer of rock about 500 feet wide and 450 feet high from the upper part of the crater wall. Many smaller slides followed, the largest of which occurred near noon on February 21. Occasional small slides continued through March. Altogether, the slides deposited more than 2 million cubic feet of broken rock on the floor of Halemaumau, and caused a retreat of the rim of the crater of as much as 10 feet. The two volcanoes continued essentially quiet through March, although the great swarm of earthquakes off the southern shore of the island was accompanied by a few quakes along the faults of the Hilina system, on the southern flank of Kilauea.

Early in April a series of earthquakes commenced along the east rift zone of Kilauea and beneath the caldera region. They were accompanied by a northward tilting of the ground surface at the northeast edge of the caldera, indicating an increase of volcanic pressure beneath Kilauea. During the last days of April the uneasiness of Kilauea subsided somewhat, but was resumed during May. Mauna Loa also showed some seismic uneasiness, and possibly a small increase of pressure during May. This uneasiness of both volcanoes continued into June.

Following the outbreak of activity at Kilauea on June 27, the uneasiness of Mauna Loa disappeared, and for the next 2 months the volcano was quiet. Through the first half of September the ground at the Whitney Laboratory of Seismology tilted eastward at a rate considerably greater than that normal for that season of the year. This eastward tilting probably resulted from a doming of Mauna Loa caused by an increase of volcanic pressure beneath it. From September 17 to 30 there was no further eastward tilting, although several earthquakes of Mauna Loa origin indicated some uneasiness of the volcano. This restlessness continued during October, and on October 24–25 a swarm of 165 very small earthquakes from the northeast rift zone of Mauna Loa indicated movement along that rift.

The eruption of Kilauea ended about November 10. Through the remainder of the year Kilauea and Mauna Loa were quiet. During November, ground tilting at the Whitney Laboratory was northeastward at a rate about normal for that season, suggesting that there was little or no withdrawal of magma with accompanying decrease of volcanic pressure following the end of the Kilauea eruption. Seismic activity was approximately normal through December. The reversal of tilting at the Whitney Laboratory, from northeastward to southwestward, took place about a month earlier than usual. This may indicate some decrease of volcanic pressure beneath Kilauea, but the time of reversal in the direction of tilting is rather variable from year to year. The rate of southwestward tilting through December was approximately normal for the period following the usual annual reversal. There was no marked reduction of pressure beneath Kilauea, such as probably caused the subsidence of the summit area of Kilauea in December 1950 (Finch and Macdonald, 1953, p. 82).

Vents on the floor of Halemaumau crater continued to liberate moderate amounts of pale, bluish-gray fume through late November and December. On the morning of December 11, Ernest Morton, manager of the Kahuku Ranch, reported large clouds of steam in the vicinity of the vents of the 1950 eruption at an altitude of about 10,000 feet on the southwest rift zone of Mauna Loa. Smaller amounts of steam were observed at the same locality at other times during the year. The prominent steam clouds on December 11 probably resulted from unusually good visibility, and from high atmospheric humidity and low temperature that caused greater than usual condensation of the steam.

THE ERUPTION OF KILAUEA

BRIEF HISTORY OF ACTIVITY IN KILAUEA CALDERA

Since Kilauea volcano first became known to Europeans in the early 19th century its activity has been predominantly confined to the caldera. Several flank flows have occurred, but their total volume is small compared with the lava erupted within the caldera.

Through the early and middle part of the 19th century the history of the caldera was one of repeated collapses and refillings. The conflicting reports of the depth of the caldera at different dates have been subjected to careful study and analysis by Finch (1940). The following brief review is taken largely from Finch's paper, and the histories of Hawaiian volcanoes assembled by Dana (1890), Brigham (1909), and Hitchcock (1909).

When viewed by William Ellis in 1823, the caldera consisted of a narrow bench (generally referred to in the literature on Hawaiian volcanoes as the "black ledge"), 600 to 700 feet below the high western rim of the caldera, and 200 to 300 feet below the level of the present caldera floor. Within the black ledge was a broad inner pit 300 feet deep, occupying most of the caldera floor. The flank flow of 1823 had occurred only a few months before, and the sinking of the central part of the caldera below the level of the black ledge was presumably the result of removal of support by draining away of underlying magma during the flank eruption. It is generally believed that a similar collapse of the central part of the caldera took place during the eruption that occurred about 1790, and that the central depression had been filled to the level of the black ledge during the interval between 1790 and 1823.

During the years following 1823, eruptions within the central basin gradually filled the central depression, and by 1832 the new floor had reached a level about 50 feet above that of the former black ledge.

Another subsidence of the central part of the caldera occurred in 1832, and in 1834 the caldera was much as it had been in 1823, having an inner basin 400 feet deep surrounded by a narrow black ledge.

In the succeeding years eruptions filled the inner basin and overflowed the black ledge with new lava. By 1840 a broad dome 100 feet high occupied the caldera floor, with its summit in the southwestern part of the caldera in the vicinity of the present Halemaumau.

The flank flow of 1840 was accompanied by another collapse of the central part of the caldera, but the area of the central basin was smaller than in 1823 and 1832. As mapped by the U. S. Exploring Expedition in 1840, the inner pit was 350 feet deep and oval in outline, having a long diameter of about 1.8 miles and an average shorter diameter of 1 mile. The average width of the black ledge surrounding the inner pit was 1,600 feet and the average level of the ledge was about 650 feet below the western rim of the caldera at Uwekahuna. By 1846 the inner basin was again filled to and above the level of the black ledge. The filling was partly by flows over the floor of the basin, but also partly by a bodily elevation of the floor. This elevation brought up not only the relatively flat lava floor of the basin, but also the banks of talus that had accumulated at the foot of the cliffs enclosing the basin. A narrow ridge of fragmental debris more than a mile long was formed standing 50 to 100 feet above the adjacent caldera floor. During 1848 a dome 3,500 feet across and 200 to 300 feet high was built, the apex of which was in the southwestern part of the caldera. Subsequent to 1838, and possibly earlier, the principal center of activity in the caldera was near its southwest edge, at or near the site of the present Halemaumau.

The eruption of 1868 was accompanied by another collapse in the caldera. An area about the size of the inner basin in 1840 sagged downward some 300 feet, and in the southwestern part of this sunken area, at Halemaumau, an inner conical pit was formed 3,000 feet in diameter at the top and 500 feet deep. The volume of the collapse was somewhat less than that of 1840 (Finch, 1940). Again there was a gradual filling of the central depression. By 1874 the cone around Halemaumau had reached a height nearly equal to that of the southern wall of the caldera, and lava streams from it were pouring northward into the central depression. The lava disappeared briefly from Halemaumau in April 1879, but there was no general subsidence of the caldera, and the molten lava reappeared in the lake about a month later.

In 1886 subsidence of the area surrounding Halemaumau produced a roughly triangular pit 2,900 feet across and 325 feet deep, with a small pit 275 feet deep in its floor. This depression was soon refilled, but 5 years later, in 1891, another similar collapse occurred. This collapse also was restricted to the area close to Halemaumau. Refilling of the pit started almost immediately, and by July 1892 the lake was again overflowing.

From 1823 to 1894, activity at Kilauea was essentially continuous. There were many intervals, especially just after the great subsidences, when liquid lava disappeared from the crater, but they were brief. Active lava returned within a few weeks or days of its disappearance. In 1894 a marked change in the character of the activity took place. A spectacular minor subsidence occurred at Halemaumau during July 1894, lowering the level of the lava 270 feet below the rim of the pit. Activity continued at depths of 300 to 600 feet in Halemaumau pit until December 1894, when molten lava disappeared. From 1894 to 1907 only occasional brief spells of activity occurred deep in the pit, although fume apparently has always been visible. This 13-year interval of relative quiescence was the first break in the continuity of the activity of Kilauea since before 1823.

From 1907 to 1924 the volcano was again essentially continuously active. Spectacular but minor collapses occurred at Halemaumau in 1916, 1919, and 1922. In May 1924 the greatest collapse since 1840 occurred, and was accompanied by strong phreatic explosions caused by the entrance of ground water into the hot throat of the volcano (Jaggar and Finch, 1924). The collapse and accompanying explosions enlarged Halemaumau from a nearly circular pit 1,400 feet in diameter, to one with major and minor diameters of 3,400 and 3,000 feet at the surface and a depth of 1,330 feet.

Active lava returned to Halemaumau in July 1924, and from then until September 1934 there were seven eruptions in Halemaumau. The longest of these was the eruption of 1934, which started on September 6 and continued for 33 days. Lava outflow during these eruptions reduced the depth of Halemaumau from 1,300 to 770 feet. Then began a period of complete quiescence of nearly 18 years, ended only by the outbreak in June 1952. During this interval there were occasional signs of subsurface activity. In November 1944 earthquakes and ground tilting indicated a rise of magma beneath Kilauea. No eruption occurred, however, and in early December a reversal of tilting indicated that the magma column was subsiding again (Finch, 1944). In December 1950 marked ground tilting accompanied by a large number of earthquakes indicated a subsidence of the top of Kilauea mountain, presumably reflecting reduction of magma pressure beneath it (Finch, 1950). Throughout the 18-year period of quiescence not even mild fuming was observed at Halemaumau. The condition of Halemaumau in mid-June 1952, is shown in figure 10.

The progressive decrease in the size of the sunken inner depression strongly suggests a corresponding decrease in the size of the mobile mass (presumably the magma column) beneath Kilauea caldera. Since 1886 its diameter appears to have been only about that of the present Halemaumau. This, together with the decrease in frequency of eruption, suggests that the general activity of the volcano may have suffered an over-all decrease during the past century and a half.

Table 9 shows the duration of each eruption in Halemaumau since 1924, the length of the repose period preceding it, and the volume of lava extruded. The 1952 eruption, which followed a much longer period of quiescence than any of the others, had a much longer duration than any of the earlier ones, and the volume of lava erupted was much greater than the total of the others.

TABLE 9.—*Data on eruptions in Halemaumau since 1924*

Year	Date of outbreak	Duration (days)	Repose period since last eruption (months)	Volume of lava (cubic yards)
1924	July 19	11	2.5	320,000
1927	July 7	13	35	3,160,000
1929	February 20	2	19	1,920,000
1929	July 25	4	5	3,600,000
1930	November 19	19	15.5	8,480,000
1931	December 23	14	12.5	9,640,000
1934	September 6	33	44	9,500,000
1952	June 27	136	202.5	64,000,000

NARRATIVE OF THE ERUPTION

OPENING PHASE OF THE ERUPTION, JUNE 27–28

Kilauea volcano resumed eruptive activity late in the evening of June 27, 1952. The exact time of the outbreak is uncertain, but it appears to have been about 23^{h}40^m. Continuous volcanic tremor commenced on the Volcano Observatory seismographs at 23^{h}37^{m}30^s, and the molten lava probably reached the surface within the next few minutes. At 23^{h}35^m on June 27 Mrs. John R. Fox was awake in the living room of her home on the northeastern rim of Kilauea caldera, from which there is an excellent view of Halemaumau crater. She noticed nothing unusual. About 23^{h}40^m she entered another room, the window of which was open, and almost immediately heard a loud whistling roar probably caused by the escape of gas at Halemaumau. Alarmed, she returned immediately to the living room, and saw a bright orange glow over Halemaumau.

At approximately 23^{h}40^m Col. B. W. Rushton, commanding officer of Kilauea Military Camp, pointed out to John Forbes, of the Volcano Observatory staff, a bright reddish glow in the direction of Halemaumau. Forbes immediately identified this glow as resulting from an eruption of Kilauea. John and LaVieve Forbes went immediately to the Volcano Observatory at Uwekahuna, where they telephoned the writer at about 23^h45^m.

At the time John and LaVieve Forbes reached the observatory, the top of a huge lava fountain was clearly visible above the rim of Halemaumau at its southwest edge. At the beginning of the eruption the floor of Halemaumau pit was about 800 feet below the level of the southwestern rim; therefore this fountain must have been more than 800 feet high! By the time the writer reached the observatory, at about 23^h55^m, the fountain was no longer visible, but scattered incandescent fragments still were being thrown above the rim, many of them landing outside of the pit and bursting in flashes of red on the caldera floor southwest of Halemaumau.

After picking up the needed equipment, we drove immediately to Halemaumau by way of the road around the southwest edge of the caldera. The fume cloud was so dense that visibility was very limited, and the fall of pumice on the road was so abundant that at times it nearly stopped the progress of the car. Some of the pumice blocks were as much as 10 inches across. Choking sulfur fumes were annoying, but not serious so long as the car windows were kept closed. Impact of pumice caused frosting of the car to such an extent that the windshield had to be replaced and the car body refinished.

We reached the southeastern rim of Halemaumau at 10 minutes past midnight. A continuous line of lava fountains, 2,600 feet in length, was playing along a fissure that extended in a northeast-southwest direction entirely across the floor of Halemaumau crater, and about 50 feet up the northeastern wall (fig. 10). Most of the fountain jets ranged from 50 to 100 feet high, but one fountain at the foot of the southwestern wall was 400 feet high. Showers of liquid ejecta from the high fountain struck the adjacent wall and trickled down it in a fiery cascade. Several minor fountains, a few feet in height, were present also on the northern part of the floor in the vicinity of the 1934 cones (fig. 10). Liquid lava was spreading from them, as well as from the fountains along the main fissure, and had already covered the entire floor of the crater.

The pool of lava was very fluid, and waves from the fountain chain swept entirely across its surface and up against the walls. Evanescent sinkholes developed near the edge of the pool, accompanied by small lava fountains. Each continued active for only a few minutes, then disappeared, to be replaced by another at some other point. Visibility in Halemaumau was poor because of the large amount of fume, but during brief glimpses of the northern part of the floor the 1934 cones could not be seen. It is probable that they were already buried, and that the liquid pool had attained a depth of more than 30 feet within

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the first half-hour of the eruption. If so, the volume of lava extruded during that brief interval was 4,000,000 cubic yards or more.

The molten lava quickly crusted over, but movement of the underlying liquid tore the crust apart along myriads of lines that revealed the brightly glowing material beneath (pl. 1). From time to time small whirlwinds moving across the lake picked up fragments of the hot crust 3 or 4 feet in diameter, lifted them 15 or 20 feet into the air, and sent them spinning off across the surface.

The lava fountains decreased rapidly in size. By 01^h15^m on June 28 the southwestern fountain was only 250 feet high, and by 03^h had shrunk to 100 feet. At 03^h15^m this fountain and the southwestern part of the fountain chain for 150 feet from the wall had become inactive except for occasional very small bursts, and activity along the next 150 feet of the fountain chain was very weak. At 04^h the entire southwestern half was totally inactive, and along the next quarter of the fissure the fountains were very small. Along the northeastern quarter of the fissure the fountains were still 50 to 75 feet high. By 04^h10^m the active fountains were mostly restricted to the northeasternmost eighth of the fissure, and volcanic tremor had nearly ceased recording on the seismographs. Activity had reached a very low ebb, and for a short time it was thought the eruption might be ending.

THE PHASE OF THE LARGE LAVA LAKE, JUNE 27–JULY 5

At 04^h20^m on June 28 small fountains resumed activity along the southwestern quarter of the fissure. These fountains were a mere bubbling of liquid lava, liberating very little gas, although abundant gas liberation continued at the northeastern fountains. At 05^h activity was restricted to three blowing vents at the base of the northeast wall talus, the new small fountains in the southwestern part of the crater, and a few small sporadic bursts along the intervening part of the fissure. Very little fume was being given off. Daylight brought a clear view of the floor of the crater, and confirmed the complete burial of the 1934 cones. The thickness of the new lava fill was estimated to be 50 feet and the volume about 8,000,000 cubic yards.

About 06^h one of the small fountains near the southwest edge of the crater floor began to increase. By 06^h15^m a strong dome-shaped fountain, 25 feet across had formed. Typical lava fountains are semiexplosive in nature, resembling a jet from a hose playing spasmodically into the air, and liberating a cloud of gas. This fountain, however, was nonexplosive, with little gas liberation, resembling half an orange placed flat side down on the surface of the lava lake, similar to the dome of water that is sometimes observed above the aperture of a freely flowing artesian well. Crusts of the surrounding lava lake were drawn toward the fountain, and foundered around its edge. By 07^h15^m the fountain occasionally reached heights as great as 50 feet.

At 06^h30^m, a double fountain jet in a small cone built on the lower slope of the northeastern talus was spurting to heights of 30 to 40 feet, and throwing occasional bursts of spatter as high as 60 feet. A sluggish lava stream issued through a breach in the southeastern wall of the conelet and ran down its side at a speed of about 5 miles an hour. Another small vent 50 feet farther northeast was spurting from time to time, and sending a trickle of lava down the western side of the conelet. Both vents were roaring, and liberating more blue fume than the southwestern fountain. Two small fountains about 200 feet southwest of the northeastern conelet were spurting sporadically.

Throughout the morning of June 28 the southwestern fountains gradually increased, and the northeastern fountains decreased. At 11^h a small flow of aa was issuing from the northeasternmost vent of the northeast conelet. This single small flow, which continued for the balance of the day, was the only aa observed during the entire eruption. By noon the northeastern fountains had become very small, and the principal southwestern fountain had increased to about 75 feet in height and 100 feet in diameter at the base. It was no longer a dome-shaped fountain of gently rising liquid, but instead was a typical semiexplosive, flinging fountain. Fifty feet to the northeast a new small fountain played nearly continuously, and 100 feet farther northeast another played spasmodically. Around the fountain group concentric waves spread out in the crust of the lake over a radius of 500 feet. A slump scarp 10 to 15 feet high had formed around most of the circumference of the new lava floor, a few feet to 50 feet from its margin, owing to vertical shrinkage of the central part of the new fill.

At 15^h30^m the fountains near the southwestern wall had become small and sporadic, but a new fountain just northeast, about 300 feet from the southwest wall, was playing to an average height of 150 feet. The amount of gas being given off had increased greatly. The northeast fountains remained about the same as they had been at noon, but about 600 feet to the southwest a prominent sinkhole had developed. Lava streamed toward it from all directions. As the lava was drawn toward the sinkhole the crust was broken and torn apart, and as the fragments reached the sink they tilted on edge and plunged beneath the surface. Small sporadic fountains played in the sinkhole.

At many other places on the lake the crust was rifted open from time to time, often repeatedly along the same line. There also, crust fragments were drawn in, tilted up, and plunged under. This generally was followed by a row of tiny fountains, lasting only a few seconds, over the place where the crust fragments disappeared.

During the evening of June 28 the fountain 300 feet from the southwest wall continued to increase until by midnight it was playing steadily to heights around 150 feet, with occasional bursts reaching 300 feet. Late in the evening a very active sinkhole developed at the southwest edge of the lake, over the course of the eruptive fissure. A river of lava about 25 feet wide flowed into it from the area of the nearby fountains, and small edge fountains played sporadically in and around it. The northeast sinkhole continued active.

By midnight the vents at the northeast edge of the crater had built narrow-throated conelets and were blowing explosively with loud booming noises and throwing showers of ejecta to a height of 150 feet. Banners of pale blue flame 5 to 15 feet long played intermittently over the mouth of the conelets.

Activity continued much the same through June 29 and 30. By noon of June 29 the slump scarp near the edge of the floor had been reburied, and a bench of semisolid pahoehoe crust was beginning to form around the edge, gradually restricting the size of the central lava lake. The bench was at about the same level as the general surface of the lake, and as the level of the latter rose slowly during the succeeding days, repeated small overflows moved out across the bench from the edge of the lake, or from fractures within the bench itself. From time to time fragments as much as 150 feet across became detached from the bench and formed islands in the lake. These islands moved across the lake toward the fountains, presumably carried along by a return circulation in the lower part of the lake. They appeared, however, to be floating, rising and falling with the level of the liquid around them.

The prominent southwestern and northeastern sinkholes continued active. Directly following the engulfment of especially large or numerous crust fragments, fountaining within the sinks increased notably. However, these sinkholes appeared to be primary fountain vents in their own right as well. Small sporadic fountains played within the sink even when crustal foundering was not marked, and from time to time sinking gave place entirely to fountain action.

On June 29 sporadic fountains played along most of the length of the eruptive fissure southwest of the northeast sinkhole. Along this line lava moved slowly inward and sank, dragging the crust with it and producing a puckered cicatrice extending from the northeast sinkhole to the main southwestern fountain.

By the afternoon of June 29 the conelet at the northeast edge of the lake had grown to a height of about 50 feet. At $00^h\ 30^m$ on

June 30 a small glowing spot appeared on the eastern wall of the conelet, apparently caused by melting of the cone wall from within, and a few minutes later a small pahoehoe flow issued from this aperture. At 01^h the walls of the conelet collapsed, liberating a small flood of very hot lava from the interior of the conelet. At the same time the northeast fountains increased from scattered showers of ejecta barely visible above the rim of the conelet, to a strong jet 150 feet high. The conelet quickly commenced rebuilding, and by late afternoon spatter from the fountains had again nearly sealed over the top of the conelet. Similar activity occurred for the next several days, the cone alternately sealing nearly or completely over, and reopening as the top was weakened by melting and collapsed. Occasional small flows spread over the crust bench near the conelet. The northeastern vents finally became inactive on July 6.

On June 30 a large fountain, averaging 150 feet in height, was playing about 500 feet from the southwest edge of the lake, and on both sides of it along the line of the fissure were 16 smaller fountains (fig. 11).

Early on June 29 a crust island about 150 feet across became detached from the marginal bench at the northern edge of the lake and moved slowly southward. On the evening of June 30 the island reached the main fountain area 800 feet northeast of the southwest sinkhole (fig. 11). About $18^h\ 30^m$ this island moved over the northeasternmost small fountain and immediately started to disappear, partly by crumbling away of its edges, and partly by foundering and being overflowed by fluid lava. The disintegration of the large island produced two small islands, which assumed positions just east and northwest of the principal fountain. By the night of July 1 these islands appeared to be grounded. Instead of rising and falling with the surrounding liquid as they had previously, they remained essentially stationary, the liquid lava around them rising and falling with the surges from the fountains, alternately exposing and concealing a brightly glowing band at their bases.

The crust bench had gradually widened until by the afternoon of June 30 it was encroaching on the northeast sinkhole. On the afternoon of July 1 the sinkhole ceased to function, and was replaced by a constant fountain 75 to 150 feet high. Spatter from this fountain accumulated on adjacent parts of the crust bench, and a small cone began to build around the fountain. On July 2 the conelet was widely breached on the eastern side, and small flows from the fountains were moving over the bench nearby. On July 3 the conelet was about 20 feet high and beehive shaped. By July 4 the cone was nearly sealed in after which the fountain activity ceased.

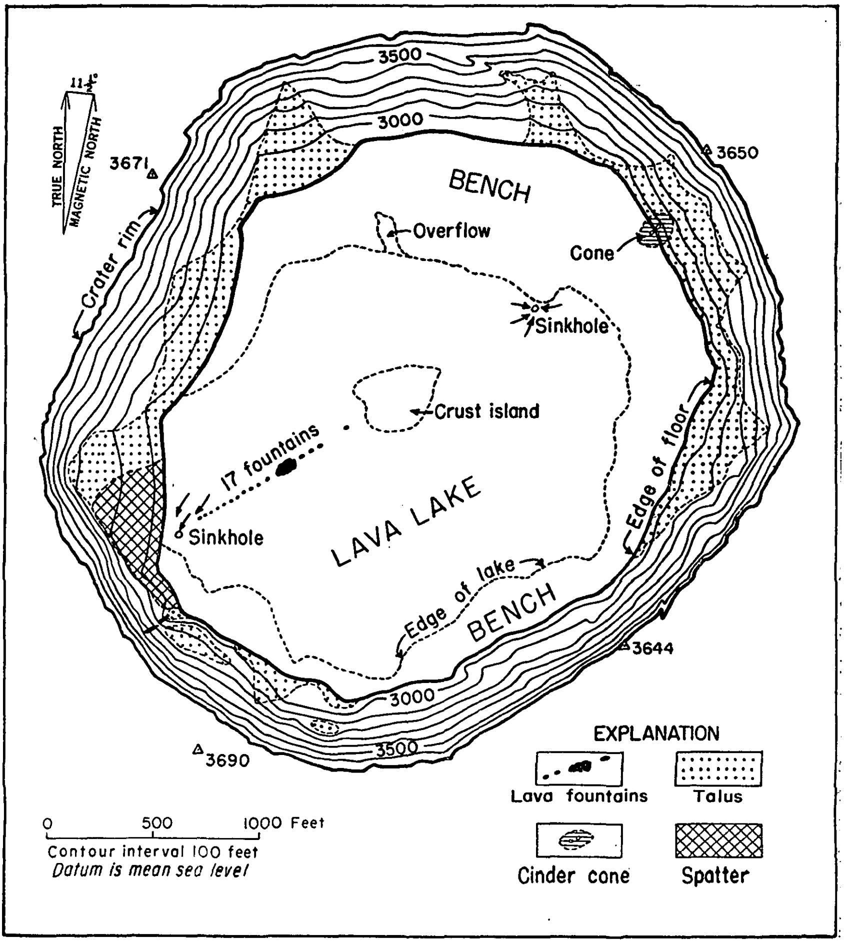

FIGURE 11.—Map showing conditions in Halemaumau crater at 13h on June 30, 1952.

The progressive change of conditions from July 1 to 6 is shown in figures 12–15. The bench of semisolid pahoehoe around the edge of the crater floor gradually widened, decreasing the area of the central lake of fluid lava. On the morning of June 28 the lake extended across the crater from wall to wall, and had an area of about 100 acres. By July 1 the bench at the north side ranged from 400 to 700 feet wide, and the area of the lava lake had been reduced to 68 acres. On July 4 the lake area was 44 acres, including the area of the two large islands (fig. 13). On July 5 one of the islands became joined to the eastern shore, transforming it into a peninsula (fig. 14), and the other island disintegrated. Early on July 6, however, overflows of the isthmus again isolated the island from the shore (fig. 15).

On the morning of July 2 the activity of the southwestern sinkhole was weak. At 10^h55^m it suddenly reversed, and became a large fountain that increased until at 11h30m it was throwing ejecta regularly to a height of 200 feet, and occasionally as much as 300 feet (pls. 2, 3). At the same time the central fountains increased in activity and became explosive, throwing rocketlike bursts as high as 250 feet, accompanied by loud detonations. By midafternoon a large lava flow, about 10 feet thick, was moving eastward from the southwest fountain along the base of the crater wall, and another was advancing northeastward between a pressure ridge on the crust bench and the central fountains. By 14h30m the whole central part of the lake appeared to be heating up, and at 15h30m overflows from the lake were spreading over the marginal bench on the northern and western sides. At 15h40m

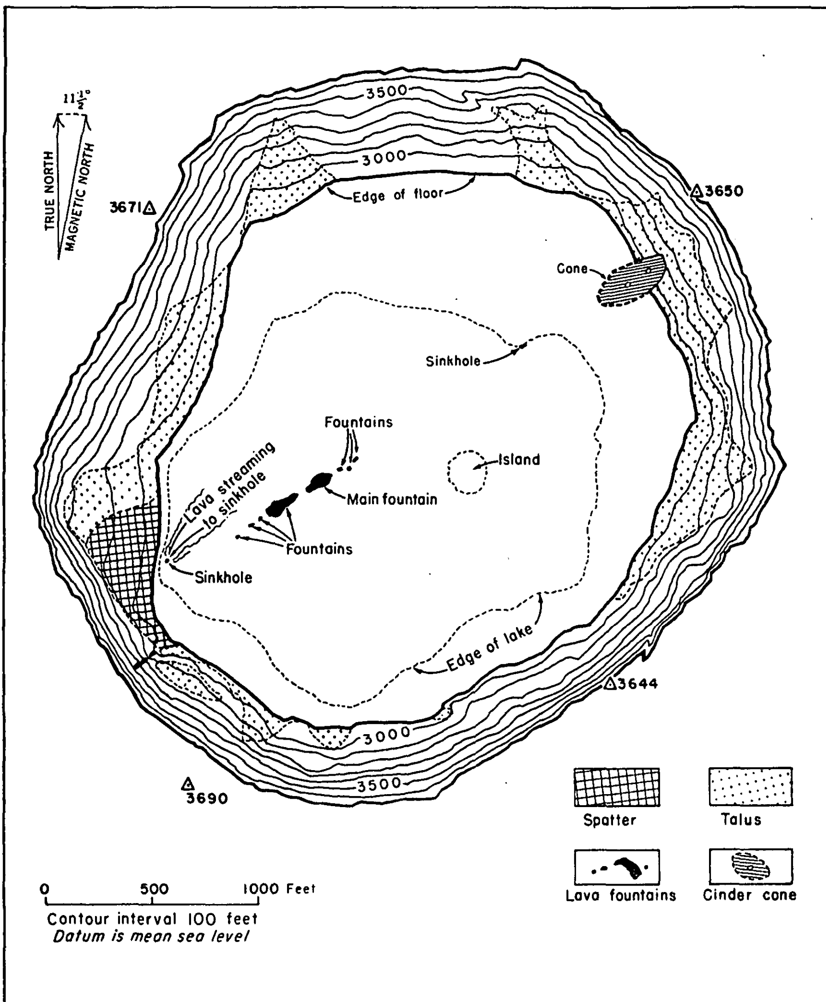

FIGURE 12.—Map showing conditions in Halemaumau crater on July 1, 1952.

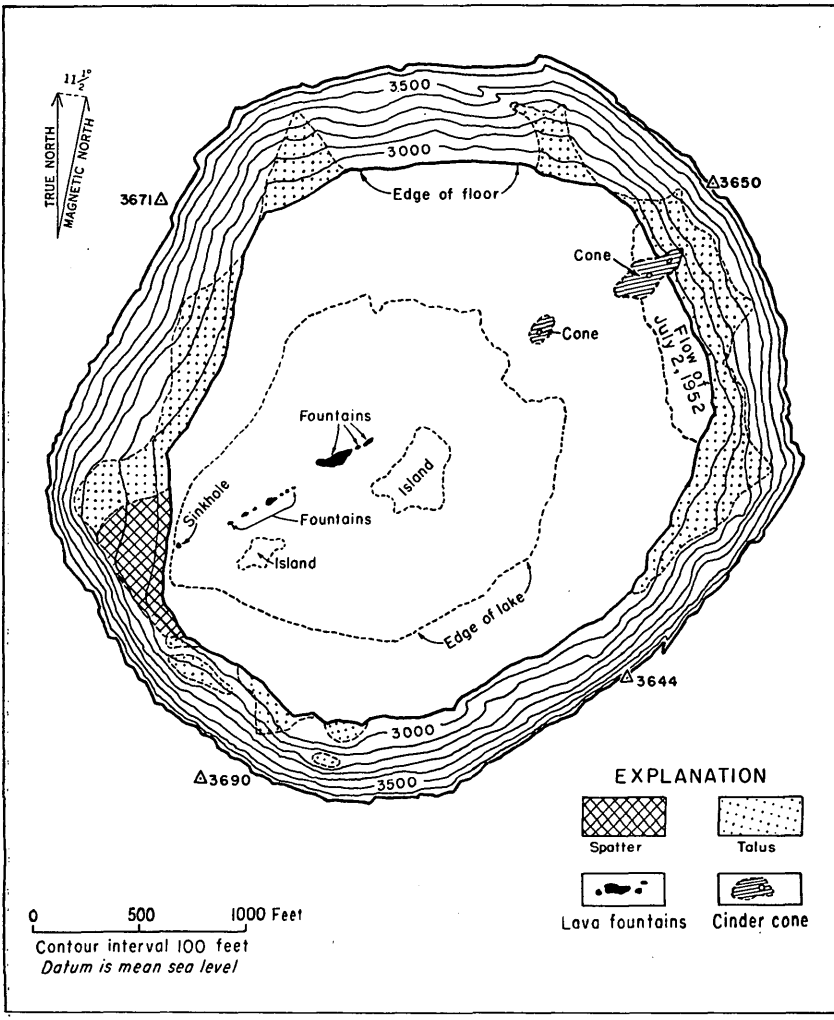

FIGURE 13.—Map showing conditions in Halemaumau crater on July 4, 1952.

the southwest fountain abruptly stopped, then spurted briefly three times, the last at 15^h45^m. It remained inactive for the remainder of the afternoon. At 19^h the site of the southwest fountain was inundated by a southwestward spreading of the lava lake. About 21^h the sinkhole resumed sluggish activity.

At 05^h30^m on July 3, the southwest sinkhole again suddenly became a fountain which increased rapidly to a height of 400 feet. Again, as on the previous day, the central fountains became noisily explosive. The strong fountaining lasted until about 07^h, then subsided until all activity was very weak. By 07^h30^m the southwest sinkhole resumed sluggish activity, and the central fountains gradually regained their former size. Conditions continued much the same for the remainder of the day.

Weak sporadic fountaining began again at the southwest sinkhole at 22^h15^m. By 22^h40^m the height of the fountain had increased to 100 feet, and by 23^h45^m had reached 400 feet. E. L. Bohlin reported that the fountaining continued strong until 03^h30^m on July 4, playing steadily like the jet of water from a hose to heights of about 400 feet, with occasional bursts going above the rim of the pit, a height of more than 600 feet. Pumice fell on the road at the southwest edge of the caldera. This fountain activity was the strongest after the first few hours of the eruption. As in the previous spasms, the central fountains were very noisy, sending long rocketlike strings of molten lava high into the air. The whole central lake and part of the marginal

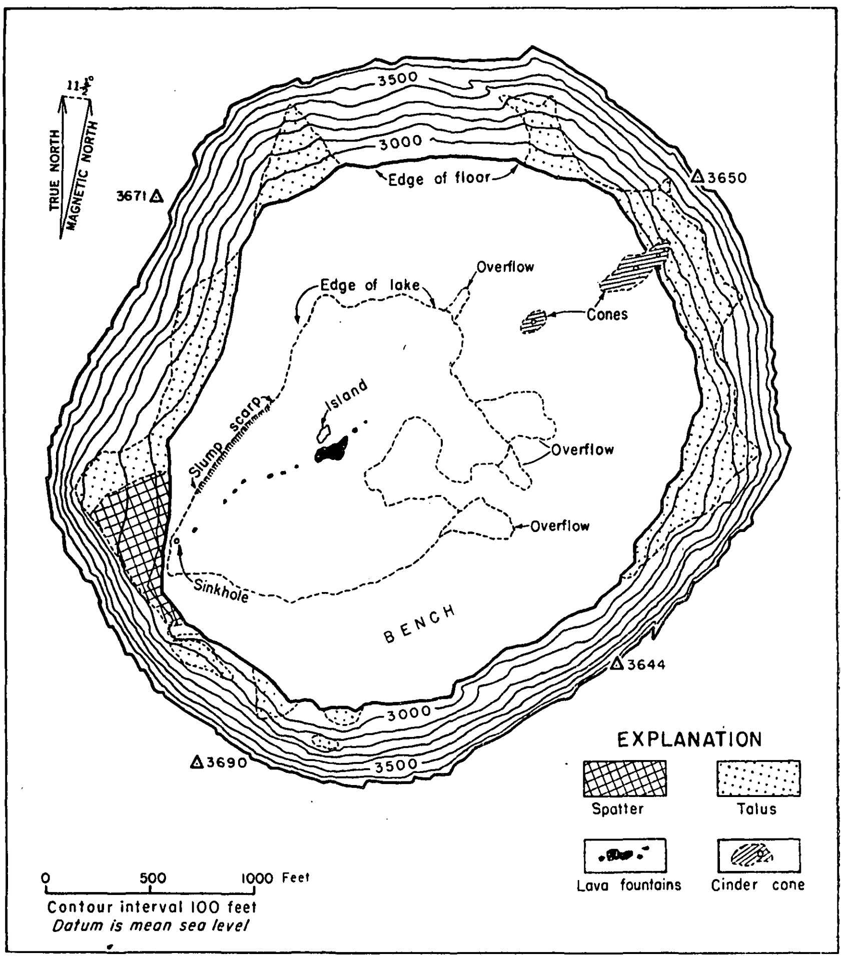

FIGURE 14.—Map showing conditions in Halemaumau crater on July 5, 1952.

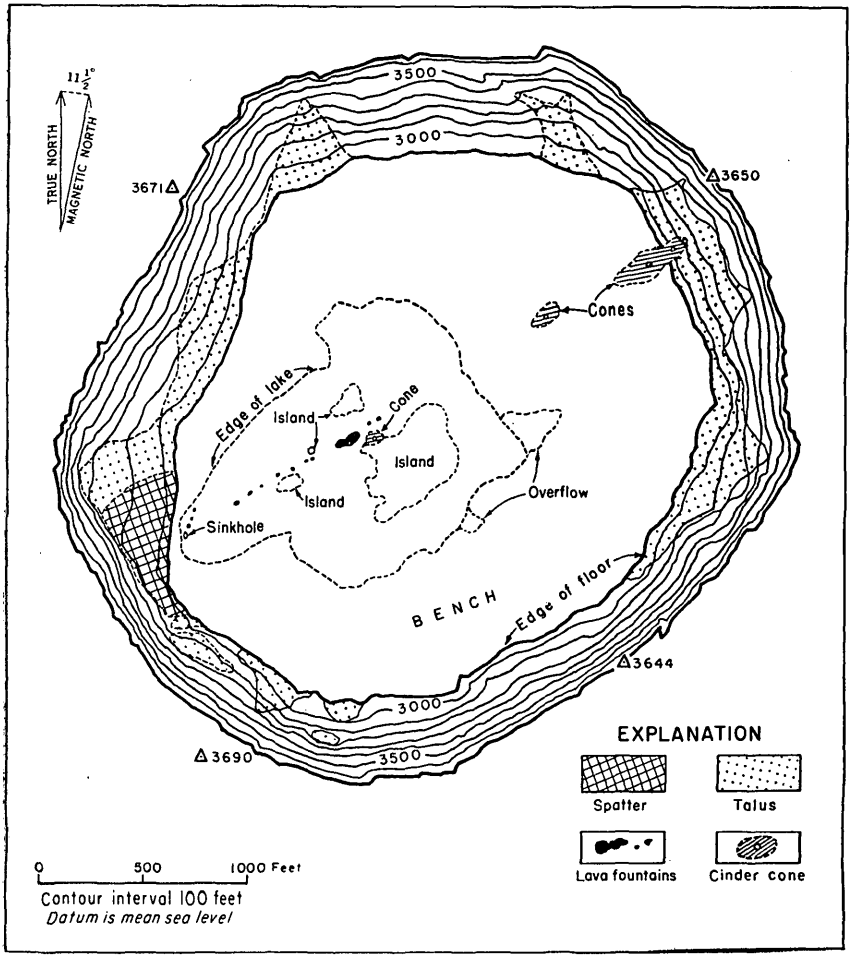

FIGURE 15.—Map showing conditions in Halemaumau crater on July 6, 1952.

bench were inundated by new flows. At 03h30m both the main southwest fountain and the central fountains suddenly subsided, nearly disappearing within a few minutes.

Through the morning of July 4 the southwest sinkhole was alternately moderately active and sluggish. About 15h00m it again became a fountain, which by 15h30m was reaching heights similar to those of the night before. Again, also, the central fountains became very active, shooting long stringlike "rockets" as high as 250 feet, with noisy detonations. Balloonlike balls of lava, as much as 20 feet in diameter, rose in the central fountain pits until they appeared to be almost detached from the underlying lava, then burst to release a large puff of pale-brown gas. The strong activity was short lived, and by 16h15m activity had returned to normal. Still another flareup of the southwestern fountain occurred at 04^{h}00^m on July 5, but the fountain reached a height of only 200 feet. After July 5 no great increases of the southwest fountain occurred, although for several days conditions alternated between sinkhole and fountain activity.

CONE-BUILDING PHASE, JULY 5–AUGUST 9

During the first few days of the eruption the deep pool of fluid lava around the central fountains offered no place for the accumulation of fountain ejecta, and cone building was impossible. By the night of June 30, however, a sufficient amount of pasty material had accumulated in the lower part of the lake to support the crust islands on the two sides of the fountains (pl. 4). Spatter from the fountains accumulated on the islands, initiating the cone-building phase of the eruption. Building was slow at first, and by the morning of July 5 the island just west of the central fountain had been built up to a height of only 25 feet, partly because the underlying material was not strong enough to support the island and allowed it to sink somewhat as it built up. Further evidence of the mobile character of the lake bottom is shown by a gradual southwestward shifting of the island along the edge of the fountain chain. During the 24 hours from 17^h on July 5 to the same hour on July 6, the island shifted about 100 feet.

During the next few days, as the islands increased in height they occasionally became unstable. The lower part on the side toward the fountain was prevented from building, and even eaten away, by the fluid lava surging against it, and as the upper part accumulated more and more spatter, the face toward the fountain became very steep, or even overhanging. Sometimes this unstable condition was relieved by the steep face slumping off, but at other times the entire island leaned slowly fountainward, rocked majestically in the surge, and eventually rolled slowly over.

On the afternoon of July 7 an arcuate rampart of spatter 150 feet long and 20 feet high had formed on the east side of the principal fountain, and a similar one on the southwest side. By July 9 the substratum of the lake had become sufficiently firm to consistently support the accumulations of spatter that built around the fountains, and the principal phase of cone building began. By July 10 the cone surrounding the main central fountain was 30 to 50 feet high, and lava streams were spilling through gaps in it eastward and northward. The average height of the fountain within the cone was about 50 feet, but some bursts were as high as 200 feet. Southwest of the main fountain, smaller fountains were building a row of low spatter cones.

On July 5 a steep-sided wall of spatter, known as a lava ring (Daly, 1914, p. 135) started to form around the edge of the lava lake, and by July 6 the lake stood about 10 feet above the surrounding bench (pls. 5, 6). At the southwest edge of the crater floor a small, nearly circular lake 300 feet across behaved somewhat independently from the main lake. This southwest lake was fed by the large southwest fountain at the site of the former sinkhole, and by a group of smaller associated fountains. Commonly, the smaller fountains were arranged along an arc concave to the northeast extending northwestward about 75 feet from the large fountain. The southwest lake was enclosed in its own lava ring, and on the morning of July 6 stood about 10 feet above the level of the main lake.

Occasional overflows of the main lake and the southwest lake sent tongues of lava onto the marginal bench. These overflows gradually raised the level of the bench. As the eruption progressed it became evident, however, that only a small part of the rise of the marginal bench was the result of overflow of lava onto its surface. Even when no overflow occurred, the bench rose at a rate approximately equal to the rise of the central lava lake. Obviously the rise of the bench must have been caused largely by the addition of plastic material beneath it. This may have resulted from an isostatic adjustment whereby the increasing depth of the lake caused the still-mobile substratum to flow outward and elevate the bench—a process that was really nothing more than the tendency of a fluid mass, however viscous, to assume a uniform surface level.

On July 12 the cone around the main central fountain was about 60 feet high, and lava rivers spilled from it eastward and westward to feed the main lava lake. Another cone was forming around a slightly smaller fountain about 300 feet farther southwest. From this cone a lava stream escaped southward, then turned northeastward to join the lava from the larger fountain. This circulation remained the same for several days (fig. 16). The southwestern pool was a true independent lava lake, with a constant sinkhole at its northeast edge around a permanent fountain, and a gradual outward movement of the lava all over the surface from the source fountains to the edge. Occasional crustal foundering and marked downflow occurred at other points around the rim, followed by evanescent rim fountains.

During the next few days the two central cones increased in diameter until by July 14 they coalesced, although the southern fountain pit remained isolated from the larger northern one (fig. 16). On July 17 the wall between the two pits broke down, and the central cone became a single structure with a fountain pit elongated southwestward and containing both the large central fountains (pl. 5). Flows continued to spill from the central cone southward, westward, northeastward, and eastward, feeding the surrounding lava lake. The lake had an area of 30 acres, and was very active. Currents of lava moved outward from the gaps in the cone to the edge of the lake,

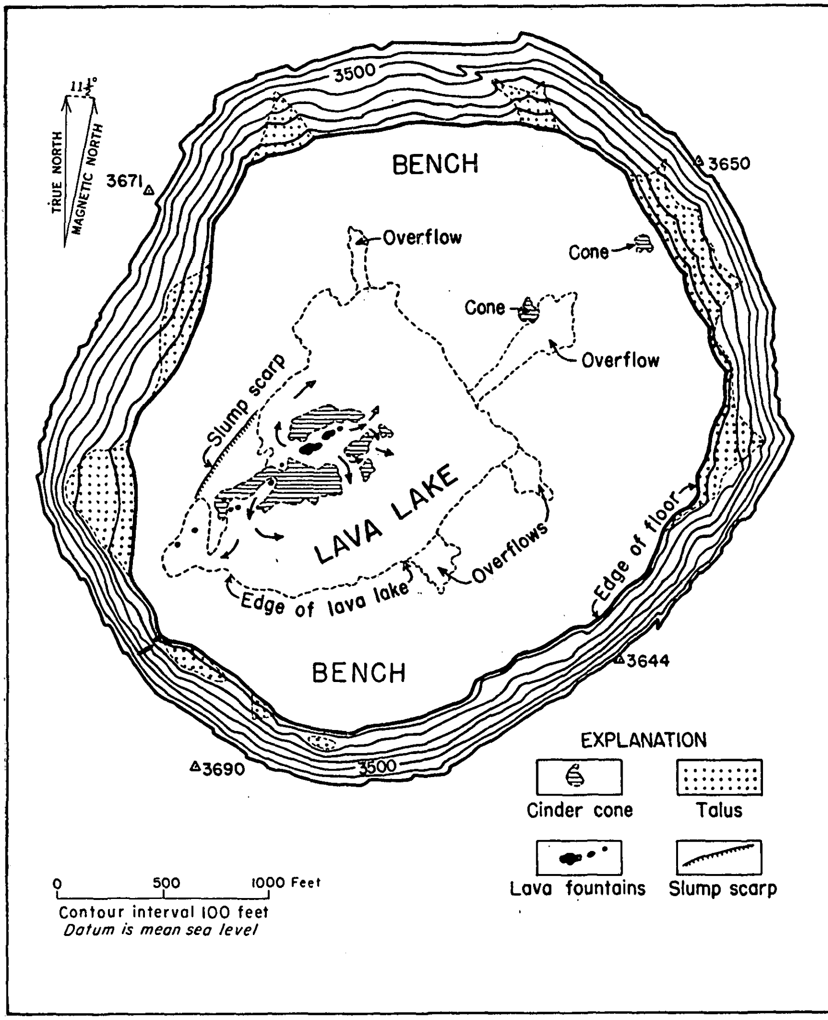

FIGURE 16.—Map showing conditions in Halemaumau crater on July 16, 1952.

where they plunged downward, carrying with them fragments of the crust. Crustal engulfment occurred occasionally at any point on the lake surface, but was most common at two general locations: the edge of the lake, and along lines where flows from different gaps in the cone merged. The engulfment of each large crust fragment was followed by small short-lived fountains. At the edge of the lake the accumulation of spatter from these fountains built the lava ring, which in succeeding weeks confined the liquid of the lake at a level as much as 20 feet above the adjacent marginal bench.

On July 15 a small fountain at the north edge of the southwest lake had built a beehive-shaped cone 30 feet high. The southwest fountains had, however, become very weak, and on July 16 the main lake overflowed into the southwest lake (fig. 16). The southwest fountains again became strong on July 18, and continued active until July 22. On July 23, however, they became small and sporadic, and after July 24 they disappeared, leaving the south lake as a lobe of the main lake fed by lava streaming southward from the central fountains.

A general overflow of the main lava lake began at 12^h15^m on July 20, and continued until midnight. Flows moved outward across the bench to, or nearly to, the crater walls on the northwest, north, and northeast sides. This completed the obliteration of the cones

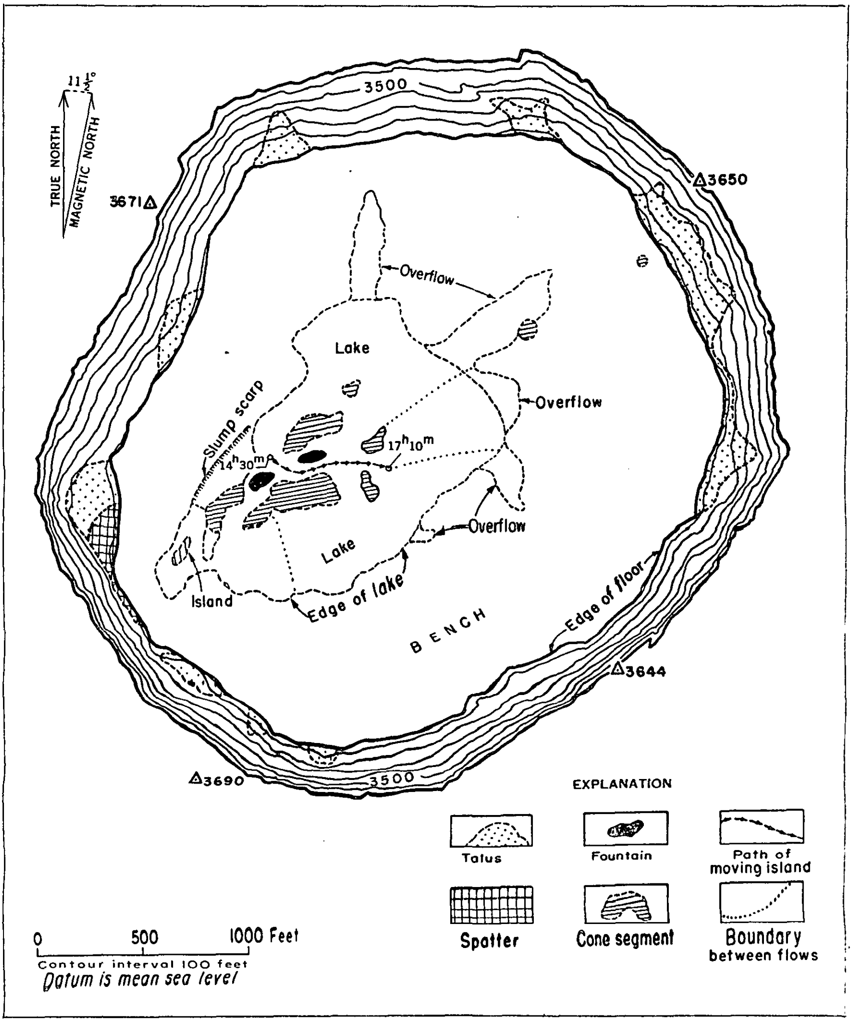

FIGURE 17.—Map showing conditions in Halemaumau on July 25, 1952.

at the former northeast sinkhole and at the foot of the northeast talus, which had already been partly destroyed through collapse and burial by new lava.

By July 25 the gaps in the northern and eastern sides of the cone had become much enlarged (fig. 17), partly by fraying away of the cone walls along the edges of the powerful lava rivers that poured out of the central fountain pit (pls. 6, 7), and partly by an actual outward movement of the cone segments themselves. Persistent fumaroles developed at the lava ring along the eastern side of the lake (pl. 7).

On July 29 several small flows issued along the edge of the bench at, or near, the wall of the crater. The molten lava apparently rose along the boundary of the new lava plug in the bottom of the crater. These lava flows were the first of several similar flows occurring at intervals during the remainder of the eruption.

Activity continued essentially the same until August 7. The average size of the central fountains decreased to about 40 feet, but their explosiveness increased somewhat, and occasional explosive bursts reached great heights. Northrup Castle reported that, about midnight on August 5, one explosive burst from the fountain farthest north reached a level above the rim of the crater. Similar bursts were observed at 19^h45^m on August 6 and 20^h30^m on August 7. These bursts reached a height of about 550 feet. The greater explosiveness may have resulted from some increase in viscosity of the escaping lava. A gradual decrease in the amount of lava being poured out caused a retreat of the margins of the lava lake, which between August 1 and 7 moved inward 50 to 75 feet.

The cone reached its maximum development early in August. On August 11 it was 65 feet high, and about 800 feet in basal diameter.

DECLINING PHASE OF THE ERUPTION, AUGUST 9–NOVEMBER 10

Early in August there began a period of fluctuating but gradually decreasing lava output, and apparent decrease in the amount of superheat in the lava, with a tendency to increased viscosity and clogging of the vents. On August 9 the southern gap in the cone became blocked, and the north and northeast lava rivers increased greatly in volume, plunging over spectacular cascades as much as 20 feet high. On August 10 the south river became reestablished, and the east river was blocked by a partial collapse of the adjacent cone wall. By August 12 the east river was flowing again, but the northeast river had in turn been choked off (fig. 18 and pl. 8). On August 13 the west and south rivers became inactive. Cessation of the south river was followed by draining of the southern lobe of the lava lake, leaving a broad basin about 20 feet deep with a nearly flat, irregular floor. On August 18 lava overflowed the south wall of the cone and reestablished the south river, refilling the basin.

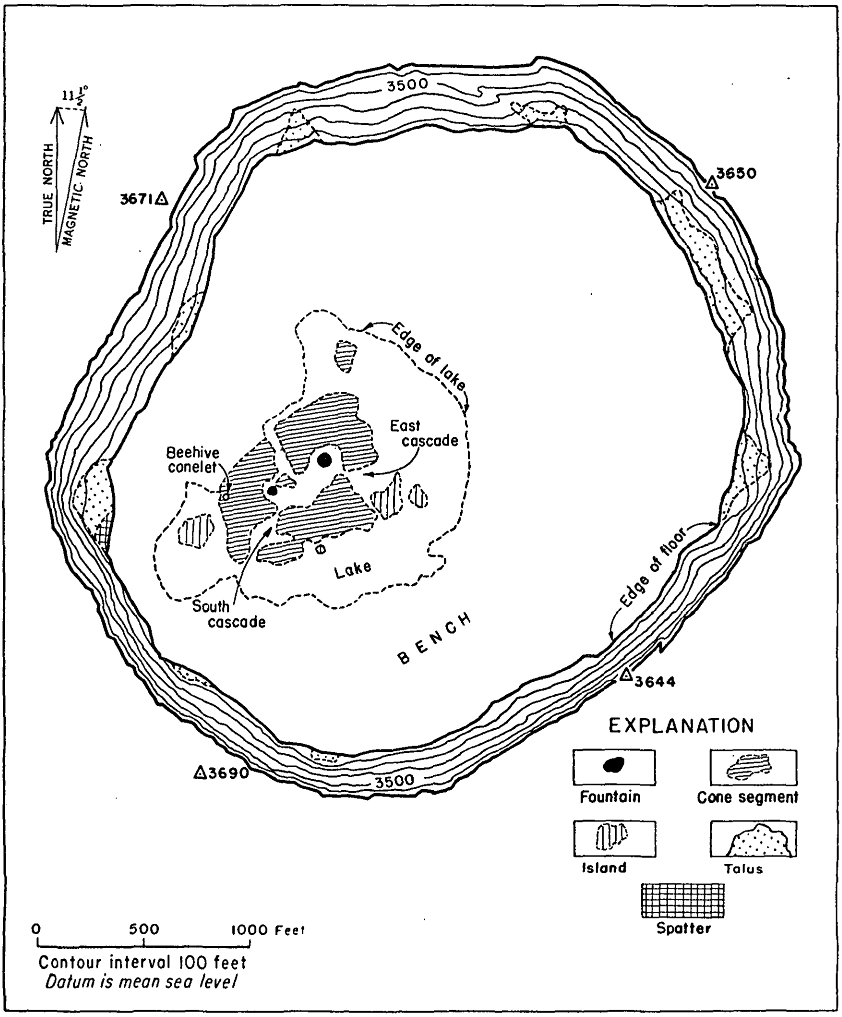

FIGURE 18.—Map showing conditions in Halemaumau on August 12, 1952.

From August 11 to 28 there was a progressive but irregular decrease in the size of the lava fountains. At the same time there was a crude alternation in the degree of activity of the two central vents, the northern vent being more active than the southern one at some times, and less active at others. This alternation resulted largely from variations in fountaining at the northern vent, activity at the southern vent remaining relatively constant.

Early on the morning of August 11 the northern fountain was small and intermittent, whereas the southern fountain was playing constantly to heights of 25 to 50 feet, with occasional bursts as high as 200 feet. By late morning the northern fountain had again increased in height until it slightly exceeded the southern fountain, which reached a maximum height of about 50 feet. This increased activity continued through August 12 and 13. On August 14 the size of the northern fountain gradually diminished, until in early evening it was replaced by a row of four tiny fountains playing in the northern fountain pit along the line of the original eruptive fissure of June 28. The southern fountain remained fairly large, playing to an average height of 25 to 30 feet. These conditions continued essentially unchanged until August 18, with the row of fountains in the northern pit being replaced by one small sporadic fountain. In spite of this, most of the lava liberated apparently came from the northern vent, the southern fountain consisted largely of a spattery release of gas. On August 19 the northern fountain became totally inactive. It resumed weak activity early on August 20, and by August 21 it was again vigorous, exceeding the southern fountain in height. On August 22 the average height of both fountains was about 20 feet, with some bursts of glowing ejecta reaching heights of 200 feet.

On August 21 lava ceased flowing from the central cone, and the lava lake surrounding the cone had become inactive (pl. 9). On August 23 the two fountains were small and sporadic, throwing showers of glowing fragments as high as 150 feet. The fountains had built beehive-shaped conelets of spatter 20 feet high within the crater of the cinder cone, and a nearly circular lava lake about 120 feet in diameter had formed almost between the two conelets (fig. 19 and pl. 10). This condition persisted throughout the remainder of the eruption.

By August 25 activity had become very weak, but on August 29 was resumed. In early September activity was again spectacular, with loud roaring and whistling gas release accompanied by explosive bursts that threw showers of glowing cinders to heights of 150 to 200 feet. On the night of September 2, small glowing spots appeared on the floor north and east of the central cinder cone, and by the morning of September 3 two flows were issuing at those localities and spreading sluggishly over the adjacent floor (fig. 19). The northerly flow was fed by a tiny fountain spurting 5 or 6 feet into the air about 400 feet north of the north-central conelet.

Throughout the month of September small flows continued to issue on the floor of Halemaumau outside the central cinder cone. These small flows welled up quietly, with very small fountains at their vents, or none at all, and little evidence of gas liberation. Two flows that occurred on September 3 have already been mentioned. On September 5 another appeared on the floor northwest of the cinder cone, and still another issued at the foot of the western wall of Halemaumau. Small flows issued on the floor southeast of the cone on

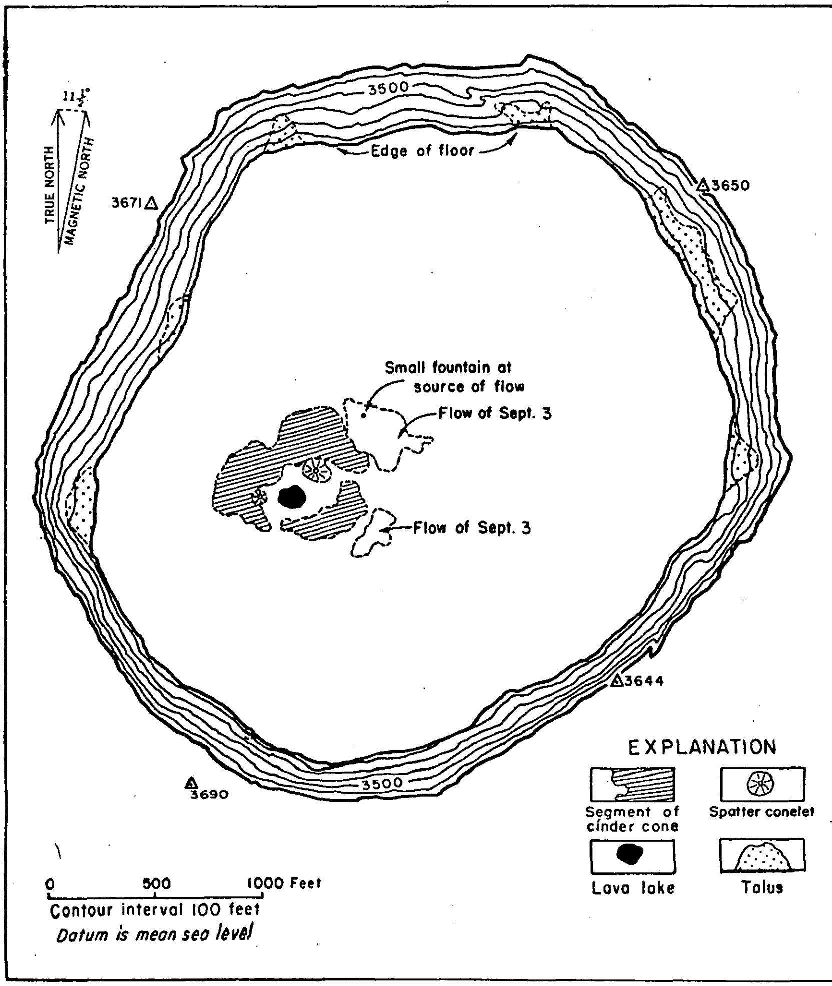

FIGURE 19.—Map showing conditions in Halemaumau on September 3, 1952.

September 8, northeast of the cone on September 12 (fig. 20), at the western wall on September 16, northwest and northeast of the cone on September 17, at the foot of the southwestern wall on September 19–21, and at the foot of the northwestern wall on September 27. On the night of October 3 a flow broke out at the foot of the southwestern wall of Halemaumau and spread rapidly around the edge of the crater floor for a distance of 2,200 feet.

Part of the time from September 1 to 10 there apparently was moderately regular alternation in the strength of activity of the two central vents, the activity of one decreasing while that of the other increased (Wentworth, 1953). The common length of the cycle from maximum activity of one vent to maximum activity of the other, then back to maximum activity of the first, was 4 to 6 hours. Concurrently, there were shorter period changes that affected both vents essentially simultaneously. Thus while the general activity of one vent was slowly subsiding and that of the other slowly increasing, both vents commonly produced unusually big bursts of ejecta either at the same instant or within 1 or 2 seconds of each other. On the average, however, the northern fountain was distinctly larger than the southern one, and the northern vent appeared to be the dominant vent. Throughout most or all of this period the flow in the small lava lake between the two vents was from north to south, and a secondary fountain at a sinkhole at the south edge of the lake built a spatter heap on the south bank.

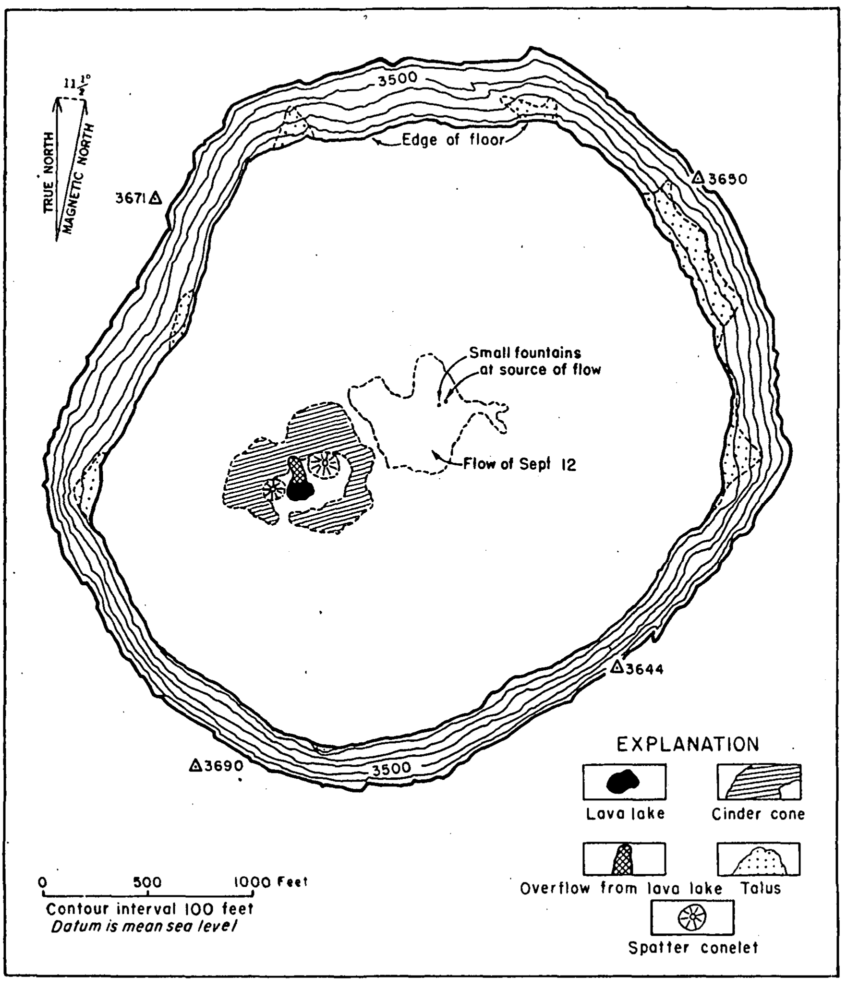

FIGURE 20.—Map showing conditions in Halemaumau on September 12, 1952.

From September 10 to 18 the more northerly of the two central vents was the more active, and its conelet gradually built up to a height of 50 feet, overtopping the rim of the surrounding cinder cone. Throughout this period the lava at the surface of the small lava lake flowed slowly from the north to the south edge, where it sank, producing fountains 10 to 15 feet high against the south bank. On September 19 the activity of the two conelets became reversed, and the southern one became the more active. Simultaneously, the movement of the lava in the lake reversed, rising at the south edge to flow northward and sink along the north bank. Spatter from the edge fountains and occasional small overflows had built up a low flat cone around the lake, the surface of which stood about 20 feet higher than the surrounding floor of the crater of the cinder cone.

At 01^h45^m on September 20, lava started to spill over the southern rim of the lake. The overflow increased rapidly in volume, breaking down the southern wall of the lava cone containing the lake and sending a main flow over the southern part of the floor of Halemaumau. At 10^h12^m the northeastern rim of the lake also was overflowed, and a second flow spread out to coalesce with the first one east of the cinder cone (pl. 11 and fig. 21). The northeastern overflow lasted only a few hours, but the southern overflow continued until about midnight. This was the most voluminous single outpouring of lava after August 22.

On September 22 the northern central vent again became dominant, and again the circulation in the lava lake reversed, returning to its first direction of movement from north to south. Explosive activity at the southern conelet ceased entirely and for the remainder of the eruption the conelet fumed quietly.

The northern conelet gradually built up to a height of 65 feet, and by September 26 its top was nearly sealed over. On that afternoon, at about 16^h, the top and part of the northeastern side of the conelet suddenly were blown off. Charles Bell reported that three or four explosive bursts of ejecta reached heights of about 400 feet. This was accompanied and followed by violent oscillation of the lava in the lake, the level of which rapidly dropped about 15 feet. Within a few minutes both the lake and the conelet had returned to their normal state of activity, with bursts from the conelet reaching heights of 100 to 150 feet.

A similar series of events took place on the evening of September 27. At 20^h35^m a series of about a dozen violent blasts suddenly occurred at the north conelet, throwing incandescent cinder to a maximum height of about 550 feet. The surface of the lava lake surged violently, and following the explosions its level gradually dropped about 15 feet, revealing glowing grottoes hung with fringes of stalactites in

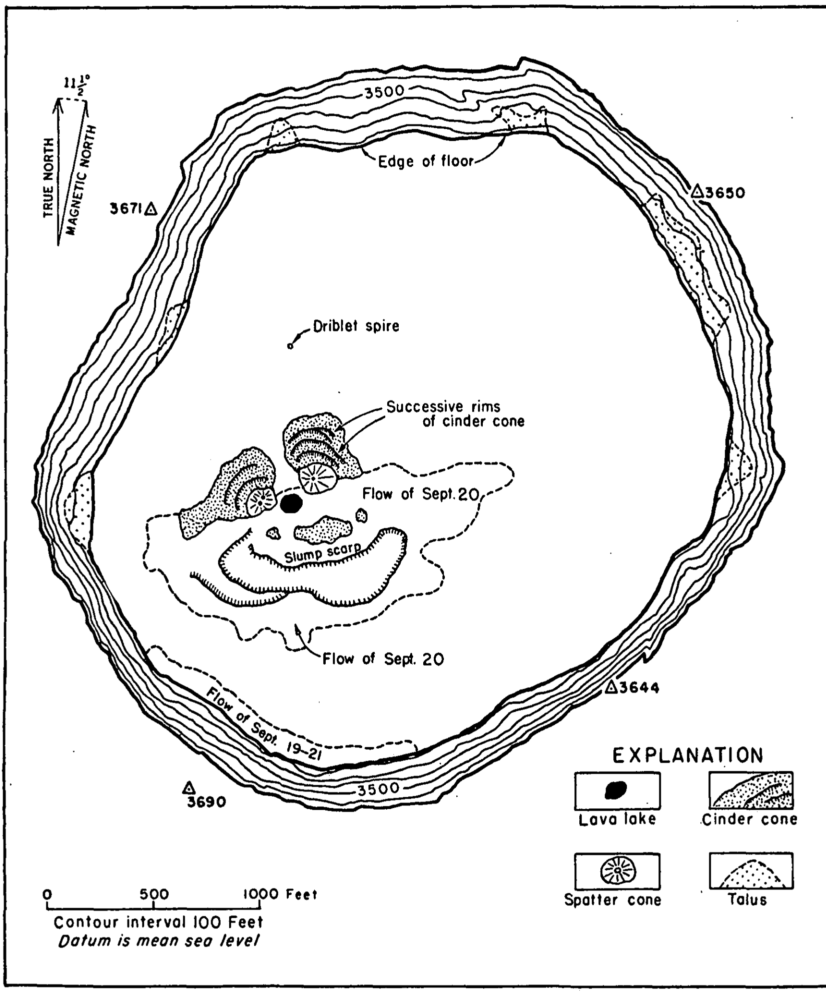

FIGURE 21.—Map showing conditions in Halemaumau on September 24, 1952.

the banks. As on the previous day, activity returned to normal within a few minutes.

During the first half of October the lava lake and the north central conelet continued active, the latter throwing frequent sporadic showers of glowing ejecta to heights of 50 to 100, and rarely 200 feet. On the afternoon of October 5 a series of explosive bursts similar to those of September 25 and 27 reached a height of 450 feet. Surface circulation in the lava lake continued from north to south. Fountains up to 15 feet high formed along the southern bank where crusts were being carried down by the descending liquid, and other smaller fountains appeared from time to time at the northern edge.

The final marginal flow of the eruption broke out at the foot of the southeastern wall of Halemaumau on the afternoon of October 12 and continued until October 15, eventually extending halfway around the crater, a distance of 4,600 feet (fig. 22).

Throughout the last 2 weeks of October the northern conelet was largely sealed over, and only occasional small bursts of glowing fragments could be seen. The cloud of gas liberated at the conelet became markedly more conspicuous, denser, and white in contrast to the thin bluish fume liberated in earlier stage with a more open vent. At night banners of pale-blue or yellowish flame as much as 25 feet long flickered over the conelet.

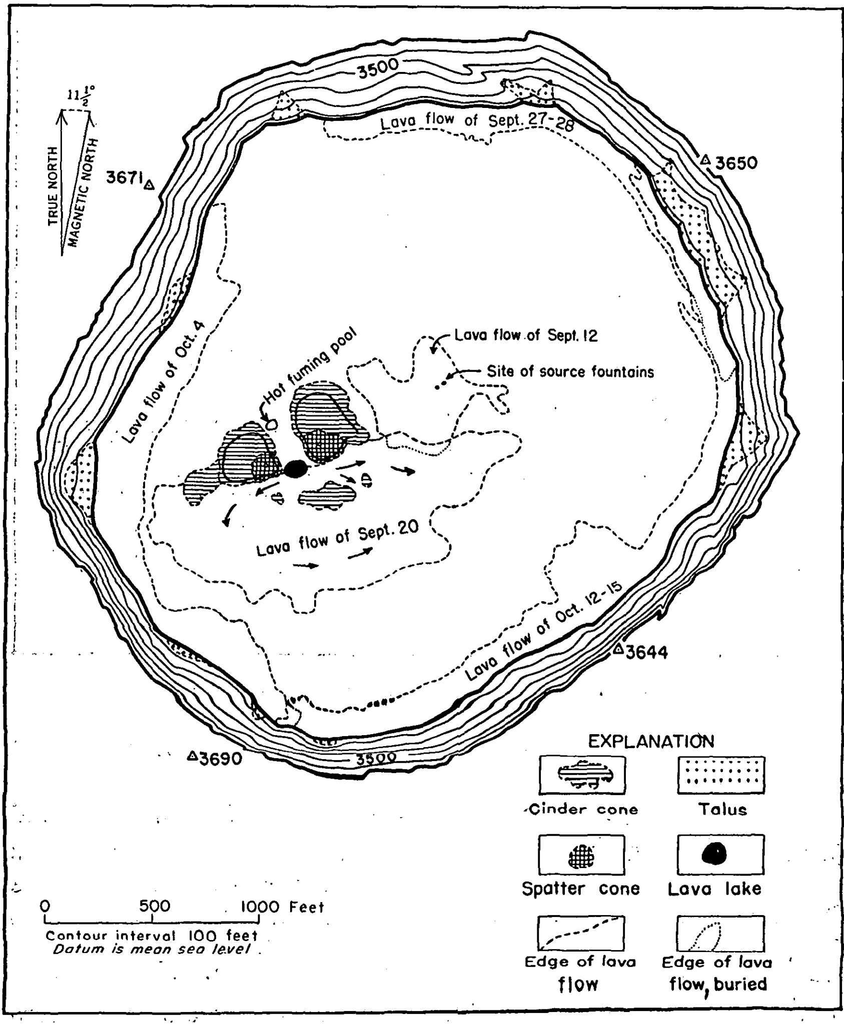

FIGURE 22.—Map showing conditions in Halemaumau on October 21, 1952.

The end of October brought a brief revival of activity. On the night of October 31 the upper part of the northern conelet collapsed, decreasing the height of the conelet from 65 to 35 feet, and big lava fountains veneered the outer slopes of the conelet with a thin layer of liquid spatter. On the next night a further collapse of the conelet reduced its height to about 25 feet, and broadened its wide-open crater to a diameter of about 90 feet. Lava overflowed the crater rim, completely covering the outer slopes of the conelet and extending thin flows to a point just beyond the north edge of the cinder cone. On the south side of the conelet the flow spilled into the lava lake. With the reopening of the vent the gas cloud became thin and bluish again. As throughout much of the eruption, heat from the crater caused a convectional rise of the air above it, and condensation formed an often conspicuous cap of cumulus cloud two or three thousand feet above the crater rim.

Another overflow of the conelet, similar to that of November 1, occurred at about 22^h00^m on November 6 (fig. 23). Within a few minutes a thin sheet of lava had covered the slopes of the conelet and the adjacent region. The area of the overflow was estimated by C. K. Wentworth to be about 5 acres. Throughout the first week of November a small lava fountain was visible in the crater of the conelet. The fountain was generally only 15 or 20 feet high, but it threw spasmodic bursts to heights as great as 150 feet.

The last activity of the lava lake was observed on November 9, and the last fountain activity on the morning of November 10.

Considering the eruption to have ended on November 10, its duration was 136 days. Glowing spots continued to be visible in the lava lake and north conelet until November 11, and at the south conelet and at solfataras on the crater floor northwest and south of the big cinder cone until November 18. At the end of 1952, moderate amounts of pale-bluish-gray fume were still issuing at these solfataras.

COMPOSITION OF THE LAVA

The only specimens of the erupted lava recovered are pumice. It is basaltic in character, the refractive index of the glass being 1.598 (± 0.003). The chemical composition and norm of the pumice are shown on page 81.

The radioactivity of the erupted lava apparently has been low. Two samples of pumice ejected the first night of the eruption and at 06^h on July 3, respectively were analyzed by Ivan Barlow and Francis Flanagan, of the Geological Survey. Each sample contained less than 5 ppm of equivalent uranium.

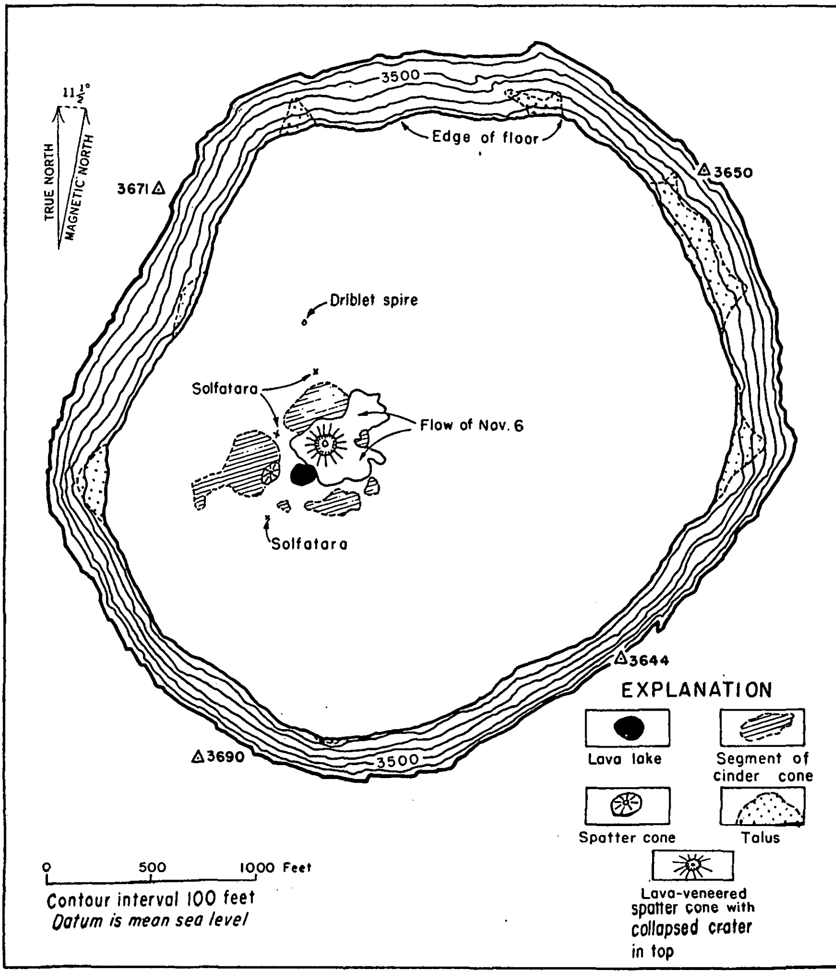

FIGURE 23.—Map showing conditions in Halemaumau on November 7, 1952.

Chemical composition and norm of pumice ejected by Kilauea volcano on June 22, 1952.

[Analyst, Lucille M. Kehl, U. S. Geological Survey]

Chemical Composition		*Norm*		
SiO_2	50. 1	Quartz		1. 74
Al_2O_3	13. 83	Orthoclase		2. 78
TiO_2	2. 71	Plagioclase		44. 99
Fe_2O_3	1. 85	albite (ab_{42})	18. 86	
FeO	9. 59	anorthite (an_{58})	26. 13	
MgO	7. 10	Diopside		22. 91
CaO	11. 29	wollastonite	11. 72	
Na_2O	2. 25	enstatite	6. 70	
K_2O	. 53	ferrosilite	4. 49	
H_2O^+	. 09	Hypersthene		18. 62
H_2O^-	. 12	enstatite	11. 10	
CO_2	. 00	ferrosilite	7. 52	
P_2O_5	. 27	Magnetite		2. 55
MnO	. 17	Ilmenite		5. 17
		Apatite		. 67
Total	99. 81			

VOLUME OF THE LAVA

The total volume of the new lava poured into Halemaumau during the 1952 eruption is approximately 64,000,000 cubic yards, and the average thickness is approximately 310 feet. The average depth to the crater floor below the visitors' observation area, at the southeastern rim of the crater, was reduced from 770 to 460 feet. Figure 24 is a cross section of Halemaumau showing progressive stages of its filling during the 1952 eruption, and the photographs, plates 12 and 13 show clearly the great reduction in depth of the crater. Figure

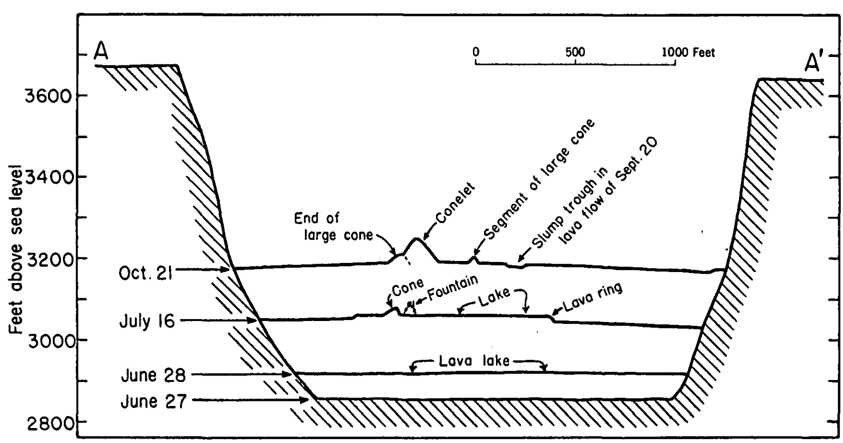

FIGURE 24.—Profiles across Halemaumau along line A–A' in figure 25 showing successive levels of the crater floor just preceding and during the 1952 eruption. The vertical scale is twice the horizontal.

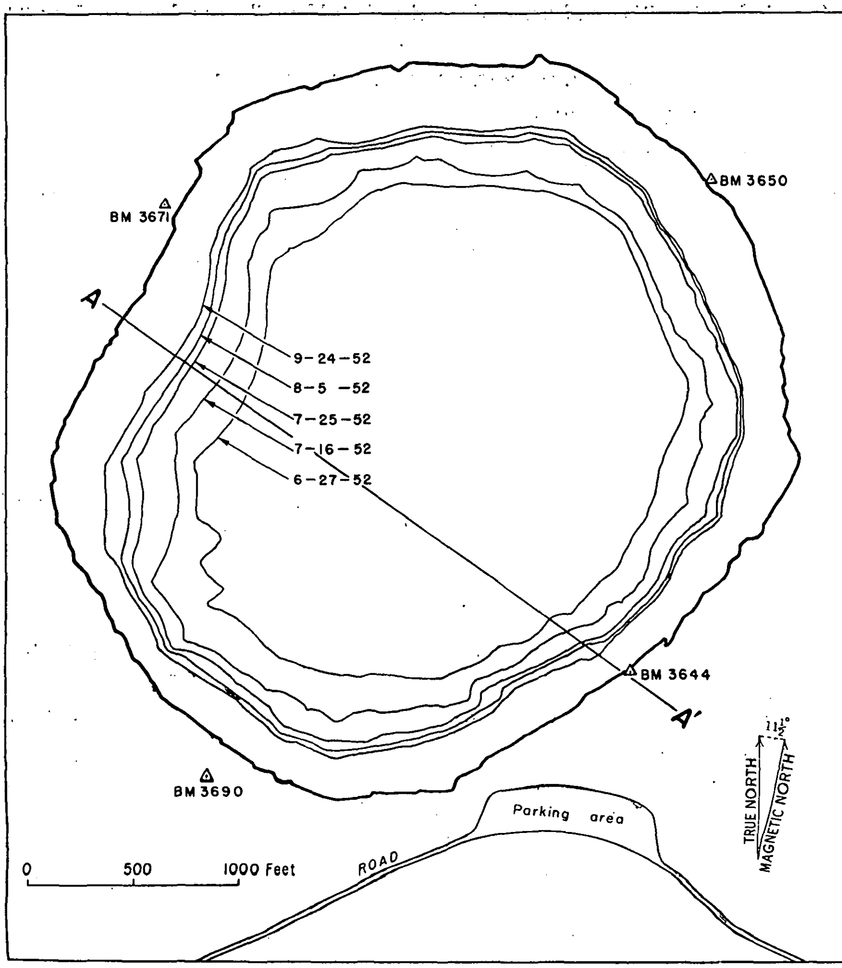

FIGURE 25.—Map showing successive outlines of the floor of Halemaumau crater just preceding and during the 1952 eruption.

25 shows successive outlines of the floor of Halemaumau, illustrating its increase in area during the same period.

Table 10 shows the volume of lava poured into Kilauea caldera during successive intervals since 1823, and the average rate of extrusion per year during each of the intervals. The volumes of flank flows are omitted, partly because they are small compared to the volume of lava erupted within the caldera, and partly because they may be reciprocal to collapses within the caldera and consequently not properly included in the total volume of lava actually liberated. The actual rate of extrusion varied widely within each interval, of course, but the column showing average rate per year gives an interesting over-all picture of variations in volcanic activity. The period

TABLE 10.—*Volumes of extruded lava and rates of extrusion in Kilauea caldera during successive intervals since 1823*

Interval	Volume of extruded lava (cubic yards)	Average rate of extrusion per year (cubic yards)
1823–32	883, 000, 000	98, 000, 000
1832–40	776, 000, 000	97, 000, 000
1840–46	287, 000, 000	48, 000, 000
1846–68	19, 000, 000	1, 500, 000
1868–86	248, 000, 000	31, 000, 000
1886–91	52, 000, 000	10, 000, 000
1891–1924	106, 000, 000	3, 200, 000
1924–34	37, 000, 000	3, 700, 000
1934–53	64, 000, 000	3, 400, 000
Total	2, 472, 000, 000	....

1846–68 is remarkable in that, although activity was nearly always present in the caldera, comparatively little lava was added to the volume of the caldera fill. Continuous lava-lake activity thus does not correlate with the large volume of lava output.

Two facts are obvious from the table. The first is that the activity of the volcano, in terms of volume of lava extruded, was much greater during the first half of the 19th century than it has been since. The second is that if the volume of lava extruded during the 1952 eruption is apportioned over the 18-year period since the last preceding eruption, the rate of extrusion per year is nearly the same as it has been since 1891. The latter suggests that since 1891 magma available for eruption at Kilauea has accumulated at a more or less regular rate, regardless of the constancy or frequency of eruption.

The total volume of lava erupted in Kilauea caldera since 1823 is approximately 0.98 cubic mile.

RATE OF EXTRUSION OF LAVA

Vertical angles were measured from triangulation stations around the edges of Halemaumau crater to selected located points on the crater floor from time to time during the eruption. From these the altitudes of the individual points and the average altitude of the floor were calculated, and by making use of the topographic map of the crater the approximate volume of lava added to the crater fill since the date of the last previous measurements was obtained. Figure 26 shows the average daily rate of addition of lava to the crater fill for each of these periods.

About 8 million cubic yards of lava was poured into the crater by daylight on June 28, most of which probably was extruded before the great decrease in activity at 04^h. Thus the rate of extrusion for the first 4 hours of the eruption probably was on the order of at least 45 million cubic yards per day. This lava contained a large proportion of gas, and loss of gas and cooling resulted in a shrinkage of the new

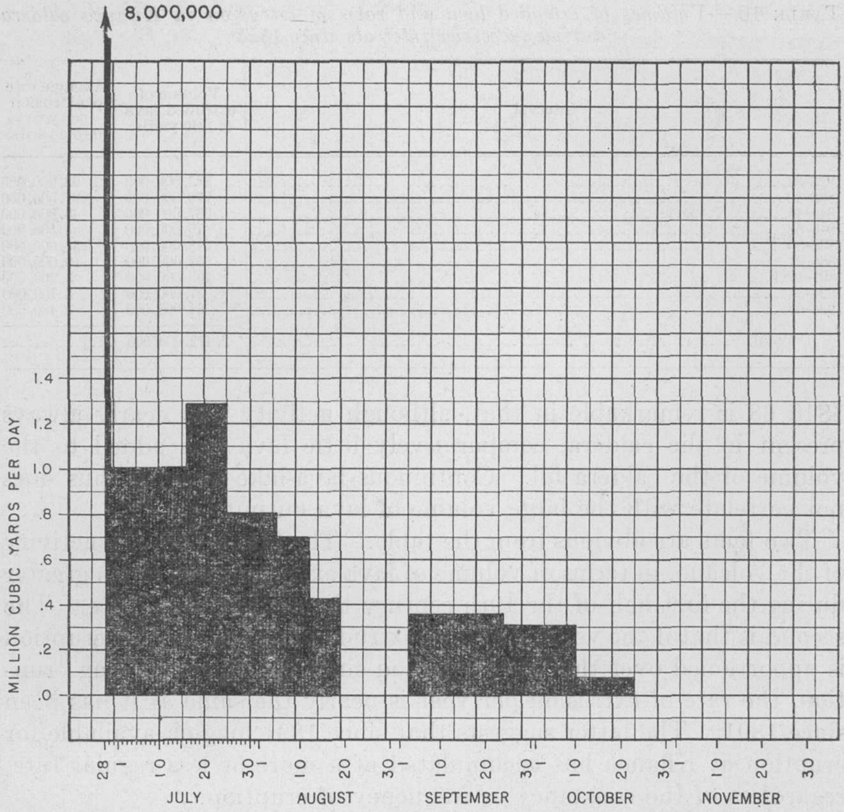

FIGURE 26.—Diagram illustrating the rate of extrusion of lava during the 1952 eruption of Kilauea volcano.

fill of about 1.4 million cubic yards, or nearly 20 percent of the original volume. This resulted in a slump scarp averaging about 10 feet high encircling the new lava floor about 50 feet in from its edge. The proportion of shrinkage was nearly the same as the 18 percent shrinkage estimated by Schulz (1943, p. 743) in the early lavas of the 1940 eruption of Mauna Loa.

After the first few hours of the eruption the rate of extrusion decreased greatly. For the interval June 28 to July 16 the average rate was about 1 million cubic yards daily. Between July 16 and 25 the rate increased again, to 1.29 million cubic yards daily. After that it dropped off fairly regularly, until during the interval from August 19 to September 3 there was no appreciable addition to the volume of the new fill in Halemaumau. Lava added during that time was only enough to compensate approximately for the shrinkage of the fill by cooling and loss of gas.

The revival of activity during early September increased the rate of extrusion to an average of 0.36 million cubic yards daily between

September 3 and 24, after which the rate again decreased essentially to zero for the period of weak activity from October 23 to the end of the eruption on November 10.

TEMPERATURE OF THE ERUPTING LAVA

The temperature of the lava fountains was measured at frequent intervals throughout the first part of the eruption with an optical pyrometer of the disappearing-dot type. After August 25 the fountains were too small and sporadic to yield satisfactory readings from the distance (1,000 to 2,000 feet) at which it was necessary to work.

Readings on the lava fountains during the first month of the eruption ranged from 1,025° to 1,055°C, the variation depended partly, on the amount of volcanic fume and ordinary mist intervening between the instrument and the fountains. Readings were not used if the amount of fume or mist was appreciable, but even an amount too small to be readily detected visually had a pronounced effect on the readings at distances of several hundred feet. Only night readings were used, as it was found during the 1950 eruption of Mauna Loa that readings made during daylight were consistently too high by an undeterminable amount (Finch and Macdonald, 1953, p. 74).

The effect on the readings of different distances, from the fountains was conspicuous. Those made at a distance of about 1,170 feet from the fountain ranged from 25° to 30° higher than those made within a few minutes of the same time at a distance of 1,660 feet. This appears unquestionably to have been the result of absorption by small amounts of fume and mist between the fountains and the instrument. Plotted on a logarithmic scale, the readings at different distances determine a curve that indicates the approximate correction to be applied to compensate for this distance effect. A correction for absorption must also be applied to the readings to obtain the true temperature of the incandescent body. The absorption coefficient of Hawaiian lavas has not been determined, but it is assumed that the correction to be applied is about the same as that (plus 25° at 1,100°C) determined by Verhoogen (1948, p. 131) for leucite basanite of Nyamuragira volcano in central Africa.

Table 11 lists temperature readings on the main lava fountains and miscellaneous readings on other objects, made with the disappearing-dot pyrometer. Both the original readings and the values including the corrections for distance and absorption are shown. From June 28 to 30 corrected measurements of the temperature of the main lava fountains ranged from 1,105° to 1,115°C. Through July the corrected temperature averaged about 1,102°C, with a range from 1,098° to 1,110°. Early in August the average of the corrected readings declined rapidly (fig. 27), bringing it to 1,060° by August 23. Although no satisfactory readings were obtained on the lava fountains after August 25, a reading of 1,050°C on a cascade of lava pouring from the lake on September 20 suggests that there was no great decrease in the temperature of the erupting lava through early and middle September.

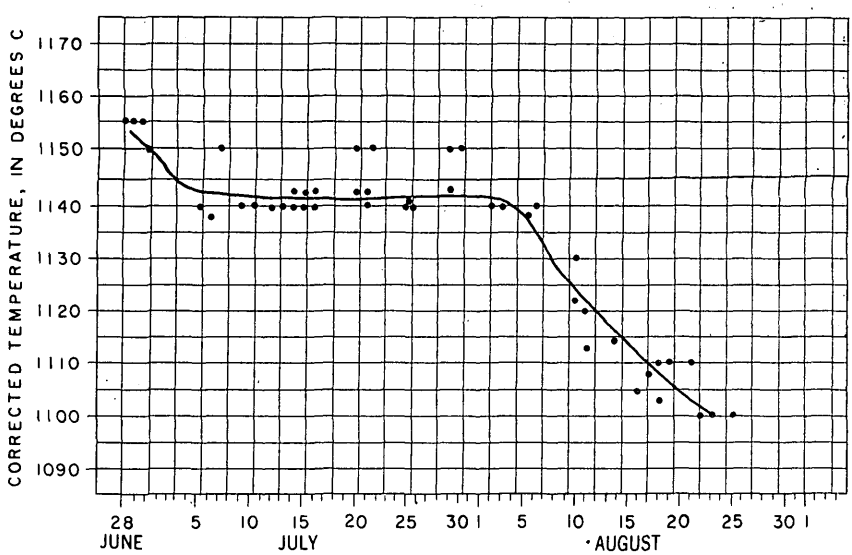

FIGURE 27.—Graph illustrating the decline in temperature of the molten lava in the cores of the principal lava fountains during the 1952 eruption of Kilauea.

The temperatures of the lava fountains near the northest edge of the lake during late June averaged about 25° lower than those of the main fountains in the southwestern part of the lake. Patches of incandescent lava near the east edge of the lake on June 28, exposed by the blowing away of crust fragments during whirlwinds, yielded corrected readings of 1,020°C, about 90° lower than the average of the corrected readings on the main lava fountains at the same time. Similar patches of incandescent lava near the southeast edge of the lake on July 10 gave corrected readings of 1,010°, and incandescent lava pouring over the lava ring at the northeast edge of the lake on July 13 gave a reading of 980°. The temperature in small flows on the bench outside the lake appeared to be still lower, and the only good reading, on July 10, gave a corrected value of 930°. The corrected reading of 1,073° on the inner walls of the glowing aperture at the head of a small flow south of the lake on July 18 may have been higher than that of the lava itself because of gas heating of the walls above the liquid lava. However, the temperatures of 1,030° and 1,050° obtained on lava in cascades at the edge of the lake on August 14 and

September 20 cannot have resulted from gas heating and apparently demonstrates the high temperature of the lake lava itself.

During the evenings of July 2–3 an optical pyrometer of the glowing-filament type was operated at Kilauea by Prof. J. J. Naughton, of the Department of Chemistry of the University of Hawaii. The telescope of Naughton's instrument had a higher magnifying power than that of the pyrometer used by the writer, and it was possible to focus it more precisely on the hot cores of the lava fountains. It appears also that, because of the presence of the graduated wedge, the disappearing-dot type of pyrometer has an integrating effect not present to the same degree in the glowing-filament type. In measuring the temperature of the lava fountains, the integrating effect results in some averaging of the temperature of the hot rising core of the fountain and the cooler ejecta falling around the edge of the fountain, whereas by careful use of the glowing-filament pyrometer it appeared possible to read the temperature of the hottest parts of the fountain with relatively little effect from the cooler parts.

After the eruption Naughton calibrated his instrument by running a cooling curve on a sample of copper furnished by the Bureau of Standards (Naughton, J. J., personal letter, July 24, 1953). Applying the correction thus determined, plus a correction of 25° for absorption of the lava, 24 readings obtained on the evenings of July 2 and 3 range from 1,085° to 1,152°C. With the exception of one reading, all were more than 1,105°. Twelve of the readings were between 1,135° and 1,152°. These presumably were readings on the hottest portions of the lava fountains, with relatively little effect from cooler falling material. Thus it appears that the true temperature of the hot core of the lava fountains was approximately 1,145°C, about 40° higher than the temperature determined with the disappearing-dot pyrometer, and that a further correction of about 40° probably should be added to the corrected temperatures shown in figure 27 and to those for the lava fountains listed in table 11. These corrected values also are shown in table 11.

In summary, through most of the period of active lava fountaining the temperature of the erupting lava in the hot cores of the primary fountains was approximately 1,145°C. The temperature may have been as high as 1,155° during the first 2 days, possibly because of a greater surficial heating effect brought about by oxidation and other exothermal shifts in equilibrium in the liberated gases, which were more abundant than during later stages of the eruption. After a little more than a month of activity the temperature of the primary fountains started to decline rapidly, reaching about 1,055° in late August. This decline of temperature was synchronous with other

Table 11.—*Temperature measurements made with disappearing-dot pyrometer during the 1952 eruption of Kilauea*

Date	Time	Distance from object (feet)	Temperature, °C			Object measured
			Actual reading	Corrected readings		
				Corrections for distance and absorption added	Correction for integrating effect of disappearing-dot pyrometer added	
	h *m*					
June 28	01 40	600	990	1,020	1,020	Glowing apertures in lava lake near east edge of crater floor.
	03 10	700	1,045	1,080	1,120	Lava fountains at northeast edge of crater floor.
	04 00	1,230	1,035	1,090	1,130	Do.
	04 10	1,850	1,020	1,100	1,140	Do.
	05 15	1,850	1,020	1,100	1,140	Do.
	05 15	1,910	1,020	1,105	1,145	Lava fountains at southwest edge of crater floor.
	23 30	1,910	1,030	1,115	1,155	Do.
29	01 30	1,850	1,000	1,080	1,120	Lava fountains at northeast edge of crater floor.
	01 30	1,910	1,030	1,115	1,155	Fountains at southwest edge of crater floor.
	22 30	1,660	1,040	1,115	1,155	Main fountains in southwestern part of crater floor.
30	23 00	1,660	1,035	1,110	1,150	Do.
	23 00	1,600	1,010	1,078	1,128	Fountain at sinkhole in northeastern part of crater floor.
July 1	22 50	1,660	1,025	1,095	1,135	Main fountains in southwestern part of crater floor.
2	22 00	1,660	1,025	1,095	1,135	Do.
3	22 40	1,660	1,030	1,100	1,140	Do.
5	21 00	1,660	1,030	1,100	1,140	Do.
6	22 00	1,660	1,028	1,098	1,138	Do.
7	23 00	1,660	1,040	1,110	1,150	Do.
9	21 25	1,660	1,030	1,100	1,140	Do.
10	21 20	1,660	1,030	1,100	1,140	Do.
	21 20	1,000	970	1,010	1,010	Incandescent lava near southeast edge of lava lake.
	21 20	560	900	930	930	Lava in driblet flow on bench 400 feet southeast of lake.
12	21 00	1,660	1,030	1,100	1,140	Main fountain.
13	22 00	1,660	1,030	1,100	1,140	Do.
	22 00	1,100	935	980	980	Lava overflowing northeast edge of lake.
14	21 45	1,660	1,030	1,100	1,140	Main fountain.
	22 30	1,170	1,055	1,103	1,143	Do.
15	22 00	1,660	1,030	1,100	1,140	Do.
	22 20	1,170	1,055	1,103	1,143	Do.
16	20 00	1,660	1,030	1,100	1,140	Do.
	20 30	1,170	1,055	1,103	1,143	Do.
	20 30	1,170	1,055	1,103	1,143	Fountains just southwest of main fountain.
18	20 00	1,660	1,030	1,100	1,140	Main fountain.
	21 00	1,230	1,050	1,105	1,145	Do.
	21 00	800	1,038	1,073	1,073	Glowing aperture at head of small flow overflowing bench south of lake.
20	20 50	1,660	1,040	1,110	1,150	Main fountain.
	21 10	1,170	1,050	1,098	1,138	Do.
21	20 15	1,660	1,030	1,100	1,140	Do.
	21 30	1,170	1,055	1,103	1,143	Do.
25	21 00	1,660	1,030	1,100	1,140	Do.
	21 15	1,230	1,045	1,100	1,140	Do.
	21 25	1,230	1,055	1,101	1,141	Do.
29	21 00	1,170	1,055	1,103	1,143	Do.
	22 00	1,660	1,040	1,110	1,150	Do.
30	23 00	1,660	1,040	1,110	1,150	Do.
Aug. 2	21 00	1,660	1,030	1,100	1,140	Do.
3	21 00	1,230	1,030	1,085	1,125	Do.
	21 30	1,660	1,030	1,100	1,140	Do.
6	19 45	1,660	1,030	1,100	1,140	Do.
7	20 30	1,660	1,030	1,100	1,140	Do.
10	21 00	1,660	1,020	1,090	1,130	Do.
	21 30	1,230	1,027	1,082	1,122	Do.

TABLE 11.—*Temperature measurements made with disappearing-dot pyrometer during the 1952 eruption of Kilauea*—Continued

Date	Time	Distance from object (feet)	Temperature, °C			Object measured
			Actual reading	Corrected readings: Corrections for distance and absorption added	Corrected readings: Correction for integrating effect of disappearing-dot pyrometer added	
	h m					
Aug. 11	20 00	1,660	1,010	1,080	1,120	Main fountain.
	20 20	1,230	1,018	1,073	1,113	Do.
14	20 30	1,660	1,005	1,075	1,115	Do.
	20 30	950	990	1,030	1,030	Lava in rapid overflow at southeast edge of lake.
	20 45	1,230	1,020	1,075	1,115	Main fountain.
16	22 45	1,660	995	1,065	1,105	Do.
17	22 00	1,660	998	1,068	1,108	Do.
18	20 30	1,660	1,000	1,070	1,110	Do.
	20 40	1,230	1,008	1,063	1,103	Do.
19	21 00	1,660	1,000	1,070	1,110	Do.
20	21 00	1,660	995	1,065	1,105	Do.
21	20 30	1,660	1,000	1,070	1,110	Do.
22	21 00	1,660	990	1,060	1,100	Do.
23	21 00	1,660	990	1,060	1,100	Do.
25	20 00	1,630	990	1,060	1,060	Glowing throat of northern conelet at site of main fountain.
Sept. 20	02 30	1,670	980	1,050	1,050	Lava in cascade pouring southward out of lake.

changes in activity, particularly an apparent increase in viscosity of the fluid lava. Temperatures at the surface of the lava lake generally were close to 1,005°.

These determinations agree reasonably well with earlier ones, both at Kilauea and at Mauna Loa. During the 1950 eruption of Mauna Loa the writer obtained corrected temperature readings of 1,050° to 1,090°C in the lava river near the active vents, and 1,080° to 1,100° on a dome-shaped fountain in the lava river near the vents (Finch and Macdonald, 1953, p. 75). The dome-shaped fountain was a primary fountain, but because it was exploding through the river it consisted partly of the already somewhat cooled lava of the river, and the temperature of the erupting lava undoubtedly was somewhat above 1,100°. In 1911 a measurement of 1,000° was obtained by Shepherd and Perret at a depth of 2 feet below the surface of the Kilauea lava lake (Shepherd, 1912, p. 51). During 1917, using Seger cones, Jaggar (1917, p. 398) obtained measurements of 1,000° at the surface of the lava lake, 910° to 960° in the zone from 1 to 5 meters below the surface, and below the 5-meter depth gradually increasing temperatures reaching a maximum of 1,170° at a depth of 13 meters, near the bottom of the lake. The latter temperature was regarded as somewhat higher than that of the magma rising through the conduits.

VISCOSITY OF THE LAVA

Because of its location deep in the crater of Halemaumau, it was not possible to approach near the liquid lava. Therefore no direct measurements of its viscosity could be attempted. A few observations on the speed of flow in narrow channels can be used, however, to obtain an approximation of the coefficient of viscosity. Several factors not known from actual measurements must be assumed in the calculations, and it is emphasized that the resulting figures represent only orders of magnitude.

Wentworth, Carson, and Finch (1945) have shown that under ordinary circumstances the flow of Hawaiian lava in narrow feeding channels is laminar in character. Therefore the Jefferys formula for laminar flow (Nichols, 1939, p. 294) can be used in the calculation of the viscosity. The formula is

$$V = \frac{g \sin A \, d^2 \, p}{3n},$$

where V is the mean velocity of flow, g is the coefficient of gravity, A is the angle of slope, d is the depth of the flowing liquid, p is the specific gravity of the liquid, and n is the coefficient of viscosity, expressed in cgs units. Two of the factors in the formula are not known from direct measurement, namely the depth of the flowing liquid, and its specific gravity. In the following calculations the specific gravity of dense Hawaiian basaltic liquid probably is about 2.65, and vesicularity of the liquid probably seldom is as much as 25 percent.

On August 10 measurements were made of the speed of movement of the liquid in the river draining northward out of the cinder cone, where it plunged over the cascade at the edge of the cone. The length of time required for fragments of crust near the centerline of the stream to move over a length of stream determined by scaling from the planetable map was measured with a stopwatch. The average of 20 readings gave a speed of 300 cm per sec (approximately 10 feet). The slope of the cascade surface was approximately 20°. A depth of 2 meters for the liquid stream is assumed, because the western river, otherwise of similar dimensions, was shown to be about the same as when it was drained a day or two earlier. The width of the river was about 25 feet. Applying the Jefferys formula to these figures, the value obtained for the viscosity is approximately 2.9×10^4 poises.

On August 12 an average of 55 readings with the stopwatch gave a speed of 588 cm per sec for the lava in the cascade draining eastward from the cinder cone. The slope of the cascade surface was approximately 29°, and again the depth of the liquid was assumed to be 2 meters. The calculation yields a value for the viscosity of approximately 2.2×10^4 poises.

On August 13, 20 readings of the speed of the lava in the east cascade yielded an average of 549 cm per sec. The height of the cascade was 15 feet, its length was 27 feet, and its surface slope was therefore approximately 25°. Assuming a depth of 2 meters, the viscosity of the liquid is found to be approximately 1.9×10^4 poises. On the same day measurements on the southern cascade indicated its height to be 15 feet, its length 45 feet, its surface slope approximately 18° 30′, and the speed of flow of the lava at the central part of the surface of the stream approximately 200 cm per sec. Assuming the depth of the stream to be 2 m, calculation indicates the viscosity of the liquid to be approximately 3.8×10^4 poises.

These calculated viscosities are somewhat greater than those calculated for Mauna Loa lavas at the vents during the 1940, 1942, and 1950 eruptions, where the values determined ranged from 3×10^3 to 4×10^3 poises (Macdonald, 1954, p. 171–173). The writer believes, however, that the viscosity of the lava in the fountain pits and cascades on August 10–13, 1952, was somewhat greater than that during earlier phases of the Kilauea eruption. A distinct change in character of the activity occurred during early August, the fountains becoming more violently explosive and the flows assuming a more viscous appearance. This apparent increase of viscosity of the erupting lava accompanied the marked decrease in temperature of the lava fountains in early August. The viscosity during earlier phases of the eruption probably was about the same as that of the lava at the vents during Mauna Loa eruptions.

THE LAVA FOUNTAINS

Fountains in the lava lake were of two distinct classes. Those of the first class, which may be termed "primary" fountains, form over vents where lava and gases are rising from depth. "Secondary" fountains, in contrast, form at any place on the lake surface where fragments of crust are dragged downward into the liquid. These two classes of fountains were recognized by Jaggar (1917a, p. 194–201) in the Halemaumau lake many years ago, and have since been observed elsewhere (Verhoogen, 1948, p. 80).

Primary fountains are stationary, commonly much larger than secondary fountains, and tend to be longer-lived. They appear to result partly from pressure of liquid in the conduit, and partly from the mildly explosive escape of gas. In extreme instances they may attain heights as great as 800 feet, or more. They are essentially similar to the fountains at the source of Mauna Loa flows or flank flows of Kilauea, where no lava lake is present. The secondary fountains probably result from the escape of gas (both volcanic gas and air) that was imprisoned in the fragments of solid or semisolid lava crust that are dragged downward into the hot underlying liquid wherever a downward circulation is established. This can occur anywhere on the lake surface, but is commonest at the edge of the lake and along lines where bodies of liquid moving outward from different fountain sources meet. Those formed at long-lived sinkholes are constant in position and often more or less continuous for long periods, but those formed at points of temporary crustal foundering on the lake surface are short-lived and commonly shift in position as the lake circulation moves the sunken fragment of crust. Fountains of the second type are the "traveling fountains" recorded by many early observers at Kilauea. Secondary fountains at well-established sinkholes may reach heights as great as 25 feet, or a little more, but most are less than 10 feet high, and many are less than 3 feet. Secondary fountains are not entirely restricted to true lava lakes. They can form on any thinly crusted pool of fluid lava. Such fountains were observed on the slowly spreading pond of lava near the source cone during the 1940 eruption of Mauna Loa (Macdonald, 1954, p. 131). A strong downward circulation often is established in the lake immediately around primary fountains, and such fountains may then become compound in character, the effect of gas liberated from the sinking crusts being added to the primary fountaining.

THE LAVA LAKE

To be of maximum usefulness, the term "lava lake" should be defined in such a manner as to distinguish such lakes from the ponds that accumulate wherever fluid lava is poured into a depression. It is here proposed to define a lava lake as a reasonably long-lived pool of highly fluid lava formed around or in direct association with vents from which the lava is rising from deep within the earth, and in which a distinct system of circulation has been established.

Throughout the 1952 eruption of Kilauea the lava lake appeared to be essentially a broad, shallow pool of liquid stirred by convection currents and the turbulence caused by the lava fountains. During the first hours of the eruption the lake was about 2,200 feet across and as much as 50 feet deep, presumably floored by the solid lava and talus that formed the bottom of Halemaumau crater before the eruption. Turbulence caused by the lava fountains set up trains of waves that swept across the surface of the lake and surged against the crater walls. These waves apparently were oscillatory in nature, except for rare "breakers" in the immediate vicinity of violent fountains. They generally were about 3 to 5 feet high and had a wavelength of about 50 feet. Study of moving pictures taken during the first night of the eruption indicates that the speed of the waves was about 25 feet per second. Within an hour of the outbreak the convective circulation was already well-established, with the lava moving outward from the source fountains across the surface of the lake to its edges, where it sank, dragging with it fragments of the quickly formed crust.

As the eruption progressed, the lava lake became smaller, and apparently also shallower. Early on the morning of June 28 it covered the entire crater floor, and had an area of approximately 100 acres. A bench of solid and semisolid crust formed around the edge of the crater which gradually reduced the size of the lake until by July 1 it had an area of 70 acres. Continued growth of the bench further restricted the lake, but about July 15 the tendency for reduction of the lake through cooling and formation of the crustal bench became approximately balanced with the rate of heat supply, and the size of the lake became stabilized. From mid-July to early August the area of the lake was approximately 34 acres. Accompanying the decrease in temperature and increase in viscosity of the lava in early and mid-August, there occurred a drastic decrease in the size of the lava lake, and during the remainder of the eruption the lake was a tiny pool with an area of only 0.2 acre.

There is little direct evidence as to the depth of the lake. Through most of its existence, particularly during the period from mid-July to mid-August, the lake was confined in a lava ring built by the accumulation of spatter from many secondary fountains at the edge. During that period the liquid surface of the lake stood 5 to 15 feet higher than the bench around it. Presumably the depth of the liquid was at least as great as the height of the enclosing lava ring, but observation of the lake gave a definite impression that the depth probably was not much greater than the height. Fluctuations of liquid level in the lake were small, seldom exceeding 5 feet. On July 5, however, the liquid in the pool around the southwestern fountain suddenly lowered about 10 feet, then rose again to its former level, indicating that the total normal depth of the liquid was more than 10 feet.

On July 29 and 30 the speed of travel of waves in the fountain pit within the cinder cone was determined with a stopwatch to be 17 feet per second. The observed wavelength was about 50 feet, and the period of the waves was 3.3 seconds. Within the limits of probable error of the observations, these waves behaved approximately as though they were short waves, the speed of which is unaffected by depth of water (Sverdrup, Johnson, and Fleming, 1946, p. 519). If so, the depth of the liquid must have been greater than half the wavelength, or more than 25 feet. This depth, however, was in the

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central fountain pit, and may not be any indication of the depth of the lake surrounding the cone.

On August 15 the southern lobe was drained, leaving an irregular basin having an average depth of about 20 feet. The floor consisted of fairly smooth, much cracked pahoehoe. The fluid lava apparently drained into the underlying rock, but there were no obvious sinkholes. The actual drainage was not observed, but took place within a few hours. The foregoing lines of evidence suggest that the highly fluid part of the lake had a depth on the order of 25 or 30 feet. Jaggar (1917a, p. 217) showed the depth of the Halemaumau lava lake to be about 50 feet in January 1917.

The compound nature of the mass of mobile lava in Halemaumau was demonstrated long ago by Jaggar (1917a). The true lake of highly mobile lava (the "pyromagma" of Jaggar) is underlain by a mass of semisolid, but still mobile, lava (the "epimagma"). This semisolid bottom of epimagma is believed to be formed by the accumulation and partial remelting of sunken crusts of the lava lake, and perhaps partly directly by degassing and partial solidification of the pyromagma. It moves partly with, and partly independently of, the lake of pyromagma. Evidence for its existence was shown during the 1952 eruption by islands that behaved independently of the surrounding lake lava. Segments of the cinder cone shifted laterally through distances of tens of feet, although the rise and fall of the liquid level around them demonstrated that they were projecting parts of the lake bottom, essentially independent of the surrounding liquid. The most spectacular example of the shifting of an island occurred on July 25, when a small island at the northwest edge of the fountain pit suddenly started to move, at about 14^h30^m, and during the succeeding 2½ hours moved eastward across the fountain pit for a distance of 560 feet (fig. 17).

Further evidence of the continued mobility of the lower part of the new fill was shown in the gradual rise of the crater floor even where no new overflows of liquid lava occurred. Thus from July 28 to 30 the floor of solidified lava at the northwest edge of the crater rose approximately 8 feet, lifting with it the heap of debris that had been deposited on it by a small landslide on July 28. Still further evidence was the movement of the solidified surficial lava toward the crater wall, resulting in crumpling and buckling of the crust and the formation of long pressure ridges parallel to the wall.

There apparently is little question of the recirculation of much of the lake lava. At different dates estimates were made of the amount of lava being poured into the lake through gaps in the cone walls. This amount greatly exceeded the rate of increase of the total mass filling the creater, as determined by repeated measurements. Thus on July 27 it was estimated that approximately 6.4 million cubic yards daily of molten lava was being poured into the lake. At the same time the rate of increase of volume of the total crater fill was only about 0.8 million cubic yards daily. Again on August 13, lava was being poured into the lake from the central cone at a rate estimated to be about 13 million yards daily, while the average rate of increase of the total crater fill was only 0.43 million cubic yards daily.

Thus, allowing for considerable error in the estimates of volume of lava being poured into the lake, and for about 25 percent shrinkage of the lava by cooling and loss of gas, it is obvious that the amount of lava being added to the lake was disproportionately greater than that being added to the crater fill. This excess must be accounted for by circulation of the lake lava either back down into the conduit, or back across the bottom of the lake to the fountains, where it is again thrown into the air and poured out of the cone into the surrounding lake. Possibly both occur. During the early days of the eruption large sinkholes lay at the southwest edge and in the northeastern part of the crater floor, directly above the erupting fissure, suggesting a return of the liquid downward into the conduit. A similar return may have gone on during later phases of the eruption from the lower part of the lake, through the epimagma bottom into the conduit, without causing obvious disturbance at the lake surface. In some respects this appears more likely than return of the lava across the floor of the lake to be reused in the fountains. It is difficult to picture the manner in which the returning bottom circulation in the lake could reenter the central cinder cone. Also, repeated reuse of the same lake lava by the fountains produces a difficult heat-loss problem. The lava cooled in the fountains and during its circulation through the lake would have to be reheated by superheat in the relatively small amount of rising new liquid and gas, and by exothermic reactions, probably largely in the gas phase. It is shown in another section that the weight proportion of gas liberated is small, and it is unlikely that either superheat or exothermic reactions would be adequate to reheat the circulating liquid. More probably the excess cool lava returns into depth in the downward moving phase of a convectional circulation in the magma conduit.

It is noteworthy that the direction of movement in major sinkholes occasionally becomes reversed, and fountains form where the lava had previously been sinking. During the 1952 eruption the largest fountains after the first few hours of activity developed for short intervals at the site of the major southwest sinkhole. Similarly, persistent fountains may be transformed into sinkholes.

From late August until the end of the eruption the lake appeared to be somewhat different in character from the lake of earlier stages.

It was very small, only about 100 feet in diameter, and situated nearly between the two spatter conelets that marked the principal vents. Some variations in the relative strength of activity of the two vents occurred over short periods of a few hours, but during most of the period the northern vent was the more active, and circulation at the surface of the lava lake was from north to south. Lava welled up gently at and near the northern edge of the lake and moved southward to sink along the south edge, accompanied by secondary fountains. Some sinking and secondary fountaining occurred at the other edges also, but it was much less marked than that at the south edge. Sudden brief subsidences of the lake on September 25 and 27 lowered the surface of the liquid 15 to 20 feet, but did not completely empty the basin. Only at the end of the eruption was the basin completely drained, leaving a pit about 25 feet deep, floored by broken and tilted slabs of pahoehoe.

For the most part, the vent south of the lake was much less active than the northern vent. Occasional fountaining occurred at the south vent, but the fountains were on the whole much smaller than those of the northern vent, and especially during the late part of the eruption most of the time its activity was restricted to fuming. The volume of fume liberated at the south vent generally appeared much greater than that at the north vent, and was dense and white, as contrasted to thin bluish-gray fume from the north vent.

On September 19 the principal fountain activity shifted from the northern to the southern vent, and simultaneously the direction of flowage in the lava lake reversed, with lava rising at the south edge, moving northward across the lake surface, and sinking at the north edge. A large-scale overflow of the lake occurred on September 20, but was over by midnight of that date. The southern vent continued more active than the northern one until September 22, and throughout that period the lava in the lake flowed from south to north. On September 22 the northern vent again became the more active, and the direction of lava movement again reversed, with surface flowage from north to south. Visible lava activity ceased altogether at the southern vent. During the remainder of the eruption the southern vent fumed quietly, but fountain activity continued at the northern vent, and lava movement in the lake was from north to south.

Thus from late August to early November the direction of movement of lava in the lake was consistently from the more active of the two vents toward the least active. Conditions during this period are pictured as being somewhat as shown in figure 28. Liquid lava rose through a conduit penetrating the semisolid to solid epimagma, moved laterally for about 300 feet, and then sank through another conduit. Active primary fountaining took place at a vent above the conduit in

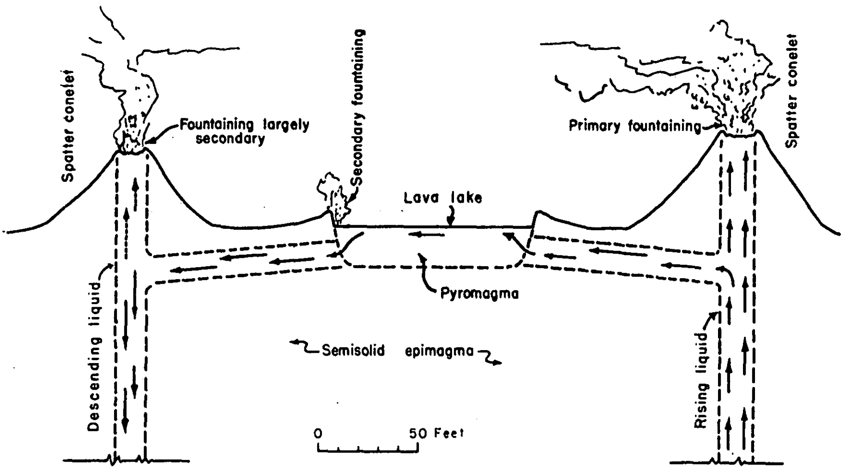

FIGURE 28.—Diagram illustrating the relationship of the fountaining vents and the small lava lake in Halemaumau during September and October, 1952.

which the lava was rising. Less active fountaining, probably at least in part, and perhaps entirely, of secondary character, occurred at a vent above the descending conduit. Through part of its lateral course the liquid lava was exposed at the surface, to form the lava lake. The cause of reversal of the direction of circulation from September 19 to 22 is not known, but undoubtedly is related to the similar reversals in the activity at the southwest sinkhole during earlier stages of the eruption. Possibly gases released from engulfed fragments of crust accumulated in the descending limb of the circulation system to the point where the lava in the descending column was lighter than that in the ascending column, causing a reversal in the direction of movement.

THE FUME CLOUD

Little is known of the chemical composition of the gas released during the eruption. Pale-bluish and yellowish flames played above the vents throughout the eruption, but attempts to get spectrograms were unsuccessful. In color, the blue flames were not unlike those produced by burning hydrogen, but neither were they markedly unlike those of burning sulfur. Atmospheric contamination of the gas cloud was so great by the time it reached the crater rim that it was not considered worthwhile to sample it for chemical analysis.

Commonly the gas cloud issuing from the fountains was pale-yellowish-brown. It has been suggested by R. E. Fosberg (oral communication) that this pale-brown color may have been caused by colloidal sulfur. Within a few feet of the top of the fountains the cloud changed to a pale-bluish-gray. The change was completed within 100 feet of the fountain top, and generally within much less than that. The change was gradual, and its appearance suggested some chemical reaction. The most probable reaction to bring about the change seems to be the oxidation of sulfur to SO_2 as it mixes with the air. Turbulence resulted in an admixture of the brown and bluish-gray fume in irregular streaks in the zone of transition.

The bluish-gray fume gave no olfactory evidence of anything but SO_2, the odor of which was exceedingly strong at the leeward edge of the crater. Steam clouds from talus near the floor of the crater evaporated as they rose, and disappeared generally within 40 feet of the vents from which they issued. The bluish-gray fume did not appear to evaporate, but rather to become more and more diluted until it faded from sight. If water were present in the fume cloud, as it probably was, it apparently did not condense into visible steam. Neither was there any sign of condensation on cold objects within the cloud. It is noteworthy that the cap of cumulus cloud that commonly forms at the top of the fume column over the crater could well result entirely from condensation of water vapor in the rising humid warm air. Results of the analysis of samples of gas from the Halemaumau lava lake collected in earlier years indicate with fair certainty that water vapor must be an important part of the fume cloud, whether or not it is one of the primary gases released from the rising magma (Shepherd, 1921; Jaggar, 1940). The lack of condensation of steam in the cloud must, therefore, be attributed to some factor other than the absence of water—possibly to the "drying" effect of SO_2.

The average composition, in volume percent at 1,200°C, of 14 samples of gas collected by Jaggar from the Halemaumau lake in 1919 and analysed by E. S. Shepherd (1921), is shown below.

H_2O	70.75	N	5.45	S	.10
CO_2	14.07	A	.18	SO_3	1.92
CO	.40	SO_2	6.40	Cl	.05
H	.33				

It is reasonable to assume that the gases liberated during the 1952 eruption were about the same in composition. If so, a calculation of their approximate amount relative to the amount of lava liberated can be made. The calculation involves certain assumptions; namely, the average analysis of the 1919 collections as the composition of the liberated gases, their behavior as perfect gases, the vesicularity of the solidified lava, the amount of atmospheric dilution of the rising gas cloud, and the temperature of the rising gas cloud. Because probably none of these assumptions are exact, the results of the calculation must be regarded as indicating only the order of magnitude of the ratio between the gas and the solidified phase of the erupted magma.

On July 27 the rate of rise of the gas cloud just above the main fountains in Halemaumau was approximately 12 meters per second, and the volume of the rising cloud was approximately 16,800 cubic meters per second. If the amount of atmospheric dilution of the cloud was 50 percent, the volume of magmatic gas liberated was approximately 8,400 cubic meters per second. Assuming the temperature of the cloud to be 1,000°C and the gases to behave as perfect gases, the number of moles of gas liberated per second can be calculated to have been approximately 72,362. If the gases had the same composition as those collected in 1919, the weight of gas liberated was approximately 1,881 kilograms per second. At the same time, the volume of lava issuing through rivers from the central cone was estimated to be 4,864,000 cubic meters (6.4 million cubic yards) daily, or approximately 56 cubic meters per second. If vesicularity of the lava was 25 percent, and the specific gravity of the dense lava is assumed to be 2.94 (Washington, 1923, p. 342), the weight of dense liberated lava was approximately 123,480 kilograms per second, and the proportion of gas in the escaping lava was approximately 0.15 percent by weight. If, on the other hand, the volume of gas is considered in relation to the average rate of increase of volume of the crater fill at that date, the proportion of gas by weight was approximately 8 percent.

The true gas content of the primary magna no doubt was somewhere between these figures, though probably nearer 0.15 percent. If the lava escaping at the fountains consisted partly of reused lava that had already been largely degassed during a former passage through the lake, the gas content of the primary portion of the liberated lava may have been twice (or even more) as great as that calculated. At any rate, the order of magnitude of the proportion of gas to dense lava appears to have been similar to that (0.4 percent by weight) calculated for the erupting magma of Mauna Loa on April 12, 1940 (Macdonald, 1954, p. 136–140).

During the first few hours of the eruption the proportion of gas liberated appeared to be notably greater than during later stages. A huge fume cloud rolled from Halemaumau crater and blanketed the entire southern part of Kilauea caldera, and a large amount of pumice was ejected. The volume of the rising gas cloud just above the fountains is estimated to have been about 30,000 cubic meters per second, and if the proportion of atmospheric dilution is again assumed to be 50 percent, the volume of volcanic gas being liberated at the fountains was about 15,000 cubic meters per second. Some gas was given off over the rest of the surface of the lake, and some was retained in vesicles in the lava, but the amount is difficult to estimate and at any rate was so small in comparison to the amount liberated at the fountains that it would not appreciably alter the results of the calculation. If the other assumptions be made as in the calculation for July 27, the weight of gas liberated was about 3,360 kilograms per second. During the same period the rate of lava extrusion was approximately 70.4 cubic meters per second, corresponding to approximately 153,056 kilograms of dense lava, and the proportion of gas in the erupting magma was approximately 2.1 percent by weight. In comparison, it has been calculated that the gas content of the erupting magma on the opening day of the 1940 eruption of Mauna Loa was approximately 0.9 percent by weight (Macdonald, 1954, p. 139). Because of the uncertainty in the estimates of volume of both lava and gas, and in the other assumptions, it is clear that neither figure should be regarded as more than an order of magnitude. They do, however, serve to demonstrate with some certainty that the weight proportion of volatiles to liquid and solid phases in the erupting magma is very small. The volume relationships are just the reverse. The total volume of the fume cloud is immensely greater than that of the solidified lavas.

EARTHQUAKES PRECEDING AND ACCOMPANYING THE ERUPTION

Early in April a series of earthquakes commenced on the east rift zone of Kilauea volcano. Thirty-three of these yielded records good enough to permit at least approximate determinations of their epicenters. The epicenters for which fair or good determinations are available are shown in figure 5. They are scattered from the vicinity of the caldera to a point about 8 miles southwest of Pahoa. This earthquake activity was accompanied by a northward tilting of the ground surface at the Whitney Laboratory of Seismology of 1.5 seconds (during a season in which the normal tilting is about the same amount southward) indicating an increase of magmatic pressure beneath Kilauea.

Seismographs at Kilauea caldera recorded 157 earthquakes during May. A few quakes continued to emanate from the region south of the island, but most originated at small depths in the vicinity of Kilauea caldera and along the east rift zone near the caldera. Others, including one strongly felt at Naalehu and Kapapala at 17^h13^m on May 21, originated on the Kaoiki fault system between Mauna Loa and Kilauea. Quakes with foci on the known trace of the Kaoiki fault system and its hypothetical extension northeastward (Macdonald, 1951, p. 3) continued during June. These movements on the Kaoiki faults may have been vertical adjustments resulting from the swelling of Kilauea volcano in response to the increase of pressure beneath.

On June 19 three quakes occurred on the southwest rift zone of Kilauea between Maunaiki and Ponohohoa (fig. 5). Throughout June many quakes originated beneath the caldera and its immediate vicinity. All were of shallow origin, and most were very small.

Between June 19 and the time of the outbreak on June 27, seismographs at Kilauea caldera recorded 84 such quakes.

Thus there was a definite seismic uneasiness of Kilauea volcano during the 3 months preceding the eruption. There was, however, no definite pattern of earthquake foci starting at considerable depth and gradually approaching the surface, such as has been recognized preceding some eruptions of Mauna Loa (Finch, 1943).

Six quakes, ranging in intensity from slight to very feeble, occurred during the hour following the outbreak. This series was ended by a moderate earthquake at 00^h47^m on June 28. From that time until midnight on June 30 only 8 very feeble and feeble quakes could be distinguished on the seismograms from the background of continuous strong tremor that accompanied the eruption.

Throughout the rest of the eruption very few earthquakes that appeared to be of Kilauean origin were recorded. During July 5 very feeble to slight quakes originated beneath the Kilauea caldera region or on nearby portions of the Kaoiki fault. Four similar quakes were recorded during August, and 6 during September. With the decline and end of the eruption in October and November, local earthquake activity increased. During October there were recorded 29 very feeble earthquakes. Fifteen very feeble earthquakes and one slight earthquake, with foci beneath Kilauea caldera or on the Kaoiki fault zone near the caldera, were recorded during November.

VOLCANIC TREMOR

Volcanic tremor, as defined by Finch (1949), was essentially continuous throughout the eruption. Through late June, July, and early August, it was generally strong. The trembling was clearly felt by persons sitting on the ground in the vicinity of Halemaumau. It was especially noticeable to me when I was working over a planetable, and at times was sufficient to induce a slight feeling of dizziness and nausea. Level bubbles on the transit and alidade oscillated rapidly over a length of one or two scale divisions, about twice a second.

During the first 3 hours of the eruption the tremor recorded on the Bosch-Omori seismograph, at the Whitney Laboratory of Seismology, showed a rhythmic waxing and waning, at intervals of 5 to 8 seconds, with a maximum double amplitude of approximately 1 mm. About 03^h30^m on June 28 the amplitude began to decrease rapidly, and by 04^h30^m had become very weak. This decrease accompanied a marked lessening of lava activity in Halemaumau. The tremor started to increase in amplitude again about 09^h, and by 11^h30^m had a double amplitude of approximately 0.3 mm. It continued at approximately that strength, and with little variation from constancy, until June 30, when it increased somewhat to a maximum double amplitude of about 0.8 mm. At the same time it again became markedly rhythmic in character.

The tremor continued similar in character and intensity until 10^h32^m on July 2, when within a few minutes it increased in intensity to a maximum of about 1.2 mm, still retaining its rhythmic character. It continued strong until 15^h17^m, corresponding to a period of increased activity of the lava fountains. At 15^h17^m the tremor again rapidly declined in strength until 17^h50^m when it was very weak. Thereafter it gradually resumed its accustomed strength, with a maximum double amplitude of about 0.8 mm. Another period of augmented tremor occurred at about 05^h36^m on July 3 lasting about 75 minutes, with a maximum double amplitude of about 1.5 mm. This tremor also coincided with a period of marked increase of lava-fountain activity, during which the southwestern fountain attained a height of 400 feet. Starting at about 22^h15^m on July 3, a period of augmented lava-fountain activity was accompanied by augmented tremor, reaching a maximum double amplitude of 1.5 mm on the Bosch-Omori seismograph at the Whitney Laboratory. Similar correlation of increased strength of tremor with increased fountain activity was observed during the periods of augmented fountaining at 15^h30^m on July 4 and 04^h on July 5. Thus there appears to have been a definite correlation between the strength of the tremor and the size of the lava fountains, although other observations show this to be only part of a more fundamental relationship.

From about 12^h50^m to 18^h20^m on July 5 tremor was again greatly augmented in strength, reaching a maximum double amplitude about the same as that during the earlier periods of increased strength. This period did not coincide with any notable increase in the size of activity of the lava fountains, but did coincide with a period of marked overflow of the lava lake. Furthermore, although there was a definite correlation between periods of strong tremor and strong fountaining, there was no apparent increase of tremor with individual exceptionally strong fountain bursts. Thus there is a strong suggestion that the correlation of earlier periods of augmented tremor with increased fountain activity, while real, is actually only coincidental. The true correlation probably is with periods of increased upward movement of liquid lava in the conduits, which in turn is generally, though not always, reflected at the surface by increased activity of the lava fountains.

During July there was a gradual increase in the strength of the tremor. From July 12 to 20 the maximum double amplitude on the east-west component of the Bosch-Omori seismograph commonly reached 2 mm. The amplitude on the north-south component was somewhat less, commonly reaching a maximum of 1.5 mm. The tremor was markedly rhythmic in nature, increasing to a maximum and then decreasing to a minimum every 5 to 15 seconds.

The maximum ground displacement was about 22 microns, and the period of the tremor was approximately 0.58 second. By July 25 the maximum double amplitude on the east-west component was as much as 3 mm, and the maximum ground displacement was about 30 microns (pl. 14). This exceedingly strong tremor continued until August 8. After that date the tremor gradually declined in strength, and by August 22 had again become weak, with a maximum ground displacement of only about 6 microns. This decrease coincided with a marked reduction in lava activity.

The revival of lava activity in early September was accompanied by some increase in the strength of the tremor, but for the remainder of the eruption tremor in general remained weak, with ground movement at the Whitney Laboratory seldom reaching as much as 10 microns. No appreciable increase occurred on September 20, during the spectacular overflow of the small lava lake.

Starting on October 27 there were occasional intervals of augmented tremor, of several minutes duration. These differed from the tremor characteristic of the rest of the eruption in being markedly spasmodic in character. They appeared to consist of successions of very small earthquakes so closely spaced in time that their records merged into a continuous vibration of the seismograph. Twelve such intervals of augmented spasmodic tremor occurred between October 27 and November 9. Their duration ranged from 5 minutes on October 29 to 50 minutes, from 02^h05^m to 02^h55^m, on November 5. Several could be correlated with temporary increases of activity in Halemaumau. Thus on November 5, from 22^h09^m to 22^h18^m a marked increase of tremor coincided with a bright glow of short duration at Halemaumau, observed from Kilauea Military Camp. On November 6 an overflow of the north conelet was accompanied by augmented tremor from 21^h31^m to 22^h04^m. On November 8, from 10^h59^m to 11^h14^m, augmented tremor accompanied an increase in the strength of the lava fountaining; and again on November 9, from 04^h16^m to 04^h32^m, it accompanied an increase in activity and overflow of the north conelet. Thus, again there appears to be a close correlation of increased tremor with increased lava activity in Halemaumau, though not necessarily with increased fountain action.

The ordinary tremor that continued throughout most of the eruption corresponds with the "harmonic" tremor described during earlier years by Jaggar (1920, p. 264) and Finch (1949). The second type of tremor resembles in most respects the "spasmodic" tremor described by Jaggar (1920, p. 264, 267), but its period (approximately 0.5) is appreciably greater. The behavior of the tremor during the

1952 eruption appears to be in harmony with Finch's suggestion that it originates in the feeding conduits, not through fountain action or explosions at the surface.

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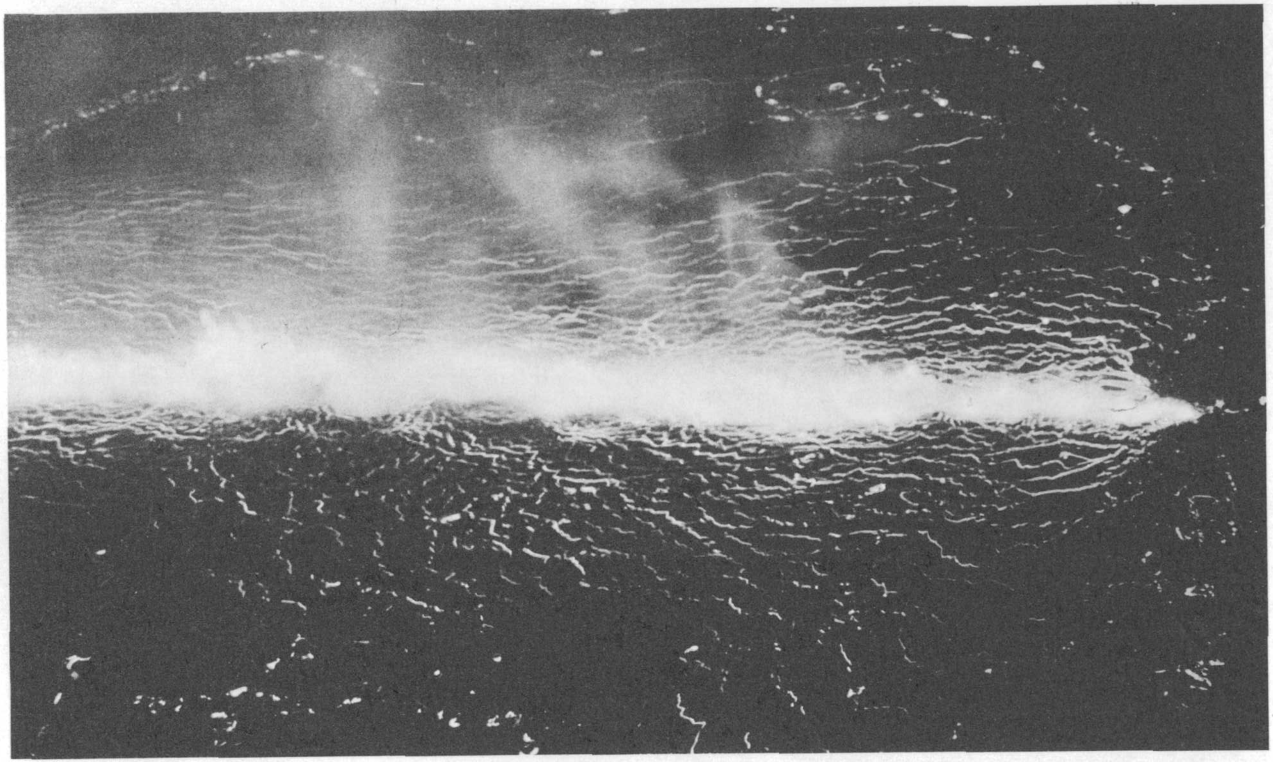
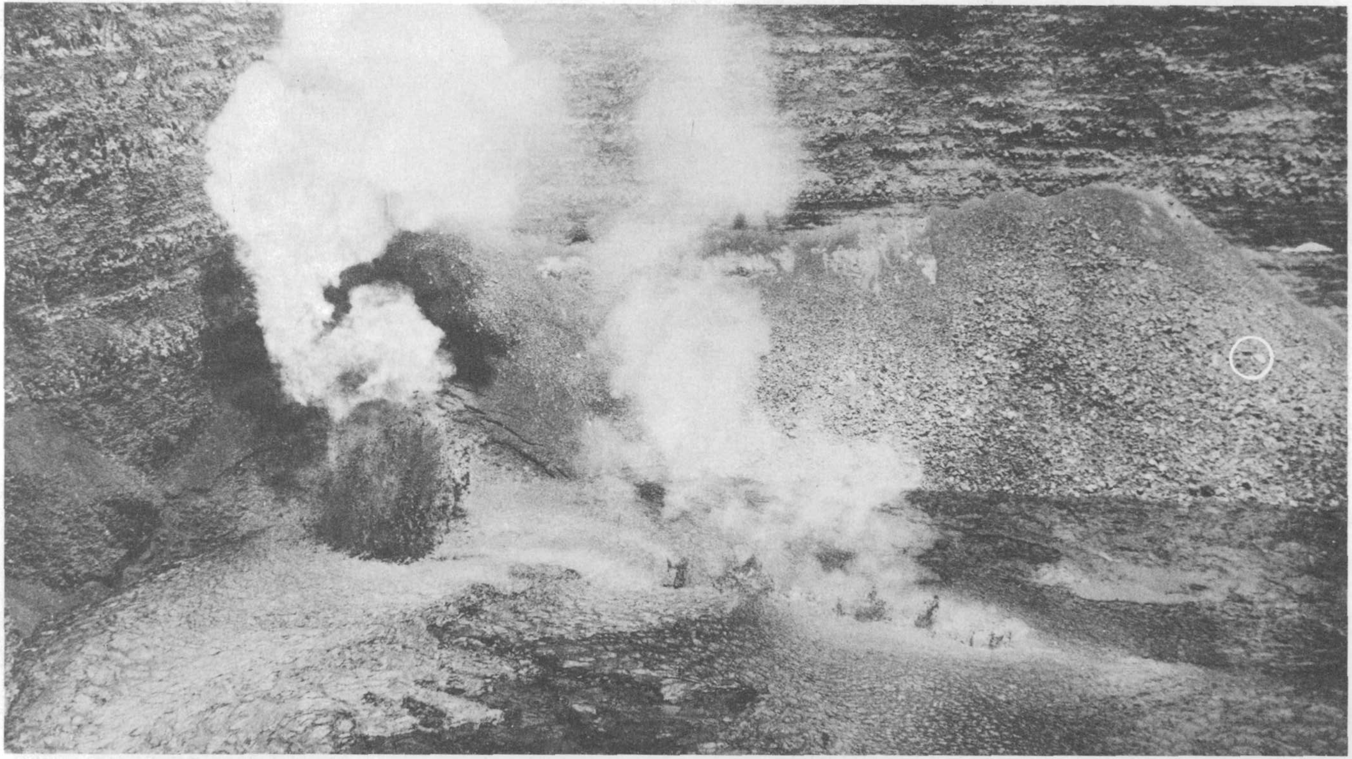
PLATES 1–14



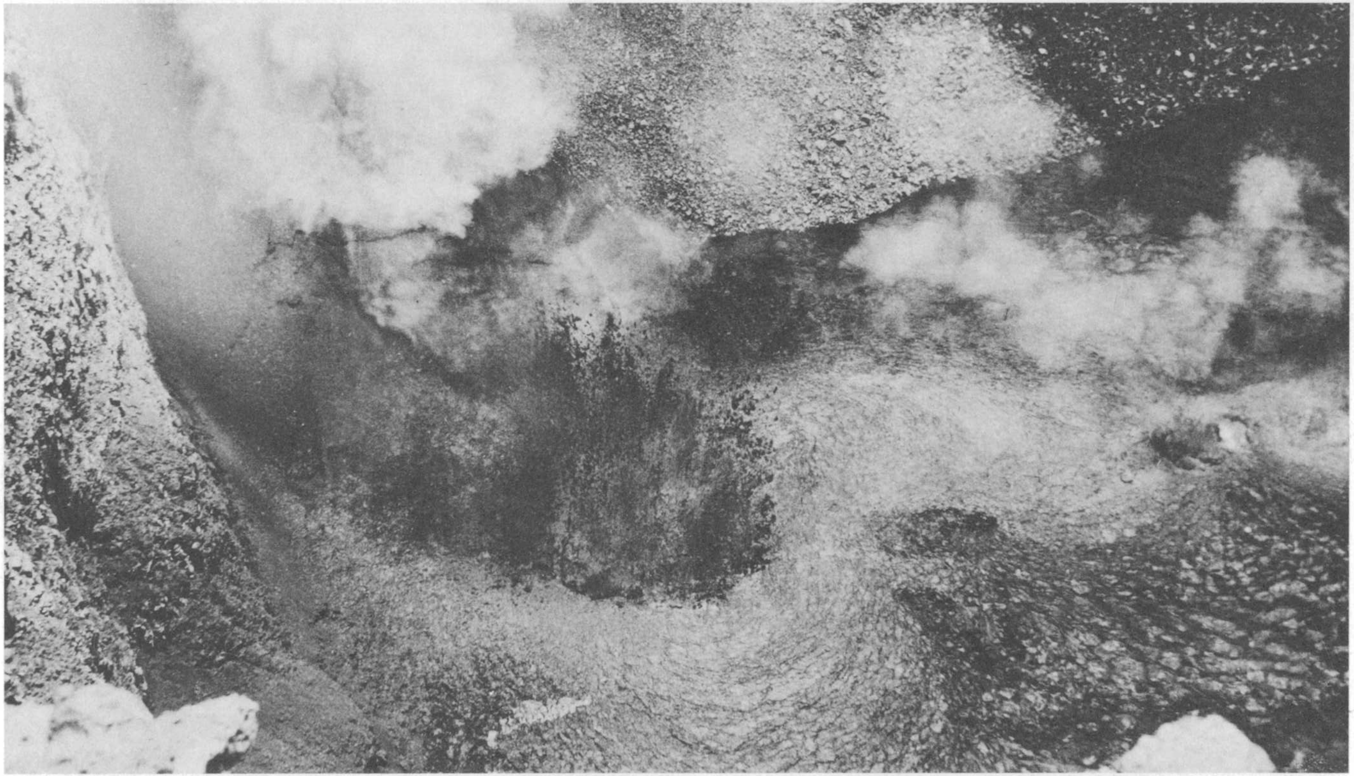
LAVA FOUNTAINS ALONG THE FISSURE IN THE NORTHEASTERN PART OF HALEMAUMAU, AND BRIGHTLY GLOWING CRACKS IN THIN CRUST OF LIQUID LAVA LAKE, 03^h ON JUNE 28, 1952.

The fountains range from about 20 to 50 feet in height. Waves in the liquid can be seen near the fountains. Photograph by C. K. Wentworth.

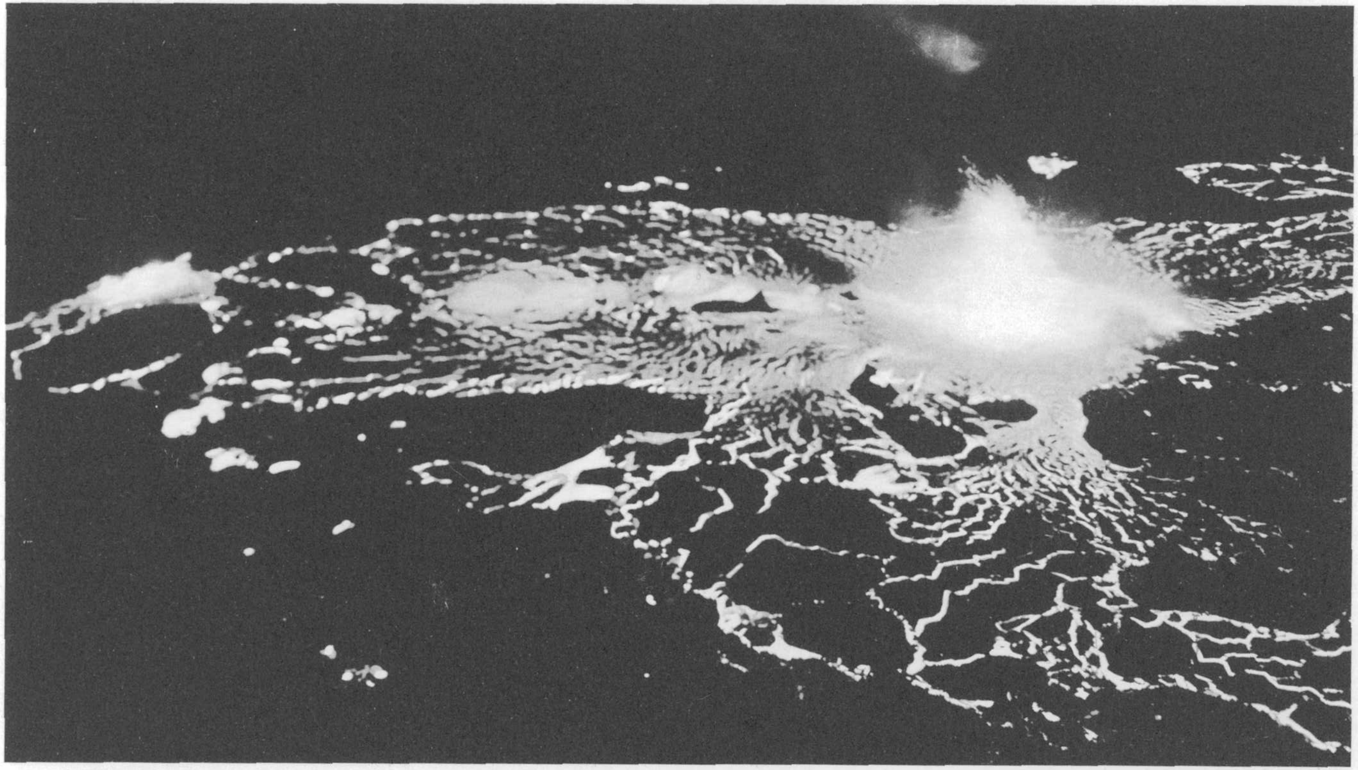


LAVA FOUNTAINS NEAR THE SOUTHWEST EDGE OF HALEMAUMAU, AT 11^h 05^m ON JULY 2, 1952.

The large fountain at the edge of the floor occupies the site of the southwest sinkhole. It is about 150 feet high. Circled area shows white boulder that can also be identified in plate 5.

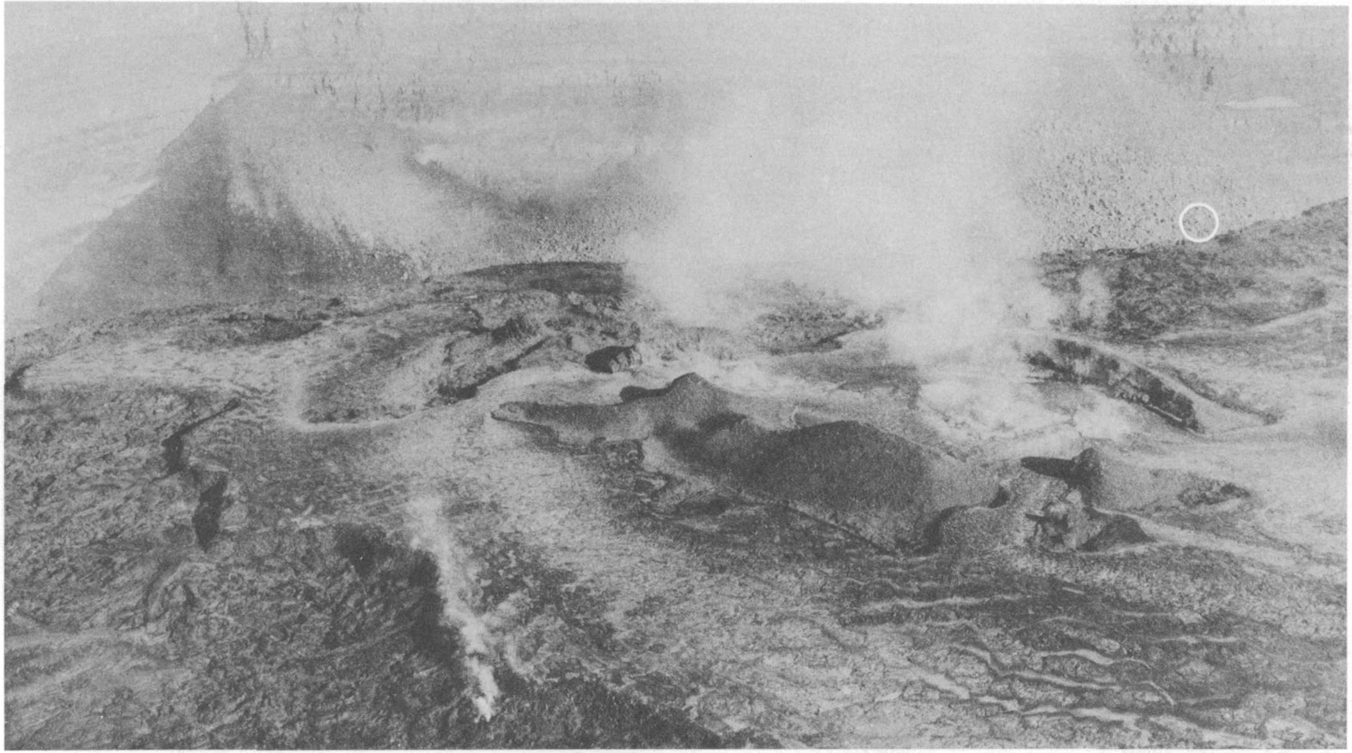


CLOSEUP OF LARGE FOUNTAIN AT SITE OF THE SOUTHWEST SINKHOLE, AT 11^h 15^m ON JULY 2, 1952.
The fountain is about 150 feet high.



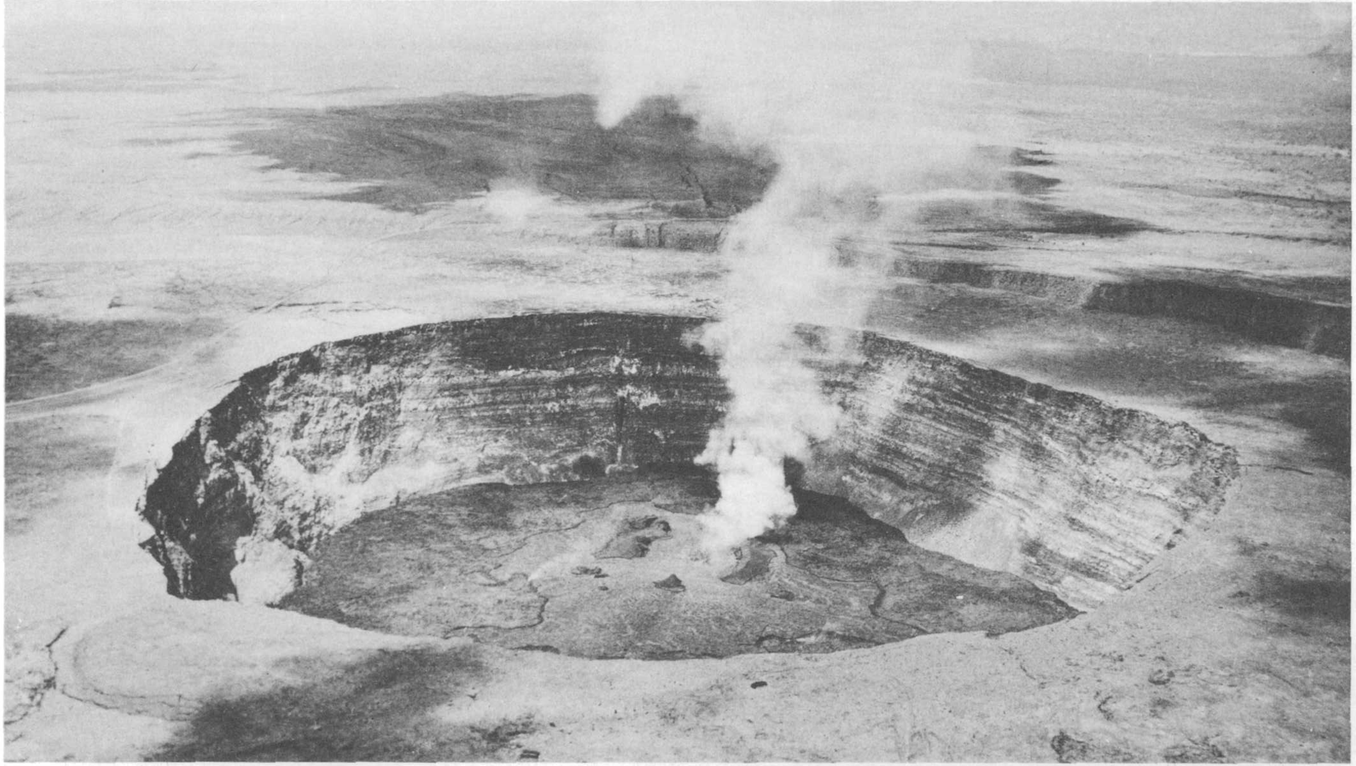
FOUNTAINS IN THE SOUTHWESTERN PART OF HALEMAUMAU ON THE NIGHT OF JULY 6, 1952.

The bright lines are caused by rifting apart of the thin crust on the lava lake. Note the dark islands near the fountains on which spatter is accumulating to build cones. Photograph by C. K. Wentworth.



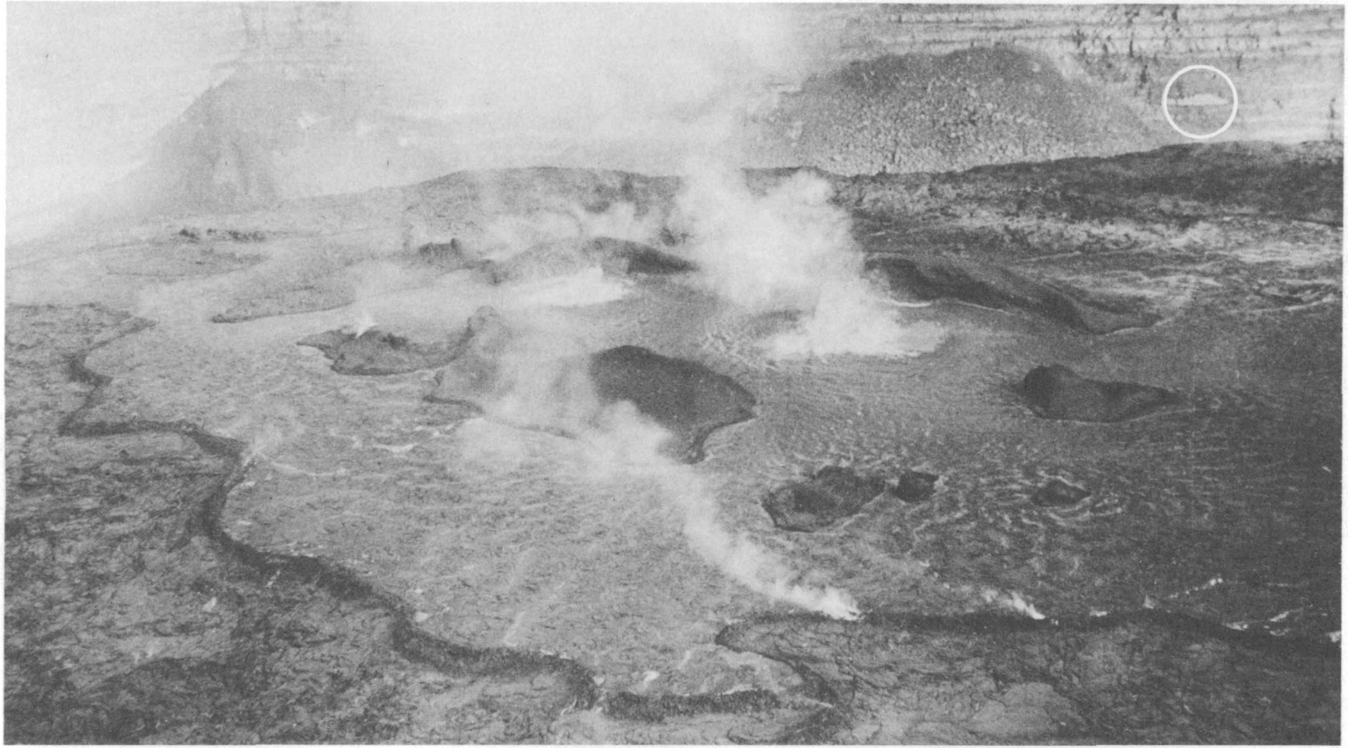
CONES AND FOUNTAIN IN HALEMAUMAU ON JULY 19, 1952, FROM THE OBSERVATION AREA AT THE SOUTHEAST RIM OF THE CRATER.

The lava ring, or natural levee, confining the lake at a level 10 to 15 feet above the surrounding bench, is clearly visible. Circled area shows position of white boulder referred to in plate 2.



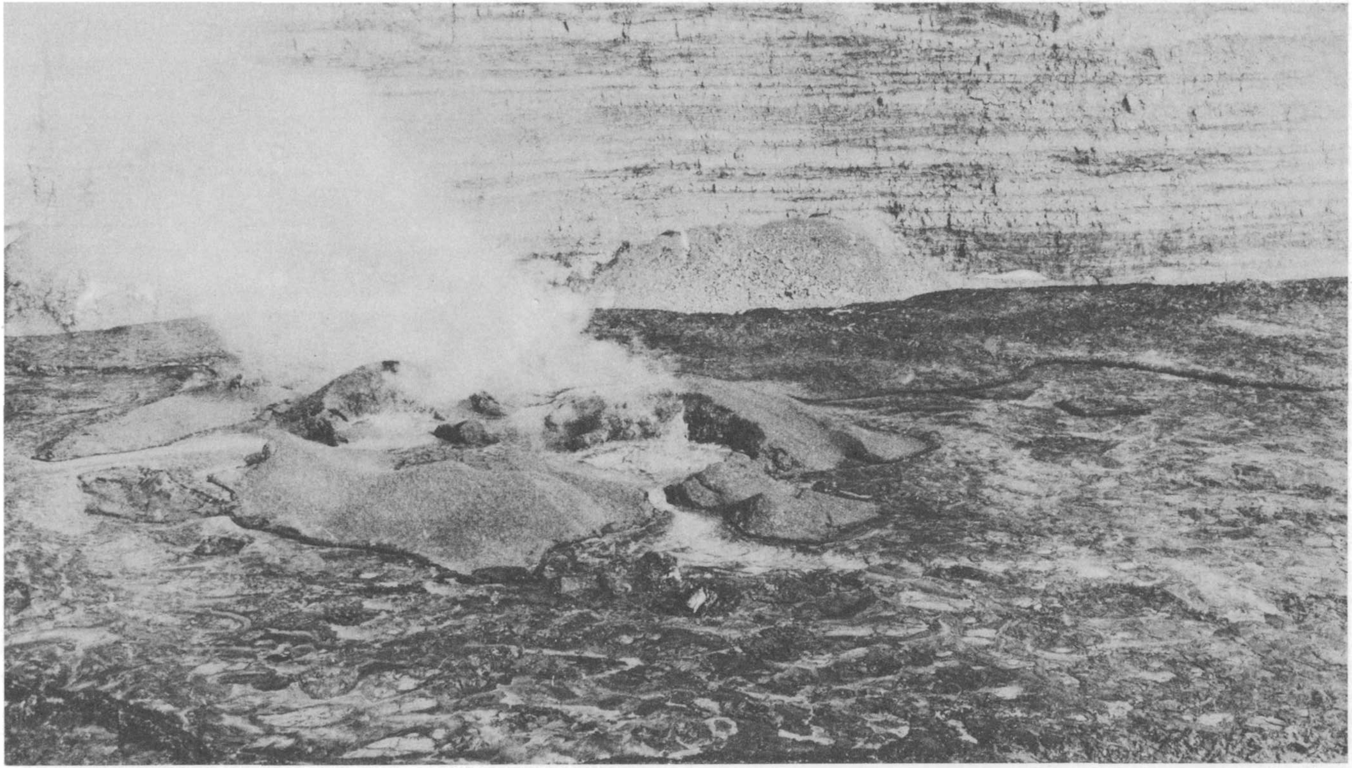
AERIAL PHOTOGRAPH OF HALEMAUMAU, LOOKING SOUTHWESTWARD, ON JULY 28, 1952.

Note the broad fountain pit in the cinder cone and the large rivers draining from it. The crater is surrounded by the floor of Kilauea caldera, the boundary cliffs of which are visible in the right background. Photograph by E. K. Field, National Park Service.

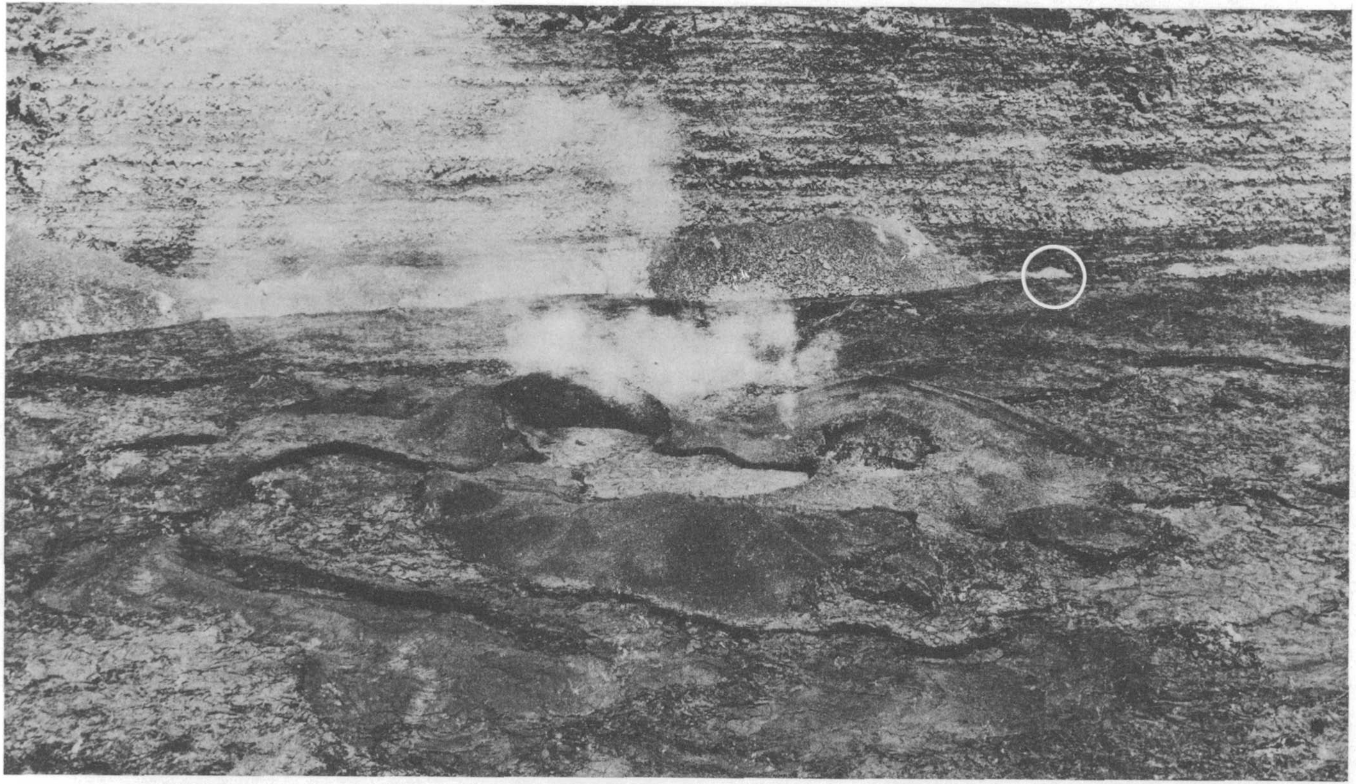


LAVA RIVERS POURING THROUGH WIDE GAPS IN THE CENTRAL CONE TO FEED SURROUNDING LAVA LAKE, JULY 29, 1952.

The lava ring along the southeast edge of the lake is in the foreground. Fumaroles are active along the lava ring. Circled area indicates position of lens on the western wall.

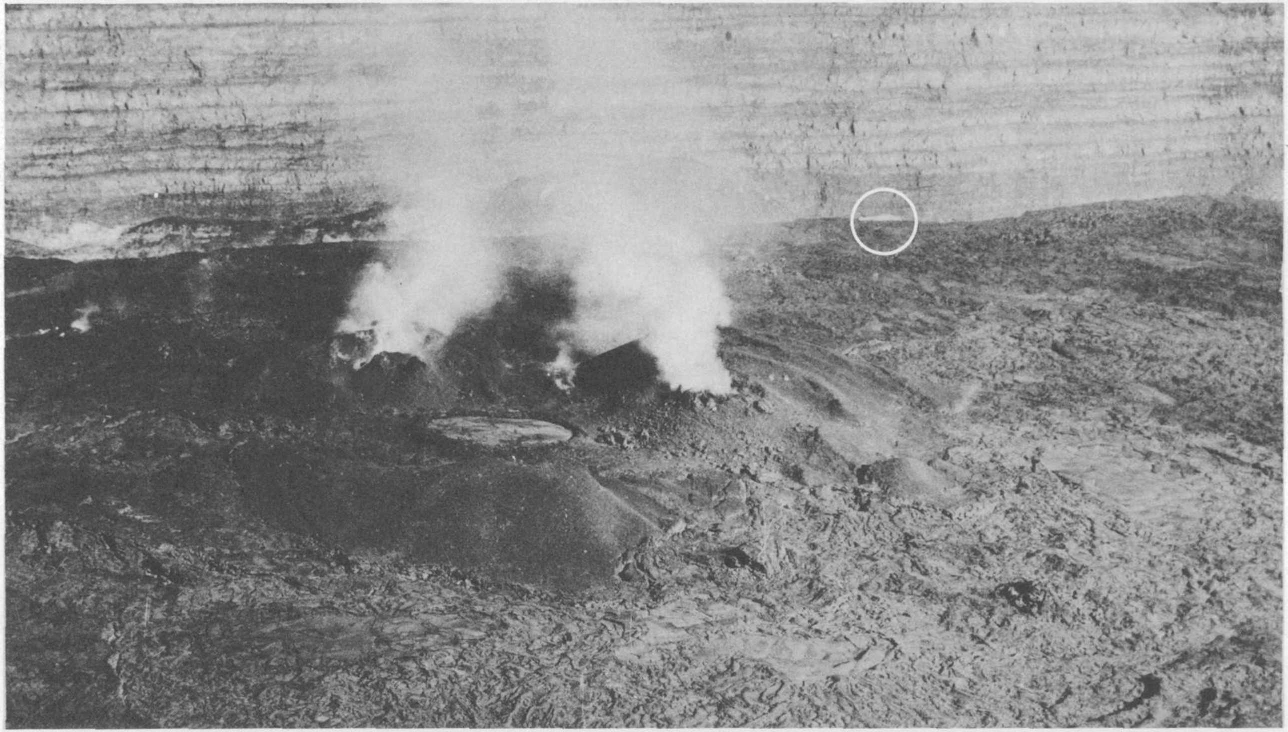


ACTIVITY IN HALEMAUMAU ON AUGUST 12, 1952, VIEWED FROM THE SOUTHEAST RIM OF THE CRATER.
The northeast river has ceased flowing, and the east and south rivers are much reduced in size. The highest segments of the cone are about 65 feet.



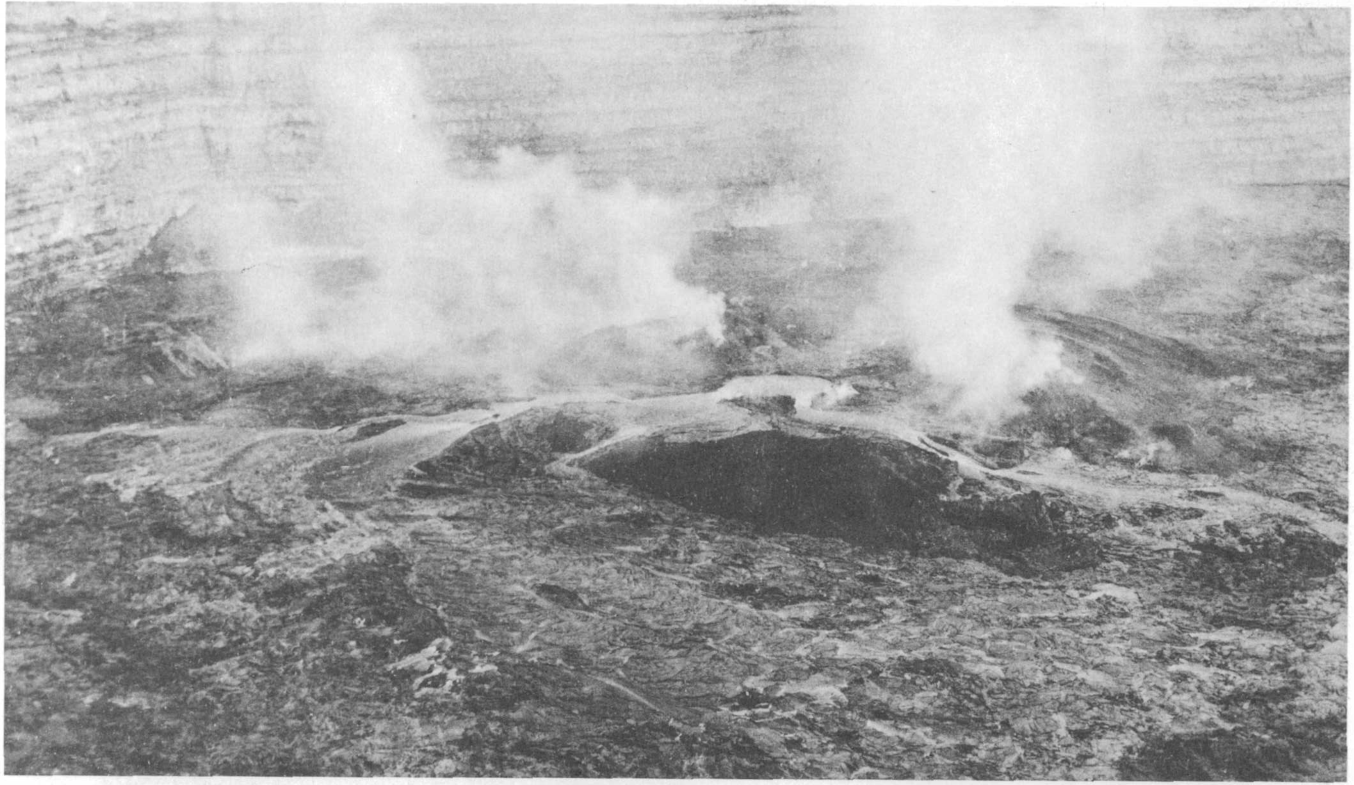
ACTIVITY IN HALEMAUMAU ON AUGUST 21, 1952.

Lava has ceased spilling from the cone, and the surrounding lava lake is inactive. Circled area indicates position of lens on the western wall.

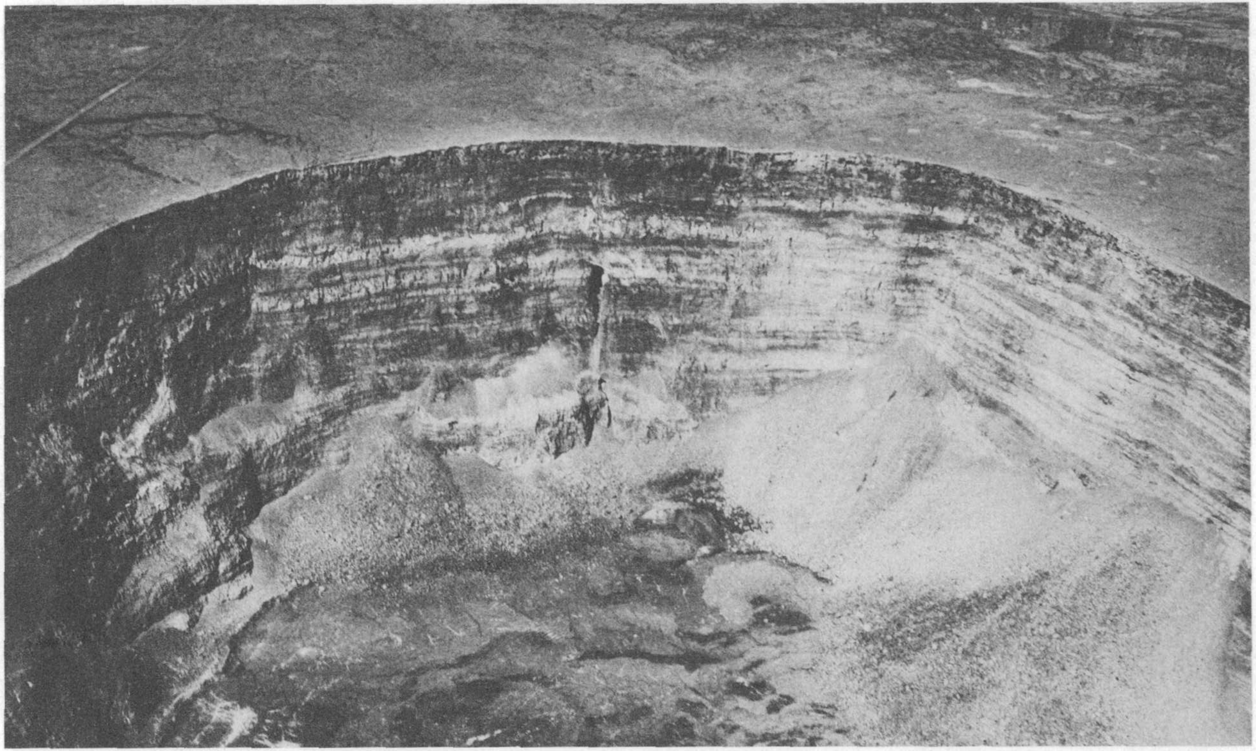


SMALL SPATTER-AND-CINDER CONES AND LAVA LAKE IN THE CRATER OF THE LARGE CINDER CONE, SEPTEMBER 9, 1952, LOOKING WESTWARD FROM SOUTHEAST RIM OF HALEMAUMAU.

Comparison of the circled area on the western wall of the crater with that shown in plate 7 gives some indication of the amount of rise on the floor during the interval between the two photographs.

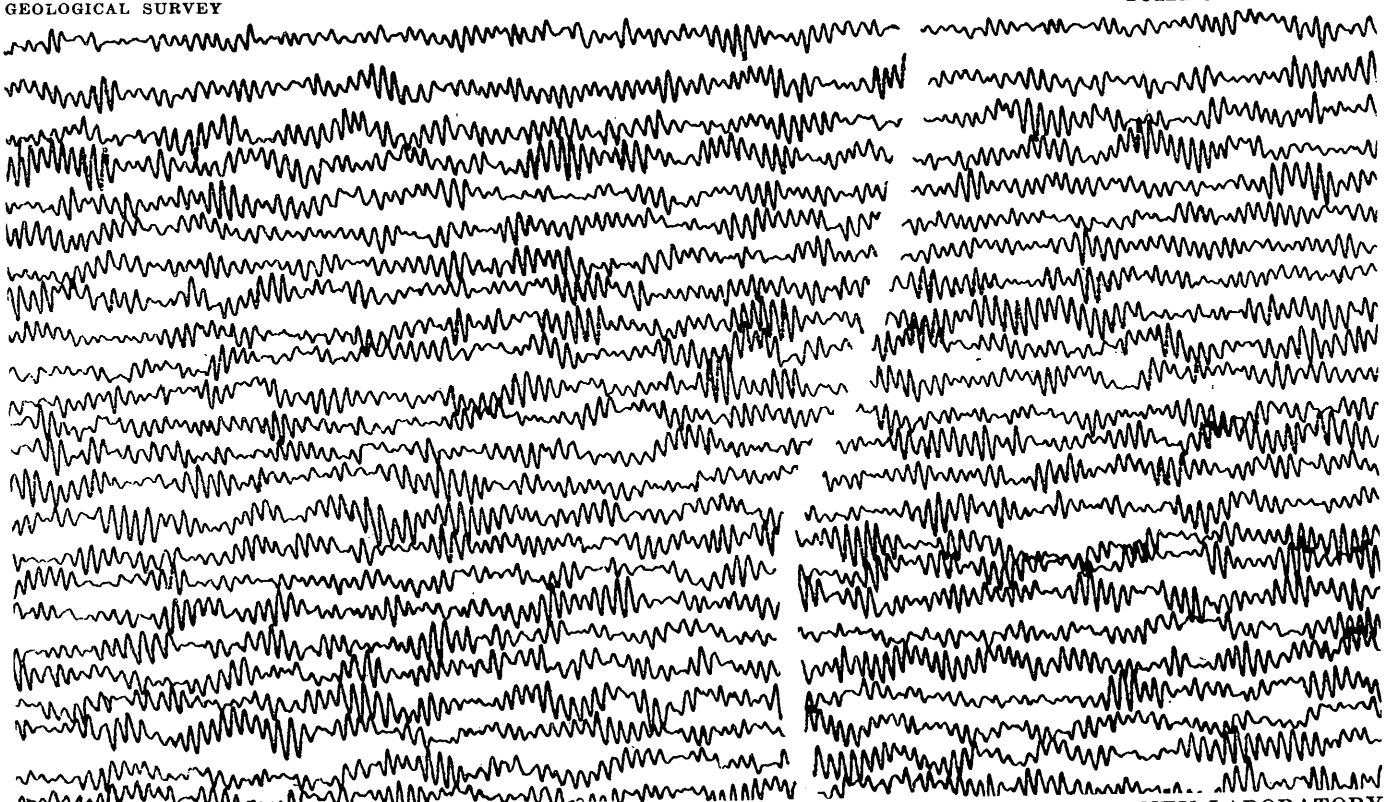


THE SMALL LAVA LAKE OVERFLOWING SOUTHWARD AND NORTHEASTWARD ON THE MORNING OF SEPTEMBER 20, 1952, VIEWED FROM THE SOUTHEAST RIM OF HALEMAUMAU.



AERIAL PHOTOGRAPH OF HALEMAUMAU, LOOKING SOUTHWESTWARD, ON JUNE 21, 1951.
The crater had an average depth of 770 feet. Note the long banks of talus. Photograph by E. K. Field, National Park Service.

AERIAL PHOTOGRAPH OF HALEMAUMAU, LOOKING SOUTHWESTWARD, ON NOVEMBER 5, 1952.
Note the great reduction in depth of the crater during the 1952 eruption. The talus banks visible in plate 12 are almost completely buried. Fissures of the southwest rift zone of Kilauea are visible in the background. Photograph by E. K. Field, National Park Service.



VOLCANIC TREMOR, RECORDED ON THE BOSCH-OMORI SEISMOGRAPH AT THE WHITNEY LABORATORY OF SEISMOLOGY, ON JULY 25, 1952.

The distance between successive minute marks on the original record is 60 millimeters. The static magnification of the instrument is 145.