The Volcano Letter

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Edited by Richard S. Fiske, Tom Simkin, and Elizabeth A. Nielsen

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Preface, Acknowledgements, Introduction, and Index

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The logo on the cover and title page of this volume first appeared in Number 436 of *The Volcano Letter*, June 1936, and was used frequently thereafter. A translation of the Latin phrase is: No More Abandoned or Buried Cities.

THE VOLCANO LETTER

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TILT CHANGES AT KILAUEA

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Tilt has been defined by T. A. Jaggar and R. H. Finch as "a change in the angular relation between a portion of the earth's surface and the plumb line". This change is measured on "tilt-sensitive" seismographs or on instruments often called clinoscopes built exclusively for tilt measurement. Usually they are pendulum devices. Horizontal pendulums of several seconds period are particularly tilt sensitive. At Kilauea the Bosch-Omori seismograph located on the NE rim of Kilauea Crater is the principal instrument used for tilt determinations. In addition there are two clinoscopes, one on the southeast rim and the other on the west rim of Halemaumau. For other tilt studies, values are also obtained from the Mauna Loa, Hilo and Pit seismographs. The Bosch-Omori seismograph consists of two components N-S and E-W, recording on a single drum. A fixed pen is made to record a reference line each time a new, smoked paper record is started. Daily measurements from this line to the second line of the regular seismograph recording, in millimeters, give the migration of the recording pens caused by ground tilt. The drums are changed each morning and evening usually at 8:00 a.m. and 8:00 p.m., thus two tilt readings per day are obtained although it has been found necessary to use only one, which is the evening reading. The Bosch-Omori seismograph at the Observatory with a static magnification of about 115 and a period of seven seconds is sensitive enough to record a depression of 1 centimeter in 16 kilometers or 0.4 inch in 10 miles. For reference, 1 second of arc is equivalent to 0.272 inches depression or elevation at a distance of 1 mile. Charts derived from measurements of tilt changes recorded by the Bosch-Omori seismograph at the Observatory are the only ones discussed in this article.

Early studies of volcanic eruptions and earthquakes in Japan drew attention to ground tilt as a factor of great importance preceding, during and after the respective disturbances. Pioneers in tilt studies in that country were the late Professor Omori and Director Emeritus Akitune Imamura his successor at the Imperial University in Tokyo. In 1930, Dr. Imamura[1] discussed at length, "Topographical Changes Accompanying Earthquakes or Volcanic eruptions". In that publication he deals in some detail with fourteen earthquakes between the Tosa earthquakes of the year 684 A.D. and the Formosa earthquake of 1906 A.D. where evidences of ground tilt have occurred but where no instrumental check was available. Tilt changes of twelve other earthquakes between 1891 and 1927 were checked by precise levelling. In addition, tilt changes associated with the volcanic eruption of Usu in 1910 and the Sakurajima eruption of 1914 are described. One of the principal conclusions drawn was that with all earthquakes and all volcanic eruptions there occur topographic changes (with emphasis on ground tilt) whether they are observed or not. Conclusions of that nature only served to emphasize the importance of tilt studies and development of instruments for determining tilt as a source of data supplementing other geophysical investigations. Such data might be of great value in predicting future earthquakes or volcanic eruptions and are particularly important from that point of view in Japan and California as well as other localities subject to sudden terrestrial changes. The Japanese seismologists have developed a wide variety of tilt measuring devices and are obtaining data in quantity from both volcanic and seismic areas with most attention probably centered on the Tokyo area, scene of the very destructive Kwanto Earthquake of September 1923. Results have proven instructive and gratifying and undoubtedly, as more knowledge is gained, will play an important role in predictions both volcanic and seismic.

In California, ground tilt is being carefully studied by the staff of Pasadena Seismological Laboratory of the Carnegie Institution, the seismological laboratory of the University of California and the United States Coast and Geodetic Survey. These groups are especially interested in tilt associated with the great earthquake-making faults of the west coast as an indicator of the approach of potential, property and life damaging earthquakes.

In Hawaii, H. O. Wood first noticed pronounced ground tilt at the Observatory with the establishment of the seismographs on the NE rim of Kilauea Crater in 1913. However, tilt was not given an important place in the study of Hawaiian Volcanoes until 1917 when Romberg and Jaggar began the systematic recording and studying of daily and seasonal tilt changes and their relationship to Kilauea and Mauna Loa. Their work has been carried on and is now considered one of the more important studies in volcanic research.

Apparently Hawaii, Japan and California are the only places in the world where tilt studies have been a serious part of the

[1] "Publications of the Earthquake Investigation Committee in Foreign Languages, No. 25."

volcanic and seismic research program. Interest in this phase of earth movement is gaining rapidly though as its importance is more generally realized. The positive results obtained are of great value in volcanologic studies.

In order that the ground tilt might be better visualized, results of the daily readings are plotted on coordinate paper lined ten to the inch. One millimeter change on the seismogram is plotted to 1/10 inch so that 1 inch on the paper is equal to 1.21 seconds of arc. The latter value is determined from the constants of the seismograph. An arbitrary numerical value was assigned to the starting point and all tilt has been plotted on this base since. The E-W migrations of the seismograph pen are plotted as abscissa and the N-S as the ordinates. During the 27 years of measurement, it has been found that tilt on the NE rim of Kilauea Crater, considered as the path of the top of a vertical rod describes an annual loop of from 5 to 20 seconds of rotational arc with the loop elongated in a NNE-SSW direction, the greater axis usually being about twice the length of the shorter one. In the course of producing the major loop many minor ones occur and both, almost without exception, progress in a clockwise direction. In general, tilt is southwesterly during the warmer summer and fall months and northeasterly during the cooler late winter and spring months. Jaggar and Finch[2] have shown that seasonal temperature changes and tilt at Kilauea are correlated; at the same time loading due to rainfall is not related. A direct relation to lava eruption, confirming tilt changes was shown by precise levelling results by R. M. Wilson in 1921 and 1927.[3] Lava movements apparently affect tilt directly. This is shown in irregularities of the annual curve and in accumulated tilt from year to year. Accumulated tilt may be thought of as relative average change of position or migration of the annual loop, or relative displacement at corresponding periods of successive years.

Three types of tilt graphs are regularly plotted at the Hawaii Volcano Observatory. One is simply a daily curve derived from lines connecting points plotted as described. This produces a rather irregular diagram at times confusing. In order to straighten out and smooth the annual curve a system of overlapping 7-day means is used for the second type. This makes any plotted point a 7-day average. The next value to be plotted is obtained by subtracting the seismogram measurement of the first date used in the average summation and then adding the value succeeding the seventh measured. As tilt moves the seismograph pens beyond normal registration range, the instrument is adjusted to realign the recording pens and proper corrections added or subtracted from the last measured tilt value depending on direction of adjustment. The third system used two separate graphs for N-S and E-W components, representing direction in one plane only. In this system the dates are on the abscissa and amount of tilt in millimeters, ordinates. Millimeter graph paper is used with the millimeter divisions used for days and millimeters of tilt as measured on the seismograph record. The advantage of this type of graph is that it shows the marked excess of N-S tilt compared with that of the E or W.

The center of Halemaumau is S 50° W and the center of

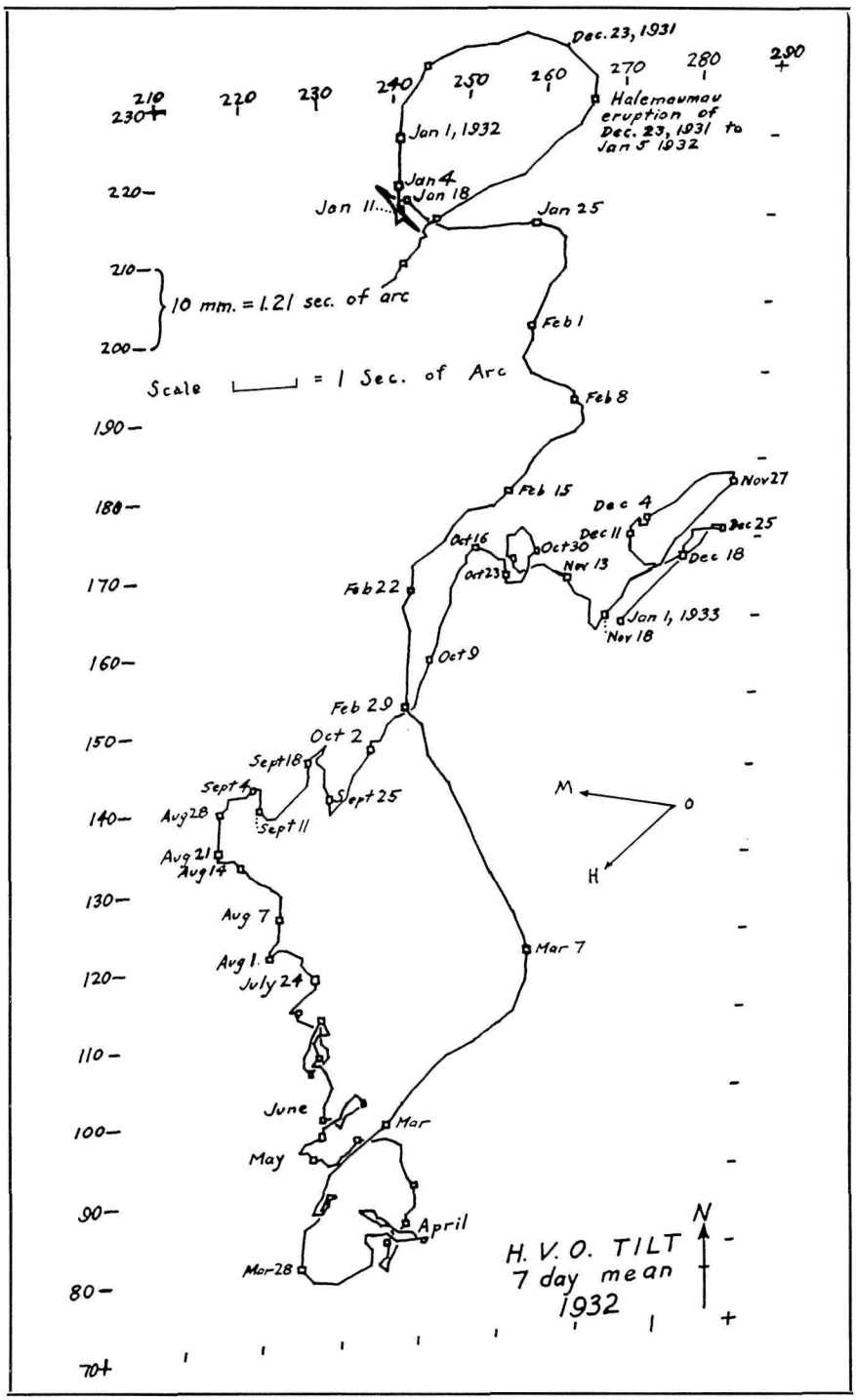

FIGURE 1

[2] Tilt Records for Thirteen years at the Hawaiian Volcano Observatory; Bulletin of the Seismological Society of America, Vol. 19, No. 1, March 1929.

[3] Ground Surface Movements at Kilauea Volcano, University of Hawaii Research Publications, Number 10, 1935.

Kilauea Crater is S 40° W from the Observatory. The longer axes of the annual loops average S 30° W. The figures suggest that factors other than concentric tumescence around either Halemaumau or Kilauea influence the direction of tilt at the Observatory. The factors may be topographic and/or structural. It seems likely that the area S of the Observatory is made up of a series of fault blocks stepped downward toward the sea and roughly paralleling the Hilina Fault system and the Mauna Loa rift system. If this is true there would be the SW Kilauea rift as indicated by the fractures in the SW Crater wall and dykes in Halemaumau, and another rift running to the east through Kilauea Iki. The Keanakakoi-Chain of Craters rift would be echelon connecting the Kilauea Crater with the Hilina Pali toward Puna. Such a fault block system might easily explain the lack of E-W tilt on the NE Kilauea Crater rim, which would tip more to its N than E with reference to the direction of greatest ease of ground movement.

The accompanying charts are copies of original plats which have been made at the Observatory. Figure 1 shows the Bosch-Omori, 7-day mean, tilt path for 1932. The yearly loop was very irregular. Apparently during 1931 the lava-gas pressure under Kilauea Crater had forced the tilt well to the N and E. This effect continued until December 23 when Halemaumau inflow began. As the eruption continued, pressure was released resulting in the westerly and southerly tilt lasting until January 18. After that easterly tilt of 2 seconds of arc occurred presumably because some pressure built up after the vent had sealed off. During the sealing period, probably January 4 to 18, irregularities which may have been sympathetic to resulting pressure changes in the crater occurred. The pressure release as a result of the eruption allowed considerable southerly tilt to occur. However, reference to figure 2 shows that the more easterly accumulated tilt of 1932 was a forerunner of the building up of pressure under Mauna Loa preceding the eruption of the summit crater December 2 to 18, 1933 almost due west of the Observatory. Simultaneously Kilauea Crater was no doubt adding to the increased easterly tilt.

In Figure 2, south and easterly tilt began building up about October 29, 1933. A maximum was reached about November 26. On December 2, Mauna Loa erupted at the summit crater. Tilt showed sympathetic reactions between December 3 and December 24. The "jog" in the line, December 17, corresponds to the sealing off and end of the eruption December 18. Tilt continued west and north until December 24 when it moved east and north, possibly because of increases of pressure under Kilauea resulting from termination of the Mauna Loa activity. It is of interest to note that 1933-tilt ended to the N and W of its starting point—indicating that tilt had accumulated to the N from Kilauea pressure and probably had altered to the W as a result of pressure release from Mauna Loa.

Figure 3 is a continuation of the 1933 chart (Fig. 2). Starting with January 7, the general progress of

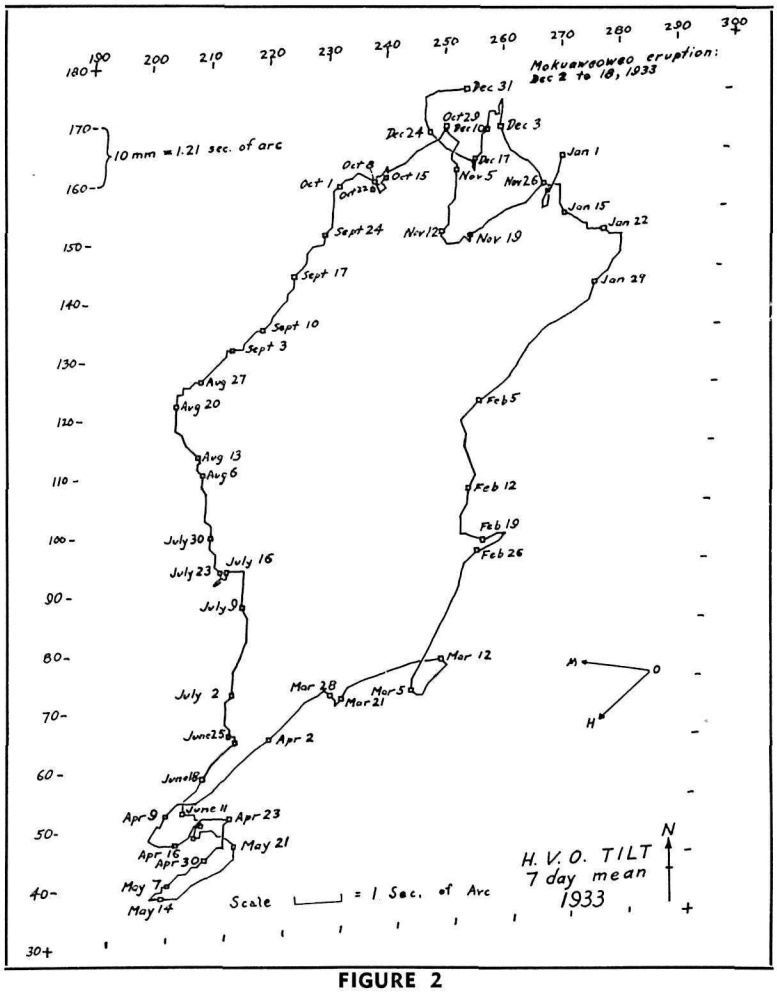

FIGURE 2

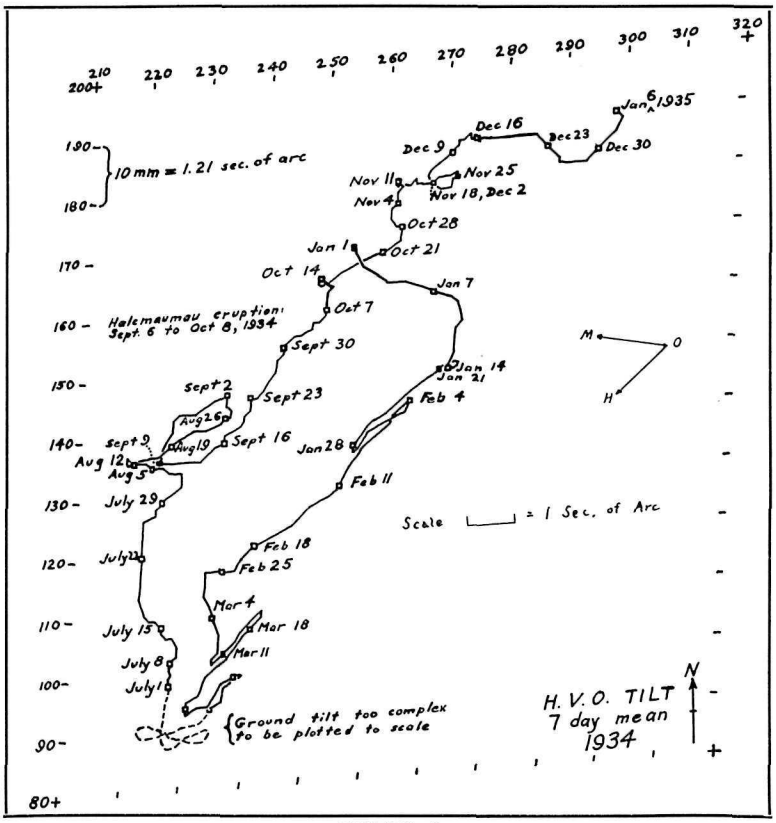

FIGURE 3

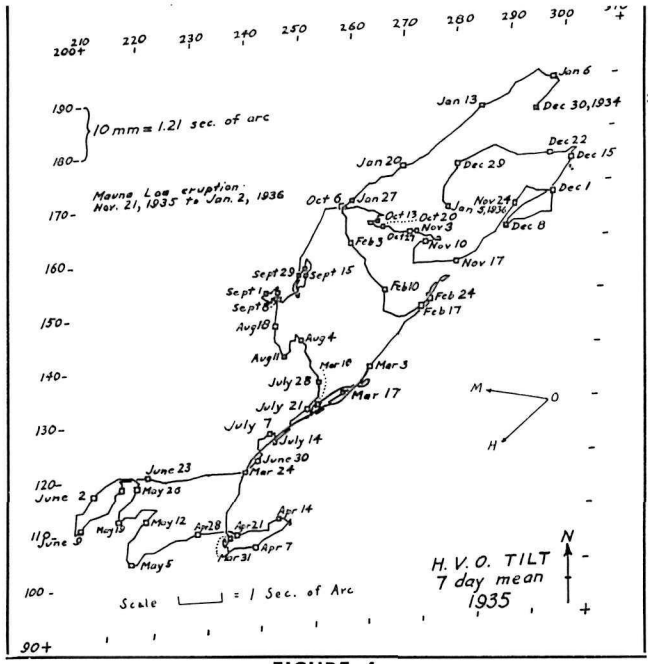

FIGURE 4

the annual loop is to the south and west in normal fashion. The interesting point however is that the southwesterly tilt ceased about five and one half seconds from the low of 1933 and moved steadily north until August 5 when irregularities began to occur. Halemaumau began erupting in the early morning hours of September 6. Tilting to the SW followed until September 9 when recovery started and the normal trend continued in a northeasterly direction until January 6, 1935. At that time the ground on the NE rim of Kilauea had tilted approximately three seconds of arc northeast of its position at the same date the preceding two years. In other words, in 1933 and 1934 tilt had accumulated to the north and east.

Figure 4, 1935 continues from the preceding chart and marks the last tilt-eruption curve. This curve is highly irregular. In June, some two seconds of arc had again accumulated to the northeast over a similar period in the preceding year. On October 6, southeasterly tilt began, continuing until November 17 when Mauna Loa summit crater and N E rift began an eruption which continued until January 2, 1936. The tilt

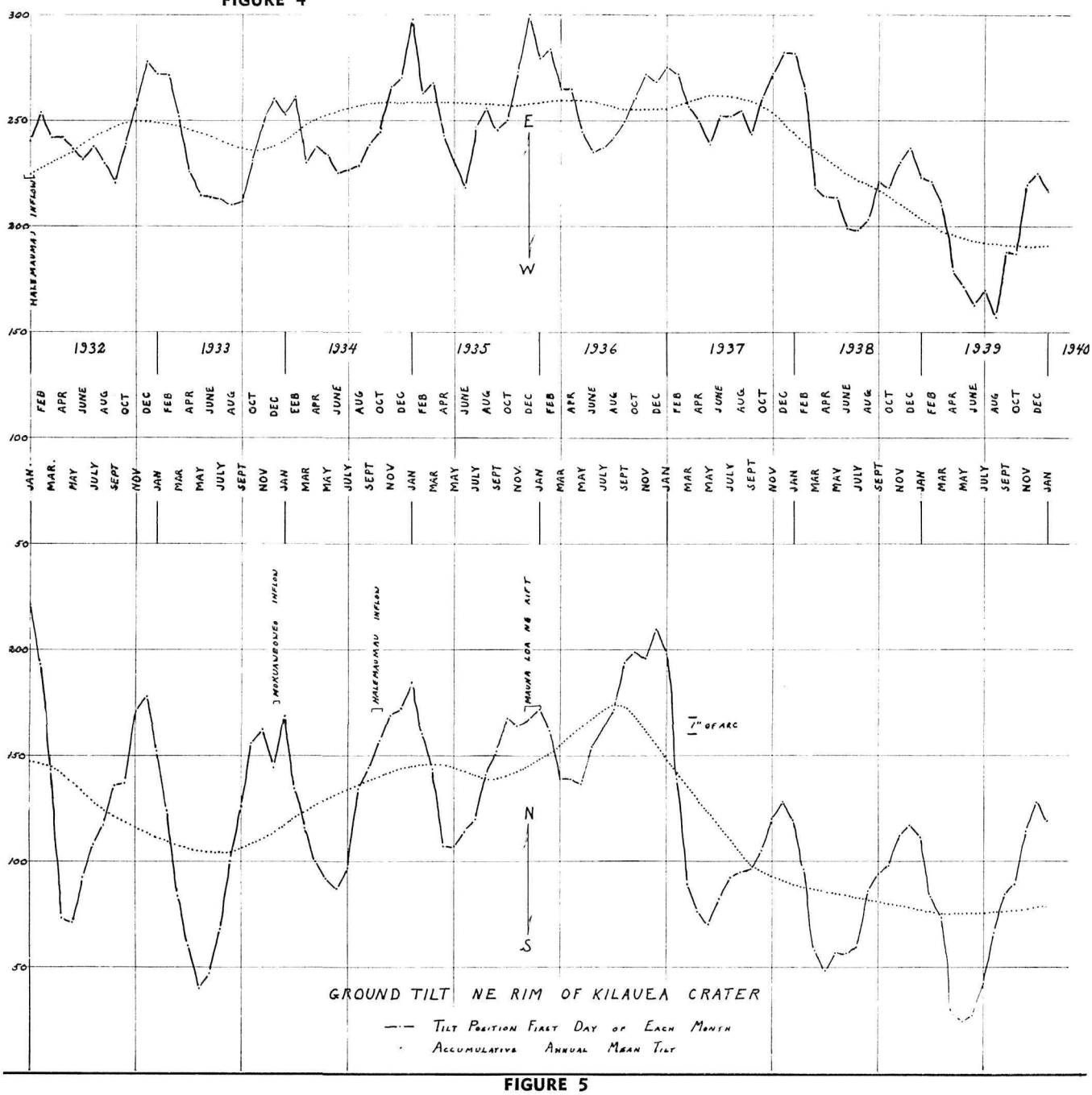

FIGURE 5

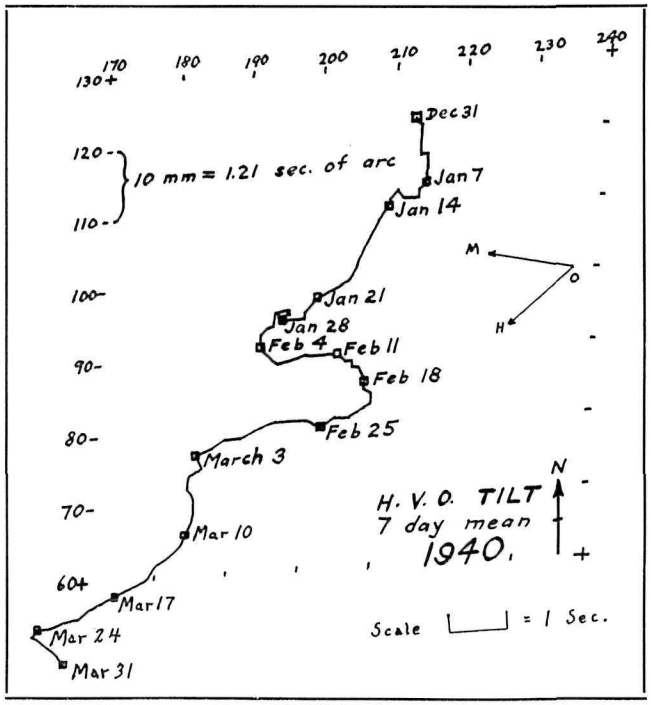

FIGURE 6

recovered most of its northerly trend which would be normal for Kilauea and then moved rapidly to the west December 22 to December 29, during the decline of the Mauna Loa eruption. It is striking that northerly tilt did not recover as it had done in preceding years. Possibly sympathetic pressure under Kilauea had been reduced with the Mauna Loa eruption.

Reference to Figure 5 will show relations which followed. Accumulated tilt increased in 1936 and then steadily receded during 1937 and 1938 but began to recover during the last six months of 1939. By December 1939, northerly tilt had recovered beyond that of the same period in 1937 although easterly tilt had not so recovered. The dotted line marking mean annual tilt indicates a definite recovery corresponding roughly with the peaks. Furthermore, the plotted 7-day mean loops of 1937, 1938 and 1939 were open and relatively regular.

Figure 6 shows the tilt for the first quarter of 1940. On March 31, 1940 the tilt position was 2.6 seconds N and 1.37" W of the same relative position for preceding year. Northerly tilt has recovered much but easterly tilt has lost. However, the strong northerly trend in contrast to condition of three preceding years may be strongly significant of volcanic changes to come.

Figure 7 illustrates the appearance of the tilt curve plotted on a daily basis rather than as a smoothed curve. Sharp irregularities are diurnal in nature and may be related to temperature changes between day and night. It covers the same period as Figure 6.

In the smooth curves, dates of tilt changes do not correspond exactly to visible or other volcanic changes as they are affected by possible sudden changes three days before or after the date concerned which are of course not clearly shown because of the smoothing by overlapping means.

The most interesting chart of the entire group is Figure 8 which gives a general picture of tilt changes at the NE rim of Kilauea Crater from 1913 to the end of 1939. In this case average monthly tilt has been determined and these values plotted as overlapping means in groups of five in the same manner that the daily Bosch-Omori tilt was plotted by 7-day means. The relative position of each month is represented by a square and in order to simplify the resulting maze, each yearly trace is given a different design. During a large portion of each of the two years, 1916 and 1917, tilt records either were not kept or were lost. That period is indicated by a dotted line using an X for each month rather than a square. The major loop progresses counter-clockwise but all others are of normal clockwise movement. That part of the plat from 1913 to 1931 inclusive was worked up and plotted by Dr. H. A. Powers, the remainder by the author.

Changes in ground tilt represented by Figure 8 bear a direct relation to volcanic activity during the same period. A direct relation also was found to exist between the tilt and ground surface changes determined by surveys of precise levels and triangulation in 1912, 1921 and 1927 as described by R. M. Wilson.

Reference to Figure 8 shows that there was strong easterly tilt from July 1913 to July 1918 with only slight westerly recession in 1919. Mauna Loa summit crater erupted in 1914; the SW rift was active in 1916 and in 1919 it produced the Alika flow. The flows were progressively bigger. From March to August 1919 there was considerable westerly tilt. This continued until August 1924 when marked easterly tilt developed. In 1926 the Hoopoloa flow from the SW rift of Mauna Loa occurred. In 1928 and 1929 there was recession to the west again but recovery to the east was resumed in 1930 which continued until 1936. During that period there occurred the Mauna Loa summit eruption of 1933 and the NE rift eruption of 1935-36. Westward tilt followed in 1937, 1938 and 1939. Relative E-W position at the beginning of 1940 is about the same as 1914 and 1926 indicating that pressure conditions from Mauna Loa as affecting tilt at Kilauea at no period have been less than at present and on this basis do not alter its eruptive possibilities, compared with the years referred to.

The proximity of Kilauea makes its effects on the Observatory tilt more striking. It should and apparently does affect the NE Crater rim tilt more in the N-S direction than in the E-W direction. In 1913, 1914, 1915, 1916 and 1917 there was pronounced annual fall tilt. Lava rising occurred simulta-

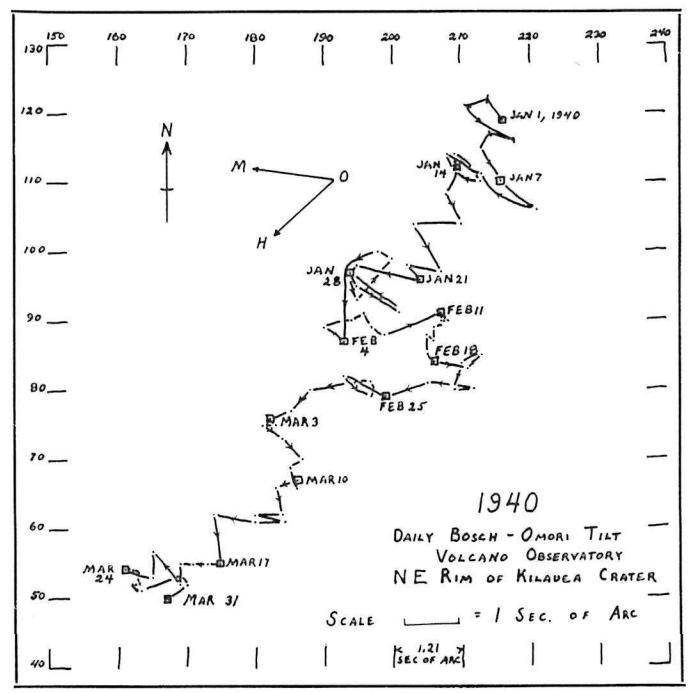

FIGURE 7

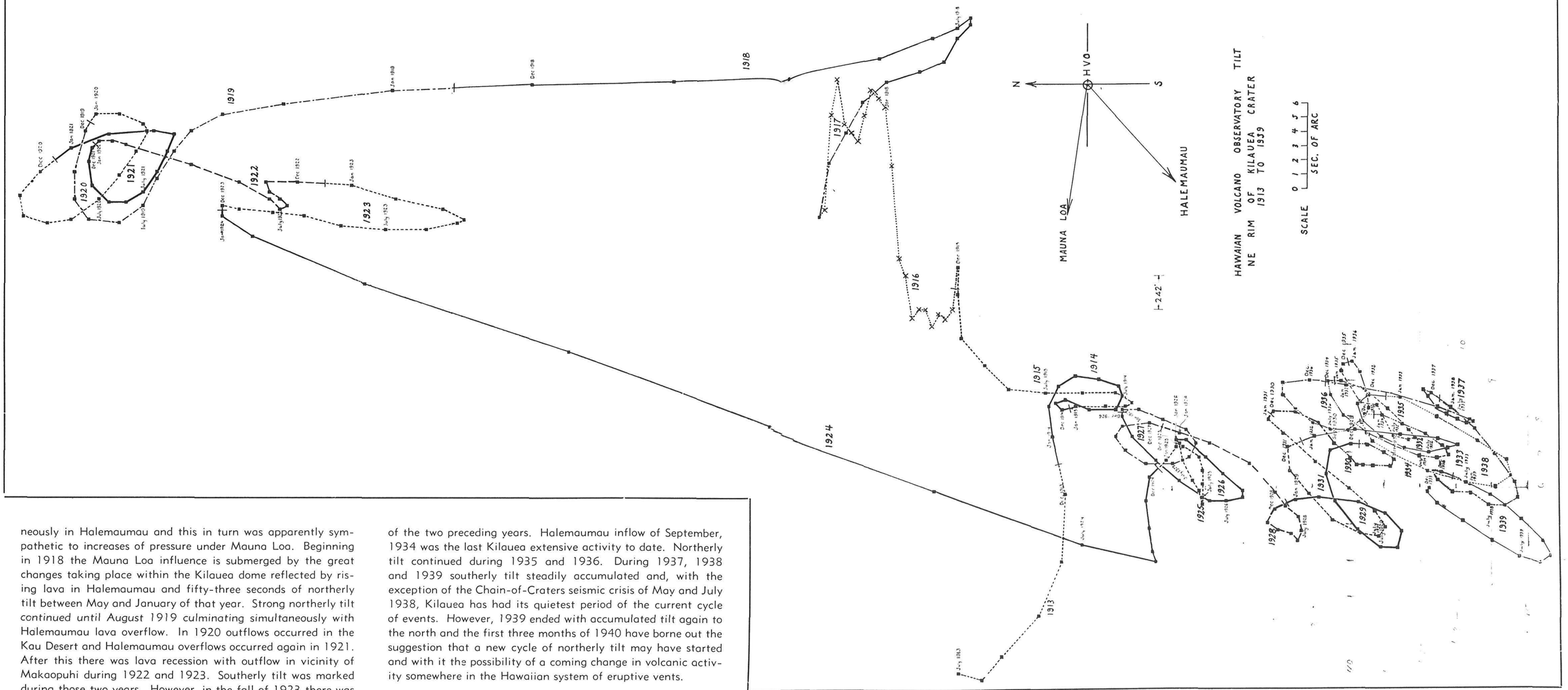

FIGURE 8

neously in Halemaumau and this in turn was apparently sympathetic to increases of pressure under Mauna Loa. Beginning in 1918 the Mauna Loa influence is submerged by the great changes taking place within the Kilauea dome reflected by rising lava in Halemaumau and fifty-three seconds of northerly tilt between May and January of that year. Strong northerly tilt continued until August 1919 culminating simultaneously with Halemaumau lava overflow. In 1920 outflows occurred in the Kau Desert and Halemaumau overflows occurred again in 1921. After this there was lava recession with outflow in vicinity of Makaopuhi during 1922 and 1923. Southerly tilt was marked during those two years. However, in the fall of 1923 there was recovery of north tilt with an accompanying rise in lava in Halemaumau. This was followed by strong southerly tilt of eighty-one seconds between January and July, 1924. In May 1924, lava in Halemaumau receded to unknown depths and activity reached a culmination during that month by steam blast explosion and finally collapse of Halemaumau and to some extent the entire dome of Kilauea. After this, Kilauea Crater was only periodically active with Halemaumau inflows which occurred in July 1924, July 1927, January 1928, February and July 1929, November-December 1930, December-January 1931-32 and September-October 1934. Southerly accumulative tilt continued during 1925 and 1926 but recovered in 1927 to the north. Southerly tilt again occurred for 1928 and 1929 with little change during 1930-31. Slight southerly tilt accumulated during 1932, 1933 and then recovered in 1934 to a point north of the two preceding years. Halemaumau inflow of September, 1934 was the last Kilauea extensive activity to date. Northerly tilt continued during 1935 and 1936. During 1937, 1938 and 1939 southerly tilt steadily accumulated and, with the exception of the Chain-of-Craters seismic crisis of May and July 1938, Kilauea has had its quietest period of the current cycle of events. However, 1939 ended with accumulated tilt again to the north and the first three months of 1940 have borne out the suggestion that a new cycle of northerly tilt may have started and with it the possibility of a coming change in volcanic activity somewhere in the Hawaiian system of eruptive vents.

R. M. Wilson's work has confirmed the major changes described. Precise levels were run from Hilo to Kilauea in 1912, 1921 and 1927. These showed that apparently between 1912 and 1921 the Volcano House B. M. was elevated about two feet and between 1921 and 1927 it was lowered about 3.5 feet. Comparison with Figure 8 shows that the values coincide with tilt changes both in time and relative amounts.

Levels have been run periodically around the SW rim of Halemaumau from the Spit B. M. on the SE Crater rim to a B. M. on the NW rim of Halemaumau. Since 1934 there had been relative lowering of the NW Pit B. M. of 2.02 feet by April 1940. If it is assumed that the Spit has remained more or less stationary, then the Crater floor of Kilauea has settled, and accumulated tilt should be to the south. All other evidence confirms this condition.

From the facts here illustrated and discussed it seems obvious that ground tilt is an extremely revealing as well as important factor in volcanic studies. More instruments should be developed. Dr. Willard H. Eller of the University of Hawaii Physics Department, in cooperation with the Volcano Observatory, is working on the problem and several new instruments have been developed which are promising. The need is for a self recording "tiltmeter" little affected by temperature which will give a clear picture of ground movement in any direction. Such instruments well placed and in sufficient numbers would not only be useful in determining changes in lava movements but would also be of help in straightening out the complicated structural relations of the Hawaiian Volcanoes.

In acknowledgment, the author wishes to thank Mr. P. E. Schulz of Hawaii National Park for tracings made of charts Nos. 1, 3, 4 and 6 and used for reproductions here illustrated, and to Dr. H. A. Powers and Mr. A. E. Jones for figures and computations on earlier charts.

Hawaiian Volcano Observatory Report for January-March 1940

VOLCANOLOGY

January 1940

The month of January began with still less seismicity than December but the third and fourth weeks produced excess of disturbances on the Mauna Loa seismograph, and the half of these recorded at Kilauea were mostly of Mauna Loa origin (29 out of 31 shocks third week). Nothing is known to have happened at the craters, and the island was going through a period of excessive drouth with very light southerly winds and calms. Humps in the Chain-of-Craters road were increasing in number between Devil's Throat and Aloi pit.

The following are the local data for January:

Week Ending	Halemaumau Slides	Halemaumau Crack Openings	Seismic Disturbances
January 7	2	4.0 mm. closed	11
" 14	0	2.0 mm. opened	18
" 21	0	2.5 mm. opened	31
" 28	0	4.0 mm. closed	26

Two rock slides from the southeast rim of Halemaumau down the interior wall were indicated by dust clouds seen from the Uwekahuna Museum January 4 at 9:45 a.m. and 9:57 a.m.

February 1940

The month of February was without unusual volcanic events. The drouth continued and the burning down of Volcano House February 6 produced danger to the wooden Observatory a few hundred feet away. A peculiar tremor on the seismograph was recorded between 6:15 a.m. and 7:10 a.m. while the fire was at its height, possibly correlated with flame pulsations of the conflagration as well as related traffic movement.

The first week of the month at Mauna Loa seismograph continued to show more very feeble earthquakes than the one at Kilauea but this peculiarity was declining. Of the feeble and very feeble earthquakes of the month, 31 in number, only 10 were from distances corresponding to Mauna Loa or beyond, the others chiefly Kilauea shocks.

No slides were reported at Halemaumau. Inspection February 17 showed a thin blue haze reflecting sunlight between 10:00 a.m. and noon. For the first time a bright orange-yellow spot was observed on the floor between the center and the southeast rim wall, making a faint plume of fume, with yellow-lined cracks adjacent. Presumably sulphur was being deposited.

The following are the local data for February:

Week Ending	Halemaumau Slides	Halemaumau Crack Openings	Seismic Disturbances
February 4	0	2.5 mm.	43
" 11	0	3.0 mm.	42
" 18	0	2.0 mm.	50
" 25	0	2.5 mm.	34

March 1940

The month of March produced notable increase in Mauna Loa earthquakes, solfataric stains were increasing on the Halemaumau floor and some feeble earthquakes were felt during the month. Of 26 feeble and very feeble local earthquakes registered during the month 13 were from Mauna Loa distances and two were reported felt.

In Halemaumau on March 1 there was faintly visible fume and much white and yellow stain along the southeast edge of the pit floor. The solfatara at the base of the west wall is apparently dead. Accompanying a felt earthquake at 9:47 a.m. March 2 rocks fell from the WNW wall of Halemaumau and there was a scar of recent sliding at the south. A moderate slide sent up a dust cloud lasting 10 minutes at NE wall of Halemaumau 5:28 p.m. March 4. The end of the month produced a few rock slides and the fuming and yellow spots were still in evidence at the southeast in Halemaumau. Observation at Devil's Throat March 30 showed fresh rocks on the floor from the west wall.

The Mauna Loa seismograph showed a spell of seismic activity more intense than that at Kilauea for forty-eight hours between noon March 8 and noon March 10. Approximately 40 seismic disturbances were registered, whereas Kilauea recorded only 23. All but two at Kilauea were tremors, whereas Mauna Loa registered 15 as very feeble earthquakes. Apparently Mauna Loa was in local agitation under the northeast rift, and Mauna Loa was again focus of swarms of small earthquakes at the end of the month. This was precursory to the outbreak of Mauna Loa of April 7, and these interesting demonstrations of how differently two seismographs behaved only 9.4 miles (15 km.) apart show how desirable are multiple instruments of simple design over a uniform net of locations, recording time and intensity at a central station.

The following are the local data for March:

Week Ending	Halemaumau Slides	Halemaumau Crack Openings	Seismic Disturbances
March 3	1	1.0 mm. opened	52
" 10	1	2.5 mm. closed	45
" 17	0	5.5 mm. opened	22
" 24	0	0.5 mm. closed	24
" 31	few	7.0 mm. opened	26

Change of Annual Tilt

Referring to the notable change of tilt at the end of each month for the year next preceding, tabulated in page 5 of Volcano Letter No. 466, it is of interest to exhibit a general continuance of tilt to the west and north at the Observatory northeast rim of Kilauea Crater, for the year preceding the date indicated, respectively in north-south azimuth and east-west azimuth at the Bosch-Omori seismograph.

January 28, 1940	S 0.88 seconds	W 3.27 seconds
February 25, 1940	N 0.97 seconds	W 1.34 seconds
March 31, 1940	N 2.6 seconds	W 1.37 seconds

All of this is in contrast to a strongly southwesterly tilt of over 5 seconds between May and July 1939, this changing to an aggregate of about 3 seconds of northwesterly tilt between December 1, 1939 and March 31, 1940.

T. A. J.

SEISMOLOGICAL DATA

Earthquakes

Week Ending		Minutes of Tremor	Very Feeble	Feeble	Slight	Moderate	Distant*	Weekly Seismicity†
January	7....	11	0	0	0	0	2	2.75
"	14....	17	1	0	0	0	0	5.25
"	21....	23	7	1	0	0	1	9.75
"	28....	22	4	0	0	0	0	7.50
February	4....	31	12	0	0	0	0	13.75
"	11....	31	11	0	0	0	4	13.25
"	18....	41	8	1	0	0	0	15.25
"	25....	34	0	0	0	0	2	8.50
March	3....	46	5	1	0	0	0	15.00
"	10....	38	6	1	0	0	0	13.50
"	17....	19	2	1	0	0	0	6.75
"	24....	19	1	4	0	0	0	7.75
"	31....	21	5	0	0	0	1	7.75

* Including teleseisms or earthquakes over 5000 km. from Kilauea.
† For local seismicity definition see Volcano Letter 371.

Epicenters of the following local disturbances were determined by means of seismograms from the stations operated by the Hawaiian Volcano Observatory on the Island of Hawaii. Kilauea earthquakes were located by means of the seismograph station at the Observatory and the two subsidiary stations at Uwekahuna and the SE rim of Halemaumau respectively. The more distant shocks were located with the aid of seismograms from Hilo and Kealakekua. The disturbances began at the time indicated and whenever possible a determination of depth of focus has been made.

January 9, 7:47 pm, very feeble, probably originated in Kilauea SW rift about 8.0 miles SW of Halemaumau.

January 16, 11:06 pm, feeble, of shallow origin Mauna Loa summit crater, 19° 28.0′ N; 155° 37.5′ W.

January 16, 11:08 pm, very feeble, same location as preceding quake.

January 16, 11:32 pm, very feeble, 9.0 miles deep in area 4.5 miles W of Kilauea crater (Kaoiki Pali). 19° 25.2′ N; 155° 20.5′ W.

January 16, 11:45 pm, very feeble, probably originated in Kilauea SW rift.

January 17, 10:50 am, probably of Hualalai origin.

January 20, 12:34 am, very feeble, probably originated in Hilina Fault about 3.5 miles SW of Kamakaia Hills.

January 28, 1:06 am, very feeble, 2.3 miles deep, Kilauea SW rift, 0.8 mile NE of Cone Peak. 19° 23.9′ N; 155° 17.9′ W.

January 28, 6:18 pm, very feeble, Mauna Loa NE rift about 6.5 miles NE of Puu Ulaula.

January 28, 9:14 pm, very feeble, Mauna Loa NE rift about 3.0 miles NE of Pohaka Hanalei.

January 29, 8:06 am, very feeble, probably originated under N slope of Mauna Loa.

January 30, 1:11 am, very feeble, Mauna Loa NE rift about 3.0 miles NE of Pohaka Hanalei.

January 30, 11:32 am, very feeble, 1.1 miles deep, SE rim area of Halemaumau. 19° 24.4′ N; 155° 16.6′ W.

January 30, 1:54 pm, very feeble, Mauna Loa NE rift 6.0 miles NE of Puu Ulaula.

January 31, 2:19 am, very feeble, 1.1 miles deep, near SW rim junction of Kilauea Crater with SW rift. 19° 23.9′ N; 155° 17.6′ W.

February 2, 12:29 am, very feeble, of shallow origin, SE rim of Halemaumau. 19° 24.5′ N; 155° 16.9′ W.

February 2, 9:14 am, very feeble, from central portion of Kilauea Crater.

February 3, 12:49 pm, very feeble, probably originated in vicinity of Ahua Kamokukolau.

February 5, 7:50 pm, very feeble, E rim area of Kilauea Crater near Byron Ledge.

February 7, 11:43 am, very feeble, of shallow origin, Mauna Loa NE rift 5.0 miles SW of Puu Ulaula. 19° 31.0′ N; 155° 31.0′ W.

February 8, 7:19 am, very feeble, 11.0 miles deep, near junction of Hilina Pali fault with Kilauea SW rift. 19° 15.0′ N; 155° 21.5′ W.

February 8, 10:42 am, very feeble, of shallow origin, Kilauea Crater 0.9 mile NE of center of Halemaumau. 19° 24.9′ N; 155° 16.4′ W.

February 9, 7:42 am, very feeble, probably originated in Chain-of-Craters near Puhimau.

February 9, 10:47 pm, very feeble, probably originated under E rim of Kilauea Crater.

February 10, 4:44 am, very feeble, originated under Halemaumau not over 0.3 mile in depth and near SE rim. 19° 24.3′ N; 155° 17.2′ W.

February 12, 11:18 pm, very feeble, NE rim area of Kilauea Crater.

February 14, 8:54 pm, very feeble, NE portion of Kilauea Crater.

February 15, 3:03 am, very feeble, 11.0 miles deep near junction of Hilina Fault with SW rift of Kilauea. 19° 13.5′ N; 155° 21.5′ W.

February 16, 9:12 am, very feeble, probably originated 13.0 miles from the Observatory in the Kilauea SW rift.

February 16, 4:09 pm, very feeble, 2.3 miles deep under NE rim of Kilauea.

February 17, 7:03 am, feeble, 4.2 miles deep in rifts 0.9 mile S of Ahua Kamokukolau. 19° 22.2′ N; 155° 15.9′ W.

February 28, 10:38 am, very feeble, probably originated in Kilauea SW rift.

March 1, 1:58 am, very feeble, 12.0 miles deep, Mauna Loa NE rift, 8.0 miles NE Puu Ulaula and 18.0 miles SW of Hilo. 19° 36.0′ N; 155° 22.0′ W.

March 2, 9:47 am, feeble, of shallow origin SE rim area of Kilauea Crater. 19° 23.8′ N; 155° 16.5′ W. Dismantled N.S. component of Pit seismograph and reported sharply felt on SW rim of Halemaumau.

March 2, 10:20 am, very feeble, same origin as preceding quake.

March 4, 8:15 pm, very feeble, probably originated under SW end of Mauna Loa summit crater.

March 8, 10:40 pm, very feeble, Mauna Loa NE rift.

March 9, 4:00 pm, Mauna Loa summit crater.

March 10, 4:06 pm, feeble, 17.0 miles deep, Mauna Loa NE rift about 4.0 miles NE of Puu Ulaula. 19° 34.0′ N; 155° 24.5′ W. Reported felt at Uwekahuna.

March 11, 11:43 pm, feeble, of shallow origin under Byron Ledge, E rim of Kilauea crater. 19° 24.8′ N; 155° 15.7′ W.

March 14, 11:26 am, very feeble, probably originated in cracks 0.8 mile NE of Puu Ohale.

March 18, 3:27 am, very feeble, 18.0 miles deep under Hualalai. 19° 40.0′ N; 155° 48.0′ W.

March 20, 7:46 pm, feeble, 11.0 miles deep, Hilina Pali, 4.0 miles S SE of Makaopuhi. 19° 19.0′ N; 155° 09.0′ W.

March 21, 11:11 pm, very feeble, probably originated under Mauna Kea area.

March 22, 3:23 am, very feeble, probably originated in Hilina Pali.

March 26, 12:45 am, very feeble, NE slope of Mauna Loa, 4.0 miles SW of Hilo seismograph.

March 27, 7:27 am, very feeble, 18.0 miles deep under Mauna Loa summit crater. 19° 28.0′ N; 155° 37.0′ W.

March 27, 5:54 pm, very feeble, Mauna Loa NE rift near Mauna Loa seismograph station.

March 27, 6:50 pm, very feeble, of shallow origin, Kilauea Crater, 0.4 mile E of east rim of Halemaumau. 19° 24.5′ N; 155° 16.5′ W.

March 28, 2:31 am, very feeble, 18.0 miles deep, Mauna Loa NE rift, 2.0 miles SW of Puu Ulaula. 19° 31.0′ N; 155° 29.0′ W.

Teleseisms

January 2, 1h 06m 34s am, unidentified portion registered. Location by U.S.C. and G.S. Vicinity of Easter Island. 31° S; 108° W.

January 6, 3h 42m 51s am, "P" waves registered. 3775 miles from Kilauea in vicinity of New Hebrides and Loyalty Islands. 22° S; 170° E.

January 16, 2h 54m 18s pm, "P" waves registered. 3700 miles from Kilauea in vicinity of Marianas Trough. 17° N; 148° E.

February 7, 6h 53m 37s am, "P" waves. 2810 miles from Kilauea in the Aleutian Islands. 52° N; 174.5° E.

February 8, 1h 09m pm, unidentified portion. No information concerning point of origin obtained.

February 11, 9h 59m 17s pm, "P" waves. 3115 miles from Kilauea in vicinity of Tonga Trough. 22.6° S; 177.5° W.

February 11, 10h 53m 04s pm, unidentified portion recorded. Originated in Aleutian Trough. 54° N; 160° W.

February 19, 3h 56m 56s pm, "P" waves. 3250 miles from Kilauea in Solomon Islands. 12° S; 167° E.

February 24, 1h 40m 54s, am, "P" waves.

March 27, 2h 18m am, unidentified portion.

Microseismic Motion

January

Moderate—1, 13, 14, 17, 31.

Strong—2 to 12, 15, 16, 18 to 30.

February

Light—1, 2.

Moderate—3, 8, 9, 12, 13, 17 to 19, 26.

Strong—4 to 7, 10, 11, 14 to 16, 20 to 25, 27 to 29.

March

Light—

Moderate—8, 11 to 13, 21, 22, 30.

Strong—1 to 7, 9, 10, 14 to 20, 23 to 29, 31.

Time used throughout is Hawaiian Standard, 10h 30m slower than G. C. T.

Tilting of the Ground

The following tables show tilt by weeks as recorded on the Observatory seismograph, NE rim of Kilauea Crater and at Halemaumau, *the algebraic sum toward or away from the Pit as indicated* by stations on the W and SE rims respectively.

At the Observatory the total accumulated tilt for the year ending January 28, was 0.88" S and 3.27" W.

For the year ending February 25, was 0.97" N and 1.34" W.

For the year ending March 31, was 2.6" N and 1.37" W.

Table of Tilt

Week Ending	Observatory	Halemaumau West Station
January 7	1.12" S 10° E	0.00
" 14	0.77" S 56° W	0.00
" 21	1.94" S 37° W	0.00
" 28	0.73" S 59° W	1.58" N 71° W
February 4	0.63" S 39° W	4.23" N
" 11	1.34" S 88° E	0.98" N 79° W
" 18	0.66" S 45° E	1.37" N 16° E
" 25	1.09" S 44° W	1.72" S 20° W
March 3	2.15" S 76° W	0.00
" 10	1.41" S 8° W	1.19" S 71° W
" 17	1.68" S 48° W	2.38" N 56° E
" 24	1.46" S 66° W	1.04" N 49° W
" 31	0.77" S 39° E	0.51" S 72° W

Week Ending	Halemaumau Southeast Station	Halemaumau Resultant
January 7	12.77" S 36° E	12.79" from
" 14	6.48" S 80° W	4.86" toward
" 21	3.89" S 39° W	0.98" from
" 28	3.82" N 68° W	1.59" toward
February 4	0.74" S 70° W	1.95" toward
" 11	3.43" S 55° E	4.13" from
" 18	0.00	0.60" toward
" 25	0.00	0.89" from
March 3	3.24" S 34° E	3.40" from
" 10	3.24" N 34° W	2.21" toward
" 17	10.37" S 8° E	7.14" from
" 24	2.20" S 68° W	0.11" from
" 31	3.82" N 10° E	1.99" toward

Crater Angles

Measurement of horizontal angles across Kilauea Crater from the Observatory was made once during the month of January. On January 11, the measurement indicated closing of 0.42" for the Halemaumau value and closing of 0.41" for the Crater value compared with similar measurements of December 19.

Angle values February 8, indicated closing of 0.08" for Halemaumau and opening of 1.41" for the Crater. February 28, Halemaumau angle had closed 2.19" and Crater angle had opened 2.06". Change January 11 to February 28, closing of 2.17" for Halemaumau and opening of 2.45" for Kilauea Crater.

Angle values March 16, indicated opening of 2.00" for Halemaumau and closing of 1.39" for the Crater. March 28, Halemaumau angle had opened 0.26" and Crater angle had opened 1.59". Change February 28 to March 28, Halemaumau opened 2.26" and Crater closed 1.56".

Total change December 19 to March 28. Halemaumau angle from Pit seismograph to NW Pit BM, closed 0.33"; Crater angle from SE rim station to Uwekahuna opened 1.50".

Spirit Levelling Around Halemaumau

On February 9, a line of levels was run from the Spit B.M., SE rim of Kilauea Crater to the NW Pit B.M., on the NW rim of Halemaumau. Compared with a similar run made August 30, 1939, the NW Pit B.M., had lowered 0.067 meters with reference to Spit. This relative lowering, since July 2, 1934 has amounted to 0.697 meters or 2.26 feet.

Chain-of-Craters Road Cracks

Date	101	102	103	104	105	106	107
Jan. 26	404.70	64.60	101.55	17'9"-⅛	87.35	88.75	39.50
Feb. 23	404.85	64.60	101.55	same	87.30	88.75	39.50
Mar. 29	404.80	64.65	101.55	same	87.35	88.65	39.50
Total change in mm. since Dec. 29, '39	+2.5	+0.5	.....	.....	.....	—1.0	.....

The rim crack at Pauahi at edge of Chain-of-Craters road closed 2.5 millimeters between December 29, 1939 and March 29, 1940.

H. H. W.

HAWAIIAN VOLCANO RESEARCH ASSOCIATION
in cooperation with
UNIVERSITY OF HAWAII

The **Hawaiian Volcano Research Association** was founded in 1911 for record of volcanoes in the Hawaiian Islands and around the Pacific Ocean. Its equipment at Kilauea Volcano, Hawaii Island, is leased and operated by the United States Government, Department of the Interior, National Park Service.

The **University of Hawaii** cooperates in maintaining a research laboratory at Hawaii National Park. The **Association** and the **University** maintain outside seismograph stations and supplement the work of the government with research associates, instrumental plants and special investigations.

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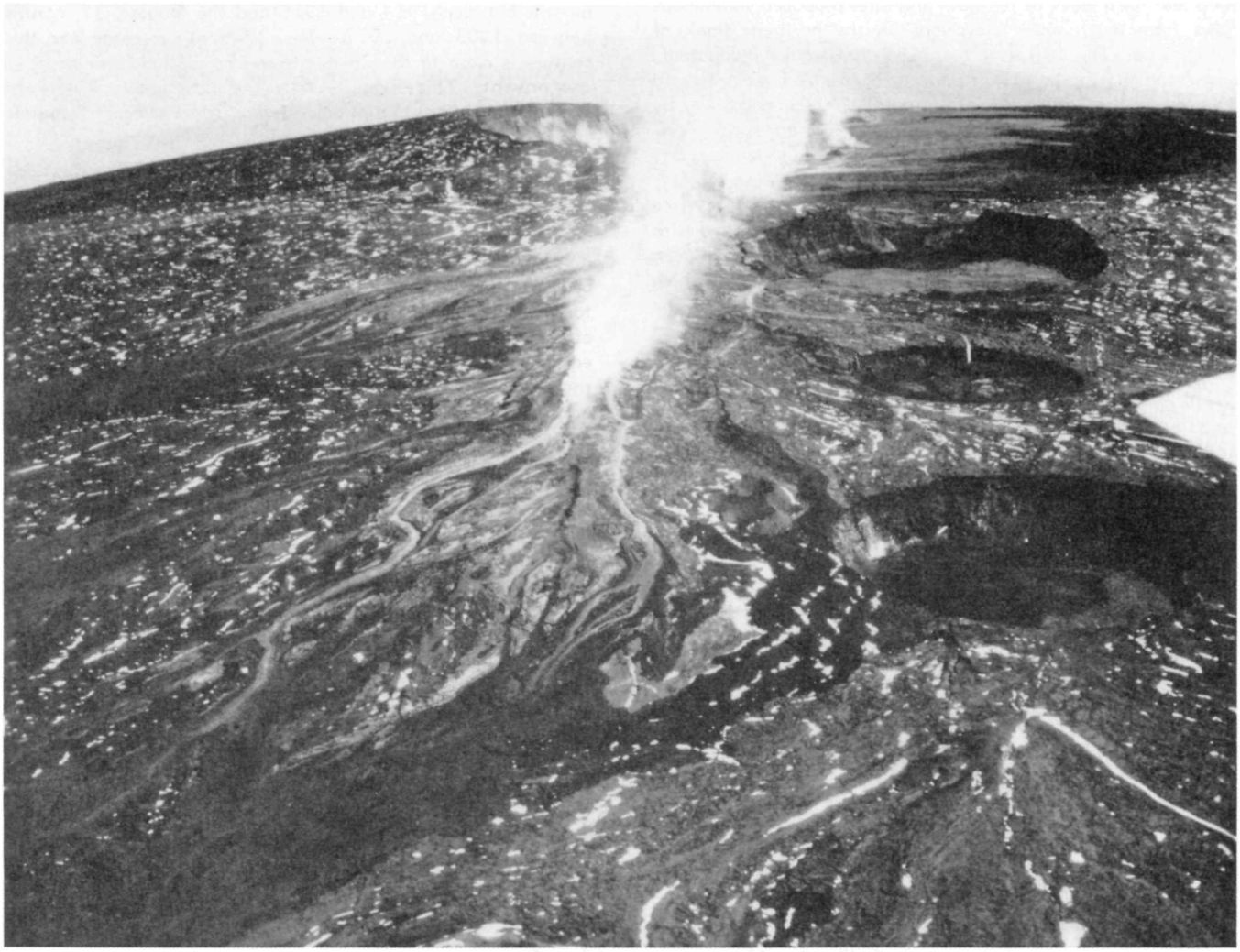

Fig. 1.—Mauna Loa summit crater eruption of 1940. Flows and fountains along southwest rift, the morning of April 8. Photo by 18th Air Base Photo Laboratory, A.C., Wheeler Field, T. H.

MAUNA LOA SUMMIT CRATER ERUPTION 1940

By HUGH H. WAESCHE
Acting Principal Scientist

Historical Background

With very little immediate warning, Mauna Loa became active with a summit crater outbreak during the late evening hours of April 7, 1940. That event was not unexpected as numerous data had indicated the possibility of volcanic activity and only a few weeks before, Dr. T. A. Jaggar had publicly stated that Mauna Loa should produce activity, probably in the summit crater, about May 1, 1940. This statement was based principally on known periodicity of Mauna Loa outflows and on average lengths of periods between eruptions during the current century compared with corresponding similarity of events in the nineteenth century. The first eruption of Mauna Loa reported observed was that of 1832; the next, and well observed, was the northeast rift flow of 1843. The similarity of conditions during the 1843 eruption and that of 1935 is striking. Both issued from the same approximate elevations and were accompanied by minor activity in Mokuaweoweo at the outbreak. Both were active with fountains in the vicinity of twelve thousand feet for a week or ten days and later produced voluminous flows from much lower elevations on the northern flank of Mauna Loa. The course of the 1935 flow would undoubtedly have been that of 1843 if it had not been interfered with and diverted by the earlier flow. The parallel was carried over by the recent 1940 summit eruption. The 1843 outbreak was followed 6 years and 4 months later by a Mokuaweoweo outflow; the one of 1940 followed the 1935 activity in 4 years and 5 months. Like 1849, the activity of 1940 was remarkably free of seismic effects which are normally expected before and with any eruption. The 1935 eruption is thought to have been stopped by bombing. If this is true the inactive period which followed may have been shortened accordingly to keep the parallelism, and also may have allowed a more rapid build-up of lava pressure under the mountain. If, on the other hand, average periodicity of eruption for Mauna Loa is considered, it will be observed that that alone was sufficient for expected activity at approximately the time it occurred. Seismic activity and tilt also suggested coming volcanic changes.

Since 1899 there have been 9 Mauna Loa eruptions. Of these 4 have been purely summit activity while the other 5 have been flank outflows accompanied for the first few hours by activity in Mokuaweoweo. Eruptions of this century and their respective sources are as follows:

1899—July 4, summit 4 days, northeast rift 19 days
1903—October 6, summit 2 months
1907—January 9, summit short, southwest rift 15 days
1914—November 25, summit 6 weeks
1916—May 19, southwest rift 2 weeks
1919—September 29, summit short, southwest rift 6 weeks
1926—April 10, summit short, southwest rift 2 weeks
1933—December 2, summit 17 days
1935—November 21, summit short, northeast rift 42 days
1940—April 7, summit 19 weeks

Tilt Change Diagrams Volcano Letter 467

The millimeter divisions of original chart make non-rectangular coordinate lines at side and top of some of the figures by the angular amount the seismograph booms were permanently set oblique to the N-S and E-W azimuths.

Study of this list shows that with the exception of the 1916-1926 eruptions, summit eruptions have alternated with flank outflows. In general the same relations seems to have existed during the nineteenth century and this may be accepted as the normal succession although by no means an iron-clad rule.

The average period of quiescence between eruptions since 1899 has been 4 years, 6 months with a maximum interval of 7 years and 10 months between 1907 and 1914 and a minimum between 1914 and 1916 of one year and 6 months. If the average interval had occurred between 1935 and 1940, the latter eruption would have begun, probably late in May. Actually it came nearly two months ahead. The 4 years and 3 months-period between 1899 and 1903 was very close to the average and the 1935-40 interval. Another interesting relation is the time interval between a summit eruption and a rift flow. The average is 25 months, with the shortest, 16 months between 1914 and 1916 and the longest, 37 months between 1903 and 1907. The 25-month average for this century is close to the 28-month average value from 1849 to the present. This suggests that the time interval between summit and flank eruptions of the same volcanic episode stays fairly constant within close limits.

Seismic Events

Although there was a remarkable absence of seismic phenomena associated with the 1940 period of activity, there was no lack of earthquakes in the 12-month period which preceded the outbreak. All eruptions are preceded by premonitory seismic disturbances and also are succeeded by after effects of a similar nature. It is difficult to distinguish where earthquakes associated with one eruption end, and those of the next begin. Then too, there are other shocks which probably have no direct relation to the subterranean lava movements.

In 1935 premonitory earthquakes of the Mauna Loa eruption, which came in November, probably began with the strong shock which caused some damage in Hilo, June 28, at 9:00 a.m. It was located in the Mauna Loa northeast rift about 10 miles from Hilo. Mauna Loa shocks increased in number and reached a climax on the night of September 30-October 1 when 1 strong (11:58 p.m. strongest recorded at Observatory in over 5 years), 3 moderate, 2 slight, 3 feeble and 20 very feeble earthquakes registered within a period of 12 hours from 10:00 p.m. to 10:00 a.m. They originated at points scattered throughout the Mauna Loa rift system from Hoopuloa to Hilo. At 1:11 a.m., November 21, a moderate earthquake originating at a point 5.0 miles from the summit crater in Mauna Loa northeast rift marked the locality from which, 17 hours later, floods of lava were to issue. With the outbreak there were 2 slight, 2 feeble, 2 very feeble earthquakes and then a period of 3,198 minutes of tremor. During that eruption there were almost no earthquakes. One hundred twenty-five earthquakes, from very feeble to strong, had been located in 1935, and of these 23 were of Mauna Loa origin with 4 locations in southwest rift, 9 near Mokuaweoweo and the remainder from the northeast rift. In 1936, after the Mauna Loa eruption, there were no notable earthquakes of Mauna Loa origin and about the normal number from Kilauea.

The figures for the years 1935 to 1939 inclusive are tabulated as follows:

Year	Total Locations	Mauna Loa Total	Mokuaweoweo	SW Rift	NE Rift
1935	125	23	9	4	10
1936	195	10	3	1	0
1937	257	20	4	1	15
1938	386	32	6	2	24
1939	217	47	14	1	32
1940, to June 30	106	20	9	0	11
Jan. 1 to Mar. 31	50	16	7	0	9

These figures fit in very well with the known volcanic developments; 1935 was the year succeeding the last Kilauea outflow.

The Observatory seismographs are located on the northeast rim of Kilauea Crater and show the very large excess of recorded Kilauea earthquakes over those from Mauna Loa. That also explains the increase of total locations of epicenters in successive years from the low of 1935 (Kilauea in repose following the 1934 eruption) to the high of 1938 which was the year of the Kilauea Chain of Craters crisis in May and August. The approaching Mauna Loa activity probably explains the slower decline in seismic activity after 1938 compared with the rise preceding that year. The Mauna Loa column is clear-cut in its significance; 1935 relatively high wtih Mauna Loa in eruption, then a low in 1936 with repose of lava movement. Starting in 1937, Mauna Loa seismic disturbances steadily increased with their highest increment (last figure in column 6) between January and April, 1940. In the first half of 1940 there were 20 Mauna Loa earthquakes located with 16 of these in the first quarter. Thus for the first quarter of 1940 the Mauna Loa earthquake rate at the Observatory was an increase in ratio over 1939 of 64 to 47. During the period of activity following the release of initial energy there were only 4 located Mauna Loa shocks by the end of the second quarter. The remaining three columns are identified with the sites of eruption and outflow. The 1935 northeast rift activity was the first from that source since 1899. That 1899 eruption high on the slope (12,500±) was the last of the nineteenth century series which had successively sealed the northeast rift from the vicinity of Kulani Cone. It was followed by 1907, 1916, 1919, and 1926 flows, successively higher on the Mauna Loa southwest rift effectively sealing that section which was the only part of the rift open after 1899. Many more earthquakes occurred to the southwest than to the northeast in those years and they were still plentiful through 1933. Four earthquakes in 1935 were

Fig. 2.—Fountains and rift in Mokuaweoweo the morning of April 8. Note small fountain to the north of Na Puu Waenakonu, left center; 1914 cone in right foreground, later center of activity. Photo by 18th Air Base Photo Laboratory, A.C., Wheeler Field, T. H.

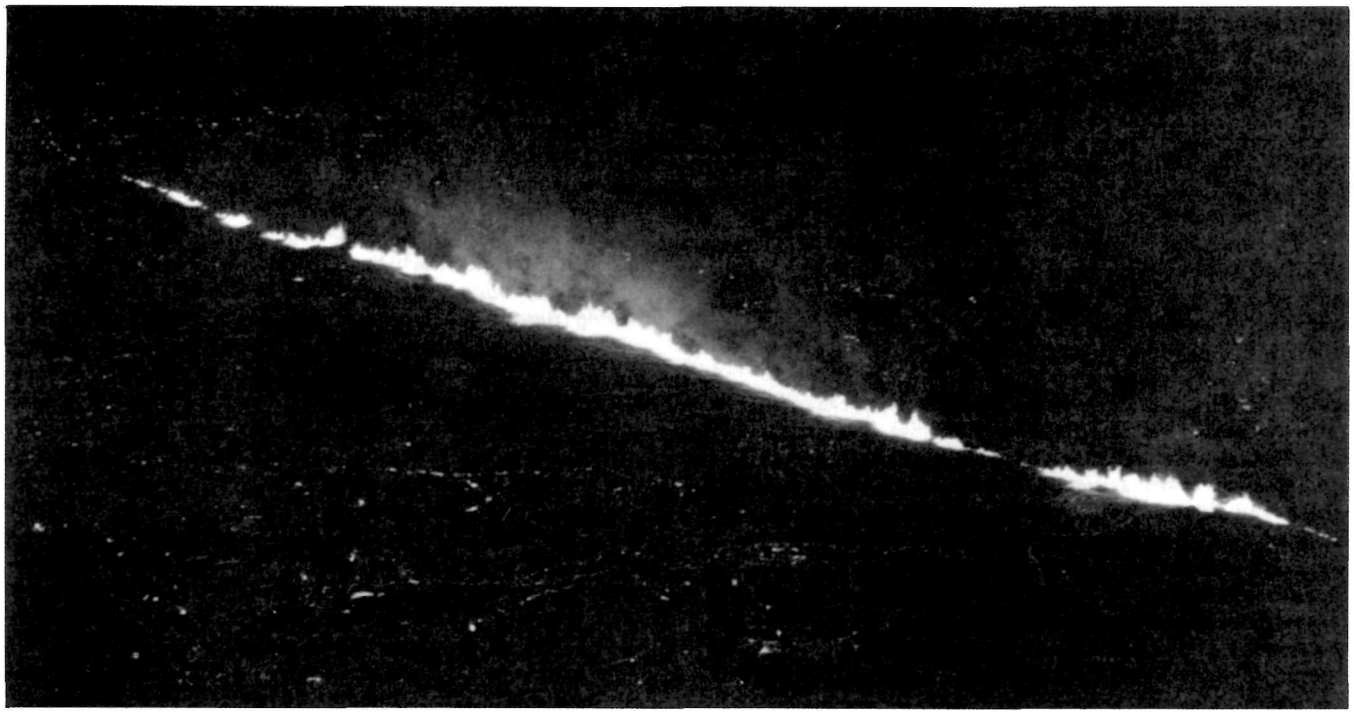

Fig. 3.—Air photograph, showing fountains along rift in Mauna Loa about 4:30 a.m. April 8. Fountains at right foreground start at base of south lunate platform. Note Na Puu Waenakonu, left center. Photo by 18th Air Base Photo Laboratory, A.C., Wheeler Field, T. H.

located in the southwest rift including a very heavy shock the night of September 30-October 1. Intrusion at least was probably going on then in the southwest rift. After that year there were almost no southwest rift earthquakes and this was borne out by the Kona seismograph at Kealakekua.

By far the greater proportion of the earthquakes from Mauna Loa originated in the northeast rift which is probably "open" and "working." Theory here fits with fact. The "liveness" of the Mauna Loa northeast rift was confirmed by the registration in January and March, 1940, of earthquake swarms on the Mauna Loa seismograph, which is located at an elevation of about seven thousand feet and 6 miles southeast of Puu Ulaula on the northeast rift. In 48 hours, January 16-18, more than 60 seismic disturbances registered. They were of tremor or very feeble classification, most of which did not register at the Observatory. Distances indicated were such as to give locations along the rift toward the summit crater. The Volcano Weekly Report No. 1462 of the week ending January 28 says, "The Mauna Loa seismograph has continued to show more earth disturbances than the seismographs at the Observatory . . . . Evidence still points to some movement along the Mauna Loa northeast rift. Between noon, March 8 and the same time March 10 (48 hours), 40 seismic disturbances registered on Mauna Loa compared with 23 at Kilauea. Fifteen of these were very feeble earthquakes."

Seismic activity is usually more intense before pending eruptions and with the possible exception of the one of 1849 the current activity has probably the lowest record of seismic disturbance before and during the activity. The strong earthquake of January 22, 1938, felt throughout the Island group, as well as registered all over the world, may well have been the beginning of the Chain of Craters crisis at Kilauea during the summer of 1938 and the beginning of the summit eruption of 1940 on Mauna Loa. In any case, such earthquakes, located a hundred or more miles from the Observatory and under the sea floor to the north and west of Hawaii have been usual rather than unusual in the past history of Hawaii and its volcanoes. In 1912 there were 2, and one each in 1913 and 1914. The last preceded the 1914 eruption by 3 months. In 1916 (Mauna Loa year) there were 3 earthquakes; 2 in 1918; 3 in 1919 (Mauna Loa year); one in 1923; one in 1926 (which preceded Mauna Loa eruption by 3 weeks); and, in 1927 there were 2 (1929 was Hualalai earthquake year).

Unless the relatively heavy earthquake shocks of May, June, and July, 1939, may be similarly classed there were no unusual seismic events leading up to the 1940 eruption other than an increase in numbers. It is possible that the heavy seismic activity (intensity not quantity) of 1935 so shattered the northeast rift and summit cracks that the lava could later rise and flow along them without producing any great amount of crustal disturbance. Also the 1935 eruption may have been artificially halted leaving the magma column well up in the volcanic system ready to break through at the slightest increase of pressure.

Activity on Mauna Loa was first observed as bright glow from summit fountains of lava the evening of April 7, 1940, at about 11:30 p.m. On the seismograph, the usual harmonic type of tremor began at 10:59 p.m. and continued until 4:00 a.m., April 8; this latter time corresponded with a visible diminishing of glow and fume. The tremor was interrupted by very feeble earthquakes at 11:09, 11:21, 11:35 and 11:38 p.m. Apparently these were felt by no one. Other than a feeble earthquake at 12:07 p.m., May 17, felt widely on the Island of Hawaii and a slight to moderate one at 5:32 p.m., June 11, also reported felt, there was no other seismic disturbance of importance that could have been said to originate under Mauna Loa. Practically no shocks were reported by observers stationed near the scene of activity. Probably indirectly connected with the summit eruption was the strong earthquake, felt throughout [illegible]sland group and of world-wide registration which rec[illegible]t 11:57 p.m., June 16. The Pasadena seismological

laboratory classified this shock as grade 7, a major earthquake. It was followed by many after shocks of various intensities.

Tilt

The possibility of some volcanic change either at Kilauea or Mauna Loa was suggested by the fact that the annual Observatory ground tilt of Kilauea showed accumulation to the north for the first time since 1936 in December, 1939. This northerly accumulation was increased during the first three months and all southerly tilt ceased in April as usual. However, there were erratic changes from normal westerly tilt to easterly tilt in February and March when there should be almost exclusively westerly tilt and a relatively smooth curve when plotted.

Outbreak

Between 11:30 p.m. and midnight April 7, residents of the Hawaii National Park heard a great amount of squawking by pheasants in nearby groves of ohias and ferns. This peculiarity is usually significant of earth disturbances and in this case indicated that the seismic effects of the Mauna Loa outbreak were detected by the birds but in no case seem to have affected any humans. A roar like the sound of a distant automobile motor was distinctly heard about 11:45 p.m. by one resident who dismissed the sound as that. Telephone communications from the Kona section of the Island to the Park superintendent announced that Mauna Loa was in eruption. That occurred at or about 12:10 a.m., April 8. At 12:30 a.m. a bright orange red glow, illuminating the entire western sky, was visible from the National Park residential area. From the Volcano Observatory a clear view of the glow from fountains, fume column and red reflection from nearby clouds, was obtainable. Extent of the fountaining area appeared to be from the northeast rim of the summit crater to a point well over the summit curve to the southwest. Measurements by transit from the Observatory bench mark indicated that activity was from the north bay of Mokuaweoweo to a point in the region west of Lua Hohonu, the second pit crater to the southwest. A more accurate location could not be determined from that point; however, airplane pictures made of the summit about 4:30 a.m., April 8, showed fountains extending along a crack from about the center of the main crater, southwestward across the south lunate platform, through the southwest rim and along old rifts toward Kahuku, a total distance of about three and one half miles. Terminals were approximately 1903 cones (Na Puu Waenakonu) at north, and cracks west of Lua Hohonu. The line of the rift was S 23° W and was in direct line of connection between cones of 1903, and those of 1914 and 1926. It seems likely that the wider glowing expanse measured by transit from the Observatory included fresh lava flows which may have flowed over the northern half of Mokuaweoweo with great rapidity in the first few hours of activity when the lava is always most fluid. If there were fountains in the northern half of the Crater, no pictures show them. However, soldiers who left the north rim at 2:30 p.m., April 8, reported fountains in the north bay with lava rising rapidly and at that time within five feet of the rest house on the northeast brink of the north bay. In spite of this it is doubtful if deep-seated fountains actually developed north of the center of Mokuaweoweo.

At 1:15 a.m., the light from 6 main fountaining areas was readily discernible with their accompanying columns of fume. Smaller fountains and fume columns were interspersed with the larger ones. Most intense glow seemed toward north with others slightly less toward center of body of glowing region; to the south light was fainter and fume thinner. At 2:00 a.m., 8 fountaining areas were visible but by 4:00 a.m., they had dwindled to 4 with largest still at center and to north. Fume columns were still faintly visible to south.

During these first few hours, pahoehoe lava streams covered practically the entire floor of Mokuaweoweo with the

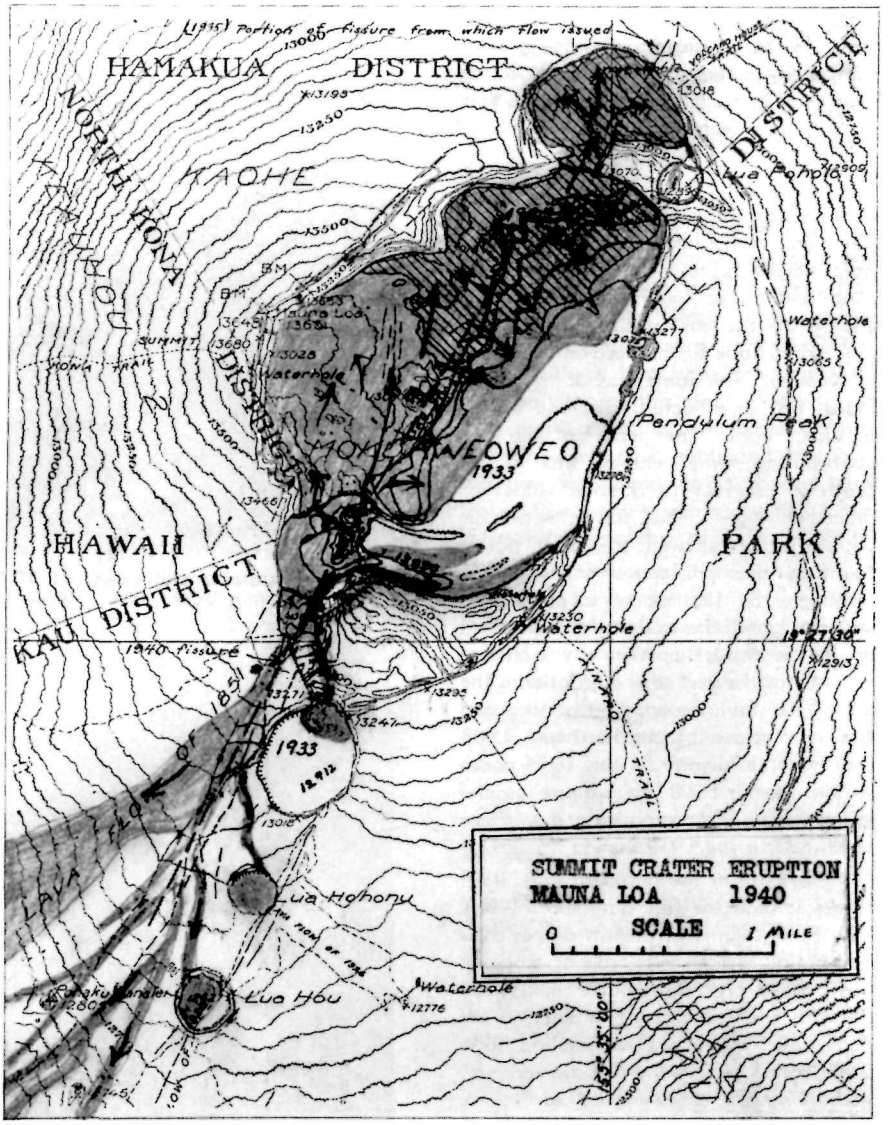

Fig. 4.—Map of Mokuaweoweo, 1940. Shaded areas show approximate extent of *lava flows during the first twenty-four hours of activity. Arrows indicate direction of* flow. Hatched area to north is 1935 lava. Light area to southeast is 1933 aa, extensively covered by later flows during May and June. Base map, U. S. Geological Survey, preliminary sheet of 1926.

exception of the southeast portion which was partially filled with 1933 aa preventing extension there of the new flows. One flow, however, which originated at the fountains on the south lunate platform, moved north to cascade into the main crater and then turned eastward across the 1933 aa nearly reaching the east well of the Crater before the source fountains ceased and stopped its further progress. Another flow from same source cascaded into the first pit crater to the southwest. Undoubtedly all of these flows were extremely fluid, highly gas-charged, and covered the floor of Mokuaweoweo with extreme rapidity as is characteristic of the early hours of all eruptions.

To the southwest of the Crater, on the outer slope of Mauna Loa, pahoehoe streams turned into aa further down the slope and cascaded from the rift into all three of the pit craters with the greater part of the activity taking place in the vicinity of Lua Hohonu. Greatest extent of this flow seems to have been about four miles.

At 9:00 a.m., April 8, a large column of fume was visible over Mauna Loa summit rising vertically from two areas to a great height, possibly ten to fifteen thousand feet above summit where it bent sharply to the east and extended in a long broad zone to the horizon southeast of Kilauea. The fume was of the usual bluish tint in reflected light and amber in direct light. The denser of the two contributing fume columns was to the south in contrast to relative values of preceding night. This confirms the air picture which showed the most active fountains near the center of the crater although the first party to reach the summit found the activity concentrated in the southwest portion where it remained for the rest of the eruption. The main fountaining apparently changed from the region of the northeast 1903 cones to the vicinity of the 1914 cones within the first 18 hours, just as the extra-crateral fountaining did from southwest to the 1914 cones.

A party from the National Park went to the summit the first day. On the way up a fume column of whitish-amber color was plainly visible. Its rate of emission was variable with some puffs being given off with a great amount of energy. At Puu Ulaula rest house a rumbling noise came from the direction of the activity resembling the pounding of surf on a distant shore. The morning after the outbreak, Pele's hair was found distributed over the entire southern portion of the island, including the vegetable gardens northeast of Kilauea.

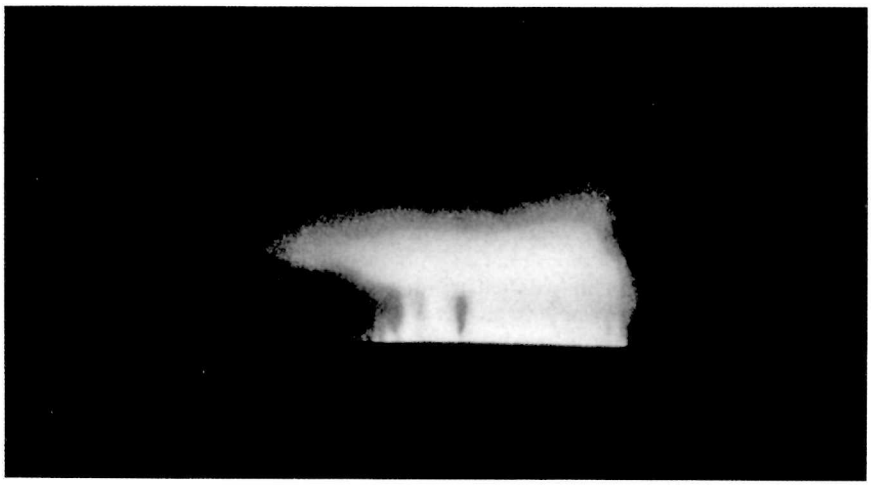

Fig. 5.—Mauna Loa eruption from northeast rim of Kilauea Crater, 12:30 a.m., April 8. Photo by Mollenhoff.

Fig. 6.—Fountains and flows, 11:30 a.m., April 9; 1914 cone right, 1933 to left. Photo by Mollenhoff.

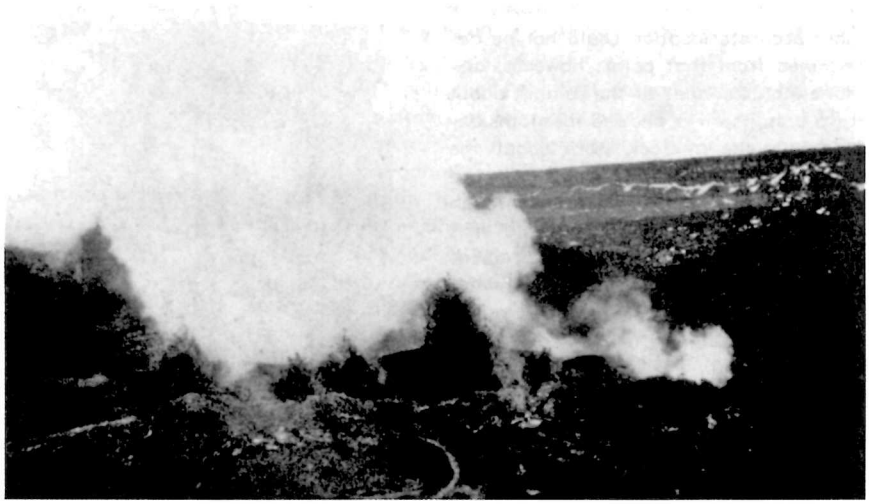

Fig. 7.—Fountains from west rim, 3:00 p.m., April 11. Photo by Jess.

Fig. 8.—High fountaining (600 feet ±) from rim of north bay, 8:30 a.m., April 16. Photo by Jess.

Fig. 9.—Pressure ridge in gap to north bay looking south, 3:50 p.m., April 4. Photo by Waesche.

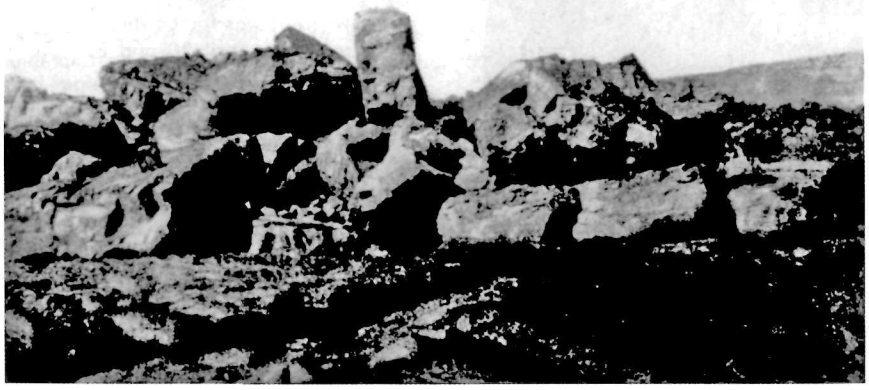

Fig. 10.—Detail of pressure ridge, 4:00 p.m., April 24. Photo by Waesche.

Initial Crater Phase

By the time the first party had reached the summit crater at 6:10 p.m., April 8, all activity had become concentrated in a series of fountains toward the southwest end of Mokuaweoweo between the 1903 cones and the south lunate platform. Their exact position could not be identified at first as they were observed end on. The north bay had been partially filled with black pahoehoe which had reached a level about 10 or 15 feet below the rest house ledge. This already had cooled enough to slump downward 5 to 10 feet by shrinkage and probably by some runoff of liquid lava below the surface. Where the crust had fractured, glowing cracks and caverns were produced; faint bluish fumes hung over the entire crater. There was no conclusive evidence that fountains had been active in the north bay. A tongue of pahoehoe had moved along a crack toward the pit crater Lua Poholo but had stopped on its rim. Pele's hair was seen floating in large quantities in the air.

There was now only one fume column and the fountains at its base were extremely active, of orange red color and were playing two to three hundred feet above the crater floor throwing out liquid, lava spatter but apparently few cinders; there had been practically no cone building at this stage. Heat waves caused all objects in the crater to appear to waver considerably and the glowing flow fronts moving north and west looked like many small fountains. Much snow clung in patches to the crater walls.

On the morning of April 9, there was little apparent change. Observations from the west rim showed the main fountaining concentrated in a portion of the rift about 1,400 feet long with its northern extremity between the 1914 and 1933 source cones. A crack in the crater floor was plainly visible extending from the fuming 1903 cones south-southwest to a point on the rim near the first south pit crater. At the main fountaining area there were 6 jets or centers of activity with the most energetic to the north. The largest jets played to heights of 300 feet and relative intensity remained almost constant. To the south of the main fountain there were 5 smaller, independent fountaining areas of diminishing size. The largest may have been 50 feet in height. Other fountains which had been active on the south lunate platform were producing fume only. The 5 smaller fountains between the main fountaining area and the south lunate platform apparently stopped after this date

as they were not mentioned in later reports, although the jets of the large fountaining area continued and even increased in size during later periods of the eruption.

Two main lava flows issued from the large fountain; one from its south side flowed west and a second from the north side to the north. They were producing pahoehoe. Near the fountain the two streams were extremely fluid and flowed with rapidity. Although the front of the flow was dark and black, the remainder was of a light bronze color. These flows were covering black pahoehoe of an earlier stage of the 1940 eruption, probably first night outpourings contemporaneous with lava of the north bay. The pahoehoe fronts advanced in a normal manner by the projection of advancing arms and toes. No gas vents similar to those seen at the 1935 eruption were noticed. Occasionally bright flashes of lava issued from the flanks, near the base of the old cones.

During the afternoon of April 9, the north lava flow front advanced to within a half mile of the north bay. Movement along the front was plainly visible from the rest house and by the morning of the tenth had advanced to within a quarter of a mile of the north bay. However, the low gradient of the crater floor and the increased distance from the cones had resulted in a slowing down of the flow's advance; accompanying this was the beginning of the next phase of crater activity, the formation of pressure ridges, dome building and cone development at the vents. By 8:30 a.m., April 10, the front of the flow moving to the north had increased from about five feet in thickness to 10 or 20 feet.

Pressure Ridges and High Fountains

Continual observation of eruption progress was meanwhile being made and there was an unbroken line of daily reports throughout the continuously visible activity.

By 6:00 p.m., April 11, the pahoehoe front had reached the gap between the main crater and the north bay. There the general shape of the crater was such that the forward movement of the lava for the next few days was deflected with a curved front to the east. This slowed down the actual flow front to a standstill where it had a chance to cool and form a resistant dam to farther advances into the north bay. Meanwhile, great volumes of liquid lava were pouring northward behind this front and as a result enormous horizontal pressures were produced between the hydraulic effect of the liquid lava and the crater walls. Great sections of the floor in the northern end of the main crater were ruptured, slipped over lower layers, and piled into ridges sometimes 50 feet in height. Blocks of dense lava 15 or 20 feet across and several feet thick were stacked in heaps and along ridges like molehills. In places where the uppermost crust of the crater floor had slid over lower layers lava had been ground to a pink rock flour. A chaotic condition over the greater portion of the crater was the result and this made most of the area nearly inaccessible. This type of activity continued through April 19, when most of the flow to the north ceased along with a general decrease in activity.

The fountains continued with little change through noon, April 12. Most energetic portion of the fountain was at north end of a series of 8 jets, and played to heights of 300 feet, throwing out molten spatter. By 2:30 p.m., there was a notable increase with ejecta from the north jet going to heights of 500 feet. During the remainder of the afternoon the intensity increased until at 6:00 p.m., spatter, pumice and cinders were being thrown to heights of 600 feet. From then on through April 19, this type of activity, pulsating in character, was a daily occurrence with the fountains reaching a low, liquid lava stage in the morning and then gradually reaching a climax in the late afternoon. The high fountains produced much pumice accompanied by increased cone construction; the low fountain periods produced almost exclusively liquid spatter. The cone had developed to a height of about 175 feet and was still most active at the north jet.

On April 15, 11:00 a.m., from an airplane, one large jet was seen to be active with 4 smaller ones of diminishing intensity to southwest. The large fountain had built up a cone which had by now almost completely covered the 1914 and 1933 cones. Fountains were pulsating considerably and producing pumice. These pulsations apparently became more erratic and at greater intervals with the passing of the next few days.

Period of Crateral Flow and Cone building

After April 19, there was a rapid decline in fountain activity and almost no lava movement until on April 23 only a faint fume column was visible and a report of "no glow visible" at the cinder cone was received from the observer at the summit. The afternoon of April 24, a party made its way one mile into the main crater. From there much fume was visible at the cone but no incandescent material was in evidence. However, many hot, glowing cracks were encountered in northeast portion of crater and in most cases the glow was at least 5 feet below the surface. Aa was found, confirming the earlier reports of that type of flow being produced at north bay gap and in northeast portion of main crater where it was forced through frozen pahoehoe crust April 20 and 21.

At 6:30 p.m., April 24, glow from the cone indicated activity was continuing in spite of apparent lull of preceding day and pasty lava spatter "sloshed" from the mouth of the vent and splashed fluidly down the cone slopes. On the morning of the twenty-fifth, observations from the west rim of Mokuaweoweo showed considerable activity at the portion of the cone to south in contrast to the previous greatest intensity point to the north. Lava was agitated in the mouth of vent and from time to time

Fig. 11.—Cone as seen from west rim, 8:30 a.m., April 25. Note pressure ridges in foreground. Photo by Hagerlund.

splashed over the north rim. The vent to the north subsided entirely within the next few days and all activity became centered in the more southerly one. A small pahoehoe flow issued from the west flank of the cone through the cinders and fanned out toward the west wall. Every five to ten minutes lava was thrown from the vent with greater than average violence and accompanied by booming, explosive noises. The 1903 cones had been almost buried by 1940 lava. This general type of activity continued with little change until May 9, adding cinders and spatter to the cone and gradually increasing lava accumulations on the crater floor to the north and west. The fountains rarely played more than 50 feet above the cone summit.

Beginning May 9, explosions occurred within the vent of varying intensities, some quite violent, and general activity appeared to increase with the fountains at times playing to heights of 100 feet above the cone crest. A new flow developed from the north base of the cone May 11. This type of activity continued with unusually heavy explosions May 13, at 12:30 a.m., and May 15, at 4:30 p.m., both of which ruptured and altered the shape of the cinder cone. On May 25, the cone apparently split open near the center of its ridge to form a transverse east-west rift. Three lava streams issued as a result, flowing east, west and south with great rapidity. The east stream coalesced with the south flow and nearly inundated a small spatter cone formed during earlier stages of eruption, about one quarter of a mile to the southwest. The west flow then swung south to join the other two and a new flow developed to the north which at 5:00 p.m. was rapidly advancing. On May 26 most of the flow was to the east with tongues of pahoehoe advancing across the 1933 aa and at several points contacting the east wall. This type of activity continued with flows constantly spreading to east and north of the center of activity and the fountain playing with little change. During May 27, 28, and 29 there was much puddling of lava to east and north, forming a large lake near the center of the crater. The contributing lava stream cascaded down the east slope of the high portion of the cone. On June 5, a flow was moving over 1933 aa toward the east wall; the fountain increased in height and appeared to be producing more pumiceous material. At 6:00 p.m. new flows developed to east and west, and east rim of cone partially foundered; a small spatter cone developed several hundred feet to east of main vent. At this time fume increased considerably and a dense column was visible from Kilauea daily.

A large rounded lava dome, like Mauna Iki in Kau Desert, had formed around and under the cone by May 8. It measured possibly 75 to 85 feet above the average crater floor and was surmounted by the still active cinder cone which was about 190 feet in height with the greatest length south-southwest-north-northeast, at its base, about 1400 feet. With flows moving east, north and at times to the west and with almost continuous fountaining to heights of 50 to 100 feet there was little change until June 19, when there began periods of intermittent quiet and renewed activity which continued the remainder of the month of June.

Areal Extent and Volume

Between April 7 and June 30, the almost continuous outpouring of lava within the summit crater of Mauna Loa resulted in an enormous volume of filling over practically the entire crater floor. The greatest fill was in the vicinity of the center of activity to the southwest. Next in order were the west and north portions of the crater followed by the north bay and finally the east portion, probably far below the other areas in quantity because of the presence of the higher 1933 fill. If the greatest fill was 90 feet apart from cone and zero taken as the minimum, it would be reasonably safe to say that the fill of 1940 had an average depth of 45 feet for all of Mokuaweoweo. Forty-five feet are equivalent to approximately 14 meters. The area of Mokuaweoweo is about thirty-two million square meters. Then the total volume of new lava in Mokuaweoweo should be about four hundred and forty-eight million cubic meters. The 1933 eruption was estimated to have produced sixty-eight million cubic meters. The 1940 figures do not include the flows in the pits to the southwest or along the rift.

Kilauea Reaction

Throughout the Mauna Loa eruption, Kilauea showed little or no sympathetic effects. Crack openings increased somewhat but were not abnormal. Levelling showed Kilauea floor to be still lowering relative to Spit B M. It has shown no appreciable changes since.

Conclusion

The Mauna Loa eruption of 1940 was expected and its location in the summit crater was normal based on observations of previous eruptions. Earthquakes show the northeast rift still to be restless and the southwest rift to be quiet. Mauna Loa summit eruptions are invariably followed by flank eruptions. They usually come within 2 years, occasionally less than one, and at other times at periods as great as 3 years. It is not altogether impossible that alternation of flows might take place and that the next outflow may be on the Kona side. It seems more likely it will be on the Hilo side and there is no doubt but what a flow will come in the not too distant future.

The 1940 Mauna Loa eruption was the longest duration of summit crater activity of any such since 1873-74.

The author is indebted to the National Park summit observers for their daily reports, which contributed much of the data here used, and to Dr. T. A. Jaggar for his helpful comments and criticism.

References used:

T. A. JAGGAR, "History of Mauna Loa," *Paradise of the Pacific*, Vol. 46, No. 2, February 1934.

WILLIAM T. BRIGHAM, "The Volcanoes of Kilauea and Mauna Loa," *Memoirs of the B. P. Bishop Museum*, Vol. II, No. 4, 1909.

The Volcano Letter, 1935-1940.

Hawaiian Volcano Observatory Report for April-June 1940

VOLCANOLOGY

April 1940

In April an eruption of the summit crater of Mauna Loa began about 11:00 p.m. April 7 and continued throughout the month. The number of earthquakes was unusually small for a time of lava eruption. Nothing notable happened at Kilauea. The Observatory staff and the Park rangers visited the summit camp of Mokuaweoweo in relays, so that this was the best observed Mauna Loa source in action on record.

The outbreak fulfills expectations in that Mauna Loa intervals have been somewhat over four years average for this century, and the last eruption ended in January, 1936. The lack of earthquakes resembles the 1849 summit eruption. This followed 1843 which like 1935 had flowed in the Humuula saddle. The partial outflows of 1940 south of Mokuaweoweo, just where 1851 erupted, strongly suggests that the next decade will have voluminous outflow at the north, like the decade that followed 1851. That also was a time of no mention of earthquakes, and as the 1940 eruption proved to be a long one in the summit crater like 1849, the danger of a Hilo outflow within the next few years is considerable. There is every reason to acquire the whole summit region of Mauna Loa for the National Park and to build there stations for scientific observation.

Army airplane photographs by Brig. Gen. W. F. Frank, Capt. M. W. Kaye, Col. G. W. Fitzgerald's party and others were in part taken the first night and morning, developed and printed in Honolulu, and delivered at the Volcano Observatory at 6 p.m. the same day. The Park telephone to the summit and Puu Ulaula camps kept the Observatory in constant touch with the activities as never before. Color photographs both in motion and still, some of them by the Park staff, are among the most remarkable that were ever taken of Hawaiian activity. Ranger Olson and party spent the night at the actual fountains inside Mokuaweoweo Crater April 17-18, and their experiences almost duplicated the descriptions of the several active cones of October, 1919 as published in Observatory Bulletin. On April 12 Dr. S. S. Ballard collected gases at the summit, for analysis at the University of Hawaii, returning to Honolulu April 14. As the summit crater camp had been threatened by rising lava the first day it was torn down with a view to rebuilding it later on the east margin.

The eruption is fully reported in Hugh H. Waesche's article herewith. It began along the rift from the plateau of the 1851 source west of the south pits of Mokuaweoweo, with first seismic record 10:59 p.m. April 7, and extended its crack through the 1914 and 1903 cone (Puu Waenakonu) regions of the main crater. Intensity declined throughout the month with floods of lava into the main bowl. Streams of pahoehoe the first night flowed southwest from the upland into Kahuku and South Kona, turning into aa further down. Streams also cascaded into the southern pits. Flows outside of the crater stopped within half a day. Inside the crater torrents of frothy pahoehoe flowed around all the cones, but mostly at the west.

There was from a distant view the usual broad band of lighted fume the first night, dwindling until April 18, when the fume was seen best in afternoon light with the sun behind it. At the end of April, glow and fume were visible chiefly at the summit station. There the fountain April 17-21 occasionally jetted up 700-900 feet through vents, becoming clogged along a fissure line of seven jets heaping up a ridge of basaltic pumice, from about the 1914 cone position southward. The concentrated building of a dome inside the crater centered between the 1914 and 1933 cones in the southwestern part of Mokuaweoweo sink. The old cones were buried under the new accumulations. The April eruption closely resembled that of 1933, but did most of its filling on the west side of the crater, whereas the December, 1933 eruption had been to the east. The first pahoehoe fills of the north bay, and the central crater became ruptured by aa lava rising up cracks, making pressure ridges so as to leave a chaotic floor. At the end of April there were fountains 50 feet high. Absence of felt earthquakes at the Mauna Loa camps was remarkable.

There was continuous tremor at the beginning of the Mauna Loa eruption lasting five hours. A feeble shock, felt as a jolt like blasting, occurred at Kilauea Crater April 16 and a slight shock also felt near Kilauea occurred April 21; a deeper shock April 26 was located under the Kilauea-Puna rift near the east point of the island.

The following are the local data for April, counting tremor spasms as single seismic disturbances:

Week Ending	Halemaumau Slides	Halemaumau Crack Openings	Seismic Disturbances
April 7	0	1.5 mm. closed	24
" 14	0	2.0 mm. "	26
" 21	3	1.5 mm. opened	16
" 28	several	8.0 mm. "	11

May 1940

Throughout the month the eruption of the summit crater of Mauna Loa built up a large heap of pahoehoe lava in the southwest part of the main bowl of Mokuaweoweo, so that from a side channel in the top of the heap a cascade overflowed the 1933 lava at the east side of the floor. This process continued into June. Nothing notable happened at Kilauea. Parties of rangers and workers built a trail from the end of the northeast trail around the northeast side of the crater to the flat plateau of the Wilkes Camp of 1840 where it is planned to rebuild the summit resthouse.

There was a seeming lull in the activity the middle of May, with only slight visibility of fume and no glow as seen from Kilauea. There was marked revival at the end of the month with glow at night plainly visible, and fume column showing at times the amber or cinnamon color of the early days. After two months of activity the fountain source produced more heavy pahoehoe and less pumice, and the pahoehoe was now burying part of the earlier pumice beds, and part of the pressure ridges and aa that welled up cracks, but still leaving the Mokuaweoweo floor very rough.

There was said to be increased heat and fume coming up the cracks in such early surfaces of the eruption as the fill of the north bay near the older resthouse location. This suggested that intrusive lava was penetrating under the earlier crater fillings, as in the case of Halemaumau in October, 1934, when also the fountaining of the cone center became pulsatory with gushing at intervals. The local seismic index of only 4 to 5 at Kilauea for each week was remarkably small for a period of continuing eruption. The measured earthquakes in National Park station were mostly at Mauna Loa distances, and nothing happened to suggest any change at Halemaumau.

A feeble earthquake May 17 was strongly felt at Kapapala

Ranch and feebly felt at Hilo. There was continuous tremor for six minutes the evening of May 21, but there is no reason to correlate these later spasms with Mauna Loa. The Mauna Loa seismograph on east flank of mountain did not show them. This quarter was a time of many distant earthquakes, especially the month of May, with disturbances in the Philippines, Aleutian Islands, Imperial Valley of California, Peru, and northwest Canada, all of these around the Pacific Ocean.

The following are the local data for May, counting tremor spasms as single seismic disturbances:

Week Ending	Halemaumau Slides	Halemaumau Crack Openings	Seismic Disturbances
May 5	1	2.5 mm. closed	17
" 12	0	3.5 mm. "	14
" 19	0	0.5 mm. opened	15
" 26	0	2.5 mm. "	15

June 1940

The month of June found the Mauna Loa summit eruption continuing with the large slag heap growing in Mokuaweoweo Crater, and the tendency to alternation between gushes and intrusions increasing. Nothing notable happened at Kilauea. Observers lived at the summit of Mauna Loa continuously. A new feature of great importance, which has happened before in connection with eruptions of the Hawaiian volcanic system, was a strong and perhaps relatively deep earthquake on June 16, followed by many aftershocks for a fortnight, and centering about the ocean deep northwest of Maui and about 185 miles east of Honolulu.

It happens that in this general vicinity there is a deep trench of 3,000 fathoms bordering the southwest side of a large triangular plateau in the ocean bottom 170 nautical miles long, containing a high peak rising 8,000 feet above it, 240 miles northeast of Honolulu. The deep trench is between this seemingly submerged island and Maui, and it is in this trench 75 miles north of Ookala that the disturbances occurred which generated these earthquakes. The earthquake of June 16 was strong and profound enough to register on the seismographs of Pasadena as a teleseism.

From past experience there seems to be good reason to connect such earthquakes as this with the reactions of magma pressing upward under the larger Hawaiian ridge, in some way related to the clogging effects of the cooling and restraining plug that was solidifying in the Mauna Loa crater and bringing the eruption to a close after three months of outpouring. There is here matter for a seismological study worthy of extended investigation.

Mauna Loa in June showed a succession of lulls followed by outbursts at or near the top of the new inner dome of floor in Mokuaweoweo Crater. Apparently the lowerings were times of intrusion, as on May 27-29, when glow-cracks developed even as far away from the center as the north bay. Then at the cone center May 29 the liquid lava came up with fountaining, and overflows of the inner dome occurred, mostly to the east. The alternations were, down June 1-4, up after June 5, down June 10-12, up June 13-16, down June 17-24, up June 25-26, down June 27-July 2, and up July 3-5.

The duration of the gushes decreased from four days to two days; the duration of the intrusive spells increased from two days to eight days. The intervals between gushes increased from five to twelve days between the end of May and June 25: the intervals between intrusive spells increased from five to ten days in the same period. There was a pronounced quake felt in Kona during the low level following June 10, and the large earthquake northeast of Maui of June 16-17 near midnight was felt even in Honolulu and accompanied the quiescence of Mauna Loa lava that began June 17.

The gushing spells were accompanied by rupture and caving in of the summit craterlet, followed by fountains spurting 50 to 100 feet above the top of the dome, along with strong glow and fume as seen from Kilauea, and cascading torrents of lava to both west and east sides of the Mokuaweoweo floor, but mostly to the east. The structure built up stands more than 300 feet above the floor of 1939, it surmounts in height the east wall of Mokuaweoweo, and the recurrence of heat and glow was marked under the floor of the north bay of the greater crater during June, suggesting intrusive confinement of gas.

The following are the local data for June, counting tremor spasms as minutes of duration:

Week Ending	Halemaumau Slides	Halemaumau Crack Openings	Seismic Disturbances
June 2	0	0.0 mm. opened	15
" 9	1	1.5 mm. closed	10
" 16	0	2.5 mm. opened	10
" 23	0	1.0 mm. closed	119
" 30	0	1.0 mm. opened	25

Felt earthquakes occurred June 11, June 16, June 17 twice, and tremor spasms were notably small the first half of June, the 144 minutes of tremor indicated being recorded during the fortnight of aftershocks following the large earthquake.

T. A. J.

SEISMOLOGICAL DATA

Earthquakes

Week Ending	Minutes of Tremor	Very Feeble	Feeble	Slight	Moderate	Distant*	Weekly Seismicity†
April 7	76	8	0	0	0	1	23.50
" 14	260	5	0	0	0	0	67.50
" 21	9	4	2	1	0	1	8.25
" 28	6	4	1	0	0	0	4.50
May 5	14	3	0	0	0	0	5.00
" 12	12	2	0	0	0	0	4.00
" 19	12	2	1	0	0	2	5.00
" 26	19	1	0	0	0	3	5.25
June 2	12	3	0	0	0	2	4.50
" 9	9	1	0	0	0	1	2.75
" 16	7	2	0	0	1	0	9.75
" 23	99	16	1	2	1	1	40.75
" 30	20	4	1	0	0	0	7.00

* Including teleseisms or earthquakes over 5,000 km from Kilauea.
† For local seismicity definition see Volcano Letter 371.

Epicenters of the following local disturbances were determined by means of seismograms from the stations operated by the Hawaiian Volcano Observatory on the island of Hawaii. Kilauea earthquakes were located by means of the main seismograph station at the observatory and the two subsidiary stations at Uwekahuna and the SE rim of Halemaumau respectively. The more distant shocks were located with the aid of seismograms from Hilo and Kealakekua. The disturbances began at the time indicated and, whenever possible, a determination of depth of focus has been made.

April 3, 2:49 pm, very feeble, originated under NE rim of Kilauea Crater.

April 4, 4:29 pm, very feeble, 8.0 miles deep, Hilina Fault, 3.6 miles S of Puaialua. 19° 19.0′ N; 155° 09.2′ W.

April 4, 11:08 pm, very feeble, 6.0 miles deep, Mauna Loa NE rift 5.0 miles NE of Puu Ulaula. 19° 34.0′ N; 155° 24.0′ W.

April 4, 11:24 pm, very feeble, 0.9 mile deep, SE portion of Halemaumau. 19° 24.5′ N; 155° 17.0′ W.

April 7, 11:09 pm, very feeble, of shallow origin, Mauna Loa summit crater. Associated with outbreak of eruption. Others followed at 11:21 pm, 11:35 pm and 11:38 pm.

April 10, 2:00 pm, very feeble, from Mokuaweoweo.

April 11, 2:33 pm, very feeble, 10.0 miles deep, Mauna Loa NE rift, vicinity of Puu Ulaula. 19° 32.0′ N; 155° 28.6′ W.

April 14, 12:46 am, very feeble, of shallow origin, 0.5 mile E of Ahua Kamokukolau. 19° 22.9′ N; 155° 15.6′ W.

April 14, 8:10 pm, very feeble, same source as preceding.

April 15, 12:00 noon, feeble, 4.2 miles deep, vicinity of Cone Peak, Kilauea SW rift. 19° 23.6′ N; 155° 18.4′ W.

April 16, 6:06 am, very feeble, 0.6 mile deep, SE portion of Kilauea Crater 0.6 mile E of Pit Seismograph. 19° 24.3′ N; 155° 16.4′ W.

April 16, 8:51 am, very feeble, from E rim of Kilauea Crater (Byron Ledge).

April 16, 4:53 pm, feeble, of shallow origin, NE rim of Kilauea Crater, 19° 15.6′ N; 155° 15.9′ W. Felt by residents in Hawaii National Park headquarters area as a sharp hump similar to heavy blasting.

April 20, 5:06 pm, very feeble, of shallow origin in cracks between Kokoolau Crater and Ahua Kamokukolau.

April 21, 1:06 am, slight, 0.4 mile deep, Kilauea Crater, 0.9 mile E of center of Halemaumau. 19° 14.5′ N; 155° 16.3′ W. Felt by few persons in Hawaii National Park. Dismantled Pit seismograph.

April 21, 12:32 pm, very feeble, from vicinity of Puhimau and Kokoolau Craters.

April 22, 11:01 pm, very feeble, 5.0 miles deep, 6.0 miles S of Pahoa, Kilauea Puna rift. 19° 25.0′ N; 154° 57.0′ W.

April 23, 1:16 am, very feeble, 12.0 miles deep, Kilauea SW rift, 6.6 miles SW of Pit seismograph. 19° 21.0′ N; 155° 22.0′ W.

April 23, 9:38 am, very feeble, Kilauea Crater, 0.7 mile, NE of Pit seismograph.

April 26, 11:56 am, feeble, probably 15.0 miles deep, Kilauea-Puna rift near Cape Kumukahi.

May 5, 10:13 am, very feeble, probably originated off coast of Hawaii in vicinity of Laupahoehoe. Reported felt at Paauhau.

May 5, 8:47 pm, very feeble, about 15.0 miles deep off coast of Hawaii, 4.0 miles NE of Ninole. 19° 58.0′ N; 155° 07.0′ W. Reported felt at Paauhau.

May 10, 12:37 pm, very feeble, 2-5 miles deep under Mokuaweoweo, summit crater of Mauna Loa. 19° 28.0′ N; 155° 35.5′ W.

May 17, 5:41 am, very feeble, of shallow origin, 5 miles off seacoast near Punalulu. 19° 04.5′ N; 155° 29.5′ W. Reported felt at Pahala and Kapapala Ranch.

May 17, 12:06 pm, feeble, of relatively shallow origin, under Mauna Loa summit crater. 19° 28.0′ N; 155° 35.0′ W. Reported felt at Kapapala Ranch and Hilo.

May 18, 10:56 am, very feeble, origin probably same as preceding.

May 26, 3:32 am, very feeble, probably originated in E central portion of Kilauea Crater.

May 27, 2:10 am, very feeble, of Halemaumau origin.

May 27, 2:49 am, very feeble, originated in NE portion of Kilauea Crater.

May 28, 11:12 pm, very feeble, 10 miles deep, Kilauea SW rift. 2.0 miles NW of Koae Cone. 19° 22.8′ N; 155° 19.5′ W.

June 11, 5:32 pm, slight to moderate, 18.0 miles deep, Mauna Loa. 19° 26.8′ N; 155° 31.6′ W. Felt in Kona at Hookena and Kealakekua and at Hawaii National Park.

June 13, 11:18 pm, very feeble, Mauna Loa NE rift near Pukauahi Crater.

June 16, origin time 11h 56m 49s pm, a strong earthquake was felt throughout Hawaiian group and particularly Hawaii, Maui and Oahu. No damage reported. Reported as major earthquake of grade 7 by seismological laboratory of California Institute of Technology at Pasadena. All seismographs in Territory dismantled with exception of strong motion instrument at Hawaiian Volcano Observatory. Awakened most sleepers on islands referred to. Most people report roaring noise preceding felt portion. Dogs howled, pheasants squawked and loose objects in or attached to buildings rattled violently. Location as worked out in cooperation with Lt. E. O. Heaton of the U. S. Coast and Geodetic Survey in Honolulu was: depth probably normal; epicenter 21.0° N. latitude; 155.3° W longitude. This would place epicenter approximately 85 miles N of Hilo and 185 miles E of Honolulu.

The main shock was followed by many after shocks chronologically arranged as follows:

June 17, 12:14 am, slight
12:38 am, very feeble
12:40 am, very feeble
3:28 am, very feeble
7:47 am, moderate; felt; Hawaii, Maui, Oahu.
11:20 am, very feeble
11:28 am, very feeble
12:13 pm, very feeble
12:39 pm, slight; felt; Hawaii, Maui, Oahu.
3:47 pm, very feeble
4:27 pm, very feeble
5:04 pm, very feeble
June 18, 11:52 am, very feeble
June 19, 12:20 pm, very feeble
June 23, 1:14 am, very feeble
June 26, 8:44 am, very feeble
10:15 am, very feeble
10:21 am, very feeble
June 28, 7:54 pm, feeble

All of the above were apparently located within an area bounded by lats. 20° 45′ to 21° 15′ N and longs. 155° 0′ to 155° 3′ W. This area would be centered approximately 75.0 miles N of Ookala, NE coast of the Island of Hawaii.

June 17, 1:48 am, very feeble, 1.3 miles deep under cracks, 0.8 mile SE of Ahua Kamokukolau. 19° 22.5′ N; 155° 15.5′ W.

June 19, 1:54 pm, feeble, originated under seacoast area S of Kilauea crater near Keahou landing.

June 19, 4:35 pm, very feeble, of shallow origin Mauna Loa summit crater.

June 21, 6:46 am, very feeble, of shallow origin SE rim area of Halemaumau 19° 24.4′ N; 155° 16.9′ W.

June 21, 7:45 pm, very feeble, 0.6 mile deep, 1.1 mile S of Pit seismograph. 19° 23.5′ N; 155° 16.7′ W.

June 25, 1:33 am, very feeble, originated near center of Kilauea crater to NE of Halemaumau.

Teleseisms:

April 1, 1h 00m 08.0s am, "P" waves. Probably originated in the vicinity of the Philippines.

April 15, 7h 45m 28.0s pm, "P" waves. 2,710 miles from Kilauea in region of Aleutian Islands. 52.6° N; 173.8° W.

May 18, 6h 14m 08.0s pm, "P" waves, probably originated about 2,575 miles from Kilauea; Imperial Valley disaster of California.

May 19, 4h 56m 26s am, "P" waves, distance about 3,200 miles.

May 21, 8h 26m 55s am, "P" waves, distance undetermined.

May 24, 6h 16m 24s am, "P" waves, probably originated near Peru, about 5,645 miles distant.

May 24, 12h 10m 31s pm, unidentified portion.

May 27, 11h 22m pm, "P" waves, location of point of origin undetermined.

May 30, 6h 53m pm, unidentified portion.

June 5, 12h 40m am, "P" waves, from NW Canada; 68° N; 138° W.

June 22, 1h 18m 49s am, "P" waves, distance about 5,500 miles.

Continuous tremor:

April 7, 10:59 pm to midnight, 61 minutes and April 8, midnight to 4.00 am, 240 minutes with visible outflow of lava Mauna Loa summit crater; total 301 minutes. May 21, 7:06 pm, 6 minutes of tremor. June 1, 11:20 pm, 3 minutes and 11:52 pm, 4 minutes.

Microseismic Motion:

April:

Light—28, 30.
Moderate—15, 16, 19 to 27, 29.
Strong—1 to 14, 17, 18.

May:

Light—5 to 7, 15 to 30.
Moderate—2, 3, 11, 13, 14, 31.
Strong—1, 2, 8 to 10, 12.

June:

Light—1, 2, 5 to 10, 12, 13, 15 to 18, 21, 23, 28, 29.
Moderate—3, 4, 11, 14, 19, 20, 22, 25, 26, 30.
Strong—24, 27.

Tilting of the Ground:

The following tables show tilt by weeks as recorded on the Observatory seismograph NE rim of Kilauea Crater and at Halemaumau, the algebraic sum toward or away from the Pit as indicated by stations on the W and SE rims respectively.

At the Observatory the total accumulated tilt for the year ending April 28 was 2.58″ N and 0.53″ E.

For the year ending May 26, 3.20″ N and 0.90″ E.

For the year ending June 30, 4.90″ N and 0.33″ E.

Table of Tilt

Week ending	Observatory	Halemaumau West Station
April 7	0.78″ S 13° W	0.00″
" 14	0.73″ S 67° W	1.64″ N 7° E
" 21	0.95″ N 71° E	1.91″ S 20° W
" 28	0.24″ N 81° E	0.54″ N 70° E
May 5	0.52″ N 77° W	0.54″ S 70° W
" 12	1.27″ S 75° W	0.00
" 19	0.74″ N 57° E	0.00
" 26	0.77″ N 58° E	0.00
June 2	0.93″ N 20° W	0.00
" 9	0.73″ N 85° W	0.00
" 16	1.82″ N 35° E	0.00
" 23	0.90″ N 45° E	3.58″ S 60° E
" 30	0.88″ N 4° E	0.00

Week ending	Southeast Station	Halemaumau Resultant
April 7	1.59″ N 25° W	1.42″ toward
" 14	4.92″ S 25° E	4.25″ from
" 21	4.92″ N 25° W	3.81″ toward
" 28	0.00	0.45″ toward
May 5	2.49″ S 68° W	1.59″ from
" 12	3.24″ S 20° E	2.03″ from
" 19	6.71″ N 6° W	5.23″ toward
" 26	2.33″ N 20° E	1.89″ toward
June 2	0.00	0.00
" 9	2.33″ N 70° W	1.79″ toward
" 16	1.39″ N 60° E	0.17″ from
" 23	2.17″ N 9° E	4.44″ toward
" 30	2.17″ S 72° E	1.62″ from

Crater angles

Measurement of horizontal angles across Kilauea Crater from the Observatory was made April 11. At that time the measurement indicated closing of 0.17" for the Halemaumau value and closing of 1.51" for the Crater value compared with similar measurements made March 28.

Determinations of May 14, indicated closing of 0.42" for Halemaumau and opening of 1.26" for the Crater. Between May 14 and May 29, Halemaumau angle closed 1.08" and Crater angle closed 2.25". Total change April 11 to May 29, Halemaumau angle closed 1.50" and Crater angle closed 0.99".

Final measurements of the quarter was made June 20. May 29 to June 20, Halemaumau angle showed no change and the Crater angle opened 1.25".

Total change March 28 through June 20, Halemaumau angle (Pit seis. to NW Pit BM) closed 1.65" and the Crater angle (SE Crater rim to Uwekahuna) closed 1.25".

Chain-of-Craters Road Cracks

Of the seven principal Chain-of-Craters Road Cracks normally measured, only two have shown any appreciable changes between March 29 and June 28. Numbers 101 and 102, both near Devil's Throat showed increases (openings) of 1.0 millimeter each during that period.

H. H. W.

HAWAIIAN VOLCANO RESEARCH ASSOCIATION
in cooperation with
UNIVERSITY OF HAWAII

The **Hawaiian Volcano Research Association** was founded in 1911 for record of volcanoes in the Hawaiian Islands and around the Pacific Ocean. Its equipment at Kilauea Volcano, Hawaii Island, has been transferred to the United States Government, Department of the Interior, National Park Service.

The **University of Hawaii** cooperates in maintaining a research laboratory at Hawaii National Park. The **Association** and the **University** maintain outside seismograph stations and supplement the work of the government with research associates, instrumental plants and special investigations. Dr. T. A. Jaggar is their geophysicist resident in the National Park.

The **Volcano Letter,** a quarterly record of the Hawaiian volcano laboratories and published by the University of Hawaii, is issued by authority of the Department of the Interior and supplied to a restricted membership and exchange list of the above establishments.

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A CHEMICAL STUDY OF KILAUEA SOLFATARIC GASES, 1938-40

By STANLEY S. BALLARD and JOHN H. PAYNE*

The current research project on the collection and analysis of volcanic gases was begun in the fall of 1935. It was the first project under the new cooperative agreement between the University of Hawaii and the Hawaii National Park. Many collections of solfataric gases have been made at Kilauea, and two at Mauna Loa, but as yet there has been no suitable opportunity to collect primary volcanic gases from either vent. A report on the first stages of the investigation appeared in The Volcano Letter[1] over two years ago. Since that article was written, a number of improvements have been made both in the technique of collection and in the method of analysis employed. Also, since September, 1938, we have attempted to make monthly gas collections at the Sulphur Banks wells, or "Kilauea Solfatara," and 23 collections were made in the succeeding two-year period.

There is a dual purpose in making regular analyses of the Sulphur Banks gases. The first is to accumulate a long-time record of the constitution of the gases of a well-established solfatara. This has never been done in America, and its importance has recently been given recognition by the Geological Society of America, which is aiding our project with a research grant from the Penrose fund. The second purpose involves the search for variations in the gases that might correlate with periods of volcanic activity. If such a correlation can be found, another method of prediction will be available and supplementary to the cyclic, seismic and tilt methods that have been used for so many years in Hawaii. Fluctuations in the sulphur dioxide content of the exhalations were indeed noted, but we have not as yet been able to correlate these with any of the volcanic phenomena at Kilauea. However, just prior to the 1940 eruption of Mauna Loa, hydrogen sulphide was noted for the first time at the Sulphur Banks.[2]

From September, 1938, to August, 1939, gas was collected by the "vertical wet" method described elsewhere.[1] This setup is pictured on page 2 of The Volcano Letter, No. 453 (November, 1937). The objection to this method was that when two or three tubes were collected in succession on the same day, considerable variation was found from tube to tube. One tube was used in determining sulphur dioxide, and the remaining one or two tubes in determining the sulphur dioxide plus carbon dioxide total. In view of the possible variation between the tubes of a given collection, this introduced considerable doubt as to the reliability of the results. Also, the collections of May, June, and July, 1939, seemed to be of progressively poorer quality. Therefore a new method of making collections was introduced in September, 1939. As shown in Figs. 1 and 2, three tubes were mounted in series, and the gas reached them only after being drawn through a long copper coil which was immersed in an ice bath. Because of the high thermal conductivity of copper, practically all steam was condensed before the gas left the upper end of the coil, and any condensate that might have been drawn through the coil was trapped in a flask mounted between the coil and the tubes. The gas finally collected in the three tubes was free from condensate, and if care was taken in making the collection, gas samples from the three tubes were of uniform composition.

The analytical methods described previously[1] involved the determination of all constituents by the absorption pipette method. It was realized in the spring of 1938, however, that this method was giving incorrect results, since the absorbent for sulphur dioxide also absorbed large percentages of the much more abundant carbon dioxide. The results of the analyses as previously reported[1, 3] were hence in error. During the summer of 1938 we introduced the present analytical method in which the sulphur dioxide is determined gravimetrically by precipitation as barium sulphate; the sulphur dioxide plus carbon dioxide total is determined by absorption in caustic potash solution; and, the carbon dioxide is computed by difference. The only other regular constituent is air; oxygen is determined by absorption in alkaline pyrogallol and the residuum is regarded as

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nitrogen. Spectroscopic tests[1] confirmed the identity of the nitrogen and failed to show any other gases in the residuum except traces of argon. Combustibles have been sought in every analysis by the combustion pipette method but have never been detected. The volume percentages of the chief constituents, air, sulphur dioxide, and carbon dioxide in the various samples, are presented in Table I. Two or three 250-cubic-centimeter tubes of gas were collected on each date, but because of the analytical methods employed, only a single set of percentages was obtained in some cases. It is seen that the proportion of air varies widely, between zero and 40 per cent. It seems to us that this gives an indication of the quality of the collection, and that in satisfactory collections the air content should be one per cent or less. The wide variation of sulphur dioxide, from 0.5 to 18 per cent, is much too large to be occasioned by possible analytical errors. Figure 3 is a graph showing the fluctuation of the sulphur dioxide during the two-year period starting September, 1938. The percentage of sulphur dioxide showed a sudden rise to approximately 15 per cent in the January, 1939, collection. This high value remained fairly constant for a period of five months, after which it dropped to the previous lower value of about 2 per cent. A second increase occurred in October, 1939, but lasted for only a month. There appears to be no regularity about this variation, and the wirters have not been able to find any correlation between it and any of the volcanic or meteorological phenomena measured regularly at the Hawaiian Volcano Observatory.

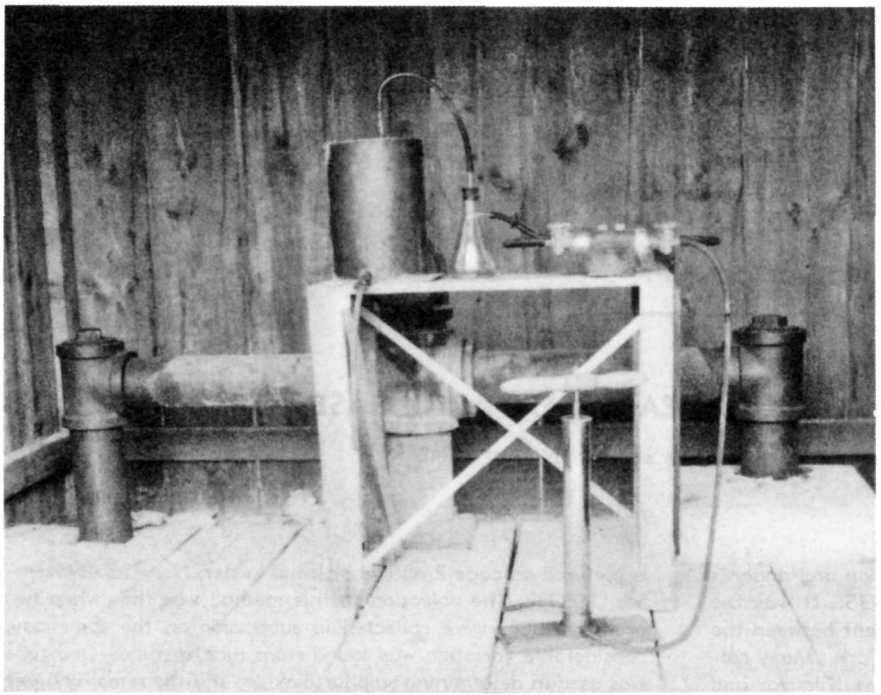

Fig. 1.—Gas collecting setup used at Sulphur Banks wells from September, 1939, to September, 1940. Photo by Fagerlund.

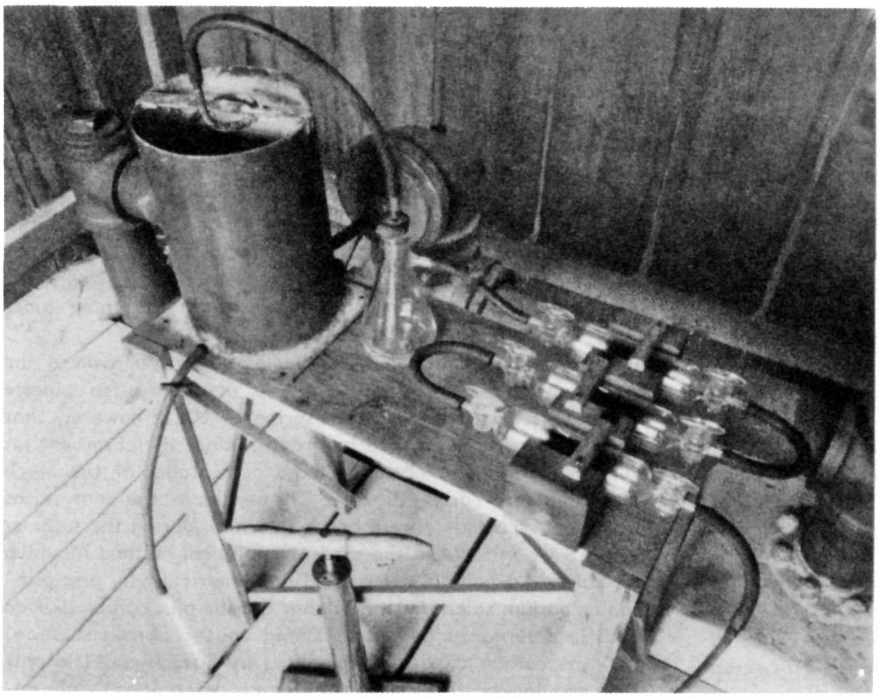

Fig. 2.—Top view of apparatus shown in Fig. 1. When gas is being collected, the copper coil is cooled by filling the brass drum with ice and water. Photo by Fagerlund.

In the collection of March 14, 1940, hydrogen sulphide appeared for the first time. It was easily detected qualitatively by odor, by the darkening of lead acetate paper, and by the formation of yellow cadmium sulphide when the gas was passed into cadmium sulphate solution. There was not sufficient hydrogen sulphide to make its quantitative determination possible. On April 7, 1940, volcanic activity broke out at the summit of Mauna Loa. Samples of gas collected at Kilauea on April 11 and on April 21 contained hydrogen sulphide, but none was found in the collections of May 10 and June 18, even though Mauna Loa was still erupting, although with greatly lessened activity.

The appearance of hydrogen sulphide in the Kilauea solfataric gases just prior to Mauna Loa activity may have been a premonitory sign. If so, this appears to afford an exceedingly valuable method of forecasting volcanic outbreaks. Furthermore, its occurrence suggests a close relationship between solfataric activity and primary volcanism.

The only previous analyses of these gases were made by Brun[4] and by Allen[5]. Brun's analyses were only partial. Allen determined the steam content to be 96.2 per cent. He found 0.1 per cent sulphur dioxide, traces of sulphur vapor and of

hydrochloric acid, and 3.7 per cent of "fixed gases." It appears from our analyses that Allen's "fixed gases" consisted of air or carbon dioxide or both. We have not as yet determined the steam content of these exhalations.

Further improvements were made in the collection methods in September, 1940. We are also starting to investigate different analytical methods, including especially the possibility of determining sulphur dioxide by the thermal conductivity method.

Many of the gas collections were made by members of the Park staff; we wish to acknowledge particularly the assistance of H. H. Waesche and P. E. Schulz in this regard. Thanks are due L. M. Foster for assistance in making the analyses.

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TABLE I.
SUMMARIZED ANALYSES OF KILAUEA SOLFATARIC GASES

Date of Collection	Per Cent Air	Per Cent SO_2	Per Cent CO_2	SO_2:CO_2 Ratio
Sept. 17, 1938	1.4	1.4	97.2	1:69
Sept. 17, 1938	2.9	2.0	95.1	1:48
Oct. 20, 1938†	-----	-----	-----	-----
Nov. 22, 1938	0.8	2.3	96.9	1:42
Nov. 22, 1938	33	-----	-----	-----
Jan. 3, 1939	1.1	14.3	84.6	1:5.9
Feb. 8, 1939	36.9	13.9	49.2	1:3.5
Mar. 14, 1939	1.1	13.8	85.1	1:6.2
Apr. 15, 1939	1.2	14.2	84.6	1:6.0
May 15, 1939	20.0	16.7	63.3	1:3.8
June 20, 1939	32.8	10.6	56.6	1:5.3
July 21, 1939†	-----	-----	-----	-----
Sept. 11, 1939	9.0	1.8	89.2	1:50
Sept. 11, 1939	9.4	1.8	88.8	1:49
Sept. 11, 1939	7.8	1.8	90.4	1:50
Oct. 13, 1939	9.9	16.5	73.6	1:4.5
Oct. 13, 1939	1.6	17.7	80.7	1:4.6
Nov. 17, 1939	8.8	16.6	74.6	1:4.5
Nov. 17, 1939	2.2	17.8	80.0	1:4.5
Dec. 15, 1939	18.4	0.6	81.0	1:135
Dec. 15, 1939	40.0	0.4	59.6	1:149
Dec. 15, 1939	38.8	0.9	60.3	1:67
Jan. 15, 1940	1.3	1.7	97.0	1:57
Jan. 15, 1940	1.1	1.7	97.2	1:57
Jan. 15, 1940	1.1	1.7	97.2	1:57
Feb. 12, 1940	1.3	1.0	97.7	1:98
Feb. 12, 1940	1.2	1.0	97.8	1:98
Feb. 12, 1940	1.1	1.0	97.9	1:98
Mar. 14, 1940	6.5	1.5*	92.0	1:61
Mar. 14, 1940	0.0	1.6*	98.4	1:61
Mar. 14, 1940	0.9	1.6*	97.5	1:61
Apr. 11, 1940	0.6	1.4*	98.0	1:70
Apr. 11, 1940	0.6	1.4*	98.0	1:70
Apr. 21, 1940	1.0	1.2*	97.8	1:81
Apr. 21, 1940	10.3	1.1*	88.6	1:81
May 10, 1940	0.3	1.2	98.5	1:82
May 10, 1940	0.6	1.2	98.2	1:82
June 18, 1940	16.8	0.45	82.7	1:185
June 18, 1940	0.7	0.54	98.8	1:185
June 18, 1940	3.2	0.53	96.3	1:185
July 17, 1940	1.0	3.0	96.0	1:32
July 17, 1940	10.5	2.7	86.8	1:32
Aug. 10, 1940	1.2	0.44	98.4	1:223
Aug. 10, 1940	0.0	0.45	99.5	1:221
Aug. 10, 1940	1.8	0.43	97.8	1:227

† Poor collection; not analyzed. * H_2S present also; H_2S calculated as SO_2.

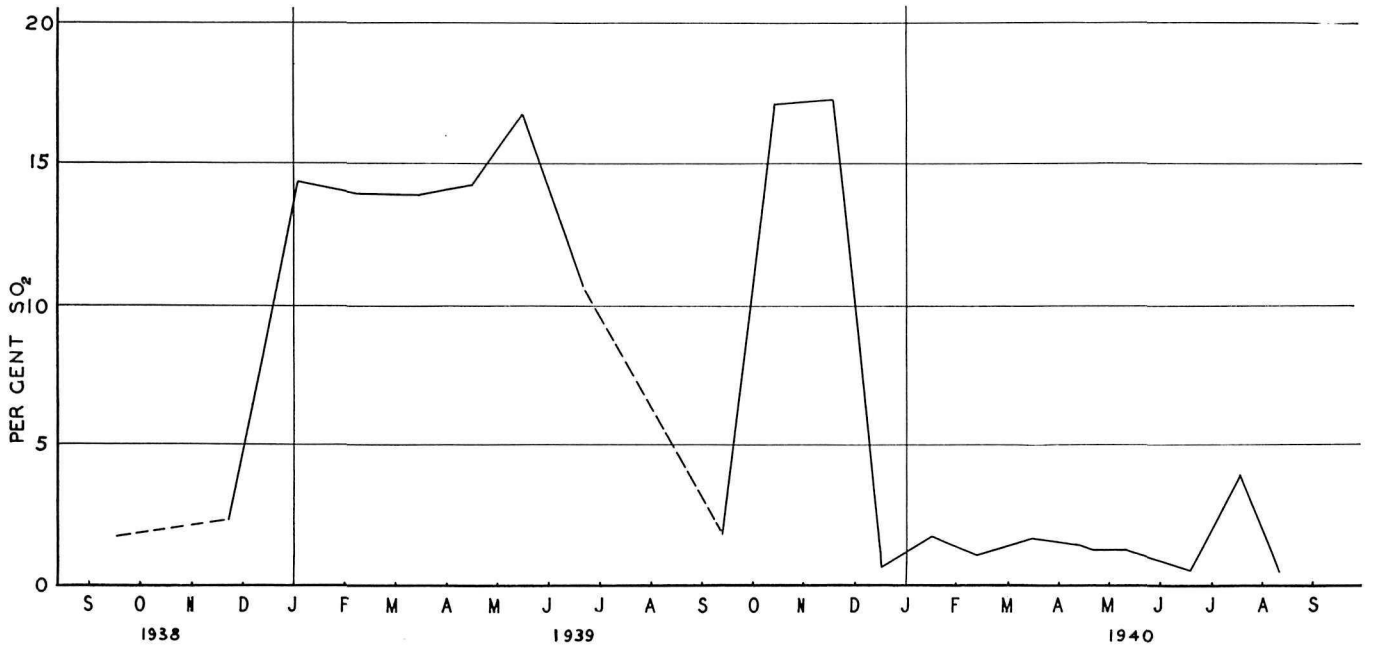


Fig. 3.—Variation of percentage of sulphur dioxide in Kilauea Sulphur Banks gases, September, 1938, to September, 1940.

Hawaiian Volcano Observatory Report for July-September 1940

VOLCANOLOGY

July 1940

The Mauna Loa eruption at the summit crater waned to a seeming standstill with decreasing intervals and decreasing activities. Observation of it by Park employees continued, and nothing new happened at Kilauea.

The alternations between activity and quiet in Mokuaweoweo, the summit crater of Mauna Loa, to which the outflow of lava was confined, were as follows:

Quiet	00 a.m.	July 1	to	8:30 a.m.	July 4
Active	8:30 a.m.	July 4	to	8:00 a.m.	July 10
Quiet	8:00 a.m.	July 10	to	6:00 p.m.	July 18
Active	6:00 p.m.	July 18	to	9:30 a.m.	July 21
Quiet	9:30 a.m.	July 21	to	9:15 a.m.	July 23
Active	9:15 a.m.	July 23	to	8:00 a.m.	July 24
Quiet	8:00 a.m.	July 24	to	4:15 p.m.	July 26
Active	4:15 p.m.	July 26	to	6:00 p.m.	July 26
Quiet	6:00 p.m.	July 26	to	12:00 noon	July 27

Only activity after 12:00 noon July 27 was feeble glow the nights of July 27 and July 28 followed by quiet thereafter.

The duration of active spells in sequence according to this table appears to be 24, 64, 23, 2, 36 hours.

The duration of quiet spells appears to be 202, 48, 56, 18, 36-plus hours.

The activity was from the vent in the top of the new inner summit lava cone of Mokuaweoweo southwest of the center of the crater, with fume from internal fountains rising from that vent all the time, and outflows from the cone as indicated. After July 4, flows within Mokuaweoweo streamed to the north, east, west and south from fountains 50 to 75 feet high. On July 8, there was one fountain at the cone center, two in a lake northwest of the cone. On July 18, a fountain in the cone vent shot up 150 feet, and made a strong roar at midnight July 18-19. The fountain was again 150 feet high July 23 at 12:55 p.m., and a strong flow poured into the lake north of the cone in Mokuaweoweo. On July 26, at 5:00 p.m., flowing lava was seen in a crack at the northeast base of the inner Mokuaweoweo cone.

The only slide at Halemaumau reported for July was at 6:34 p.m., July 3, when thin dust rose above the northern half of the pit. There was unusual closing of rim cracks around Halemaumau in the first and last weeks of the month. An important near shock felt from Honolulu to Hawaii at 4:48 p.m., July 15, was located under the sea floor 90 miles east of Maui like the one a month before; there were four other shocks located in this vicinity during the quarter-year.

The following are the local data for July, counting tremor spasms as seismic disturbance for each minute of duration:

Week Ending	Halemaumau Slides	Halemaumau Crack Openings	Seismic Disturbances
July 7	1	2.5 mm. closed	28
" 14	0	2.5 mm. opened	26
" 21	0	3.5 mm. opened	57
" 28	0	6.5 mm. closed	50

August 1940

After 18 days of seeming quiet, Mauna Loa resumed gushing of lava through the summit inner cone of Mokuaweoweo crater during the afternoon of August 15 about 5:00-6:00 p.m. At 9:30 p.m. the same date, a strong fume column, colored bright red with reflected light of the fountain, rose several thousand feet above the Mauna Loa summit. On August 16, a fume column hung over Mauna Loa throughout the day and red glow was faintly visible through clouds in the evening. This kind of activity continued, but declined August 17-18, and observers at the summit rest camp reported one large fountain in the inner cone and a north flow during the evening on the Mokuaweoweo floor. The fume column was less dense August 18 and a pulsating glow was visible over Mauna Loa as seen from Kilauea. This period of activity came to an end during the night August 18-19, some fume was seen at 7:00 a.m., August 21, and no further lava activity was observed.

Rocks were heard falling from the northeast, east and southeast walls of Halemaumau 10:00 to 11:00 a.m., August 25 and a period of continuous tremor lasted five minutes after 6:19 p.m., August 21. During the last week of the month rocks fell at Halemaumau frequently, and a larger slide at the northeast wall occurred at 3:35 p.m., August 31.

A sharp increase in local seismic activity followed the cessation of lava gushing at Mokuaweoweo. Another moderate earthquake was felt slightly in Hawaii National Park at 10:15 p.m., September 1, originating 117 miles from the Observatory with center probably at the sea-floor east of Maui like the felt, stronger shocks of June 16 and July 15. A very feeble shock from a similar distance occurred August 27.

The following are the local data for August:

Week Ending	Halemaumau Slides	Halemaumau Crack Openings	Seismic Disturbances
Aug. 4	0	2.5 mm. opened	33
" 11	0	2.5 mm. opened	25
" 18	0	3.0 mm. opened	28
" 25	3	1.0 mm. opened	19
Sept. 1	6	0.5 mm. opened	45

September 1940

During the first week of the month Mauna Loa and Kilauea were quiet, two earthquake shocks were felt and all but one of the feeble shocks were under Kilauea. Tilting of the ground away from the crater became pronounced at the Kilauea Observatory in August and September.

The second week indicated concentrations of seismic activity in the Chain-of-Craters where the highway has shown some increased movement. The third week produced earthquake shock from various distances, and the same may be said of the fourth week, with no notable changes at the crater of Kilauea.

The following are the local data for September:

Week Ending	Halemaumau Slides	Halemaumau Crack Openings	Seismic Disturbances
Sept. 8	0	0.0 mm.	45
" 15	0	5.0 mm. opened	21
" 22	0	0.5 mm. opened	19
" 29	0	0.5 mm. opened	21

T. A. J.

SEISMOLOGICAL DATA

Earthquakes

Week Ending	Minutes of Tremor	Very Feeble	Feeble	Slight	Moderate	Distant*	Weekly Seismicity†
July 7	25	1	2	0	0	1	8.75
" 14	21	5	0	0	0	1	7.75
" 21	52	4	0	0	1	0	18.75
" 28	42	6	2	0	0	1	15.25
Aug. 4	32	1	0	0	0	1	8.50
" 11	20	3	1	1	0	0	10.50
" 18	24	4	0	0	0	0	8.00
" 25	19	0	0	0	0	2	4.75
Sept. 1	35	9	0	0	1	0	17.25
" 8	32	10	3	0	0	0	16.00
" 15	14	5	2	0	0	1	8.00
" 22	11	7	1	0	0	2	7.25
" 29	16	4	0	1	0	0	8.00

* Including teleseisms or earthquakes over 5,000 km from Kilauea.
† For local seismicity definition see Volcano Letter 371.

Epicenters of the following local disturbances were determined by means of seismograms from the stations operated by the Hawaiian Volcano Observatory on the island of Hawaii. Kilauea earthquakes were located by means of the main seismograph station at the observatory and the two subsidiary stations at Uwekahuna and the SE rim of Halemaumau respectively. The more distant shocks were located with the aid of seismograms from Hilo and Kealakekua. The disturbances began at the time indicated and, whenever possible, a determination of depth of focus has been made.

July 1, 4:23 pm, very feeble, probably originated in E central portion of Kilauea Crater.

July 4, 3:55 pm, feeble, probably originated 40.0 miles NE of Hilo.

July 6, 2:54 am, feeble, 1.8 miles deep in area between Devil's Throat and Puu Ohale. 19° 22.0′ N; 155° 15.4′ W.

July 9, 7:30 pm, very feeble, probably originated off NE coast of Hawaii about 12 miles E of Ookala.

July 12, 10:14 am, very feeble, Mauna Loa NE rift near Puu Kulua.

July 14, 12:39 am, very feeble, associated with earthquake of 4:48 pm, July 15, and others listed as follows:

July 14, 10:40 pm, very feeble.

July 15, 9:13 pm, very feeble (reported felt in Hamakua at Paauhau and on Maui at Ulupalakua).

July 16, 3:48 pm, very feeble.

August 16, 11:27 pm, very feeble.

August 27, 2:35 pm, very feeble.

September 20, 10:29 am, very feeble.

All of these originated in area under the sea floor about 80 miles N of Hilo bounded as follows: 20° 45′ to 21° .00′ N and 155° to 155° 15′ E.

July 15, 4:48 pm, moderate, probably of normal depth located 65.0 miles N of Laupahoehoe and about 90 miles E of Kahului, Maui. 20° 54′ N; 155° 08.0′ N. Felt generally over all the Islands with the exception of Kauai.

July 19, 7:42 am, very feeble, off sea coast in vicinity of Kawaihae Bay. Reported felt in Kohala.

July 24, 10:50 am, very feeble, of shallow origin, NW rim area of Kilauea Crater 0.6 mile NE of Uwekahuna. 19° 25.6′ N; 155° 17.0′ W.

July 26, 3:49 am, very feeble, Hilina Fault zone S of Puaialua.

July 26, 4:24 am, feeble, 8.0 miles deep, Hilina Fault system, 4.0 miles SSE of Puu Ohale. 19° 18.5′ N; 155° 14.6′ W.

July 26, 4:26 am, very feeble, Hilina Fault, same general locality as preceding.

July 26, 5:34 am, very feeble, Hilina Fault, 3.0 miles NW of Apua point. 19° 17.0′ N; 155° 15.0′ W.

July 26, 11:52 am, feeble, located 11.0 miles deep off sea coast S of Hilina Fault near Apua Point. 19° 16.3′ N; 155° 09.0′ W.

August 1, 1:49 pm, very feeble, 6.0 miles deep on E slope of Mauna Loa, 5.0 miles E of the Pit Crater, Lua Hohonu. 19° 27.0′ N; 155° 31.6′ W.

August 5, 3:27 am, slight, 0.4 mile deep, NE rim of Kilauea Crater near the National Park Headquarters. 19° 25.7′ N; 155° 15.5′ W. Most persons in immediate vicinity of epicenter were awakened by this earthquake.

August 5, 7:31 am, feeble, of shallow origin near junction of Byron and Waldron Ledges, NE rim of Kilauea Crater. 19° 25.5′ N; 155° 15.5′ W. Reported felt in Hawaii National Park.

August 7, 5:51 am, very feeble, Mauna Loa summit crater.

August 10, 1:44 pm, very feeble, 3.0 miles deep near center of Kilauea Crater. 19° 25.2′ N; 155° 16.5′ W.

August 10, 5:34 pm, very feeble, 12.0 miles deep under S coast of Hawaii 9.0 miles E of Pahala. 19° 12.0′ N; 155° 20.6′ W.

August 12, 10:04 pm, very feeble, probably originated in vicinity of Pahala or adjoining sea coast area.

August 14, 2:32 pm, very feeble, 25.0 miles deep, Hualalai, 8.0 miles E of summit. 19° 40.0′ N; 155° 45.0′ W.

August 30, 5:02 am, very feeble, NE portion of Kilauea Crater.

August 30, 1:09 pm, very feeble, 2.4 miles deep under SW rim of Kilauea Crater 0.6 mile W of center of Halemaumau. 19° 24.6′ N; 155° 17.8′ W.

August 30, 5:33 pm, very feeble, of shallow origin, Byron Ledge. 19° 24.6′ N; 155° 15.7′ W.

August 30, 6:35 pm, very feeble, 0.4 mile deep, E portion of Kilauea Crater near Kilauea Iki gap. 19° 24.8′ N; 155° 15.8′ W.

August 31, 6:18 pm, very feeble, of shallow origin, area near junction of Hilina Fault and SW rift (Kilauea). 19° 17.5′ N; 155° 21.0′ W.

September 1, 4:53 am, very feeble, probably originated SE rim area of Kilauea Crater.

September 1, 3:02 pm, very feeble, located 0.5 mile deep under E rim of Halemaumau. 19° 24.5′ N; 155° 16.7′ W.

September 1, 10:15 pm, moderate, 90.0 miles NNW of Hilo. 21° 00.0′ N; 155° 16.0′ W. Reported felt generally on Island of Hawaii.

September 2, 1:43 am, very feeble, of shallow origin near center of Kilauea Crater. 19° 24.7′ N; 155° 16.6′ W.

September 2, 5:12 pm, feeble, 13.0 miles deep, Hilina Fault, 3.0 miles N by E of Keahou Point. 19° 18.5′ N; 155° 13.3′ W.

September 4, 4:02 am, very feeble, originated in rift zone about 1.5 mile W of Devil's Throat.

September 4, 11:48 am, very feeble, Hilina Fault, 4.0 miles SE of Kamakaia Hills.

September 4, 10:44 pm, very feeble, 1.3 miles NE of Puu Ohale.

September 5, 1:07 am, very feeble, Chain-of-Craters near Pauahi.

September 5, 3:11 am, very feeble, Mauna Loa NE rift between Pukauahi Crater and Puu Ulaula.

September 5, 10:09 am, feeble, 0.8 mile deep, 0.4 mile N of Puhimau Crater (Chain-of-Craters). 19° 24.1′ N; 155° 15.1′ W.

September 6, 9:09 am, very feeble, Kilauea NE crater rim.

September 6, 2:01 pm, very feeble, 3.5 miles NW of Hawaiian Volcano Observatory.

September 6, 10:24 pm, feeble, SE rim of Kilauea Crater, of shallow origin, 0.6 mile SE of Pit seismograph. 19° 24.0′ N; 155° 16.5′ W.

September 9, 10:09 am, very feeble, S rim area of Kilauea Crater about 0.7 mile S of Pit seismograph.

September 10, 3:03 pm, very feeble, 1.7 miles deep, 1.4 miles NE of Puu Ohale. 19° 21.6′ N; 155° 16.0′ W.

September 12, 9:59 am, very feeble, 1.3 miles deep, Kilauea SE crater rim near Keanakakoi. 19° 24.3′ N; 155° 15.8′ W.

September 12, 10:07 am, very feeble, of shallow origin, Kilauea E crater rim (Byron Ledge). 19° 24.9′ N; 155° 15.9′ W.

September 12, 4:31 pm, feeble, 1.5 miles deep, 3.5 miles NW of Volcano Observatory. 19° 28.4′ N; 155° 17.6′ W. Reported felt in Hawaii National Park.

September 14, 5:25 pm, feeble, 5.0 miles deep, SW rim of Kilauea Crater at junction with SW rift. 19° 24.0′ N; 155° 17.8′ W.

September 16, 6:06 am, very feeble, of Halemaumau origin.

September 17, 9:35 pm, very feeble, of Halemaumau origin.

September 18, 3:24 am, very feeble, S portion of Kilauea Crater.

September 21, 5:18 pm, feeble, 12.0 miles deep, Hilina Fault, 4.0 miles SE of Kamakaia Hills. 19° 17.7′ N; 155° 18.5′ W.

September 24, 12:56 pm, very feeble, 5.0 miles deep, E slope of Mauna Loa, 7.0 miles SE by S of Mokuaweoweo. 19° 23.0′ N; 155° 32.0′ W.

September 26, 6:14 pm, very feeble, probably same general location as preceding.

September 26, 6:47 pm, slight, of Kilauea origin.

September 27, 12:21 am, very feeble, 3.0 miles deep near center of Kilauea Crater. 19° 25.1′ N; 155° 16.4′ W.

September 27, 11:14 am, very feeble, of shallow origin, Halemaumau. 19° 24.5′ N; 155° 17.2′ W.

Continuous Tremor:

July 17, 9:28 to 9:50 pm, 22 minutes.

August 21, 6:20 to 6:25 pm, 5 minutes.

August 26, 9:34 to 9:52 am, 18 minutes.

Teleseisms

July 2, 8h 56m am, unidentified portion.

July 13, 7h 30m 16s pm, "P" waves, distance 2,620 miles. Located in Aleutian Island region, 52.7° N; 177.6° W. Reported by Jesuit Seismological Association.

July 27, 3h 12m 40s am, "P" waves. 13.7° N; 91.3° W. Honduras.

August 1, 4h 48m 32s am, "P" waves, distance 4,165 miles; Island of Hokkaido, northernmost of Japan group, 44.0° N; 139.6° E.

August 20, 8h 54m 30s am, unidentified portion.

August 21, 5h 04m 04s pm, "P" waves, distance 2,285 miles.

September 12, 2h 56m 51s am, "P" waves, distance 4,060 miles.

September 19, 8h 14m 05s am, "P" waves, distance 3,525 miles.

September 22, 12h 33m 00s am, "P" waves, distance 4,700 miles.

All time H.S.T. (10h 30m slower than Greenwich).

Microseismic Motion

July:

Light: 2, 3, 24, 26, 27, 29.

Moderate: 1, 5, 6, 8, 10 to 14, 16 to 18, 22, 23, 25, 28, 30, 31.

Strong: 4, 7, 9, 15, 19 to 21.

August:

Light: 2 to 5, 12 to 14, 18, 19, 23, 25 to 27.

Moderate: 1, 8, 10, 11, 15 to 17, 20 to 22, 24, 28 to 31.

Strong: 6, 7, 9.

September:

Light: 17 to 20.

Moderate: 2 to 5, 11 to 16, 21, 22, 28, 29.

Strong: 1, 6 to 10, 23 to 27, 30.

All dates inclusive.

Tilting of the Ground

The following tables show tilt by weeks as recorded by the Observatory seismograph and at Halemaumau, the algebraic sum toward or away from the Pit.

At the Observatory the total accumulated tilt for the year ending July 28, 1940, was 5.50" N and 1.21" W.

For the year ending September 1, it was 7.22" N. and 1.1" E.

For the year ending September 29, it was 7.05" N and 2.18" E.

Table of Tilt

Week ending	Observatory	Halemaumau West Station
July 7	1.08" N 8° W	0.00
" 14	1.55" N 13° W	0.54" N 75° E
" 21	0.63" N 8° W	0.45" S 70° E
" 28	0.33" N 47° W	0.00
Aug. 4	1.67" N 57° E	1.79" N 42° E
" 11	1.21" N 56° E	Aug. 5 to 15 repairs made to cellar
" 18	1.23" N 26° E	0.00
" 25	1.23" N 3° E	2.98" N
Sept. 1	0.94" N 54° E	1.31" S 87° E
" 8	0.48" N 86° E	0.00
" 15	0.22" N	1.43" N 9° E
" 22	0.61" S 71° E	0.00
" 29	1.60" N 60° E	7.21" N 58° W

Week ending	Halemaumau Southeast Station	Halemaumau Resultant
July 7	0.00	0.00
" 14	3.98" N 71° W	3.69" toward
" 21	4.92" S 49° E	4.40" from
" 28	3.34" W	1.46" toward
Aug. 4	1.45" N 60 ° E	0.91" toward
" 11	3.24" S 31° E	3.24" from
" 18	3.82" S 40° W	0.81" from
" 25	6.48" S 20° E	6.01" from
Sept. 1	4.86" N 20° W	4.69" toward
" 8	3.24" N 20° W	4.72" toward
" 15	3.63" N 38° E	1.11" toward
" 22	5.99" S 11° W	4.05" from
" 29	0.00	5.81" from

Crater Angles

Measurement of horizontal angles across Kilauea Crater from the Observatory June 20 indicated closing of the Halemaumau value and opening of the Crater value compared with similar measurements May 29. The Halemaumau angle between the Pit seismograph station and the NW Pit BM decreased 2.50" and the crater angle between the SE rim station and Uwekahuna increased 1.75".

Angle determinations August 7, showed that the Halemaumau value decreased 1.65" and the Crater value increased 0.85" between that date and June 20.

On September 4, the Halemaumau angle had increased 1.81" and the Crater angle had increased 0.23".

Total Halemaumau change, June 20 to September 4: 0.16" increase; Crater: 1.0" increase.

Levelling at Kilauea

The level circuit on Kilauea Crater floor from the Spit BM on the S Crater rim to the NW Halemaumau rim BM was run September 18, 1940. Compared with determinations of April 18, there was only 5.0 millimeters lowering of the NW Pit BM relative to the Spit BM.

The Crater floor has been apparently settling since the 1934 Kilauea eruption and with the exception of a short period during the 1935 Mauna Loa eruption this is the first run in the last 5 years that such a slight change has occurred. It would seem that Kilauea Crater floor had reached a more stable condition or that lava pressure has increased under Kilauea since April 18.

Chain-of-Craters Crack Measurements

June 28 to October 4: 101—increased 2.0 millimeters; there were no changes in the others during this period.

At Devil's Throat, one crack on the SE rim increased 4.0 millimeters.

It appears that the only measurable movement in the Chain-of-Craters region is taking place in the vicinity of Devil's Throat (No. 101 is about one-quarter of a mile to the NW).

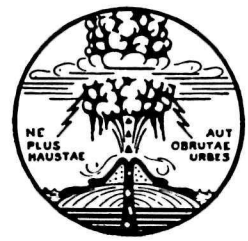
H. H. W.

HAWAIIAN VOLCANO RESEARCH ASSOCIATION
in cooperation with
UNIVERSITY OF HAWAII

The **Hawaiian Volcano Research Association** was founded in 1911 for record of volcanoes in the Hawaiian Islands and around the Pacific Ocean. Its equipment at Kilauea Volcano, Hawaii Island, has been transferred to the United States Government, Department of the Interior, National Park Service.

The **University of Hawaii** cooperates in maintaining a research laboratory at Hawaii National Park. The **Association** and the **University** maintain outside seismograph stations and supplement the work of the government with research associates, instrumental plants and special investigations. Dr. T. A. Jaggar is their geophysicist resident in the National Park.

The **Volcano Letter,** a quarterly record of the Hawaiian volcano laboratories and published by the University of Hawaii, is issued by authority of the Department of the Interior and supplied to a restricted membership and exchange list of the above establishments.



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ENGULFMENT AT KILAUEA VOLCANO

By R. H. FINCH

The amount of engulfment at the time of the explosive eruption at Kilauea in 1924 was computed by T. A. Jaggar[1] and the writer. T. A. Jaggar in the same bulletin (p. 119), discussed the volume of Kilauea Crater fill for the first century of its recorded history.

In this paper the computations have been extended to include the volume of engulfment at the time of each major collapse, as in 1823, 1832, 1840, 1868, 1886, 1891, 1894, 1916, 1919, and 1922. In most cases the collapse occurred at the time of a Kilauea lava flow at a lower elevation, or immediately followed the cessation of a Mauna Loa outbreak. It is suspected that if we had more complete data on subterranean and submarine lava flows, the correlation between flow and collapse would be nearly one hundred per cent. There were other years with rapid drop in the lava column, notably in 1849, 1855, 1871, 1879, and 1913, but the volumes involved for the most part were not large.

In attempting to compute the volume relations for 1823, the first recorded collapse at Kilauea, we quickly found that the accounts as given by Ellis,[2] Brigham,[3] Dana,[4] and Hitchcock[5] gave widely varying values for the depth of the crater.

Ellis, the first to give a written account of Kilauea, in August, 1823, observed a black ledge about 400 feet below the crater rim and 300-400 feet above the main floor. He wrote, "It was evident that the large crater had been recently filled with liquid lava up to the black ledge, and had, by some subterranean canal, emptied itself into the sea or upon the lower land on the shore." There had been a lava flow from the southwest rift of Kilauea near sea level shortly prior to his visit.

Edward Loomis, in a letter published by Brigham (p. 42), indicates there were several small pits in 1824 with a depth of 200-300 feet which probably had been full of molten lava in 1823. The total depth of Kilauea, referred to Uwekahuna, in 1824 must have been about 1,315 feet. If the computations for volume of engulfment were made for 1824 instead of 1823, the value would be changed by only a small percentage. Loomis made the depth of the main floor 600 feet below the rim where he descended. Malden's depth figures, as given by Dana, are 1,300 feet (p. 51) and 1,700 feet (p. 127). Let us set the various estimates and measurements in tabular form, in order to arrive at a probable figure for the depth of the crater.

Authority	Elevation of rim at place of estimate	Elevation of crater floor	Elevation of black ledge
Ellis, 1823.....	3800 feet	3000 feet	3400 feet
Loomis, 1824	3625 "	3025 "	3325 "
Chamberlin, 1824		3000 "	.....
Malden, 1825	4090? "	2790 "	3190 "
Bingham, 1830 ..	4000? "	3000 "	3400 "
Alexander, 1833..	4000? "	2000 "	Not mentioned
Douglas, 1834	4090 "	2975 "	3375 "
Wilkes, 1840	4000? "	3010 "	3350 "

Ellis made an attempt to check his estimate, first with a string 100 feet long and then with one 230 feet in length. He commented that the string of 100-feet "did not appear to reach near half way to the black ledge of lava." Loomis made his estimate at the lowest point on the rim where the dimensions were small, and, knowing that he measured the width of the black ledge, one can assume that his estimate is not seriously in error. Dana found serious errors in Malden's computation and it may well be that there was an error in his base line. Subsequent careful measurements are in close agreement with the Loomis estimate.

Goodrich estimated that by 1832 the black ledge had been covered with 50 feet of new lava. Subtracting this 50 feet from the Douglas elevation of the black ledge in 1834 gives 3,325 feet, the same as the Loomis estimate. It should be noted that this value differs from the Ellis estimate by only 75 feet. It should not be assumed that the black ledge was an exact level surface around the pit, though judging from the sketches and from the type of activity in 1832 and probably in 1823, the ledge had quite uniform height. By 1840 there was a conical mound around Halemaumau 100 feet above the general floor. The total depth of the crater as given by Malden may be

[1] T. A. Jaggar, "Volume Relations of the Explosive Eruption 1924," *Bulletin of Hawaiian Volcano Observatory*, December 1924, p. 117.
[2] William Ellis, *Journal* (Reprinted Honolulu, 1917), pp. 177-189.
[3] William T. Brigham, "The Volcanoes Kilauea and Mauna Loa," *Memoirs Bernice P. Bishop Museum*, Honolulu, 1909.
[4] J. D. Dana, *Characteristics of Volcanoes*, New York, 1891.
[5] C. H. Hitchcock, *Hawaii and Its Volcanoes*, Honolulu, 1911.

10% should be added to these figs. — See U.S.L. 471.

brought into closer agreement with most of the others if we assume that his figures are for one of the several pits in the crater floor at that time.

An interesting item gleaned from the Ellis account is the report of a chasm across the black ledge apparently where the Puna rift cuts the crater wall.

The average drop of the crater floor in 1823 must have been close to 400 feet. As a convenience in computing the area involved, it was divided into two parts: the northern and wider portion with an area of 40,750,000 sq. ft., and the narrow southern portion with an area of 2,550,000 sq. ft., or a total of 43,300,000 sq. ft. With a drop of 400 ft. the volume engulfed would be 17,320,000,000 cu. ft.

The estimates of the depth of the crater in 1832 vary from 2,000 feet (unsupported) to 1100 feet. The area affected by this collapse was but little less than in 1832, or 41,430,000 sq. ft. With a drop of 450 feet, that means an engulfment of 18,640,000,000 cu. ft.

An observation by Goodrich (Dana, p. 55) indicates that the collapse of 1832 may well have occurred in the latter part of July. This would make it coincide with the cessation of the 1832 outbreak of Mauna Loa.

The collapse of 1840 left an inner pit much smaller than that of 1823 or 1832. The estimate of average depth involved for this year is rendered somewhat uncertain by the considerable relief of the crater floor. The total area of collapse was about 22,120,000 sq. ft. With an average drop of 350 feet, the amount engulfed would be 7,752,000,000 cu. ft.

After the drop of 1868, there was considerable difference in level of the crater floor with the most profound sinking at Halemaumau. This was to be expected because, since 1840, the principal seat of activity was at Halemaumau. The great pit had the outline of an inverted frustum of a cone, with an upper diameter of 2,000 feet, and a lower one of 1,500 feet. It was 500 feet deep. This gives the collapse at Halemaumau of 650,000,000 cu. ft. The sunken portion of the crater, less Halemaumau, had an area of 30,000,000 sq. ft. An average drop over this area of 200 feet would mean a volume of 6,000,000,000 cu. ft. The total engulfed in 1868 then was 6,650,000,000 cu. ft.

The collapse in 1886 left a triangular area with sides about 3,350 feet long. There was a sink near the center of the depression 590 feet deep, but it was only 600 feet across and affected the total volume but slightly. The average drop of about 250 feet over an area of 5,600,000 sq. ft. represents a volume of 1,400,000,000 cu. ft. In addition to the above, there may have been some down-warping as indicated by a pronounced crack that opened near the northern end of the crater.

Since 1868 the source of volcanic activity has become quite centralized in the southern end of the crater at Halemaumau, or its immediate vicinity. In 1891 the collapse was confined to Halemaumau. The estimates of the depth of Halemaumau after the collapse of 1891 vary from 500 to 700 feet. The diameter of the pit was 2,500 feet. The average of the computed values of the volume evacuated was 1,200,000,000 cu. ft.

In 1894 the volume represented in the formation of two benches on the rim of the collapsed pit was about 30,000,000 cu. ft. The pit itself had a diameter in one direction of 900 feet and 1,000 feet in the other. After the initial drop in 1894, there was considerable movement at the bottom with some slight infilling. The estimates of depth clustered around 500 feet. The average based on different estimates and measurements and various methods of calculating makes the 1894 engulfment 300,000,000 cu. ft.

The collapse of 1916 left a void that may be thought of as a frustum of a cone with diameters of 1,100 and 375 feet. The drop in level was 400 feet. These figures give the volume displacement in 1916 as 260,000,000 cu. ft.

The 1919 collapse left a void 1,200 feet in diameter at the top and about 200 feet at the bottom, 591 feet below. At a depth of 275 feet, the diameter was 1,060 feet. The void created by a shelf at the north rim was 600,000 cu. ft. The volume of the main pit, computed as upper and lower frusta of cones, was 353,500,000 cu. ft. This gives for 1919 a total of 354,100,000 cu. ft.

Early in May, 1922, the lava was within about 50 feet of the rim of Halemaumau, while crags stood nearly 50 feet above the rim. By the last of the month there was a void 861 feet deep with a width at the rim of 2,000 feet in a NE-SW direction, and 1,485 feet in a NW-SE direction. This void comprised 750,000,000 cu. ft.

A summation of the computations is shown in the following table:

Volume Engulfed by Principal Collapses in Kilauea

Year	Volume in Cu. Ft.
1823	17,320,000,000
1832	18,640,000,000
1840	7,752,000,000
1868	6,650,000,000
1886	1,400,000,000
1891	1,200,000,000
1894	300,000,000
1916	260,000,000
1919	354,100,000
1922	750,000,000
1924	7,120,000,000
Total	61,746,100,000

After each collapse the crater floor was raised by inflows and in some periods, at least, by marked tumescence. During the period under discussion the total filling exceeded the total engulfment.

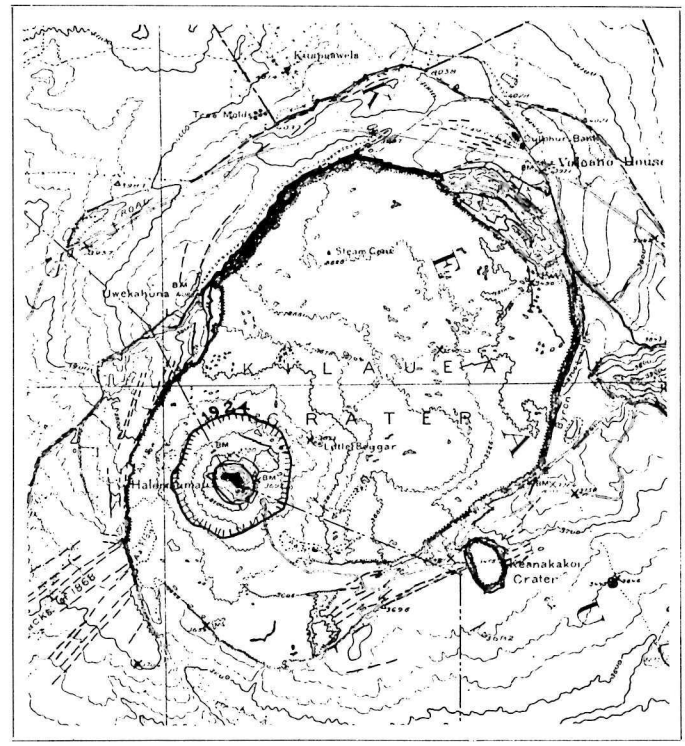

Fig. 1.—Map of Kilauea Crater, 1912 to 1924; enlargement of Halemaumau by engulfment.

Hawaiian Volcano Observatory Report for October-December, 1940

VOLCANOLOGY

October 1940

No glow was visible in the summit crater of Mauna Loa when it was visited on October 14-16, though there was heavy fuming at the 1940 source cone. A portion of the summit of this cone had collapsed.

Kilauea was quiet throughout the month though rock slides were observed on October 18, 29, and 30.

Tilting to the northeast accumulated more than the seasonal normal.

Exceptionally strong microseisms were recorded on October 18 at a time of unusually high waves on Hawaiian shores.

November 1940

There was increase of rock slides from Halemaumau, particularly from the western wall, otherwise Kilauea was quiet in November. Faint bluish fume was noticed over Halemaumau on November 8 and 29.

No activity was observed on Mauna Loa.

December 1940

During the second week of December there was increase in seismicity. The majority of the shakes originated near Kilauea. Rock slides were frequent during the month. A slide at noon December 4 made a large dust cloud.

Tilt for December was to the east. For the year ended December 31, 1940, there was an accumulation of ENE tilt. This tilt indicates that a volcanic low may have been reached in 1939.

The following are the local data for October, November, and December.

Week Ending	Halemaumau Slides	Halemaumau Crack Openings (Millimeters)	Seismic Disturbances
Oct. 6	0	1.0 opened	15
" 13	0	1.0 "	7
" 20	0	2.5 closed	14
" 27	1	5.5 opened	37
Nov. 3	4	4.0 "	13
" 10	2	3.0 "	8
" 17	2	0.5 closed	0
" 24	1	0.5 "	14
Dec. 1	10	6.0 opened	21
" 8	4	3.0 "	32
" 15	1	2.5 "	25
" 22	3	0.5 "	12
" 29	1	3.5 "	10

R. H. F.

Errata

Volcano Letter No. 467, January-March 1940, "Tilt Changes at Kilauea," p. 2, second paragraph, ninth line, should read: During the 27 years of measurement, it has been found that the tilt on the NE rim of Kilauea Crater, considered as the path of the top of a vertical rod, describes an annual clockwise loop of from 5 to 10 seconds of rotational arc with the loop elongated in a NNE-SSW direction, the greater axis being about twice the length of the shorter one. In the course of producing the major loop many minor ones occur and the latter almost without exception progress in a counter-clockwise direction. In general tilt is **northeasterly** during the warmer summer and fall months and **southwesterly** during the cooler late winter and spring months.

Volcano Letter No. 469, July-September 1940, p. 7, Table of Tilt, Halemaumau resultant Sept. 29: change "5.81" from" to "2.48" from." H.H.W.

SEISMOLOGICAL DATA

Earthquakes

Week Ending	Minutes of Tremor	Very Feeble	Feeble	Slight	Moderate	Distant*	Weekly Seismicity†
Oct. 6	14	1	0	0	0	1	4.00
" 13	5	1	1	0	0	0	2.75
" 20	13	1	0	0	0	0	3.75
" 27	34	1	1	1	0	1	12.00
Nov. 3	10	2	1	0	0	0	4.50
" 10	6	2	0	0	0	0	2.50
" 17	20	0	0	0	0	1	5.00
" 24	11	3	0	0	0	0	4.25
Dec. 1	19	2	0	0	0	0	5.75
" 8	30	2	0	0	0	0	8.50
" 15	16	8	1	0	0	0	9.00
" 22	7	5	0	0	0	1	4.25
" 29	8	2	0	0	0	1	3.00

* Including teleseisms or earthquakes over 5,000 km from Kilauea.
† For local seismicity definition see Volcano Letter 371.

Epicenters of the following local disturbances were determined by means of seismograms from the stations operated by the Hawaiian Volcano Observatory on the island of Hawaii. Kilauea earthquakes were located by means of the main seismograph station at the Observatory and the two subsidiary stations at Uwekahuna and the SE rim of Halemaumau respectively. The more distant shocks were located with the aid of seismograms from Hilo and Kealakekua. The disturbances began at the time indicated and, whenever possible, a determination of depth of focus has been made.

October 7, 5:19 am, feeble, of shallow origin, NE rim of Kilauea Crater not over 0.5 mile from the Observatory. 19° 25.6′ N; 155° 15.8′ W.

October 11, 11:34 am, very feeble, Mauna Loa NE rift near Pukauahi Crater.

October 16, 3:03 pm, very feeble, probably originated in Mauna Loa NE rift about 5 miles SW of Hilo.

October 22, 3:17 am, feeble, of Kilauea origin, Hilina Fault zone 3.5 miles SE of Kamakaia Hills.

October 26, 7:57 pm, slight, 5.0 miles deep, E slope of Mauna Loa, 7.5 miles E of Pohaka Hanalei. 19° 31.0′ N; 155° 26.5′ W. Reported felt in Hawaii National Park and sharply felt by many persons at Pahala.

October 28, 9:27 pm, feeble, 15.0 miles deep, in the vicinity of Hilina Fault about midway between Puu Ohale and Keahou Landing. 19° 20.0′ N; 155° 16.0′ W. Reported felt by a few persons in Hilo.

November 3, 4:36 am, very feeble, probably originated in Kilauea SW rift about 15 miles from the Observatory.

November 4, 11:03 am, very feeble, Hilina Fault, 3.5 miles SW of Kamakaia Hills.

November 6, 5:54 am, very feeble, Hilina Fault system, 5.0 miles deep, 7.0 miles SW of Makaopuhi. 19° 19.5′ N; 155° 05.0′ W.

November 18, 6:35 am, very feeble, of shallow origin, SE portion of Kilauea Crater, 0.7 mile SE of Pit seismograph. 19° 23.9′ N; 155° 16.4′ W.

November 22, 5:33 am, very feeble, Mauna Loa NE rift, about 5 miles NE of Mokuaweoweo.

November 24, 11:26 am, very feeble, Hilina Fault system, SE of Makaopuhi.

November 25, 7:34 am, very feeble, 2.0 miles deep, central portion of Kilauea Crater. 19° 25.0′ N; 155° 16.7′ W.

November 30, 9:52 am, very feeble, of shallow origin under Mauna Loa summit crater.

December 8, 5:48 am, very feeble, Kilauea Puna rift SE of Makaopuhi.

December 9, 1:21 am, very feeble, 1.3 miles deep S rim of Kilauea Crater. 19° 23.8′ N; 155° 17.1′ W.

December 9, 8:27 am, very feeble, 1.7 miles deep S rim of Kilauea Crater. 19° 24.1′ N; 155° 17.2′ W.

December 9, 1:24 pm, very feeble, 0.7 mile deep, Kilauea Crater near E rim of Halemaumau. 19° 24.5′ N; 155° 16.7′ W. Dismantled Pit seismograph.

December 9, 5:05 pm, S rim of Kilauea Crater near Halemaumau.

December 9, 7:35 pm, very feeble, Kilauea SW rift 1.0 mile SW of Halemaumau.

December 11, 9:02 am, feeble, 0.6 mile deep, Kilauea SW rift, 0.3 mile NE of Cone Peak. 19° 24.0′ N; 155° 18.4′ W.

December 12, 9:52 am, very feeble, 12.0 miles deep, 12 miles NE by N of the Observatory. 19° 30.0′ N; 155° 13.0′ W.

December 15, 3:26 pm, very feeble, 40 miles ± deep under Mauna Kea. 19° 49.0′ N; 155° 29.0′ W.

December 19, 1:00 pm, very feeble, of shallow origin, Mauna Loa NE rift near Mokuaweoweo. 19° 31.0′ N; 155° 32.0′ W.

December 20, 2:48 am, very feeble, 18.0 miles deep, Hilina Fault system, N of Apua Point. 19° 18.3′ N; 155° 11.5′ W.

December 20, 3:26 am, very feeble, 15.0 miles deep, 8.0 miles S of Kilauea Crater in Hilina Fault system. 19° 18.0′ N; 155° 16.5′ W.

A number of disturbances, which registered on the Observatory seismograph as tremors, reported elsewhere as follows:

November 8, 5:54 pm, very feeble on Mauna Loa seismograph.

November 12, 1:53 pm, very feeble on Mauna Loa seismograph.

November 16, 8:17 pm, very feeble on Mauna Loa seismograph.

November 25, 4:59 pm, feeble on Mauna Loa seismograph.

November 27, 10:12 pm, reported felt at Paauhau.

December 9, 6:51 am, reported felt at Hookena.

Teleseisms

October 3, 10:08 pm, unidentified portion. Originated in Chile. 19° S; 67° W.

October 26, 7h 37m 40s pm, surface waves. Originated in Central America region. 9.9° N; 84.4° W.

November 16, 5:42 pm, unidentified portion.

December 22, 2:20 am, unidentified portion.

December 28, "P" waves at 6h 17m 15s am. Originated 3,775 miles from Kilauea.

Microseismic Motion

October:

Light: .....
Moderate: 3 to 5, 7, 8, 15, 23, 24.
Strong: 1, 2, 6, 9 to 14, 16 to 22, 25 to 31.

November:

Light: .....
Moderate: 16, 17.
Strong: 1 to 15, 18 to 30.

December:

Light: .....
Moderate: 18, 27 to 31.
Strong: 1 to 17, 19 to 26.

Tilting of the Ground

The following tables show tilt by weeks as recorded by the Observatory seismograph and at Halemaumau, the algebraic sum toward or away from the Pit.

At the Observatory, the total accumulated tilt for the year ending on each of the following dates was:

October 27—8.23" N and 3.60" E.
December 1—5.60" N and 5.30" E.
December 29—7.83" N and 9.90" E.

Table of Tilt

Week ending	Observatory	Halemaumau West Station
Oct. 6	1.11" N 75° E	1.91" N 81° E
" 13	0.75" N 32° E	0.00 .....
" 20	1.17" N 49° E	1.40" S 11° E
" 27	2.44" N 43° E	2.26" N 42° E
Nov. 3	1.53" N 62° E	1.91" S 84° E
" 10	0.46" S 3° W	1.40" N 9° E
" 17	1.05" N 30° E	1.40" S 9° W
" 24	2.04" S 6° E	1.40" N 9° E
Dec. 1	1.27" N 39° E	2.18" N 79° W
" 8	1.70" N 86° E	0.00 .....
" 15	1.24" S 43° W	0.00 .....
" 22	1.76" N 4° E	0.00 .....
" 29	3.20" N 75° E	0.00 .....

Week ending	Halemaumau Southeast Station	Pit Resultant
Oct. 6	3.24" S 19° E	1.29" from
" 13	3.73" N 45° W	3.73" toward
" 20	1.62" N 76° E	0.50" from
" 27	1.56" S 17° E	0.18" toward
Nov. 3	3.30" N 20° W	6.48" toward
" 10	6.45" S 19° E	5.86" from
" 17	4.89" N 19° W	4.25" toward
" 24	9.98" S 7° E	8.30" from
Dec. 1	3.24" N 17° W	1.15" toward
" 8	7.35" N 10° E	5.19" toward
" 15	2.20" N 65° W	1.46" from
" 22	1.72" N 21° W	4.36" toward
" 29	6.38" N 23° E	2.75" from H. H. W.

Crater Angles

Measurement of horizontal angles across Kilauea Crater from the Observatory October 1, 1940, indicated closing of both the Halemaumau and the Crater values compared with similar measurements made September 4. The amount of closing of the Halemaumau angle, between the Pit seismograph station and the NW Pit BM, was 0.32" and the crater angle, between the SE rim station and Uwekahuna, was 2.16".

Between October 1 and October 24, the Halemaumau angle opened 0.49" and the crater angle closed 0.92".

October 24 to November 12: Halemaumau angle opened 0.52" and the crater angle opened 3.33".

November 12 to November 29: Halemaumau angle opened 0.08" and the crater angle closed 0.92".

November 29 to December 19: Halemaumau angle closed 0.66" and the crater angle opened 0.69".

Net Halemaumau change, October 1 to December 19: 0.33" open; crater change: 2.16" open. H. H. W.

Chain-of-Craters Crack Measurements

On the Chain-of-Craters Road there have been no appreciable changes in cracks except at No. 108, S rim of Aloi Crater. This crack has opened as follows:

October 4 ..... 97.30
October 25 ..... 97.35
November 29 ..... 97.40
December 27 ..... 97.75

Total opening ..... 4.5 millimeters

Crack No. 2, N rim of Devil's Throat opened a total of 2.0 millimeters in the same period. H. H. W.

Time used throughout this report is Hawaiian Standard time, 10h 30m slower than Greenwich.

THE VOLCANO LETTER

No. 471 Department of Interior National Park Service January-March 1941

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THE FILLING IN OF KILAUEA CRATER

By R. H. FINCH

The net result of the first century of the recorded history of Kilauea Volcano, despite numerous breakdowns, has been a gradual filling of the crater. To facilitate computations of the volume of the uneven filling from 1823 to the present, the areas between convenient contours on the 1922 edition of the Kilauea Crater advance sheet of the U.S. Geological Survey were determined by planimeter. The collapse of 1823 left a comparatively narrow, black ledge around the inner margin of Kilauea Crater. This ledge, 3,400 feet above sea level, was taken as a base. The volume computed from this base plus the amount of the collapse in 1823 would give the total fill since the first recorded visit to Kilauea (in 1823) to the present time. The planimeter measurements indicate that the volumes given in Volcano Letter No. 470 for the collapses in 1823 and 1832 should be increased by about 10 per cent.

The amount of filling can be computed for only a few of the many periods of inflow and tumescence because of lack of adequate data. The volume for the period between 1823 and 1832 would be, to a close approximation, the amount engulfed in 1823 plus a layer 50 feet deep over the entire crater. Just prior to the collapse of 1832, the lava stood 50 feet higher than the black ledge of 1823. The total fill for the period then was about 23,850,000,000 cu. ft. The filling must have taken place within eight years as the lava was at as low a level in 1824 as in 1823, or perhaps a little lower. This would make the average per year about 3,000,000,000 cu. ft. The maximum rate of filling is not readily determinable and was quite likely much higher than the average.

Between 1840 and 1846 a large percentage of the increase in elevation of the crater floor was due to tumescence. However the ratio of the volume due to tumescence to that of inflow cannot readily be determined. In some places a canal or moat that separated the interior platform from the black ledge was 200 feet deep. Because the inner crater was

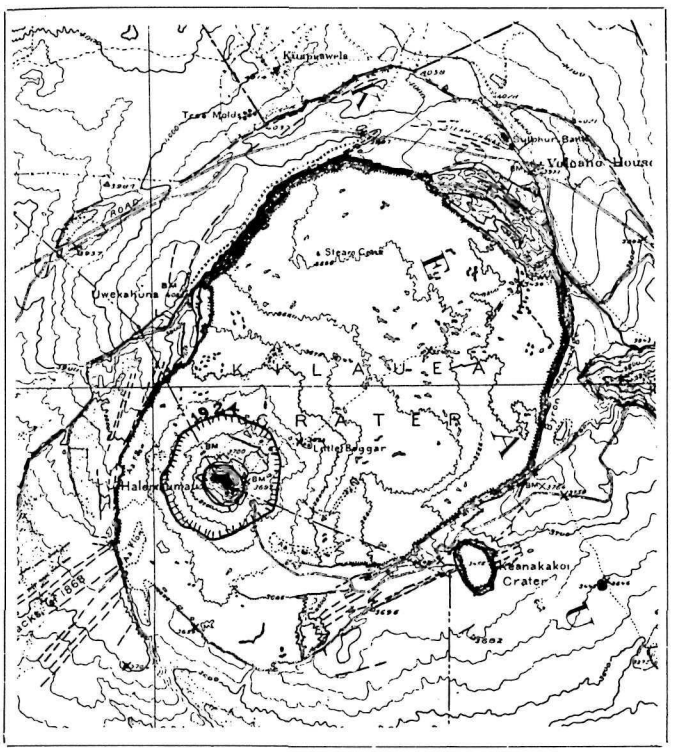
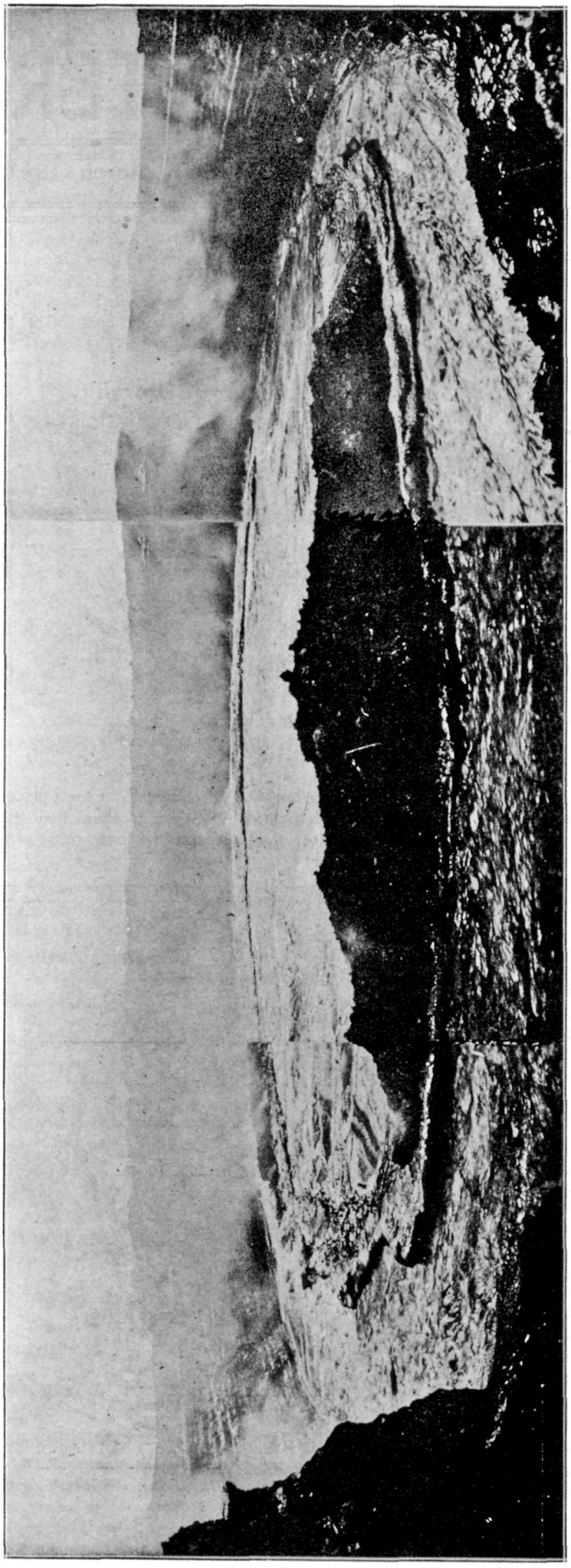


Fig. 1—Map of Kilauea, 1912 to 1924.



funnel-shaped, gaps were left between the resulting interior platform and the walls of the black ledge when the floor was bodily elevated. These gaps were the canals observed in 1844 and 1846 by Titus Coan and Prof. C. S. Lyman. The 200-foot depth of the canal does not necessarily mean that the platform was elevated uniformly through that range. The interior basin may have been elevated much less. Then too, the accumulation of talus blocks around the margin of the lower floor prior to the uplift would have been an important factor in making the margin the highest part of the elevated platform.

Brigham,[1] referring to Lyman's explanation of the canals of 1846, states, "The rise of a cylinder of lava a mile in diameter some 200 feet would be remarkable, but with an overflowing bowl of lava more than a thousand feet in diameter in its very midst the phenomenon would be incomprehensible." But that is exactly what did happen, as correctly explained by Lyman whose visit to Kilauea was at about the end of the tumescing period.

A similar phenomenon was the subject of daily measurements by the Hawaiian Volcano Observatory in 1919. Immediately after the collapse of November 28, 1919, it was noted that the bottom of Halemaumau (see map Fig. 1) was being elevated as a unit. In the lava lake was a ring-shaped island surfaced in many places with talus blocks as shown in Fig. 2. This island mantained its identity while the lava column rose vertically 450 feet in 17 days. The upper half of Fig. 3 shows the plan of Halemaumau at the end of the uplift, and the lower half, a section, illustrates the nature of the island and the relation of the superficial lava lakes to the more plastic portions of the lava column. The fact that lava lakes are but comparatively shallow depressions in a pasty plug was not known to Brigham when he wrote.

Tumescing accompanied many, if not all, periods of rapid rise and inflow, but in most cases was not as pronounced as that between 1840 and 1846. The ascensive force of the lava affects not only the more mobile portions of the lava column, but the entire region surrounding Kilauea Crater.[2]

Sometime in 1846 it was observed that the surface of Kilauea was nearly back to its position before the collapse of 1840. This would make the fill of six years about equal to the amount engulfed in 1840, or 7,750,000,000 cu. ft. The average per year would be 1,290,000,000 cu. ft.

Dividing the total fill of several years by the number of years obviously does not give a true rate.

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[1]William T. Brigham, **Volcanoes Kilauea and Mauna Loa,** p. 60.
[2]T. A. Jaggar and R. H. Finch, **Tilt Records for Thirteen Years at the Hawaiian Volcano Observatory,** p. 43.

Fig. 2—Halemaumau on Dec. 16, 1919, after a rapid rise from a depth of 591 feet. Photo by T. A. Jaggar.

Observations as to the time of beginning and ending of activity are lacking, and also, in some of the longer periods, one or more years may have been periods of inactivity or even recession. Nevertheless, it is a rough measure of activity. In 1919 the rise took place within 17 days, and the average rate fill for this period if continued for an entire year would have amounted to 2.2 cu. mi.

The 1922 map of Kilauea Crater is substantially correct for 1941 save for the 1924 enlargement of Halemaumau and the subsequent inflows. The least elevation change since 1823, unless it be near the southwest rim of Kilauea, is just below Byron's Ledge. There the present surface is but 100 feet above the back ledge of that year. The greatest depth of fill was a little more than 700 feet, at the rim of Halemaumau.

The total fill between 1823 and 1924 was 70,280,000,000 cu. ft. If we subtract the amount engulfed in 1924, 7,120,-000,000 cu. ft., from this total we will have the net fill up to the time of the inflow of July, 1924, or 63,160,000,000 cu. ft. To this net, however, must be added the total volume of the several inflows into Halemaumau from 1924 to 1934. These inflows have lessened the depth of Halemaumau from 1,335 feet below the rim in 1924 to its present depth of 770 feet. Part of the elevation of the Halemaumau floor has been due to the accumulation of landslides from the walls. It is thought that about 800,000,000 cu. ft. was due to inflows. The net fill between 1823 and 1941 then, is 63,960,000,000 cu. ft. The gross filling between 1823 and 1941 would be the above total plus the amount of engulfments from 1832 to 1922 inclusive, or 101,266,000,000 cu. ft.

The history of Kilauea shows that there has been a diminution in size of the volcanic conduit under the crater floor. In 1823 and 1832 nearly the entire crater floor responded to volcanic pressure changes. Between 1840 and 1846, half the crater floor was bodily elevated indicating plastic material under that much of the crater. Most of the inflows of that period, however, came from the site of Halemaumau, and the canal near the southwest end of the crater was obliterated before there were any appreciable flows in the remainder of the canal. The breakdowns of 1868, 1886, and 1891 showed that the mobile portion of the crater got progressively smaller until from 1891 on, it was confined to Halemaumau and the immediate vicinity. That a mobile lava column still exists under Kilauea is indicated by an accumulation of 17 seconds of northeast tilt at the Hawaiian Volcano Observatory since 1939. Northeast tilt at the Observatory means an increase in elevation of Kilauea mountain.

What happened at Kilauea for many years after the explosive eruption of 1790 is not known, but at least by 1823, 33 years afterwards, there was intense activity over the entire crater. The interval of inactivity after 1790 may have been much less than 33 years, for native accounts given in 1823 said that there had been many lava flows but no explosion since 1790.

If Kilauea continues to be periodic in its activity and repeats the conditions following 1790, the 1924 explosion should be followed by a very active Halemaumau in or before the latter part of this decade.

Hawaiian Volcano Observatory Report for January-March, 1941

VOLCANOLOGY

January 1941

An unusual feature of the month was the continuation of northerly tilt until the last week of the month. Seasonal southwesterly tilt normally sets in about the first of the year. The tearing down of a part of the Hawaiian Volcano Observatory should, apparently, have been effective in increasing the normal southwest tilt.

There were no reports of unusual activity on Mauna Loa and surface activity at Kilauea was confined to rock slides from Halemaumau walls which were frequent January 20-22.

February 1941

A light fume column was visible over Mokuaweoweo at 5:15 pm, February 11. On the morning of March 12, Navy aviators reported heavy fume from the same place.

During the two weeks ended February 16 there was a slight southeast tilt instead of the normal southwest tilt for this time of year. The amount was slight but the actual figures do not tell the whole story. To produce an easterly tilt in February it would appear that some deep-seated pressure change, call-

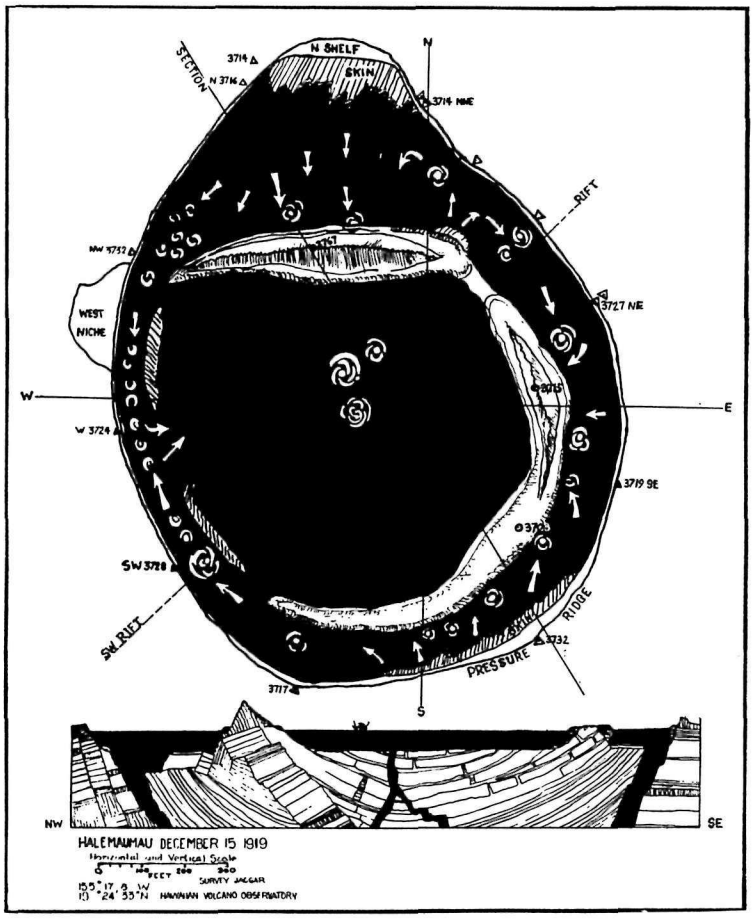

Fig. 3—Plan and section across Halemaumau, Dec. 15, 1919, showing the relation of lava lakes to the viscous and solid material below. From Volcano Observatory records by T. A. Jaggar.

ing for an easterly tilt, must first exceed the seasonal westerly tilt before it can become manifest.

Landslides from Halemaumau have a tendency to occur in groups and this was shown by several on February 17 and 21.

March 1941

Tilting of the ground at the Observatory continued to be erratic in March. In the first ten days the tilt was to the *northeast and during the last week it was to the northwest.* This means that there will be but little seasonal tilt to the southwest during the first four months of the year. Under normal conditions such a tilt would justify a prediction of volcanic activity but current work on the new hotel adjacent to the seismograph cellar may be affecting the records.

The 1940 Mauna Loa eruption cone was observed to be fuming on March 25.

Some of the local data for January, February, and March are as follows:

Week Ending	Halemaumau Slides	Halemaumau Crack Openings (Millimeters)	Seismic Disturbances
Jan. 5	0	2.5 opening	10
" 12	1	0.5 "	5
" 19	2	0.0	15
" 26	15	2.0 opening	18
Feb. 2	3	1.0 closing	7
" 9	0	3.5 "	15
" 16	1	6.0 opening	11
" 23	4	0.5 closing	21
Mar. 2	0	2.0 opening	7
" 9	0	6.5 "	7
" 16	0	1.5 "	5
" 23	0	0.5 "	7
" 30	0	5.0 "	11

R. H. F.

SEISMOLOGICAL DATA

Earthquakes

Date	Minutes of Tremor	Very Feeble	Feeble	Slight	Distant*	Weekly Seismicity†
January 5	10	0	0	0	0	2.50
" 12	5	0	0	0	0	1.25
" 19	12	2	1	1	1	7.00
" 26	10	8	0	0	0	6.50
February 2	7	0	0	0	0	1.75
" 9	12	1	2	0	1	5.50
" 16	9	1	1	0	0	3.75
" 23	17	3	0	1	0	7.75
March 2	2	5	0	0	0	3.00
" 9	3	4	0	0	0	2.75
" 16	4	1	0	0	0	1.50
" 23	6	1	0	0	0	2.00
" 30	5	6	0	0	0	4.25

* Including teleseisms or earthquakes over 5000 km from Kilauea.
† For local seismicity definition see Volcano Letter 371.

Epicenters of the following local disturbances were determined by means of seismograms from the stations operated by the Hawaiian Volcano Observatory on the island of Hawaii. Kilauea earthquakes were located by means of the main seismograph station at the observatory and the two subsidiary stations at Uwekahuna and the SE rim of Halemaumau respectively. The more distant shocks were located with the aid of seismograms from Hilo and Kealakekua. The disturbances *began at the time indicated and whenever possible, a* determination of depth of focus has been made.

January 15, 7:45 am, very feeble, 0.8 mile deep, Chain of Craters between Kokoolau and Devil's Throat. 19° 23.0′ N; 155° 14.6′ W.

January 17, 7:30 am, slight, 14.0 miles deep under W slope of Hualalai near seacoast at Kaiwi Point. 19° 40.3′ N; 156° 03.5′ W. Reported felt at Naalehu, Kailua, Hookena, Hilo, and strongly felt by everyone at Puuwaawaa.

January 18, 9:34 am, feeble, probably originated about 15 miles N of Papaaloa, in general area of earthquakes of summer of 1940 which originated in same region.

January 19, 6:20 pm, very feeble, 11.0 miles deep under E slope of Mauna Loa, 17 miles W of Kilauea Crater. 19° 25.5′ N; 155° 27.8′ W.

January 20, 11:01 pm, very feeble, 4.0 miles deep, 1.7 miles SSE of Volcano Observatory; 0.3 mile S of S rim of Kilauea Iki.

January 21, 2:15 am, very feeble, probably originated SW rift of Kilauea near Hilina Fault.

January 21, 7:24 pm, very feeble, 10.0 miles deep, Mauna Loa NE rift near Puu Ulaula. 19° 33.0′ N; 155° 28.0′ W.

January 22, 3:26 am, very feeble, of shallow origin, Mauna Loa summit crater.

January 25, 3:56 am, very feeble, 15.0 miles deep, 4.0 miles NNW Kailua, W slope of Hualalai on seacoast. 19° 41.0′ N; 156° 01.0′ W. Reported felt at Kailua and Kealakekua.

January 26, 8:42 am, very feeble, 3.5 miles NE Puu Kulua, Mauna Loa NE rift.

February 3, 2:08 pm, feeble, 14.0 miles deep, E slope Mauna Loa, 5.1 miles W of W rim of Kilauea Crater. 19° 25.0′ N; 155° 20.0′ W. Reported felt by many persons in Pahala.

February 8, 9:19 am, feeble, located about 37.0 miles N of Hilo under sea floor; 24 miles NE of Ookala. 20° 10.2′ N; 155° 0.00′ W.

February 11, 9:56 pm, feeble, 60 miles N by E of Hilo. 20° 34.0′ N; 154° 49.0′ W.

February 13, 12:05 pm, very feeble, Kilauea Puna rift area in general vicinity of Kalapana.

February 18, 11:53 am, slight, 30 miles deep, 14 miles E of summit of Hualalai. 19° 41.0′ N; 155° 39.0′ W.

February 20, 12:48 am, very feeble, probably originated 8.5 miles SW of Kilauea Crater in vicinity of Kamakaia Hills.

March 1, 12:16 pm, very feeble, Mauna Loa summit crater.

March 1, 3:46 pm, very feeble, Mauna Loa NE rift, 15.0 miles from Hilo.

March 4, 12:37 am, very feeble, Hilina Fault 7.0 miles W of Kalapana.

March 6, 4:28 pm, very feeble, located at base of NE rim of Kilauea Crater and of shallow origin. Sharply felt at Volcano Observatory.

March 8, 9:14 am, very feeble, Kilauea SW rift near junction with Hilina Fault.

March 13, 12:49 pm, very feeble, Hilina Fault N of Apua Point.

March 22, 5:54 pm, very feeble, located under NE rim of Kilauea Crater.

March 25, 5:57 pm, very feeble, probably originated in the vicinity of Punaluu.

March 30, 0:54 pm, very feeble, located on the SW rift of Kilauea, 0.6 mile beyond the SW rim and 0.6 mile NE of Cone Peak. 1.6 miles deep. 19° 24.1′ N; 155° 18.3′ W.

March 30, 3:42 pm, very feeble, located 20 miles north of Hilo and 8 miles off shore of Laupahoehoe. Depth 20 miles. 20° 00.8′ N; 155° 07.3′ W.

March 30, 6:54 pm, same location as earthquake of 3:42 pm.

March 30, 9:23 pm, same location as earthquake of 3:42 pm.

March 30, 11:48 pm, same location as earthquake of 3:42 pm.

H. H. Waesche

Teleseisms

January 13, 6h 08m 03s am, probable distance from Kilauea, 3,480 miles.

February 8, 11h 18m 49s am, distance not readily determined, probably 4,540 miles.

Microseismic Motion

January

Light: 1, 4, 5, 8, 9, 15, 16.
Moderate: 3, 6, 7, 10, 14, 17, 19, 25.
Strong: 2, 11 to 13, 18, 20 to 24, 26 to 31.

February

Light: 17 to 22.
Moderate: 6, 7, 14 to 16, 23 to 25.
Strong: 1 to 5, 8 to 13, 26 to 28.

March

Light: 13, 21 to 23.
Moderate: 2 to 4, 6, 12, 18 to 20, 24.
Strong: 1, 5, 7 to 11, 14 to 17, 25 to 31.

Tilting of the Ground

The following tables show tilt by weeks as recorded by the Observatory seismograph and at Halemaumau, the algebraic sum toward or away from the Pit.

At the Observatory the total accumulated tilt for the year ending on each of the following dates was:

January 26 - 12.22″ N and 11.16″ E.
March 2 - 10.20″ N and 12.64″ E.
March 30 - 12.58″ N and 10.41″ E.

Table of Tilt

Week Ending	Observatory	Halemaumau West Station
January 5	0.95″ W	0.00 - - -
" 12	1.49″ N 6° W	2.77″ N 64° W
" 19	1.80″ N 76° W	1.61″ S 10° E
" 26	0.77″ S 21° W	1.31″ N 28° E
February 2	0.91″ S 14° W	2.90″ S 28° E
" 9	1.82″ S 72° E	3.19″ S 22° W
" 16	0.73″ S 13° E	5.42″ N 38° E
" 23	3.44″ S 24° W	1.31″ S 10° W
March 2	1.88″ N 45° E	2.26″ S 55° W
" 9	5.53″ N 18° E	0.00 - - -
" 16	4.63″ S 54° W	2.32″ S 6° W
" 23	5.81″ S 19° W	1.37″ N 21° W
" 30	2.17″ N 19° W	0.44° S 16″ E

Week Ending	Halemaumau Southeast Station	Pit Resultant
January 5	6.48″ S 29° W	2.75″ from
" 12	7.87″ N 19° E	3.31″ toward
" 19	13.93″ S 15° E	12.98″ from
" 26	3.24″ N 31° W	3.28″ toward
February 2	3.24″ S 30° E	2.24″ from
" 9	14.58″ N 30° W	13.84″ toward
" 16	13.71″ S 61° E	8.74″ from
" 23	5.83″ N 78° W	3.91″ toward
March 2	2.85″ N 45° E	1.45″ from
" 9	5.77″ N 30° E	2.27″ toward
" 16	3.40″ S 2° E	3.37″ from
" 23	5.93″ S 7° W	4.82″ from
" 30	5.93″ N 7° E	4.52″ toward

H. H. Waesche and P. E. Schulz

Crater Angles

Measurement of horizontal angles across Kilauea Crater from the Observatory, January 14, 1941, indicating closing of the Halemaumau value and opening of the Crater value compared with similar measurements made December 19. The amount of closing of the Halemaumau angle was 1.51″ and of opening of the Crater value was 1.09″.

Between January 14 and January 30, the Halemaumau angle closed 1.24″ and the Crater angle closed 1.26″.

Between January 30 and February 17, the Halemaumau angle opened 1.16″ and the Crater angle opened 0.09″.

Between February 17 and March 4, the Halemaumau angle closed 1.57″ and the Crater angle closed 2.17″.

Net Halemaumau change December 19 to March 4: Halemaumau 2.16″ closed; Crater 2.25″ closed.

H. H. Waesche

Kilauea Crater Floor Levels.

A level circuit was run from Spit B.M., S rim of Kilauea Crater, to NW Pit B.M., January 16, 1941. There was no relative change in elevation between these two stations compared with a similar run made September 18, 1940.

Chain-of-Craters Crack Measurements

On the Chain-of-Craters road there have been no appreciable changes in measured cracks except at #108, S rim of Aloi Crater. This crack has opened as follows:

December	27	measurement	was	97.75 cm
January	31	"	"	98.25
February	28	"	"	98.70
March	28	"	"	98.90
Total opening				1.15 cm

Devil's Throat rim cracks indicated only slight changes.

H. H. Waesche

HAWAIIAN VOLCANO RESEARCH ASSOCIATION
in cooperation with
UNIVERSITY OF HAWAII

The **Hawaiian Volcano Research Association** was founded in 1911 for record of volcanoes in the Hawaiian Islands and around the Pacific Ocean. Its equipment at Kilauea Volcano, Hawaii Island, has been transferred to the United States Government, Department of the Interior, National Park Service.

The **University of Hawaii** cooperates in maintaining a research laboratory at Hawaii National Park. The **Association** and the **University** maintain outside seismograph stations and supplement the work of the government with research associates, instrumental plants and special investigations. Dr. T. A. Jaggar is their geophysicist resident in the National Park.

The **Volcano Letter,** a quarterly record of the Hawaiian volcano laboratories and published by the University of Hawaii, is issued by authority of the Department of the Interior and supplied to a restricted membership and exchange list of the above establishments.

THE VOLCANO LETTER 472

No. 472 **Department of Interior** **National Park Service** **April-June 1941**

● The Volcano Letter, a quarterly record of the Hawaiian volcano laboratories, published by the University of Hawaii, is issued by authority of the Department of the Interior and supplied to a restricted membership and exchange list of the Hawaiian Volcano Research Association and the University of Hawaii.

● The Hawaiian Volcano Research Association was founded in 1911 for record of volcanoes in the Hawaiian Islands and around the Pacific Ocean. Its equipment at Kilauea Volcano, Hawaii Island, is leased and operated by the United States Government, Department of the Interior, National Park Service.

● The University of Hawaii (T. A. Jaggar, geophysicist) cooperates in maintaining a research laboratory at Hawaii National Park (Edward G. Wingate, superintendent, R. H. Finch, volcanologist). The Association and the University maintain outside seismograph stations and supplement the work of the government with research associates, instrumental plants, and special investigations.

CALDERAS AND THEIR ORIGIN, BY WILLIAMS

Review by R. H. FINCH

Calderas and their Origin, by Dr. Howell Williams, [Bulletin of the Department of Geological Sciences, University of California, Vol. 25, No. 6, 107 pages, 1941], offers geologists a thought-provoking and comprehensive discussion on caldera and crater formation. "Calderas are large volcanic depressions, more or less circular or cirque-like in form, the diameters of which are many times greater than those of the included vent or vents, no matter what the steepness of the walls or form of the floor." A crater is limited to "a constructive apparatus from which ejecta escape to build up positive land forms." It follows then that "calderas are almost invariably large volcanic basins produced by engulfment."

He lists six classes of calderas: 1, explosion calderas; 2, collapse calderas; 3, erosion calderas; 4, volcanic graben; 5, volcanic rents or fissure troughs; and 6, major volcano-tectonic depressions. Erosion calderas are probably included for the sake of completeness as they result from modification of other forms. It will be noted that some form of collapse is present in all classes except for the "rare and relatively small explosion calderas."

Uniformity in names such as Dr. Williams proposes would make for clarity, but it will be some time before all volcanologists will cease to use the word crater in the sense of depressions in the surface of the earth caused by volcanic processes. In some ways it would be more in keeping with the ordinary meaning of caldera if the proposed definitions of caldera and crater were interchanged. At Kilauea it is easy to think of Halemaumau as a cauldron in Kilauea crater.

It is gratifying to see proper recognition given to the splendid work of the geologists of the Dutch East Indies, especially Stehn, van Bemmelen, van den Bosch, and Neumann van Padang. The above are included under the term field volcanologists. This would imply that the other class would be library volcanologists. Williams' interest in calderas was aroused by a visit to Kilauea and subsequently he did extensive work on the Brokeoff caldera in California, the Newberry and Crater Lake calderas in Oregon. He also spent considerable time at the calderas in New Zealand, Dutch East Indies, and Japan.

One of the effects of the paper will be to lay forever the idea that explosions by themselves are competent to account for large calderas. In each case discussed, the volume of coarse lithic debris about the rim is strikingly insufficient to account for the material removed. It is surprising that so slight attention has been paid to the scarcity of the old lithic material around each volcano "that blew its head off," for this scarcity was recognized at Santorin by Fouque published in 1879, and by Diller at Crater Lake published in 1902. Van den Bosch is quoted as saying that it is the scarcity of such lithis debris that "explodes the explosion hypothesis."

That small craters may be due to explosions is accepted. Three examples of known small calderas produced by explosion, Rotomahana in New Zealand, Bandai-san in Japan, and Chaos Crags in California are described.

Before discussing 20 illustrative examples of collapse calderas about whose origin there is but little doubt, three calderas doubtfully ascribed to explosion are discussed. They are the Valles caldera in New Mexico, Aniakachak in Alaska, and Mount Multnomah in Oregon. The Valles caldera with diameters of 17 and 18 miles is "probably the largest caldera in the world." The discussion on these three calderas convinces one that Williams was quite conservative in labelling them "doubtfully ascribed to explosion."

These large calderas, often with rim volcanoes, suggest to the reviewer that the great volcanic arcs, such as the Aleutian, mark portions of ancient subsidence basins with rim volcanoes that were many hundreds of miles in diameter.

Krakatau is taken as the type where engulfment follows repeated and usually short-lived explosions of pumice and juvenile ash. An excellent review of the history of Krakatau is given. On page 262 listing some of the possible causes of the activity there, is the statement that the magma prior to 1883 may have been "potentially explosive owing to a high content of dissolved gases, perhaps absorbed from the walls of the reservoir." The mechanism of such an absorption introduces grave difficulties aside from the relatively small volume of gases available from such a source. Escher's gas-coring hypothesis is inadequate to account for the formation of large calderas and comes in for just criticism.

On page 256 occurs the statement that the earlier small explosions of Krakatau of May 20 "were chiefly of vulcanian type —— whereas the culminating explosions were of pelean type, the overwhelming mass of pumice being deposited with *great rapidity as glowing avalanches (nuees ardentes)*." This seems to be overworking the term nuees ardentes which by many means a more or less downward component of a pumice-charged explosion and not merely a glowing cloud. Ver Beek and Dana long ago assumed that the caldera at Krakatau was produced by engulfment and to this most of the later workers there, Stehn, van Bemmelen, van den Bosch, Neumann van Padang, Reck, and Williams, agree.

The next caldera discussed is Santorin caldera of Greece. The pioneer studies of Fouque have in the main been verified by the comprehensive work of Neumann van Padang and Reck. Fouque's calculation indicated that the ratio of pumice to old lithic material was about 99 to 1.

Eight pages are devoted to the history of Crater Lake which is in fact but a resume of his monograph on that subject which will appear shortly. The arguments that Crater Lake is due

to engulfment should convince the most skeptical of the explosion school. The ancestral cone of Crater Lake is assumed to have had a small crater atop its summit at a height of about 12,000 feet. It would seem that a height of about 10,000 feet could account for the glaciation. The extra 2,000 feet in height would increase the total snowfall but slightly. The top may have been made up of at least two peaks. Such a difference in the original height would decrease the amount of material that disappeared from 17 cu. mi. to about 12 cu. mi. The estimate of the volume of the old lava in the ejecta is not over 2 cu. mi. Hence whether the amount engulfed was 12 or 17 cu. mi. affects his argument not at all. It is exceedingly hard to follow, however, the argument that the "frothy magma was expelled in so great a volume that instead of being thrown high above the cone it rose but a short distance and falling back on the slopes of the mountain rushed headlong in a series of glowing clouds (nuees ardentes)." The distribution of the pumice indicates that wind may have been an important factor in some of the blasts. The "prodigious speed" with which "the avalanches raced down the canyons and spread out on the encircling lowlands for distances as great as 35 miles" may be questioned. Apparently prodigious velocities of translation were not attained in the nuees ardentes (horizontal blasts) at Mt. Pele, Soufriere or Lassen. The velocity of the explosion avalanche at Bandai-san was 48 miles an hour.

The four great calderas of Kyusu, Japan, that lie along a north-south line are next taken up. Of the numerous calderas to be found in Japan these four receive special treatment because of the greatness of their size and because Aso is the only one well known outside of Japan. The smallest of these, Kikai, has an area of 230 km^2. Each has a "central cone," though active vent might be a more appropriate term; Sakurajima, for instance, is at the southern rim of the Aira caldera. The subsidence following the 1914 eruption of Sakurajima is nearly symmetrical about the Aira caldera instead of the Sakurajima cone.

Other cases described under the Krakatau type are Lago di Bolsena in Italy, Mount Gambier in Australia and the Knebel See in Iceland.

Next discussed are calderas whose collapses are occasioned by the lowering of the magma level in the central conduit by dike intrusion injection at depth or lateral outflow at low levels. Kilauea is taken as the type volcano. If explosions accompany the formation of this type, they are phreatic. Sandberg's contention that the walls of Kilauea represent the sides of the original conduit that has progressively grown smaller until it has reached the very small dimensions of Halemaumau is refuted. In defense of Sandberg's idea, however, it should be remembered that nearly the entire crater was active in 1823 and 1832, not, of course, over a conduit of that size but over a network of feeding fissures. Following a collapse in 1840 involving about one square mile, the collapsed area rose bodily in some portions at least 200 feet. Since 1891 the active conduit has been restricted to Halemaumau. The sinking of the lava column in 1919 is attributed to the opening of a lateral fissure. Why not attribute it to a withdrawal into the depths? If there can be deep-seated pressure increase under a volcano, then why not deep-seated decrease?

Stearns is followed in his belief that Mokuaweoweo is the result of the coalescing of small pit craters fluxed and stopped along the rift zone. However, arguments such as one or more peripheral cracks—not parallel to the rift zone—can be produced pointing to a more widespread collapse at Mokuaweoweo.

Other calderas of the Kilauea type discussed are Nyamlagera in Africa, Batoer on Bali, Medorika in the Kurile Islands, Nemrut Golu in Turkey, and Newberry caldera in Oregon.

Katmai is put in a class by itself. The discussion of the volcanoes up to Katmai suggests that there is a unity in the broader aspects of volcanism. General considerations make one question Fenner's rapid assimilation theory as an explanation of Katmai's activity. This theory is considered a possibility though Fenner himself raised four serious objections to it.

The discussion of cryptovolcanic calderas is especially interesting as indicating that vestiges of volcanism may still be found in regions long free from orogenic disturbances and quite deeply mantled with sedimentary deposits. Why subterranean explosions are thought to be a necessary accompaniment of such formations is not clear. A decrease of pressure, probably following an increase, and withdrawal of magma into the depth or dike intrusions could account for most of such depressions. The wide distribution of cryptovolcanic calderas is evidenced by the examples offered: Bosumtwi and Nebiewale of the Gold Coast of Africa, the Pretoria Salt Pan of South Africa, the Steinheim Basin and Rieskessel in Germany, and one each in Indiana, Illinois, Kentucky, Ohio, Tennessee, and Utah.

Glen Coe, Scotland, is taken as the type where a caldera results from the collapse of a large cylindrical block along ring fractures. Other calderas described with distinct ring fracture features are those of Ossipee, New Hampshire; Silverton, Colorado; and Buell-Park, New Mexico.

Stromboli is the type for the volcanic sector graben. The sector collapse here has progressed to the northwest producing a series of terrace-like benches. The Somma-vesuvius system is included in this type. As the Vesuvian cone has been built up near the lower western wall of the Somma caldera formed at the time of the 79 A. D. eruption one wonders why it is placed in this group.

Volcanic rents or fissure troughs are depressions formed on volcanic cones by horizontal movement. Crescentic troughs on several volcanoes of Java appear to be of this origin.

Some very large depressions related to areal eruptions from extensive fissure systems are classed as major volcano-tectonic depressions. Examples in Sumatra and New Zealand are cited. Such crustal collapses in regions without a large central vent edifice are on a vast scale and not readily apparent as such.

After the discussion of specific volcanoes, 16 pages are devoted to a review of the different theories that have been advanced to account for crater and caldera formations. Serious objections are found to all theories except explosion for small calderas and engulfment for large ones.

This caldera paper is an essential part of the library of every student of volcanoes. No single paper excels it in giving so comprehensive a view of the development of volcanic structures.

Hawaiian Volcano Observatory Report for April-June, 1941.

VOLCANOLOGY

April 1941

There was no visible activity at the Hawaiian Volcanoes during April. A glow was reported over the northeast slope of Mauna Loa the evening of April 1st. It is doubtful if it was of volcanic origin as the moon set at about the time and in the direction of the reported light. There were several earthquakes centering at Kilauea during the last 10 days of the month.

May 1941

Landslides were frequent at Halemaumau during the first half of the month. Pronounced southerly tilting that started on March 10, 1941 continued through April and May.

It appears that many of the Kilauea earthquakes occur at origins deeper than was common at times when molten lava was present as some of the feeble Kilauea shakes are reported as perceptible in Hilo.

June 1941

The 1940 cone in Mokuaweoweo continues to fume quite noticeably. Sulphate and sulphurous deposits are locally conspicuous on last year's lavas.

At Kilauea southwest tilt continued throughout the month. The short period irregularities in the tilt curve and the total accumulated tilt in April, May, and June were greater than common for the past several years. In fact the tilt charts for these months and March resemble those obtained prior to 1924 when there was molten lava in Halemaumau.

Some of the local data for April, May, and June are as follows:

Week Ended	Halemaumau Slides	Halemaumau Crack Openings (Millimeters)	Seismic Disturbances
April 6	1	2.0 closing	13
" 13	0	2.0 opening	9
" 20	3	0.5 "	37
" 27	2	4.0 closing	49
May 4	1	0.5 "	27
" 11	3	1.0 opening	13
" 18	0	0.5 closing	15
" 25	1	1.0 "	28
June 1	0	2.5 opening	14
" 8	2	0.5 "	13
" 15	0	0.0	4
" 22	0	2.5 opening	11
" 29	0	0.5 closing	10

R. H. F.

VOLCANIC ACTIVITY IN THE MARIANAS ISLANDS

An observer reports that on the night of March 28-29, 1941, while passing between the two northernmost islands of the Marianas, fire was observed shooting out of the top and lava flowing down from the volcano on Uracas Island. When first sighted the eruption of this volcano appeared as a bright clear light due to apparent refraction, but later, when closer, it appeared bright near the top and dull red farther down the mountain. It was visible about 40 miles at night. (Hydrographic Bulletin July 2, 1941)

April-June, 1941

SEISMOLOGICAL DATA By P. E. Schulz

Earthquakes

Date	Minutes of Tremor	Very Feeble	Feeble	Slight	Moderate	Local Seismicity*	Teleseisms
April 6	10	3	0	0	0	4.00	1
" 13	9	0	0	0	0	2.25	0
" 20	30	5	0	1	1	15.00	1
" 27	38	10	1	0	0	15.50	0
May 4	21	6	0	0	0	8.25	0
" 11	10	2	1	0	0	4.50	1
" 18	13	2	0	0	0	4.25	2
" 25	19	9	0	0	0	9.25	0
June 1	13	1	0	0	0	3.75	0
" 8	8	5	0	0	0	4.50	1
" 15	2	2	0	0	0	1.50	0
" 22	10	1	0	0	0	3.00	0
" 29	5	2	3	0	0	5.25	1

* For local seismicity definition see Volcano Letter No. 371.

Epicenters of the following local disturbances were determined by means of seismograms from the stations operated by the Hawaiian Volcano Observatory of Hawaii National Park on the island of Hawaii. A new station was established May 22 on Haleakala, Maui, but no disturbances were recorded there during the quarter. Kilauea earthquakes were located by means of the main seismograph station located at the Observatory and the subsidiary stations on Uwekahuna Bluff and near the SE rim of Halemaumau. The more distant shocks were located with the aid of seismograms from Hilo and Kealakekua. The disturbances began recording at the time indicated, and wherever possible a determination of depth of focus has been made.

The number preceding each earthquake date is the serial number of the quake for the current year.

30. April 3, 10:25 am, very feeble, Mauna Loa NE rift near Puu Ulaula.

31. April 6, 5:22 am, very feeble, Mauna Loa NE rift 15 miles from Hilo Bay, depth 20 miles, 19° 38.1′ N, 155° 19.3′ W.

32. April 6, 5:51 am, very feeble, Mauna Loa NE rift, 19 miles from Hilo Bay, depth 18 miles, 19° 35.5′ N, 155° 20.3′ W. Reported felt by a few persons in bed at "29 miles," 1.5 miles east of the Observatory.

33. April 20, 1:17 am, very feeble, of Kilauea origin, probably same location as No. 34.

34. April 20, 1:34 am, very feeble, 0.4 mile east of Cone Peak on the Kilauea SW rift, 2.3 miles deep, 19° 23.7′ N, 155° 18.3′ W.

35. April 20, 2:40 am, slight, location same as No. 34.

36. April 20, 3:33 am, very feeble, location same as No. 34.

37. April 20, 3:51 am, very feeble, Kilauea SW rift, 0.9 mile from Cone Peak at 3,729 foot B. M.

38. April 20, 4:47 am, very feeble, location probably same as No. 37.

39. April 20, 10:46 am, moderate, 0.3 mile south of Keanakakoi Crater, depth 1.0 mile, 19° 23.9′ N, 155° 16.0′ W. Generally felt in the Kilauea area, Kau, and Kona, and by some persons in Hilo.

40. April 22, 6:04 am, very feeble, origin undeterminable.

41. April 24, 7:09 pm, very feeble, central portion of Kilauea Crater.

42. April 25, 2:23 pm, very feeble, location same as No. 41.

43. April 25, 2:36 pm, very feeble, location same as No. 41.

44. April 26, 8:17 am, very feeble, east flank of Mauna Loa about 8.5 miles north of the Volcano Observatory.

45. April 26, 4:10 pm, feeble, Kilauea Crater, 0.9 mile NE of the center of Halemaumau, depth 0.9 mile, 19° 25.1′ N, 155° 16.9′ W.

46. April 26, 7:13 pm, very feeble, probably Mauna Loa NE rift midway between Hilo and Mokuaweoweo. Reported felt by a few persons in Hilo.

47. April 27, 3:08 am, very feeble, SE rim of Kilauea Crater, 1.6 miles deep, 19° 24.4′ N, 155° 16.1′ W.

48. April 27, 4:47 am, very feeble, SE rim of Kilauea Crater, 0.9 mile deep, 19° 24.4′ N, 155° 16.1′ W.

49. April 27, 7:16 am, very feeble, center of Kilauea Crater, 1.0 mile deep, 19° 25.0′ N, 155° 16.3′ W.

50. April 27, 9:12 am, very feeble, probably north of Kilauea Iki.

51. April 28, 1:04 am, very feeble, origin undeterminable.

52. April 29, 7:08 am, very feeble, Kilauea Crater at the 3,646 B. M. just west of Halemaumau, depth 1.0 mile, 19° 24.7′ N, 155° 16.8′ W.

53. April 30, 10:20 am, very feeble, south rim of Halemaumau, depth 0.8 mile, 19° 24.2′ N, 155° 17.2′ W.

54. May 1, 9:03 am, very feeble, Kaoiki Pali 2.2 miles SW of the Halfway House on the Mamalahoa Highway, depth normal, 19° 20.2′ N, 155° 24.3′ W.

55. May 1, 8:43 pm, very feeble, probably of Kilauea Crater origin depth fairly great.

56. May 2, 10:53 am, very feeble, adjacent to the Mauna Loa NE rift zone 1.0 mile west of Kiipu Cone, depth normal, 19° 33.3′ N, 155° 20.0′ W.

57. May 6, 1:46 am, very feeble, Mauna Loa NE rift, 2.5 miles from Mokuaweoweo Crater, depth 7.5 miles, 19° 31.6′ N, 155° 31.5′ W.

58. May 9, 4:34 am, feeble, east flank of Mauna Loa

half way between Mokuaweoweo and Kilauea Craters, depth about 28 miles, 19° 27.5′ N, 155° 27.6′ W.

59. May 9, 3:23 pm, very feeble, central Mokuaweoweo Crater, depth 15 miles, 19° 29.0′ N, 155° 36.3′ W.

60. May 12, 5:10 am, very feeble, of Kilauea origin, exact locality undeterminable.

61. May 13, 3:47 am, very feeble, about 50 miles from the Observatory, off the SE shore of Hawaii probably on the extension of the Puna rift.

62. May 20, 3:10 am, very feeble, NE rim area of Kilauea Crater.

63. May 21, 8:20 pm, very feeble, junction of the SW rift with the SW rim of Kilauea Crater, depth 1.0 mile, 19° 24.1′ N, 155° 17.7′ W.

64. May 22, 1:59 pm, very feeble, Uwekahuna Bluff of Kilauea Crater, depth 5.0 miles, 19° 25.2′ N, 155° 17.4′ W.

65. May 22, 2:49 pm, very feeble, Kilauea Crater 0.3 mile NE of Halemaumau, depth 2.7 miles, 19° 24.9′ N, 155° 16.8′ W.

66. May 23, 8:25 am, very feeble, of Halemaumau origin, depth shallow.

67. May 23, 9:45 pm, very feeble, 0.8 mile SW of Kilauea Crater, depth 0.8 mile, 19° 24.1′ N, 155° 18.3′ W. Felt by a few persons at "29 miles" and at Hilo.

68. May 24, 11:10 am, very feeble, probably in the north portion of Kilauea Crater.

69. May 24, 6:46 pm, very feeble, east flank of Mauna Loa in the Keawe Wai region.

70. May 25, 6:30 pm, very feeble, 1.4 miles ESE of the Observatory, depth 4.0 miles, 19° 25.8′ N, 155° 14.9′ W. Felt by a very few persons in Hilo.

71. May 26, 1:49 am, very feeble, south of Halemaumau, depth 0.7 mile deep, 19° 24.5′ N, 155° 17.3′ W.

72. June 3, 5:35 pm, very feeble, center of Halemaumau, depth 1.0 mile, 19° 24.5′ N, 155° 17.0′ W.

73. June 4, 7:36 am, very feeble, south of Halemaumau.

74. June 4, 3:18 pm, very feeble, probably near summit of Mauna Loa.

75. June 5, 4:40 pm, very feeble, of Kilauea origin, location undeterminable.

76. June 8, 6:39 pm, very feeble, Mauna Loa NE rift 3 miles SW of Hilo Bay, depth 13.0 miles, 19° 42.7′ N, 155° 07.5′ W. Felt by a few persons in Hilo.

77. June 12, 9:59 pm, very feeble, 10 miles NE of Cape Kunakaki, 17 miles deep, 19° 39.2′ N, 155° 42.5′ W.

78. June 14, 1:33 pm, very feeble, east flank of Mauna Loa probably half way between Mokuaweoweo and Kilauea Craters.

79. June 16, 8:34 pm, very feeble, probably Mauna Loa NE rift in the Puu Kulua area.

80. June 24, 11:22 am, very feeble, of Kilauea origin, exact location undeterminable.

81. June 25, 2:35 am, feeble, SE flank of Mauna Loa, 7.7 miles WNW of the Observatory, depth 2.1 miles, 19° 28.9′ N, 155° 21.6′ W.

82. June 25, 10:54 pm, very feeble, Cone Peak on the Kilauea SW rift, depth 1.3 miles, 19° 23.7′ N, 155° 18.6′ W.

83. June 29, 6:48 am, feeble, Mauna Loa NE rift zone 4.5 miles NE of Puu Ulaula, depth 8.0 miles, 19° 34.5′ N, 155° 26.1′ W. Felt by a few persons at "29 miles."

84. June 29, 8:25 am, feeble, Mauna Loa NE rift 2.0 miles SW of Puu Ulaula, depth 7 miles, 19° 31.7′ N, 155° 26.3′ W.

Teleseisms

April 1, 00h 27m 43s distance undetermined
April 14, 08h 47m 30s distance approximately 3,600 miles
May 7, 11h 59m 05s distance undetermined
May 13, 5h 41m 51s distance 1,750 miles
May 16, 4h 03m 38s distance 5,955 miles
June 8, 8h 00m ?s low amplitude, distance doubtful

Microseismic Motion

	April	May	June
Light	None	2, 14, 19, 24, 26, 27, 29-31	1-3, 7-9, 11, 14-18, 21-26, 29, 30
Moderate	2, 12, 13, 15, 19, 20, 22-25, 28-30	11-13, 15-18 20-23, 25, 28	4-6, 10, 12, 13, 19, 20, 27, 28
Strong	1, 3-11, 14, 16-18, 21, 26, 27	1, 3-10	None

Tilting of the Ground Surface

Several changes have been made in this section of the Seismological Report, which appears at the bottom of this page. It is believed that the changes are justified in that (1) the original data are less manipulated, and (2) the same method is now applied to all 3 tilt stations.

At the Observatory the total accumulated tilt for year ending

April 30: 10.65"N and 10.65"E
May 31: 2.54"N and 10.41"E
June 30: 4.96"S and 7.87"E

MISCELLANEOUS DATA By P. E. Schulz

Crater Angles, Horizontal	Halemaumau Angle	Kilauea Crater Angle
March 4 to April 17	+0.1"	+2.0"
April 17 to May 6	- 1.0"	- 1.9"
May 6 to June 27	+2.2"	+3.0"
Net Change March 4 to June 27	+1.3"	+3.1"

Kilauea Crack Measurements

During the quarter 3 Halemaumau rim cracks opened 1.0 millimeter each, and 2 opened 1.5 millimeters each; 2 closed 1.0 millimeter each and one closed 1.5 millimeters.

No appreciable changes occurred in the Devil's Throat cracks. Of the remaining Chain of Craters road cracks only #108 parallel to the rim of Aloi Crater changed; it opened 1.0 millimeter. Since January 1, 1940, crack #108 has opened 12.5 millimeters.

Week Ending	NE Rim Kilauea Crater			Halemaumau West Station			Halemaumau SE Station		
	Total Amount	Direction	Tilt to (+) or from (-) Halemaumau	Total Amount	Direction	Tilt to (+) or from (-) Halemaumau	Total Amount	Direction	Tilt to (+) or from (-) Halemaumau
April 6	1.61"	S67°W	+1.50"	2.68"	S52°E	+2.00"	2.27"	S13°E	- 2.11"
" 13	0.46"	N37°E	- 0.44"	1.64"	N7°W	- 0.09"	3.73"	S86°E	- 2.40"
" 20	2.09"	S21°W	+1.84"	1.49"	S12°W	- 0.39"	5.18"	N78°W	+3.92"
" 27	2.61"	S62°E	- 0.97"	3.58"	N51°E	+2.92"	0.00"	—	0.00"
May 4	0.52"	N76°W	+0.31"	0.75"	S63°E	+0.67"	2.43"	N79°E	- 1.00"
" 11	0.99"	S59°E	- 0.33"	6.56"	S17°W	- 2.50"	4.54"	N22°W	+4.41"
" 18	2.23"	S12°W	+1.77"	4.62"	N29°E	+2.65"	3.40"	S4°E	- 2.88"
" 25	6.22"	S01°E	+3.92"	1.49"	N38°E	+1.01"	3.73"	S9°W	- 2.59"
June 1	2.50"	N29°W	- 0.52"	1.49"	S45°E	+1.01"	4.54"	N10°W	+4.02"
" 8	3.30"	S04°W	+2.31"	1.49"	N45°W	- 1.01"	8.10"	S13°E	- 7.39"
" 15	0.65"	W	+0.48"	1.79"	S18°W	- 0.72"	8.10"	N13°W	+7.39"
" 22	0.64"	S40°E	+0.12"	1.79"	N72°E	+1.70"	3.40"	S59°E	- 3.05"
" 29	0.57"	S65°W	+0.36"	0.75"	N43°W	- 0.48"	3.40"	N59°W	+3.05"
	Net tilt toward (+) 10.35"			Net tilt toward (+) 6.77"			Net tilt toward (+) 1.37"		

THE VOLCANO LETTER 473

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Published by the University of Hawaii. HAWAII NATIONAL PARK: Edward G. Wingate, Superintendent; R. H. Finch, Volcanologist. UNIVERSITY OF HAWAII: T. A. Jaggar, Geophysicist.

TILT RECORDINGS AT THE HAWAIIAN VOLCANO OBSERVATORY AND THEIR CONVERSION TO SECONDS OF ARC

By P. E. SCHULZ

The measuring and plotting of ground tilt is an important factor in volcanologic studies at the Hawaiian Volcano Observatory. The status of this work is summarized in "Tilt Changes at Kilauea" by H. H. Waesche, Volcano Letter No. 467, January-March 1940.

The purpose of the present article is to show the relationship of the undamped period of the Bosch-Omori seismograph to the conversion factor for stylus displacement to seconds of ground tilt, and the order of magnitude of error in tilt determination which results from the tilting of the instrument itself unless proper corrections are made.

The curve in Fig. 1 was computed for the Bosch-Omori seismograph from the formula developed in "Tilt Records for Thirteen Years at the Hawaiian Volcano Observatory" by T. A. Jaggar and R. H. Finch, Bulletin of the Seismological Society of America, Vol. 19, No. 1, March 1929 which is:

$$\phi = \frac{4\pi^2 l}{g T_o^2} \times \frac{D\,s}{A\,l} = \frac{4\pi^2 \times 25}{978.236\,T_o^2} \times \frac{10 \times .86}{102 \times 245} \times 206265$$

where ϕ is the tilt in seconds, L is the reduced length of the pendulum, D is the displacement of the stylus. s and l are the short and long sides of the pivoted stylus (magnifying arm) respectively, and A is the length of the seismograph boom. The right hand member of the equation is multiplied by 206265 so that the result will be in seconds.

The undamped period of 7.70 seconds of the Bosch-Omori seismograph at Kilauea seems to approach the ideal, for at this value the instrument is a sensitive 2-component tiltmeter whose styli are displaced one centimeter for each 1.21 seconds of tilt, and yet the instrument responds readily to microseisms, tremors, and local earthquakes. It follows that the registry of teleseisms is not all that could be desired, but the registering of teleseisms is a relatively unimportant part of the work of the Observatory.

Changes in the height of the magnifying lever above the recording drum, which occur from occasional instrumental maintenance, result in slight changes in magnifying lever-stylus length l. In the equation given above for the Bosch-Omori seismograph, however, changes of as much as 5 millimeters in this value do not appreciably alter the conversion factor ϕ.

Tilting of the ground itself, however, may be of sufficient magnitude to change the angle i (between the plumb line and the line joining the 2 suspension points) of the pendulum enough to cause appreciable changes in the undamped period of the instrument, and hence in the conversion factor. This condition exists at Kilauea. The 2 largest tilt-change components for short periods are those of 53 seconds to the north May 1918 to January 1919, and 81 seconds to the south December 1923 to July 1924. Had the north-south pendulum period been 7.70 seconds at the outset of each, it would have increased or decreased 0.06 and 0.09 seconds respectively depending on whether the pendulum was hung on the south side or the north side of the support. (The Bosch-Omori instrument at the Observatory has its masses suspended on the south and west sides of the supports). From Fig. 1 the conversion factor changes corresponding to 0.06 and 0.09 are 0.03 and 0.04. The net north-south tilting of the ground between the extremes of 1920 and 1939 was 110.0 seconds and the net east-west tilting between the extremes of 1913 and 1918 was 46.4 seconds. The 110.0-second tilt on a 7.70 seconds seismograph period basis causes a change in period of 0.12 seconds with a factor change, from Fig. 1, of 0.06. The 46.4-second tilt results in 0.04-second period increase or decrease in the east-west pendulum with a 0.02 factor change. The approximate average annual range of ground tilt on the northeast rim of Kilauea Crater is 15 seconds north-south and 5 seconds east-west. Even the largest of these figures results in only a 0.02 second period change which does not appreciably affect the conversion factor.

The north-south component of the Bosch-Omori seismograph was reoriented July 1, 1941 by rotating it clockwise 7½ degrees into a true east-west position. Since the true tilt varies with cosine of the orientation angle it follows that measured north-south tilt values were 99 percent of the true north-south tilt values before the reorientation.

The writer is indebted to Mr. R. H. Finch for suggesting the consideration of this subject.

Hawaiian Volcano Observatory Report for July-September, 1941

VOLCANOLOGY

July 1941

The 1940 cone in Mokuaweoweo was observed to be fuming strongly during the latter part of the month. The solfataric deposits on the 1940 lava showed a noticeable increase.

Two earthquakes that occurred on July 8 had their origin at the junction of Waldron and Byron ledges. This would indicate a slight sinking at the northern end of Kilauea Crater. There is evidence in several places that the crater floor has sunk slightly with reference to the crater walls since 1924.

August 1941.

During August, as for the three preceding months, a majority of the earthquakes recorded on the seismographs at the Observatory originated on the northeast slope of Mauna Loa. The rim cracks around Halemaumau showed a distinct opening during the last week of the month. The normal northeast tilt that did not set in until early in July, about two months later than common, continued through most of August.

September 1941

During the first two weeks in September earthquakes of Kilauea origin predominated. An earthquake on September 25 with origin on the east flank of Mauna Loa, about 15 miles from the Observatory, did considerable damage at Kapapala and Pahala. It was strongly felt all over the island of Hawaii and as far northwest as Oahu. The main shaking merged into a continuous tremor that continued for 45 minutes, quite similar in this respect to the shake of September 14, 1919, with about the same indicated origin.—R.H.F.

July-September, 1941
SEISMOLOGICAL DATA by P. E. Schulz

Week Ending	Minutes of Tremor	Very Feeble	Feeble	Slight	Moderate	Local Seismicity*	Teleseisms
July 6	6	1	0	0	0	2.00	0
" 13	5	4	0	2	0	7.25	0
" 20	8	4	1	0	0	5.00	0
" 27	11	2	0	0	0	3.75	1
Aug. 3	11	12	1	0	0	9.75	2
" 10	9	5	1	0	0	5.75	0
" 17	7	4	0	0	0	3.75	0
" 24	9	2	0	0	0	2.75	0
" 31	16	4	0	0	0	6.00	0
Sept. 7	9	10	0	0	0	7.25	1
" 14	15	6	0	0	0	7.25	1
" 21	10	6	0	0	0	5.50	0
" 28	75	5	3	0	1	28.25	0

*For local seismicity definition see Volcano Letter No. 371.

Epicenters of the following local disturbances were determined by means of seismograms from the stations operated by the Hawaiian Volcano Observatory of Hawaii National Park on the islands of Hawaii and Maui. Kilauea earthquakes were located by means of the main seismograph station located at the Observatory and the subsidiary stations on Uwekahuna Bluff and near the SE rim of Halemaumau. The more distant shocks were located with the aid of seismograms from Hilo, Kealakekua, and Haleakala (Maui). The disturbances began recording at the Hawaiian Standard time indicated, and wherever possible, a determination of depth of focus has been made and is given relative to a horizontal plane of 4000 feet elevation passing approximately through the Observatory.

Building construction at the Observatory causing occasional disruptions such as stoppage of the master clock, of the automatic relay circuit, of the seismographs, and of the reception of the radio time signal has rendered the earthquake times given below inaccurate after August 5, 1941.

The number preceding each earthquake date is the serial number of the quake for the current year.

85. July 2, 01:11, very feeble, Mauna Loa NE rift, 1 mile NE of Puu Ulaula, depth 4.8 miles.

86. July 8, 10:14, slight, felt by many persons at Kilauea, NE rim of Kilauea Crater at the junction of Waldron's and Byron's Ledges, depth 0.7 mile.

87. July 8, 20:02, slight, felt generally in the Kilauea area, stronger than No. 86. Location and depth the same.

88. July 9, 15:25, very feeble, NE rim of Kilauea Crater near the Observatory.

89. July 9, 17:53, very feeble, probably on the Mauna Loa NE rift 19 or 20 miles from Hilo.

90. July 11, 21:30, very feeble, probably Mauna Loa NE rift near Hilo, of deep origin.

91. July 12, 17:46, very feeble, SW rim of Kilauea Crater 0.5 mile from the center of Halemaumau, depth 1.0 mile.

92. July 14, 02:40, very feeble, Hilina Pali fault zone about 4 miles south of Kamakaia Hills.

93. July 16, 04:25, very feeble, generally felt in Kona, just north of Akahipuu on the west Hualalai slope, depth 18.5 miles.

94. July 17, 05:16, very feeble, central portion of Kilauea, of shallow origin.

95. July 18, 05:21, very feeble, Mauna Loa 1.0 mile NE of Kiipu Cone, depth 6 miles.

96. July 19, 07:44, feeble, Mauna Loa NE rift, 20 miles from Hilo, felt by few persons in Hilo, depth 8 miles.

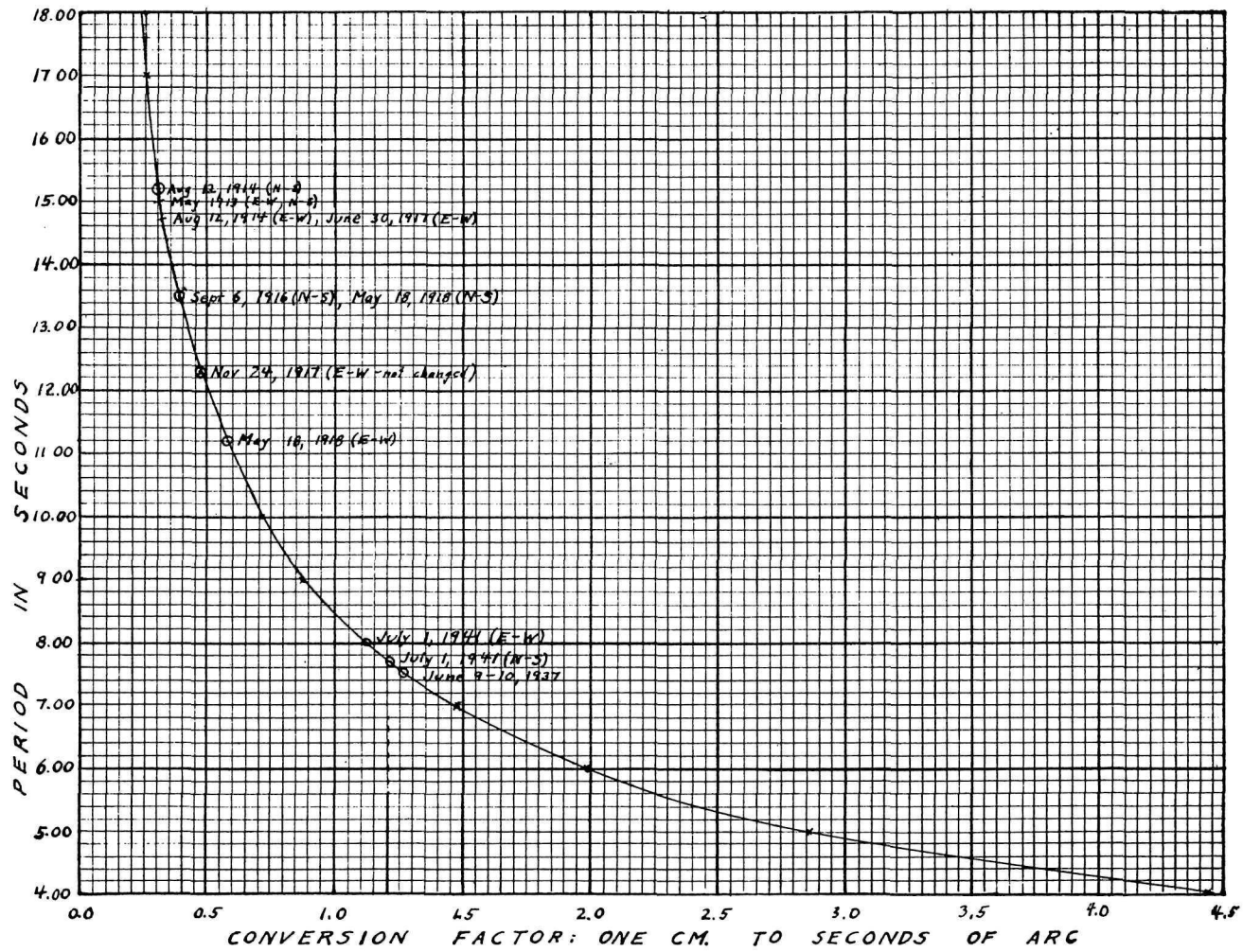

Fig. 1. Curve computed for the Bosch-Omori Seismograph pen arm displacement resulting from tilting of the ground.

97. July 21, 13:20, very feeble, Mauna Loa NE rift, 4 or 5 miles of Puu Ulaula, depth about 8 miles.

98. July 25, 13:31, very feeble, Kaoiki fault, 3.3 miles west of 3913 BM, Kilauea SW rim, depth 2.7 miles.

99. July 28, 03:07, very feeble, 1.1 miles ENE of Puu Ohale, depth 2 miles.

100. July 28, 07:31, very feeble, summit of Mauna Loa, 1.2 miles west of Mokuaweoweo, depth about 15 miles.

101. July 28, 08:32, very feeble, Mauna Loa, probably in the summit area, depth moderate.

102. July 30, 17:14, very feeble, Kilauea Crater area, of shallow origin.

103. August 1, 05:50, very feeble, Hilina Pali fault system, 3.0 miles NW of Apua Point, felt by a few persons in Hilo, depth 9 miles.

104. Aug. 2, 07:56, very feeble, Kilauea Crater, 0.2 mile west of Byron's Ledge, depth 1.0 mile.

105. Aug. 2, 10:30, very feeble, east flank of Mauna Loa, 5.3 miles NW of Uwekahuna, felt by a few persons at "29 miles," 1 mile east of the Observatory, depth 4.3 miles.

106. Aug 2. 13:21, very feeble, of Halemaumau origin, shallow depth.

107. Aug. 2, 20:09, very feeble, SW rim of Kilauea Crater, shallow depth.

108. Aug. 3, 11:16, very feeble, Puna rift, 0.1 mile NW of Devil's Throat, depth 1.5 miles.

109. Aug. 3, 12:43, very feeble, Puna rift, 0.1 mile east of Kokoolau Crater, depth 1.4 miles.

110. Aug. 3, 21:00, very feeble, probably along the Puna Rift near Kilauea Crater.

111. Aug. 3, 23:29, feeble, Puna rift, 0.2 mile north of Kokoolau Crater, depth 1.5 miles.

112. Aug. 4, 01:28, feeble, Puna rift, Kokoolau Crater, of shallow depth.

113. Aug. 4, 01:31, very feeble, Kilauea Crater probably near Byron's Ledge, shallow depth.

114. Aug. 5, 11:14, very feeble, probably Mauna Loa NE rift 4 or 5 miles NE of Puu Ulaula.

115. Aug 6, 17:15, very feeble, of Kilauea origin, possibly near the NW rim of the Crater.

116. Aug. 8, 22:28, very feeble, probably Mauna Loa NE rift area about 5 miles NE of Puu Ulaula.

117. Aug. 10, 09:32, very feeble, summit of Mauna Loa, 1.2 miles NE of Mokuaweoweo Crater, depth 12 miles.

118. Aug. 12, 22:40, very feeble, Mauna Loa NE rift, 8.0 miles NE of Puu Ulaula, depth 6 miles.

119. Aug. 14, 03:09, very feeble, Kilauea east flank 4.0 miles WSW of Pahoa, depth 16 miles.

120. Aug. 15, 17:?, very feeble, Mauna Loa NE rift probably about 6 miles NE of Puu Ulaula.

121. Aug. 17, 00:02, very feeble, Mauna Loa NE rift, Pukauahi Crater, depth 6 miles.

122. Aug. 22, 09:36, very feeble, Kilauea Crater, originated in the Halemaumau area at shallow depth.

123. Aug. 22, 11:04, very feeble, same as No. 122.

124. Aug. 27, 16:10, very feeble, probably in the vicinity of Hilea.

125. Aug. 28, 04:37, very feeble, Hilo 2.3 miles NW of the center, depth about 20 miles, felt by a few persons.

126. Aug. 30, 04:17, very feeble, Kilauea Crater, probably east central portion, of shallow depth.

127. Aug. 30, 17:56, very feeble, Kealakekua Bay, felt by a few persons in Kona, depth probably about 4 miles.

128. Sept. 1, 03:59, very feeble, Kilauea Crater central portion, felt by a few persons at Kilauea and "29 miles," of shallow depth.

129. Sept. 2, 01:10, very feeble, SE rim of Kilauea Crater, depth 0.8 mile.

130. Sept. 2, 10:08, very feeble, central Kilauea Crater, of shallow origin.

131. Sept. 2, 23:47, very feeble, probably 21 miles N of Hilo, depth 10 or 12 miles.

132. Sept. 5, 14:59, very feeble, 2.6 miles W of Uwekahuna near Kaoiki Pali, depth probably 10 miles.

133. Sept. 5, 21:26, very feeble, probably Puna rift near Heiheiahulu Crater.

134. Sept. 6, 18:34, very feeble, SE rim of Kilauea Crater 0.3 mile from Byron's Ledge junction, depth 3.5 miles.

135. Sept. 7, 03:20, very feeble, Kilauea Crater 0.2 mile SW of Halemaumau, depth 1.0 mile.

136. Sept. 7, 14:41, very feeble, pali NW of Kaoiki fault 3.9 miles west of Uwekahuna, depth 3.4 miles.

137. Sept. 7, 19:26, very feeble, Kilauea Crater, 0.2 mile south of 3646 BM, depth 0.8 mile.

138 Sept. 8, 09:20, very feeble, probably east central portion of Kilauea Crater.

139. Sept. 8, 16:25, very feeble, east rim of Keanakakoi Crater, depth 2.7 miles.

140. Sept. 8, 17:29, very feeble, NE portion of Kilauea Crater.

141. Sept. 9, 08:35, very feeble, 0.2 mile SE of Kilauea Crater near Keanakakoi, depth 1.5 miles.

142. Sept. 11, 15:17, very feeble, Kau Desert, 0.4 mile north of Cone Peak, depth 6.8 miles.

143. Sept. 14, 11:57, very feeble, probably NE central portion of Kilauea Crater.

144. Sept. 15, 01:48, very feeble, 2.0 miles east of the Observatory.

145. Sept. 16, 01:51, very feeble, 2.0 miles west of the south end of Pauahi Crater, depth 2 miles.

146. Sept. 18, 12:24, very feeble, probably of Halemaumau origin.

147. Sept. 19, 00.04, very feeble, SW portion of Mokuaweoweo Crater, depth 19 miles.

148. Sept. 19, 19:13, very feeble, NE portion Kilauea Crater.

149. Sept. 21, 16:42, very feeble, 0.3 mile SW of the center of Halemaumau, depth 1.7 miles.

150. Sept. 25, 02:07, very feeble, center of Kilauea Crater, depth 1.5 miles.

151. Sept. 25, 07:18, moderate to strong, SE flank of Mauna Loa 4.0 miles north of Kapapala Ranch House, depth 7.0 miles. Felt sharply over the whole island of Hawaii and by some persons in Honolulu. Dismantled all seismographs on the island of Hawaii (low magnification instrument not in operation) and at Haleakala on Maui. Several thousand dollars worth of damage done at Pahala where safes were moved over 1 inch northward, plaster cracked, pipes were sprung, roadfills cracked and some shoulders failed, furniture overthrown and dishes were broken in homes, pharmaceuticals at the Pahala hospital, chemicals in the Pahala Sugar Laboratories and package goods in stores were thrown from shelves. Some persons were injured in flight from houses. At Kapapala Ranch two windows and many dishes were broken, several stone walls were partially thrown down. No disturbance of the sea was reported observed at Punaluu. At Kealakekua a few books were thrown from shelves but no damage was reported. Boulders were shaken loose from steep slopes at the head of Wood Valley and on Hilina Pali. Numerous slides from Halemaumau's walls caused great dust clouds, but no damage was reported in the Kilauea area. Hilo also was strongly shaken but with only slight effect; an old earthquake crack in one building reopened. Residents in the Pahala and Kapapala area were agreed that this earthquake was stronger than any since 1929 and many claimed it was the strongest in 30 to 50 years.

152. Sept. 25, 07:30, feeble, approximately same location as No. 151, but probably deeper, sharply felt at Pahala and Kapapala.

153. Sept. 25, 07:43, feeble, probably near Ainapo, depth perhaps 20 miles, sharply felt at Pahala and Kapapala.

154. Sept. 25, 08:28, very feeble, 2.0 miles NE of Kapapala Ranch house, depth 7.0 miles, felt generally at Pahala and Kapapala.

155. Sept. 25, 09:51, very feeble, Kilauea Crater, probably of shallow Halemaumau origin.

156. Sept. 25, 10:54, very feeble, same as No. 155.

157. Sept. 25, 13:25, very feeble, SE flank of Mauna Loa, 4.0 miles NNW of Kapapala Ranch house, depth 7.0 miles, felt by many persons at Kapapala and Pahala.

158. Sept. 28, 14:11, feeble, Mauna Loa NE rift near Puu Ulaula, depth of the order of 20 miles; felt by some persons in Hilo and at "29 miles."

159. Sept. 30, 11:32, very feeble, Kilauea Kau rift 0.6 mile SE of Cone Peak, depth 2.3 miles.

160. Sept. 30, 11:32, feeble, Kilauea SE rim just SW of Keanakakoi Crater, depth 3.7 miles.

161. Sept. 30, 12:28, slight, Kilauea Kau rift, 1.2 miles SW of Cone Peak, depth 2.0 miles.

Teleseisms: Hawaii Standard time of first wave arrival used; J. S. A. data gives time of origin in Greenwich Time.

July 26, 09: 41 (?), unidentified phase; J. S. A. provisional data 20: 11: 21, 19°.1 N, 142°.2 E.

July 29, 15: 29, weak, undetermined, short period; J. S. A. data 01: 51: 28, 60°.7 N, 149°.5 W, shallow.

Aug. 2, 01: 21, distance 3775 miles; J. S. A. data 11: 41: 25, 30°.3 S, 177°.8 W possibly fairly deep.

Sept. 4, 00: 01, undetermined, recorded at Pasadena.

Sept. 13, 08: 03, undetermined.

Microseismic Motion

	July	August	September
Light	1—31	1—31	1-4, 7-30
Moderate	None	None	5, 6
Strong	None	None	None

Crater Angles, Horizontal: Measured from the 3974-foot bench mark on the NE rim of Kilauea Crater. Between June 27 and July 22, the Halemaumau angle closed 0.5" while the Kilauea Crater angle opened 3.5". Additional measurements were prevented by construction and weather conditions.

Kilauea Crater Levels

A level circuit was run from the SE crater rim to the Spit BM. From thence it was run via the Pit Seismograph counter clockwise around Halemaumau in a complete circuit. The results show an appreciable decrease in elevation of points adjacent to Halemaumau with respect to the Spit BM. Between January 16 and August 14-25, the level changes were:

South side crack #43	— 0.060 meter	(.1969 feet)
NW Pit BM	— 0.035 meter	(.1148 feet)
West Tilt Station	— 0.032 meter	(.1050 feet)
Pit Side Crack #40	— 0.029 meter	(.0952 feet)
Pit Seismograph BM	— 0.031 meter	(.1017 feet)

Crack Changes

On Friday of each week, 28 stations on rim cracks around Halemaumau were measured. During the quarter, there was a general increase in both the number of and amount of crack changes, especially in the case of openings. The total of 41 measured crack openings for the quarter amounted to 34.5 millimeters. Of these the least weekly opening was measured on July 25 and August 1, when in each instance only one crack opened 0.5 millimeter. Largest crack openings were recorded August 29, when 7 cracks opened 4.0 millimeters and September 26, when 7 cracks opened 13.5 millimeters. The largest opening unquestionably resulted from the earthquake of September 25. The total of 38 measured crack closings during the quarter amounted to 21.5 millimeters. July 4 revealed no closing; greatest closing was recorded September 26, when 8 cracks closed 6.5 millimeters.

Monthly measurements of 9 Chain of Craters cracks also showed progressive openings: July 25, none opened, and 3 closed 1.5 millimeters, on August 29, 3 opened 4.5 millimeters, and none closed, and on September 26, 6 opened 5.5 millimeters, and one closed 2.0 millimeters.

The Aloi rim crack showed a uniform rate of opening during the entire quarter save the last week in September when an opening of 7.0 millimeters was recorded due no doubt to the earthquake of September 25. The total opening of this one crack for the quarter was 15.5 millimeters.

The 5 rim cracks around Devil's Throat showed no appreciable change.

Tilt

The following tables give a summary of the tilting of the ground as measured at 3 stations on the summit of Kilauea Volcano. The ** sign indicates approximation only because of loss of tilt records from September 14 to 28 resulting from reconstruction in the seismograph cellar.

Week Ending	Tilt NE Rim Kilauea Crater			Tilt Halemaumau West Station			Tilt Halemaumau SE Station		
	Total Amount	Direction	Tilt to (+) or from (—) Halemaumau	Total Amount	Direction	Tilt to (+) or from (—) Halemaumau	Total Amount	Direction	Tilt to (+) or from (—) Halemaumau
July 6	1.67"	S11°W	+1.32"	3.10"	N29°E	+1.79"	1.61"	S60°E	—1.46"
" 13	1.28"	N48°W	+0.16"	1.49"	S45°W	—1.19"	3.56"	N39°W	+3.56"
" 20	1.21"	N12°W	—0.59"	1.49"	N45°E	+1.19"	4.99"	S86°E	—3.24"
" 27	2.47"	N39°W	—0.08"	0.00"	—	0.00"	23.98"	S15°E	—22.49"
Aug. 3	2.42"	N3°W	—1.46"	3.93"	S38°E	+2.18"	19.12"	S12°E	—17.30"
" 10	6.57"	S9°E	+3.47"	1.97"	N35°W	—0.98"	9.56"	N10°W	+8.59"
" 17	1.78"	S86°E	—1.28"	0.00"	—	0.00"	5.38"	N43°W	+5.38"
" 24	1.21"	N38°W	—0.04"	0.00"	—	0.00"	1.65"	N18°W	+1.59"
" 31	2.53"	N32°W	—0.41"	0.00"	—	0.00"	6.93"	N15°E	+4.47"
Sept. 7	2.93"	S55°W	+2.93"	3.22"	N26°E	+1.70"	3.11"	N9°W	+2.85"
" 14	1.91"	N86°E	—1.52"	1.37"	S44°E	+0.86"	1.91"	S64°E	—1.75"
" 21	Tilt undeterminable			1.58"	S49°W	—1.28"	0.00"	—	0.00"
" 28	Tilt undeterminable			8.46"	N88°E	+8.46"	25.69"	N35°W	+25.69"
Quarter Ending Sept. 28	Net tilt toward (+)2.03"**			Net tilt toward (+)12.73"			Net tilt toward (+)5.89"		

NE Rim Kilauea Crater

Year Ending	Total Amount	Direction	Tillt to (+) or from (—) Halemaumau	Net N-S Tilt	Net E-W Tilt
July 31	8.75"	S46°E	—2.11"	6.17"S	6.29"E
Aug. 30	11.95"	S16°E	+5.07"	11.50"S	3.27"E
Sept. 30	12.62"**	S 3°W**	+8.76"**	12.58"S**	0.73"W**

THE VOLCANO LETTER

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Hawaii National Park
Edward G. Wingate, Superintendent
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University of Hawaii
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LAVA FLOWS IN EASTERN PUNA

By GORDON A. MACDONALD
Associate Geologist, U. S. Geological Survey*

Introduction. Only once since the beginning of written records in Hawaii have lava flows inundated part of eastern Puna. That once was in 1840. But there is ample evidence that in geologically recent times Puna has often been the site of eruption of cinder cones and extensive lava flows. More than sixty cinder and spatter cones dot the east rift zone of Kilauea volcano from the end of the Chain of Craters Road to Cape Kumukahi. Some are 150 to 200 feet high and half a mile or more in diameter, and others are mere hillocks. It is probable that all of the surface lavas throughout this region should be considered geologically Recent, but many of them are of such late date that it is surprising not to find more mention of them in native tradition. Few references to prehistoric lava flows have been preserved by the Hawaiian chroniclers however, perhaps because eruptions were so commonplace.

Much of the northeastern slope of Kilauea between the towns of Olaa and Pahoa is covered by flows of pahoehoe basalt that cannot be more than a few hundred years old. Not only are they nearly devoid of any soil or ash cover, but the vegetation which covers them is often scant and is of the type composed largely of small ohia trees and abundant staghorn fern which characterizes the younger lava flows, such as those of 1793 (?) and 1840. Through these younger lavas protrude **kipukas**, or "islands" of older rock, covered by several inches of ashy soil and the tree-fern jungle which typifies the more mature forests of Puna. Although these late lavas must certainly have been erupted within the time of residence of the present Hawaiian people, who are believed to have arrived in the islands about 1100 A.D.,[1] no mention of them is found in native tradition.

Traditional prehistoric eruptions. A few eruptions recorded by tradition before the arrival of the missionaries in 1820 may be mentioned. The dates are, of course, uncertain. The earliest is an eruption near Kapoho, probably between 1340 and 1380 A.D.[2] This eruption is incorporated in a legend which relates how Pele, goddess of volcanoes, attended in disguise a great **holua**, or sliding contest, held near Kapoho by Kahawali, the chief of the neighborhood. Challenging Kahawali to a race, Pele was badly beaten. She then asked the chief to lend her his sledge so that she might try again. When he refused, the angry goddess stamped upon the earth, and there burst forth showers of heated rocks. Realizing too late the identity of his competitor, the chief fled panic-stricken to Puu Kukii and then northward to the coast, pursued all the way by Pele's magmatic missiles. A crack trending N 60° E, which still exists between Kapoho and Koae, is said to have opened up before him, but he crossed it by laying down his spear for a bridge. Not until he had paddled far out to sea did he escape.

Translating this story into terms of the modern volcanologist, a flank eruption of Kilauea appears to have commenced with the opening of a fissure and the ejection of cinders at Kaholua o Kahawali (Kahawali's holua-slide). As the fissure opened farther and farther down the flank of the mountain the eruption progressively shifted farther seaward, building the line of small cinder and spatter cones which terminates at Kapoho.

Another eruption is said to have occurred near Kaimu in the reign of Alapai, probably between 1730 and 1754.[3] This eruption probably produced the fresh-appearing aa flow crossed by the Pahoa-Kalapana road a mile north of Kaimu. At this altitude the lava is covered only by lichens and moss, and appears as fresh as the 1922 lava in Napau Crater. But farther mountainward, in regions of greater rainfall, it supports thick vegetation, although not much more than the 1793 (?) and 1840 lavas.

Eruption of 1793 (?). When William Ellis, in 1823, questioned the natives about early eruptions of Kilauea, part of the meager information he elicited was mention of an eruption thirty years or so before.[4] The eruption was said to have produced voluminous lava flows contiguous to the cones of Honuaula, Puulena, and Kaliu, along the east rift zone of Kilauea, 3½ to 7 miles southwest of Kapoho. The boundaries of this lava flow as shown in the accompanying figure were mostly mapped by the topographers of the U. S. Geological Survey in 1922 (Kalapana quadrangle), but it was labeled "Lava flow of 1840." However, the distribution of the lava fits so well the traditional description of the 1793 (?) flow that there can be little doubt that it originated at that time. The lava differs in composition from the adjacent flow which reached Nanawale Bay in 1840, and moreover the map prepared by Commodore Wilkes only a few months after the 1840 eruption does not show the 1840 lava approaching within a mile of the line of

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* Published by permission of the Director, Geological Survey, U. S. Dept. of the Interior.

[1] Buck, P. H., **Vikings of the Sunrise**, p. 252, New York, 1938.

[2] Ellis, William, **A Narrative of a Tour Through Hawaii, or Owhyhee**, pp. 219-223, Honolulu, 1917.
Hitchcock, C. H., **Hawaii and Its Volcanoes**, pp. 164-165, Honolulu, 1911.

[3] Hitchcock, **op. cit.**, p. 164.

[4] Ellis, **op. cit.**, pp. 214, 218.

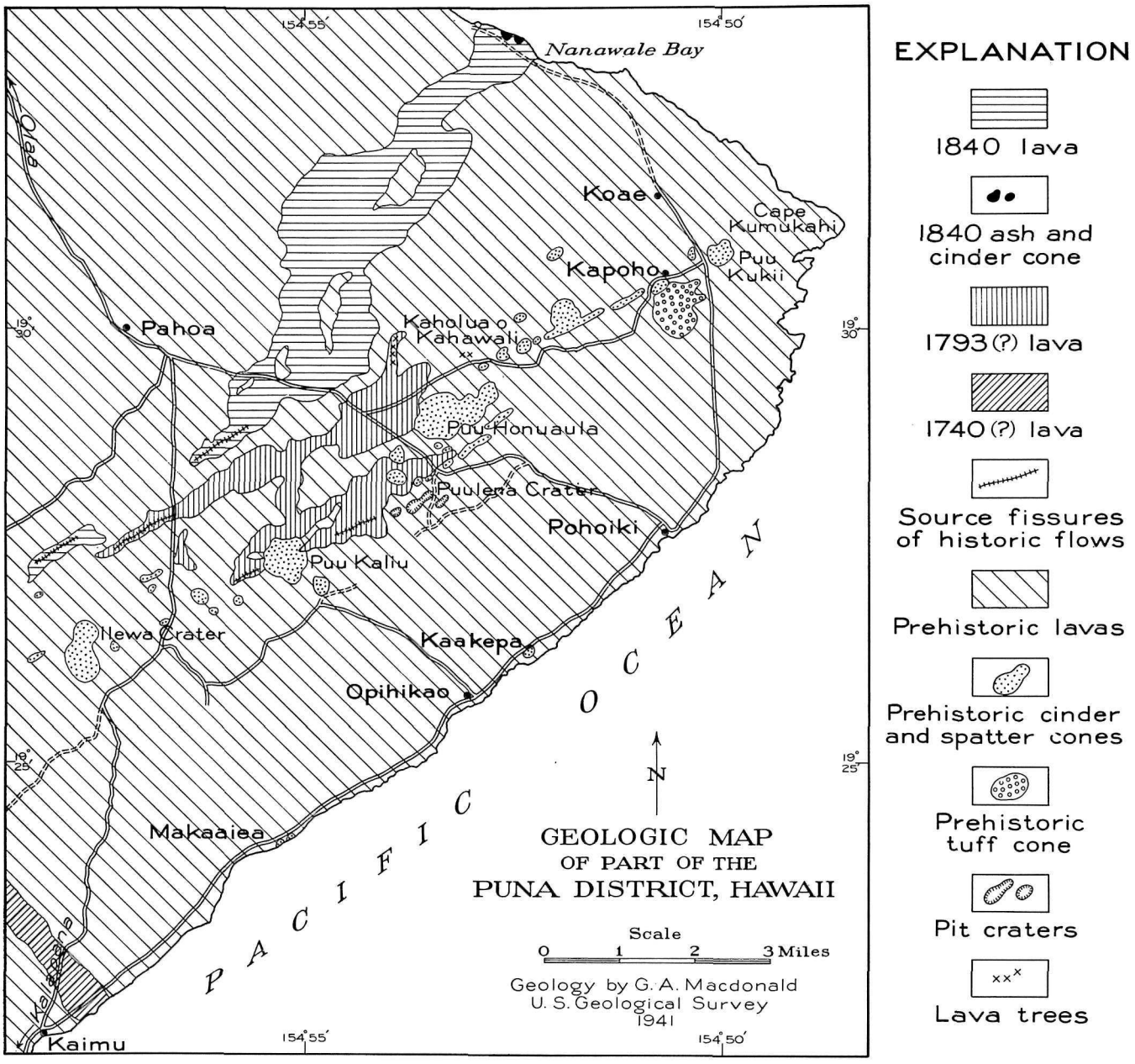
cinder cones.[5] The 1793 (?) lava issued from fissure vents and is largely pahoehoe. Lava trees are well preserved along the narrow northern tongue of the flow north of the Pahoa-Kapoho road and northwest of Puu Honuaula.

Eruption of 1840. The only large eruption which has occurred in eastern Puna since the advent of white men in Hawaii is that of 1840. The eruption was not witnessed by white men, but the region was traversed shortly afterward by Father Coan, who for 40 years was the faithful chronicler of Hawaiian volcanoes, and by Commodore Wilkes, Dr. Pickering, James D. Dana, and other members of the United States Exploring Expedition. The outbreak commenced with the appearance of lavas in Alae Crater, a pit crater near the Chain of Craters Road, on May 30.[6] The lava level rose about 300 feet in the pit crater but fell again when new eruptions appeared on the flanks of the lava cone Kane Nui o Hamo, and north and west of Napau Crater. The spatter left at the "high water mark" in Alae Crater was examined soon afterward by Dr. Pickering. Cracking continued along the east rift zone toward Kapoho, fissures a few inches to 10 or 12 feet wide being opened, but no lava reached the surface. Finally, on June 1, the principal flow commenced near the present Pahoa-Kalapana road. Three days later it reached the sea at Nanawale Bay, and it continued to flow into the sea for three weeks, building out the shore line about a quarter of a mile.

Where the lava encountered sea water, violent steam explosions resulted, and the liquid lava was hurled into the air as by a giant atomizer, to be drifted inland by the wind or heaped into small hills of glassy sand on the fresh lava at the edge of the water. Three of these hills were built, ranging in height from 150 to 250 feet, but because of their unconsolidated nature and their exposure to the full impact of the ocean waves and the nearly constant northeast trade winds, they were rapidly eroded away. There are now only two of them left, and the highest is only 78 feet high.

Coan[7] tells of a man who went to watch the 1840 flow and, wishing to take no chances, stopped some distance away on

[5] Wilkes, Charles, **Narrative of the U. S. Exploring Expedition, 1838-1842**, vol. 4, p. 110, 1845.
[6] Coan, Titus, **Missionary Herald**, vol. 37, p. 283, 1841.
[7] **Op. cit.**



open lava, whence he had a good view of the moving stream. He was therefore considerably startled suddenly to find the lava crust rising beneath his feet. Escaping from his dangerous position, he looked back and saw that where he had stood the crust had been buckled up to a height of 15 or 20 feet, and that liquid lava was escaping through crevices. This man appears to have had the unusual experience of standing on an actively developing tumulus.

Hawaiian Volcano Observatory Report for October - December 1941

VOLCANOLOGY

October 1941

Conspicuous fuming at Mokuaweoweo was noted early in the month. The majority of the October earthquakes were of Kilauea origin. The widely felt earthquake of October 25 had its origin near Waimea well down the northwestern slope of Mauna Kea. It was deep seated and may well have originated along the fundamental NW-SE rift of the Hawaiian ridge.

November 1941

As the month progressed it was found that the earthquakes of October 25 and November 8 were premonitory of the swarm of shakes that started at Waimea on the north slope of Mauna Kea on November 13. The shaking was more or less continuous, and by December 7 over 2,000 quakes had been recorded on the Mauna Loa seismograph, the instrument nearest the epicenter. No cracks were observed at the surface in the epicentral area. The characteristics of the shaking indicated that the focus extended into a region with an appreciable degree of mobility. This is not surprising when one considers that the quakes originated 27 miles below the surface.

December 1941

Immediately following the Waimea shakes, which ceased on December 8, there commenced a seismic lull that continued through the rest of December. There are some reasons for thinking that such a seismic lull indicates a high or increasing lava pressure under Hawaiian volcanoes.

SEISMOLOGY

Earthquakes October - December 1941

Week Ending	Minutes of Tremor	Very Feeble	Feeble	Slight	Moderate	Local Seismicity*	Teleseism
Oct. 5	20	1	1	1	0	8.50	0
12	7	4	0	0	0	3.75	0
19	14	0	0	0	0	3.50	0
26	4	1	2	0	0	3.50	0
Nov. 2	13	8	5	3	0	18.75	0
9	5	2	0	0	0	2.25	0
16	52	13	1	1	1	25.50	0
23	68	16	4	1	1	35.00	0
30	40	4	0	0	0	12.00	1
Dec. 7	373	2	0	0	0	94.25	1
14	49	2	0	0	0	12.75	0
21	9	2	0	0	0	2.75	0
28	5	0	1	0	0	2.25	0

* For definition of local seismicity see Volcano Letter No. 371.

The data of the following local disturbances was determined from six seismograph stations operated on the islands of Hawaii and Maui by the Hawaiian Volcano Observatory of the Hawaii National Park. Time is Hawaiian Standard. Distances are from Observatory.

The number preceding each earthquake date is the serial number of the quake for the current year.

162. October 7, 14:29, very feeble, distance 14 miles.

163. October 8, 05:24, very feeble, distance 16 miles NE slope, Mauna Loa.

164. October 10, 11:22, very feeble, distance 3 miles SW of Kilauea.

165. October 12, 08:07, very feeble, distance 4 miles SW of Kilauea.

166. October 20, 00:47, very feeble, N slope of Mauna Kea.

167. October 20, 00:51, feeble, near Mokuaweoweo.

168. October 25, 08:54, feeble, N slope of Mauna Kea near Waimea, generally felt on island of Hawaii.

169. October 28, 01:46, very feeble, distance 4 miles.

170. October 28, 08:06, slight, NE rift of Mauna Loa.

171. October 28, 08:07, very feeble, beginning in No. 170.

172. October 28, 08:15, feeble, distance 9 miles.

173-176. October 28, four very feeble shakes during forenoon.

177. October 29, 05:10, very feeble, distance 7 miles.

178. October 29, 08:54, very feeble.

179. October 29, 09:42, feeble, distance 7 miles.

180. October 29, 11:30, very feeble.

181. October 30, 08:31, very feeble.

182. October 30, 18:00, slight, distance 7 miles.

183. October 31, 11:51, slight, distance 7 miles.

184. November 2, 00:20, feeble, P uncertain.

185. November 8, 13:20, very feeble, distance 58 miles.

186. November 9, 05:44, very feeble, distance 16 miles NE slope of Mauna Loa, felt in Hilo.

187. November 11, 02:41, very feeble, distance 16 miles, felt locally.

188. November 13, 20:07, feeble, distance 52 miles, felt in Waimea.

189-196. November 14, 00:51-17:34, eight very feeble shakes, distance 58 miles, felt plainly at Waimea and lightly at widely scattered points on island of Hawaii, depth 27 miles.

197. November 15, 06:53, slight, distance 52 miles, 27 miles deep near Waimea, Hilo instrument dismantled.

198. November 15, 13:27, very feeble, felt in Waimea.

199. November 15, 18:37, feeble, distance 52 miles, felt generally in northern part island of Hawaii.

200. November 16, 02:31, feeble, distance 52 miles, near Waimea, depth 27 miles.

201. November 16, 02:35, very feeble.

202. November 16, 09:41, moderate, origin near Waimea 52 miles away and 27 miles deep, generally felt over island of Hawaii, some slight damage, instruments dismantled.

203-207. November 17, five very feeble shakes originating near Waimea.

208. November 18, 02:56, moderate-strong, strongly felt on entire island and to a lesser degree on Maui, near Waimea, slight damage, 27 miles deep.

209-210. November 18, two very feeble shakes, origin near Waimea.

211. November 18, 10:30, feeble, generally felt over island.

212. November 18, 10:33, feeble, generally felt over island.

213-216. November 18, four very feeble shakes with origin near Waimea.

217. November 19, 07:43, feeble, distance 52 miles, widely felt.

218-219. November 19, two very feeble shakes, origin near Waimea.

220. November 22, 10:04, feeble, near Waimea.
221-222. November 22, two very feeble Waimea shakes.
223. November 22, 21:23, slight, near Waimea, generally felt on island of Hawaii and by a few persons on Maui.
224. November 22, 22:12, very feeble, felt in Waimea.
225. November 24, 18:02, very feeble.
226-228. November 30, three very feeble Waimea shakes.
229. December 4, 09:30, very feeble, distance 52 miles, near Waimea.
230. December 6, 09:44, very feeble, distance 4 miles.
231. December 13, 23:15, very feeble.
232. December 18, 13:00, very feeble.
233. December 20, 15:30, very feeble.
234. December 24, 09:54, feeble, distance 5 miles.
235. December 30, 14:22, feeble, distance 5 miles.

Teleseisms

December 5, 10:29, distance 4,700 miles.

Microseismic Motion

Microseisms were light throughout the quarter.

Crack Changes

Crack movement around Halemaumau and along the Chain of Craters for the quarter was slight. Opening of the crack predominated over closing but most cracks remained unchanged.

Tilting of the Ground

The southeast Halemaumau station showed a slight accumulation of northerly tilt during the quarter. The accumulation of tilt at the west Halemaumau station was very slight to the ENE.

Table of tilt at Observatory on NE rim of Kilauea.

Week Ending		Amount of Tilt	Direction of Tilt
October	5	1.54″	N 51° E
	12	2.43″	N 69° E
	19	3.41″	N 18° E
	26	5.28″	N 66° E
November	2	1.64″	S 39° E
	9	3.52″	N 8° E
	16	4.32″	N 17° E
	23	0.30″	S 45° W
	30	1.70″	S 82° E
December	7	2.28″	N 32° E
	14	1.70″	S 82° W
	21	4.54″	S 34° E
	28	3.52″	S 49° W

R. H. F.

HAWAIIAN VOLCANO RESEARCH ASSOCIATION
in cooperation with
UNIVERSITY OF HAWAII

The **Hawaiian Volcano Research Association** was founded in 1911 for record of volcanoes in the Hawaiian Islands and around the Pacific Ocean. Its equipment at Kilauea Volcano, Hawaii Island, has been transferred to the United States Government, Department of the Interior, National Park Service.

The **University of Hawaii** cooperates in maintaining a research laboratory at Hawaii National Park. The **Association** and the **University** maintain outside seismograph stations and supplement the work of the government with research associates, instrumental plants and special investigation. Dr. T. A. Jaggar is their geophysicist resident in the National Park.

The **Volcano Letter,** a quarterly record of the Hawaiian volcano laboratories and published by the University of Hawaii, is issued by authority of the Department of the Interior and supplied to a restricted membership and exchange list of the above establishments.

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THE PHYSICAL PLANT—HAWAIIAN VOLCANO OBSERVATORY

BY P. E. SCHULZ

A new physical set-up is resulting in a material improvement at the Volcano Observatory, Hawaii National Park. The tearing down of the old Observatory buildings on the brink of the northeast rim of Kilauea crater was completed in September. The first unit of the Hawaiian Volcano Observatory was built in 1912 by the Hawaiian Volcano Research Association. Additions were made thereto from time to time in subsequent years. The old structures have been razed to make their site available for the new hotel in Hawaii National Park—the Volcano House. The seismograph cellar, however, remains, and a reinforced concrete slab has been emplaced over it. The slab is covered with about 18 inches of soil. This covering coupled with the location over steam cracks results in a nearly constant temperature cellar. The diurnal variation seldom exceeds 1°F. There the Bosch-Omori seismograph will continue to function **in situ** as the nucleus of the instruments of the Observatory.

During the wrecking operations and construction, tilt records (pen wanderings with respect to reference lines on seismograms) were lost or useless for 2 weeks in September, 1941, but only 3 days' seismograms were lost. The latter break in record was reasonably well filled by the records from outlying stations. The low magnification and vertical component instruments were taken out of service August 17, 1941. The former will be reinstalled in the old seismograph cellar.

The new quarters of the Hawaiian Volcano Observatory are in the Volcano Observatory and Naturalist Building, which is nearing completion, approximately 610 feet east-northeast of the old site. It will be provided with fireproof rooms for the storage of the official records of the Observatory and with ample office, machine shop, drafting, and library space. A seismograph cellar is also provided, and here the vertical component seismograph has been installed. A simple 2-component horizontal pendulum-type tilt meter is also being installed. This cellar is also built over a steam crack and but slight diurnal and seasonal temperature variations are indicated. In the near future a Hawaiian-type seismograph will be added, possibly to be replaced ultimately with a high magnification instrument.

The new physical set-up is a step forward. The most important implication may be the operation of seismographs and tilt meters in the area about 640 feet from the sheer, 220-foot cliff of Kilauea crater, at the base of which fault blocks and talus descend another 250 feet to the crater floor, and the concurrent maintenance of additional seismographs on the old site only about 30 feet from the cliff. It is expected that there will be a difference in the daily and seasonal tilt, and in the character and amplitude of local earthquakes as recorded in the two locations.

Hawaiian Volcano Observatory Report for January-March, 1942

VOLCANOLOGY

January

The seismic lull that started on December 8, 1941 continued through the month of January. More earthquakes were recorded on Mauna Loa than at Kilauea. There was no surface manifestation of volcanic activity at any Hawaiian volcano during January.

February

The history of Mauna Loa indicates that a flank eruption can be expected during 1942. An earthquake on February 8 on the northeast rift 8 miles southwest of Hilo with a depth of 30 miles was the first definite premonitory symptom in 1942 of such an eruption. A subsurface splitting progressed up the northeast rift, the foci of the earthquakes became progressively shallower. A series of earthquakes on February 21 near the source of the 1852 flow had a depth of 5 miles.

An earthquake at 00:09 February 18 which originated 8 miles under the northern end of Kilauea crater may well have been directly connected with the growing uneasiness of the Mauna Loa-Kilauea system. Coincidental with the occurrence of this shake there commenced a slight northerly tilt at the Observatory that continued until the last of March. It should be borne in mind that before there can be a northerly tilt at this time of year the pressure increase must first be sufficient to overcome the normal southerly tilt.

March

The progressive cracking along the northeast rift of Mauna Loa continued in March, first showing epicenters high up on the northeast rift, then under Mokuaweoweo, and finally on March 21 some distance down the southwest slope. When earthquakes were resumed along the northeast rift on March 28, it seemed safe to predict that Mauna Loa would soon erupt from this rift. Such a forecast was written but not published, owing to war conditions.

Tilt records for March continued and strengthened the indications that Kilauea was reacting sympathetically to Mauna Loa's preparation for an outbreak. The E-W tilt curve for March was marked by pronounced irregularities, which is what might be expected to accompany an increase of internal pressure. Records show that irregularities are more prominent when Halemaumau is active than in times of quiet. The northerly tilt, however, was insufficient to indicate that a breaking of the Halemaumau seal could be expected.—R.H.F.

SEISMOLOGY

Earthquake Data, January-March, 1942

Week Ended	Minutes of Tremor	Very Feeble	Feeble	Slight	Moderate	Local Seismicity*	Teleseisms
Jan. 4	3	1	1	0	0	2.25	0
11	18	1	2	0	0	7.00	0
18	6	3	0	0	0	3.00	0
25	6	0	0	1	0	3.50	1
Feb. 1	8	3	0	0	0	3.50	0
8	5	1	0	1	0	3.75	0
15	6	0	0	0	0	1.50	0
22	14	4	2	3	3	22.50	0
Mar. 1	11	3	0	0	0	4.25	0
8	11	2	0	1	0	5.00	0
15	8	4	1	1	0	7.00	0
22	17	5	2	2	1	15.75	1
29	7	1	0	1	0	4.25	0

*For definition of local seismicity, see Volcano Letter No. 371.

The data of the following local disturbances were determined from seismograph stations operated on the island of Hawaii by the Hawaiian Volcano Observatory of the Hawaii National Park. Time is Hawaiian Standard. Distances are from the Observatory.

The number preceding each earthquake date is the serial number of the quake for the current year.

1. January 2, 13:13, very feeble, felt in Kona.
2. January 9, 13:35, feeble, distance 25 miles.
3. January 9, 14:20, feeble, distance 3 miles, felt locally.
4. January 10, 15:20, very feeble, distance 2 miles.
5. January 12, 15:45, very feeble.
6. January 15, 17:36, very feeble, distance 4 miles.
7. January 18, 05:39, very feeble, distance 17 miles.
8. January 25, 06:13, slight, distance 16 miles, plainly felt locally, broke a few dishes at Kilauea Military Camp.
9. January 26, 22:17, very feeble.
10. January 28, 09:21, very feeble, distance 14 miles.
11. January 29, 09:38, very feeble, northeast rift of Mauna Loa.
12. February 8, 17:48, slight, 8 miles SW of Hilo, 30 miles deep, felt locally, Hilo instruments dismantled.
13. February 8, 19:56, very feeble, *same location* as No. 12.
14. February 18, 11:09, moderate, 8 miles deep, under northern end of Kilauea crater, awakened many people, dismantled local and Mauna Loa seismographs.
15. February 21, 08:11, moderate, distance 15 miles on NE rift of Mauna Loa, 5 miles deep, all island seismographs dismantled, widely felt.
16. February 21, 08:14, moderate, same as No. 15, only one seismograph recording at beginning.
17. February 21, 08:36, slight, same location as Nos. 15 and 16, E-W dismantled.
18. February 21, 10:01, very feeble.
19. February 21, 20:15, very feeble.
20. February 21, 20:32, feeble, distance 15 miles.
21. February 21, 22:28, very feeble.
22. February 22, 04:12, feeble, distance 14 miles.
23. February 22, 14:47, slight, distance 16 miles.
24. February 22, 15:05, slight, distance 15 miles.
25. February 23, 22:31, very feeble.
26. February 24, 15:34, very feeble.
27. February 26, 14:11, very feeble.
28. March 5, 12:46, very feeble, felt at Kapapala.
29. March 5, 13:14, very feeble.
30. March 7, 06:41, slight, under northern end of Mokuaweoweo.
31. March 13, 21:20, very feeble.
32. March 15, 09:35, slight, E-W dismantled, near southern end of Mokuaweoweo.
33. March 15, 11:00, very feeble.
34. March 15, 12:24, very feeble, southwest of Mokuaweoweo.
35. March 15, 12:39, very feeble.
36. March 15, 23:43, feeble, southwest rift of Mauna Loa, felt in Kona.
37. March 16, 07:08, feeble, near southern end of Mokuaweoweo, felt in Kona.
38. March 16, 21:57, slight, E-W dismantled, near southern end of Mokuaweoweo, felt in Kona.
39. March 18, 11:21, very feeble, SW rift of Mauna Loa.
40. March 18, 15:16, very feeble, northern end of Mokuaweoweo.
41. March 19, 00:17, slight, E-W dismantled, near Mokuaweoweo.
42. March 20, 01:34, very feeble.
43. March 20, 23:05, moderate, dismantled instruments, widely felt, stopped clocks in South Kona, on SW rift of Mauna Loa.
44. March 21, 01:34, very feeble.
45. March 21, 20:14, feeble, SW rift of Mauna Loa, felt in South Kona.
46. March 25, 09:14, very feeble.
47. March 28, 21:55, slight, NE rift of Mauna Loa, felt locally and in Hilo.

Teleseisms

January 19, 20:00, slight.
March 19, 01:46, slight.

Microseismic Motion

Microseisms were very light throughout the quarter.

Tilting of the ground

The southeast Halemaumau station showed a slight NNW tilt for the quarter, while the tilt at the west station was slight to the ENE.

Table of Tilt at Observatory on NE rim of Kilauea

	Week Ended	Amount of tilt	Direction of tilt
January	4	1.21″	S 45° W
	11	1.69″	E
	18	2.06″	N 32° W
	25	1.81″	S 71° E
February	1	2.81″	S 31° W
	8	4.48″	S 80° W
	15	1.60″	S 13° E
	22	2.78″	N 62° W
March	1	1.94″	N 86° E
	8	1.10″	N 41° E
	15	2.42″	N 71° W
	22	4.96″	E
	29	6.41″	N 87° W

Crack Measurements

During the quarter 21 Halemaumau cracks opened an average of 4.2 millimeters, 7 remained unchanged, and no crack showed a closing. Of the 13 cracks that were measured along the Chain of Craters Road, 7 opened an average of 26.2 millimeters, one closed 1 millimeter, and 6 remained unchanged. R.H.F.

THE VOLCANO LETTER 476

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PUBLISHED BY THE UNIVERSITY OF HAWAII

Hawaii National Park
Edward G. Wingate, Superintendent
R. H. Finch, Volcanologist

University of Hawaii
T. A. Jaggar, Geophysicist

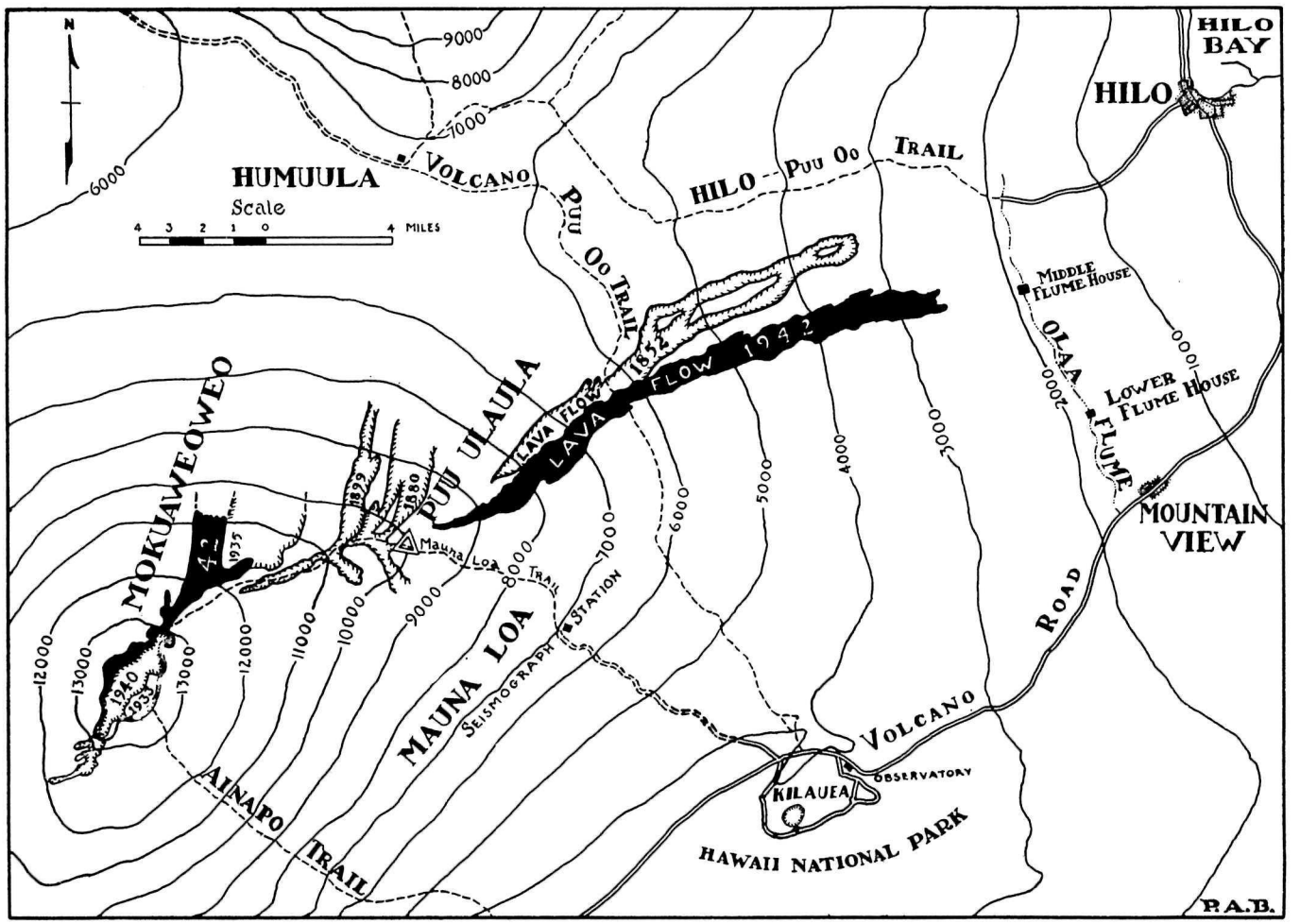

Fig. 1—The northeast slope of Mauna Loa, showing the approximate location of the 1942 flows.

THE 1942 ERUPTION OF MAUNA LOA

By R. H. FINCH

The expected eruption of Mauna Loa began on April 26, 1942 when a line of fountains appeared in the northern part of Mokuaweoweo and for a short distance down the northeastern rift. The summit of Mauna Loa was obscured by clouds at the beginning of the outbreak, though the recording of continuous tremor on the seismographs indicated that it began a little after 5:00 P.M., daylight-saving time, (4:00 P.M., H.S.T.).

The events leading up to the eruption were of especial interest, as they made it possible to predict both the approximate time and place of the outbreak. The history of Mauna Loa teaches us that it is periodic in its activity. After reviewing the historical record, Dr. T. A. Jaggar wrote in 1937 that a lava flow from the northeast rift of Mauna Loa could be expected anytime from 1942 on. The summit eruption of 1940 made 1942 a year with very definite prospects for a flank eruption. Such a historical background gave one complete confidence that an eruption was imminent when seismological evidence pointed to the same conclusion.

Possibly the seismic prelude to the 1942 eruption may be thought of as starting with the seismic crisis near Waimea in November and December, 1941, when about 2,000 earthquakes with depth of focus of about 27 miles occurred. Such shakes indicate an adjustment along the southeastern part of the fundamental Hawaiian rift, though the records were insufficient to show conclusively whether the shaking accompanied an increase or decrease in pressure. Most of the evidence, however, indicated a pressure increase.

On February 8, 1942, an earthquake occurred 8 miles southwest of Hilo, with an indicated depth of 30 miles. The origin was 37 miles southeast of the Waimea shakes and underneath the extension of the northeast rift of Mauna Loa. There was a progressive movement of the epicenters of the earthquakes up the northeast rift after this date, and on February 21 a series of shakes with depth of origin of about 5 miles originated nearly under the source of the 1852 lava flow or about where the 1942 flank eruption was to break out later. During February, 50 earthquakes were recorded at Kilauea, while 143 were recorded on the Mauna Loa seismograph. The preponderance of Mauna Loa shakes was about the same in March, or 57 at Kilauea, and 136 at Mauna Loa.

After February 21 the epicenters of the earthquakes continued to progress along and up the Mauna Loa rift from northeast to southwest. The northern end of Mokuaweoweo was reached on March 7. A shake on March 20 that originated 5 miles southwest of and across Mokuaweoweo was widely felt over the island of Hawaii. It was especially strong along the Kona coast, where some clocks were stopped and objects thrown from shelves. This shake marked the end of progressive cracking and when earthquakes were resumed along the northeast rift on March 28, it seemed safe to assume that an eruption of Mauna Loa could be expected anytime and that it would occur along the northeast rift. Owing to war conditions, a forecast was not made public, though one was included in the March report of the Observatory to Park Superintendent Edward G. Wingate. Press reports in February and March had called attention to the growing uneasiness of Mauna Loa.

The nature of the splitting action or movement that produced the shakes when the earthquakes were progressing from the northeast to southwest is not clear. A wedging force, applied at a depth of 5 miles or more, from below upward seems indicated. The splitting action down the mountain just preceding a flank eruption produces shallow foci earthquakes and cracks that reach the surface. In many cases the depth of this cracking may well be less than 10,000 feet. The depth of foci of earthquakes and the fact that summit activity nearly always precedes a flank eruption indicate that the ascent of lava at Mauna Loa is restricted to the feeding conduits under Mokuaweoweo.

From observations made after the eruptions, in August, Dr. G. A. Macdonald of the U. S. Geological Survey reports that summit activity originated along a fissure that started near the large bend in the northwestern wall of Mokuaweoweo. After roughly following the northwest wall of the main crater, the fissure crossed the North Bay and extended down the northeast rift for about 2 miles. Within Mokuaweoweo the fissures were, for the most part, well up on the crater wall though they came down to the floor in places. There were several lava cascades into Mokuaweoweo from wall cracks 200 to 300 feet above the crater floor. New lava made an appreciable fill near the western edge of the main crater and covered over half of the North Bay. From the crack outside the crater, a lava flow poured northward for several miles. The upper part of the upper 1935 lava flow was largely buried and the cone of that year entirely surrounded (fig. 1).

By early morning of April 27 the summit activity was about over, and splitting down the rift was in progress as evidenced by numerous perceptible earthquakes. According to G. O. Fagerlund and B. J. Loucks of the Hawaii National Park staff, who arrived at Puu Ulaula at 8:40 A.M. after spending the night on the trail, earthquakes were so frequent that sleep was impossible.

At 3:34 P.M. a vent opened at about 12,000 feet that emitted great quantities of fume. Coincident with the opening of this vent, earthquakes diminished as though the escape of gas had released the pressure to a stage below that necessary for continuance of splitting. The shaking had noticeably increased by 9:00 P.M. and reached a climax at 10:41 P.M. with an earthquake of alarming

proportions. The Mauna Loa seismograph (see map, fig. 1), which is but 6 miles from the epicenter of this shake, suffered considerable damage.

At 4:40 A.M., April 28, lava made its appearance along a crack three-fourths of a mile long, extending from an elevation of 9,500 feet to 9,100 feet. By 9:00 A.M. the upper 500 feet of the fountaining chain was sealing off after having built up a low spatter rampart. By 1:40 P.M. activity had nearly ceased along the next 500-foot stretch, and fountaining was becoming concentrated near the lower end. The lower fountains ejected frothy slag as well as pumice (fig. 2). From the ground it appeared as though there were a distinct northerly bend in the live rift near the lower end. An airplane view by the Army Air Corps indicates that there were two nearly parallel cracks 20 to 30 feet apart, from which lava issued. The lava river from the upper northern crack in joining that from the lower one produced the illusion of a sharp bend.

Airplane observations at 9:30 A.M., April 28, showed that the front of the lava river which issued from the lower end of the fountaining area was obscured by clouds below the Puu Oo trail. This meant a progress of over 6 miles in 5 hours.

As the 1942 flow was partly on top of and moving parallel to the 1852 flow, and thus heading in the general direction of Hilo, its progress was watched with considerable apprehension. Observations of the front of the flow were difficult, owing to its location in a dense jungle and to its being obscured by clouds most of the time. Transit observations by Park Engineer A. L. Jess at 8:00 P.M., April 30, indicated that the front of the flow was at an elevation of 3,500 feet and had progressed nearly 2 miles in the preceding 12 hours.

On May 1, sites for bombing, with a view of diverting lava rivers into new channels and thus making two or more short flows instead of one long one, were selected by A. L. Jess and the writer while flying over the flow in a United States Army airplane. A secondary source,

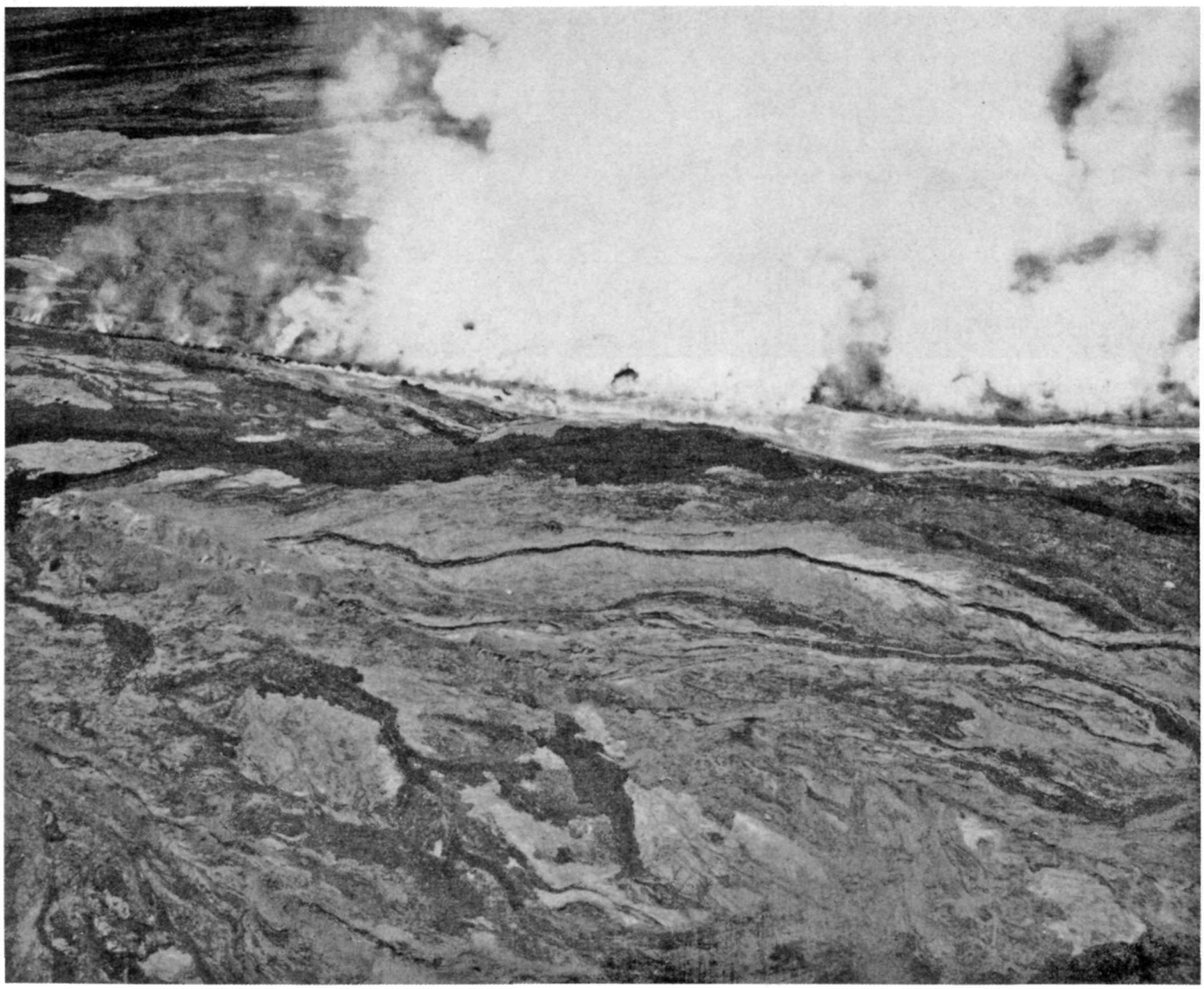

Fig. 2—Looking across the northeast rift of Mauna Loa, April 28, toward the source of the 1942 flank eruption. Though taken early after the outbreak, lava fountains have ceased in the upper 1,000 feet of the fissure. Photo by Base Photo Lab., A. A. F.—A. P. O. No. 953.

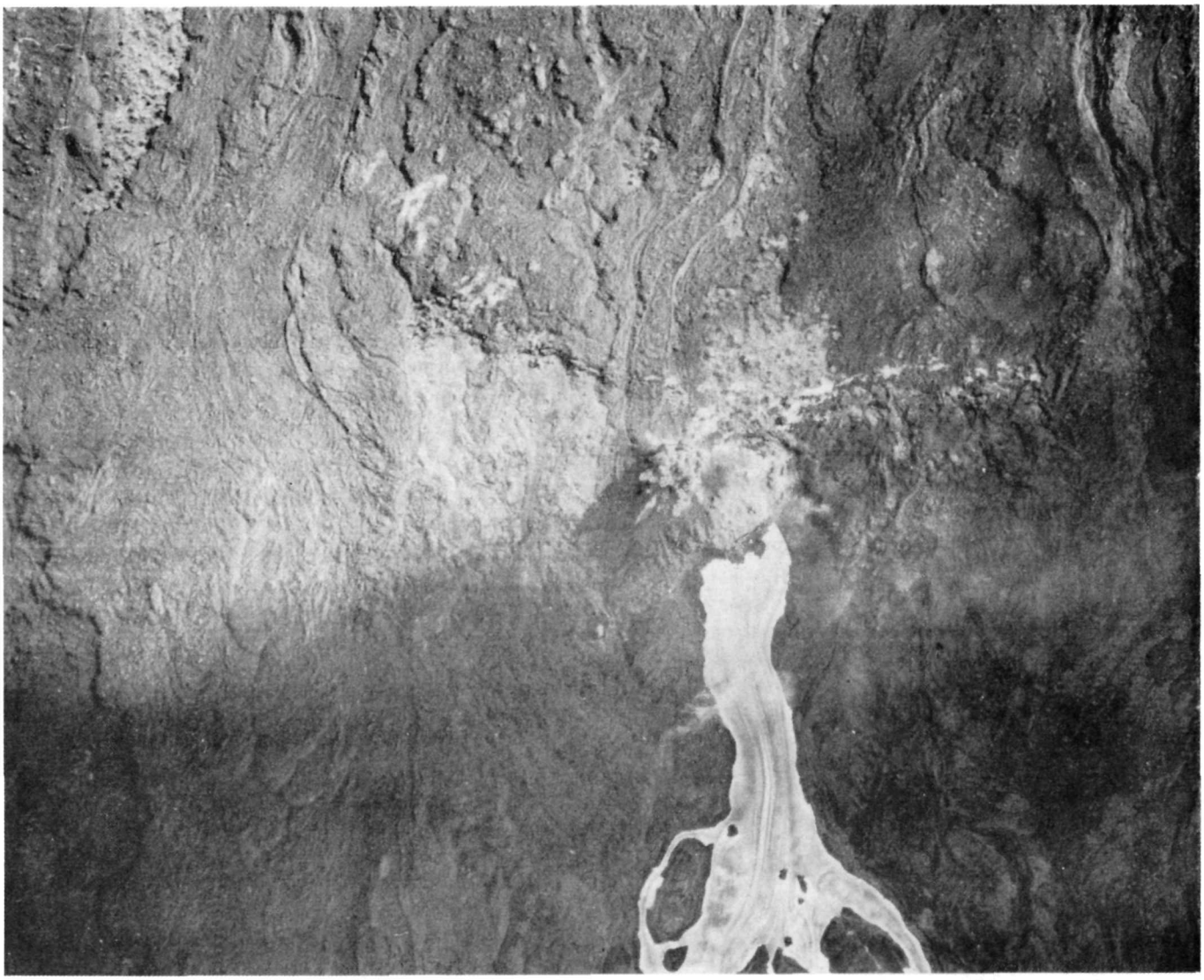

Fig. 3—Lower source 2½ miles below source cone of flow on Mauna Loa, May 1, 1942, with bomb exploding beside it. Photo by Base Photo Lab., A. A. F.—A. P. O. No. 953.

which was suspected on April 30 on account of a noticeably bright spot in the flow area, was found to be in a patch of old reddish-brown lava about 2½ miles below the source cone. A lava river with approximately the same volume as the one from the main source quietly poured out of what appeared to be an old lava tube. There was no fountaining at this source, though fume was issuing from some small cracks aligned at right angles to the northeast rift. Dr. Macdonald examined this area in August and found that there had been three vents along one of these cracks from which lava had issued. The lava emerged from a pahoehoe flow which was overlain by old aa lava. Possibly the crack over which the source cone was located cut across an old tube, and after a little more than a day the tube had become sufficiently heated to allow lava to flow through it. Bombs were dropped alongside this source (fig. 3).

The streams from the 2 sources divided, and for some distance there were 4 or more parallel lava rivers. The 4 rivers came together lower down and continued as pahoehoe for about a mile before becoming an aa stream. This mile of channel seemed to offer the best place for a diversion experiment. Places near the two sources offered other favorable locations. Before a return trip could be made, however, the lower place was obscured by clouds. Several 600-pound bombs were dropped at the upper places during the afternoon of May 1 and on the morning of May 2. At least one stream was diverted, but it returned to its old channel a short distance below. Molten lava cools so rapidly that a diversion lasting but a minute or two is not without appreciable effects on the front of a flow.

Airplane observations by A. L. Jess on the morning of May 2 showed that the front of the flow had widened greatly in the preceding 24 hours and was about 3,000 feet across. The thickness of the front averaged about 25 feet (fig. 4).

On May 1, P. E. Schulz reached the flow by going in from the Kaumana Road to the 1880-81 flow and following up this flow for 3 or 4 miles, thence by more or less following a contour he came to the active front about 1½ miles south of the 1852 flow. Explosions were frequent many

feet back from the edges of the flow. They are caused by the gases resulting from distillation of vegetal matter becoming mixed with air in underground chambers and then ignited. Mr. Schulz reports that they produced billowing black clouds that reached heights of over 500 feet and that the larger explosions produced craters 10 feet across and 2 feet deep. The front of the flow was advancing 300 to 500 feet an hour.

According to observations made by Dr. Macdonald on May 2, the upper 2,000 feet of the active fissure was mainly a fume producer. Blue flames were observed at two localities in the lower part of the inactive fissure. The flame at the lower of these two vents—just above the source cone—was more or less continuous for several days. The extreme upper end of the source cone continuously emitted large volumes of fume. Occasionally, however, pumice was ejected explosively. At other times spindle and ribbon bombs were hurled out. The fume smelled principally of sulphur dioxide. The odor of boric acid was detected over the upper part of the fissure and in the steam from several places in the flow. The main bulk of the fountains averaged nearly 200 feet high, with occasional jets reaching 400 feet.

Nearly all observers noticed fluctuations in fountaining activity. Park Superintendent Wingate at 6:00 P.M., May 3, estimated that the fountains averaged about 100 feet in height, with occasional maxima of about 190 feet. He observed a noticeable increase in activity at 11:00 P.M., which reached a maximum about 2:00 A.M., May 4, when the height of the fountains averaged 140 feet, with occasional jets at least 100 feet higher. The writer on May 5, noticed high fountains in the late afternoon and early evening, a minimum at 11:00 P.M. to 3:00 A.M., May 6, and a noticeable increase in height starting about 5:00 A.M. By 6:00 A.M. the tips of the fountains were reaching heights in excess of 400 feet. It should be noticed that these estimates of height are largely just opposite of what one might expect from the relative visual effects of daylight and darkness. Coincident with the decrease in fountaining, there was an increase in the temperature

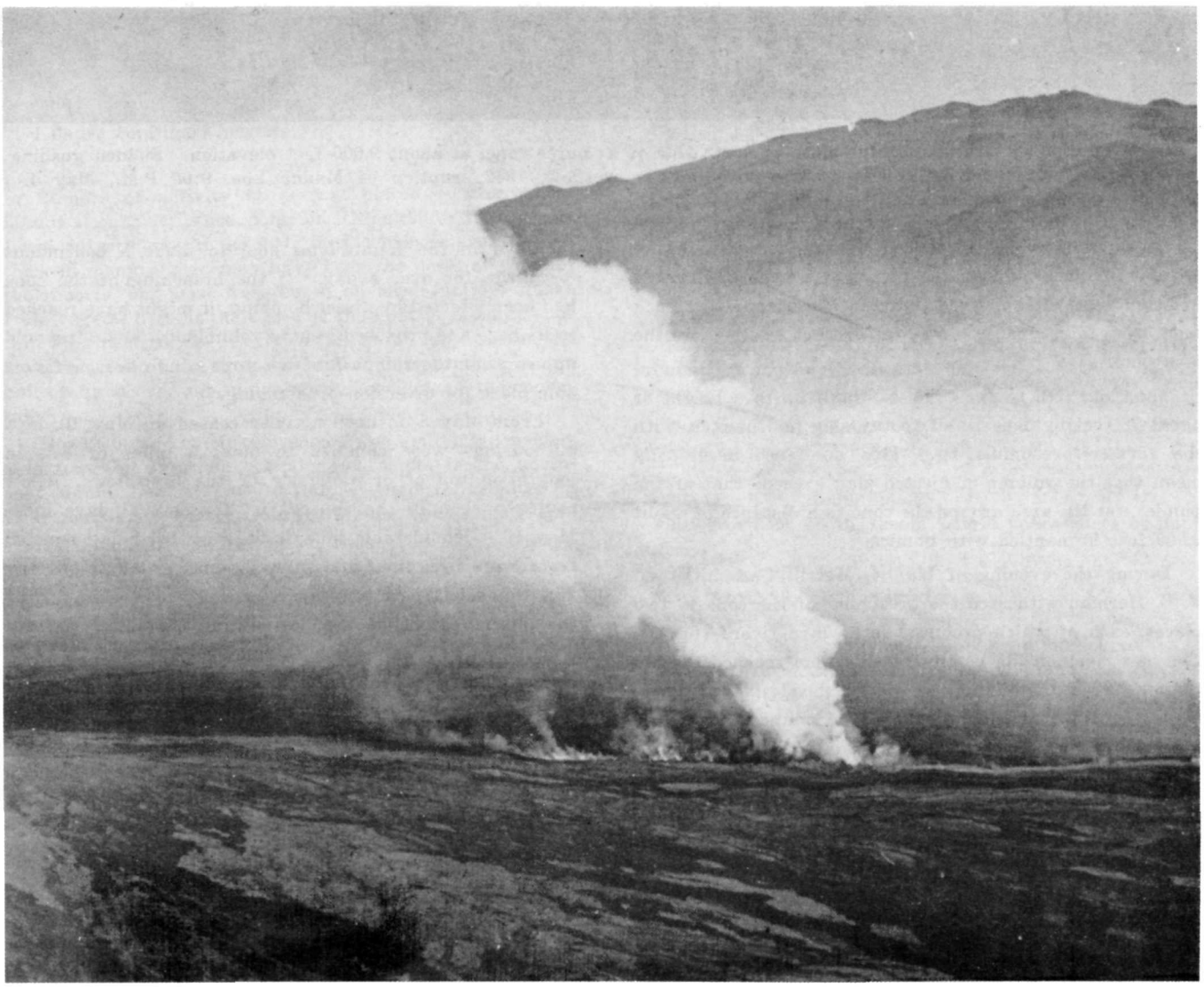

Fig. 4—Northeast slope of Mauna Loa and distant Mauna Kea, showing cone source of 1942 lava flow and live channel, about May 2. Photo by Signal Corps, U.S.A.

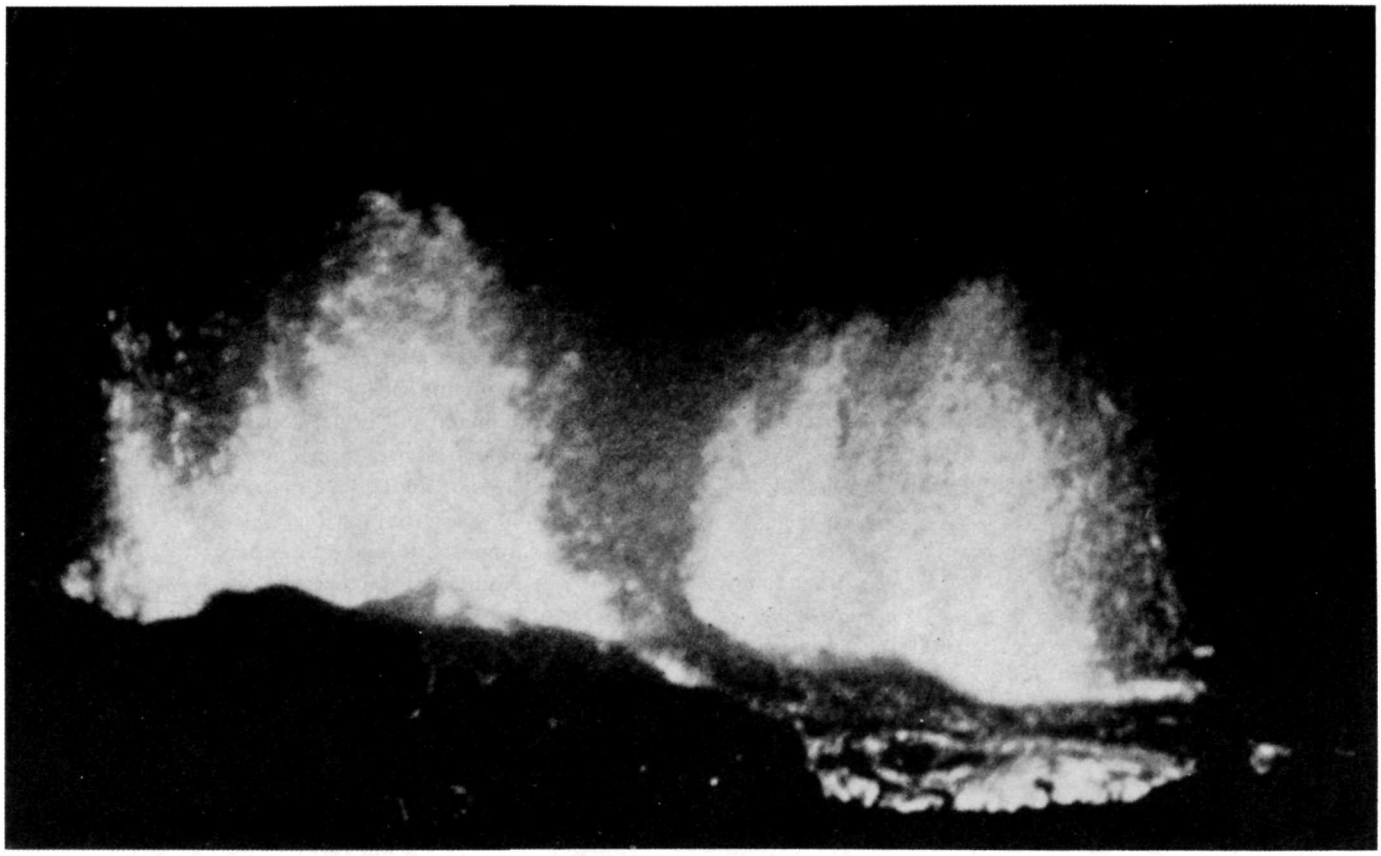

Fig. 5—Motion picture photograph close to north side of s ource cone, at about 9,000 feet elevation. Sudden gushing 600-foot fountains jetting southwestward with intense overflow, 1942 eruption of Mauna Loa, 9:00 P.M., May 4. Photo by Lt. Commander F. B. Herman, U.S.N.R.

of the lava river, as evidenced by the decrease in the amount of black skin on the lava and a general increase in brightness. It appeared that the material falling back from the fountains produced a distinct cooling in the lava pool.

The elongated source cone was built up to a height of about 75 feet by deposits of frothy slag and pumice, with the former predominating. This does not necessarily mean that the volume of ejected slag exceeds that of the pumice, for the area around the cone to a distance of about 2,000 feet is mantled with pumice.

During the evening of May 4, Merrill Carlsmith and F. B. Herman witnessed the breaching of the cone in two places, each of which produced large lava rivers (fig. 5). The new river on the northwest side soon reached the old channel, while the one on the southeast side flowed parallel to the old channel and reached a distance of about 6 miles before lateral flows from it, and cooling, stopped forward progress.

The natural diversion accomplished what was expected could be done by further bombing had such a step been necessary, and may have been a backing-up of the May 1 bombing. Progress at the lower front of the flow practically ceased on May 5 at an elevation of 2,750 feet, or a little less than 3¼ miles west of the middle flume house of the Olaa Sugar Company.

The breach on May 4 reached a little over half way down the cone rampart, or low enough for the surging of the lava in the fountaining pool to make a continuous discharge for over a day. If the breaching of the cone had been effected by direct bombing, it might have reached to its base and produced a more voluminous flow. It would appear that the rampart of a source cone offers a favorable place for diversion by bombing.

From May 5 on until activity ceased on May 10, lava outpourings were confined to flows 5 miles or less in length on top of or alongside of the first flows. Glow could be seen in the source rift for several days after May 10. Considerable blue fume was still being emitted from the source area and some distance below it on May 22. Smoke, largely of vegetal origin, was observed over the lower regions of the flow during the latter part of June.

The length of the flank eruption flow was about 17 miles. The area covered with new lava was roughly 5 square miles. An accurate estimate of the volume of the flow is difficult to make without a reasonably good map. Rough calculations, however, indicate that it exceeded 2,000,000,000 cubic feet.

The author is indebted to nearly all members of the Hawaii National Park staff for notes and observations, though but few are mentioned in the text. Of the many others to whom I am indebted for details of the outbreak, especial mention should be made of Dr. G. A. Macdonald of the U. S. Geological Survey. He not only allowed the use of his excellent notes but also read and discussed the manuscript while it was being prepared.

Hawaiian Volcano Observatory Report for April-June, 1942

VOLCANOLOGY

April

That seismicity is often low during the few weeks just preceding a Mauna Loa eruption was again demonstrated in 1942. The premonitory shakes in 1940 preceded the outbreak by 4 weeks. The premonitory shakings in 1942 occurred in Febuary and March. The interval between the earthquakes and the appearance of the lava at the surface accounts for the rather common statement that "Mauna Loa erupted with but little or no seismic warning."

The seismograph not only records the premonitory symptoms of Mauna Loa eruptions but usually accurately times the start of the outbreak. Continuous tremor that began to be recorded a few minutes after 5:00 P.M., April 26, showed that the outbreak began over an hour before it was visible from Kilauea.

Activity at Kilauea was limited to the landslides at Halemaumau caused by several of the stronger Mauna Loa shakes.

May

By May 5, the intensity of the continuous tremor accompanying the Mauna Loa eruption and the rate of outpouring of lava had decreased appreciably. The continuous tremor was recorded on the Mauna Loa seismograph until May 9. The flow stopped during the forenoon of May 10. Considerable fume continued to issue from the source cone and from many places in the flow until the last of the month.

Kilauea continued inactive.

June

Rumors of activity at several places on the recent Mauna Loa flow were common throughout the month. Local adjustments in the 1942 flow, which is over 40 feet thick in many places, may have been the basis of some of the reports, but most were based on local fuming, smoke from vegetal fires at the edges of the flow, or steam clouds following rainstorms. Early in the month smoke from the lower reaches of the flow was sufficient to produce a thin pall of fume over the upper northeast flank of the mountain.

The 1940 cone in Mokuaweoweo was emitting considerable fume on June 30. Local adjustments in the northeast Mauna Loa rift on June 13, 14, and 15, resulted in 92 tremors being recorded on the Mauna Loa seismograph.

Halemaumau remained quiet, though 19 Kilauea tremors were recorded on the Observatory seismograph on June 20 and 21.

R.H.F.

SEISMOLOGY

Earthquake Data, April-June, 1942

Week Ended	Minutes of Tremor	Very Feeble	Feeble	Slight	Moderate	Local Seismicity*	Teleseisms
Apr. 5	8	0	0	0	0	4.50	0
12	14	1	0	0	0	4.00	1
19	8	11	1	0	0	4.50	0
26	277	3	0	0	1	72.75	0
May 3	509	23	12	9	1	164.25	0
10	6	3	0	0	0	3.00	0
17	9	0	1	0	0	3.25	1
24	9	1	0	0	0	2.75	0
31	7	1	0	0	0	2.25	0
June 7	2	1	1	0	0	1.50	0
14	10	0	0	0	0	2.50	0
21	20	1	0	1	0	6.50	0
28	14	2	0	0	0	4.50	0

*For definition of local seismicity, see Volcano Letter No. 371.

The data of the following local disturbances were determined from seismograph stations operated on the island of Hawaii by the Hawaiian Volcano Observatory of the Hawaii National Park. Time is Hawaiian Standard. Distances are from the Observatory.

The number preceding each earthquake date is the serial number of the quake for the current year.

48. April 8, 14:23, very feeble, near Mokuaweoweo.

49. April 14, 12:31, feeble, under Kilauea.

50. April 14, 22:11, very feeble.

51. April 19, 22:23, very feeble, Kilauea shake.

April 26, 16:05, start of continuous tremor that continued for 270 minutes, and beginning of summit eruption of Mauna Loa.

52-54. April 26, three very feeble shakes at 20:03, 22:39, and 22:50.

55. April 26, 23:41, moderate, felt locally and Hilo, instruments dismantled, upper NE rift of Mauna Loa, vertical indicates shallow focus.

56. April 27, 00:01, slight, origin same as No. 55.

57. April 27, 04:21, slight, origin same as No. 55.

58. April 27, 08:49, slight, E-W dismantled, upper NE rift of Mauna Loa.

59. April 27, 09:52, slight, near Mokuaweoweo.

60-62. April 27, three very feeble shakes, 10:04 to 10:41.

63. April 27, 11:53, slight, above Puu Ulaula.

64-69. April 27, six very feeble shakes, 11:59 to 13:57.

70. April 27, 14:12, slight, record confused.

71. April 27, 14:15, feeble.

72. April 27, 14:23, slight.

73. April 27, 16:44, slight.

74-78. April 27, five feeble shakes, 16:30 to 21:17.

79. April 27, 21:43, moderate, instruments dismantled, pronounced at Puu Ulaula.

80-87. April 27, eight feeble shakes, 22:01 to 23:50.

88. April 28, 01:45, very feeble, Mauna Loa flank eruption started 1½ miles below Puu Ulaula about this time.

89. April 28, 10:30, feeble.

90. April 29, 06:15, feeble, origin near source of flank outbreak.

91. April 29, 11:10, slight.

92. April 29, 23:14, very feeble.

93. April 30, 02:39, very feeble.

94. April 30, 07:43, slight, flank eruption source.

May 1, eleven shakes recorded on Mauna Loa seismograph but not at Kilauea.

95. May 2, 04:02, very feeble.

96. May 2, 18:00, very feeble.

97. May 2, 19:00, very feeble.

98-100. May 3, three very feeble shakes, 14:41 to 21:43.

101. May 4, 00:26, very feeble, felt at source.

102. May 4, 01:46, very feeble, continuous tremor greatly diminished though prominent on Mauna Loa instrument until 23:00.

103. May 4, 23:54, very feeble.

104. May 14, 22:40, feeble.

105. May 19, 01:34, very feeble NE rift Mauna Loa.

106. May 27, 14:45, very feeble.

107. June 1, 03:45, feeble Kilauea shake accompanied by a rumble.

108. June 18, 08:05, slight, E slope of Mauna Loa.

109. June 21, 05:54, very feeble.

110. June 24, 16:40, very feeble.

111. June 26, 17:10, very feeble.

112. June 30, 19:05, very feeble.

Teleseisms

April 8, 05:26, slight.

May 13, 16:45, moderate.

Microseismic Motion

Microseisms were present, though slight, throughout the quarter.

Tilting of the Ground

The southeast Halemaumau station showed a distinct southeast tilt early in April but practically no movement during the remainder of the quarter. At the west station there has been but little tilt for the past six months.

Tilt

Table of Tilt at Observatory on NE Rim of Kilauea

Week Ended		Amount of tilt	Direction of tilt
April	5	5.44″	S 67° E
	12	1.94″	S 82° W
	19	1.88″	N 66° W
	23	0.64″	S 13° W
May	3	2.48″	S 81° W
	10	3.39″	N 70° E
	17	1.91″	S 26° W
	24	1.33″	S 29° W
	31	1.82″	N 37° W
June	7	0.36″	N 45° W
	14	2.31″	N 87° W
	21	1.45″	N 21° W
	28	1.03″	N 21° W

Crack Measurements

Crack movement around Halemaumau was distinctly less during April-June than during the preceding 3 months, 16 cracks opened an average of 2.8 millimeters, 11 remained unchanged, and one closed 0.5 millimeters. Movement of the cracks along the Chain of Craters Road was very slight, with the majority showing a slight closing tendency. At the Devils Throat one crack opened 1.5 millimeters, and the others remained unchanged.

R.H.F.

HAWAIIAN VOLCANO RESEARCH ASSOCIATION
in cooperation with
UNIVERSITY OF HAWAII

The **Hawaiian Volcano Research Association** was founded in 1911 for record of volcanoes in the Hawaiian Islands and around the Pacific Ocean. Its equipment at Kilauea Volcano, Hawaii Island, has been transferred to the United States Government, Department of the Interior, National Park Service.

The **University of Hawaii** cooperates in maintaining a research laboratory at Hawaii National Park. The **Association** and the **University** maintain outside seismograph stations and supplement the work of the government with research associates, instrumental plants and special investigation. Dr. T. A. Jaggar is their geophysicist resident in the National Park.

The **Volcano Letter**, a quarterly record of the Hawaiian volcano laboratories and published by the University of Hawaii, is issued by authority of the Department of the Interior and supplied to a restricted membership and exchange list of the above establishments.

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Hawaii National Park
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THE DUG WELL AT OLAA MILL

By GEORGE DUNCAN

The Olaa Sugar Company recently sank a well shaft 10 feet in diameter in the mill grounds, where the elevation is 220 feet above sea level. Such a shaft gives a detailed exposure of the geologic structure in this part of Puna, where cliffs or other good exposures are lacking, as well as information on the amount of mobile ground water in the vicinity of the conduits of Hawaiian volcanoes.

The author acknowledges his indebtedness to Dr. G. A. Macdonald of the United States Geological Survey and R. H. Finch, Volcanologist, Hawaii National Park, for aid in preparing this article, particularly those parts dealing with geologic interpretation.

The well is located on the northeastern slope of Mauna Loa 3½ miles from the ocean, a little to the north of the Kilauea-Mauna Loa contact. It is thought that most of the lavas exposed in the well are of Mauna Loa origin, though some may be from Kilauea, as in this vicinity there must be some interfingering of Kilauea and Mauna Loa lavas.

The log of the well by Dr. Macdonald, describing each layer, is shown in Table 1.

TABLE 1.
LOG OF OLAA WELL—1941
(On file in Honolulu office of U. S. Geological Survey)
By G. A. Macdonald

Depth	Description	Depth	Description
Feet		*Feet*	
0–23	Aa clinker, containing scattered olivine phenocrysts up to 2 mm. across in an aphanitic ground mass.	64–66	Dense to sparingly vesicular light-gray pahoehoe, dikytaxitic, essentially nonporphyritic but with a few olivine phenocrysts less than ½ mm. across.
23–47	Medium-gray sparingly vesicular to dense aa, with moderately abundant phenocrysts of olivine up to 3 mm. long. (Contains hypersthene.)	66-70	Highly to moderately vesicular medium-gray pahoehoe with a few phenocrysts of feldspar up to 1½ mm. long and a very few of olivine less than 1 mm.
47–54	Reddened aa clinker, with moderately abundant olivine phenocrysts up to 3 mm. long.	70-73	Dark-gray moderately vesicular pahoehoe with a few phenocrysts of feldspar up to 1 mm. or a little more in length. The flow shows a reddened ropy top.
54–56	Fine powdery red ash.	73–81	Dark-gray moderately vesicular pahoehoe, essentially nonporphyritic, but with a few small phenocrysts of olivine and feldspar.
56–61	Moderately vesicular dark-gray pahoehoe with a few small phenocrysts of olivine less than 1 mm. across.		
61–64	Dark-gray sparingly to moderately vesicular pahoehoe with a few olivine phenocrysts less than 1 mm. across and scattered phenocrysts up to 1½ mm. long.		

Depth	Description
Feet	
81–88	Moderately to highly vesicular dark-gray pahoehoe, nonporphyritic, approaching clinker in places. Shows ropy flow surfaces.
88–92	Light-gray sparingly to moderately vesicular pahoehoe; some vesicles are as large as 2 mm. across, containing a few phenocrysts of feldspar and olivine up to 1½ mm. Many of the vesicles are lined with platy feldspar crystals.
92–97	Sparingly vesicular to dense light-gray pahoehoe containing scattered small phenocrysts of olivine and feldspar up to 1½ mm. in diameter. (Probably same as above.)
97–107	Moderately vesicular dark-gray pahoehoe with a few phenocrysts of feldspar up to ½ mm. long.
107–115	Sparingly vesicular dark-gray pahoehoe with scattered phenocrysts of feldspar and a few of olivine up to 1 mm. in diameter. (May be same as above.)
115–120	Reddened aa clinker, aphanitic and nonporphyritic.
120–139	Dense to sparingly vesicular medium-gray basalt with a few phenocrysts of olivine up to 1 mm. and feldspar up to 2 mm. across.
139–150	Reddened aa clinker with scattered phenocrysts of feldspar up to 2 mm. Caved badly in shaft.
150–206	Dense medium-gray aa with scattered phenocrysts of feldspar up to 1½ mm. Shows good columnar jointing.
206–217	Aa clinker.

The first 23 feet was composed of aa clinkers so loose that a cement retaining wall was necessary. Retaining walls were also necessary for the ash layer at 54-56 feet and for the clinkery portions of aa flows at 115-120 and 139-150 feet. The massive portion of the aa layer, 150-206 feet, caused real difficulty. It was so abrasive that the best of drills was completely worn out in penetrating 8 to 14 inches of rock.

The ash layer at 54 feet was the only one encountered. The thinness of this layer and the absence of others indicate that this part of the Puna district geologically is comparatively young.

The water in the older drilled wells in the same grounds stands about 17 feet above sea level. Such a level is about what is to be expected, as the normal ground-water-level gradient in regions of moderate to heavy rainfall is about 4 feet for each mile of distance from the shore. At the distance of 3½ miles from the shore, the normal elevation of the ground-water level then would be 14 feet. As the Olaa Mill is located in a region of about 200 inches of rainfall a year, a level averaging a little higher than 14 feet is what is to be expected.

A chamber for housing pumps and motors with a floor 17 feet above sea level was excavated in the massive part of the thick aa flow (150-206 feet, Table 1). After the chamber was excavated and lined with cement, work was commenced to deepen a hole for the sump. The water level was found at 14 feet above sea level. Pumps were installed, and by removing 7,000,000 gallons per day the level of the water was kept at about 6 feet above sea level. A tunnel, the bottom of which was at an elevation of 3¼ feet, was excavated in a northwest direction for about 35 feet in the aa clinker. In view of the fact that pumping was keeping the water at least 8 feet below the normal and that there was a rapid inflow into the tunnel, it appeared too hazardous to continue the excavation. Very rapid rises in the water level that were measured later justified such a belief.

The rise of the water level in the well shows a good correlation with heavy rains. The interval between a heavy rain and the peak of the water level is about 3 days. However, a rain occurring after a dry spell of appreciable length is not followed by a rise in the water level, though it may decrease the rate of lowering. The water of such a rain is used up in saturating the ground. For local rains the rise is very rapid, and the interval a little less than 3 days. For rains higher up the mountain slope the rise is more gradual, and the interval a little more than 3 days. The range of the fluctuation of the water level is considerable. In April 1938 the water reached a height of 22.7 feet and flooded some of the machinery, though most items had been removed before the water reached them. A false floor was installed 6½ feet above the original one. In March 1939 a level of 25.86 feet was reached. Following a dry spell in 1940, the lowest level recorded—13 feet above sea level—was observed. Generally the water level stands at an altitude of about 17 feet.

No evidence of volcanic heat was found anywhere in the shaft. The temperature of the water is constant at 66°F., and the salt content at 0.85 grains per gallon.

No water ran into the shaft even during the heaviest rainfalls. After the shaft was completed and the adit to the pump chamber commenced, there was no sign of water from the sides. This circumstance shows that for 217 feet below the surface there is no impervious ash layer and that the descent of the rainwater is essentially vertical.

The well produces from the lens of fresh water which, owing to its lesser specific gravity, floats on top of the salt ocean water beneath it.

Hawaiian Volcano Observatory Report for July-September, 1942

VOLCANOLOGY

July

Smoke was reported from the 1942 Mauna Loa flow on July 17. This appears to be the last observation of smoke over the flow, though fume continues to be emitted from the source cone.

A landslide from the north rim of Halemaumau on July 16 produced a conspicuous dust cloud.

August

Fume was noticed from the source cones of both 1940 and 1942. More earthquakes were recorded at Kilauea than at Mauna Loa. This relation of earthquake frequency will probably continue for most months until Mauna Loa shows signs of preparing for another eruption.

September

A rainstorm about the middle of the month produced pronounced steam clouds over the lower half of the 1942 Mauna Loa lava flow. The general rise of the steam indicated that nearly all portions of the flow were still hot.

A swarm of Kilauea earthquakes that occurred during the last few days of September may be taken as evidence of subterranean activity. The climax was reached on September 27, when 28 local seismic disturbances were recorded. The tilt curves for July, August, and September indicated that such a swarm of earthquakes was not a premonitory symptom of impending activity.

The September earthquakes caused several landslides from the walls of Halemaumau and one from the southwest wall of Kilauea.

R.H.F.

SEISMOLOGY

Earthquake Data, July-September 1942

Week Ended	Minutes of Tremor	Very Feeble	Feeble	Slight	Moderate	Local Seismicity*	Teleseisms
July 5	6	2	0	0	0	2.50	0
12	8	4	0	1	0	5.75	0
19	5	1	0	0	0	1.75	0
26	7	0	0	0	0	1.75	1
Aug. 2	20	2	0	0	0	6.00	0
9	15	0	0	0	0	3.75	1
16	8	3	0	0	0	3.50	0
23	4	0	0	0	0	1.00	0
30	8	1	1	0	0	3.50	1
Sept. 6	11	2	0	0	0	3.25	0
13	12	2	0	1	0	6.00	1
20	17	3	1	0	0	6.75	0
27	22	6	1	2	0	13.50	0

*For definition of local seismicity, see Volcano Letter No. 371.

The data of the following local disturbances were determined from seismograph stations operated on the island of Hawaii by the Hawaiian Volcano Observatory of the Hawaii National Park. Time is Hawaiian Standard. Distances are from the Observatory.

The number preceding each earthquake date is the serial number of the quake for the current year.

113. July 3, 17:50, very feeble.

114. July 8, 5:15, very feeble, distance 3 miles.

115-117. July 8, 17:27 to 22:33, 3 very feeble shakes.

118. July 9, 3:00, slight, E-W component dismantled, felt locally and strongly in Kohala, in ocean north of Kohala.

119. July 19, 23:30, very feeble, felt at Kapapala.

120. July 29, 06:45, very feeble, Kilauea shake.

121. August 2, 23:05, very feeble, NE rift of Kilauea.

122-123. August 10, 10:35, very feeble, twin shakes.

124. August 15, 06:37, very feeble.

125. August 27, 02:38, very feeble, NW of Mauna Kea.

126. August 27, 10:25, feeble near Mokuaweoweo.

127. September 4, 00:48, very feeble.

128. September 6, 05:20, very feeble.

129. September 9, 21:37, very feeble, Kilauea shake.

130. September 11, 16:50, very feeble, felt in Kohala.

131. September 12, 10:25, slight, Kilauea shake.

132. September 18, 01:51, feeble, felt locally, Kilauea shake.

133. September 19, 09:56, very feeble, distance 2 miles.

134. September 20, 13:31, very feeble.

135. September 20, 14:26, very feeble, Kilauea shake.

136. September 26, 16:55, very feeble, Kilauea shake.

137. September 27, 01:41, feeble, felt locally, distance 2 miles.

138. September 27, 02:57, slight, felt locally.

139-141. September 27, 11:33-13:15, 3 very feeble shakes.

142. September 27, 17:36, slight, felt locally, accompanied by rumble, distance 3 miles.

143-144. September 27, 18:46-19:17, 2 very feeble shakes.

145. September 28, 14:15, feeble, felt locally, distance 3 miles.

146. September 30, 10:20, very feeble.

147. September 30, 10:21, feeble, felt locally.

148. September 30, 10:21, slight, felt locally, E-W dismantled. Accompanied by a landslide from NE wall of Halemaumau.

Teleseisms

July 25, 05:00, slight.

August 6, 13:01, slight, Guatemala.

August 24, 14:36, slight, Peru.

September 8, 15:05, slight.

Microseismic Motion

Microseisms were slight though noticeable throughout the quarter.

Tilting of the Ground

A conspicuous feature was the strong ESE tilt at the Observatory from July 1-10. The E-W tilt curve, which usually is in agreement with the seasonal temperature curve, did not change from westerly to easterly until September 26. Except for the southerly tilt in the first decade of July, tilt in the N-S direction was quite uniformly to the north, or normal for this season of the year.

There were but negligible changes in direction and amount in the tilt at the two stations near the rim of Halemaumau.

Table of Tilt at Observatory on NE Rim of Kilauea

Week Ended		Amount of tilt	Direction of tilt
July	5	2.12″	N 66° E
	12	9.20″	S 46° E
	19	1.04″	N 35° E
	26	0.36″	S
Aug.	2	1.45″	N 45° W
	9	0.71″	S 31° E
	16	0.92″	N 66° W
	23	1.23″	N 11° W
	30	0.12″	N 45° E
Sept.	6	1.04″	N 70° W
	13	0.60″	N 36° E
	20	0.24″	S 45° E
	27	0.71″	N 31° W

Crack Measurements

Crack movement during the quarter was slight. There was no change along the Chain of Craters Road or at the Devil's Throat. At Halemaumau movement was confined to 2 cracks which showed openings of 1 millimeter each.

R.H.F.

HAWAIIAN VOLCANO RESEARCH ASSOCIATION
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The **University of Hawaii** cooperates in maintaining a research laboratory at Hawaii National Park. The **Association** and the **University** maintain outside seismograph stations and supplement the work of the government with research associates, instrumental plants and special investigations. Dr. T. A. Jaggar is their geophysicist resident in the National Park.

The **Volcano Letter,** a quarterly record of the Hawaiian volcano laboratories and published by the University of Hawaii, is issued by authority of the Department of the Interior and supplied to a restricted membership and exchange list of the above establishments.

THE VOLCANO LETTER

478

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Hawaii National Park
Edward G. Wingate, Superintendent
R. H. Finch, Volcanologist

University of Hawaii
T. A. Jaggar, Geophysicist

THE SURFACE ASH DEPOSITS AT KILAUEA VOLCANO

BY R. H. FINCH

The object of this paper is to show that there have been eight, perhaps nine, explosive periods in the geologically recent history of Kilauea. The older ash beds exposed in the walls of the crater and good evidence that at least a portion of the Pahala[1] ash had its origin at Kilauea indicate that explosive eruptions at Kilauea have been rather common through a considerable portion of its history.

A study of the ash deposits indicates that there have been more magmatic than phreatic explosions and that the magmatic explosions were in most cases larger than the phreatic. (A magmatic explosion is one that has fluid or essential material in the ejecta; a phreatic explosion is one without contemporaneous molten lava.)

The area surrounding Kilauea crater is covered with ash to an appreciable depth. At the northeast rim the depth is as much as 6 feet in places; at the southwest end of the crater, depths of 35 feet may be found. The greater depth at the southwest is owing to the prevailing northeast trade winds. A cave-in at an old lava tube half a mile southwest of the Kilauea rim reveals a thickness there of 20 feet of ash (fig. 1). The total depth of the ash deposited can not be determined, as appreciable quantities of most layers were removed by the wind before the next succeeding layer was laid down. The southwest side of the crater is especially susceptible to wind erosion, as it is in the Kau Desert. The deposits on the northeast side are in a region of about 100 inches annual rainfall and are much less subject to wind erosion. At the northeast the terrain is relatively flat and stream erosion has been very slight. At the southwest rim of Kilauea, 5 inches of the ash of that year was still in place one year after the small explosions of 1924. Within a few years it was reduced to a barely discernible trace.

Stone[2] found evidence of at least four carbonaceous or soil layers in the ash around the northern rim. Stearns[3] reports six different vegetal horizons. The six different vegetal horizons in the ash would mean, of course, that there had been seven different explosive periods.

One erosional unconformity is distinct at many places in the ash at the southwest side of Kilauea. If sufficient time had elapsed between explosive eruptions for vegetation and soil layers to develop at the northeastern end of the crater, it seemed that more unconformities could be found at the southwest side. Some time was spent in looking for such unconformities at places favorable for the development of small streams.

Stone[4] reported an ash bed at least 3 feet thick in an open fissure near Cone Peak (fig. 1) that is separated from the surface ash by 12 feet of lava flow. Stearns[5] surmised from discrepancies in the thickness of the ash near Cone Peak that some of the basal layers of ash in this vicinity had been buried by lava flows. On the same page Stearns also mentions a line of driblet cones along a fissure concentric to and 0.7 mile southwest of the Kilauea rim (fig. 1). He found a lava flow from the fissure interbedded in ash. A little study of Figure 1 shows that the drainage pattern has been interrupted by the opening of the crack. As the drainage pattern is in the ash, it is obvious that the fissure opened after at least one ash layer was laid down.

Figure 2 shows a lava flow interbedded in ash in the wall of the fissure. There is a thickness of 132 inches of ash under the flow, and 34 inches over it. At some places near the crack, 10 feet of ash is still in place, though

[1] For a discussion of the Pahala ash which forms the yellow soil layer especially noticeable in the vicinity of Pahala, see Stone and Stearns, references 2 and 3 respectively.

[2] Stone, John B. "The Product and Structure of Kilauea." Bishop Museum Bulletin No. 33, 1926, p. 34.

[3] Stearns, H. T. "Geology and Water Resources of the Kau District, Hawaii." U. S. Geological Survey Water Supply Paper No. 616, 1930, p. 151.

[4] Stone, John B., loc. cit., p. 34.

[5] Stearns, H. T., loc. cit., p. 150.

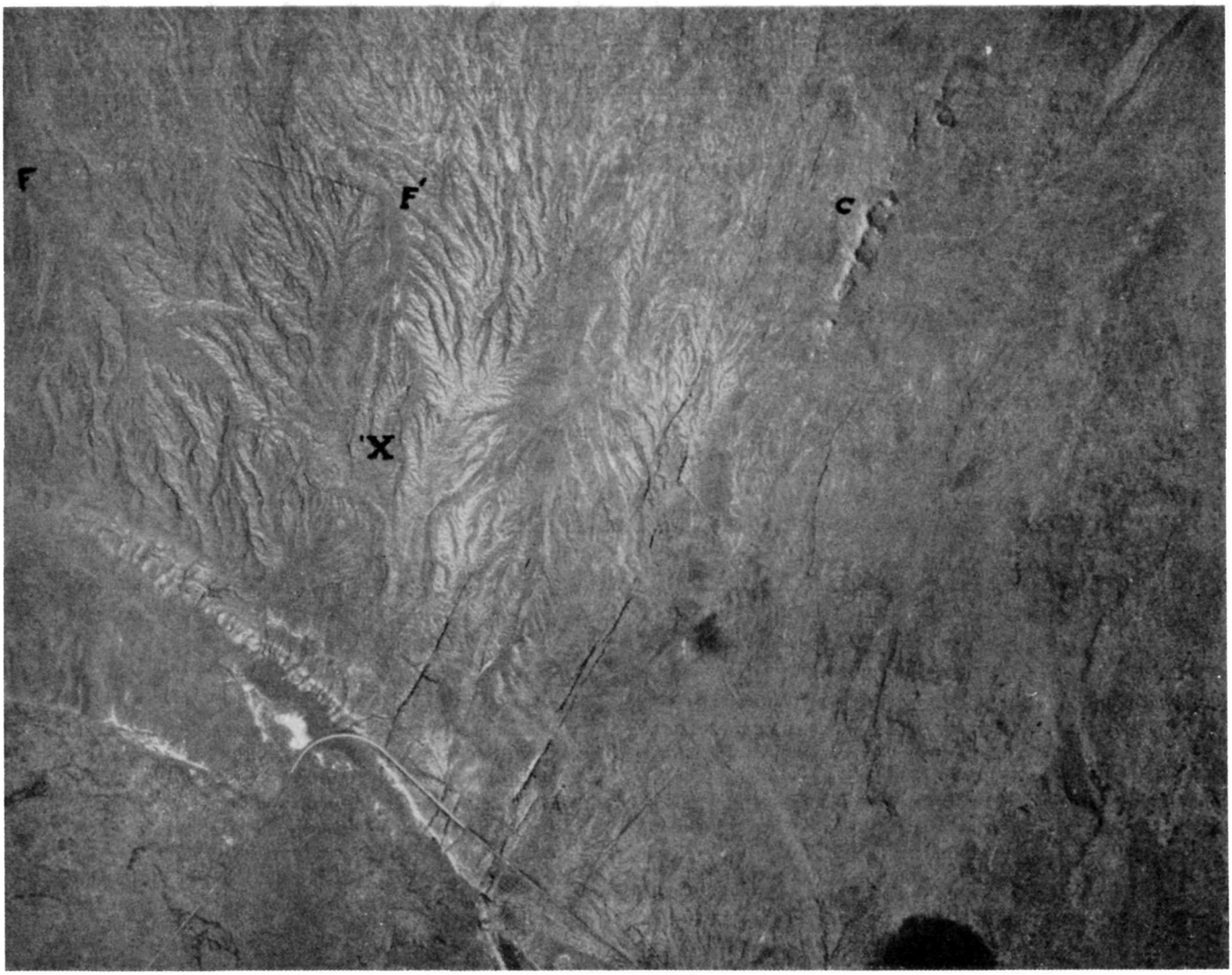

Figure 1. The Kau Desert southwest of Kilauea Crater. X marks the breakdown in an old lava tube where the ash is 20 feet thick. FF' is the concentric fissure, with lava flows interbedded in the ash. C is Cone Peak. Note the numerous cracks in the southwest rift zone. (Photo by Base Photo Laboratory, A.C.)

generally the depth is much less. The fact that the ash section containing the flow is thicker than at many places nearer the crater is what is to be expected when one considers that the lava may have protected the covered layers from wind erosion for an appreciable time interval. There were several different lava flows from this fissure, all probably contemporaneous. It is not certain whether these lava flows occurred during the interval that produced the pronounced unconformity shown in the ash beds near the southwest rim, but such may well be the case.

The basal layer of the ash series is a thin, discontinuous, gray, clayey ash readily discernible only at the northern rim. This is not surprising, as any such ash deposited at the southwest, which is in a desert area, would quickly be removed by the wind. Before the next true explosion occurred there must have been a magnificent display of fire fountains, as the country for several miles around the northern part of the crater is covered with a very light pumice—the "thread-lace scoria" of Dana. The basal layer at the southwest is a somewhat indurated bed of yellow, glassy ash. Indications of an unconformity in this layer suggest that it is the product of two explosive periods. Above this layer is another glassy layer with an appreciable percentage of conspicuous pumice fragments. It is probably the product of but one explosive period. Above the pumice charged layer is another one of rather fine glassy texture, in which there is a distinct unconformity; hence it is the product of two different eruptive periods. A rather coarse, gravelly layer is the topmost member. It has heretofore been considered the product of the 1790 explosions, with traces from 1924. Suggestions of unconformities in this layer indicate that the basal portions may have been ejected prior to 1790. Although most of the products of the 1790 eruption are composed of old lithic material, the fact that it contains bombs causes it to be classed either as a magmatic or a mixed explosion. The products of the 1924 eruption contain nothing but old lithic material; hence it was a phreatic explosion.

There are indications, then, of nine different explosive periods in the recent history of Kilauea. The possibility of there having been explosions, the records of which are lost, with intensities comparable to those of 1924, must also be considered. If the floor of Kilauea crater should again be covered by lava flows, but precious little field evidence of there having been an eruption in 1924 would remain.

Sweeping statements that explosions at Hawaiian volcanoes are of the phreatic type are hazardous. Of the last nine indicated explosive eruptions at Kilauea, at least six appear to have been of the magmatic type.

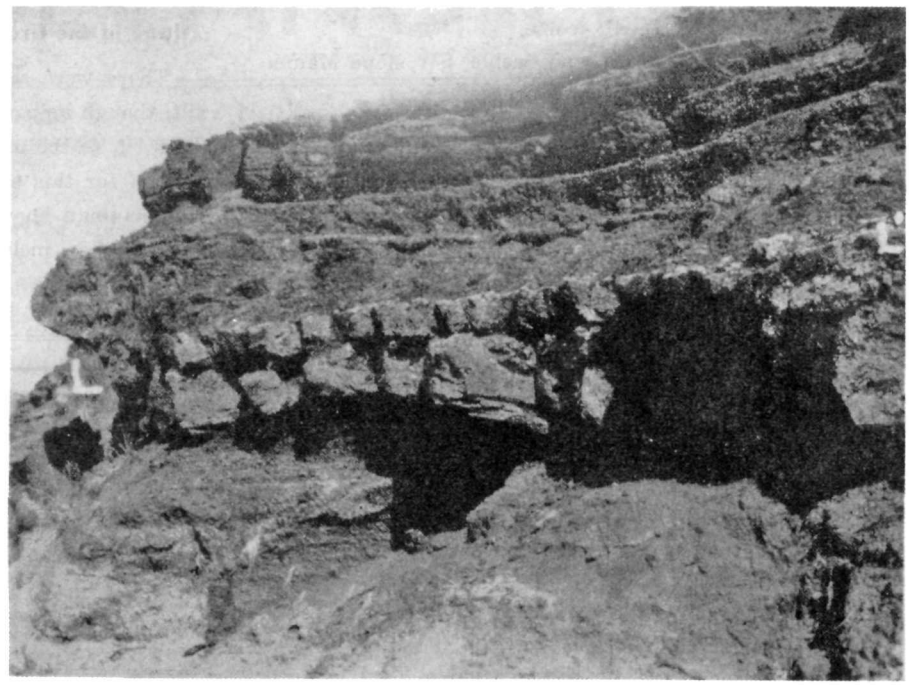

Figure 2. Lava flow, LL[1], interbedded in ash at the fissure shown in Figure 1. (Photo by G. O. Fagerlund, Hawaii National Park.)

Hawaiian Volcano Observatory Report for October-December, 1942

VOLCANOLOGY

October

There was no visible activity at Hawaiian volcanoes in October. During the first few days of the month there were several small aftershocks from the swarm of Kilauea shakes of September 27. During the remainder of the month, Mauna Loa shakes predominated. The only felt earthquake occurred at 12:43 p.m., October 11. It originated on Mauna Loa and was strong enough to dismantle both the Mauna Loa and Kilauea seismographs.

November

Hawaiian volcanoes continued inactive in November. Forty-five seismic disturbances were recorded at Kilauea, while 56 were registered on the Mauna Loa seismograph.

Strong winds on November 13 raised conspicuous dust clouds on the southwestern floor of Kilauea Crater and in the Kau Desert, although the material of the clouds—ash from the explosive eruption in 1924—was deposited over 18 years before.

December

Observations at Mokuaweoweo on December 17 showed that some fume was escaping from the 1942 vents.

Forty-four earthquakes occurred on December 21. They originated about 2 miles east of Napau Crater along the Puna rift of Kilauea. With a shallow focus 11 miles from Halemaumau, it is believed that they have no special volcanic significance. They probably resulted from local and superficial adjustments along the Puna rift.

R.H.F.

SEISMOLOGY

Earthquake Data, October-December 1942

Week ended	Minutes of tremor	Very feeble shakes	Feeble	Slight	Local seismicity*	Teleseisms
Oct. 4	34	1	3	1	13.00	0
11	22	2	0	1	8.50	0
18	11	1	0	0	3.25	0
25	3	0	0	0	0.75	1
Nov. 1	6	0	1	0	2.00	0
8	5	1	1	0	2.75	0
15	8	0	0	0	2.00	1
22	11	0	0	0	2.75	0
29	17	2	1	0	6.25	0
Dec. 6	4	2	1	1	4.50	0
13	11	0	0	0	2.75	1
20	7	0	0	0	1.75	0
27	76	10	4	4	36.00	0

*For definition of local seismicity, see Volcano Letter No. 371.

The data of the following local disturbances were determined from seismograph stations operated on the island of Hawaii by the Hawaiian Volcano Observatory of the Hawaii National Park. Time is Hawaiian Standard. The number preceding each earthquake date is the serial number of the quake for the current year.

149. October 1, 06:04, very feeble, NE rift Mauna Loa.

150. October 5, 23:47, very feeble.

151. October 6, 13:33, very feeble, Kilauea shake.

152. October 11, 11:43, slight, E-W dismantled, both components dismantled, Mauna Loa, northern end of Mokuaweoweo.

153. October 16, 09:21, very feeble.

154. October 29, 22:30, Kilauea shake.

155. November 5, 12:56, feeble.

156. November 8, 00:47, very feeble, SW slope Mauna Loa.

157. November 25, 01:54, feeble, felt locally.

158. November 25, 10:20, very feeble, Kilauea shake.

159. November 26, 03:59, very feeble.

160. December 1, 17:03, very feeble.

161. December 4, 18:28, very feeble, Kilauea shake.

162. December 5, 07:07, very feeble, Kilauea shake.

163. December 6, 12:08, slight, felt from Hilo to S. Kona, in Kahuku near source 1868 flow.

164. December 21, 05:28, slight, instruments dismantled, felt locally and in Hilo, 2 miles east of Napau Crater.

165. December 21, 06:50, feeble, felt locally, same origin as No. 164.

166. December 21, 07:47, feeble, same as No. 164.

167-176. December 21, record confused, 7 very feeble and 3 slight shakes.

177. December 21, 23:57, feeble, same as No. 164.

178. December 22, 07:45, very feeble.

179. December 24, 15:15, feeble, Kilauea Crater.

180. December 26, 10:41, very feeble.

181. December 29, 16:33, very feeble.

Teleseisms

October 21, 06:09, slight, southern California.

November 10, 01:30, moderate, Indian Ocean.

December 9, 12:10, slight.

Microseismic Motion

Microseisms were present, though uniformly slight through October-November.

Tilting of the Ground

There were some slight variations in the direction of tilt, though as a whole there was a slight and rather uniform tilt to the northeast. The direction and amount was normal for this season of the year. The tilt stations at Halemaumau showed almost no movement from October to December, inclusive.

Table of Tilt at Observatory on NE Rim of Kilauea

Week ended		Amount of tilt	Direction of tilt
Oct.	4	1.11″	N 13° E
	11	0.97″	N 29° E
	18	0.17″	S 45° E
	25	0.27″	N 63° W
Nov.	1	0.98″	N 83° E
	8	1.21″	N 45° W
	15	1.95″	N 30° E
	22	0.80″	S 34° E
	29	0.12″	N
Dec.	6	0.39″	N 19° E
	13	0.54″	S 63° E
	20	0.63″	N 45° E
	27	0.63″	N 45° E

Crack Measurements

In October there was no appreciable movement in the cracks around Halemaumau or along the Chain of Craters Road. In November many of the cracks immediately adjacent to the rim of Halemaumau opened slightly, while those farther back and along the Chain of Craters Road showed no movement. Many of the cracks at both places opened slightly in December.

R.H.F.

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479

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HAWAII NATIONAL PARK: Edward G. Wingate, Superintendent; R. H. Finch, Volcanologist

UNIVERSITY OF HAWAII: T. A. Jaggar, Geophysicist

LAVA SURGINGS IN HALEMAUMAU AND THE EXPLOSIVE ERUPTIONS IN 1924

By R. H. FINCH

The object of this paper is to show a possible relation between fluctuations in the lava column of Halemaumau and the steam blast eruptions in 1924, as well as to point out the limitations in the quantity of heat and amount of water available for such steam blasts.

A remarkable series of fluctuations in the height of the molten lava in Halemaumau commenced in December 1923 and continued until the lava disappeared on February 21, 1924. The fluctuations suddenly began near the culmination of the steady rise in the lava column that followed the collapse accompanying the small lava flow near Makaopuhi in August 1923. There were short-period fluctuations of approximately 6 to 8 hours, superposed on fluctuations with a period of almost exactly 1 week. The amplitude of the short-period fluctuations was about the same as that of the week-period fluctuations, often amounting to over 60 feet.[1] The general rise in the lava level continued until January 21. Until that date the risings usually exceeded the sinkings. After January 21, however, there was a gradual lowering and the sinkings usually exceeded the rises. This last relation continued until the lava disappeared from view on February 21.

After the disappearance of molten lava in February, harmonic tremor and the smoky condition of the pit, through which glow was occasionally visible, indicated that the lava column remained rather high and nearly stationary until the time of rapid subsidence in the latter part of April. The pasty lava that was revealed at the beginning of this subsidence strengthened such indications.

[1] Bulletin, Hawaiian Volcano Observatory, December 1923, January 1924, and February 1924.

Previous to the disappearance of the lava, the area of the lava lake that was fluctuating through a range of 50 to 60 feet was about 40 acres. This meant that a large amount of molten lava was involved. In one half-hour period observed, over 10,000,000 cubic feet of lava poured into the lake basin. Some of the withdrawals were even more rapid. If, as seems probable, the total area in cross section of the feeding conduits was small compared to the lava lake, then surgings with similar volume, when confined to the conduits, would mean large vertical ranges. Even if much smaller volumes of lava were involved, the vertical range might well have been much larger than the observed 50 to 60 feet when the upper ends of the conduits terminated in a lake basin.

The possibility of large vertical ranges in the lava surgings being established, indications for such surgings are now required. Harmonic tremor[2]—seismic indications of underground movement of molten lava—furnishes just such evidence. This type of tremor diminished on the seismograms of the Hawaiian Volcano Observatory just before the lava disappeared in February and then was barely visible until April 29, when there was a noticeable increase. Coincidental with the increase in harmonic tremor, a strong southwest tilt and a marked subsidence in the lava column began. Lava drainage into the Puna rift[3,4] may have begun about this time.

A distinct increase in harmonic tremor started on May 7,

[2] Jaggar, T. A. "Seismometric Investigation of the Hawaiian Lava Column." Seismological Society of America Bulletin, December 1920, page 267.

[3] Jaggar, T. A., and Finch, R. H. "The explosive eruption of Kilauea in Hawaii 1924." American Journal of Science, November 1924, page 358.

[4] Jaggar, T. A. "Kilauea's Lost Lava Flow." Paradise of the Pacific, Vol. 46, No. 6.

just 4 days prior to the onset of the explosions. This type of tremor was moderate to strong until May 17 and slight through the remainder of the explosive period. The maximum in explosive intensity was reached on May 17 to 18, though earthquakes increased in frequency after this date, reaching a maximum on May 24. There is evidence, then, of lava surging prior to and during the explosive period. If the amplitude of the harmonic tremor is an indication of the amplitude of the surgings, the range of movement of the lava column preceding and during the explosions may have exceeded those during the preceding winter.

Dr. T. A. Jaggar has demonstrated that the explosions in May 1924 must have had their origin in steam blasts.[5] The following discussion attempts to indicate in a more detailed way a possible mechanism and the periodicity of the steam blasts. The potency of volcanic heat in producing steam blasts is easily recognized. A cubic foot of water at a pressure of 1 atmosphere and a temperature of 1,700° F. would yield over 5,000 cubic feet of steam, or, if confined, produce a pressure of over 80,000 pounds per square inch. If one considers these figures only, the mechanism of volcanic steam blasts appears rather simple.

Difficulties arise, however, when one considers that with any ingress of water the hot volcano conduit system immediately produces a pressure that greatly retards, if not precludes, further entry of water. If the pressure build-up were at a moderate rate, then some seal to confine the steam before a disruptive pressure was reached would be necessary. (It would appear that landslide material could make but a poor seal, even with optimum arrangement.) If the pressure had built up rapidly, the heat supply would have had distinct limitations. It would have to come from a thin surface layer of the conduit walls and from any landslide material that fell into the conduit, say about one-eighth inch thick. The receding magma must have left appreciable areas of hot wall uncovered. A mechanism producing a very rapid generation of steam and not requiring a thorough seal, such as a "flash boiler," seems indicated.

Before proceeding with the discussion of a "flash boiler" system, a few words concerning the probable height and distribution of ground water in the vicinity of Kilauea seem desirable. For ideas on this subject, the writer acknowledges his indebtedness to Dr. G. A. Macdonald of the United States Geological Survey.

Conditions observed elsewhere in the Hawaiian Islands indicate that large amounts of ground water are trapped in compartments between dikes at relatively high levels. Dr. Macdonald believes that the ground water in some compartments near Kilauea may be as much as 1,500 feet above sea level. The normal elevation of the Ghyben-Herzberg lens of fresh water in the vicinity of Kilauea would be about 35 feet above sea level. The shape and orientation of such compartments in the vicinity of the Kilauea conduit system are probably very irregular. Evidence indicates considerable relatively high-level ground water in close juxtaposition to the volcanic conduits. As lava is a very poor conductor of heat, the horizontal temperature gradient in the conduit walls must thus have been very steep.

[5] Jaggar, T. A. Bulletin, Hawaiian Volcano Observatory, May 1924, page 35.

There can be but little doubt that an abundance of heat was available for the explosions. All that remains is to find a means whereby a considerable volume of ground water could be dropped into hot openings left empty by the receding lava.

The rapid subsidence that started on April 29 was accompanied by many earthquakes of Halemaumau origin. As previously mentioned, the retreat of the lava column was probably made up of fluctuations in which the drops exceeded the rises. The collapse of the entire floor of Halemaumau indicated a series of collapses of the walls of the feeding fissures. The downsurgings of the lava may well have timed the moment of the collapses. Sometime during this pulsating descent of the lava column, a trapped ground-water pocket was encountered, and with the shattering of the conduit walls a comparatively small amount of water gained access to the volcano system. This could account for the first small explosion on May 11. The next indicated withdrawal of lava and collapse of the conduit walls was on May 13, and explosions resulted. If the bottom of the pit was 1,000 feet below the rim, which, in turn, was 3,700 feet above sea level, and if the height of the trapped ground water was 1,500 feet above sea level, then 1,200 feet of fragmental material would have to be lifted to make an appreciable showing in the bottom of the pit. With an average specific gravity of 2 for such a plug, the pressure generated would have to exceed 1,000 pounds per square inch. Pressures of this magnitude should be developed easily. As the explosions progressed, there may have been an increase in the specific gravity of the fragmental material filling the vent because of an increase in the amount of dense material from more deep-seated walls of the conduit and a decrease in the percentage of vesicular lava from the upper walls. If, as is probable, there was a more or less progressive increase in depth of the seat of the explosions, there may not have been a striking increase in the weight of the plug, for there was a gradual increase in the depth of Halemaumau, the maximum being indicated about May 17.

In order to arrive at possible explosion pressures, let us assume probable temperatures and a possible amount of water. If, as has been assumed, most of the explosions occurred just following a downsurge in the lava column, the walls of the conduit had a temperature of about 1,700° F. Let us assume a surface area in the evacuated conduit of 6,000 square feet. An opening 50 feet long and 60 feet deep would furnish such an area. Hot fragmental material that might have fallen into the cracks would also have been an important additional source of heat. Hot volcanic gases would have been a minor contributing factor. If the explosion pressure was developed as a "flash boiler," then the heat available was confined to a layer about one-eighth inch thick in the rock surface. The volume of the rock, if one computes only the surface of the walls of the fissure, would be 62.5 cubic feet. With a specific gravity of 2.5, this volume of rock would weigh about 10,000 pounds. The number of available B.T.U.'s above 210° F. in 10,000 pounds of basalt with an initial temperature of 1,700° F. is 4,470,000, if we assume the specific heat of basalt in this temperature range to be 0.30.

If we assume a final temperature of 900° F. for the boiler system, the available heat in 10,000 pounds of basalt would amount to 2,400,000 B.T.U.'s. This amount of heat would be nearly enough to raise the temperature of 2,000 pounds of water from 66° to 210° F., evaporate it, and then superheat the steam to 900° F. Evaporation, of course, would take up most of the heat. The pressure generated by such a system with a constant volume would be over 3,000 atmospheres. Of course, there was no constant volume system, but the pressure developed must have been many times the minimum requirement of 1,000 pounds per square inch mentioned previously.

Now the question arises as to whether it is possible to inject suddenly an appreciable amount of water into an evacuated conduit. The Olaa well,[6] with a drawdown by continuous pumping of 8 feet, showed a continuous inflow of 80 gallons a second. If a void with the same capacity as that of the sump below the water surface were suddenly created, the amount rushing in during the first half second might well be several times that of any half second after pumping had been in progress for some time. Likewise the discharge during the first half second from water trapped in a dike compartment, when the wall separating it from a volcano conduit is suddenly shattered, might greatly exceed that of any subsequent half second. Furthermore, if the shattering occurred at the same time as a rapid downsurge of the lava, there might be a pressure decrease that would facilitate the inflow of water. A considerable vertical range in the shattered conduit would speed up the inflow of water, for the velocity of inflow varies roughly as the square root of the depth below the surface of the water table.

The temperature of the dust of the explosion column as it cleared the crater rim must have been nearly 900° F., for on several occasions it was observed to have a dull red glow. The expanding steam, then, in the midst of the hot dust, would have had a volume about 3,500 times that of its water equivalent when it reached atmospheric pressure and would have condensed only in the extreme upper and cooler portions of the cloud. Steam was first definitely observed in the explosion cloud on May 14, though whether it had its origin in the explosion or from steaming vents in the crater wall is not known. The amount of condensation of water vapor in the explosion clouds was never striking, in fact, not much more than might be expected from such a column of hot air with appreciable indrafts of humid air. The explosions must have been produced by relatively small amounts of steam.

Although there was no apparent regularity in timing with many of the explosions that occurred during the early part of the explosive period, the most common interval between explosions[7] was 6 to 8 hours. This interval was in accord with observations on lava fluctuations in Halemaumau. The early irregularities might be expected when one considers the possible existence of a network of feeding fissures under Halemaumau that decreased in number with increase of depth and the possibility that collapsing in the different walls may not have taken place simultaneously. Then, too, the explosion pressures themselves may have been the cause of some of the collapses and thus may have resulted in a series of explosions closely following one another. It should be noted that whether there was one feeding conduit with a diameter equal roughly to the bottom of Halemaumau or a series of feeding wells, the preceding discussion is little affected. If there were but one conduit, variation in the timing of the shattering of different portions of the conduit walls could have produced the observed effects.

Two conditions could have prevented further explosions: a lava column that had become stationary and the cessation of the shattering of the walls of the dike-inclosed compartments containing water.

Many of the explosions, perhaps all, produced air-pressure waves preceding the sound waves. This indicates that the onset of the explosions was rapid, like that of dynamite. The idea of a "flash boiler" mechanism to account for the May 1924 explosions of Kilauea does not seem incompatible with possible available heat and ground water nor with the observed facts of the explosions.

AUTHOR'S ACKNOWLEDGMENT: The author is indebted to Dr. T. A. Jaggar and Dr. G. A. Macdonald for reading and criticizing the manuscript, and to Mr. Williard M. Eller of the Hilo Electric Light Company, Ltd., for checking the computations.

COMMENTS

By T. A. JAGGAR

The foregoing discussion on a possible mechanism for comparatively shallow focus explosions is interesting.

I think of the surgings as deeper and place more emphasis on the magmatic furnace than on incandescent walls. With deeper surgings, the wall breakage with each retreat would let in fresh water from the Ghyben-Herzberg lens at the same time that magma was cascading into the evacuated chamber. The effect would be similar to the surface cascade shown in the figures in the Bulletin of the Hawaiian Volcano Observatory for August 1919.

With the Ghyben-Herzberg ground water standing at 35 feet above sea level, the bottom contact with salt water was 1,400 feet below sea level. If the lava outflow undersea was at one-fourth the depth found 40 miles off Cape Kumukahi (east point of the island) and emerged one-fourth the way down the submarine slope at an elevation of about 4,500 feet below sea level, it was 3,000 feet below the bottom of the fresh water lens.

If the rushing lava was cascading past Kilauea from a head relatively high within Mauna Loa, one cascade or rift tunnel could furnish either a continuous or intermittent furnace, such as the cascades and tunnels that were observed for days in 1919 to 1920.

Surgings and drainages would suck down air from the fissured mountain above ground-water level and so increase the

[6] Duncan, George. "The Dug Well at Olaa Mill." Volcano Letter No. 477, July-September 1942.

[7] Finch, R. H. "Seismic Sequences of the Explosive Eruption at Kilauea in May 1924." Seismological Society of America Bulletin, December 1924, page 217.

heat supply with intense gas oxidation. Cascades of retreat are nothing more than excessive convectional fountaining. Far below water level a downsurge of 10,000,000 cubic feet of lava within a half hour cannot leave a vacuum. Evacuated by steam explosions, a shatter chamber, below 1,500 feet of head of water and still lying higher than at least 3,000 feet of head of much heavier rushing lava that sends up a roaring gas furnace through the well, is likely to suck water into the chamber and make steam that pulsatingly escapes. The bulk of the magma rushes on to effervesce into the ocean. With surges of collapse a Bessemer-furnace process would be set up through the collapse debris. Flash-boiler heavings would punctuate the collapse around the deep chamber—collapses having nothing to do with faulting at the surface.

The mechanism may be thought of as a pouring torrent released through a rift tunnel. The geyser shaft was pulsating accordingly as ground water, alternately heated, blasted upward and rushed in cool. The blasts aided rupture for pumping in new water.

I think the end of the explosions resulted because of a backing up of the submarine outflow, the lava filling fracture fissures and losing pressure through satisfying the new rift-system that was generated in the first place by the tumescent stress under the whole island in surgings of 1915 to 1923. This merely makes the tumescence of the upper island extend itself eastward to the submarine island whenever the century-long cycle between steam blast eruptions shifts its surging from high under Mauna Loa to low under Kilauea or Hualalai. The 130-year period for explosions at Kilauea represents something fundamental in the volcano mechanism that cannot be satisfied with superficial relations only.

The arrangements of the 1919 to 1920 flow from Kilauea that built up Mauna Iki serve as a model of the 1924 system. The Mauna Iki flow was fed by a rift tunnel from Halemaumau through an arcade that still shows in the southwest wall. A little way down the slope from Halemaumau was a lava well, with fountaining lava and escaping gas. In 1924 the entrance arcade was somewhere in the depths under Mokuaweoweo; Halemaumau was the well over the rift tunnel; and the lava flow issued somewhere on the submarine slope east of Cape Kumukahi. With such an arrangement we get three possibilities:

(1) That the tunnel is shelled over water tight and lava tight, and the ground water outside like a tubular boiler. This is not possible, as it was recently feeding the pit and in April 1924 was in a belt of shattering.

(2) That the tunnel is a longitudinal rift torrent, open to the pit, its gases rising to the Halemaumau vents in debris; that these vents in turn are water pipes of the shatter belt under hundreds of feet of hydrodynamic head, the water surging downward as the lava fountains surge upward and downward.

(3) That the feeding vent is an independent upright dike under Kilauea, trending to Puna under the openings of 1920 (Mauna Iki), 1921 (Halemaumau), 1922-1923 (Makaopuhi), and April 1924 (Kapoho)—all sealing above and splitting wide open below to rupture a way along the under-ocean dome surface, just as the Kau Desert ruptured in December 1919 to January 1920. The water conditions were the same as (2).

Probably both (2) and (3) are true, the November 28, 1919 sympathy with the end of the Mauna Loa eruption being the beginning of the rupturing downward that fractured open the Kau Desert rifts in 1920. The upsurges of 1923 must have been dike splitting to introduce the dike fillings of the downsurges. A colossal volume of liquid had to go somewhere and come from somewhere, and neither source nor destination appeared.

All the events were a part of the same Mauna Loa-Kilauea pulse series—like 1914, 1916, 1919, 1920, 1921, 1922, and 1923—which left their output on the surface and also within the internal dikes of tumescence. Thus it is only reasonable to believe that the main vent is under Mauna Loa and deep, that the 1923 surgings were the culmination of lava lowering within Mauna Loa, and that the destination was on the same enormous submarine mountain beyond Cape Kumukahi. That Kilauea was internally robbed is proved by Wilson's shrinkage.[1]

Ground water was essential to the occurrence of any explosions at all. When the lava column, its outer armor broken, got below ground water, a phreatic accident was initiated. This means that if the 1942 flow from Mauna Loa, say, had had a head of ground water above, it would have been accompanied or followed by upper-well explosions. Just such explosions are the rule in heavily watered continental volcanoes. This would be particularly the case if the andesites were viscous and the fountaining subterranean. Ergo: Lassen, Vesuvius, Pelee, and Merapi.

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[1] Wilson, R. M. "Ground Surface Movements at Kilauea Volcano, Hawaii." University of Hawaii Research Publication No. 10, 1935.

Hawaiian Volcano Observatory Report for January-March, 1943

VOLCANOLOGY

January

The beginning of 1943 found both Kilauea and Mauna Loa inactive. Heavy rains during the first week of the month caused conspicuous steam clouds over the 1942 lava flow from Mauna Loa. These clouds started rumors that Mauna Loa was in eruption. A landslide at Halemaumau raised a conspicuous dust cloud at 13:45, January 26. There was an unobserved landslide from the southwest wall of Kilauea. At Kilauea 82 seismic disturbances were recorded and at Mauna Loa 32.

February

Only one of the 83 seismic disturbances recorded at Kilauea was strong enough to be perceptible at the Observatory. On the Mauna Loa seismograph, 33 quakes were registered. There was a perceptible widening of the cracks around Halemaumau.

The thermometer shelter was moved to the new observatory grounds in 1941. The new location, slightly lower than the old, is on the windward side of the northeastern-rim steam cracks; therefore, minimum temperatures now recorded are frequently lower than those at the old location.

March

The preponderance of Kilauea shakes over those of Mauna Loa origin, exhibited in January and February, continued in March. There were 71 shakes at Kilauea and 47 at Mauna Loa. None of the quakes appeared to have any special volcanic significance, and Hawaiian volcanoes remained quiet throughout the month.

R.H.F.

SEISMOLOGY

Earthquake Data, January-March, 1943

Week Ended		Minutes of Tremor	Very Feeble	Feeble	Slight	Local Seismicity*	Teleseisms
Jan.	3	9	1	0	0	2.75	0
	10	5	1	0	0	1.75	0
	17	9	4	0	1	6.25	0
	24	38	0	1	1	12.50	0
	31	15	2	0	0	3.75	0
Feb.	7	10	0	0	1	4.50	0
	14	29	1	0	0	7.75	0
	21	22	2	0	0	6.50	1
	28	27	1	0	0	7.25	0
Mar.	7	18	0	0	0	4.50	0
	14	14	5	2	0	8.00	0
	21	16	1	1	0	5.50	2
	28	9	0	0	1	4.25	0

* For definition of local seismicity, see Volcano Letter No. 371.

The data of the following local disturbances were determined from seismograph stations operated on the Island of Hawaii by the Hawaiian Volcano Observatory of the Hawaii National Park. Time is Hawaiian Standard. The number preceding each earthquake date is the serial number of the quake for the current year.

1. January 9, 20:04, very feeble, felt in S Kona.
2. January 11, 14:32, very feeble, Mauna Loa.
3. January 15, 17:41, very feeble.
4. January 16, 03:38, very feeble.
5. January 16, 04:22, very feeble, origin at Kilauea.
6. January 17, 14:08, slight, felt locally, NE rift Mauna Loa.
7. January 19, 02:48, slight, felt locally and in Hilo.
8. January 24, 03:09, feeble, felt in Pahala.
9. January 27, 19:06, very feeble, felt at Kukaiau.
10. January 30, 13:53, very feeble.
11. February 1, 22:10, slight, felt in Hilo, Mauna Loa origin.
12. February 8, 10:35, very feeble.
13. February 15, 06:30, very feeble, felt in Kohala.
14. February 16, 03:59, very feeble.
15. February 27, 07:04, very feeble.
16. March 10, 07:34, feeble, Kilauea shake.
17. March 10, 22:52, feeble, Kilauea shake.
18. March 11, 03:06, very feeble.
19. March 11, 04:11, very feeble.
20. March 11, 10:26, very feeble.
21. March 12, 19:26, very feeble.
22. March 13, 19:25, very feeble.
23. March 15, 12:06, feeble, between Mauna Loa and Mauna Kea.
24. March 16, 01:54, very feeble.
25. March 25, 13:05, slight, Mauna Loa.

TELESEISMS

February 21, 23:00, slight.
March 15, 12:30, very slight.
March 21, 10:10, very slight.

MICROSEISMIC MOTION

Microseisms were present throughout the quarter but especially noticeable on February 13 only.

TILTING OF THE GROUND

The normal southwest tilt prevailed during the quarter save for a slight north-northeast tilt during the last few days of January and the first few days of February. For the past several months the tilt stations at Halemaumau showed almost no movement.

Table of Tilt at Observatory on NE Rim of Kilauea

Week Ended		Amount	Direction
January	3	0.27″	S28° E
	10	1.46″	S42° W
	17	0.48″	S
	24	1.33″	S
	31	0.51″	S13° E
February	7	1.40″	N53° E
	14	0.74″	S80° W
	21	1.17″	N71° W
	28	1.39″	S38° W
March	7	0.57″	N45° E
	14	1.00″	S76° W
	21	0.72″	S
	28	0.84″	W

CRACK MEASUREMENTS

All cracks around Halemaumau except one showed a slight opening during the quarter. One crack along the Chain of Craters Road showed a slight opening; the other crack in this area exhibited no movement.

R.H.F.

HAWAIIAN VOLCANO RESEARCH ASSOCIATION

in cooperation with

UNIVERSITY OF HAWAII

The **Hawaiian Volcano Research Association** was founded in 1911 for record of volcanoes in the Hawaiian Islands and around the Pacific Ocean. Its equipment at Kilauea Volcano, Hawaii Island, has been transferred to the United States Government, Department of the Interior, National Park Service.

The **University of Hawaii** cooperates in maintaining a research laboratory at Hawaii National Park. The **Association** and the **University** maintain outside seismograph stations and supplement the work of the government with research associates, instrumental plants and special investigation. Dr. T. A. Jaggar is their geophysicist resident in the National Park.

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HAWAII NATIONAL PARK: Edward G. Wingate, Superintendent; R. H. Finch, Volcanologist

UNIVERSITY OF HAWAII: T. A. Jaggar, Geophysicist

LAVA RIVERS AND THEIR CHANNELS

By R. H. FINCH

Estimates by reliable authorities of the depth of rapid-flowing lava rivers of Mauna Loa and the observed depth of the channels after flowing has ceased are often in disagreement. The discrepancy arises from the fact that the observed channel depths are too great.

Lava rivers are comparatively narrow streams flowing within well-defined banks. Where such streams flow out onto a relatively flat terrain, especially if the lava is in the aa stage, a slow-moving lava field covering a considerable area may develop. Short-lived lateral overflows often build up the banks of the channel so that frequently lava rivers are appreciably depressed within their banks. Discrepancies persist, however, even after due allowances for such depressions are made. In 1942, for instance, after the Mauna Loa flow had ceased, a channel about 16 feet deep was found where the river was estimated to have been not over 4 to 6 feet deep and depressed within its banks from 3 to 4 feet. This leaves a discrepancy of over 6 feet to be accounted for. In some cases, discrepancies are even greater.

The order of magnitude of the depth of Mauna Loa lava rivers is determined by noting the behavior of a stream at a cascade and by estimating the percentage of the large bank segments that remain visible after having broken off and fallen into the stream. Often lava rivers branch to make braided streams (fig. 1). The majority of these branches persist but a short time and thus offer opportunities to check estimates of depth. Here, estimated and measured depths are in close agreement. The shallow depth of short-lived streams might be taken as an indication that time is an all-important factor in regard to depth and that long-continued rivers erode or melt material to form a deep channel. These possibilities can be discarded, however, as such erosion cannot be appreciable. Moreover, the possibility of lava fusing the bottom of its channel to give the indicated increase in depth is very remote, because the temperature required to fuse lava does not obtain in such a river. Some other explanation must be sought. Furthermore, because lava rivers tend to crust over and the crust tends to become broken into blocks which sink into the melt, one might expect the channel to grow progressively shallower unless there is some mechanism whereby such sunken blocks are continually removed.

Dr. T. A. Jaggar made the first detailed observations on the mechanics of a Mauna Loa lava river at the Alika flow in 1919.[1] Describing the lava river, he stated: "The effect in the lava stream was as though the bottom were everywhere at shallow depth, and perhaps itself shifting downhill at a slower rate than the liquid film on top." In another paragraph he said: "After seeing the marked differentiation between the liquid lava in the channel and the evident semi-solid matter of the channel bottom and sides—the writer surmised that there were here present two kinds of magma, just as in Halemaumau. There we have the sharply differentiated lake magma and bench magma."

Irregularities in the bottom of lava rivers often manifest themselves as stationary waves at the surface. The progressive movement downstream, observed on several occasions, of some of the obstructions causing these stationary waves is a good indication of the dual nature of such streams—that is, of an upper rapid-flowing stream with low viscosity superposed on a sluggish viscous one. The closing stages of Mauna Loa lava rivers fur-

[1] Jaggar, T. A. "Activity of Mauna Loa." Bulletin, Hawaiian Volcano Observatory, October 1919, page 136.

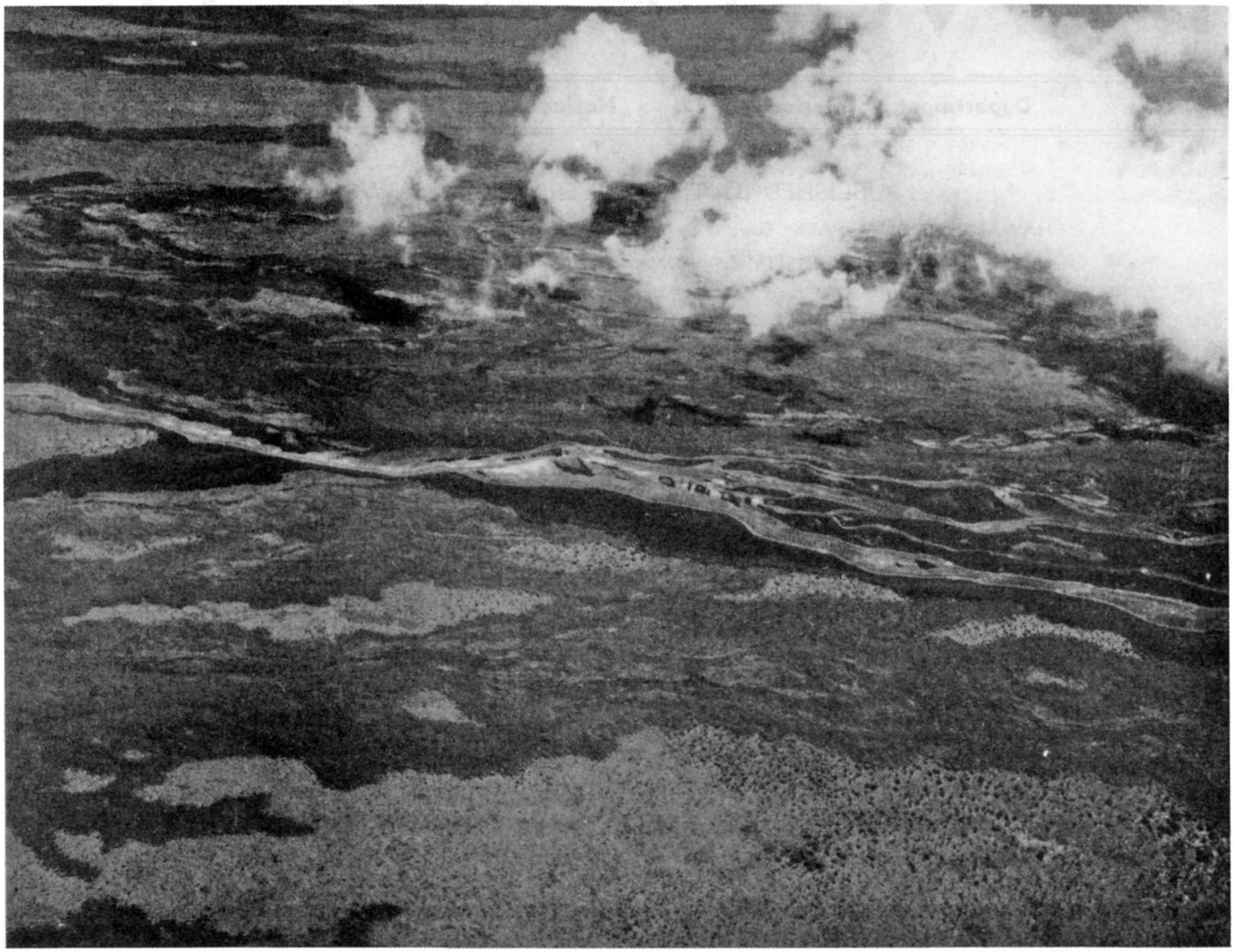

Figure 1—The 1942 Mauna Loa lava river a little below the source cone, where it divided to form a "braided" stream. These branches returned to a single channel lower down. (Photo by Base Photo Laboratory, A.A.F.—APO No. 953.)

nish further evidence on the dual nature of such streams. When diminishing activity at the source cuts off the supply, the material in the upper river quickly drains away, while the slower-moving lower stream continues for some time. Accurate timing of the cessation of the two streams would give some idea of their relative viscosities. Probably, just as perceived by resistance to sounding pipe in Halemaumau, there is gradation of viscosity from liquid vitreous foam on top of the lava rivers to semi-crystalline paste at the bottom. The flowing onward of this paste at the end of an eruption should shallow the delta region stream and deepen the upstream gorge. Exactly this occurred in 1919, 1935 and 1942.

Dr. Jaggar's observation in 1919 that the rapid-flowing Mauna Loa lava rivers are shallow and superposed on slow-moving channel material seems to be justified.

THE VISCOSITY OF MAUNA LOA LAVA FLOWS

By R. H. FINCH

The viscosity of flowing lava is constantly changing. The change is generally to a higher viscosity, because of a decrease in temperature. At the surface of a lava flow, the change is much more marked than in the interior. In pahoehoe flows, the formation of skins gives a very high viscosity for an outer layer. This outer layer, being a good insulator, helps the interior to maintain a high temperature and a relatively low viscosity. The surface granules of an aa flow likewise act as an insulator and allow this type of lava to flow to considerable distances. The rapid cooling of overflows from lava rivers and of the tongue-like extensions by which lava advances causes a rapid change in viscosity within a few seconds.

Because of these factors, one might expect to find a great range in the estimates of the viscosity of lava flows. The data for the estimates of the Alika flow were taken where it crossed the road, which is 9 miles from the source. The apparent viscosity of the lava river changed but slightly in the nine miles, although from the preceding article one might expect that the

volume of the low-viscosity surface portion of the river was relatively greater near the source than at a point 9 miles away. The figure determined by Palmer[1] may be essentially correct for a lava river near the source. Palmer gave the viscosity of the Alika flow as 15 times that of water. Whether the Palmer value is multiplied by 2, or 3, or even 10, it gives us the order of magnitude of the viscosity and is much nearer the truth than the computations of Nichols.[2] The tremendously high viscosity arrived at by Nichols—4,300,000 times that of water—was largely due to erroneous assumptions in regard to field data. For the Alika flow, he made his computations for a river channel and used a depth that was undoubtedly too great. In his computations on the 1887 flow, he had the flow moving as a unit. This, of course, was not the case.

A rough check on the errors in the Nichols' determination is provided by the data he gives on the temperature of dry melt. The formula he used gave the Alika and the 1887 flows higher viscosities than those of dry melts! Now it is well known, although often overlooked, that to reheat lava and get the same degree of mobility that it had when cooling at, say 650° C., it must be heated several hundred degrees higher. Day[3] gives the difference in temperature for lava in which movement can just be detected and the same lava reheated until it will flow under its own weight as 700° C. This is about the same temperature difference that Rittman[4] believed obtains for similar stages in Vesuvian lava. Shepherd[5] has pointed out the importance of small percentages of volatiles in melts and hence the danger of comparing the viscosity of lava flows with the viscosity of reheated devolatilized or partially devolatilized lavas.

The determinations of viscosity made by Nichols appear to be applicable to the tongue of a lava flow that has about ceased moving, but not to Mauna Loa lava rivers. His value may be too low for a moving lava field devolatilized and away from the river.

[1] Palmer, Harold S. "A Study of the Viscosity of Lava." Bulletin, Hawaiian Volcano Observatory, January 1927, page 1.
[2] Nichols, Robert L. "Viscosity of Lava." Journal of Geology, April-May 1939, page 295.
[3] Day, A. L. "Some Causes of Volcanic Activity." Franklin Institute, 1925, page 5.
[4] Rittman, A. "Oral communication." 1934.
[5] Shepherd, E. S. "The Gases in Rocks and Some Related Problems." American Journal of Science, 1938, page 311.

Hawaiian Volcano Observatory Report for April-June 1943

VOLCANOLOGY

April

April was a month of low seismicity. At Kilauea, 36 seismic disturbances were recorded and at Mauna Loa, 35. None of the shakes was perceptible in the vicinity of the Observatory. The scarcity of earthquakes and a southwest tilt that was less than normal for this season of the year may be taken as indications of rather high internal pressure in the Mauna Loa-Kilauea system. However, despite the scarcity of earthquakes and lack of much tilt, landslides from the walls of Halemaumau were rather frequent.

May

The spell of seismic quiet that marked April continued through May. At Kilauea, 29 seismic disturbances were recorded and at Mauna Loa, 26. An earthquake that originated on the eastern flank of Mauna Loa was felt slightly at widely scattered points in the eastern part of the island of Hawaii at 5:10 a.m. on April 8.

Fume in about the usual amount was observed from the center of Mokuaweoweo on May 29. Several places in the vicinity of the source cone of the 1942 Mauna Loa flow were still quite hot on May 29. The odor of free sulphur was detected at one hot spot about one-quarter mile below the cone. This spot appears to be the place from which conspicuous fume was emitted during the progress of the flow and for a week or two after the eruption ceased.

Along the northwestern edge of the flow, not far from the previously mentioned hot spot, new black aa spatter may be found on the old lava. No cone structure or spatter rampart was built up here and there is little evidence to show where the spatter came from, as the source was buried by a subsequent aa flow. The only clue is the end of a small new crack in the old lava. This crack may be taken as an indication that 1942 lava in an old tube developed sufficient pressure to disrupt the roof at this place and forcibly eject black aa spatter.

June

June is the third month with little seismic activity. At Kilauea, 22 local disturbances were recorded and at Mauna Loa, 15.

After a heavy rain during the latter part of June, the outline of the 1942 Mauna Loa flow was plainly revealed by dense steam clouds. In other words, the 1942 lava, nearly 14 months after the flow ceased, is still hot.

BLOCK LAVA IN THE 1942 FLOW FROM MAUNA LOA

A small patch of block lava may be found in the midst of aa lava near the northwestern edge of the 1942 Mauna Loa flow about one-quarter mile below the source cone.[1] This lava resembles broken brick, having none of the spiny or clinkery surface characteristic of aa. When viewed from a distance, however, its fragmental nature gives it the appearance of aa.

Block lava is distinctly different from slabby pahoehoe. The blocks were formed during the declining days of the eruption by the collapse of the walls of the lava river channel just below the source cone. An appreciable number of the blocks fell upon an aa stream, which transported them to their present position. The uniformity that exists to a greater or lesser degree in the size of the blocks is to be expected when one considers that the thickness of the different flows from which they originated was about the same. Moreover, the larger fragments would be broken during the transportation. R.H.F.

[1] For use of the term block lava, see R. H. Finch, Journal of Geology, October-November 1933, page 769.

SEISMOLOGY

Earthquake Data, April-June 1943

Week Ended		Minutes of Tremor	Very Feeble	Feeble	Slight	Local Seismicity*	Teleseisms
April	4	9	0	0	0	2.25	0
	11	3	0	0	0	0.75	2
	18	16	0	0	0	4.00	0
	25	7	0	0	0	1.75	0
May	2	5	0	0	0	1.25	0
	9	12	1	1	1	6.50	0
	16	11	1	0	0	3.25	0
	23	4	0	0	0	1.00	0
	30	6	1	0	0	2.00	2
June	6	4	0	0	0	1.00	0
	13	4	0	0	0	1.00	0
	20	5	0	1	1	2.75	0
	27	5	0	0	0	1.25	0

* For definition of local seismicity, see Volcano Letter No. 371.

The data of the following local disturbances were determined from seismograph stations operated on the Island of Hawaii by the Hawaiian Volcano Observatory of the Hawaii National Park. Time is Hawaiian Standard. The number preceding each earthquake date is the serial number of the quake for the current year.

26. May 7, 02:09, feeble, felt Kapapala to Hilo, E slope Mauna Loa.
27. May 8, 04:10, slight, generally felt eastern Hawaii, near Mokuaweoweo.
28. May 9, 02:20, very feeble.
29. May 10, 05:20, very feeble.
30. May 30, 12:53, very feeble.
31. June 14, 03:24, very feeble.
32. June 14, 21:38, slight, widely felt island of Hawaii, near Waimea.

TELESEISMS

April 5, 05:51, moderate.

April 8, 21:25, slight.

May 25, 12:50, moderate, distance 8250 km.

May 26, 00:20, slight.

MICROSEISMS

Microseisms were strong on April 10 and 11, moderate on April 28 to 30 and June 10 and 11, and slight throughout the rest of the quarter.

Tilting of the Ground

During the late winter and spring of the year, the southerly tilt was less than normal. The change to northerly tilt occurred about the middle of June. Westerly tilt, which was normal for the first five months of the year, ceased about the middle of May, and the usual easterly tilt began. There was but little movement at the tilt stations near the rim of Halemaumau during the period April to June.

Table of Tilt at Observatory on NE Rim of Kilauea

Week Ended		Amount	Direction
April	4	0.87″	S34° W
	11	1.37″	N63° W
	18	0.51″	N45° E
	25	0.39″	N71° W
May	2	0.88″	S74° W
	9	0.88″	S56° W
	16	0.51″	N45° W
	23	0.76″	S19° E
	30	0.65″	N68° E
June	6	0.60″	S37° W
	13	0.76″	S72° E
	20	0.76″	N18° W
	27	1.08″	N63° E

Crack Measurements

A majority of the cracks in the vicinity of Halemaumau showed slight openings. The opening near the south rim was appreciable in April and May. In June, one of the cracks along the Chain of Craters Road opened 6 millimeters; no movement was detected at other cracks in this vicinity. R.H.F.

HAWAIIAN VOLCANO RESEARCH ASSOCIATION

in cooperation with

UNIVERSITY OF HAWAII

The **Hawaiian Volcano Research Association** was founded in 1911 for record of volcanoes in the Hawaiian Islands and around the Pacific Ocean. Its equipment at Kilauea Volcano, Hawaii Island, has been transferred to the United States Government, Department of the Interior, National Park Service.

The **University of Hawaii** cooperates in maintaining a research laboratory at Hawaii National Park. The **Association** and the **University** supplement the work of the government with research associates, instrumental plants and special investigation. Dr. T. A. Jaggar is their geophysicist resident in the National Park.

The **Volcano Letter**, a quarterly record of Hawaiian volcano laboratories and published by the University of Hawaii, is issued by authority of the Department of the Interior and supplied to a restricted membership and exchange list of the above establishments.

THE VOLCANO LETTER

481

No. 481 **Department of Interior** **National Park Service** **July-September 1943**

PUBLISHED BY THE UNIVERSITY OF HAWAII

HAWAII NATIONAL PARK: Edward G. Wingate, Superintendent; R. H. Finch, Volcanologist

UNIVERSITY OF HAWAII: T. A. Jaggar, Geophysicist

WORK OF UNIVERSITY AND RESEARCH ASSOCIATION

By T. A. JAGGAR

In June, 1938, Dr. T. A. Jaggar, after reviewing twenty-six years of work at the Hawaiian Volcano Observatory, reported in Volcano Letter 460 a planned program for the Hawaiian Volcano Research Association. The plan included making secure the scientific archives, getting the new Observatory building, completing technical publications, creating a publication committee, shifting the volcanologist's work to new hands, and allowing Dr. Jaggar, as Research Associate of the University of Hawaii, to act as editor and writer with the Hawaiian Volcano Research Association collaboration. Various reports on the progress of the plan have been made. Cooperation of the three establishments, Hawaii National Park, University of Hawaii, and Hawaiian Volcano Research Association, was described in Volcano Letter 454, for December, 1937. Dr. Jaggar finished his writing of the "Volcanology" for the quarterly Observatory report of July-September, 1940. "The Physical Plant" of the Hawaiian Volcano Observatory in Hawaii National Park was reviewed by P. E. Schulz in Volcano Letter 475 of January-March, 1942. This issue of the Volcano Letter is a report by the Research Associate of the University of Hawaii on the accomplishments by the University and the Hawaiian Volcano Research Association in accordance with Dr. Jaggar's plan.

The scientific records are being worked over by both R. H. Finch, Volcanologist, and by Dr. Jaggar. The latter has sent two finished memoirs to the Geological Society of America. The new Observatory building at National Park is occupied. The publication committee in Honolulu consists of F. C. Atherton, Gregg M. Sinclair, and T. A. Jaggar. Finch writes, and Jaggar edits the quarterly Volcano Letter published by the University under authority of the National Park Service: its primary function is to maintain a continuous record of the volcano measurements. The making of duplicates of the more valuable volcano records by microfilm, photostat, and carbon copies to be kept at the University has been started.

Some publications appearing later than those listed in Volcano Letter 456 are given below:

PUBLICATIONS OF THE OBSERVATORY

Wentworth, Chester K. *Ash Formations of Hawaii,* Third Special Report of the Hawaiian Volcano Observatory. Honolulu, 1938. (Copies of this volume will be sent to anyone applying for it while the edition holds out.)

Waesche, H. H. *Maui Earthquake of 1938.* Volcano Letter 457, March, 1938.

Philippson, P. and Jaggar, T. A. *Excursion to Nyamlagira Volcano.* Volcano Letter 458, April, 1938.

Verhoogen, Jean. *Eruption of Nyamlagira 1938.* Volcano Letter 459, May, 1938.

Jaggar, T. A. *Planned Program for Hawaiian Association.* Volcano Letter 460, June, 1938.

Waesche, H. H. *An Equatorial Cruise.* Volcano Letter 461, July, 1938.

——— *Chain-of-Craters Earthquakes 1938.* Volcano Letter 462, August-December, 1938.

——— *Time-control of Seismographs.* Volcano Letter 464, April-June, 1939.

Jaggar, T. A. *Expedition to Lava-bombing Site.* Volcano Letter 465, July-September, 1939.

Waesche, H. H. *1935 Lava in Mokuaweoweo Crater.* Volcano Letter 466, October-December, 1939.

Jaggar, T. A. *Exploration NE Rift Mauna Loa.* Volcano Letter 466, October-December, 1939.

Waesche, H. H. *Tilt Changes at Kilauea.* Volcano Letter 467, January-March, 1940.

——— *Mauna Loa Summit Eruption 1940.* Volcano Letter 468, April-June, 1940.

Ballard, Stanley S. and Payne, J. H. *Chemical Study of Kilauea Gases.* Volcano Letter 469, July-September, 1940.

Finch, R. H. *Engulfment at Kilauea.* Volcano Letter 470, October-December, 1940.

——— *The Filling in of Kilauea Crater.* Volcano Letter 471, January-March, 1941.

Williams, Howell and Finch, R. H. *Calderas and Their Origin.* Volcano Letter 472, April-June, 1941.

Finch, R. H. *Volcanic Activity in the Marianas.* Volcano Letter 472, April-June, 1941.

Schulz, P. E. *Tilt Conversion to Seconds of Arc at Hawaiian Volcano Observatory.* Volcano Letter 473, July-September, 1941.

Macdonald, G. A. *Lava Flows in Eastern Puna.* Volcano Letter 474, October-December, 1941.

Schulz, P. E. *Physical Plant of Hawaiian Volcano Observatory.* Volcano Letter 475, January-March, 1942.

Finch, R. H. *The 1942 Eruption of Mauna Loa.* Volcano Letter 476, April-June, 1942.

Duncan, George. *Dug Well at Olaa Mill.* Volcano Letter 477, July-September, 1942.

Finch, R. H. *Surface Ash Deposits at Kilauea.* Volcano Letter 478, October-December, 1942.

——— and Jaggar, T. A. *Lava Surgings in Halemaumau 1924.* Volcano Letter 479, January-March, 1943.

——— *Lava Rivers and Their Channels.* Volcano Letter 480, April-June, 1943.

——— *Viscosity of Mauna Loa Flows.* Volcano Letter 480, April-June, 1943.

PUBLICATIONS IN OUTSIDE JOURNALS

Jaggar, T. A. *A Star Zenith-finder.* Trans. Amer. Geophys. Union, Wash'n. 1938. 60 Pp., illus.

Payne, J. H. and Ballard, Stanley S. *Hydrogen Sulphide at Kilauea 1940.* Science, Vol. 92, 1940. Pp. 218-219.

Ballard, Stanley S. *Solfataric Gases at Kilauea.* Phys. Rev., Vol. 54, 1938. P. 236.

Jaggar, T. A. *Magmatic Gases.* Amer. Jour. Sci., May, 1940. P. 313.

Waesche, H. H. *Ground Tilt at Kilauea Volcano.* Jour. Geol., August-September, 1942. P. 643.

Schulz, P. E. *Summit Eruption of Mauna Loa 1940.* Geol. Soc. Amer. Bul., Vol. 54, 1943. P. 739.

Macdonald, G. A. *Eruption of Mauna Loa 1942.* Amer. Jour. Sci., April, 1943. P. 241.

Eller, W. H. *A New Recording Tiltmeter.* Seis. Soc. Amer. Bul., July, 1939. P. 481.

WORK OF THE UNIVERSITY

The last lecturing to students by Dr. Jaggar was to a class of 70 in July, 1938, and to audiences of 300 persons in the Adult Education Service in March, 1939. Funds were appropriated for special geophysical research in the University by the Territorial Legislature for the biennia 1939-1941, 1941-1943, and 1943-1945, and Dr. Jaggar was appointed Research Associate in charge, to work in collaboration with University departments, the Hawaii National Park, and the Hawaiian Volcano Research Association. After December, 1941, research manuscripts were compiled (to the number of twelve by 1944) and sent to the Government. At regular intervals reports on the geophysical research, including illustrations and laboratory phases, have been made to the President of the University. Laboratory work on "Abrasion Hardness" of substances has been in progress since July, 1942, in a laboratory and shop created by the Association.

The manuscript reports include inventions used in exploration, in seismology, in mineralogy, and in volcanology, which cover a range of activities of the Hawaiian Volcano Observatory from microscope to mountain top, and under the waters of the ocean, from Alaska to New Zealand, and from Italy to Central America. The manuscripts and their illustrations are voluminous, serving in the laboratories to assemble for University use a compendium of forty years of work in geology, and bringing into system what would otherwise have been loose notes. The compendium is matter for scientific recording; publication is gradually being achieved. Samples of such publication are the papers previously listed on ash, magmatic gases, and tilting of the ground. The effort in all this work has been to aim at the principles of comparative volcanology, and not merely to give local description.

Titles of typescripts (the first fourteen written by Dr. T. A. Jaggar) that have been filed are as follows:

1. "Origin and Development of Craters." 843 pages, 93 plates. (Prepared under a grant from the Geological Society of America.)
2. "Expeditions on Certain Hawaiian Beaches." 11 pages, 1 plate.
3. "Conflagration from Earthquakes." 7 pages, 1 plate.
4. "Exploration of Alaskan Beaches." 21 pages, 1 plate.
5. "Mechanical Features of Vehicles for Exploration." 32 pages, 8 plates.
6. "Aleutian Shorelines." 117 pages, 65 plates.
7. "Volcano Explorations in Japan." 120 pages, 49 plates.
8. "Artificial Defense Against Lava-flow Damage." 139 pages, 12 plates.
9. "Expeditions to New Zealand, Tonga, Samoa, and South Sea Islands." 162 pages, 27 plates.
10. "Journals of Caribbean Earthquake Disasters." 276 pages, 36 plates.
11. "Lava Activity of Hawaii Island." 275 pages, 93 plates.
12. "Steamblast Disasters in Caribbean and Pacific." 284 pages, 39 plates. (Received as a memoir by Geological Society of America.)
13. "Volcanoes Around the Pacific." About 1200 pages, with 100 plates selected.
14. "Abrasion Hardness." About 200 pages, with miscellaneous illustrations. (Is in preliminary typescript and photostat.)
15. "Volcano Warfare," by L. W. de Vis-Norton, Secretary-Treasurer of the Hawaiian Volcano Research Association. 15 chapters, 243 pages.

Number 1 is a memoir embodying twenty-six years of experience at the Hawaiian Volcano Observatory, outlining the field of volcano science, and developing some principles of crater evolution. It assembles observations, maps, sections, diagrams, curves, photographs, reviews, and narrative histories of craters. Numbers 2, 4, and 6 deal with the physical geology of Hawaiian and Alaskan shorelines. Numbers 3 and 7 describe explorations among Japanese volcanoes and some disasters due to earthquakes adjunct to volcanic districts. Numbers 5 and 13 have chapters dealing with instrumental invention and special cross-country vehicles designed to apply power engines in exploration instead of pack animals. These publications also describe Pacific and other volcanic activities. Number 8 is a report on the history in Hawaii of an engineering attempt to protect Hilo harbor from lava-flow damage. Number 9 describes expeditions to New Zealand in 1920, Howland and Baker Islands in 1924, and Niuafoou in Tonga in 1930 by Dr. Jaggar, and to six equatorial islands of the Pacific by H. H. Waesche in 1938. It was in 1938 that an earthquake annunciator was experimented with on two of the islands, just as in New Zealand, on Niuafoou, and on Howland portable shock-recorders had been planted for testing seismicity. Number 10 is a comparative study of two earthquake disasters in the field at opposite ends of the Caribbean Sea—the Cartago shocks of Costa Rica in 1910 and the Montserrat spasms of 1933 to 1936. Number 11 is a condensation of Kilauea record books from 1909 to 1935. Number 12 is based on the author's investigation of the Pelée and Soufrière disasters in Martinique and St. Vincent in 1902, and the comparative volcanology of Kilauea, Tarawera, Sakurajima, Katmai, Taal, and Tomboro volcanoes, with especial reference to the reports of wounded persons. Number 13 is a book on twentieth century volcanology. Number 14 is unfinished and dependent on investigations in progress designed to show that physical hardness is probably a fundamental property of the association of particles measurable in terms of kinetic energy. Number 15 is Mr. Norton's book, a popular exposition of field volcano science, admirably suited to magazine publication if it can be illustrated with pen sketches by a good artist.

A sixteenth typescript of importance is a master's thesis entitled "Chemical Decomposition of Rocks at Kilauea" written by K. T. Mau in June, 1940. It includes 103 pages, 13 tables, and 8 figures. This work awaits publication: it investigates relationship between solfataric alteration and final resulting soil. Rock samples were analyzed chemically, microscopically, and spectroscopically. Natural solfatara alteration is examined with reference to decrease and increase of constituents. Decomposition by hot acid steam prolonged for six months artificially included combinations with air, carbon dioxide, and sulphur dioxide. Sulphur dioxide was proved the most active decomposing agent. Methods of analysis are described critically, and the analyses carried to 24 constituents including nickel, copper, chromium, vanadium, strontium, barium, and zirconium. The spectrographic analysis adds cobalt.

These writings are to be issued as scientific memoirs or books as the occasion to publish arises and are in part on their way into print. Other compilations dealing with field and laboratory notes on experiments with volcanoes, experimental geology, graphical position-finding by stars, simplified earthquake recorders, and Aleutian geology are in various stages of manuscript compilation.

The laboratory and offices of this work for the University are divided between 25 Hawaii Hall Annex, which is Dr. Jaggar's Honolulu office, and the Kilauea Laboratory of the University in Hawaii National Park. Dr. Jaggar's annual routine is divided between six summer months at Kilauea and the six winter months in Honolulu. The research associate's personal instruments, tools, and collections from expedition fields are in Honolulu, and the accumulated instruments and records of thirty or more years of the Volcano Observatory are at Hawaii National Park. Cordial assistance is given by the University departments and by the Hawaii National Park. The immediate cooperation of University departments of chemistry and physics at the Kilauea Laboratory was suspended in 1941.

WORK OF HAWAIIAN VOLCANO RESEARCH ASSOCIATION

In 1941, the Hawaiian Volcano Research Association assisted with materials, equipment, and labor in promoting the duplication of records for the University, and in improving the shop of the Kilauea Laboratory and the Chemical Building in Hawaii National Park when the Volcano Observatory was moved. At that time there was great disruption owing to the moving of the hotel to the old Observatory site. The Association has financed illustrations for manuscripts and preparation of collections. In 1941, Dr. Jaggar's assistant at the University was Sutejiro Sato. In 1942, the assistant was Miss Ruth Baker (Mrs. Burton Loucks) who resigned in 1943. Mr. Sato and Miss Baker typed the numerous manuscripts and did valuable work of classification and labelling, assisted in experiments and compiling, as well as in handling much material that required heavy work in the moves from building to building, and from Kilauea to Honolulu and back. The Kilauea laboratories are two buildings distinct from the new Observatory building. Formerly the property of the Research Association, they have since been rebuilt and transferred to the Park Service for the use of the University workers.

The present Board of Directors of the Hawaiian Volcano Research Association consists of: F. C. Atherton, president; W. F. Dillingham and A. L. Dean, vice-presidents; L. W. de Vis-Norton, secretary and treasurer; and C. M. Cooke, J. R. Farrington, W. F. Frear, G. M. Sinclair, W. W. Thayer, and L. P. Thurston. In 1942, there were sixty members and fourteen donors in the Association.

At that time many boxes of records and specimens from expeditions had accumulated. When the crisis of war activity called for suddenly speeded-up laboratory activity in Honolulu there was no room in which to operate. Accordingly, the Association rented a small building near the University where Dr. Jaggar, as their Scientific Director, placed and classified the collections. These included minerals and implements of his own, formerly the subjects of abrasion hardness investigation at Harvard University and the Massachusetts Institute of Technology. A shop was equipped for rebuilding instruments. Throughout 1942 and 1943 a succession of model sclerometers has been tested on specimens of glasses, minerals, woods, and metals.

A paper on the "Hardness of Hawaiian Woods" was read before the Hawaiian Academy of Science October 16, 1942, and a sclerometer was exhibited in the form of a drill-press with a steel milling tool. It was shown that the hardness of substances varied inversely as the depth of boring during a constant interval, the result having been read by micrometer indicator where the pressure and speed were kept constant.

Such model instruments, used where volume abraded under identical conditions is the end sought, are parallel to the devices employed in metal-working where "machinability" is measured. Complexity of the aggregate of particles, whether atoms, molecules, or granules in a bond, and such qualities as sharpness of tool, toughness, brittleness, and viscosity of substances, all make the investigation a prolonged puzzle. Simple indentation is used in metallurgy as a measuring device. This, however, gives inconsistent results, and is quite inapplicable to minerals, rocks, glasses, and porcelains. Progress has been made since the work on abrasion hardness of woods was made public, and it is believed that a device will be worked out that will be fundamentally sound as a physical implement.

Preparation of a manuscript in connection with the subject of abrasion has proceeded with the assembling of matter from modern reference books. It deals with the great recent extension of the grinding industry and the metallurgy of alloys and welding, a science now so important in ship and airplane construction. There is also much need for abrasion measurement of woods, plastics, earthenware, stones, and minerals. Implements are now in use that deal with wear and degradation in commerce, or with ductile or malleable flow, but the aspect in physics of mutual collision-resistance by molecules appears to have been neglected in elementary textbooks.

The results of founding the Hawaiian Volcano Research Association in 1911 were the creation of the Volcano Observatory at Kilauea, establishment of Hawaii National Park, sending forth of Pacific expeditions, extension of work to California, Alaska, and the Caribbean, and obtaining the increasing cooperation of the Federal Government, the University of Hawaii, and outside research establishments. In volcanology, there is the same need for study of the hot interior earth, including the foundation of three-quarters of the earth's surface under oceans, as there is in astronomy for the physical exploration with instruments of the hot stars of the outer universe. The importance of the Research Association's making such field study possible should be emphasized.

As accented in Volcano Letter 454, the greatest need at present is for a fireproof building for valuable records in the University grounds in Honolulu: the records are now scattered in pine buildings. On February 6, 1940, the total destruction of the hotel by fire at Hawaii National Park taught a lesson. The second need in the current situation is a lava diversion channel, constructed according to surveys which have been finished, to defend Hilo from a Mauna Loa flow: the summit eruption of November, 1943, may be the portent of a coming 1945 outflow.

The Research Association is grateful to E. G. Wingate, superintendent, Hawaii National Park, for construction improving the Kilauea laboratories of chemistry and geophysics for University use. Unfortunately, a grant for critical hydrogen study made in 1941 by the Geological Society of America was suspended by the war crisis.

Summarizing joint activities of the last five years, we report memoirs completed, many thick illustrated and bound reports put into use, laboratories extended, publications issued, physical investigations in progress of service to technology made, records duplicated, a popular book sent to a publisher, and collections of specimens from world localities assembled. These are products of the University of Hawaii and the Hawaiian Volcano Research Association. Likewise, the engineering and scientific staff of Hawaii National Park has continued steadfastly its task of accumulating records and meeting crises in the face of untold reduction of resources.

Hawaiian Volcano Observatory Report for July-September 1943

VOLCANOLOGY

July

The spell of seismic quiet that started in April continued through July. Of the 28 seismic disturbances recorded at Kilauea, 2 are classed as earthquakes and the rest as tremors. Thirty-one seismic disturbances were recorded at Mauna Loa.

Following a heavy rain during the afternoon of July 8, steam clouds were conspicuous over the 1942 flow. The outline of the clouds was so sharp that rumors of a Mauna Loa eruption were started.

August

There was less seismic activity in August than in July. At Kilauea, 21 seismic disturbances were recorded and at Mauna Loa, 26.

Several slides from the walls of Halemaumau were noticed during the first half of the month.

September

Eighteen seismic disturbances were recorded at Kilauea and 20 at Mauna Loa.

September marked the sixth consecutive month in which but very few earthquakes were recorded at the Hawaiian Volcano Observatory. This is the longest period of seismic quiet in the history of the Observatory and is probably the longest in the last 120 years.

The present 6 months period of seismic quiet occurs during the longest period without volcanic activity at Kilauea on record. Nearly 9 years have elapsed since molten lava was visible in Kilauea. For about 6½ years no fume has been visible in Halemaumau, and but very little steam has escaped.

R.H.F.

SEISMOLOGY

Earthquake Data, July-September 1943

Week Ended		Minutes of Tremor	Very Feeble	Feeble	Slight	Local Seismicity*	Teleseisms
July	14	9	0	1	1	5.25	0
	11	9	0	0	0	2.25	1
	18	2	0	0	0	0.50	0
	25	3	0	0	0	0.75	0
August	1	5	0	0	0	1.25	1
	8	6	0	1	0	2.50	0
	15	2	1	0	0	1.00	0
	22	5	0	0	0	1.25	0
	29	5	0	0	0	1.25	0
September	5	3	0	0	0	0.75	1
	12	3	0	0	0	0.75	0
	19	6	2	0	0	2.50	4
	26	2	2	0	1	3.50	0

* For definition of local seismicity, see Volcano Letter No. 371.

The data of the following local disturbances were determined from seismograph stations operated on the island of Hawaii by Hawaiian Volcano Observatory of the Hawaii National Park. Time is Hawaiian Standard, 10 hours and 30 minutes slower than Greenwich. Distances are from the Observatory. The number preceding each earthquake date is the serial number for the current year.

33. July 1, 01:51, slight, felt locally and at Kapapala, near Ainapo.
34. July 3, 04:26, feeble. NE rift Mauna Loa above Puu Ulaula.
35. August 7, 12:40, Puna rift, 17 miles.
36. August 9, 02:14, very feeble.
37. September 13, 12:34, very feeble, near Mokuaweoweo.
38. September 17, 05:11, very feeble, felt Kohala.
39. September 21, 09:04, very feeble.
40. September 21, 16:17, very feeble, Kilauea crater.
41. September 21, 17:19, slight, Kilauea crater.

TELESEISMS

July 11, 15:49, slight.
July 28, 16:45, moderate, distance 7400 km.
September 13, 16:01, slight.
September 13, 17:45, slight.
September 13, 20:59, moderate, distance 5900 km.
September 19, 14:46, slight.

MICROSEISMS

Microseisms were moderate from July 6 to 9 and on July 19. During the remainder of the quarter microseisms were present though slight.

Tilting of the Ground

Westerly tilt prevailed during July and until the latter part of August when easterly tilt set in and continued through September. There was a slight and more or less continuous northerly tilt during the quarter. After having been nearly stationary for several months, the tilt instruments near the rim of Halemaumau showed some oscillations during the latter part of September.

Table of Tilt at Observatory on NE Rim of Kilauea

Week Ended		Amount	Direction
July	4	0.40″	W
	11	0.74″	N10° E
	18	1.12″	N13° E
	25	0.77″	S51° W
August	1	0.77″	N71° W
	8	0.27″	N27° W
	15	0.27″	N27° W
	22	0.48″	W
	29	0.54″	N26° E
September	5	0.17″	S45° E
	12	0.62″	N79° W
	19	1.45″	N48° E
	26	0.54″	S64° E

Crack Measurements

The majority of the cracks around Halemaumau showed no movement during July while most of those along the Chain of Craters Road closed slightly. With the exception of 1 crack which opened 3 millimeters, there was very little movement at the Halemaumau rim in August. The majority of the cracks along the Chain of Craters Road opened slightly. In September there was but very little movement either at Halemaumau rim or along the Chain of Craters Road. R.H.F.

HAWAIIAN VOLCANO RESEARCH ASSOCIATION
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THE VOLCANO LETTER 482

No. 482 **Department of Interior** **National Park Service** **October-December 1943**

PUBLISHED BY THE UNIVERSITY OF HAWAII

HAWAII NATIONAL PARK: Edward G. Wingate, Superintendent; R. H. Finch, Volcanologist

UNIVERSITY OF HAWAII: T. A. Jaggar, Geophysicist

ACTIVITY AT MAUNA LOA IN NOVEMBER 1943

By R. H. FINCH

Conspicuous fume clouds over Mokuaweoweo and spells of continuous tremor on the seismographs indicate that there was slight activity at Mauna Loa in November 1943. The first observation of unusually heavy fume arising from Mokuaweoweo was made on October 10 by A. L. Jess from the summit of Mauna Kea. Steam always rises from the west central part of the crater. Mr. Jess made his observations at 6:45 a.m. and reported heavy fume from the southwestern part.

There had been some indications of a sustained and fairly high pressure under the Kilauea-Mauna Loa volcano system for several months. The indications were chiefly lack of southwest tilt in the spring of 1943 and extraordinarily low seismicity from April to the middle of October. Northeast tilt in the fall of 1943 was about the seasonal normal or, at least, not enough to indicate a return of lava to Kilauea. The number of seismic disturbances at Mauna Loa in October greatly exceeded those at Kilauea; they were 33 and 22, respectively. In November the corresponding numbers of seismic disturbances were 93 and 79. The majority of the November disturbances occurred on the 21st, 22nd, and 23rd. The excess of the number of Mauna Loa shakes over those from Kilauea in October and the observed fume on October 10 were definite indications of a growing uneasiness of Mauna Loa. The indications were not definite enough, however, to indicate impending activity at Mauna Loa.

Further evidence of Mauna Loa's uneasiness was the conspicuous earthquake at 5:22 p.m. (war time) November 10, in which movement of a large block in the southwestern slope of Mauna Loa was involved. Then during the morning of November 11, employees of the Puu Oo ranch on the southeastern slope of Mauna Kea observed conspicuous fume clouds over Mokuaweoweo. During the late afternoon of the same day a conspicuous fume cloud over the southern end of Mokuaweoweo was observed from Park headquarters. The fume was observed from the same place a few times on subsequent days.

Like the spells of continuous tremor, the fuming was intermittent. A National Park party was at the summit of Mauna Loa on November 19, and noticed nothing more than rather heavy steaming from the usual vents in the west central part of the crater. Tremor that continued for several minutes at a time became conspicuous on the seismographs on November 21, reached a maximum on November 22, and practically disappeared on November 23. It is interesting to note that a few reports of glow over Mauna Loa at this time were made on days of maximum spells of continuous tremor. The reports of glow would indicate that cracks heated to incandescence were exposed or else small amounts of molten lava reached the surface. The slight amplitude of the continuous tremor indicates that but a small amount of molten lava was involved, whatever the height the lava may have reached in the Mokuaweoweo conduits.

This quiet November 1943 activity brings to mind the possibility of there having been several unrecorded outbreaks in the past. If such activity had occurred when Kilauea was also active, the continuous tremor on the seismographs might well have been masked by harmonic tremor originating at Halemaumau. The continuous tremor of full-fledged Mauna Loa eruptions, having a much greater amplitude, usually overshadows the harmonic tremor from Kilauea. A conspicuous cloud developed over Mokuaweoweo in March 1921 at a time of intense activity in Halemaumau. There must have been, for a short duration, a pronounced increase in temperature of some of the cracks in the floor of Mokuaweoweo. Whether any molten lava reached the surface at that time is not known.

Apparently most, but not all, Mauna Loa summit eruptions have produced spectacular lava fountains. It is not surprising to find reports of a few outbreaks which produced little or no lava. In 1875 there was a short summit eruption in which pronounced glow was lacking. Starting in December 1887, a fume column was observed over Mokuaweoweo for more than a month. The fact that no glow was reported during this time does not necessarily mean that some short-lived glow would not have been observed had cloud conditions been favorable at the time of observation. From the Volcano House on September 10, 1907, about 8 months after the eruption of that year, a black cloud was observed over Mokuaweoweo that lasted for at least 1¾ hours. Some observers reported a glow in the cloud. At 4:00 a.m. September 11, a glow attributed to a lava flow was reported in the vicinity of Red Hill.

Fume and steam, unless dense, is more conspicuous by transmitted light than by reflected light. For instance there is a steam vent between 11,000 and 12,000 feet on the northeast slope of Mauna Loa whose presence is often plainly revealed at the Observatory by the rays of the setting sun in spring and early summer. At other times of the year the steam is seldom if ever seen. As viewed from the Observatory in June, the sun sets nearly behind the vent. Then the ascending steam is sometimes so conspicuous that it resembles lava fountains. It is interesting to note that the fume clouds of November 1943 were mainly observed by reflected light. That is, their presence was easily observed without the magnifying effect afforded by transmitted light at times of sunrise or sunset.

There is a fairly good correlation between summit eruptions and subsequent flank flows. Whether the fuming of November 1943 is to be interpreted as an added indication of a flank eruption within the next two years remains to be seen.

Hawaiian Volcano Observatory Report for October-December 1943

VOLCANOLOGY

October

The seismic lull that started in April 1943 was interrupted about the middle of October by the occurrence of several shakes, most of which were of Kilauea origin. During the month, 22 seismic disturbances were recorded at Kilauea, and 33 at Mauna Loa.

Large dust clouds from landslides were observed over Halemaumau on October 12 and 20.

November

The preponderance of Mauna Loa shakes over those of Kilauea origin in the latter part of October and the first part of November was the only authentic indication of a growing uneasiness of Mauna Loa. The interpretation of the seismograph records of the earthquake of November 10 suggests a rotational movement of a block in the southwest slope of Mauna Loa. Ninety-three seismic disturbances were recorded on Mauna Loa; 79 were recorded at Kilauea. The majority of the disturbances occurred on November 21, 22, and 23, or at the time of the maximum activity of Mauna Loa.

December

A conspicuous fume cloud was observed over Mokuaweoweo on December 19, first from Kona and later from Waimea. However, there were no signs of continuous tremor on the seismographs on this day. On December 25, steam in somewhat greater amount than usual was observed under the high western wall of Mokuaweoweo, but there was no fuming in the vicinity of the 1940 cone or elsewhere in the crater.

The number of seismic disturbances at Mauna Loa again exceeded that from Kilauea, 52 to 38, respectively.

R.H.F.

SEISMOLOGY

Earthquake Data, October-December 1943

Week Ended		Minutes of Tremor	Feeble Very	Feeble	Slight	Moderate	Local Seismicity*	Teleseisms
October	3	1	0	0	0	0	0.25	0
	10	1	0	1	0	0	1.25	0
	17	4	0	0	1	0	3.00	0
	24	4	2	0	1	0	4.00	0
	31	5	3	0	0	0	2.75	0
November	7	2	2	0	0	0	1.50	2
	14	7	2	0	0	1	5.75	0
	21	17	2	0	0	0	5.25	1
	28	59	0	0	0	0	14.75	0
December	5	9	2	1	0	0	4.25	0
	12	13	0	1	0	0	4.25	0
	19	5	2	1	0	0	3.25	0
	26	5	1	0	1	0	3.75	1

* For definition of local seismicity, see Volcano Letter No. 371.

The data of the following local disturbances were determined from stations operated on the island of Hawaii by the Hawaiian Volcano Observatory of the Hawaii National Park. Time is Hawaiian Standard. Distances are from the Observatory. The number preceding each earthquake date is the serial number for the current year.

42. October 7, 08:50, feeble, Kilauea shake.
43. October 16, 02:36, slight east slope Mauna Kea, felt at Hakalau and locally.
44. October 18, 05:06, very feeble, Kilauea shake.
45. October 20, 02:07, slight, felt locally and at Hilo. Five miles deep under southern end of Kilauea crater.
46. October 22, 18:43, very feeble.
47. October 30, 18:23, very feeble, Kilauea shake.
48. October 30, 19:06, very feeble.
49. October 31, 13:28, very feeble, Kilauea shake.
50. November 4, 00:38, very feeble.
51. November 5, 15:35, very feeble.
52. November 8, 14:15, very feeble, felt in Pahala as a sharp jolt.
53. November 10, 16:18, very feeble, felt at Pahala.
54. November 10, 16:22, moderate, dismantled instruments, widely felt southern half island of Hawaii; stonewalls thrown down southwest of Pahala.
55. November 16, 23:26, very feeble.
56. November 21, 22:51, very feeble.
57. November 29, 13:45, feeble.
58. December 1, 19:52, very feeble.
59. December 3, 11:09, very feeble, lower SW rift of Mauna Loa.
60. December 7, 05:47, feeble, NE rift of Mauna Loa.
61. December 13, 19:43, very feeble.
62. December 15, 08:58, feeble, felt at Pahala.
63. December 18, 21:14, very feeble.
64. December 22, 19:50, slight, felt locally and at Hilo, southwest slope of Mauna Loa.
65. December 24, 01:51, very feeble.

TELESEISMS

November 3, 04:12, moderate, Alaska, 4550 km.
November 5, 22:15, slight, 8000 km.
November 20, 08:56, slight.
December 23, 08:45, slight, 6360 km.

MICROSEISM MOTION

Microseisms were strong on October 8, 16, December 9 to 10, and December 26 to 27, and moderate on November 18, 26, and 27. Throughout the rest of the quarter slight microseisms were recorded.

Tilting of the Ground

Normal northeast tilt prevailed during October, November, and until the middle of December except for the pronounced northwest tilt accompanying the distinct earthquake of November 10. The quake produced a permanent offset to the west in the E-W tilt curve. The sharp northerly tilt due to the quake was followed by a southerly tilt of like amount within about a day.

During 1943 there was a slight accumulation of westerly tilt due largely to the quake of November 10. The total northerly tilt for the year slightly exceeded the southerly.

Table of Tilt at Observatory on NE Rim of Kilauea

Week Ended		Amount of Tilt	Direction of Tilt
October	3	1.21″	N54° E
	10	1.02″	N45° E
	17	1.30″	N22° E
	24	0.78″	N52° E
	31	1.18″	S24° W
November	7	1.85″	N31° E
	14	3.87″	N82° W
	21	0.62″	N11° W
	28	0.48″	S
December	5	0.88″	N16° W
	12	1.48″	S81° E
	19	0.84″	S45° W
	26	0.43″	S34° E

Crack Measurements

Crack movement during the quarter was slight. Five cracks near Halemaumau opened an average of 2 millimeters. The rest of the cracks measured near Halemaumau and those along the Chain of Craters Road were stationary.

R.H.F.

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THE VOLCANO LETTER 483

No. 483 **Department of Interior** **National Park Service** **January-March 1944**

PUBLISHED BY THE UNIVERSITY OF HAWAII

HAWAII NATIONAL PARK: Edward G. Wingate, Superintendent; R. H. Finch, Volcanologist

UNIVERSITY OF HAWAII: T. A. Jaggar, Geophysicist

HARMONIC TREMOR

By R. H. FINCH

Shortly after the seismographs were installed at the Hawaiian Volcano Observatory in 1912 it was noticed that they were recording small tremors continuously.[1] Omori had noticed similar tremors near some of the Japanese volcanoes. From their obvious connection with volcanic activity H. O. Wood called them volcanic vibrations. It was soon noticed, however, that there was no obvious connection between the outbreaks of the periodic fountain, "Old Faithful," in Halemaumau and the tremors as recorded at the Observatory 2.1 miles away. In general the tremors were most conspicuous during times of violent fountaining. The idea that such tremors are due to volcanic activity was confirmed when the seismographs that were installed in Hilo, 22 miles away, failed to record such tremors. When magmatic action totally ceased at Kilauea in 1924 the volcanic vibrations, as was to be expected, disappeared from the seismograms.

After seismograph drums with higher speed were installed at the Observatory in 1918, it was found that there were two types of tremors, one with a quite uniform period and amplitude and the other with a greater range in period and amplitude. To distinguish between the two, Dr. T. A. Jaggar in November, 1918[2] called the more rhythmic vibration "harmonic microtremor." This term was later shortened to "harmonic tremor." The less regular vibrations which often resemble miniature earthquakes were named "spasmodic tremor."[3] Austin E. Jones[4] divides spasmodic tremors into two classes and illustrates the two by idealized sketches. Mixed continuous tremor is recorded at the Observatory during Mauna Loa eruptions even though the source may be 22 miles away.

Harmonic tremor that was recorded under different conditions of the lava column at Halemaumau is shown in figure 1. In most cases the portion reproduced is typical of the tremor as recorded for days preceding and following the sample selected. *A* of figure 1 was taken when the lava lake was high and a flow was pouring on to the southwest floor of Kilauea through a tunnel the intake of which was a small distance below the Halemaumau rim. It is not likely that any of the tremors recorded were due to lava surging in this tunnel. *B* is from the record when lava was flowing at Makaopuhi and Napau craters along the Puna rift. Considering the small scale of these outbreaks and the indicated distance—over 7 miles—it seems probable that the tremors were due to lava surging in conduits under Halemaumau rather than from the seat of the outbreak. *C* shows a portion of the record in 1924 just preceding the explosive eruption of that year and at a time when no molten lava was visible. Numerous earthquakes along the Puna rift, the sinking of the lava column at Halemaumau, and harmonic tremor at this time indicated lava drainage through this rift. *D* is a portion of the record during the short-lived activity at Halemaumau starting on September 6, 1934. The especially large tremors were recorded during some of the most violent fountaining ever observed at Kilauea. Each spell of violent fountaining was usually followed by a rather quiet interval of about 30 minutes as shown by the two comparatively straight lines just below the lower large harmonic tremor. In this case there was a direct correlation between fountaining action in Halemaumau and harmonic tremor. This was due as Dr. T. A. Jaggar has explained[5] to a rather high viscosity of the lava and the inception of the fountains at the bottom of a shaft.

[1] H. O. Wood, "The Hawaiian Volcano Observatory," *Bulletin Seismological Society of America*, Vol. III, No. 1 (1913), p. 17.

[2] T. A. Jaggar, *Bulletin Hawaiian Volcano Observatory*, Vol. VI, No. 11 (Nov., 1918), p. 131.

[3] T. A. Jaggar, "Seismometric Investigations of the Hawaiian Lava Column," *Bulletin Seismological Society of America*, Vol. X, No. 4 (Dec., 1920), p. 264.

[4] Austin E. Jones, "Empirical Studies of Seismic Phenomena of Hawaii," *Bulletin Seismological Society of America*, Vol. XXVIII, No. 4 (Oct., 1938), p. 316.

[5] T. A. Jaggar, *Volcano Letter*, No. 415 (Sept., 1934).

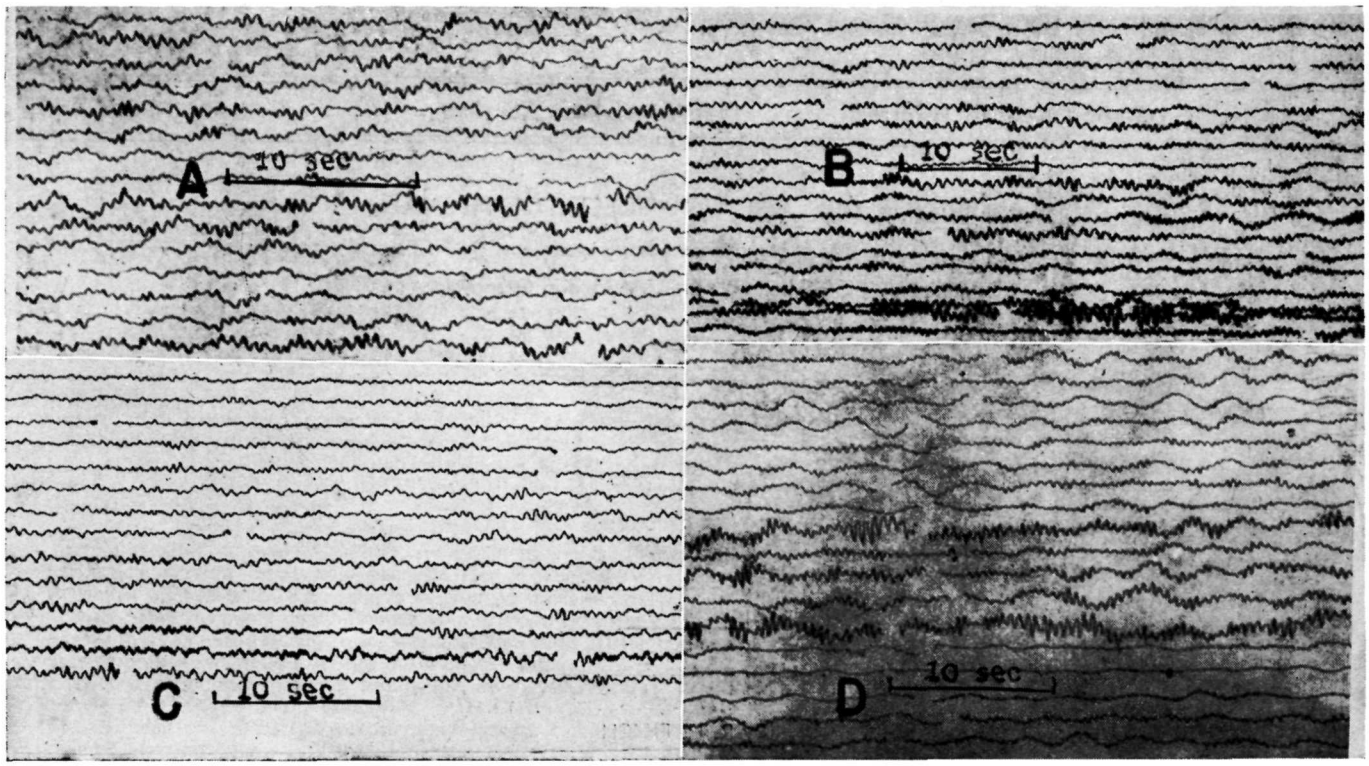

Fig. 1.—Harmonic tremor as recorded on the Bosch-Omori seismograph at Hawaiian Volcano Observatory, 2.1 miles northeast of Halemaumau. Travel from right to left. E-W component.

A. March 26, 1921—lava was high in Halemaumau and flowing in southwest part of Kilauea Crater. ×2½.

B. May 29, 1922—lava was flowing from the Puna rift. No lava was visible in Halemaumau. ×2⅓. Local earthquake is shown in second line from bottom.

C. May 8, 1924—no lava was visible in Halemaumau. Underground movement of lava in the Puna rift was suspected. ×2⅓.

D. September 30, 1934—was taken during lava activity lasting one month in 1934. The especially large tremors accompanied intermittent strong explosive fountaining. ×2½ (magnification of the seismogram, itself magnifying the earth motion about 100 times).

The absence of harmonic tremor at the time of the "False Eruption" on January 11, 1928, strengthens the belief that the small amount of lava which appeared on this date owed its appearance to being squeezed from a crusted pool of 1927 lava by a heavy landslide.

Harmonic tremor at Kilauea appears to be due to underground surging in feeding conduits below Halemaumau. If the surging is induced by the movement of very large gas bubbles in magma, then with a nearly stationary lava lake the bubbles moving through lake magma cannot set up harmonic tremor large enough to be recorded by the Observatory seismographs. When the surging takes place in a conduit of more or less restricted dimensions the solid walls of the conduit may be induced to vibrate with sufficient amplitude to be recorded. In general the tremor is larger when the magma column is falling than when rising.

Harmonic tremor affords good evidence of underground surging of lava whether magma is visible in the pit or not.

Hawaiian Volcano Observatory Report for January-March 1944

VOLCANOLOGY

January

The year opened with both Mauna Loa and Kilauea inactive. The number of Mauna Loa shakes exceeded those from Kilauea; records showed 43 and 39, respectively. The northeast rift of Mauna Loa was more active than the southwest one. The strongest shake during the month, which originated near Puu Ulaula on the NE rift of Mauna Loa on January 23, was generally felt over the southern part of the island of Hawaii.

At 2:00 p.m. on January 15, while on the road between Mauna Loa and Mauna Kea, A. L. Jess observed a distinct fume cloud with a faint yellow tinge over Mokuaweoweo.

Two landslides from the walls of Halemaumau were observed during the afternoon of January 19. Some more slides were observed during the latter part of the same week.

February

Despite the fact that the 4 perceptible earthquakes that occurred during February were of Kilauea origin, more seismic disturbances were recorded at Mauna Loa than at Kilauea; they were 41 and 33, respectively.

Clouds, lacking the characteristics of ordinary cumulus formation that frequently develops over isolated mountain peaks, were observed over Mokuaweoweo during the late afternoon of

February 7. On February 23, a white vapor cloud was visible above the radiation fog which capped Mauna Loa from 8:05 to 8:30 a.m. At other places humps in the fog marked the sites of hot spots in the crater floor.

March

While flying over Mauna Loa on March 30, Ranger Frank Hjort observed blue fume arising from Mokuaweoweo.

A total of 7 seismic disturbances was recorded in about 3 hours during the evening of March 29. Three of the shakes were strong enough to be felt locally. The series of shakes began with the strongest which dismantled the Bosch-Omori seismographs near Park Headquarters. The origin of the shakes was quite deep under the southern end of Kilauea Crater. Forty-four seismic disturbances were recorded at Kilauea and 59 at Mauna Loa.

The strong southerly wind of March 4 raised conspicuous dust clouds over the Kau Desert and adjacent cultivated fields of the Kapapala Ranch. Such winds—opposite in direction from those commonly observed transporting ash in the Kau Desert—though rare, may have been an appreciable factor in developing some soil over portions of the NE slope of Mauna Loa.

R.H.F.

SEISMOLOGY

Earthquake Data, January-March 1944

Week Ended		Minutes of Tremor	Very Feeble	Feeble	Slight	Local Seismicity*	Teleseisms
January	2	4	0	0	0	1.00	0
	9	12	2	0	2	8.00	0
	16	8	2	0	0	3.00	0
	23	3	3	1	1	5.25	0
	30	3	1	0	0	1.25	0
February	6	0	7	0	3	9.50	0
	13	1	1	0	0	0.75	0
	20	7	0	0	0	1.75	0
	27	11	1	1	0	4.25	0
March	5	6	1	0	2	6.00	0
	12	4	1	0	0	1.50	0
	19	8	0	0	0	2.00	0
	26	8	3	0	0	4.50	0

* For definition of local seismicity, see Volcano Letter No. 371.

The data of the following local disturbances were determined from seismograph stations operated on the island of Hawaii by the Hawaiian Volcano Observatory of the Hawaii National Park. Time is Hawaiian Standard, 10 hours and 30 minutes slower than Greenwich. The number preceding each earthquake date is the serial number of the quake for the current year.

1. January 4, 02:48, slight, northern end of Kilauea Crater.
2. January 5, 00:05, very feeble, Kilauea shake.
3. January 5, 04:47, very feeble, Kilauea shake.
4. January 7, 09:42, slight. Felt as a sharp jolt, NE end of Kilauea Crater.
5. January 10, 23:25, very feeble, SW part of Mauna Loa.
6. January 12, 20:04, very feeble, shallow focus NE rift of Mauna Loa, 12 miles SW of Hilo.
7. January 17, 01:00, very feeble, SW part of Mauna Loa.
8. January 22, 02:38, very feeble.
9. January 23, 14:40, slight, E-W dismantled, Mauna Loa instrument dismantled. Felt locally and Pahala, near Puu Ulaula.
10. January 23, 15:28, very feeble, probably same origin as No. 9.
11. January 23, 23:42, feeble, NE rift of Mauna Loa.
12. January 28, 17:23, very feeble, Mauna Loa instrument dismantled, NE rift of Mauna Loa.
13. February 1, 11:31, very feeble.
14. February 2, 19:18, very feeble, NE rift of Mauna Loa.
15. February 3, 01:02, slight, near SW end of Kilauea Crater.
16. February 3, 01:16, slight, under Kilauea Crater.
17. February 3, 01:19, very feeble, Kilauea shake.
18. February 3, 01:27, very feeble.
19. February 3, 01:28, slight, Kilauea Crater.
20. February 3, 03:37, very feeble, NE rift of Mauna Loa.
21. February 5, 21:49, very feeble, near Mokuaweoweo.
22. February 5, 23:32, very feeble.
23. February 8, 02:41, very feeble, SW rift of Mauna Loa.
24. February 22, 09:47, very feeble, near Mokuaweoweo.
25. February 27, 04:49, feeble, under Kilauea Crater.
26. February 29, 04:53, slight, E-W dismantled, underneath observatory.
27. March 3, 12:37, very feeble, E flank of Mauna Loa.
28. March 5, 09:39, slight, felt locally, NE rift of Mauna Loa.
29. March 8, 04:47, very feeble.
30. March 23, 10:36, very feeble, NE rift of Mauna Loa.
31. March 25, 10:45, very feeble.
32. March 25, 20:18, very feeble.
33. March 29, 19:54, slight, dismantled instruments, under southern end of Kilauea Crater.
34. March 29, 20:38, very feeble, same origin as No. 33.
35. March 29, 22:20, slight, probably same origin as No. 33, though initial wave was compressional in No. 35 and dilatational in No. 33.
36. March 29, 22:41, slight, similar to No. 35.
37. March 30, 00:55, very feeble.

TELESEISMS

With the exception of what appeared to be feeble long waves of two teleseisms recorded in the midst of large microseisms on March 6, no teleseisms were recorded during the quarter.

MICROSEISMS

Microseisms were strong on February 12, and March 4, moderate on February 20, March 4, and 5. Throughout the rest of the quarter microseisms were present though slight.

Tilting of the Ground

Normal southwesterly tilt started early in January and continued throughout the quarter. The direction of tilt was really south-southwest as westerly tilt was less than normal and southerly tilt above the average. In fact southerly tilt for the first three months of 1944 exceeded that for similar periods of every year since 1937. If, as seems probable, easterly tilt correlates with increase in internal pressure under Mauna Loa the less than normal westerly tilt indicates a sustained high pressure under that mountain. There were some fluctuations in the direction of tilt at the stations near the rim of Halemaumau.

Table of Tilt at Observatory on NE Rim of Kilauea

Week Ended		Amount of Tilt	Direction of Tilt
January	2	1.14″	N 58° E
	9	0.60″	N
	16	2.30″	S 25° W
	23	0.65″	S 22° W
	30	1.45″	S
February	6	0.33″	S 45° W
	13	0.53″	S 68° E
	20	1.09″	S 27° E
	27	1.74″	S 33° W
March	5	1.27″	S 17° E
	12	3.60″	S 39° W
	19	0.44″	S 34° W
	26	1.46″	S 5° W

Crack Measurements

There was a slight opening of 5 of the cracks around Halemaumau though most of those measured showed no movement. No movement was detected in the cracks at the Devil's Throat and along the Chain of Craters Road. R.H.F.

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HAWAII NATIONAL PARK: Edward G. Wingate, Superintendent; R. H. Finch, Volcanologist

UNIVERSITY OF HAWAII: T. A. Jaggar, Geophysicist

RADIO TRANSMISSION OF EARTHQUAKE RECORDS

By ROBERT J. STRATTON[1]
Federal Communications Commission
Radio Intelligence Division

Time control for several of the seismographs operated by the Volcano Observatory of the Hawaii National Park is obtained by a phantom circuit on Park telephone lines.[2] The location of outlying seismographs is determined by existing roads and telephone lines. This leaves a vast expanse of Mauna Loa where it is impractical to locate ordinary seismographs. If all the instruments could be made to register at one central point continuously, much travel could be avoided.

The use of radio at once suggests itself as a possible solution. The radio seismographs could be made to record on one shaft and the problem of synchronizing would be solved. Also in the case of a disturbance, records would be immediately available at the Observatory.

Radio links for the remote recording of seismographs were utilized in 1931 by Seizo Haeno.[3] He developed a short-distance, short-time scale instrument based upon the principle of frequency modulation for use in geophysical prospecting. His transmitter was a simple self-excited oscillator in which the capacity in the tank circuit was varied by the displacement of the seismograph mass. His receiver was an equally simple Tuned Radio Frequency receiver tuned off resonance and using galvanometer recording. This system was sufficiently stable for geophysical work since the recording run is normally only for a few minutes. It would not be stable, however, for continuous recording because of frequency drift.

Frequency stability could be gained by using crystal controlled transmitters. Moreover, the frequency of a crystal oscillator may be varied within limits by the use of a variable capacity across the crystal. It is proposed, therefore, that each element of the outlying Hawaiian Volcano Observatory seismographs should be equipped with a low-powered, battery-operated, crystal-controlled transmitter as shown in figure 1. Each transmitter would be far enough separated from the others in frequency so that mutual interference would be avoided. The variable "seismograph" condenser shown in figure 1 would have its rotor plates attached to the movable arm of the seismograph, while the stator plates would be attached to the seismograph frame. Any movement of the arm, however slight, would cause a corresponding change in the frequency of the oscillator. This is, of course, nothing more than frequency modulation of the rest-position carrier.

Several of the Hawaiian Volcano Observatory seismograph stations are within reach of A.C. power lines. The radio transmitters at these stations could be supplied from A.C. power in conventional ways. Some of the Hawaiian Volcano Observatory seismograph stations, both present and proposed, are in remote areas and would necessarily be battery operated. With the proper choice of frequency, tubes, and oscillator design, the use of number 6 dry cells for filament supply and 45 volt B-batteries for plate supply would be economically possible.

The continuously emitted signal would be received with a well-designed Tuned Radio Frequency receiver as shown in figure 2. As shown in the diagram, the amplified radio frequency output of this receiver is fed into a Wheatstone bridge which is

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[1] The author is indebted to Mr. Guy Omer for finishing this manuscript and drawings.—R.H.F.

[2] Waesche, H. H. "Time Controls for Seismographs Operated by the Hawaiian Volcano Observatory." *Volcano Letter* No. 464 (April-June 1939).

[3] Haeno, Seizo. "The Radio-Seismograph," *Japanese Journal of Astronomy and Geophysics*. Vol. VIII, (1931), pp. 39-50.

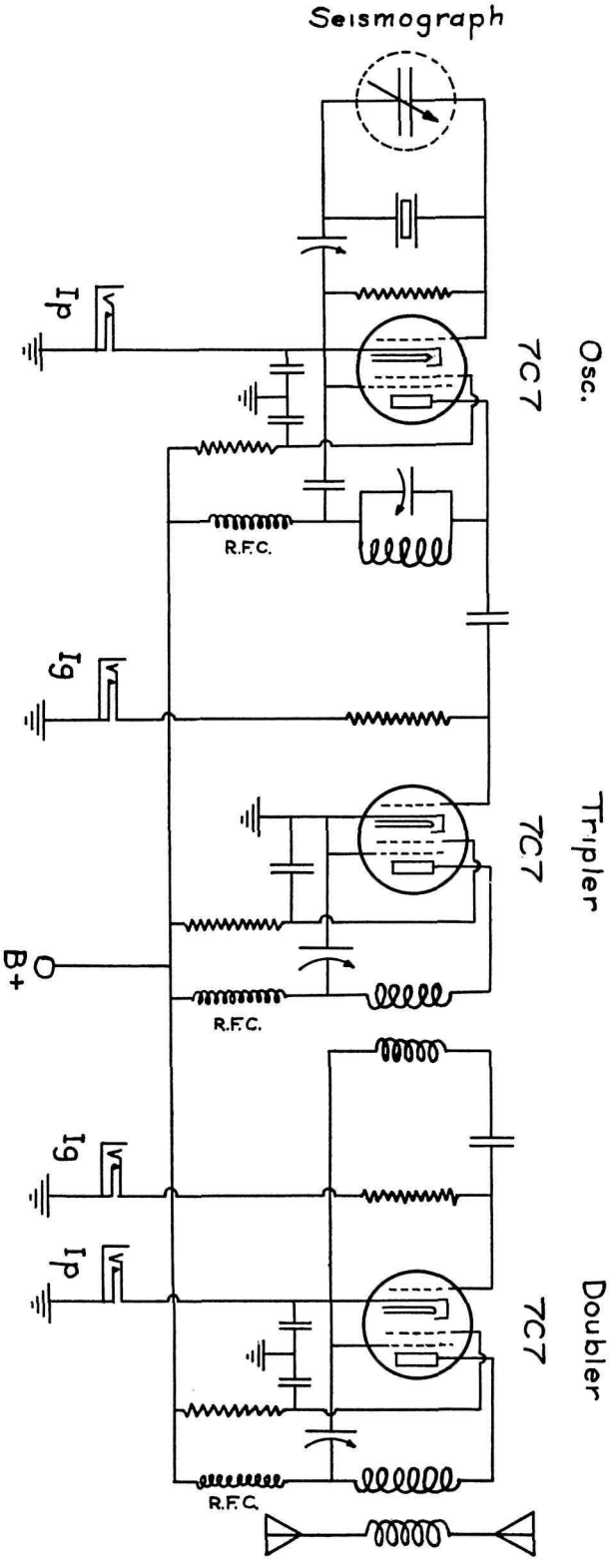

Fig. 1—Transmitter for radio seismograph.

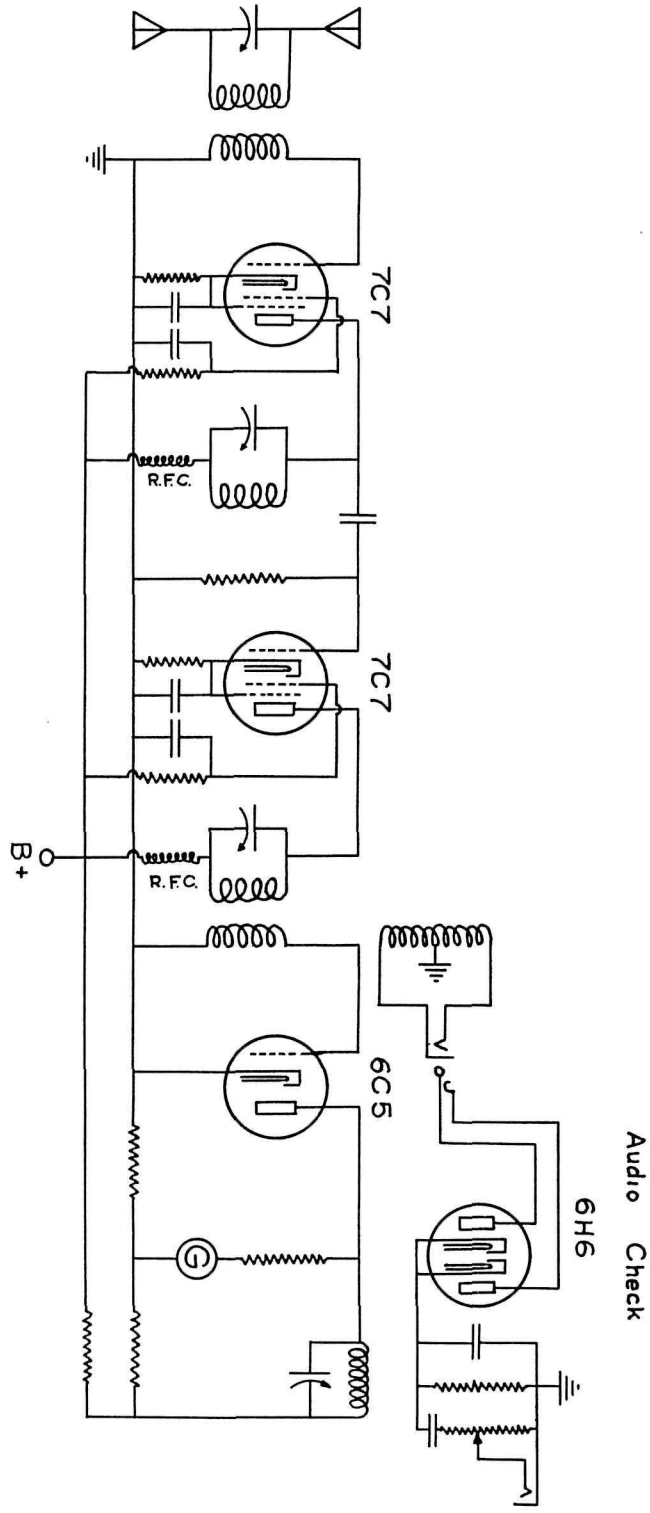

Fig. 2—Receiver for radio seismograph.

balanced at the rest-position carrier frequency. When the seismograph arm is displaced, the frequency changes, the bridge is then unbalanced, and the galvanometer is deflected. For proper operation, of course, the parallel tuned circuit in the bridge must be tuned far enough away from the rest-position frequency so that it presents a linear rising impedance over the modulation range. The actual production of the seismograph record would be by optical recording by a pin-point beam of light, reflected from the galvanometer mirror onto a continuously moving photographic film.

This system, of course, requires a separate receiver and recording chain for each transmitter. All of the receiving and recording equipment at the Observatory would be A.C. operated.

The recording of tilt is much simpler. The proposed plan for this also makes use of the principle of varying the frequency of an oscillator but with a different application. Since the change in tilt is very slight over a considerable period of time, no rapidly variable indicating instrument is necessary. For this purpose, it is proposed to use two crystal oscillators with a difference of frequency of 440 cycles per second. Only one of these oscillators will be equipped with a variable capacity as described in figure 1. The other oscillator remains constant. It then is apparent that, with the arm of the tilt instrument at center position, the two oscillators will beat against each other producing a resultant audio tone of 440 cycles. Any change in the position of the movable arm on the tilt instrument will vary the resultant tone. If the tilt is in one direction, the tone will be raised. If in the other, the tone will be lowered. The Bureau of Standards Station WWV can always be heard in this area on a frequency of either 15 mc., 10 mc., or 5 mc. depending on the time of day. This station transmits a tone standard of 440 cycles which is accurate to 0.000001 cycles per second. With this as a standard any change in the pitch of the beat of the tilt oscillators can be determined as can the direction of the tilt.

The selection of frequencies for all of these transmitters is quite important, both from the point of possible outside interference and of propagation characteristics. The latter point offers no particular difficulty for this location since all of the seismograph locations are within "line of sight" of the Observatory. Therefore, in order to avoid possible interference from extraneous signals, the use of frequencies around 50 to 60 mc. is indicated. Theoretically, no difficulty should be encountered in the use of this band of frequencies, although experiment may prove otherwise. Higher frequencies require the use of more tubes with the corresponding higher battery drain.

Owing to conditions incident to the war, it has not been possible to test the above ideas experimentally.

Hawaiian Volcano Observatory Report for April-June 1944

VOLCANOLOGY

April

Blue fume was observed over Mokuaweoweo on March 30 and again on April 1. The only other surface activity observed at Kilauea and Mauna Loa was the usual steaming. The number of steam vents as well as the amount of steam escaping at Kilauea and Mauna Loa is essentially the same as at the commencement of continuous observations in 1912.

No earthquake strong enough to be felt locally was experienced in April. Eighteen small seismic disturbances were recorded at Kilauea and 44 at Mauna Loa.

There were several small landslides from the walls of Halemaumau.

May

A conspicuous steam cloud that was observed over the lower part of the 1942 lava flow from Mauna Loa shows that the lava was still hot 2 years after it was erupted.

May continued the seismic quiet of the last several months. The Mauna Loa seismograph registered 48 seismic disturbances while the number recorded at Kilauea was 28.

June

The seismic lull that was especially noticeable in April and May continued through June. No perceptible earthquakes were recorded at the Observatory. Twenty-three seismic disturbances were recorded at Kilauea and 44 at Mauna Loa. A majority of the shakes distinct enough to show phases originated on the northeast slope of Mauna Loa at shallow depths. R.H.F.

SEISMOLOGY

Earthquake Data, April-June 1944

Week Ended		Minutes of Tremor	Very Feeble	Feeble	Slight	Local Seismicity*	Teleseisms
April	2	8	2	0	3	10.00	0
	9	4	0	0	0	1.00	0
	16	5	0	0	0	1.25	0
	23	3	3	0	0	2.25	1
	30	2	1	0	0	1.00	0
May	7	8	0	0	0	2.00	0
	14	7	0	1	0	2.75	0
	21	1	0	0	0	0.25	0
	28	2	2	0	0	1.50	2
June	4	6	3	1	0	4.00	0
	11	6	1	0	0	2.00	0
	18	6	1	0	0	2.00	0
	25	4	1	0	0	2.00	0

* For definition of local seismicity, see Volcano Letter No. 371.

The data of the following local disturbances were determined from seismograph stations operated on the island of Hawaii by the Hawaiian Volcano Observatory of the Hawaii National Park. Time is Hawaiian Standard, 10 hours and 30 minutes slower than Greenwich. The number preceding each earthquake date is the serial number of the quake for the current year.

38. April 19, 17:43, very feeble. 40 miles SE.
39. April 20, 06:03, very feeble. NE rift of Mauna Loa.
40. April 22, 08:15, very feeble. NE rift of Mauna Loa.
41. April 26, 08:23, very feeble.
42. May 12, 17:27, feeble. Deep under the northeastern rim of Kilauea crater.
43. May 23, 21:07, very feeble. SW flank of Mauna Loa.
44. May 28, 20:40, very feeble. Felt at Naalehu and Pahala. SW rift of Mauna Loa.
45. May 29, 04:21, feeble. Felt locally and at Pahala. East flank of Mauna Loa.
46. May 29, 04:27, very feeble. High up NE rift of Mauna Loa.
47. May 31, 14:12, very feeble.
48. June 1, 11:09, very feeble.
49. June 9, 12:01, very feeble.
50. June 16, 01:09, very feeble.
51. June 21, 17:34, very feeble. Near Puu Ulaula on NE rift of Mauna Loa.
52. June 23, 00:13, very feeble. NE rift of Mauna Loa.

TELESEISMS

May 23, 04:30, slight.
May 25, 02:38, moderate. 6600 km. New Ireland.
June 16, 11:42, slight.
June 27, 21:56, slight.

MICROSEISMS

Microseismic motion was quite uniformly slight throughout the quarter.

TILTING OF THE GROUND

Southerly tilt was more pronounced during the first three months of 1944 than for the corresponding period in the last several years. The total, however, was not unusual as northerly tilt set in on April 1, or over a month earlier than common.

Table of Tilt at Observatory on NE Rim of Kilauea

Week Ended		Amount of Tilt	Direction of Tilt
April	2	0.75″	S 56° W
	9	0.12″	E
	16	0.44″	N 56° W
	23	1.77″	N 16° E
	30	1.31″	S 67° W
May	7	1.36″	N 80° W
	14	0.74″	N 70° E
	21	0.74″	N 70° W
	28	0.24″	N
June	4	0.44″	N 34° W
	11	0.98″	S 30° W
	18	0.17″	N 45° W
	25	0.55″	N 64° E

CRACK MEASUREMENTS

There was but little movement of the cracks at the Devil's Throat and along the Chain of Craters Road. The cracks near Halemaumau opened slightly in April and June and were stationary during May. R.H.F.

HAWAIIAN VOLCANO RESEARCH ASSOCIATION
in cooperation with UNIVERSITY OF HAWAII

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The **University of Hawaii** cooperates in maintaining a research laboratory at Hawaii National Park. The **Association** and the **University** supplement the work of the government with research associates, instrumental plants and special investigation. Dr. T. A. Jaggar is their geophysicist resident in the National Park.

The **Volcano Letter,** a quarterly record of Hawaiian volcano laboratories and published by the University of Hawaii, is issued by authority of the Department of the Interior and supplied to a restricted membership and exchange list of the above establishments.

THE VOLCANO LETTER 485

No. 485 **Department of Interior** **National Park Service** **July-September 1944**

PUBLISHED BY THE UNIVERSITY OF HAWAII

HAWAII NATIONAL PARK: Edward G. Wingate, Superintendent; R. H. Finch, Volcanologist

UNIVERSITY OF HAWAII: T. A. Jaggar, Geophysicist

OUTPUT CHANGES IN KILAUEA STEAM VENTS

By GUNNAR O. FAGERLUND
Naturalist and Chief Ranger
Hawaii National Park

There is some evidence that the volume of steam from vents at the northern end of Kilauea Caldera has decreased in the last 100 years.

In 1823 Ellis[1] reported pools of water there adjacent to and on the lee side of steaming chasms. These condensation pools could exist only with much greater steam volume than there is at present. The pools subsisted during rainless periods. However, the 1790 explosion may have provided an impervious ash layer that helped in pool formation for many years.

Accompanying Kilauea activity in 1886, the steaming at Sulphur Bank fluctuated for a short period. First the steam temperature increased, then the steaming almost ceased, and finally normal temperature and volume resumed.[2] Normally the volume and temperature of the steam change little if any to correlate with Halemaumau activity.

Gordon A. Macdonald[3] states: "The distribution of altered rock and deposits of sulfur and salts, indicates that solfataric activity was once more extensive than now. Some migration of the active vents occurs."

Photographic stations have recently been established for photographing the steaming vents. Photographs taken at ten-year or greater intervals under nearly identical conditions of humidity, air temperature, and wind velocity should show whether or not the steam volume is changing.

The visibility of the vapor varies with different conditions of air temperature, humidity, and wind velocity. Actually the amount of water vapor escaping from any one vent is nearly constant. Figures 1 and 2 show visibility difference under somewhat different air conditions, but by no means do they show the maximum visibility contrast. On warm, sunny days with comparatively low humidity, some vents produce no visible vapor, while on cold damp days the same vents produce conspicuous vapor clouds. Even during a single clear day a marked contrast may be seen between early morning or evening and noon visibility of the vapor. On cold days the vapor density of the steam increases and its increased condensation forms conspicuous fog clouds. An increase in the number of hygroscopic nuclei also causes greater condensation. This fact can be demonstrated by directing tobacco smoke into steam vents where no vapor is visible. This causes a visible cloud to appear instantly. It is by this effect of nuclei that air humidity influences vapor visibility. Wind also affects visibility by dispersing and evaporating the fog.

Though air conditions affect the vapor visibility most markedly, a difference exists too when vapor is viewed in transmitted and in reflected light; this is most manifest when the sun is low. The greater visibility is in transmitted light. There is also a color difference—the vapor appearing bluish in reflected light and trending toward the red end of the spectrum in transmitted light.

The making of reliable photographic records of the vapor volume output from the steaming vents must take into account all the conditions that affect the visibility, or more precisely the photoactinicity, of the vapor. Pictures taken at intervals to show change, if any, in the actual steam volume output must

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[1] ELLIS, WILLIAM. THE JOURNAL OF WILLIAM ELLIS. P. 179. Hawaiian Gazette Co., Ltd., Honolulu. 1917.

[2] BRIGHAM, WILLIAM T. THE VOLCANOES OF KILAUEA AND MAUNA LOA. Bernice P. Bishop Museum Memoirs. 2(4):162. 1909.

[3] MACDONALD, GORDON A. SOLFATARIC ALTERATION OF ROCKS AT KILAUEA VOLCANO. Am. Jour. Sc. 242(9):497. 1944.

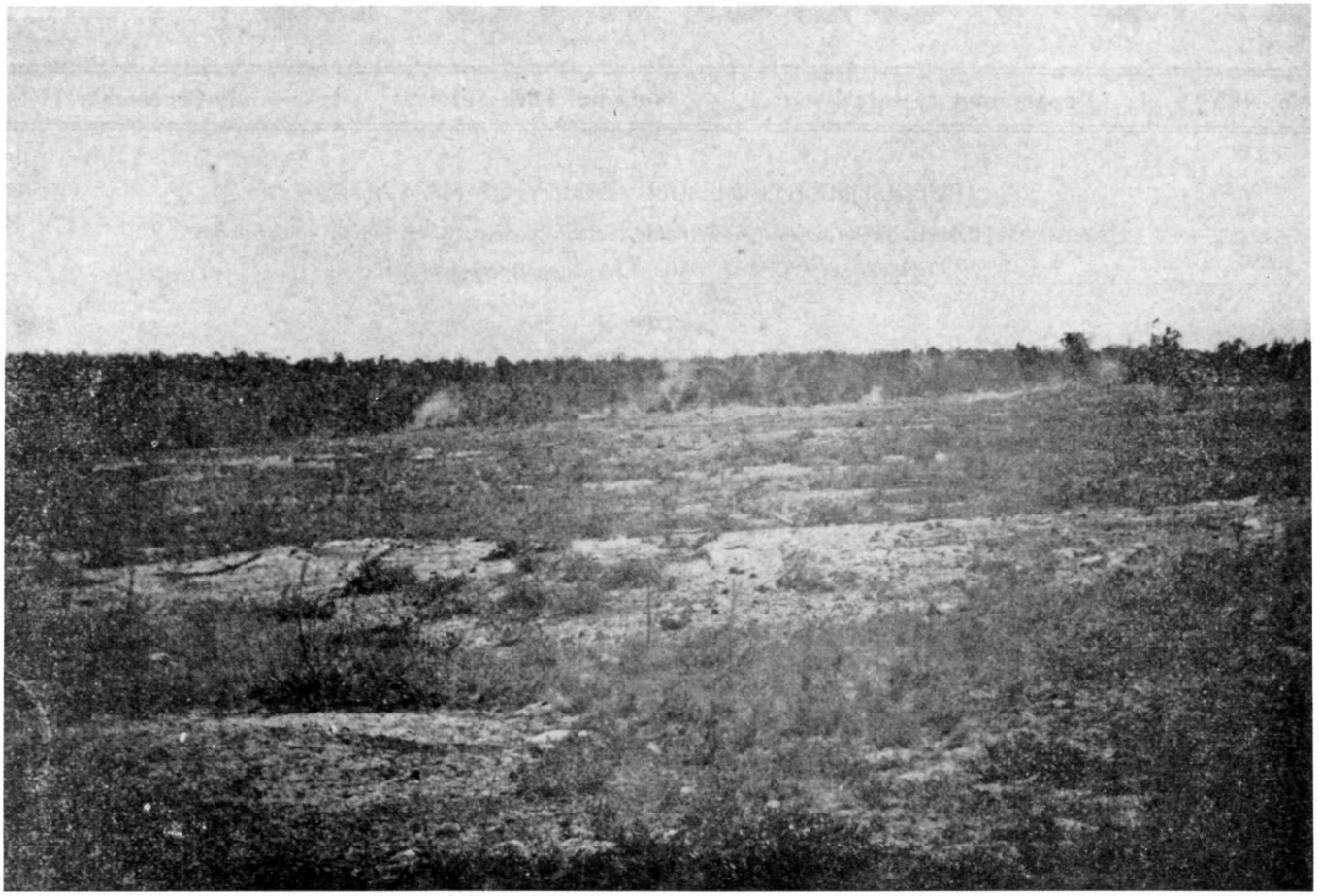

Figure 1.—Vapor issuing from vents west of Sulphur Bank. Photographed on November 19, 1944, with air temperature 62° F., humidity 68%, wind velocity 8 to 10 m.p.h. (Photographic station located on steaming flat 80 feet north of road, on line 12°49′ left from Uwekahuna to Observatory bench marks.)

be taken under nearly identical air and light conditions, with similar color sensitive film, and printed on similar paper. It would be advisable to use similar processing methods.

A factor that will affect the reliability of photographic records, and therefore should be given attention, is the pulsating manner in which the steam issues from the vents. The photographs herein were exposed as near to the instant of maximum output for the existing conditions as could be determined. The effect of the pulsating action becomes less as the distance between the vent and the camera increases. The volume of vapor recorded on a photograph encompassing considerable horizontal and vertical distances, as in the illustrations herein, would be little if at all affected by the pulsating action, except in high wind velocity.

Hawaiian Volcano Observatory Report for July-September 1944

VOLCANOLOGY

July

The seismic quiet of the last several months continued through July. No earthquakes strong enough to be perceptible at the Hawaiian Volcano Observatory were recorded though some shakes were felt at Kapapala 17 miles to the southwest. Thirty-two seismic disturbances were recorded at Kilauea and 58 at Mauna Loa.

August

A conspicuous fume cloud was observed over Mokuaweoweo from Puu Ulaula on August 12. A similar cloud was observed from the rim of Mokuaweoweo during the afternoon and evening of August 14. No glow was detected. By morning of August 15, however, nothing but the usual steaming was noted. On August 31, another conspicuous cloud was observed from the rim of Mokuaweoweo. During the fuming spell of August 12 to 14, two sharp earthquakes were felt at Puu Ulaula. The seismograph indicated that these shakes, like many that have been recorded here during the past year, occurred at very shallow foci along the upper northeast rift of Mauna Loa. Fourteen seismic disturbances were recorded at Kilauea and 56 at Mauna Loa.

September

Unusually heavy steam clouds were observed over Mokuaweoweo during the afternoons of September 11, 12, and 16. Three of the 19 earthquakes recorded at Kilauea were strong

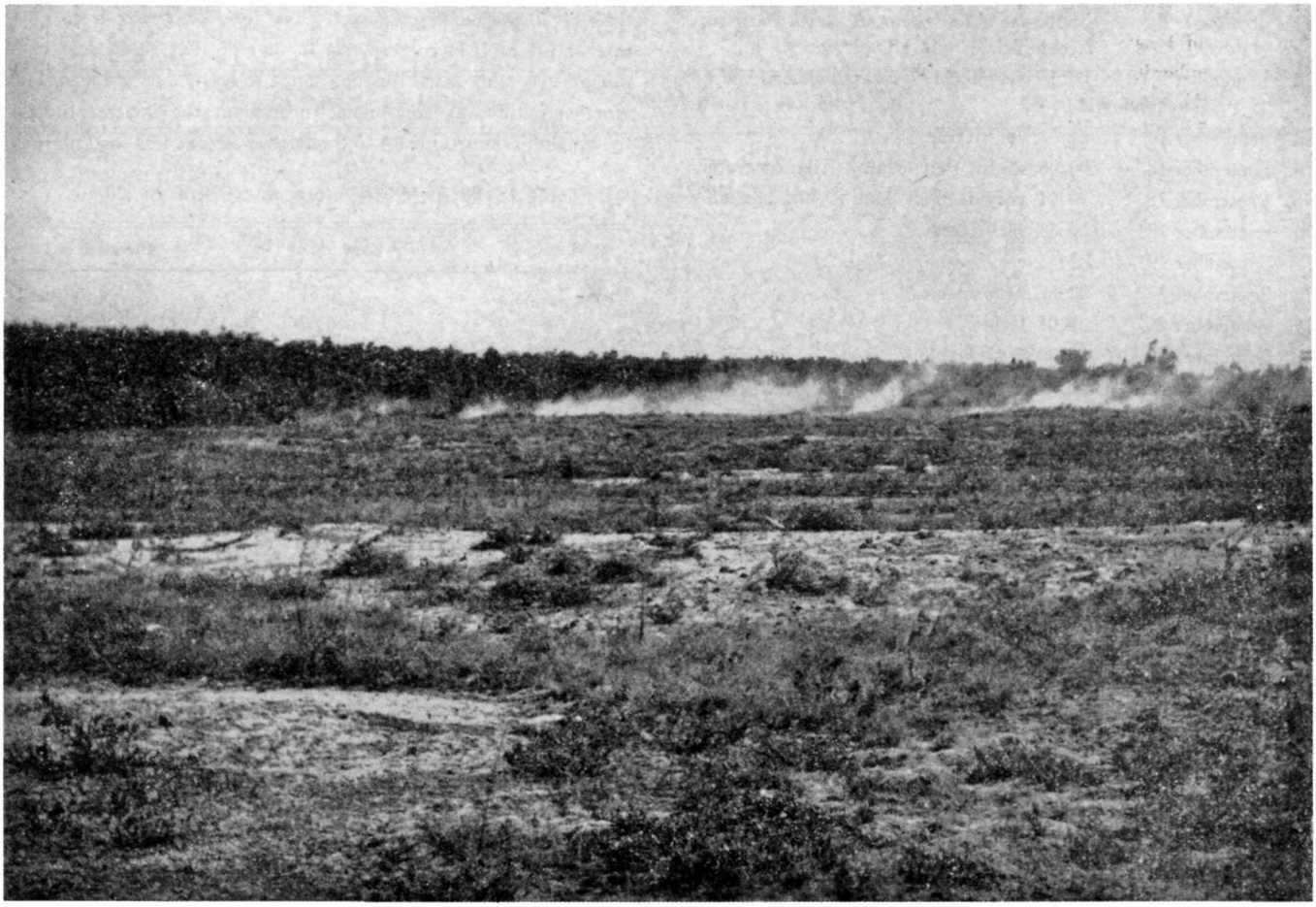

Figure 2.—Vapor issuing from same vents as in Figure 1, showing the higher visibility associated with somewhat lower temperature and higher humidity. Photographed on December 18, 1944, with air temperature 54° F., humidity 81%, wind velocity 10 to 15 m.p.h. (Photographic station the same as for Fig. 1.)

enough to be felt locally. They appear to have originated under the northern end of Kilauea crater. A majority of the 48 shakes recorded at Mauna Loa originated along the northeast rift. R.H.F.

SEISMOLOGY

Earthquake Data, July-September, 1944

Week Ended		Minutes of Tremor	Very Feeble	Feeble	Slight	Local Seismicity*	Teleseisms
July	2	5	0	2	0	3.25	1
	9	4	1	0	0	1.50	0
	16	2	3	0	0	2.00	0
	23	5	4	0	0	3.25	2
	30	3	0	0	0	0.75	1
August	6	3	2	1	0	2.75	0
	13	0	0	1	0	1.00	1
	20	4	0	0	0	1.00	1
	27	1	2	0	0	1.25	0
September	3	1	1	0	0	0.75	1
	10	1	2	1	1	4.25	0
	17	1	0	0	0	0.25	0
	24	5	4	0	1	5.25	1

* For definition of local seismicity, see Volcano Letter No. 371.

The data of the following local disturbances were determined from seismograph stations operated on the island of Hawaii by the Hawaiian Volcano Observatory of the Hawaii National Park. Time is Hawaiian Standard, 10 hours and 30 minutes slower than Greenwich. The number preceding each earthquake is the serial number of the quake for the current year.

53. July 1, 16:00, feeble. In hour mark.
54. July 2, 20:48, feeble. In NW Hawaii.
55. July 6, 22:23, very feeble.
56. July 14, 10:47, very feeble.
57. July 16, 01:01, very feeble.
58. July 16, 16:01, very feeble.
59. July 18, 01:01, very feeble. NE rift Mauna Loa.
60. July 20, 07:53, very feeble. Eastern slope of Mauna Loa.
61. July 22, 08:30, very feeble. NE rift of Mauna Loa.
62. July 22, 21:52, very feeble. In NW Hawaii.
63. July 31, 22:33, very feeble.
64. August 2, 00:04, very feeble. NE rift of Mauna Loa.
65. August 5, 18:53, feeble. SW slope of Mauna Loa.
66. August 7, 10:53, feeble. NE rift of Mauna Loa.
67. August 22, 06:15, very feeble. Lower NW slope of Mauna Kea.
68. August 23, 01:32, very feeble.
69. August 30, 08:47, very feeble.
70. September 4, 16:18, slight. Felt locally. Northern end of Kilauea crater.

71. September 7, 16:36, feeble. Felt locally. Northern rim of Kilauea. Accompanied by a rumble.
72. September 9, 09:14, very feeble. Near northern end of Mokuaweoweo.
73. September 10, 21:37, very feeble.
74. September 18, 00:06, slight. Felt locally. Kilauea crater.
75. September 18, 10:01, very feeble. Mauna Loa shake.
76. September 18, 19:33, very feeble.
77. September 19, 22:45, very feeble.
78. September 23, 02:52, very feeble.
79. September 29, 09:05, feeble.
80. September 29, 09:20, very feeble.
81. September 30, 18:34, very feeble.

TELESEISMS

July 19,	00:36, slight.	Off Japan.
July 20,	02:12, slight.	
July 26,	13:41, slight.	Off Aleutians.
August 9,	15:40, slight.	Off British Columbia.
August 18,	00:13, slight.	Japan.
September 3,	09:04, slight.	
September 23,	01:52, slight.	5400 km.

MICROSEISMS

Microseisms were present though slight throughout the quarter.

TILTING OF THE GROUND

Very slight westerly tilt prevailed during July and until August 20, when normal easterly tilt set in and continued through the rest of the quarter. The time of change from west to east tilt in 1944 corresponds to that of 1941, 1942, and 1943 though it is more usual for the change to occur during the spring. Northerly tilt was continuous throughout the quarter though the amount from August 4 to September 30 was less than normal.

Table of Tilt at Observatory on NE Rim of Kilauea

Week Ended		Amount of Tilt	Direction of Tilt
July	2	0.51″	N 15° E
	9	0.62″	N 79° W
	16	0.62″	N 11° E
	23	0.37″	N 45° E
	30	0.86″	N 45° W
August	6	0.74″	N 10° E
	13	0.85″	N
	20	0.65″	S 68° W
	27	0.87″	N 74° E
September	3	0.54″	N 27° E
	10	0.39″	S 71° E
	17	0.48″	W
	24	1.60″	S 81° E

CRACK MEASUREMENTS

There was practically no movement at any of the cracks measured during July and August. A majority of the cracks around Halemaumau opened slightly during September, and at the Devil's Throat and along the Chain of Craters Road a few showed a slight opening. R.H.F.

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THE VOLCANO LETTER 486

No. 486 **Department of Interior** **National Park Service** **October-December 1944**

PUBLISHED BY THE UNIVERSITY OF HAWAII

HAWAII NATIONAL PARK: Edward G. Wingate, Superintendent; R. H. Finch, Volcanologist

UNIVERSITY OF HAWAII: T. A. Jaggar, Geophysicist

THE NOVEMBER-DECEMBER 1944 CRISIS AT KILAUEA

By R. H. FINCH

For over a year and a half the seismographs and tilt records have indicated a fairly high pressure under the Kilauea-Mauna Loa volcano system. In November, 1943, Mauna Loa produced several rather conspicuous fume clouds.[1] In August, 1944, fuming greater than the normal from Mokuaweoweo was observed.

It was not surprising then to find Kilauea showing definite signs of uneasiness starting with an earthquake on November 12 that originated 8 to 10 miles below the southwest rim of Halemaumau. The history of Kilauea indicates that some form of activity might be expected at any time now. In a press release dated September 13, 1943, the following statement was made: "If the present period of volcanic activity is to parallel the probable sequence following the 1790 explosive eruption, lava activity at Kilauea or Mauna Loa, or both, may be expected about the middle of this decade."

It has been over ten years since molten lava was present in Halemaumau. This is the longest period of inactivity in the recorded history of Kilauea. This is not overlooking the thirteen more or less quiet years from 1894 to 1907. During this thirteen-year period molten lava was visible for short intervals on several occasions, and considerable fume was always present. The longest period of total inactivity was the three years from July, 1924, to July, 1927. The interval between the last activity which started on September 6, 1934, and the next previous outbreak was two years and eight months or well above the average of such intervals since molten lava disappeared from Halemaumau in 1924. It is interesting to note that the 1934 outbreak was the most gaseous and lasted the longest of any of the short-lived outbreaks that have occurred since 1924. It might be expected then that a return of activity to Halemaumau will be marked by high pumice producing fountains.

On November 15, 1944, there was another earthquake with about the same epicenter as the one on November 12, but with a much more shallow focus. From November 15 until December 6 there were a few scattered Kilauea shakes with indications of a more or less progressive decrease in depth of foci. Two earthquakes on November 29 that were felt as sharp jolts at Halemaumau and recorded as feeble or slight shakes only at the Observatory twenty-two miles away were obviously of very shallow foci. The fact that the earthquakes occurred as separate shakes, often several days apart, rather than in swarms is what might be expected if molten lava were rising in the feeding conduits under Halemaumau.

At the Observatory, on the northeast rim of Kilauea, the northeast tilt was but little more than normal for this season of the year though rather definitely indicating a pressure increase under Kilauea. Beginning about the 12th of November, however, tilt instruments near Halemaumau showed a pronounced tilt; this indicated that the crater floor was doming appreciably with the maximum rise in the vicinity of the southern edge of Halemaumau. The amount of tilt during the last week in November at the Halemaumau tilt cellars is not known since the index of each instrument went completely off the scale and was stopped by horizontal braces.

[1] FINCH, R. H. ACTIVITY AT MAUNA LOA IN NOVEMBER 1943. Volcano Letter No. 482. October-December, 1943.

The focus of application of the force producing this final spurt of tilting must have been rather high to produce such marked effects near Halemaumau and so comparatively little effect at the Observatory.

The retreat of the lava column also indicates that a high level of the molten magma was reached. By the morning of December 7, both Halemaumau tilt instruments had gone completely off their scales and were resting against their frames. In this case the direction was the opposite of that during November; this indicated a sinking of the crater floor. The rapid sinking of the crater floor occurred on December 6 and 7, but a sharp southerly tilt did not start in at the Observatory until December 21. This southerly tilt continued until December 30 and amounted to 3.6 seconds of arc.

The earthquake pattern accompanying this minor 1944 crisis is rather typical. First one or two rather strong shakes of appreciable depth occurs marking the introduction of lava to the conduits under Halemaumau. (The earthquake of November 12 appears to have been of this type.) Then follow scattered lighter shakes of decreasing depth of foci accompanying the upsurge of molten lava. The spreading apart of walls of fissures and introduction of hot lava and gases reduce the tendency of seismic grating. At times of rapid recession of the lava column and appreciable subsidence of the crater floor, earthquakes are numerous. Twenty-nine earthquakes occurring between 08:30 December 6 and 13:50 December 7 accompanied the suspected 1944 recession.

The uneasiness manifested at Kilauea in the autumn of 1944 was the most conspicuous indication of fairly high internal activity that has been observed since the 1934 outbreak. It should be borne in mind that lava pressure in a volcano conduit can vary through a large range without any lava appearing at the surface. Whether molten magma reaches the surface or not depends upon, among other things, the duration of high pressure and the amount of lava involved in any particular upsurge.

Hawaiian Volcano Observatory Report for October-December 1944

VOLCANOLOGY

October

Mauna Loa and Kilauea were both quiet throughout October, Forty-eight seismic disturbances were recorded at Mauna Loa and 26 at Kilauea. Four shakes were felt at the Observatory and six were felt at Hilo. The number of distinctly Mauna Loa shakes was the smallest for the last several months.

November

For the first time in several months more earthquakes of Kilauea than of Mauna Loa origin were registered. The fact that 36 seismic disturbances were recorded at Mauna Loa and 35 at Kilauea does not show the true relative seismicity because most of the Kilauea shakes were recorded at Mauna Loa and several of the Mauna Loa shakes did not register at Kilauea. Starting with an earthquake on November 12 that was widely felt on the island of Hawaii, Kilauea showed distinct signs of uneasiness. The origin of the shake was 8 to 10 miles below the surface to the southwest of Halemaumau. On November 15, there was another Kilauea shake with about the same epicenter but with more shallow focus. A progressive decrease in depth of foci of earthquake continued until the end of the month. The tilt instruments on the crater floor indicated a distinct doming of the crater floor with the maximum rise in the vicinity of the southwest rim of Halemaumau.

December

The uneasiness of Kilauea continued until December 6. A series of earthquakes that started on this day and tilt indications of subsidence of the crater floor in the vicinity of Halemaumau clearly showed that a return of lava to the fire pit of Kilauea could not be expected.

A strong earthquake on December 27 caused Mauna Loa again to be the main center of interest. This quake as well as four others that followed within 3 days originated about 15 miles below the eastern rim of Mokuaweoweo. There was a slight migration of epicenters in a northeasterly direction in this series of shakes as though they followed along a fault block connecting southwest and northeast branches of the fundamental Hawaiian rift.

The strong earthquake of December 27 started many landslides at Halemaumau. The largest produced a roar that was audible 3 miles away, which was reminiscent of the explosions in 1924. R.H.F.

SEISMOLOGY

Earthquake Data, October-December 1944

Week Ended		Minutes of Tremor	Very Feeble	Feeble	Slight	Moderate	Strong	Local Seismicity*	Teleseisms
October	1	0	2	1	0	0	0	02.00	0
	8	3	3	1	1	0	0	05.25	1
	15	2	0	2	0	0	0	02.50	0
	22	3	1	1	0	0	0	02.25	0
	29	3	0	1	0	0	0	01.75	0
November	5	4	2	2	0	0	0	04.00	0
	12	4	3	0	0	1	0	05.50	0
	19	6	0	1	0	1	0	05.50	1
	26	3	2	2	1	0	0	05.75	1
December	3	8	0	3	1	0	0	07.00	0
	10	15	13	2	2	0	0	18.25	1
	17	6	4	0	0	0	0	03.50	0
	24	1	2	0	0	0	0	01.25	0
	31	12	6	0	1	2	1	18.00	3

* For definition of local seismicity, see Volcano Letter No. 371.

The data of the following local disturbances were determined from seismograph stations operated on the island of Hawaii by the Hawaiian Volcano Observatory of the Hawaii National Park. Time is Hawaiian Standard, 10 hours and 30 minutes slower than Greenwich. The number preceding each earthquake is the serial number of the quake for the current year.

82. October 2, 17 : 27, slight. Deep focus, near Ookala.
83. October 4, 15 : 22, very feeble.
84. October 6, 14 : 30, feeble.
85. October 6, 14 : 40, very feeble. Probably same origin as No. 84.
86. October 7, 14 : 41, very feeble.
87. October 11, 21 : 11, feeble. Felt locally, under Mokuaweoweo.
88. October 11, 21 : 12, feeble. Felt locally. Probably same origin as No. 87.
89. October 17, 13 : 54, feeble. Felt in Hilo, Mauna Kea.
90. October 17, 14 : 52, very feeble.
91. October 29, 17 : 17, feeble. Felt locally and in Hilo, Mauna Kea.
92. October 31, 04 : 26, feeble. Felt in Hilo.
93. October 31. 04 : 28, feeble. Felt in Hilo.
94. October 31, 04 : 32, very feeble.
95. November 5, 01 : 46, very feeble. Kilauea shake.
96. November 8, 02 : 16, very feeble.
97. November 8, 02 : 18, very feeble.
98. November 9, 08 : 25, very feeble.
99. November 12, 04 : 56, moderate. Widely felt in southern half island of Hawaii. Eight to 10 miles deep to the SW of Halemaumau. Dismantled seismograph at Hilo and Kona as well as at the Observatory.
100. November 15, 18 : 19, moderate. Felt locally. About same epicenter as No. 99 but with shallower focus.
101. November 15, 19 : 33, feeble. Felt locally. Origin at NE rim of Kilauea.
102. November 22, 22 : 53, slight. Under Kilauea.
103. November 23, 13 : 43, feeble. SW of Halemaumau.
104. November 23, 21 : 16, very feeble.
105. November 26, 00 : 48, very feeble.
106. November 26, 13 : 02, feeble.
107. November 28, 00 : 43, feeble.
108. November 29, 09 : 34, feeble. Felt as a sharp jolt at Halemaumau.
109. November 29, 09 : 36, slight. Felt as a sharp jolt at Halemaumau.
110. December 2, 00 : 17, feeble. Under Kilauea.
111. December 6, 07 : 38, very feeble. Under Kilauea.
112. December 6, 08 : 08, very feeble. Same as No. 111.
113. December 6, 09 : 47, feeble. Same as No. 112.
114. December 6, 11 : 51, very feeble.
115. December 6, 11 : 54, very feeble.
116. December 6, 19 : 29, very feeble. Under Kilauea.
117. December 6, 22 : 07, very feeble. Same as No. 116.
118. December 7, 00 : 58, very feeble. Same as No. 116.
119. December 7, 02 : 51, very feeble. Same as No. 116.
120. December 7, 05 : 15, very feeble.
121. December 7, 07 : 17, slight. Felt locally. Under Kilauea.
122. December 7, 08 : 46, very feeble. Accompanied by rumble audible at Halemaumau rim.
123. December 7, 11 : 18, very feeble.
124. December 7, 11 : 22, very feeble. Under Kilauea.
125. December 7, 11 : 39, feeble. Same as No. 124.
126. December 7, 12 : 50, slight. Same as No. 124.
127. December 9, 12 : 40, very feeble. Under Kilauea.
128. December 11, 22 : 01, very feeble.
129. December 15, 16 : 17, very feeble.
130. December 16, 15 : 08, very feeble. Kilauea shake.
131. December 16, 23 : 45, very feeble.
132. December 18, 10 : 38, very feeble. Kilauea shake.
133. December 21, 00 : 36, very feeble.
134. December 26, 09 : 35, very feeble. Probably Mauna Loa origin.
135. December 27, 03 : 42, strong. Dismantled all seismographs on island of Hawaii. Plainly felt on Oahu. Some objects toppled from shelves at places as widespread as Pepeekeo and Naalehu, stone fences were thrown down in vicinity of Hilea. Origin about 15 miles below eastern edge of Mokuaweoweo.
136. December 27, 04 : 21, very feeble. Same as No. 135.
137. December 27, 04 : 27, very feeble.
138. December 27, 05 : 46, slight. E-W instruments dismantled the same as by No. 135.
139. December 30, 09 : 21, moderate. Instruments dismantled the same as by No. 135.
140. December 31, 11 : 10, moderate. Instruments dismantled near Wood Valley. Twelve to 14 miles deep.
141. December 31, 19 : 53, very feeble.

TELESEISMS

October 5, 07 : 07, very slight. 4790 km.
November 16, 02 : 13, near Solomon Islands.
November 23, 16 : 26, slight.
December 6, 18 : 16, moderate. 3700 miles, Japan.
December 29, 12 : 50, slight.
December 29, 13 : 39, slight.
December 30, 11 : 47, slight.

MICROSEISMS

Microseismic motion was strong on October 12 and 13, moderate from October 14 to 20, 27 to 30, and on November 23. Throughout the rest of the quarter microseisms were present though slight.

TILTING OF THE GROUND

Northerly tilt was normal to the north in October, above the normal during the first three weeks in November, and about normal to the north until December 21, when a pronounced southerly tilt set in that continued until the end of the month. Easterly tilt was about normal in October and November. From December 6 to 26 there was a slight westerly tilt. A distinct east tilt accompanied the strong Mauna Loa earthquake of December 27, then the seasonal westerly tilt started.

Table of Tilt at Observatory on NE Rim of Kilauea

Week Ended		Amount	Direction
October	1	1.50″	N 14° E
	8	1.11″	N 40° E
	15	1.03″	S 45° E
	22	1.23″	N 11° E
	29	0.34″	N 45° E
November	5	1.75″	N 34° E
	12	0.72″	N
	19	1.45″	N 55° E
	26	0.44″	S 34° E
December	3	0.64″	N 22° W
	10	0.44″	N 34° W
	17	0.76″	N 18° W
	24	0.61″	S 11° E
	31	3.02″	S 37° E

CRACK MEASUREMENTS

During October there was no movement of consequence at any of the cracks around Halemaumau nor along the Chain of Craters Road. In November a majority of the cracks around Halemaumau showed an opening accompanying a rather rapid doming of the crater floor, though a few showed a distinct closing as is to be expected during times of such movements. There was considerable movement, both opening and closing, accompanying the rapid subsidence of the crater floor in December.

R.H.F.

HAWAIIAN VOLCANO RESEARCH ASSOCIATION
in cooperation with UNIVERSITY OF HAWAII

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THE VOLCANO LETTER 487

No. 487 **Department of Interior** **National Park Service** **January-March 1945**

PUBLISHED BY THE UNIVERSITY OF HAWAII

HAWAII NATIONAL PARK: Edward G. Wingate, Superintendent; R. H. Finch, Volcanologist

UNIVERSITY OF HAWAII: T. A. Jaggar, Geophysicist

ON MAGNETIC STUDIES

By GUY C. OMER, JR.

On leave of absence from the Department of Physics

University of Hawaii

While a remarkable amount of data pertaining to the internal status of the volcanoes has been collected by the seismographs of the Hawaiian Volcano Observatory, this is only one of the many possible geophysical methods that could be used. Other geophysical procedures that suggest themselves are magnetic, gravitational, and earth-current programs. The advantages of using several geophysical methods simultaneously are first, that additional data is obtained, since different effects are being measured, and second, that a very valuable cross-check is possible in the interpretation of the collated data.

A rising or falling magma column could be expected to have at least two magnetic effects. One is the local change in the permeability of the earth's crust produced by the presence of the hot magma column and the associated heating of the surrounding rock. The other is a Lenz law local field produced by eddy currents induced in the hot magma column while it is rising or falling. A change in the measured magnetic elements between two observational dates spaced a month or so apart, might well correlate with volcanic activity while the absolute value at any one date might not in itself have much significance.

The first magnetic work at Kilauea was done by J. W. Green[1] of the United States Coast and Geodetic Survey at the suggestion of Dr. T. A. Jaggar. This consisted of many magnetic measurements around Kilauea and Mauna Loa during the winter of 1913. During this time Mauna Loa was quiet and Kilauea was relatively quiet between short periods of visible activity. Many striking magnetic variations were observed, but the time available for this work was too short to allow any definite conclusions.

Magnetic observations have been made upon the volcanoes of Japan. Typical of this would be the work of Y. Kato[2] who compared regional magnetic surveys made before and after volcanic eruptions and found large and regular local changes in the magnetic elements.

It is not possible to make magnetic surveys without special instruments, so a full-fledged magnetic program cannot be immediately started at Hawaiian Volcano Observatory. However, some preliminary work has been done using instruments and data that are available. This preliminary work is of value, however, since it indicates the fruitfulness of the magnetic method and the scope and nature of an enlarged magnetic program that could be begun.

The first of this preliminary work was a crude dip survey of the entire island. The instrument used was a Swedish mining compass, which could be read to 0.2°. However, the greatest

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[1] JAGGAR, JR., T. A. SPECIAL BULLETIN OF HAWAIIAN VOLCANO OBSERVATORY, p. 9, 1913.

[2] KATO, Y. SEISMIC AND VOLCANIC ACTIVITIES AND CHANGES IN THE EARTH'S MAGNETIC FIELD (three papers). Japanese Journal of Astronomy and Geophysics Vol. 10, No. 2, pp. 249-262; Vol. 12, No. 1, pp. 1-26; Vol. 12, No. 2, pp. 237-243.

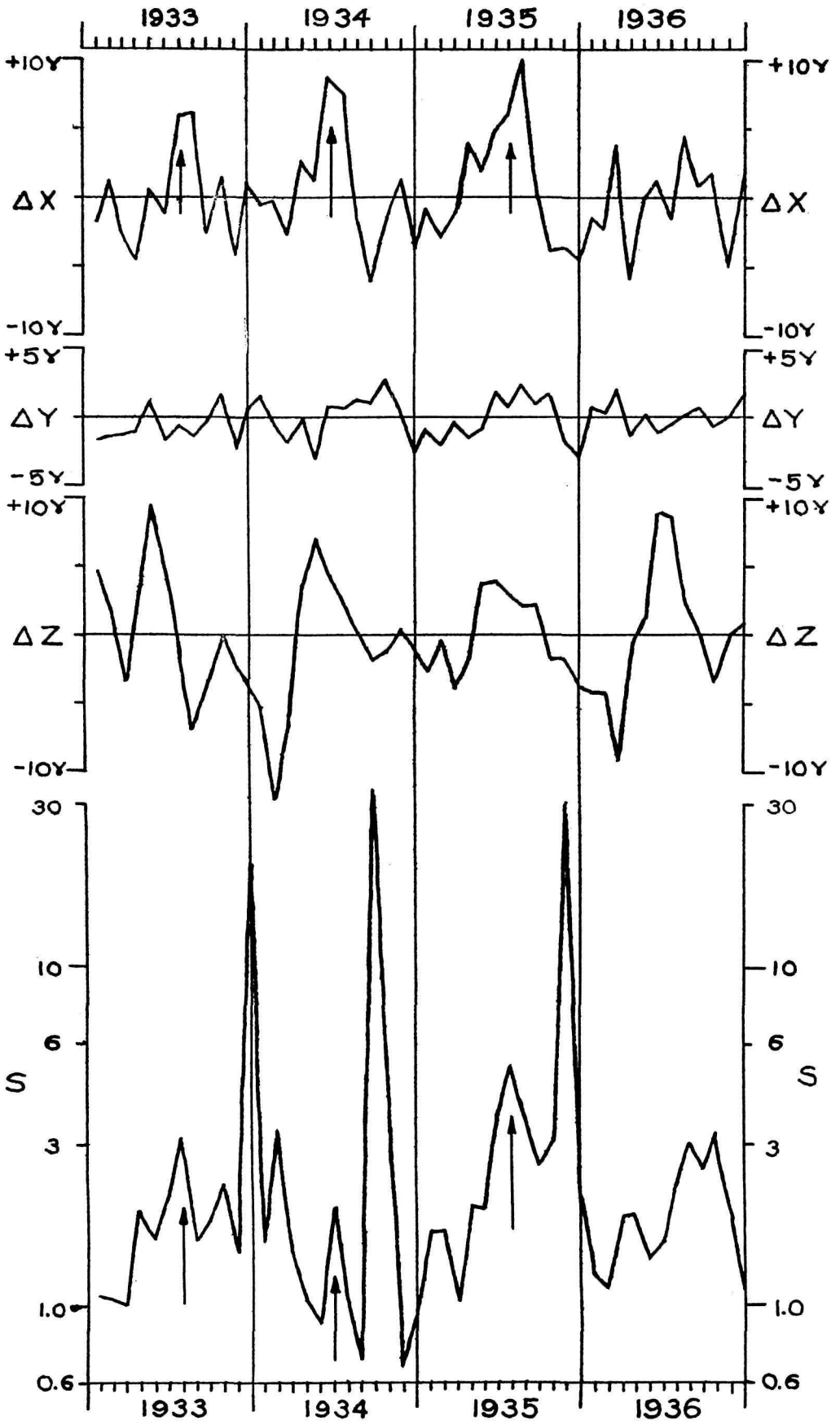

Figure 1.—Magnetic departures at Honolulu and seismicity at the Hawaiian Volcano Observatory. ΔX, ΔY, and ΔZ show the departures from the mean in gammas for the north-south, east-west, and vertical fields, respectively. *S* shows the monthly seismicity.

handicap to this survey was the extreme variation in local magnetic conditions. An attempt was made to correct this by taking an areal average, but the scatter in the data was still too great to allow the construction of a reliable iso-dip map. Nevertheless, a decrease in magnetic dip averaging between one and two degrees between the shore line and the summits of the volcanoes was definitely indicated. This is the effect to be expected if the heating of the rock under the volcano is higher in temperature than that for areas some distance from the summit caldera.

Another available source of magnetic data is the published results of the Honolulu Magnetic Observatory of the United States Coast and Geodetic Survey. While the Magnetic Observatory is about 190 miles away from the volcanoes, it is a highly sensitive station that is in continuous operation. The reduced data[3] for this station from 1933 to 1936 is plotted in Figure 1 against the monthly seismicity at Hawaiian Volcano Observatory.

The earth's magnetic field is continually varying because of a number of causes, most of which are balanced out in the published monthly means through the system of selected averaging. The remaining variations are those of secular change and any peculiar local effect. The secular change is a slow continuous varying of the magnetic field which is world-wide and of unknown cause. The secular change was eliminated from the published data by determining a smooth running mean and plotting the departures from this mean as the upper three curves of Figure 1. This should be the peculiar local effect which might correlate with volcanic activity. The unit used in plotting this magnetic data is the *gamma* which is 10^{-5} gauss. The ΔX curve shows the departures from the mean for the north-south field, the ΔY curve shows the departures from the mean for the east-west field, while the ΔZ curve shows the departures from the mean of the vertical field. This latter data is subject to the greatest instrumental inaccuracy.

Since the magnetic data plotted are monthly averages, the seismicity curve plotted is also for corresponding monthly averages, slightly adjusted in two cases to compensate for distance effects. This period included three eruptions indicated by the momentarily extremely high seismicity. These eruptions are: Mauna Loa in December, 1933; Kilauea in September, 1934; and Mauna Loa in November, 1935.

The most striking coincidence that will be noted in these curves is the high sustained positive departure in the ΔX curve which preceded each of the three eruptions by several months. The three sets of corresponding arrows on the ΔX curve and the seismicity curve indicate the probable time at which magma began to rise in the upper system of the volcano as determined by analyzing the seismic data. This occurs during the marked positive departure. A closer inspection will show the coincidence of most of the maxima and minima of these two curves. The correspondence is not one-to-one since sometimes a maximum will coincide with a maximum, and at other times a maximum will coincide with a minimum. However, a reversal of magnetic polarity is to be expected for rising and for falling magma; but a seismic maximum may occur with both.

On the other hand, there seems to be but a very slight correlation between the ΔY curve, the ΔZ curve and the seismicity. However, it must be remembered that the data plotted is only for four years and three eruptions. No definite conclusions can be drawn upon any seeming correlation over so short an epoch. The United States Coast and Geodetic Survey has just recently furnished us with the Honolulu Magnetic Observatory results from 1905 to 1943, inclusive. This data for thirty-nine years and for many eruptions of Mauna Loa and Kilauea will be handled in the same way as the data of Figure 1. From this much longer epoch the reality or the nonreality of these seeming correlations should be definitely shown.

A third possible bit of preliminary work is to determine the variation in the magnetic declination at certain selected stations around the volcanoes to the accuracy inherent in a good modern transit. This program has just been begun. The stations indicated on the map of Figure 2 have been established. Each station consists of a nonmagnetic bench mark along with a corresponding nonmagnetic azimuth mark, which fix an observing point and a fixed azimuth line. The magnetic bearing of this fixed azimuth line is read on the transit each time that the station is reoccupied. The error in resetting the transit over the bench mark and in reading the magnetic needle should not exceed 0.1° and is certainly not over 0.2° at the most.

Stations A to H inclusive were established at an average date of about February 1, 1945, and were reoccupied at an average date of about March 20, 1945. The variation found in these two readings is:

Station	Variation	
A	0.35° W	
B	0.35° W	
C	0.15° W	
D	0.00°	(Station disturbed)
E	0.15° E	
F	0.25° W	
G	0.05° E	
H	0.10° E	

The variation for some of the stations is much higher than the maximum possible error; hence the variation must be real. If this variation is plotted on the map, it will be found that the vector lines radiate out from a point which very roughly might be guessed to be on the northeast rift of Mauna Loa at about 8,000 feet. These readings coincide with a seeming period of rising magma in Mauna Loa as indicated by a seismic series which came to a climax on April 2, 1945.

No data is given for stations I and J since these were established only recently. Immediate plans are to construct a simple suspended magnet to be read optically with a telescope and scale at a fixed location each day to determine changes in declination to within a minute of arc or better.

[3] Magnetic Observatory Results at Honolulu, Hawaii, for 1933-34, MO-14, and for 1935-36, MO-19.

University of Hawaii Outline Map No. 5—Island of Hawaii

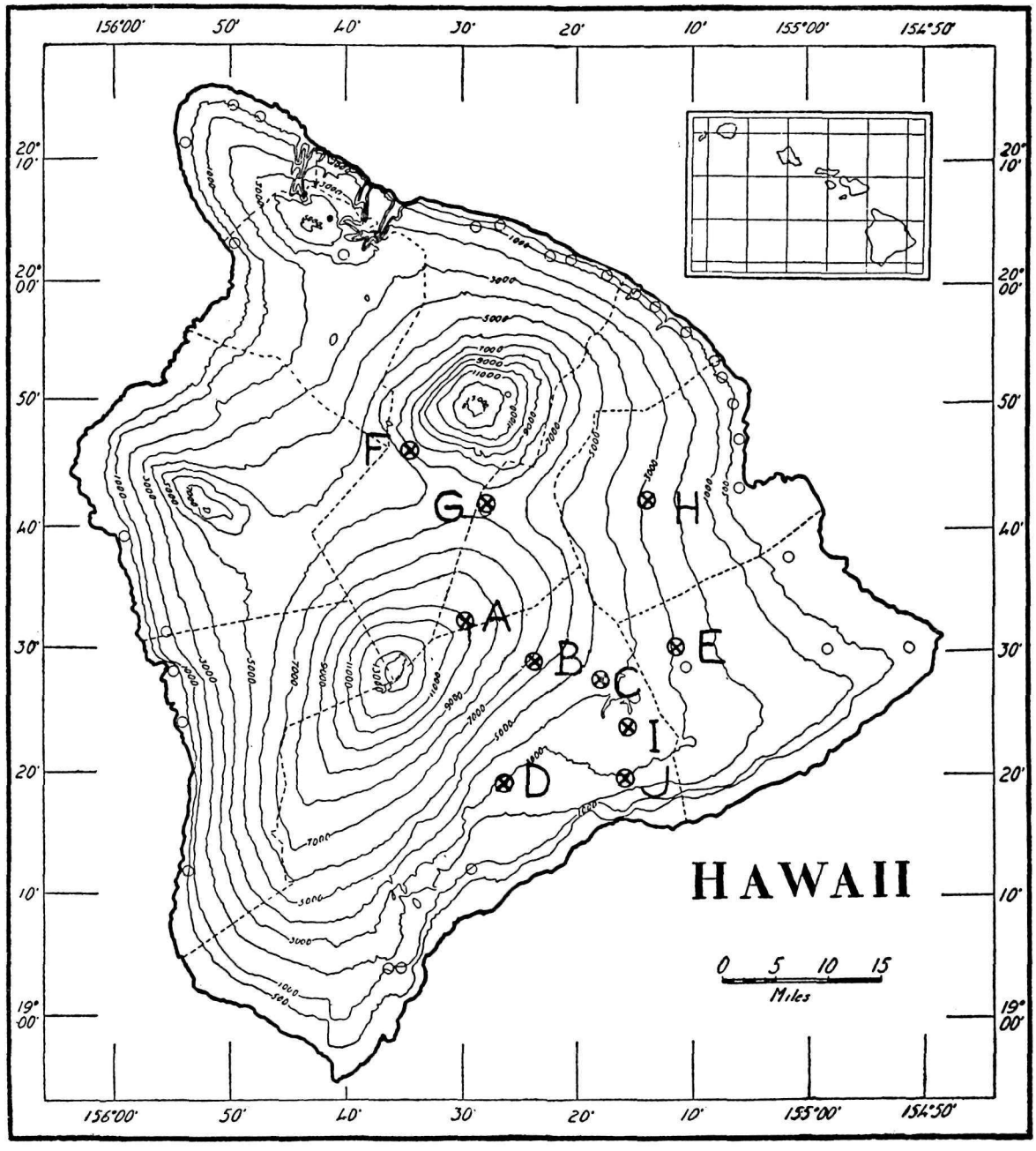

Figure 2.—Temporary declination stations.

Hawaiian Volcano Observatory Report for January-March 1945

VOLCANOLOGY

January

Following the earthquakes of the last of December, 1944, Mauna Loa continued to show signs of uneasiness with shakes on January 6 and 9 that originated near Wood Valley and in the southwestern part of Mauna Loa. Thirty earthquakes were recorded at Kilauea and 22 at Mauna Loa.

February

Several times during the last of January and the first of February distinct fume clouds were observed over Mokuaweoweo.

The tilt record gives evidence of continuing high pressure under the Kilauea-Mauna Loa volcano system. Seasonal southwesterly tilt stopped about the middle of the month and by the last of the month there was a noticeable easterly tilt. A volcanic tilt sufficiently strong to overcome the southwest tilt that is normal for this season of the year is really a positive northeast tilt.

Several landslides from the Halemaumau rim were noticed during the month. A large one on February 11 filled the pit with dust and sent up a cloud with definite outlines well above the Halemaumau rim.

Twelve seismic disturbances were recorded at Kilauea and 22 at Mauna Loa.

March

The tilt records for March show that the uneasy condition of Kilauea mentioned for February continued into March. Northerly tilt, an indication of doming at Kilauea volcano, was strong enough during the first half of the month to overcome the normal southerly tilt and show an actual accumulation to the north. The spell of uneasiness was over about the middle of the month and during the last half of the month there was about the normal accumulation of southerly tilt. An easterly tilt that set in about the middle of February continued until March 6, when the usual westerly tilt was resumed. It continued until the end of the month.

This period of uneasiness coming only two and a half months after the one of November-December, 1944, indicates that the possibility of surface manifestations of volcanic activity at Kilauea within the next year or so are rather good. The easterly tilt and the distribution of earthquakes indicate that Mauna Loa is sharing the uneasiness with Kilauea.

Forty-two seismic disturbances were recorded at Mauna Loa and 37 at Kilauea.

R.H.F.

SEISMOLOGY

Earthquake Data, January-March 1945

Week Ended	Minutes of Tremor	Very Feeble	Feeble	Slight	Moderate	Local Seismicity*	Teleseisms
January 7	9	1	1	0	0	3.75	0
14	3	2	0	1	0	3.75	0
21	8	0	0	0	0	2.00	0
28	8	0	0	0	1	5.00	0
February 4	1	0	0	0	0	0.25	0
11	0	0	1	0	0	1.00	0
18	1	1	0	1	0	2.75	0
25	0	2	1	0	0	2.00	0
March 4	3	1	0	0	0	1.25	0
11	3	0	0	0	1	3.75	0
18	5	1	1	0	1	5.75	0
25	6	0	1	0	0	2.50	0

* For definition of local seismicity see Volcano Letter No. 371.

The data of the following local disturbances were determined from seismograph stations operated on the island of Hawaii by the Hawaiian Volcano Observatory of the Hawaii National Park. Time is Hawaiian Standard, 10 hours and 30 minutes slower than Greenwich. The number preceding each earthquake is the serial number of the quake for the current year.

1. January 4, 12:18, very feeble.
2. January 6, 05:57, feeble, near Wood Valley. Felt at Kapapala and Pahala.
3. January 9, 18:57, slight. Felt at Pahala.
4. January 9, 19:08, very feeble.
5. January 11, 18:53, very feeble.
6. January 24, 10:38, moderate. Widely felt in SE half of the island. 10 to 15 miles below east rim of Kilauea.
7. February 5, 18:43, feeble. Felt locally. Probably at NE rift of Mauna Loa.
8. February 17, 04:24, very feeble.
9. February 18, 15:55, slight. Felt locally; E-W dismantled. Both components dismantled at Mauna Loa. About 9 miles deep near Ohaikea.
10. February 21, 02:00, very feeble.
11. February 23, 10:53, feeble. Origin about same as No. 9.

12. February 24, 18:43, very feeble. Origin probably same as No. 9.
13. February 26, 06:34, very feeble.
14. March 4, 00:00, moderate. At SW rift of Mauna Loa. Widely felt over island. Stopped clocks in South Kona.
15. March 12, 19:00, moderate. Instruments dismantled. Felt locally. In ocean off the Puna-Kau boundary.
16. March 13, 09:03, very feeble.
17. March 18, 07:54, feeble.
18. March 24, 13:33, feeble.
19. March 26, 10:04, slight. Felt locally.
20. March 26, 10:37, slight. Off coast south of Kilauea. Felt in eastern part of island.
21. March 28, 05:22, very feeble.
22. March 28, 19:58, feeble. At NE rift of Mauna Loa.
23. March 29, 18:32, very feeble.
24. March 30, 05:34, very feeble.
25. March 30, 08:31, very feeble.
26. March 31, 20:02, very feeble. Origin near Puu Keokeo. Felt in South Kona.

TELESEISMS

No teleseisms were recorded during the quarter.

MICROSEISMS

Microseisms were present though slight throughout the quarter.

TILTING OF THE GROUND

The seasonal SW tilt that started in December continued until about the middle of February when a NE tilt set in. The easterly tilt ceased on March 6 though the northerly tilt continued until March 14. During the last half of March the usual seasonal SW tilt prevailed.

Table of Tilt at Observatory on NE Rim of Kilauea

Week Ended	Amount	Direction
January 7	1.21″	S 48° W
14	0.88″	N 17° W
21	0.48″	S
28	0.62″	N 79° W
February 4	1.91″	S 26° W
11	1.46″	S 45° W
18	0.54″	N 63° E
25	0.17″	S 45° W
March 4	1.84″	N 62° E
11	1.47″	N 75° W
18	0.72″	S
25	0.71″	N 58° W

CRACK MEASUREMENTS

In January a majority of the cracks at Halemaumau rim and along the Chain of Craters Road showed a slight opening though a few showed some closing. There was considerable fluctuation in the width of these cracks in February. The net result, however, was a distinct opening in a few cracks and no change in the majority of them. In March a majority of the cracks around Halemaumau showed an opening and none showed a closing. There was no movement at any of the cracks along the Chain of Craters Road.

R.H.F.

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THE VOLCANO LETTER 488

No. 488 **Department of Interior** **National Park Service** **April-June 1945**

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HAWAII NATIONAL PARK: Edward G. Wingate, Superintendent; R. H. Finch, Volcanologist

UNIVERSITY OF HAWAII: T. A. Jaggar, Geophysicist

A FLOOD-DEVELOPED CHASM OVER A BURIED FAULT

By GUNNAR O. FAGERLUND

Naturalist and Chief Ranger, Hawaii National Park

An apparent seismic movement occurred on April 8, 1945, along a concealed fault about eighteen miles southwest of Kilauea near the old belt road. A chasm approximately 325 feet long, 40 feet wide, and 20 to 40 feet deep was formed in the Pahala ash that lies 30 to 50 feet thick upon prehistoric basalt.[1] The northern end of the chasm is about 1,800 feet southwest of the benchmark at 1,856 feet elevation near Kapapala Ranch gate and about 100 feet east of the old belt road.

Figure 1.—General view of the flood-developed chasm. (Photo by G. O. Fagerlund.)

The ash lying above the section of the fault disappeared into a fissure in the underlying prehistoric lava and created the chasm (Fig. 1). Extension of the northern end of the chasm was stopped by a bridging lava flow that withstood undermining. Beyond the southern end of the chasm the ash slumped some. A block 18 feet wide and 150 feet long dropped as much as 2 feet (Fig. 2). This slump block and the topographic sag shown in the background of Figure 2 indicate the continuation of the buried fault. A wider fissure in the basalt probably accounts for the sag in the ash that was laid down upon it at this point. Another slumped section, about twelve feet long and as wide as the chasm, occurs near the southern end of the chasm and breaks its continuity.

Only the west wall of the chasm shows two lava flows, one at zero to two feet and the other at four to ten feet below the surface. Before the breakdown, the edges of these flows probably lay almost directly above the buried fault. The upper flow bridges the northern end of the chasm.

A direct seismic cause of the chasm is precluded by the absence of earthquakes at the time it was formed. However, earthquakes of former years may have fractured or weakened the ash structure.

Extraordinarily heavy rainfall occurred on April 7 and 8 of this year. The total for the storm in the vicinity of Kapapala was about twenty-five inches. The prolonged downpour caused

[1] STEARNS, HAROLD T., AND CLARK, WILLIAM O. GEOLOGY AND WATER RESOURCES OF THE KAU DISTRICT, HAWAII (INCLUDING PARTS OF KILAUEA AND MAUNA LOA VOLCANOES). Plate 1. U. S. Geological Survey Water-Supply Paper 616. 1930.

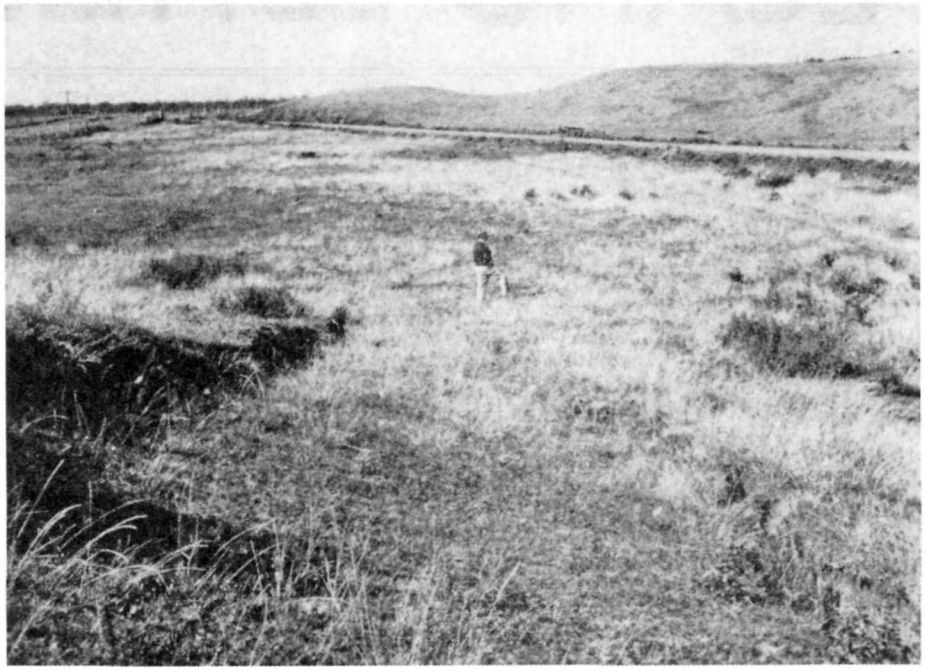

Figure 2.—Slump block near the southern end of the open chasm. The sag in the background shows extension of the buried fault. (Photo by G. O. Fagerlund.)

floods of uncommon magnitude and destructiveness. Sections of highway were washed out and fences were carried away. At Kapapala Ranch, one building was carried away and others were shifted.

Boulder-carrying floodwater moved over the area where the chasm formed. Sustained flooding probably led to seepage through the ash. Seepage may have been promoted at the fault line by earlier seismic movement there and by the edging lava flows above the fault. The seepage undermined the ash from the bottom of the bed upward in the manner of a linear swallet. This accelerating process developed into a waterfall that carried the ash into the fissure in the underlying basalt. The undermining continued until the roof collapsed.

Partial collapse followed lesser undermining near and beyond the southern extremity of the chasm, where the two slump blocks previously mentioned wedged into the ash above the fissure. Because these slumped sections formed on higher ground that was not covered by floodwater, they did not wash away, although a section of equally high ground between them collapsed completely. About twelve feet from the top of this high slumped section the presence of a water line indicates that the floodwater nearly filled the chasm for some time. Thus the length of the chasm was determined by a bridging lava flow at one end and by high ground at the other.

Figure 3 shows boulders on the edge of the chasm. Their presence indicates that the breakdown occurred after the maximum flood had passed. Floodwater, in this instance, produced a physiographic feature, viz., a chasm, of which a superficial inspection could lead one to conclude that it had been caused by seismic movement.

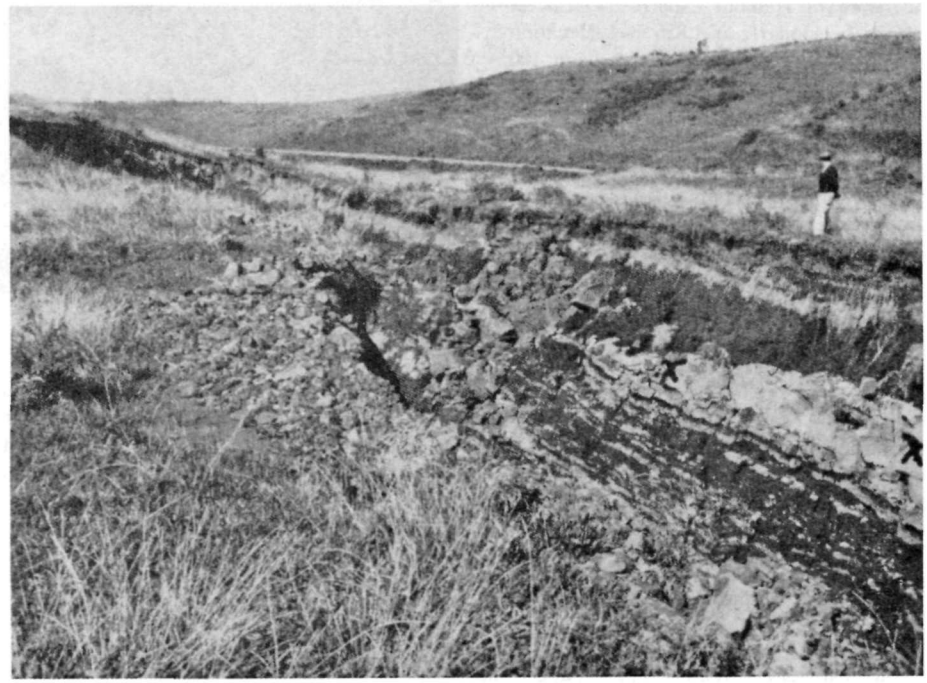

Figure 3.—The west wall of the chasm shows an interbedded lava flow from X to X. Note the fresh boulder deposit on the left rim. (Photo by G. O. Fagerlund.)

Hawaiian Volcano Observatory Report for April-June 1945

VOLCANOLOGY

April

A strong northeast tilt accompanied the torrential rains of April 7 and 8. The north tilt recovered rapidly after the rain stopped, but a slight easterly tilt continued for over a week before there was a recovery to the west. There were no signs of uneasiness at either Kilauea or Mauna Loa, though internal pressure continued high. A total of 54 seismic disturbances was recorded at Kilauea and 32 at Mauna Loa.

Several of the rim cracks at Halemaumau showed distinct openings.

May

An earthquake which occurred at 02:48 (HST) on May 19 is of especial interest. It originated at a depth of 12 to 15 miles below the surface on the east slope of Mauna Loa, about half way between Halemaumau and Mokuaweoweo. It was just strong enough to awaken light sleepers on the island of Hawaii and appears to have been only slightly less intense on Oahu. The shake produced a good record on the U. S. Coast and Geodetic Survey seismograph in Honolulu. Only one component of the horizontal seismograph at the Observatory was dismantled, though both were dismantled at the Mauna Loa station, which is about 3 miles nearer the epicenter. The widespread and rather uniform intensity suggests that the origin may have been at an even greater depth than the indicated 12 to 15 miles. At any rate, the energy of the surface waves was not much greater in the epicentral region than at places 50 miles and more away.

A total of 25 shakes was recorded at Mauna Loa and 19 at Kilauea.

June

Pressure under Kilauea and Mauna Loa changed little during June. Only two earthquakes strong enough to be felt locally were recorded. They originated along the lower southwest Kilauea rift.

Forty-one seismic disturbances were recorded at Mauna Loa and 19 at Kilauea.

R.H.F.

SEISMOLOGY

Earthquake Data, April-June 1945

Week Ended	Minutes of Tremor	Very Feeble	Feeble	Slight	Moderate	Strong	Local Seismicity*	Teleseisms
April 1	12	5	1	2	0	0	10.50	0
8	18	6	2	1	1	0	14.50	0
15	4	4	2	1	0	0	7.00	0
22	5	3	1	2	0	0	7.75	0
29	3	0	0	1	0	0	2.75	0
May 6	0	1	0	0	0	0	0.50	0
13	2	0	0	0	0	0	0.50	0
20	3	2	1	1	1	0	7.75	1
27	3	0	0	0	0	0	0.75	0
June 3	3	2	0	2	0	0	5.75	0
10	2	2	0	0	0	0	1.50	0
17	3	0	0	1	0	0	2.75	0
24	2	0	0	0	0	0	0.50	1

* For definition of local seismicity, see Volcano Letter No. 371.

The data of the following local disturbances were determined from seismograph stations operated on the island of Hawaii by the Hawaiian Volcano Observatory of the Hawaii National Park. Time is Hawaiian Standard, 10 hours and 30 minutes slower than Greenwich. The number preceding each earthquake is the serial number of the quake for the current year.

27. April 2, 00:54, very feeble.
28. April 2, 11:23, very feeble. Kilauea origin.
29. April 2, 18:37, moderate. East-west dismantled. Origin under Kilauea. Felt locally.
30. April 2, 19:51, slight. Origin under Kilauea.
31. April 3, 01:38, feeble. Kilauea shake.
32. April 3, 20:50, feeble. Kilauea shake.
33. April 4, 20:36, very feeble. Felt at Pahala.
34. April 6, 14:03, very feeble.
35. April 6, 23:52, very feeble.
36. April 8, 22:10, very feeble.
37. April 12, 21:49, feeble.
38. April 13, 04:06, slight. Kilauea shake.
39. April 13, 07:02, very feeble.
40. April 13, 18:43, very feeble.
41. April 14, 04:46, very feeble.
42. April 15, 01:35, feeble.
43. April 16, 18:52, feeble. Kilauea shake.
44. April 18, 06:41, slight. Kilauea shake.
45. April 18, 09:04, slight. Kilauea origin.
46. April 20, 16:08, very feeble. East slope of Mauna Loa.
47. April 21, 02:41, very feeble. Mauna Loa origin.
48. April 22, 18:33, very feeble.
49. April 29, 01:59, slight. Felt locally.
50. May 1, 13:33, very feeble.
51. May 19, 01:48, moderate. East-west dismantled. East slope of Mauna Loa. Generally felt on Hawaii and slightly felt on Oahu.
52. May 19, 02:05, very feeble.
53. May 19, 02:18, very feeble.
54. May 19, 03:33, feeble. Felt by a few.
55. May 19, 21:21, slight. Origin on Mauna Loa.
56. May 29, 18:45, slight. East slope of Mauna Loa, 5 miles southwest of Red Hill, 12 to 14 miles deep. Felt locally, at South Kona, and at Hilo.
57. May 30, 01:27, very feeble.
58. May 31, 15:06, slight. Five to 7 miles deep off coast south of Kilauea. Felt locally.
59. June 1, 16:13, very feeble.
60. June 7, 00:26, very feeble.
61. June 8, 04:25, very feeble. Origin in Kona.
62. June 14, 19:46, slight. Near Pahala. Felt locally and at Pahala.
63. June 27, 08:34, feeble. Kilauea shake.
64. June 27, 19:40, very feeble. Mauna Loa shake.
65. June 28, 04:08, feeble. Felt locally.
66. June 29, 16:37, feeble. Upper northeast rift of Mauna Loa.

TELESEISMS

May 19, 04:40, slight. Off northern California.
June 21, 22:58, slight.
June 27, 02:56, slight.
June 29, 19:05, slight.

MICROSEISMS

Microseisms were moderate on June 3 and 4 and unusually small throughout the rest of the quarter.

TILTING OF THE GROUND

Except for a sharp northeast tilt accompanying the unusually heavy rain of April 6 to 8, the southwest tilt that commenced in March continued until May 8. The westerly tilt, however, continued a month longer. The seasonal southwest tilt that started on June 8 continued into July.

CRACK MEASUREMENTS

In April several of the cracks around Halemaumau showed a distinct opening and none showed a closing. One crack along the Chain of Craters road opened slightly. One crack near the southwest rim of Halemaumau opened 16 mm. in May. Most of the other rim cracks also opened considerably. Only slight movement of the cracks around Halemaumau was detected in June.

R.H.F.

Table of Tilt at Observatory on Northeast Rim of Kilauea

Week Ended	Amount	Direction
April 1	1.76″	S 73° W
8	4.96″	N 60° E
15	4.13″	S 14° E
22	0.88″	S 74° W
29	1.57″	W
May 6	0.53″	S 45° W
13	1.96″	S 68° W
20	1.57″	N 58° E
27	0.77″	N 18° E
June 3	2.17″	S 68° W
10	1.21″	N 24° E
17	0.48″	N
24	1.10″	N 40° E

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The **University of Hawaii** cooperates in maintaining a research laboratory at Hawaii National Park. The **Association** and the **University** supplement the work of the government with research associates, instrumental plants and special investigation. Dr. T. A. Jaggar is their geophysicist resident in the National Park.

The **Volcano Letter**, a quarterly record of Hawaiian volcano laboratories and published by the University of Hawaii, is issued by authority of the Department of the Interior and supplied to a restricted membership and exchange list of the above establishments.

THE VOLCANO LETTER

489

No. 489 **Department of Interior** **National Park Service** **July-September 1945**

PUBLISHED BY THE UNIVERSITY OF HAWAII

HAWAII NATIONAL PARK: Edward G. Wingate, Superintendent; R. H. Finch, Volcanologist

UNIVERSITY OF HAWAII: T. A. Jaggar, Geophysicist

SUMMIT AND NORTHEAST RIFT ZONE OF MAUNA LOA

By GORDON A. MACDONALD

Associate Geologist, U. S. Geological Survey

The summit and northeast rift zone of Mauna Loa were mapped by the writer in the summer of 1942 as a part of the study of the geology and ground-water resources of the island of Hawaii made by the U. S. Geological Survey in cooperation with the Territory of Hawaii. The mapping of the vents and identifiable historic lava flows is shown in the accompanying figures. It is a pleasure to acknowledge the aid of Harvey Finch during field work in the summit area of Mauna Loa. The National Park Service permitted the use of rest houses on the mountain, and extended many other courtesies. James Y. Nitta prepared figure 2.

The topographic base used in the accompanying figures was prepared several years ago by the topographic branch of the Geological Survey. Boundaries of the historic lava flows to and including the 1926 flow which were shown on earlier topographic maps were re-examined. The delineation by E. G. Wingate and his associates of the 1926 and 1851 lava flows on the upper southwestern slopes of the mountain was found to be excellent, and the boundaries of these flows on the accompanying maps are taken from the topographic map. The flow of 1880 on the southern side of the northeast rift zone also is taken from the topographic map. But the boundaries of the flows of 1880-81 and of 1899 on the north side of the rift zone required extensive revision. In general, the area of these flows as indicated on the topographic map includes only the pahoehoe phase of the flow, the aa phase having been ignored.

Remapping of the flows of 1880-81 and 1899, and original mapping of the lavas of 1935, 1940, and 1942, was done partly on the ground and partly with the aid of aerial photographs. The source of one of the 1935 flows (A, fig. 2) was mapped on the ground by H. T. Stearns and checked with aerial photographs. The area of 1933 lava in Mokuaweoweo was shown on a map by F. M. Bullard and P. H. Baldwin,[1] and the outline of the 1940 lava in Mokuaweoweo is taken from the map by P. E. Schulz,[2] after checking in the field. There follow a few brief notes on volcanic features along the northeast rift zone and in the summit area.

A cone northeast of Puu Ulaula (C, fig. 2) gave vent to lavas rich in large crystals of olivine. It may be the source of similar lavas exposed along the trail below Puu Ulaula. The top of this cone has partly collapsed inward, possibly owing to failure of support on withdrawal of the fluid lava at the end of the eruption.

The cone with a summit altitude of 9,617 feet, and 1.4 miles N. 24° E. of Puu Ulaula (D, fig. 2), may be a source of the lava flow of 1880-81, as suggested by Jaggar.[3] The adjacent cones lie east of the flow boundary, however, and are older than the 1880 lava.

The 1899 flow issued at Pukauahi[4] and also along a fissure a mile farther west-southwest. A small tongue of lava flowed southeastward for about a mile, parallel to the Kau branch of the 1880 flow. The southeastward-flowing branch was mentioned in contemporary accounts. The northeastern branch of the 1899 flow is considerably more extensive than is shown on previous maps.

The lava flow of 1855, which lies to the north of the area shown in figure 2, cannot be traced upslope beyond the point where it is overlapped by a branch of the 1880 flow. Undoubtedly it is largely buried by the flows of 1880 and 1899, and parts of it which are not buried are indistinguishable by ordinary field methods from the many late prehistoric flows. The place of eruption is variously stated as 12,000 feet altitude, and 5 miles from Mokuaweoweo.[5] Judging from these locality descriptions and the position of the known portion of

[1] Volcano Letter 466, p. 1, 1939.

[2] SCHULZ, P. E. SOME CHARACTERISTICS OF THE SUMMIT ERUPTION OF MAUNA LOA, HAWAII, IN 1940. Geol. Soc. Amer. Bul., Vol. 54, pp. 739-746, 1943.

[3] Volcano Letter 466, p. 3, 1939.

[4] *Op. cit.*

[5] HITCHCOCK, C. H. HAWAII AND ITS VOLCANOES. Pp. 94-95, 1911.

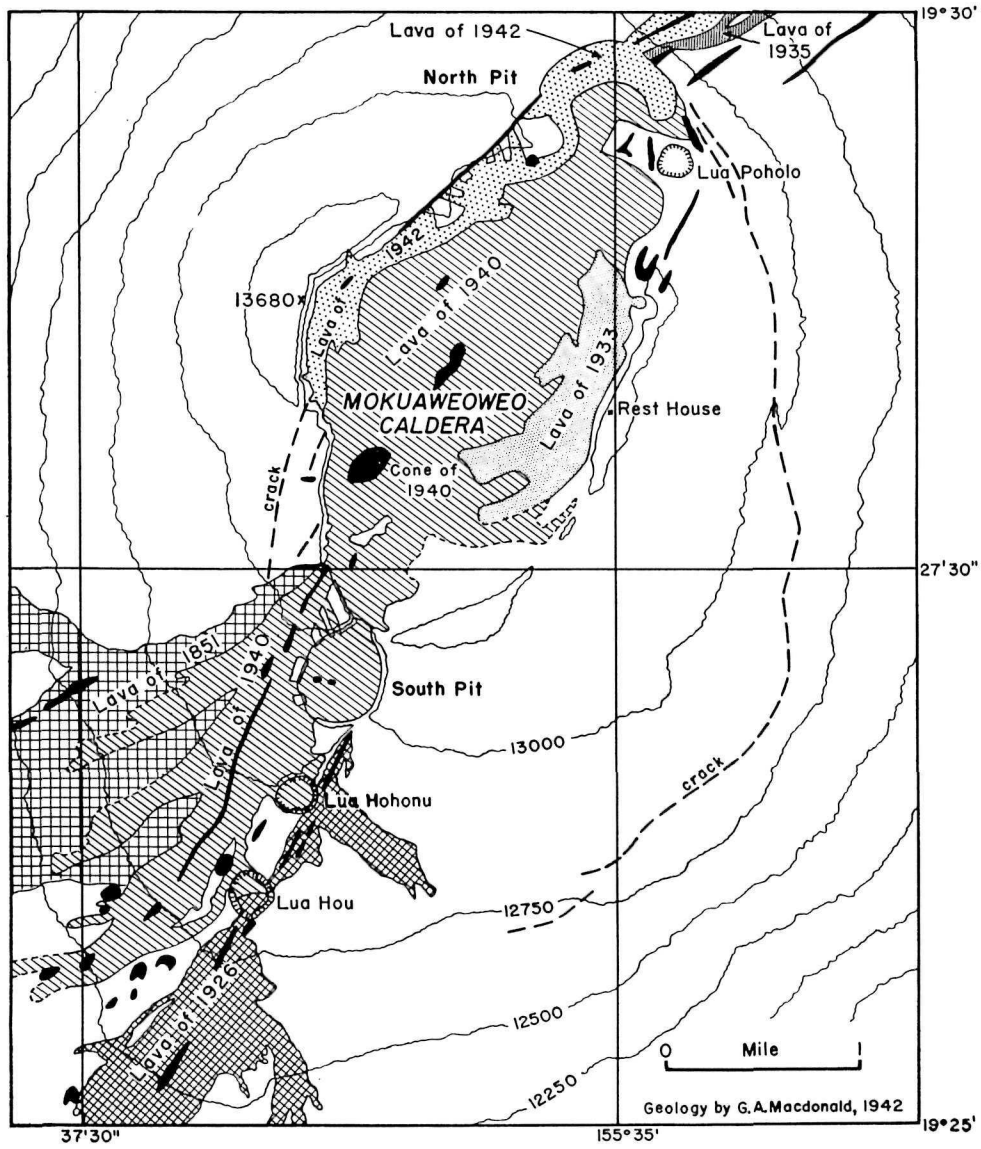

Figure 1.—Map of the summit of Mauna Loa, showing the location of vents and the areas covered by identifiable historic lava flows. Cinder and spatter cones are shown in solid black.

the flow, it probably was near Pukauahi. One possible source is a cone of unknown date west of Pukauahi (E, fig. 2). Another is a cone just south of the trail at 11,750 feet (F, fig. 2), from which the channel of a lava river leads eastward to the vicinity of Pukauahi. Hot rock is still present at some unknown but probably shallow depth beneath this cone which frequently gives off visible steam clouds when weather conditions are favorable.

Besides the generally recognized vents at higher altitude, during the 1935 eruption a small amount of lava issued from a fissure slightly offset from the alignment of the main fissure along the edge of the flow at 11,550 feet altitude (G, fig. 2). During the eruption of 1942 the principal eruptive fissure crossed North Pit and extended along the western wall of Mokuaweoweo (figure 1), sending cascades of lava into the caldera. The fissure in North Pit was largely buried by the lava flow, but one small cone of spatter and cinder is still visible there. At several places just east of the rim of North Pit, lava issued from concentric fissures as well as from the normal radial fissures of the rift zone.

It would undoubtedly prove worthwhile to continue the mapping of the rift zone of Mauna Loa after each eruption.

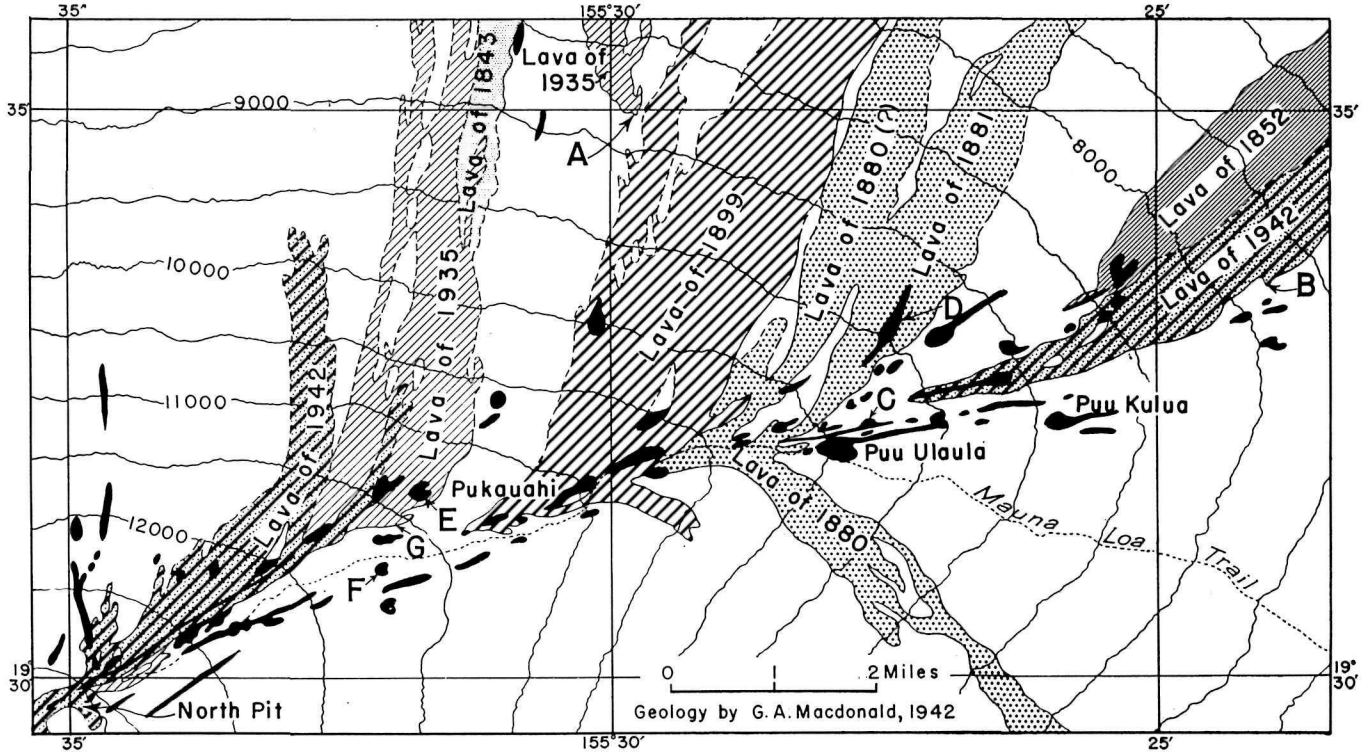

Figure 2.—Map of the upper part of the northeast rift zone of Mauna Loa, showing the location of vents and the areas covered by identifiable historic lava flows. Cinder and spatter cones are shown in solid black.

A NEW BOOK ON PACIFIC VOLCANOES

Volcanoes Declare War: logistics and strategy of Pacific volcano science. By Thomas Augustus Jaggar. 166 pp. Quarto 8 x 11 inches. Copyright 1945. 32 halftone plates, 34 text figures, 5 color plates, 2 cartoons. Paradise of the Pacific, Ltd., Honolulu, T. H. $3.75.

This handsome volume, with colored picture of Paricutin in eruption on the jacket, contains 173 separate reproductions of photographs and drawings, and a text intended for popular reading. The plates have full descriptive titles and are together in the middle of the volume. There is a glossary of technical terms and a list of references.

The table of contents covers Hawaiian volcanoes, south sea outbreaks, East Indian explosions, western Pacific rim, the Aleutian islands, Canada and the Cascade mountains, Mexico, Central America, the Caribbee eruptions, and Chile. This is followed by a review of volcano science, accenting insurance and protection, and specifically giving the author's conclusions based on studies from Pelée in 1902 to Mauna Loa in 1942.

Here are descriptions, engineering experiments, statistics, journals of expeditions, theories, adventures and surveys, insurance, and economic use of power. The author reserves his experiments with earthquakes for a later volume. He insists on the need for core drilling to rock under the oceans.

Hawaiian Volcano Observatory Report for July-September 1945

VOLCANOLOGY

July

Small fume columns were visible from the Observatory in afternoon sunlight over Mokuaweoweo on July 31. About the usual fuming was observed from the rim of Mokuaweoweo from July 23 to 29.

Tilt to the north was slightly greater than normal.

A total of 27 shakes was recorded at Kilauea and 42 at Mauna Loa.

August

Fuming in amounts greater than usual was observed over Mokuaweoweo on several afternoons. Conspicuous north tilt continued during August. This tilt indicates a pressure build-up under Kilauea. There was a conspicuous widening of some of the cracks near the southwest rim of Halemaumau.

Seismicity was low in August with 32 earthquakes recorded at Mauna Loa and only 15 at Kilauea.

September

Landslides from the southwest rim of Halemaumau became unusually conspicuous on September 17 and continued for a week with diminishing frequency. Apparently the largest slide of the series occurred at 16:59 September 17 when a section of the rim about 80 feet long and 6 or 8 feet wide went in. It caused an earthquake sufficiently large to make a conspicuous record on the Observatory seismographs.

Rapid north tilt continued during the first week in September, thereafter the northerly tilt was less than normal.

A total of 25 earthquakes was recorded at Kilauea and 30 at Mauna Loa.

R.H.F.

SEISMOLOGY

Earthquake Data, July-September 1945

Week Ended		Minutes of Tremor	Very Feeble	Feeble	Slight	Moderate	Local Seismicity*	Teleseisms
July	1	3	2	3	0	0	4.75	2
	8	2	4	0	0	0	2.50	0
	15	3	1	0	0	1	4.25	1
	22	4	1	0	0	0	1.50	0
	29	5	3	0	0	0	2.75	0
August	5	1	1	1	0	0	1.75	0
	12	1	0	0	1	0	2.25	0
	19	3	1	0	0	0	1.25	0
	26	2	0	0	0	0	0.50	0
September	2	4	1	1	0	0	2.50	2
	9	3	2	1	0	0	2.75	0
	16	4	0	0	0	0	1.00	0
	23	5	1	2	1	0	5.75	0
	30	1	5	0	0	0	2.75	1

* For definition of local seismicity, see Volcano Letter No. 371.

The data of the following local disturbances were determined from seismograph stations operated on the island of Hawaii by the Hawaiian Volcano Observatory of the Hawaii National Park. Time is Hawaiian Standard, 10 hours and 30 minutes slower than Greenwich. The number preceding each earthquake is the serial number of the quake for the current year.

67. July 1, 07:46, very feeble.
68. July 3, 20:06, very feeble.
69. July 4, 18:08, very feeble. Northeast rift of Mauna Loa.
70. July 6, 06:54, very feeble.
71. July 6, 13:46, very feeble.
72. July 13, 02:15, moderate. East-west dismantled. Four to six miles deep along Puna coast southwest of Kalapana. Widely felt in eastern half of island of Hawaii.
73. July 14, 02:54, very feeble.
74. July 16, 04:15, very feeble.
75. July 25, 03:46, very feeble.
76. July 25, 07:03, very feeble.
77. July 28, 10:50, very feeble.
78. July 30, 05:14, feeble. Kilauea shake. Felt locally.
79. August 2, 07:51, very feeble.
80. August 9, 10:46, slight. Generally felt in southwest part of island. East slope of Mauna Loa above Kapapala.
81. August 15, 15:26, very feeble.
82. August 27, 03:31, feeble.
83. August 30, 06:54, very feeble.
84. September 5, 09:18, feeble. Northeast rift of Mauna Loa north of Red Hill. Felt locally and in Hilo.
85. September 7, 18:51, very feeble.
86. September 8, 15:26, very feeble.
87. September 17, 16:59, feeble. Landslide at Halemaumau at this time.
88. September 19, 05:33, slight. Widely felt over entire island. Between Mauna Loa and Mauna Kea.
89. September 21, 04:47, very feeble. Kilauea origin. Not felt, but rumble heard.
90. September 23, 15:39, feeble. Northeast rift of Mauna Loa.
91. September 29, 21:45, very feeble.
92. September 29, 21:52, very feeble.
93. September 30, 02:05, very feeble.
94. September 30, 18:18, very feeble.
95. September 30, 21:49, very feeble. North end of Kilauea Crater.

TELESEISMS

July 1, 22:24, slight.
July 14, 19:14, slight. In the Marianas.
August 28, 23:52, slight. 5400 km. New Hebrides.
September 1, 13:09, slight.
September 28, 12:08, slight.

MICROSEISMS

Microseisms were moderate from July 12 to 16 inclusive and very small throughout the rest of the quarter.

TILTING OF THE GROUND

Northerly tilt was continuous throughout the quarter though less than usual during the last three weeks of September. There was a slight westerly tilt in July. The east tilt in August and September was less than normal. There was a sharp west tilt on September 19 with a recovery to the east on September 20.

CRACK MEASUREMENTS

The only measured cracks that showed any appreciable opening in July were along the southwest rim of Halemaumau. The movement of the southwest rim cracks continued in July with one crack opening 27 mm. In September there were numerous landslides from the southwest rim. One measuring station was carried away and another made inaccessible.

R.H.F.

Table of Tilt at Observatory on Northeast Rim of Kilauea

Week Ended		Amount	Direction
July	1	0.77″	N 19° E
	8	0.99″	N 76° W
	15	0.63″	N 12° E
	22	1.08″	N 27° E
	29	0.60″	N 37° W
August	5	1.03″	N 70° E
	12	0.62″	N 12° W
	19	0.60″	N 36° E
	26	1.58″	N 23° E
September	2	0.51″	N 14° W
	9	1.56″	N 75° E
	16	0.43″	N 34° W
	23	0.43″	N 34° E
	30	0.51″	N 76° E

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THE VOLCANO LETTER 490

No. 490 | Department of Interior | National Park Service | October-December 1945

PUBLISHED BY THE UNIVERSITY OF HAWAII

HAWAII NATIONAL PARK: Edward G. Wingate, Superintendent; R. H. Finch, Volcanologist

UNIVERSITY OF HAWAII: T. A. Jaggar, Geophysicist

ON THE DEPTH OF FOCI OF EARTHQUAKES ON THE ISLAND OF HAWAII

By R. H. FINCH

The depth of foci of island of Hawaii earthquakes ranges from near the surface—sometimes distinctly less than one mile—to 25 to 30 miles. Shakes originating near the surface under the summit of Mauna Loa may actually have foci higher than most of the seismographs on the island.

The most active rift on Mauna Loa is aligned NE–SW with a distinct bend where Mokuaweoweo is crossed. Eighteen miles of the surface length of this rift is above 10,000 feet. The most active rift system at Kilauea is roughly parallel to that of Mauna Loa. Since shallow-focus earthquakes along both Mauna Loa and Kilauea rifts may have foci above sea level, the paths of the waves of nearby shakes with such depths may lie wholly in dry rock. With greater distances or greater depths the earthquake waves would traverse layers of rock saturated with ground water. As the velocity of earthquake waves is less in saturated than in dry rock, one could easily be misled into assuming a discontinuity at the ground-water level.

Hawaiian earthquakes originate in three principal types of fault systems: (1) the fundamental rift which determines the location of the Hawaiian islands; (2) comparatively superficial faults within the volcanic structures that have been built up from the ocean floor 15,000 feet below sea level; and (3) within volcanic conduits. The minimum depth of focus that is possible in the first group is, then, about 3 miles below sea level or within the original surface of the ocean floor. Usually, of course, the depth is much greater than the 3-mile lower limit. The range in depth of Group 2 is from the surface to about 5½ miles below the summit of Mauna Loa—this is nearly 14,000 feet above sea level to about 15,000 feet below sea level. If, as would appear to be the case, the NE–SW trending rifts of Mauna Loa and Kilauea represent structural weakness within the volcanic edifices, then they must of necessity terminate at or above the ocean floor. The depth of focus of Group 3 may vary from near the surface to many miles or approximately as deep as those of Group 1. Movement in Group 3 may be produced by rising or falling of the lava column or by temperature changes induced thereby. Activity in any one group may induce activity in any other group though the effect of Group 2 shakes in this respect is probably quite small.

There are some indications that there are at least two branches of the fundamental rift under the island of Hawaii—one under Kohala and Mauna Kea and the other in the vicinity of Hualalai, Mauna Loa, and Kilauea. There is not much evidence that Mauna Kea and Kilauea are located on the same rift. It might be expected that the radius of curvature of the Hawaiian arc would become shorter as the two ends are approached but not enough to put these two volcanoes on the same rift. The distribution of the foci of deeper earthquakes strengthens the idea of the two branches of the fundamental rift.

It would not be surprising to find cases where movement along the fundamental rift was contemporaneous with movement along a superficial rift and with a volcanic eruption. In 1868 there appear to have been concomitant movements along the fundamental rift under Mauna Loa and along the southwest rift of that mountain. Wood[1] has shown that the largest shake of the

[1] WOOD, HARRY A. ON THE EARTHQUAKES OF 1868 IN HAWAII. Bul. Seis. Soc. Amer. Vol. 4, No. 4, Dec. 1914.

series should be classed as of tectonic origin. The tectonic quake or quakes with some aftershocks occurred at a time when the southwest rift was working and a maze of earthquakes resulted. The strongest shake was felt on Kauai or at a distance of about 320 miles. Subsequent studies of other quakes originating in the same general area would lead one to believe that the depth of focus of the 1868 earthquake was over 30 miles.

The present writer is of the opinion that the 1868 shake had its origin along the fundamental rift under the east slope of Mauna Loa or 15 to 20 miles northeast of the then active portion of the southwest rift of Mauna Loa. The opinion is based on later determinations of many foci with depths of 20 to 30 miles in the same general area. Jones[2] shows a grouping of such earthquakes under the east slope of Mauna Loa. Other shakes with similar depths of focus are still being located in this area.

On December 27, 1944, an earthquake strong enough to dismantle all the seismographs on the island of Hawaii occurred about 20 miles below the surface of the eastern slope of Mauna Loa. The epicenter appears to have been a little to the northeast of most of the comparatively deep focus shakes that Jones located in this area. At least 10 or 12 aftershocks accompanied the December 1944 shake. The order of magnitude of the depth of focus is attested by the fact that the shake, while doing but little damage locally, was felt on Oahu and toppled objects from shelves at places as widespread as Naalehu and Pepeekeo on Hawaii.

An earthquake of the same type, which occurred on May 19, 1945, is of special interest in that despite the fact that it dismantled only one component of the Bosch-Omori seismograph, which is some 12 miles from the epicenter, it was felt on Oahu, nearly 200 miles away. The disturbance was just strong enough to awaken light sleepers on the island of Hawaii and but little less intense on Oahu. While both components of the Mauna Loa seismograph, which is about 3 miles nearer the epicenter than the Bosch-Omori, were dismantled, horizontal motion in the epicenter area was but little more than at points 50 or more miles away. There were five or six aftershocks. The epicenter was located to the southeast of the shake of December 27 or a little lower down the east slope of Mauna Loa. General considerations indicate that the depth may have been greater than the indicated 20 miles. Owing to uncertainties in interpretation of seismograms and in travel times, our locations of earthquake foci are at best but approximations.

[2] JONES, A. E. EMPIRICAL STUDIES OF SEISMIC PHENOMENA OF HAWAII. Bul. Seis. Soc. Amer. Vol. 28, No. 4, p. 326, Oct. 1938.

Hawaiian Volcano Observatory Report for October-December 1945

VOLCANOLOGY

October

Fume columns were observed over Mokuaweoweo on several afternoons during the month. On October 21 observations were made simultaneously at the Observatory and at the rim of Mokuaweoweo. The fuming as observed from the rim was distinctly more than usual.

As in September, northerly tilt was less than usual for this season of the year. Easterly tilt was about normal.

A total of 55 seismic disturbances was recorded at Mauna Loa and 48 at Kilauea.

November

Spells of conspicuous fuming were observed over Mokuaweoweo several times during the month. On November 18 the fume was visible from the Observatory even in morning light until about 8 a.m. Very distinct fume columns were observed from the east rim of Mokuaweoweo several times during the afternoon and evening of November 29.

There was a continued lack of northerly tilt which for this season of the year is equivalent to a slight southerly tilt. Easterly tilt was about normal.

Seismicity was again low with 19 seismic disturbances recorded at Kilauea and 30 at Mauna Loa.

December

Yellow fume was observed over Mokuaweoweo during the late afternoons of December 25 and 26. Some steaming was observed on other days.

Landslides at Halemaumau were frequent during the middle of the month and on the last 3 days. The majority originated at the NW rim.

A total of 31 seismic disturbances was recorded at Kilauea and 37 at Mauna Loa.

There was an accumulation of WSW tilt during the month. Despite the falling off of N tilt in September and the unusually early change to S tilt in November there was an accumulation of 3.6″ of northerly tilt during the year. This may be taken as an indication of a slight pressure build up under Kilauea. The accumulation of E tilt during the year amounted to over 6″. If, as seems to be the case, there is a correlation between E–W tilt and Mauna Loa activity, then there was a pressure build up under Mauna Loa in 1945.

R.H.F.

SEISMOLOGY

Earthquake Data, October-November 1945

Week Ended		Minutes of Tremor	Very Feeble	Feeble	Slight	Local Seismicity*	Teleseisms
October	7	2	1	0	0	1.00	0
	14	19	5	0	0	7.25	0
	21	3	3	0	0	2.25	0
	28	4	2	0	0	2.00	0
November	4	7	3	1	0	4.25	1
	11	1	1	0	0	0.75	0
	18	3	2	0	0	1.75	0
	25	2	1	0	0	1.00	0
December	2	4	3	2	0	4.50	1
	9	2	3	0	0	2.00	0
	16	3	4	0	1	4.75	0
	23	3	4	0	0	2.75	0
	30	0	3	3	1	6.50	1

* For definition of local seismicity, see Volcano Letter No. 371.

The data of the following local disturbances were determined from seismograph stations operated on the island of Hawaii by the Hawaiian Volcano Observatory of the Hawaii National Park. Time is Hawaiian Standard, 10 hours and 30 minutes slower than Greenwich. The number preceding each earthquake is the serial number of the quake for the current year.

96. October 4, 11 : 43, very feeble.

97. October 8, 13 : 04, very feeble.

98. October 8, 19 : 38, very feeble.

99. October 9, 00 : 59, very feeble.

100. October 10, 22 : 53, very feeble.

101. October 12, 15 : 15, very feeble.

102. October 15, 05 : 45, very feeble.

103. October 16, 19 : 59, very feeble.

104. October 21, 17 : 35, very feeble. In ocean north of Mauna Kea.

105. October 25, 04 : 34, very feeble.

106. October 26, 04 : 46, very feeble.

107. October 29, 02 : 23, very feeble.

108. October 29, 21 : 18, very feeble.

109. October 29, 22 : 40, very feeble.

110. October 30, 04 : 05, feeble. Felt locally. Near Hilina Pali.

111. November 5, 18 : 59, very feeble.

112. November 17, 18 : 02, very feeble.

113. November 18, 08 : 27, very feeble. Northeast rift Mauna Loa.

114. November 24, 09 : 21, very feeble. Northeast rift Mauna Loa.

115. November 27, 18 : 25, feeble. Felt in Kau and South Kona. Southwest of Pahala.

116. November 29, 08 : 12, very feeble.

117. November 30, 09 : 25, very feeble.

118. December 1, 20 : 25, feeble. Felt at Pahala.

119. December 2, 18 : 08, very feeble.

120. December 5, 22 : 28, very feeble. Felt at Pahala.

121. December 6, 18 : 21, very feeble.

122. December 6, 20 : 27, very feeble.

123. December 11, 07 : 03, very feeble. Northeast rift Mauna Loa.

124. December 15, 00 : 03, very feeble.

125. December 15, 04 : 33, very feeble.

126. December 16, 20 : 30, slight. East-west dismantled. Felt locally and at Pahala and Hilo. East flank of Mauna Loa.

127. December 16, 23 : 12, very feeble.

128. December 19, 07 : 05, very feeble.

129. December 20, 11 : 21, very feeble.

130. December 22, 05 : 32, very feeble.

131. December 23, 03 : 07, very feeble.

132. December 24, 00 : 51, slight. East-west dismantled. Felt locally. Kilauea shake.

133. December 24, 05 : 15, feeble.

134. December 26, 01 : 02, feeble. Kilauea shake.

135. December 26, 04 : 00, very feeble.

136. December 26, 08 : 05, feeble.

137. December 29, 12 : 44, very feeble.

138. December 30, 08 : 02, very feeble.

TELESEISMS

October 29, 00 : 40, slight. Off British Columbia.

November 27, 11 : 50, moderate. Arabian Sea.

December 27, 07 : 14, moderate. Distance 4,000 miles.

MICROSEISMS

Microseisms were conspicuous from October 25 to 29, on November 12, from December 2 to 5, and on December 28. During the rest of the quarter they were very small.

CRACK MEASUREMENTS

A few of the cracks near the Halemaumau rim and along the Chain of Craters Road opened slightly, though a majority that were measured showed no movement. Landslides were frequent from the northwest rim of Halemaumau during the middle and on the last three days of December.

TILTING OF THE GROUND

There was a slight northerly tilt from October 1 to November 9 though less than normal for this season of the year. From November 9 to the end of the year there was a slight southerly tilt. The change to southerly tilt came over a month earlier than usual. The seasonal change to westerly tilt occurred on December 20 or about the usual time. There was a slight accumulation of easterly tilt during the quarter.

R.H.F.

Table of Tilt at Observatory on Northeast Rim of Kilauea

Week Ended		Amount	Direction
October	7	0.86″	N 82° E
	14	0.81″	N 63° W
	21	0.62″	N 11° E
	28	0.44″	N 56° E
November	4	3.87″	N 86° E
	11	0.70″	N 31° E
	18	1.21″	S 23° W
	25	0.02″	N 45° E
December	2	0.76″	N 72° E
	9	0.36″	S
	16	1.15″	N 32° E
	23	1.33″	S 5° E
	30	3.27″	S 73° W

HAWAIIAN VOLCANO RESEARCH ASSOCIATION

in cooperation with UNIVERSITY OF HAWAII

The **Hawaiian Volcano Research Association** was founded in 1911 for record of volcanoes in the Hawaiian Islands and around the Pacific Ocean. Its equipment at Kilauea Volcano, Hawaii Island, has been transferred to the United States Government, Department of the Interior, National Park Service.

The **University of Hawaii** cooperates in maintaining a research laboratory at Hawaii National Park. The **Association** and the **University** supplement the work of the government with research associates, instrumental plants and special investigation. Dr. T. A. Jaggar is their geophysicist resident in the National Park.

The **Volcano Letter,** a quarterly record of Hawaiian volcano laboratories and published by the University of Hawaii, is issued by authority of the Department of the Interior and supplied to a restricted membership and exchange list of the above establishments.

THE VOLCANO LETTER

491

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UNIVERSITY OF HAWAII: T. A. Jaggar, Geophysicist

THE TIDAL WAVE OF APRIL 1, 1946

By H. A. POWERS

Geologist, Hawaii National Park

Figure 1.—The waterfront, city of Hilo, April 1, 1946. Two thirds of the railroad bridge spanning the Wailuku River can be seen in the right background. One span was lifted from the piers and carried upstream. The railroad station occupied the barren area on the near bank of the river. The station and the tracks which circled the bay have completely disappeared. All the waterfront buildings between the railroad station and the park (marked by the trees in the center) floated into the street and collapsed. With the exception of the reinforced concrete warehouse, all of the waterfront buildings which occupied the foreground were completely demolished and scattered inland and out to sea. HONOLULU STAR-BULLETIN Photo

The Hawaiian Islands suffered their greatest natural disaster of modern times from a tidal wave which reached the islands from the north Pacific early on the morning of April 1, 1946. Over 200 persons are known to have lost their lives or to be missing. The greatest number of casualties is from the island of Hawaii, particularly from the city of Hilo. Property damage was suffered on all the islands and will total many million dollars in loss of homes and personal property. The greatest industrial losses were concentrated in the area around Hilo Bay.

The earthquake which caused the tidal waves apparently had its epicenter in the vicinity of the Aleutian Trough, a region of great ocean depth south of and paralleling roughly the Aleutian Island chain. The earthquake was recorded on all of the horizontal component instruments operated by the Volcano Observatory of the Hawaii National Park. On the Bosch-Omori instrument at the Observatory, the first impulse of the preliminary wave was recorded at approximately 02 06 20 Hawaiian Standard Time, the exact emergence being somewhat obscured by very strong microseismic motion caused by the heavy trade-wind surf which had prevailed for a number of days. The arrival of the secondary wave was recorded approximately at 02 11 10, and of a long wave at 02 14 05, indicating a probable distance from the origin of at least 2,100 miles. Reports from other seismographs indicate that 2,300 miles is more nearly correct. The earthquake was of sufficient intensity to cause continuous disturbance of the seismographs on Hawaii for two hours, though this long duration of disturbance may be due partly to a second quake which appears to be recorded in the coda of the major quake. Seven distinct aftershocks were recorded here. Most of them were registered by impulses lasting less than a minute, but a larger one at 08 44 disturbed the seismograph for about ten minutes. A disturbance of several minutes' duration starting at 06 46 probably is the record of the primary earthquake waves which traveled around the longer arc of the earth.

It is reported that the tide gage in Honolulu Harbor showed the following record of the disturbance:

06 30 Beginning of 7½-inch rise
06 36 Crest of first wave
06 42 Trough of second wave, a drop of 26¼ inches
06 48 Crest of second wave, a rise of about 33¾ inches
06 54 Trough of third wave, a drop of 40½ inches
07 00 Crest of third wave, a rise of about 4 feet

The Hilo tide gage was destroyed. Eyewitness reports indicate that the first wave occurred at Hilo a few minutes after 07 00 and electric clocks in the first damaged area were stopped at 07 06. The Observatory seismogram shows a short electric power stoppage on the suburban line at 07 18 21. Eyewitness testimony indicates that the second wave at Hilo did damage, so it is possible that this short power interruption marks the time of the crest of the second wave in Hilo Harbor at 07 18.

If these time interpretations are correct, the time-lag between arrival of the wave at the two island harbors is exactly 30 minutes. The time of the actual earthquake, taken from seismologic tables, must have been approximately 02 00 Hawaiian time. Thus the fastest wave reached Honolulu in 4 hours and 30 minutes, and Hilo in 5 hours.

The average velocity of the water wave through the open ocean approached 460 miles an hour, but slowed down in the shallow water near the islands to 300 miles an hour. The greatest speed of a wave recorded at the Volcano Observatory was that of a wave on November 10, 1938 which traveled from the Aleutian Islands at an average of 497 miles an hour.

Measurable water waves caused by submarine earthquakes in the Pacific reach Hawaiian shores perhaps as often as once a year. However, most of them cause a water rise of only a few inches and so are not noticed. Since 1800, the wave of April 1, 1946 is the seventh from a distant source to cause damage in the Hawaiian Islands. It was by far the most destructive of the seven. Though the waves of 1837 and 1877 were of greater magnitude, there was less life and property within reach of the waves in this earlier period.

The outstanding tidal waves reaching Hawaii in the nine-

Figure 2.—Wreckage of a private home and garage in the Keaukaha residential area east of Hilo.
Photo by George Duncan

Figure 3.—Wreckage of stores in the street between the railroad station and the park (trees in left background).

Photo by Gunnar O. Fagerlund

teenth century have been described by a number of writers, and were summarized by T. A. Jaggar in THE VOLCANO LETTER, No. 321, February 19, 1931.

The earliest noted was in May 1819, but no information remains as to the possible source, or the damage done.

Three severe waves were caused by earthquakes off the coast of South America. The first, November 7, 1837, affected all the islands of the Hawaiian group. An unrecorded number of lives were lost, and a number of houses were destroyed. On August 13, 1868 a wave from near Peru reached a height of 15 feet above low water at Hilo and 12 feet deep on windward Maui. The damage caused by another from Chile on May 10, 1877 included loss of five lives at Hilo and the destruction of many dwellings. Water reached into the second business block from the waterfront along Waianuenue Street, which parallels the Wailuku River.

One tidal wave was described from an earthquake off Kamchatka on May 17, 1841, but no damage is described.

The terrific Hawaiian earthquake of April 2, 1868 caused a severe local tidal wave along the south coast of the island of Hawaii, but was not so damaging in other localities. Forty-six persons lost their lives and 108 dwellings in Puna and Kau were destroyed in addition to much other damage. Water in Hilo rose 10 feet. A smaller tidal wave, apparently of local origin, did no great amount of damage on August 27, 1872.

The source of Hawaii's damaging tidal waves of this century has shifted to the north Pacific. The first, on September 7, 1918, came from Kamchatka and caused relatively small damage. One person lost his life and extensive property damage was caused at Hilo and at Kahului, Maui, on February 3, 1923 by a wave from Kamchatka. At Hilo the funneling effect of the bay forced the third and the highest wave up to nearly 20 feet above mean low sea level in the small boat harbor at the mouth of the Wailoa River. A quake off the coast of Japan started a wave on March 2, 1933 which caused some damage along the Kona coast of Hawaii.

Table 1, compiled from seismograms at the Volcano Observatory, summarizes the date, origin, and velocity of tidal waves recorded in Hawaii during the nineteenth century. Since installation of the tide gage at Hilo in 1927, it has been possible to determine travel time of waves with more accuracy.

With the present tremendous increase of American interests in the islands of the Pacific and in Alaska, it is possible that a workable system of tidal wave warning may be placed in oper-

Table 1.—Origin and Rate of Travel of Nineteenth-Century Tidal Waves Determined from Seismograms at the Hawaiian Volcano Observatory

Date	Origin	Distance	Travel Time	Average Speed
		Statute miles		*Miles per minute*
1918, Sept. 7	Kamchatka	3,200 (approx.)	7 hrs. (nearly)	7.6
1922, Nov. 11	Chile	4,900 (approx.)	11 hrs. (nearly)	7.5
*1923, Feb. 3	Kamchatka	3,000	7 hrs. (nearly)	7.2
1923, Apr. 13	Kamchatka	3,200	7¼ hrs.	7.3
1927, Nov. 4	California	2,400	5 hrs. 10 min.	7.7
1927, Dec. 28	Kamchatka	3,310	7 hrs. 35 min.	7.3
1928, June 16	Mexico	3,915	8 hrs. 30 min.	7.7
1929, Mar. 6	Aleutian Islands	2,270	4 hrs. 35 min.	8.2
1931, Oct. 2	Solomon Islands	3,680	8 hrs. 20 min.	7.45
*1933, Mar. 2	Japan	3,950	8 hrs. 25 min.	7.95
1938, Nov. 10	Alaska	2,485	5 hrs.	8.27
*1946, Apr. 1	Aleutian Islands	2,300	5 hrs.	7.7

* Except for waves indicated by an asterisk all listed were of very small size and did no material damage. However, they were originated by earthquakes of considerable magnitude which caused damaging waves near their origin. In fact, the earthquakes of 1929 and 1938 were both recorded on the seismograph as stronger than the recent one of April 1, 1946.

ation. This can be done with proper coordination of existing facilities and service organizations at very nominal expense. A workable plan must include the following important phases:

1. Immediate detection and location of submarine earthquakes in the Pacific area by a network of seismographs.
2. Computation of possible time of arrival of ensuing tidal wave at all American island or coastal installations, and immediate notification of the installations closest to the source of the wave.
3. Observation by outposts nearest to the source of the wave as to arrival time and size of the wave, and sending of immediate reports from these outposts to Central Control.
4. Report from Central Control to all vulnerable outposts and installations based on information obtained from first outpost reports.

Seismographs which would serve to greatest advantage in a system of tidal-wave warning should have two features which are not essential to the instrument in use at present: (1) the instrument must sound an alarm to notify the attendant personnel that a teleseism is being recorded, and (2) the recording method should be such that the record can be removed and prepared for study within a very few minutes.

A net of four such instruments located, perhaps, one at Honolulu and three on the North American mainland would make possible a rapid preliminary determination of the epicenter of any Pacific earthquake. Observers at these stations would make immediate studies of a quake which might be located in a critical area and would be given priority use of long distance telephone facilities to report their data to one of the four stations designated as the Central Control. This control would quickly make the best possible determination of the location of an earthquake, and *if* a tidal wave were indicated as probable, would quickly compute the possible time of arrival of a wave at vulnerable points in and around the Pacific.

Tide observation stations, to be most useful in a system of tidal-wave warning, should satisfy the following conditions: (1) be operated by an installation which can or does maintain 24-hour watch on a two-way communication system, (2) be equipped with recording tide gages which can be read easily at any time, (3) be geographically located in all possible vulnerable places in the Pacific which can satisfy the first condition.

At present, the United States Naval installations, connected by the excellent Navy Communications net, probably offer the best organization and facilities to handle the system of observation stations.

Each of the tidal observation stations would be alerted by a priority message from the previously mentioned Central Control warning of the possibility and direction of a tidal wave and the computed arrival time. The outposts first in the path of the possible wave would be notified first.

Each outpost would make negative or positive statistical reports to the Central Control immediately as it obtained negative or positive information on the appearance of the tidal wave. From these reports, relatively competent information would then be sent to areas more remotely in the path of the wave.

The functioning of such a system need not create mass hysteria, nor need it fall into the position of Aesop's boy who cried, "Wolf!" Rapid routine location of the epicenter by the seismograph net would screen out any public mention of tidal wave in connection with all earthquakes except those which actually were so located as possibly to cause a wave. The immediate collection of reports, both positive and negative, from those outposts earliest in the path of the possible wave, would make available relatively specific warnings to areas more remotely in the path of the wave.

Communities subject to tidal waves could provide an additional simple alarm system which might prevent loss of life by taking advantage of the fact that an abnormally low water precedes by a few minutes the approach of an abnormally high wave. A tide gage could be connected with a loud siren in such a manner that the alarm would be sounded when the tide gage dropped to a point somewhat below low tide mark.

HAWAIIAN VOLCANO RESEARCH ASSOCIATION

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To the Donors and Members
Hawaiian Volcano Research Association

Your Directors this day meeting in the office of President Thurston, have to report that our Scientific Director T. A. Jaggar and his assistant R. A. Okuda are continuing laboratory work in measuring hardness of metals and minerals; the book on Pacific volcanoes was published and now is on sale on the mainland; a paper on tidal waves, a book manuscript on explosive volcanoes, and another on craters, are in press in New York; and Dr. Jaggar is now working on alleviation of tidal waves.

The disastrous beach flood of April 1 in Hawaii engages our scientists, and the Honolulu and Hilo Chambers of Commerce, and the Government. Our Association has dealt with such cataclysms and was founded to alleviate them. Some alleviation in the future is possible and with financial support our laboratories are suitable to cooperate with others in design of warning instruments.

With this program decided on, need for a larger budget is brought to your attention. We approve raising $5000 for 1946, with costs of tidal wave investigation and the usual volcanology research shared with University and National Park. We hope you will increase your generous support, and the University of Hawaii looks forward to extending this work to a Pacific Ocean Institute, a project that has been taking shape for several years past. Gifts from new donors are welcomed.

Very truly yours,

L. P. THURSTON, *President*
L. W. DE VIS-NORTON, Secretary and Treasurer

April 9, 1946

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Hawaiian Volcano Observatory Report for January-March 1946

VOLCANOLOGY

January

The year opened with both Kilauea and Mauna Loa inactive.

During heavy rains on January 31 dense steam clouds arose from the Halemaumau floor. Steam was escaping from nearly all cracks in the floor with a velocity of escape sufficient to set up a swishing roar that could be heard a few feet back from the rim.

One large landslide from the northwest notch of Halemaumau was observed at 4:25 P.M. on January 3.

No perceptible earthquakes occurred during the month. A total of 25 seismic disturbances was recorded at Kilauea and 30 at Mauna Loa seismographs.

February

Two earthquakes were felt locally during the month. A good record was obtained of a shake on February 14 which originated along the lower southwest rift of Mauna Loa. It was felt in Pahoehoe, South Kona, as a vertical drop without conspicuous horizontal motion. A total of 51 shakes was recorded at Mauna Loa and 27 at Kilauea.

Normal southwest tilt obtained during the month.

March

No perceptible earthquakes were recorded in March though 44 seismic disturbances were recorded at Kilauea and 51 at Mauna Loa.

There was a slight accumulation of north tilt during the month, abnormal for this season of the year. Westerly tilt was fairly uniform and about normal for March.

A large section of the southwest rim which had been in a precarious position since last September fell in sometime during the month.

R.H.F.

SEISMOLOGY

Earthquake Data, January-March 1946

Week Ended		Minutes of Tremor	Very Feeble	Feeble	Slight	Local Seismicity*	Teleseisms
January	6	3	5	1	0	4.25	0
	13	0	2	0	0	1.00	1
	20	1	2	0	0	1.25	0
	27	4	4	0	0	3.00	0
February	3	5	0	0	0	1.25	0
	10	2	2	0	2	5.50	0
	17	3	4	0	1	4.75	0
	24	8	0	1	0	3.00	0
March	3	9	3	0	0	3.75	0
	10	4	2	1	0	3.00	0
	17	12	2	0	0	4.00	0
	24	6	1	0	0	2.00	0
	31	7	5	0	0	4.25	0

* For definition of local seismicity, see Volcano Letter No. 371.

The data of the following local disturbances were determined from seismograph stations operated on the island of Hawaii by the Hawaiian Volcano Observatory of the Hawaii National Park. Time is Hawaiian Standard, 10 hours and 30 minutes slower than Greenwich. The number preceding each earthquake is the serial number of the quake for the current year.

1. January 2, 22:51, very feeble.
2. January 3, 05:52, very feeble.
3. January 3, 09:18, feeble. Kilauea shake.
4. January 4, 02:26, very feeble.
5. January 4, 02:28, very feeble.
6. January 8, 10:40, very feeble. Mauna Loa shake.
7. January 10, 15:13, very feeble.
8. January 15, 09:43, very feeble.
9. January 18, 13:20, very feeble.
10. January 22, 09:21, very feeble.
11. January 26, 21:56, very feeble.
12. January 27, 02:35, very feeble.
13. January 27, 10:46, very feeble.
14. February 4, 12:12, very feeble.
15. February 6, 04:45, slight. East-west dismantled. Near coast below Pahala. Felt at Kau and South Kona.
16. February 6, 17:43, very feeble. Northeast rift of Mauna Loa.
17. February 8, 06:15, slight. Felt locally, and at Pahala and Hilo. Northeast rift of Mauna Loa.
18. February 14, 09:03, slight. Middle southwest rift, Mauna Loa.
19. February 14, 16:02, very feeble.
20. February 16, 15:26, very feeble. Mauna Loa shake.
21. February 17, 02:26, very feeble. Kilauea origin.
22. February 17, 06:27, very feeble. Northeast rift, Mauna Loa.
23. February 23, 22:44, slight. Felt at North Kona and South Kohala.
24. February 26, 09:24, very feeble.
25. March 3, 08:20, very feeble.
26. March 3, 08:38, very feeble.
27. March 5, 09:42, feeble. Near Puu Ulaula, northeast rift of Mauna Loa.
28. March 6, 00:26, very feeble.
29. March 9, 17:12, very feeble.
30. March 12, 07:04, very feeble.
31. March 12, 18:19, very feeble.
32. March 20, 15:06, very feeble.
33. March 27, 18:57, very feeble.
34. March 27, 21:44, very feeble.
35. March 28, 21:36, very feeble.
36. March 29, 01:28, very feeble.
37. March 30, 16:11, very feeble.

TELESEISMS

January 12 10:03, slight.

MICROSEISMS

Microseisms were moderate on January 17-18 and February 27-28 and moderate to strong during March. During the rest of the quarter they were slight.

CRACK MEASUREMENTS

A few of the cracks around the Halemaumau rim opened slightly during the quarter. No movement was detected at the cracks along the Chain of Craters Road.

TILTING OF THE GROUND

Westerly tilt was about normal for the quarter except for an easterly excursion from January 23 to February 5. There was but little tilting in the north-south direction until January 21 when a distinct south tilt set in and continued until March 2. There was a noticeable accumulation of north tilt during March, or opposite to the normal for this season of the year. Such a northerly tilt does not necessarily mean an increase in pressure under Kilauea because the mean temperature for March was nearly 2° F. below that for January and February.

R.H.F.

Table of Tilt at Observatory on Northeast Rim of Kilauea

Week Ended		Amount	Direction
January	6	0.26″	S 25° W
	13	0.24″	N
	20	0.65″	N 68° W
	27	0.81″	S 27° E
February	3	2.38″	S 25° E
	10	1.64″	S 36° W
	17	0.50″	N 76° W
	24	0.81″	S 64° W
March	3	1.44″	S 48° W
	10	0.73″	N 10° W
	17	1.05″	N 66° W
	24	0.60″	N 52° E
	31	0.65″	N 68° W

HAWAIIAN VOLCANO RESEARCH ASSOCIATION

in cooperation with UNIVERSITY OF HAWAII

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THE VOLCANO LETTER 492

No. 492 **Department of Interior** **National Park Service** **April-June 1946**

PUBLISHED BY THE UNIVERSITY OF HAWAII

HAWAII NATIONAL PARK: Frank R. Oberhansley, Superintendent; R. H. Finch, Volcanologist

UNIVERSITY OF HAWAII: T. A. Jaggar, Geophysicist

REANALYZING TILT RECORDS AT THE HAWAIIAN VOLCANO OBSERVATORY

By H. A. POWERS
Geologist, Hawaii National Park

Tilting of the ground under the Hawaiian Volcano Observatory continues to be one of the most critical studies maintained by the Observatory.[1] The war seriously interrupted the expansion of the investigation to include installations of clinometers at critical points on the slopes of Mauna Loa, as well as the periodic triangulation and leveling surveys in the vicinity of Kilauea. However, daily readings have been maintained from the Bosch-Omori seismograph in the old instrument cellar and from the clinometer in the new instrument cellar.

Infallible interpretation of the measurements of ground movement would increase tremendously the possibility of accurate anticipation of volcanic events. In the constant effort to improve the technique of current interpretation of tilt records, the old records are periodically re-examined and subjected to various methods of analysis. Such a re-examination is now in progress at the Observatory and results will be presented from time to time in the VOLCANO LETTER.

The chart showing the general tilt changes at the Observatory from 1913 to 1939 (published as figure 8 in VOLCANO LETTER 467, January-March 1940) is reproduced on pages 4 and 5 as figure 1. The average of daily tilt coordinates from the Bosch-Omori seismograph for each month is determined, then the tilt curve is further smoothed by plotting five-month overlapping means. This plot presents the generalized seasonal tilt pattern and the longer term accumulations of tilt. Pronounced accumulations first to the north and then to the south during the period 1913 to 1925 kept the graph sufficiently open to be fairly clearly studied. The lack of large north-south accumulations in the years since 1925 has produced a maze of overlapping traces which has lost its clarity.

[1] Bibliography on page 2.

Figure 2 (page 6) presents the same type of tilt curve for the years 1940 to 1945 inclusive. It has been drawn separately, but is on the same scale as figure 1, and the months June 1929, January 1931, January 1936, and May 1939 have been added to the curve to fix its correspondence with the curve of figure 1.

Outstanding features of figure 2 are: (1) The relatively long north-east swing from May 1940 to January 1941; (2) the equally long southerly swing from February 1941 to August 1941, but with accumulation to the east; (3) the pronounced easterly swing from September 1941 to January 1942 with the annual loop of 1941 replaced by an acute angle; (4) the accumulation of westerly tilt during the two short annual loops of 1942 and 1943; (5) the almost perfect closure of the annual loop for 1944; and (6) the accumulation of north-east tilt in 1945.

The accumulation of easterly tilt prior to, and the accumulation of westerly tilt subsequent to, the flank eruption of Mauna Loa in the spring of 1942 is quite striking. Equally striking is the absence of any surface activity in Kilauea to accompany the rather large north and south swings. The details of the tilt swings during the last six years will be discussed in a later VOLCANO LETTER; the rest of this discussion will be devoted to a further study of the long-term tilt pattern.

A legible picture of the major tilt trends during the entire period 1913 to 1945 has been regained by sacrificing the presentation of the annual loops and computing one tilt position for each year. These data are further "smoothed" by plotting three-year overlapping means which eliminates part of the detailed annual change, but yields a more legible generalized curve. The coordinates used in the plot do not carry any reference to a particular time of the year.

The graph on the left in figure 3 (page 6) shows the average

tilt position for each year, further smoothed by three-year overlapping means, for the 33 years beginning with 1913. The coincidence of tilt accumulation with major volcanic events, pointed out by the previous writers, is still very apparent in this very simplified graph.

The azimuth of Kilauea collapse, so striking in figure 1, traced by the tilt line for the spring and summer of 1924, appears again as a much longer "direction line" in figure 3. Here the annual accumulation of tilt from 1922 to 1925 makes almost a straight line on the bearing South 20 degrees West. The same azimuth shows up numerous times, both in plots of daily accumulation and in those of monthly accumulation of tilt. It occurs both as a direction of subsidence towards Kilauea, as in 1924, and as a direction of uplift preceding lava appearance in Kilauea. The accumulation of evidence now seems to indicate that the azimuth N 20 E or S 20 W is the line of response to uplift or subsidence in Kilauea for the section of Kilauea rim upon which the old instrument cellar stands. At least the evidence is strong enough to warrant the use of this direction as a starting point in analysis of the accumulated tilt pattern.

Using the direction N 20 E—S 20 W instead of true N-S as a base line, the northerly or southerly accumulations shown by the annual averages have been re-computed, and similarly the easterly or westerly accumulations have been computed at right angles to the new base line, i.e., E 20 S and W 20 N, and the two accumulations plotted in the right hand graphs of figure 3. One line thus is assumed to present average annual accumulations of uplift or subsidence of Kilauea. The other line (pseudo east-west) presents accumulations of tilt at right angles to the dominant Kilauea azimuth, and may well represent, in part at least, uplift or subsidence of Mauna Loa, though the instrument location is too far from Mauna Loa to expect a tilt magnitude comparable to that of Kilauea.

The curve of Kilauea uplift and subsidence shows four main phases: the six-year uplift of 75 seconds of arc from 1914 to 1920, most of which occurred in 1918 and 1919; the five-year subsidence of 83 seconds of arc from 1921 to 1925, most of which occurred in the collapse of 1924; 14 years of interrupted subsidence from 1925 to 1939 amounting to 21.5 seconds of arc; and interrupted uplift to the present time amounting to almost 13.5 seconds of arc at the 1945 average. The first two phases were associated with volcanic events too well known to need repetition; the latter two phases have been associated with a period of extreme volcanic quiet in Kilauea. There is little correlation to be found between the slight peaks of uplift in 1927, 1931, 1936, and 1943 and the short-lived appearances of lava in Halemaumau in 1927, 1929, 1930, 1931, and 1934. The association of no appreciable volcanic activity with no appreciable accumulation of either uplift or subsidence is in itself significant. Further, it is at least suggested by the tilt curve that the bottom of Kilauea subsidence occurred in 1939. The first interruption of the big collapse occupied two years, 1926-1927, and gained 4 seconds of arc in uplift. The second interruption of the collapse again occupied two years, 1930-1931, and gained 2 seconds of arc. The third interruption occupied three years, 1934-1936, and gained 8.7 seconds of arc and the fourth, if it be only an interruption and not the turning point, gained 10.3 seconds of arc in 4 years, 1940-1943, and has continued the uplift after a minor subsidence in only one year, 1944.

The curve presenting accumulation of tilt at right angles to the line of Kilauea uplift and subsidence (the pseudo east-west tilt) shows three main phases: a sharp easterly tilt from 1913 to 1918 of 38.5 seconds of arc; a sharp westerly tilt from 1918 to 1920 of 27 seconds of arc; and a long gradual increase of easterly tilt, with several minor interruptions, from 1920 to 1942 with a total accumulation of 22.25 seconds of arc. At first glance there appears to be excellent correlation between the main peaks of accumulated easterly tilt and major Mauna Loa activity. The easterly peak in 1918 led up to the major flank eruption of 1919 with the westerly subsidence following the lava flow. The easterly peak in 1942 coincided with the flank flow of 1942, and again westerly subsidence followed the flow, though on a much smaller scale. The flank flow of 1926 occurred on a bulge of easterly tilt, but there was no westerly subsidence of magnitude great enough to affect the average for 1927, which actually shows further accumulation of easterly tilt. The summit activity of 1933 occurred with accumulation of easterly tilt, which held static then until the flank flow of 1935. There was westerly subsidence in 1936 after the flow, but 1937 shows further easterly accumulation. The major summit flow of 1940 occurred at the bottom of three years accumulation of westerly tilt. Thus the correlation is far from being "cut and dried," but it does seem apparent that increases and decreases of pressure under Mauna Loa are reflected to a considerable extent in the tilting at the Observatory at right angles to the axis of Kilauea uplift and subsidence.

Jaggar and Finch pointed out a closer correlation between the curve of temperature and the curve of east-west tilt than between the temperature and the north-south tilt. The question of a possible cumulative effect of temperature on average annual accumulation of easterly and westerly tilt will be considered in a forthcoming VOLCANO LETTER.

Two groups of five consecutive years, 1925-1929 and 1932-1936, show very modest accumulation of either easterly or westerly tilt within the span of the group. The seasonal tilt curves of these particular years are being studied in detail in an effort to evaluate quantitatively and qualitatively a "standard" seasonal tilt pattern. If such a pattern can be reasonably established, it will facilitate greatly the week to week evaluation and interpretation of the tilt curves as they are recorded.

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SEISMIC SEA WAVE VELOCITIES

In Transactions of the American Geophysical Union, 27 (3) : June 1946, E. C. McKay has supplied considerable statistical material dealing with the seismic sea waves induced by the Aleutian earthquake of April 1, 1946. In VOLCANO LETTER 491, January-March 1946, H. A. Powers discusses effects in Hawaii only. The velocities as given in the McKay table do not always agree with the velocities of waves induced by other disturbances that travel nearly identical paths.

In the following table are shown some of the data for the April 1, 1946, sea waves and for the August 11, 1868, Arica, Peru, shake.[1]

[1] MILNE, JOHN. EARTHQUAKES (London, 1913), p. 182.

Table 1.—Velocities for the sea waves of April 1, 1946 and August 11, 1868.

Place	Distance	Average velocity
	Statute miles	*Miles per hour*
Aleutian earthquake of April 1, 1946:		
Neah Bay, Wash.	1,687	375
Honolulu, T. H.	2,241	490
San Francisco, Calif.	2,197	398
La Jolla, Calif.	2,646	428
Valpariso, Chile	8,066	445
Arica, Peru, August 11, 1868:		
San Diego, Calif.	4,700	420
Honolulu, T. H.	6,510	529
Samoa	6,720	429
Sydney, Australia	8,680	366

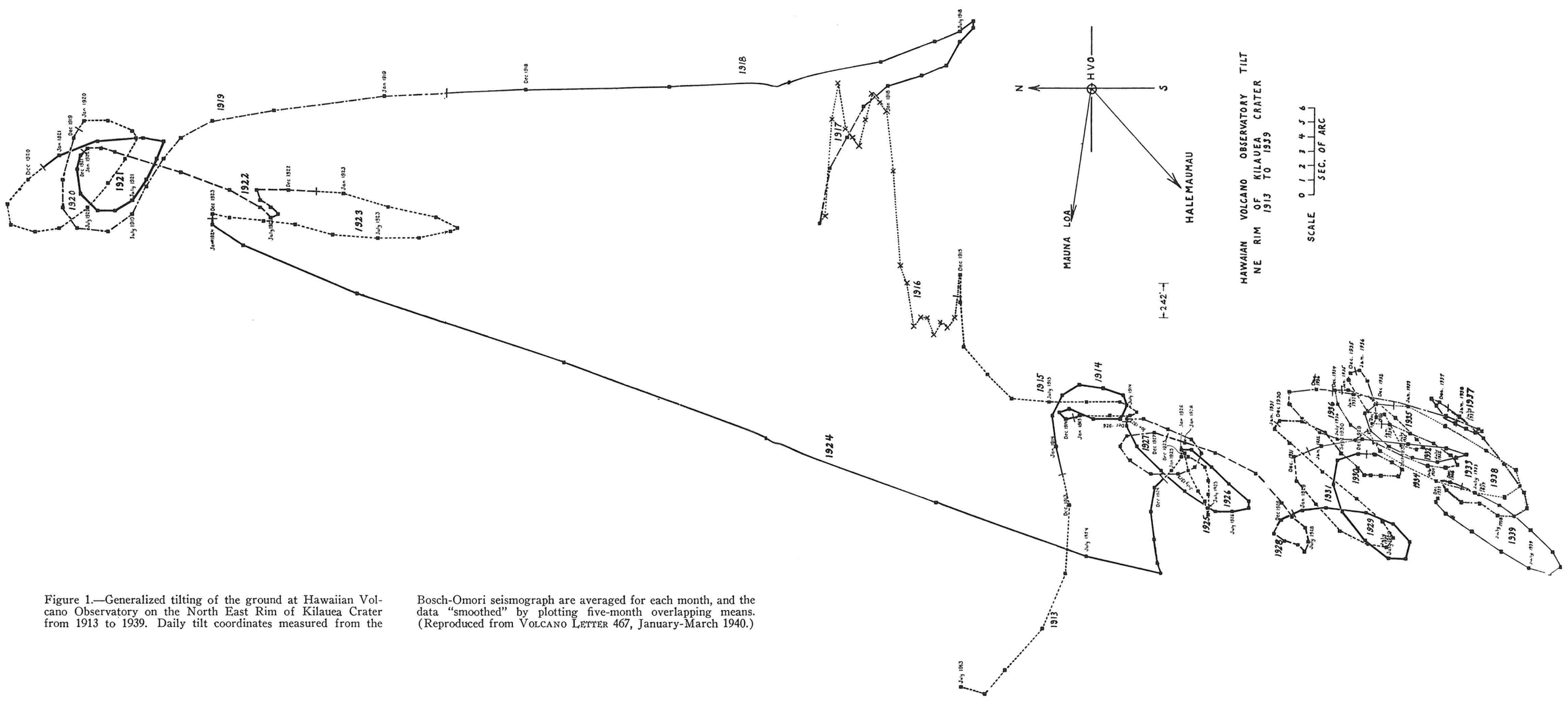


Figure 1.—Generalized tilting of the ground at Hawaiian Volcano Observatory on the North East Rim of Kilauea Crater from 1913 to 1939. Daily tilt coordinates measured from the Bosch-Omori seismograph are averaged for each month, and the data "smoothed" by plotting five-month overlapping means. (Reproduced from VOLCANO LETTER 467, January-March 1940.)

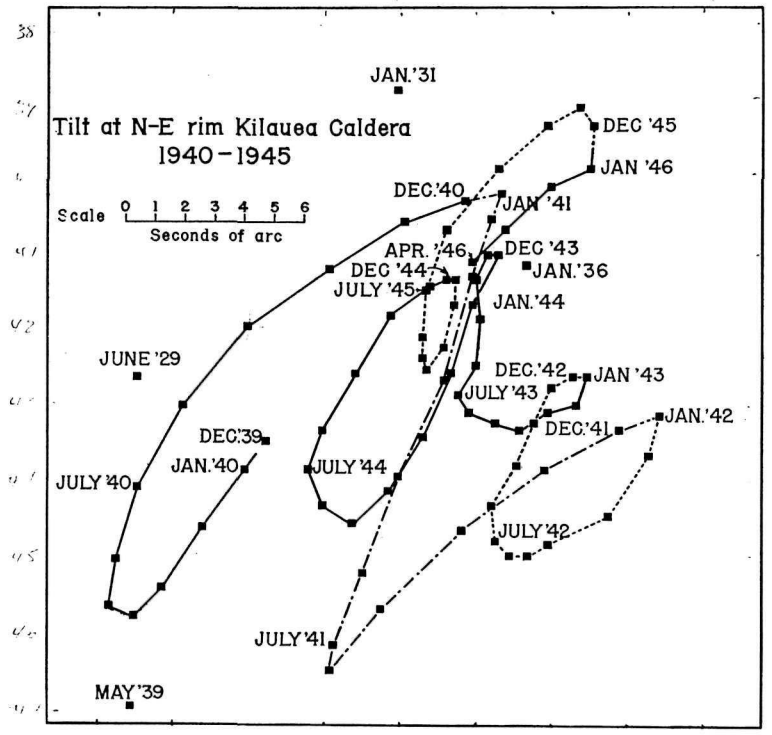
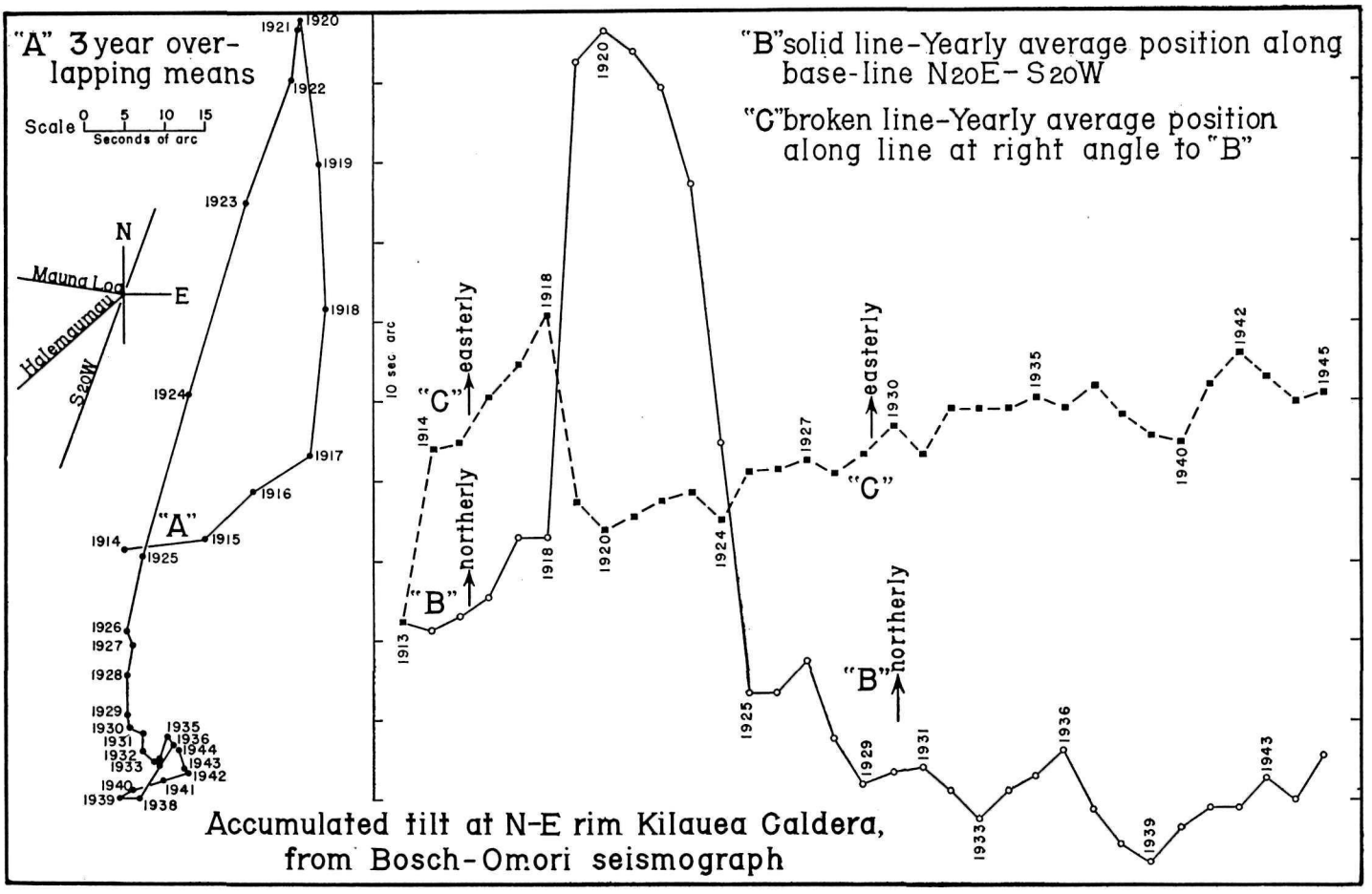


Figure 2.—A continuation of the curve of figure 1 covering the years 1940 to 1945 inclusive.

Figure 3.—"A". Data from figures 1 and 2, further smoothed by computing average coordinates for each year and plotting three-year overlapping means. "B". Accumulated annual average tilt measured on a base line N 20 E—S 20 W, the dominant direction in which the block of rim under the Observatory tilts in response to uplift and subsidence in Kilauea. "C". Accumulated annual average tilt measured at right angles to the base line used in "B," which expresses (at least in part) tilting of the Observatory rim in response to uplift and subsidence in Mauna Loa.



Hawaiian Volcano Observatory Report for April-June 1946

VOLCANOLOGY

April

A fume cloud was observed over Mokuaweoweo on April 30.

The seismographs recorded 49 local disturbances at Kilauea and 47 at Mauna Loa during April.

The tilt curve for the first four months of the year may be taken as indicating a slight build-up of internal pressure under Kilauea.

May

The number of earthquakes recorded during May was 65 at Kilauea and 68 at Mauna Loa. There has been an increase in earthquake frequency during recent months, though neither the number of shakes nor their distribution can be taken as signs of impending activity of Kilauea or Mauna Loa.

June

Mauna Loa had several spells of rather conspicuous fuming during the month. The usual amount of steaming was also observed on several days.

More earthquakes were recorded at Kilauea than at Mauna Loa—64 and 35, respectively.

Tilt records indicate that there has been a slight pressure build-up under both Kilauea and Mauna Loa during the past two years. There is, then, a possibility that either Kilauea or Mauna Loa, may erupt in the next year or two with but few additional premonitory symptoms.

R.H.F.

SEISMOLOGY

Earthquake Data, April-June 1946

Week Ended		Minutes of Tremor	Very Feeble	Feeble	Slight	Local Seismicity*	Teleseisms
April	7	10	0	0	0	2.50	3
	14	10	0	0	2	6.50	0
	21	16	4	0	0	6.00	0
	28	5	5	0	0	3.75	0
May	5	12	1	0	0	3.50	0
	12	13	1	0	0	3.75	0
	19	5	2	0	1	4.25	0
	26	15	1	0	0	4.25	0
June	2	13	1	1	0	4.75	0
	9	12	2	1	0	5.00	0
	16	6	1	1	0	3.00	0
	23	7	2	1	0	3.75	1
	30	6	5	0	0	4.00	1

* For definition of local seismicity, see VOLCANO LETTER No. 371.

The data of the following local disturbances were determined from seismograph stations operated on the island of Hawaii by the Hawaiian Volcano Observatory of the Hawaii National Park. Time is Hawaiian Standard, 10 hours and 30 minutes slower than Greenwich. The number preceding each earthquake is the serial number of the quake for the current year.

38. April 8, 08:58, slight. Deep under Mauna Loa. Widely felt.
39. April 9, 10:03, slight. Kilauea shake. Felt locally.
40. April 17, 12:56, very feeble.
41. April 18, 01:46, very feeble.
42. April 21, 07:10, very feeble. Deep under Kilauea.
43. April 21, 22:35, very feeble. Mauna Loa shake.
44. April 22, 10:48, very feeble. Kilauea shake.
45. April 23, 03:37, very feeble. Mauna Loa shake.
46. April 23, 22:24, very feeble. NE rift Mauna Loa.
47. April 25, 18:25, very feeble. Under E slope of Mauna Loa.
48. April 27, 19:11, very feeble.
49. April 30, 04:55, very feeble.
50. May 7, 14:38, very feeble. Mauna Loa shake.
51. May 15, 09:45, very feeble.
52. May 19, 18:36, slight. Felt locally and at Hilo.
53. May 19, 21:35, very feeble.
54. May 23, 08:40, very feeble. Under Mauna Kea.
55. May 30, 17:17, feeble. E slope of Mauna Loa.
56. May 31, 09:09, very feeble.
57. June 5, 02:39, feeble. E slope of Mauna Loa near Ainapo.
58. June 5, 10:02, slight. Felt in Kau. Along coast near Puu Kapukopu.
59. June 5, 16:17, very feeble.
60. June 8, 01:13, very feeble.
61. June 10, 02:56, very feeble.
62. June 10, 17:51, feeble. Felt in Kau.
63. June 20, 13:34, very feeble. Kilauea shake.
64. June 20, 13:38, very feeble. Kilauea shake.
65. June 20, 13:51, feeble. Kilauea shake.
66. June 26, 21:01, very feeble. E slope of Mauna Loa.
67. June 27, 04:38, very feeble. Felt in Kona.
68. June 29, 12:01, very feeble.
69. June 30, 22:02, very feeble.
70. June 30, 03:03, very feeble.

TELESEISMS

April 1, 02:06, strong. South of Unimak Island. Caused a destructive tidal wave.

June 22, 06:50, slight. 4300 km.

June 25, 21:33, slight.

MICROSEISMS

Microseisms were strong during April from the 1st to the 19th inclusive, and on the 26th and 27th. They were light to moderate on other days. During May they were strong on May 6 and light to moderate the rest of the month. Nothing but light to moderate microseisms were recorded in June.

CRACK MEASUREMENTS

There was but little movement at any of the cracks measured near the Halemaumau rim or along the Chain of Craters Road.

TILTING OF THE GROUND

There was a slight and rather uniform tilt to the south during April and May. The seasonal change in direction took place on May 31, and during June there was about the usual northerly tilt. Westerly tilt was slight and rather uniform during the quarter except for slight easterly excursions on May 20 to 29 and June 9 to 14.

R.H.F.

Table of Tilt at Observatory on Northeast Rim of Kilauea

Week Ended	Amount	Direction
April 7	0.60″	W
14	1.14″	S 70° W
21	0.37″	N 71° W
28	0.61″	S 53° E
May 5	0.88″	S 16° W
12	1.55″	S 39° W
19	0.98″	N 60° E
26	1.08″	S 63° E
June 2	0.60″	W
9	1.15″	N 57° W
16	0.77″	S 20° E
23	0.88″	N 74° W
30	0.51″	N 69° W

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THE VOLCANO LETTER 493

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HAWAII NATIONAL PARK: Frank R. Oberhansley, Superintendent; R. H. Finch, Volcanologist

UNIVERSITY OF HAWAII: T. A. Jaggar, Geophysicist

THE PUNA RIFT OF KILAUEA

By R. H. FINCH

Volcanologist, Hawaii National Park

The active rift systems of Mauna Loa and Kilauea are roughly parallel and aligned northeast-southwest. The last few miles of the southwest portion of the Kilauea rift trends about S 15° W while the lower southwest portion of the Mauna Loa rift trends nearly due north and south.

A glance at the map (fig. 1) shows that it is not appropriate to speak of the northeast portion of the Kilauea rift because for the first 8 miles from Halemaumau the general direction is southeast. The direction change is not by means of a sharp angle but rather by a broad sweeping curve. Makaopuhi pit crater marks the beginning of the northeast portion. From this crater the trend is about N 60° E for about 25 miles until it passes under the ocean near Cape Kumakahi. The Puna rift, as the rift in the eastern flank of Kilauea might best be called, is interesting not only for the distinct curve in its upper reaches but also for the numerous lava flows that have originated along it and for the many pit craters.

Lava flows have issued at many places along most of the length of the Puna rift. Some of the flows issued quietly from fissures and did not build up conspicuous spatter or cinder cones, but numerous cinder cones mark the point of origin of other flows that had persistent fountains at their sources. The lava in the flows from this rift came from Kilauea by means of rift tubes—that is, lava tubes that formed in cracks at varying depths below the surface. The entrance to the SW rift tube that fed the 1920 and 1921 flows from Kilauea was only a little over 100 feet below the Halemaumau rim.[1] The entrance to the tube that fed the Puna rift flows at Makaopuhi and Napau Craters in 1922 must have been about 1,000 feet below the rim as the collapse of that year left 900 feet of the Halemaumau wall exposed and no entrance was revealed. It is interesting to note that the Reverend Titus Coan surmised that the lava in the rift tube of 1840 was about 1,000 feet below the surface.[2]

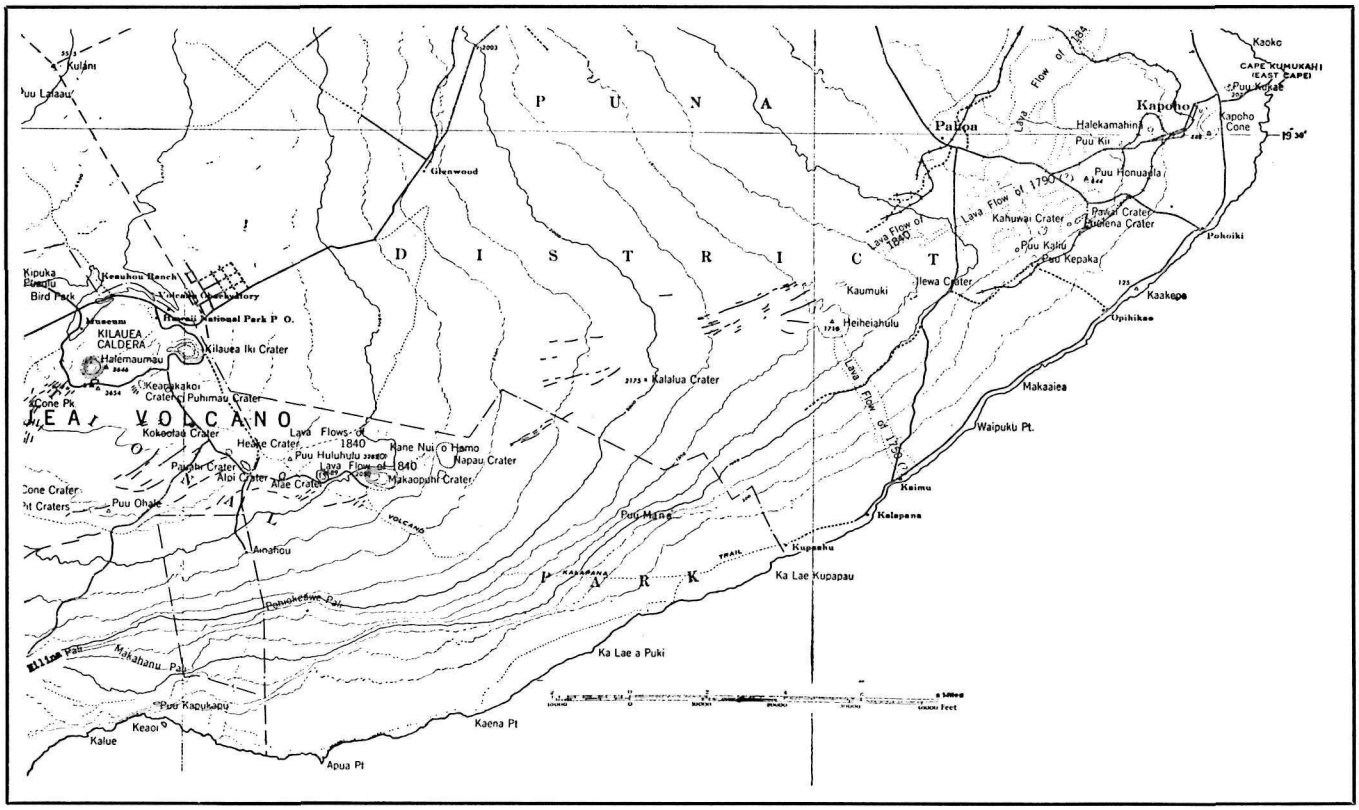
The Puna rift and its attendant tubes is continuous despite the curving upper portion. This was shown in 1840 by the lava first appearing in the curved upper portion 6 miles from the source, then near the middle portion, and finally issuing from a crack 23 miles from Kilauea caldera. The source of the lava in the flows from both the Puna and southwest rifts is in Kilauea. This has been repeatedly shown by the sinking of the lava column in Halemaumau that accompanies drainage through rift tubes. Examples are the flank flows and collapses in 1840, 1868, 1919, 1920, 1921, 1922, 1923, and probably 1924. The vents along both rifts of Kilauea are parasitic. The ascent of lava is confined to the feeding conduits under Halemaumau.

There is considerable evidence that the thickness of Kilauea lavas is comparatively slight. Stone has offered evidence that the depth of Kilauea lavas in the vicinity of Makaopuhi is about 900 feet.[3] There is, in general, a gradual decrease in the thickness of Kilauea lavas with increase in distance from the caldera. Pahala ash, which marks the base of the Kilauea series, is found at the surface with a depth of 3 to 5 feet 2.5 miles southwest of Olaa village and with lesser depths in small kipukas 0.5 and 1.3 miles southwest of Pahoa. The more southwesterly of these kipukas is very near the edge of the Puna rift zone. The Kilauea lavas of the Puna rift poured out onto a terrain that had a very flat slope on the northwest side and a steep slope with fault scarps on the southeast. These scarps are distinct in the vicinity of Hilina Pali and for 16 miles or so to the northeast. Farther on to the northeast there have been sufficient lava flows to mask

[1] Hawaiian Volcano Observatory Bul., Vol. 10, No. 5, p. 52. 1922.

[2] HITCHCOCK, C. H. HAWAII AND ITS VOLCANOES. P. 188. Honolulu, 1911.

[3] STONE, J. B. THE PRODUCTS AND STRUCTURE OF KILAUEA. Bernice P. Bishop Mus. Bul. 33, p. 38. 1926.


P U N A
D I S T R I C T
Glenwood
Kipuka Puaulu Bird Park
Keauhou Ranch
Volcano Observatory
Hawaii National Park P O.
Museum
KILAUEA CALDERA
Kilauea Iki Crater
Halemaumau
Keanakakoi Crater
Puhimau Crater
Cone Pk
EAST RIFT VOLCANO
Kokoolau Crater
Lava Flows of 1840
Heike Crater
Puu Huluhulu
Kane Nui o Hamo
Napau Crater
Pauahi Crater
Aloi Crater
Aae Crater
Lava Flow of 1840
Makaopuhi Crater
Cone Crater
Puu Ohale
Puu Mane
Ainahou
Kupaahu
Ka Lae Kupapau
Ka Lae a Puki
Kaena Pt
Apua Pt
Kalue
Keaoi
Puu Kapukapu
Mauhahanu Pali
Pohnokeowe Pali
Kalalua Crater
Heiheiahulu
Kaumuki
Ilewa Crater
Lava Flow of 1840
Lava Flow of 1790
Kahuwai Crater
Puu Kaku
Pua Kepaka
Parker Crater
Puulena Crater
Puu Honuaula
Pohoiki
Kaakepa
Upihikaa
Makaaiea
Waipuku Pt.
Kaimu
Kalapana
Kapoho
Kapoho Cone
Halekamahina
Puu Kii
Pahoa
Kaoko
CAPE KUMUKAHI (EAST CAPE)
Puu Kukae
Kulani
Puu Lalaau
Flow of 1840
Flow of 1840
Flow of 1840

Hawaiian Volcano Observatory Report for July-September 1946

VOLCANOLOGY

July

In July, as in June, considerable steaming was observed over Mokuaweoweo. Observations from the rim of Mokuaweoweo on July 23 showed both steam and dark fume escaping.

Forty-four seismic disturbances were recorded at Kilauea. An incomplete record indicates that there were more Mauna Loa than Kilauea shakes.

August

During the month of August, 53 earthquakes were recorded at Kilauea and 46 at Mauna Loa.

The volume of steam escaping from Mokuaweoweo has been more than normal for the last 3 years. Observations from the rim on August 28 and 29 revealed a distinct bluish cast to the fume.

There has been a gradual decrease in the amount of steam escaping at the hot area in the vicinity of Kokoolau Crater.

September

The Kilauea and Mauna Loa seismographs recorded the same number of earthquakes during September—33 each. This is the lowest monthly total recorded during the last 5 months.

A dark, conspicuous fume column was observed over Mokuaweoweo shortly after sunset on September 2. The fume column developed about 2 hours after a perceptible earthquake that originated deep under the east slope of Mauna Loa.

R.H.F.

SEISMOLOGY

Earthquake Data, July-September 1946

Week Ended		Minutes of Tremor	Very Feeble	Feeble	Slight	Local Seismicity*	Teleseisms
July	7	19	3	0	0	6.25	0
	14	3	2	1	0	2.75	1
	21	2	2	0	0	1.50	2
	28	1	1	2	0	2.75	0
August	4	16	2	1	0	6.00	1
	11	13	1	0	1	5.75	1
	18	14	0	0	0	3.50	0
	25	6	1	0	0	2.00	0
September	1	6	1	1	0	3.00	0
	8	4	0	1	1	4.00	0
	15	3	3	0	0	2.25	0
	22	3	3	0	0	2.25	0
	29	8	6	0	0	5.00	2

* For definition of local seismicity, see VOLCANO LETTER No. 371.

The data of the following local disturbances were determined from seismograph stations operated on the island of Hawaii by the Hawaiian Volcano Observatory of the Hawaii National Park. Time is Hawaiian Standard, 10 hours and 30 minutes slower than Greenwich. The number preceding each earthquake is the serial number of the quake for the current year.

71. July 3, 03:21, very feeble. Kilauea.
72. July 5, 12:14, very feeble. Mauna Loa, NE slope.
73. July 6, 02:06, very feeble. NE, Mauna Loa.
74. July 9, 13:33, very feeble. Deep Kilauea.
75. July 11, 04:43, very feeble. Mauna Loa, NE slope.
76. July 13, 23:34, feeble. Mauna Loa, E slope.
77. July 15, 10:45, very feeble. Mauna Loa, NE slope.
78. July 20, 11:49, very feeble. Mauna Loa, E slope.
79. July 25, 14:32, feeble. Felt at Pahala.
80. July 27, 05:51, very feeble.
81. July 28, 15:40, feeble. Kilauea.
82. July 29, 15:25, very feeble.
83. July 29, 22:51, very feeble. Mauna Loa, NE slope.
84. August 1, 12:59, feeble. Mauna Loa, NE slope.
85. August 5, 09:30, very feeble. Mauna Loa, NE slope.
86. August 8, 16:28, slight. Mauna Loa, NE slope. Felt at Kilauea.
87. August 20, 10:10, very feeble. Deep. Mauna Loa.
88. August 29, 22:45, feeble. Mauna Loa, NE slope.
89. August 30, 02:43, very feeble. Mauna Loa, SW slope.
90. September 2, 16:39, feeble. Mauna Loa, NE slope. Felt at Kilauea and Kona.
91. September 4, 13:21, slight. Mauna Loa, NE slope. Felt at Kilauea.
92. September 11, 11:59, very feeble. Mauna Loa, NE slope.
93. September 12, 10:25, very feeble. Mauna Loa, E slope.
94. September 15, 01:52, very feeble. Mauna Loa, E slope.
95. September 18, 03:33, very feeble. Shallow Mauna Loa, E slope. Felt at Kapapala.
96. September 19, 19:00, very feeble. Mauna Loa, NE slope.
97. September 20, 22:18, very feeble. Mauna Loa, NE slope.
98. September 23, 19:43, very feeble. Mauna Loa, NE slope.
99. September 24, 03:43, very feeble. Mauna Loa, NE slope.
100. September 24, 11:08, very feeble. Kilauea.
101. September 24, 20:06, very feeble. Mauna Loa, NE slope.
102. September 27, 07:00, very feeble. Mauna Loa, NE slope.
103. September 29, 23:07, very feeble. Mauna Loa, NE slope.

TELESEISMS

July 9, 02:52. Slight.
July 17, 19:50. Slight.
July 17, 21:03. Slight.
August 4, 07:33. West Indian quake.
August 8, 03:10. West Indian aftershock.
September 26, 00:28. Slight.
September 28, 16:40. About 3,750 miles distant.

MICROSEISMS

Microseisms were strong during the first 12 days of July and moderate to light during the rest of the month. August 1st to 3rd had strong microseisms with moderate and light the balance of the month. September microseisms were strong on the 1st and 2nd and again on the 29th and 30th. The rest of the month was light to moderate.

CRACK MEASUREMENTS

There was but little movement at any of the cracks measured around Halemaumau or along the Chain of Craters Road.

TILTING OF THE GROUND

The 3-month period, July-September, showed a total tilt of 4.5 seconds of arc in a direction N 26° E, which is slightly more easting than average for this season of the year.

H. A. Powers.

Table of Tilt at Observatory on Northeast Rim of Kilauea

Week Ended		Amount	Direction
July	7	1.20″	N 49° E
	14	0.60″	N 37° W
	21	1.80″	E
	28	1.70″	N 77° W
August	4	0.50″	N 45° W
	11	0.70″	N 45° E
	18	0.50″	S 62° E
	25	0.25″	N
September	1	1.10″	N 27° W
	8	0.90″	N 45° E
	15	0.60″	S 68° W
	22	0.80″	N 64° E
	29	0.50″	E

HAWAIIAN VOLCANO RESEARCH ASSOCIATION

in cooperation with UNIVERSITY OF HAWAII

The **Hawaiian Volcano Research Association** was founded in 1911 for record of volcanoes in the Hawaiian Islands and around the Pacific Ocean. Its equipment at Kilauea Volcano, Hawaii Island, has been transferred to the United States Government, Department of the Interior, National Park Service.

The **University of Hawaii** cooperates in maintaining a research laboratory at Hawaii National Park. The **Association** and the **University** supplement the work of the government with research associates, instrumental plants and special investigation. Dr. T. A. Jaggar is their geophysicist resident in the National Park.

The **Volcano Letter**, a quarterly record of Hawaiian volcano laboratories and published by the University of Hawaii, is issued by authority of the Department of the Interior and supplied to a restricted membership and exchange list of the above establishments.

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HAWAII NATIONAL PARK: Frank R. Oberhansley, Superintendent; R. H. Finch, Volcanologist

UNIVERSITY OF HAWAII: T. A. Jaggar, Geophysicist

REVIEW OF "GEOLOGY AND GROUND-WATER RESOURCES OF THE ISLAND OF HAWAII," H. T. STEARNS AND G. A. MACDONALD

By H. A. POWERS

Seismologist, Hawaii National Park

Geology and Ground-Water Resources of the Island of Hawaii, Bulletin 9 of the Hawaii Division of Hydrography of the U. S. Geological Survey, and the latest of the series describing the geology and ground-water resources of the islands of the Territory of Hawaii, is the only recent publication which presents a compilation of all that is currently known of the geology of the island of Hawaii. As such, it is in a position to become the most widely read source book on Hawaii and her volcanoes. Most sections of the book merit this outstanding position in the literature, notably those parts dealing with the geomorphology of the major volcanic cones, the historic activity of both Mauna Loa and Kilauea, the geology of Mauna Kea, the petrography of Hawaii, and the ground-water resources of the island; other parts fall short of this caliber, notably the section on vocabulary of volcanic terms, the treatment of the "ash problem" of the island, and the correlation of volcanic and erosional history with Pleistocene swings of sea level and the geologic time scale.

A line-by-line study of Bulletin 9 has been made with the thought of enhancing somewhat its value as the outstanding source book on Hawaii. In the presentation of this study, to avoid prohibitive length and at the risk of appearing over-critical, less space can be devoted to favorable comment than to constructive criticism. A few remaining editorial errata, and a very few errors in statement of fact have been picked up. Attention is called to a few misquotations and a few omissions of reference to literature. Caution is indicated in certain passages in which the authors' conclusion on an unsettled question is stated in phrases which suggest that other interpretation is no longer possible.

R. H. Finch, Volcanologist, and G. O. Fagerlund, Naturalist, of Hawaii National Park, have taken an extremely active interest in this review, and significant remarks of praise or criticism are the well-considered summation of much discussion among the three of us.

A few errata and miscellaneous comments which would fit awkwardly in the subsequent paragraphs are listed here.

Plate 3, item 67. *1924* should be *1790.*

Page 7. The use of land for ranch versus forest is poorly presented by figure 3, which appears to be a map showing classification of land for tax purposes. This is partly explained on page 10.

Page 22, line 7 from bottom. The use of *dike* here does not conform to the definition given above for *dike.*

Page 26, Plate 13. The caption 13A refers to plate 13B, plates A and B being reversed.

Page 39, line 8 from bottom. *Figure 47* should be *figure 4.*

Page 48, line 3 from bottom. *Southwestern* should be *southeastern.*

Page 48, bottom line. *60 inches* should be *120 inches.*

Page 51. *Honokane Nui Valley* should be located by the text in Kohala.

Page 70. Wentworth is misquoted in regard to Halai and Puu Hono. He says that their relationship is obscure, but probably with Mauna Loa and not Mauna Kea.

Page 99, line 16. *1928* should be *1930.*

Page 108, line 9. *Aa* should be *ash.*

Page 117, line 13. *500 feet* should be *1500 feet.*

Page 119, line 17 from bottom. *Night* has no significance except to describe a period of a few hours time.

Page 120, line 16. *Water gas* might better be expressed as *water vapor.*

Page 122, last paragraph. Much periodic fuming and occasional glow in the pit characterized the quiet period at the beginning of the century, which has not been the case in the current period of quiet.

Page 127, line 8 from bottom. *Percolating* is not a good word to express the sudden rush of water necessary to create a "flash boiler" explosion.

Page 145. The phrase "It has not been recognized previously as a lava flow," is incorrect, as Sidney Powers states "The Puu Anahulu trachyte represents a flow at least 5 miles in length and over 100 feet in thickness. . . ." on page 269 of his *Notes on Hawaiian Petrology* published in 1920.

Page 198, line 13 from bottom. *Hills* should be *sills.*

Page 209, line 6 from bottom. A breeze which reverses its direction every 12 hours should not be called a *prevailing wind.*

Abstract, Geologic and Guide Maps

A visitor may get an excellent picture of the geology, volcanology, topography, and climate of the area, with a minimum of reading, by careful study of the ABSTRACT, of the geologic map (plate 1), and of the maps of points of interest (plates 2 and 3). The abstract is particularly well written, conveying a maximum of concise information. The point made in the abstract, referring to augite phenocrysts in Mauna Loa lavas, must be based on the paper by Macdonald on petrography (waiting publication as a Professional Paper of the Geological Survey), as no reference to such petrographic detail is made in Bulletin 9. A reader not familiar with the symbolic presentation of information in a geologic cross section should be cautioned not to form his conclusions as to volcanic processes from the map without careful study of the text. For example, the map symbol picturing dikes cannot convey the fact (discussed in the text) that erupting lava may move laterally as well as vertically through a crack extending from the central vent area down one or the other of the rift zones.

Definitions and Descriptions

In a work of this nature, written for the use of persons with professional backgrounds other than geology as well as for geologists, a definition of terms is probably necessary. For the non-geologist a few of the definitions are too brief to be of the greatest vlaue, *i.e.,* the definitions of rock names and *rift zone* on page 13; a few are long enough to be descriptions rather than definitions, *i.e., vent breccia* on page 19. Most of the terms used are concisely defined and well chosen, but a few are not altogether satisfactory and justify further comment.

The specific use of the word *ash,* defined on page 16, describes a fragmental volcanic product of fine size; the use of the word in a formation name, *i.e., Pahala ash* on page 71, describes a deposit essentially consisting of fine material, and the value of the word is not disturbed by the fact that some fragments of size greater than fine may be found in the deposit. In a description of a deposit in which all the ash has been produced by magmatic explosion (vitric ash), the word *ash,* by gentlemen's agreement so to speak, may be used to mean only *vitric ash.* To make the word *ash* carry this additional restriction by definition (page 18, "the terms ash and tuff, if not qualified by descriptive adjectives, refer herein to such lava fountain deposits") is impractical because it prohibits the use of the word in its originally defined sense. The authors have been forced to violate the additional restriction in so many places that a reader will find more clarity if he ignores the statement quoted above from page 18.

The use of the word *caldera* is not clear and precise throughout the text, nor is the definition given on page 14 sufficient to clarify the authors' intended usage. Parts of the discussion on pages 29 to 33 indicate that *caldera* defines the entire area of summit collapse around Mokuaweoweo and Kilauea. However, the statements of dimension indicate that *caldera* is used to denote only the areas known in the literature as the *craters* of Mokuaweoweo and Kilauea. The mere substitution of *caldera* for *crater* seems hardly justified; the introduction of *caldera* to name the entire area of active summit collapse would be very satisfactory, as it tends to emphasize the concept that Kilauea, Halemaumau, Keanakakoi, and Kilauea Iki are *craters* of more or less fugitive existence within the active *caldera* of Kilauea. Such usage would eliminate some of the discussion as to whether certain flows are flank or summit flows (page 82), since most of the troublesome ones definitely are *caldera* flows under the broad definition of *caldera.*

At times there is a tendency in science to "over define" too many terms, leaving no "free-lance" words which can be used, with appropriate adjectives, to convey a precise meaning when needed. The point is illustrated by the restricted definition of *crater* and *pit-crater* (page 16) which literally leaves one with no precise word for Halemaumau, the pit marking the most permanent vent of Kilauea.

The definitions of *aa* and *pahoehoe* are not precise and tend more to description. More precision of definition could have been gained had the authors chosen to limit the application of the terms to congealed lava forms, following Austin E. Jones.[1] Conforming to this limitation, *pahoehoe* is congealed lava with an unbroken surface of quenched glass, and *aa* is lava with a broken surface of spiny, granular, mostly crystallized rock. A flow is called *pahoehoe* or *aa* depending on which type of surface is greatly predominant. The type of surface which will form upon quenching is determined by the nearness of the liquid lava to the crystallization range of most of its constituent minerals. Nearness to crystallization is determined greatly by temperature, and secondarily by the proportion of volatile constituents in an erupted lava. Probably all Hawaiian primitive basaltic lavas are hot enough, when erupted, to quench as pahoehoe if conditions met with after eruption are favorable, *i.e.,* the turbulence of any particular body of liquid must be low enough to permit the quenched skin of glass to remain unbroken and contain the body of liquid until it congeals. If turbulence, due to fountaining or velocity of flow, postpones the formation of a containing skin of glass long enough for loss of temperature and loss of volatile constituents to bring the liquid within the critical crystallization range, quenching can no longer produce a glass skin, *pahoehoe,* but will produce granulated, spiny rubble, *aa.*

The authors' statement on page 20, "They [tumuli or pressure domes] may be formed by collapse as well as by pressure" is not at all clear. The use of *vesicular* rather than *scoriaceous* (page 20) to describe the lava immediately next to the glassy skin of pahoehoe would be more precise, as *scoriaceous* is also used in geology to express the concept of slaggy. The statement on page 20 "No true pillow lava has been found in the island—" should have been modified to anticipate references in the text to the formation of pillow lava at the submarine end of the 1859 Mauna Loa flow (plate 2, item 24, and page 85). In the definition of explosion products on page 16, avalanche material might have been mentioned as an additional source of *accessory ejecta.*

Hawaiian Volcanism in General

The section on MAJOR CONES (page 24) is an excellent, concise discussion of the broad pattern of volcanic development in the Hawaiian Islands based on intensive field study of all the volcanoes of the group. It gives authoritative corroboration to the general concept advanced by Whitman Cross in his paper on the lavas of Hawaii and their relations.[2] The chapters on Mauna Loa and Kilauea contain detailed descriptions of the forms and products of the early stages of development. The chapter on the geology of Mauna Kea is "textbook" description of one of the best type examples of a volcano which has "lived" through almost all stages of Hawaiian volcanism. The chapter on PETROGRAPHY is an excellent presentation of the processes involved and the nature of changes accomplished in the composi-

[1] THE FORMATION OF BASALTIC LAVA FLOWS. Jour. Geol. Vol. 45, No. 8, p. 873. 1937. (Not cited by the authors.)

[2] CROSS, WHITMAN. LAVAS OF HAWAII AND THEIR RELATIONS. U. S. Geol. Survey Professional Paper 88. 1915.

tion and physical characteristics of volcanic products during the development of the entire cycle.

Perhaps a word of caution should be introduced against too complete acceptance of the concept of the Eastern and Western Fundamental Fissures. Though far too incomplete as yet to constitute proof, the gradually accumulating data on the location of deep earthquakes in the islands suggest an echelon arrangement of the deep fractures, rather than separate parallel alignment.

Pleistocene Shorelines, Age of Rocks, and Geologic History

A tabulation is made on page 54 showing all Pleistocene shorelines determined to date in the Hawaiian Islands, and a summary is presented of the evidence for each found on the island of Hawaii. Study of the text shows that some of this evidence is positive, while some is largely inference. The evidence is positive that the coast of Kohala and the northeast coast of Mauna Kea were submerged in the latest 25-foot high stand of the sea. Also positive are the shoreline deposits on Kohala at 250 feet above present sea level and the evidence that the major canyons of Kohala have been drowned and re-trenched at least once since their erosion. Some soil stripping suggests that Kohala may have been submerged to 1,200 feet below present sea level, but the evidence does not compare with that found on Lanai, the type locality. Evidence of the two intermediate negative shifts of sea level is inferred, as is also the hypothesis that the major canyons of Kohala and Ninole were cut on an old surface that antedates Stearns' Lualualei 1,200-foot negative stand of the sea.

Possible stratigraphic relations and geologic age of the five volcanic series are tabulated on page 62. The relationship of the Mauna Kea glacial deposits to the Laupahoehoe volcanic series permits a logical dating of Recent or Late Pleistocene for those volcanic series which are either younger than, or interbedded with, lavas and ash deposits of the Laupahoehoe series. This category includes the surface members of the Hualalai, the Kau, and the Puna volcanic series. Those series known to be older than the base of the Pahala ash are confidently assigned a date of pre-Wisconsin. Without question this category includes the Hawi, Hamakua, Kahuku, and Hilina volcanic series, and the much older Pololu and Ninole volcanic series. There is some question in the case of the Waawaa volcanic series. The field evidence described on page 145 places it at least correlative with the Laupahoehoe series, but the lack of exposure in deep sections precludes any assurance that the Waawaa lavas lie under all of the Pahala ash section.

By definition the Hamakua, Kahuku, and Hilina series lie under the base of the Pahala ash, but another consideration perhaps justifies caution in considering them all of the same age. The surface lava flows of the Kahuku and Hilina series show much less decomposition than those of the Hamakua series. The amount of rock decomposition depends on so many factors other than age that this fact cannot be considered as compelling evidence. Only in the narrow belt of rainfall on the southeast slope of Mauna Loa are Kahuku lavas found in moisture conditions approaching those of the northeast slope of Mauna Kea. In this one area of exposure of Kahuku lavas, the lack of rock decomposition and the absence of stream erosion in their surface at least suggest that the Kahuku volcanic series may be considerably younger than the Hamakua volcanic series of Mauna Kea.

The tentative correlation and age assignment offered for the Pololu and Ninole volcanic series seem to hinge on a comparison of local erosional history with that of Oahu and West Maui. Almost all information on this subject is gained from Kohala. No field work on the Ninole series was done for this report in addition to that upon which the earlier Kau report was based. In the discussion of the great erosional unconformity between the Ninole and the overlying volcanics, the only comment (page 66) on decomposition of the rocks is that "Some of the [lava] beds are partly altered by weathering." This modest statement is hardly what one would expect to find describing the decomposition of porous lava in an area of 120 inches of rainfall which had undergone erosion sufficient to carve the topography attributed to erosion, and is certainly different from the description of decomposition of the Pololu volcanic series. One wishes that more field work had been done in the Ninole area to yield more information about the decomposition, as the possibility that block faulting may have played a great part in the formation of this "old" topography seems still not to be excluded by the present descriptions.

In the discussion of the erosional unconformity between the Pololu series and the Hawi series the authors conclude (page 178) that "a repose period intervened between the eruption of the Pololu and Hawi volcanic series." When one considers the facts—presented in the text—that the Hawi volcanic series is made up of flows numbering in the order of magnitude of only a hundred, widely separated from each other in time, each covering a very small part of the surface, one gets the impression that the general picture of erosion and surface decomposition is equally well explained by a slow dying-out of activity, not requiring a "repose period." However, there is no dearth of evidence of a great deal of decomposition of the Pololu, as well as of the older members of the Hawi, volcanic series.

To find correlation between the erosion history of Kohala and West Maui and Oahu, the rather general statement is made on page 171 that older alluvium in the Kohala valleys "was deposited during several epochs and is separated by erosional unconformities," and the inference is drawn on page 55 that different deposits of older alluvium were graded to different stands of the sea. No outcrops of older alluvium are described, nor localities cited in the text, in which an erosional unconformity was found between two deposits of the older alluvium; nor are there descriptions of any locality in which two terraces in juxtaposition show difference of surface elevation to indicate that they were aggraded to distinctly different base levels. Since this evidence is critical in the interpretation of the erosion history of Kohala, one wishes that more detailed descriptions of localities had been given in the text.

Correlation of erosion history, extending back through Pleistocene time, on island surfaces from Oahu to Kohala, presupposes no differential isostatic movement of the islands. The discussion of the correlation back to the Pliocene would be more complete had the authors introduced the question of possible isostatic movement of Kohala Mountain during the Pleistocene in response to the heavy loading associated with the building of the domes of Mauna Kea, Hualalai, and parts, at least, of Mauna Loa and Kilauea. Some data are introduced by the authors (but not discussed in this connection) which might have a bearing on this question. In discussing the structure of Kohala Mountain (page 180), it is pointed out that "an unusual number of dikes dip northward from 60 to 85 degrees in the northern side of the mountain," which is a greater departure from vertical than is to be expected. Not pointed out in the text, but apparent on plate 1 (the geologic map), is the fact that the dip of the Pololu lava surface on the southwest slope is steeper than it is on the northeast slope; and that the southwest slope, from caldera crest to shore, is shortened in comparison with the northeast slope. It would have been interesting had the possibility been discussed that these two structural facts might be related to actual structural tipping of Kohala Mountain to southward, perhaps in connection with the loading postulated above.

The section of geologic history, which cross-correlates the stratigraphic column, the geologic time scale, and the sequence of Pleistocene changes of sea level, is not as well substantiated in two instances as one would hope for from the material presented in the preceding sections of the text. The main bulk of Kohala, the Pololu volcanic series, is considered (page 56) to

be younger than the bulk of Haleakala on Maui, but is assigned a Pliocene age; whereas Haleakala has been assigned an age of Pliocene or Early Pleistocene in the bulletin on Maui.[3] One would welcome a short discussion of the basis for this change. Field evidence presented in the discussion of Mauna Kea (page 167) shows that a glacial outwash deposit, formed during melting of the summit glacier, is older than the cutting of the present Mauna Kea gulches, which have subsequently been drowned and floored with alluvium aggraded to the latest 25-foot high stand of the sea, and lastly re-trenched to present sea level. Yet, with no explanatory discussion, the time of the melting of the Mauna Kea glacier and the described sequence of erosion history are correlated with the latest eustatic lowering of sea level from plus 5 feet to the present. One would expect the melting of the glacier to be correlated with the rise of sea level leading up to the 25-foot positive stand.

Pyroclastic Deposits

The treatment of the pyroclastic deposits of the island warrants considerable comment. The authors have abandoned Wentworth's separate formation names for the different ash deposits,[4] and have combined some of the formations into a proposed new "Pahala ash." Justification for this enlarged concept of the "Pahala ash" seems to be summed up in the statement from page 72, "Despite the fact that accumulation of the Pahala ash continued over a long period, the lower part, constituting the bulk of the deposit, appears to be essentially contemporaneous all over the island. It can be traced directly across Mauna Loa to Mauna Kea, and from Mauna Kea to Kohala Mountain. The lower part . . . serves as a widespread horizon marker. . . ." In the stratigraphic tabulation on page 62, the lower part of the deposit, considered as the horizon marker, is placed on top of the Hamakua, the Hilina, and the Kahuku volcanic series, and beneath the Laupahoehoe, the Puna, and the Kau volcanic series respectively on Mauna Kea, Kilauea, and Mauna Loa. No type locality of the horizon marker is described, but one can be deduced to be on Mauna Kea at some point along the margin of the oldest flow of the Laupahoehoe volcanic series, in a cut sufficiently deep to expose a considerable section of the upper lavas of the Hamakua volcanic series. The formation name "Pahala ash" is limited to this horizon marker in the stratigraphic column (page 62), and the same limitation apparently is in the minds of the authors in many places in the text (*i.e.*, pages 68 and 103), particularly when the reference is to "Pahala time." However, in every description of the field deposits of "Pahala ash," it is pointed out that the ash sections include pyroclastics ranging in age from "Pahala" time to Recent. The reviewer believes that clarity would have been gained by retaining Wentworth's formation names for the several deposits of ash, and by introducing a new local name for the specific horizon of geologic time during which the authors believe the basal member of many of the ash sections was deposited.

The authors' concept of the origin of the Pahala ash is summarized in the section titled ORIGIN on page 71, and the discussion which governed their conclusions is largely found in the following section on distribution and character of the Pahala ash on Mauna Loa. Mauna Kea is well substantiated as the source of much of the ash, especially on its own slopes. The importance of Kilauea as a source of part of the ash is based on the presence of coarser essential lapilli and accessory lapilli, as well as thickening of the deposits to the lee of Kilauea.

The significance of the thickening of the section as proof is depreciated, perhaps, by several points brought out in the text. An unstated proportion of the extra thickness is made up of fine ash which was moved laterally by the wind (page 75) after its initial deposition from the ash showers. Since this whole area in the lee of Kilauea is dry and wind-swept, several thin blankets from a source more distant than Kilauea might easily have been concentrated into local thicker sections. Additional field work might have been directed at a more quantitative evaluation of this factor.

The described thinning of the ash from the slope of Mauna Kea to the Glenwood locality northeast of Kilauea, and the thickening again southwest of Kilauea, is critically significant only if the Glenwood section contains all of the Mauna Kea ash section. The authors cite the test borings near Mountain View and the shaft at Olaa, which penetrate no great amount of ash, as evidence in the third dimension that the Glenwood deposit does contain the whole of the ash section. The deepest borings logged (page 257) are 160 feet deep and cut through, at the most, eight flows; and the Olaa shaft cuts 220 feet through possibly 10 flows (page 248). Both are in the area inundated by flows from Mauna Loa's northeast rift, where one would expect the greatest number of flows to be interbedded in the ash section; so there is reasonable doubt that the borings and shaft are deep enough to prove the question. The small amount of decomposition of the lava flows lying immediately under the Glenwood deposits, and the elementary development of surface streams in the area (page 218), are two other factors which point toward the probability that these lava flows are correlative with some part of the Laupahoehoe volcanic series and are interbedded in the ash series, rather than correlative with the Hamakua flows older than the basal member of the ash series.

In a different part of the text (page 93), not discussed at all in connection with the problem of origin of the ash, the authors point out the possible existence of ash-producing vents, in a position to windward as favorable as Kilauea, which may have contributed to the apparent greater thickness of the sections to the lee of Kilauea. The statement is "It is probable that Mauna Kea extends 6 to 10 miles southward under the Recent lava flows of Mauna Loa directly athwart the latter's northeast rift. The hypothesis is offered that Mauna Loa Volcano terminates against the buried Mauna Kea dome approximately under the 8,000 foot level on the northeast rift. . . ."

The presence of the accessory lapilli (probably from phreatic explosions) and coarser essential lapilli are qualitatively compelling evidence as to Kilauea's contribution to the ash deposits. More detailed field work directed specifically to this phase of the problem probably would have enabled the authors to make a more quantitative appraisal of the duration and amount of Kilauea's active contribution to these ash deposits. This is particularly desirable in this instance, because the ash relationships are the most tangible evidence available in the problem of correlating the age of Kilauea.

In discussing Hualalai as a contributor to the Pahala ash, the authors obviously refer to the original Pahala ash formation on the southeast Mauna Loa and south Kilauea slopes. Hualalai probably contributed to the ash lying on the lavas mapped on Kahuku in the cliff at Kealakekua Bay which is Pahala ash under the new definition. It also contributed to the ash on the kipukas in the Kainaliu area (page 70), and to the ash interbedded with the flows of the Kau volcanic series in Kona; all correlative with the Laupahoehoe volcanic series, and thus correlative with the upper part of the new Pahala ash.

It is apparent from their discussion of the origin and distribution that the authors consider Mauna Kea the source of much of the ash in the basal "horizon marker," the ash of "Pahala time" in the stratigraphic column. This consideration would suggest that the choice of a name for the horizon should have been made, more appropriately, from some Mauna Kea feature

[3] STEARNS, H. T., and MACDONALD, G. A. GEOLOGY AND GROUND-WATER RESOURCES OF THE ISLAND OF MAUI, HAWAII. Hawaii Div. of Hydrography, Bul. 7. 1942.

[4] WENTWORTH, C. K. ASH FORMATIONS OF THE ISLAND HAWAII. Hawaiian Volcano Observatory, 3rd Spec. Rpt. 1938.

or locality. Also, the proven diversity of origin of the ash deposits in different areas constitutes an additional strong objection to the abandonment of the several local formation names for the deposits.

On page 75 the authors describe the showers of pumice and Pele's hair produced during historic eruptions from Mauna Loa and conclude "Although such deposits during any one eruption are too small to measure, the 30,000 years of Recent time, [30,000 probably used purely to indicate order of magnitude] with several eruptions each decade, must have produced an accretion of ash measurable in feet in the leeward kipukas." According to the stratigraphic column on page 62 the ash mantle from all of the eruptions of the Lower and Upper Laupahoehoe volcanic series, and from the eruptions of the exposed part of the prehistoric member of the Hualalai volcanic series must be added to the above described showers, and be interbedded with or accumulated in kipukas in the lava flows of the Kau volcanic series. Part of this deposit is described by Wentworth and called the Kona formation, and comparable deposits are exposed on the favorable parts of the eastern flank of Mauna Loa between the rift zones. In the present text, however, the only description is as follows (page 78): "The ash deposits of the prehistoric member of the Kau volcanic series are insignificant in volume. Deposits of pumice a few inches to 2 feet thick lie just leeward of the large cinder cones but they cover too small an area to be shown on plate 1." It is regrettable that the authors did not do additional field work sufficient to present a better picture of these ash deposits associated with the Kau volcanic series which have an important bearing on their study of the Pahala ash; in fact they are the upper part of the Pahala ash as newly defined.

In the section on the ash deposits of the Puna volcanic series (page 106), the authors' use of the word *ash,* not in conformity with their restricted definition on page 18, is most confusing because these Kilauea surface pyroclastic deposits (Wentworth's Keanakakoi formation) include important horizons of pure lithic material as well as horizons of pure vitric material. Careful field recognition of these two types of deposit of different physical origin, and critical separate mapping of their aerial thickness and distribution is essential before the best analysis of Kilauea's possible contribution to the older Pahala ash sections can be made. In the present publication, the authors use Stearns' former distribution map from the Kau report,[5] which has been found to be unsastifactory for a critical analysis of ash distribution by subsequent workers.[6]

Historic Volcanic Activity

Very comprehensive, yet well-summarized, discussions of historic volcanic activity are found in the three chapters on Hualalai, Mauna Loa, and Kilauea. The information presented represents a thoughtful and selective accumulation of essential material from the maze of recorded observations and data derived from lay as well as scientific sources.

Some adverse comments seem justified on the presentation of legendary evidence of activity. The statement (page 78) "Hitchcock reports an eruption in 1780 . . . and one on January 21, 1803, [from Mauna Loa] . . . but cites no authority for these statements" is incorrect. Hitchcock cites as authority for the 1780 activity, the statements of Hawaiians who correlated the time with the time of Captain Cook's ill-fated visit, an event of sufficient interest to the Hawaiians to stand clearly in their memory. He also cites as authority for the flow of January 21, 1803, a report by John Turnbull, who saw the activity from his ship as it left Kealakekua Bay. Eruptions of Mauna Loa in about 1780, 1803, and 1832 thus are all well substantiated, whereas the location of each is not exactly described in the literature. Under the circumstances it seems inadvisable to map one of several possible flows and label it *1832-?* on the geologic map.

The references to Hitchcock (page 112) on Hawaiian legends of Kilauea activity should have been checked against Hitchcock's later book,[7] Fornander's collection, and Ellis' reports, because Hitchcock himself corrects some of the material presented in his earlier short paper. The date A.D. 140 should be about A.D. 450. The idea that the activity of 1420 (not 1620) was violently explosive was Hitchcock's own surmise and not based on legend. The quotation from Ellis suggests that there was a flank flow from a cone on the Puna rift a few miles distant from Kilauea in the time of Liloa (1420 to 1450). "Within a few miles of Kilauea, we passed three or four high and extinct craters. One of them . . . sent forth, in the days of Riroa, . . . most of the lava over which we were travelling." The legendary accounts of activity in the time of Kanipahu (1180-1210) read more like descriptions of an explosive eruption.

Sufficient detailed description of different eruptions is given to bring out material needed in the excellent discussions of typical eruptions of various nature which have taken place, and the summaries of presently known facts about volcanic activity, gained from the studies of Hawaiian activity, are thorough and very clearly presented. Attention perhaps should be called to a few specific passages.

One might possibly gain the impression from the discussion of the 1790 eruption (page 116) that the "Black Ledge" was terrace left by the engulfment of 1790. This is not intended, as the "Black Ledge" marked the high point of the tremendous refilling of the crater between 1790 and the collapse prior to Ellis' visit in 1823, probably associated with the flank eruption of 1823.

The discussions of summit caldera activity compared with flank eruptions would have been a little more complete had the authors enlarged on what appears, from the descriptions, to be a difference between certain flank flows. In one type, illustrated by the Kilauea flows of 1920, 1922, and 1923, and perhaps even by the flows of 1823 and 1840, the flank flow apparently is fed by lateral passage of the lava from a lake in the caldera through shallow rift-zone channels, and no fountaining or building of vent cones is apparent at the point on the rift where the lava re-emerges. In the other type, illustrated by most of the historic Mauna Loa flank flows, and perhaps many of the pre-historic Kilauea flows, the caldera vent appears to be abandoned after a flank vent is opened and the fountaining and vent-cone building takes place on the flank at the point where the flow emerges.

The statement (page 93) that the 1935 lava flow was "bombed . . . in an effort to stop the flow . . ." is inaccurate. Quoting from the VOLCANO LETTER for December 1935, page 4, "The volcanologist recommended bombing the source at elevation 8500 feet on Mauna Loa, to break up the stability of the flow tunnels, and to divert the flowing at the source region." The wording of the text in this section, and the paucity of references, fail to convey to the reader the fact that the plans of the Volcano Observatory for such diversion of flows which threaten vital areas date back before precision bombing was possible.

The authors have made a valuable and competent tabulation of known statistical data on all historical eruptions of both Mauna Loa and Kilauea, and submit the data to searching analysis for possible periodicity of eruption and possible correlation of eruption between the two volcanoes. They conclude that the statistical record shows no periodicity, no correlation with external influences such as sun spots, and no relation between the eruptions of Mauna Loa and Kilauea, in direct opposition to the beliefs of Jaggar and other workers who have used the same statistics to demonstrate possible periodicity and cor-

[5] STEARNS, HAROLD T., and CLARK, W. O. GEOLOGY AND WATER RESOURCES OF THE KAU DISTRICT, HAWAII. U. S. Geol. Survey Water-Supply Paper 616. 1930.

[6] FINCH, R. H. THE SURFACE ASH DEPOSITS AT KILAUEA VOLCANO. Volcano Letter 478, 1942.

[7] HITCHCOCK, CHARLES H. HAWAII AND ITS VOLCANOES. Hawaiian Gazette Co., Ltd., Honolulu. 1911.

relations. There are two relevant facts which save a cautious reader from the necessity of "jumping off either deep end." First, the fact that definite volcanic activity need not culminate in a visible surface eruption, so that it is possible that many periods of sub-surface activity have occurred without being known and recorded in the hundred-odd years for which we have eye-witness testimony. Thus the historic record of activity must be considered as incomplete at best. Second, the fact that even the eye-witness record is too short to prove or disprove statistically the existence of periodicity or correlations of the sort being considered.

The authors offer a comprehensive consideration of the evidence bearing on the age of Kilauea and its structural relation to Mauna Loa and conclude that Kilauea started activity as a vent perhaps nearly coincident with the renewal of Mauna Loa activity which produced the Kahuku volcanic series. There seems to be no serious objection to considering the Hilina and the Kahuku volcanic series as the same age. At the same time, there seems to be no compelling evidence to decide for or against the Mauna Loa origin of the lavas of both series. Projections of slopes in cross section can reasonably permit either point of view and seem to favor neither. Also there is no question that Kilauea has contributed to the Pahala ash. Its type of contribution is not associated with "old age" activity, but could have started from the first eruption of the newly opened vent. Further field work may add a good deal more specific information on the questions of how much material, what kinds of material, and in what part of the section are the contributions from Kilauea in the Pahala ash deposit. Until additional information is available, the authors' conclusions are as tenable as any which have been considered, though personally the writer favors Stone's[8] thesis that the Hilina lavas are part of Mauna Loa, and that Kilauea as a vent was "born" during the time of the accumulation of the ash series lying on the Hilina lavas.

[8] STONE, JOHN B. THE PRODUCTS AND STRUCTURE OF KILAUEA. Bernice P. Bishop Mus. Bul. 33. 1926.

ERRATUM

(in VOLCANO LETTER No. 493, July-September 1946)

Page 2, last paragraph, lines 2 and 6: *for* stopping *read* stoping.

Hawaiian Volcano Observatory Report for October-December 1946

VOLCANOLOGY

October

The number of earthquakes recorded at Kilauea and Mauna Loa was 49 and 59 respectively. The shake at 18:43 on October 29 originated deep under the east slope of Mauna Loa. This shake coupled with those of September 2 and 4 may be taken as a slight indication of uneasiness of Mauna Loa. A greater than normal easterly tilt during October is probably a further indication of such uneasiness. Northerly tilt was normal.

November

Earthquakes of Mauna Loa origin predominated in November. Sixty shakes were recorded on the Mauna Loa seismograph and 54 at Kilauea. There was no tilt in the east-west direction and a slight accumulation of southerly tilt.

Fume over Mokuaweoweo was observed from the Saddle Road during the morning of November 27.

December

During December, as in the past 2 months, more earthquakes originated under Mauna Loa than under Kilauea. Seventy shakes were recorded at Mauna Loa and 54 at Kilauea. The preponderance of Mauna Loa shakes as well as the earthquake pattern are indications of continued uneasiness of Mauna Loa. Tilt records, however, do not show indications of impending activity. There was no accumulation of tilt either east or west in December. The slight southerly tilt that started in November continued in December.

R.H.F.

SEISMOLOGY

Earthquake Data, July-September 1946

Week Ended	Minutes of Tremor	Very Feeble	Feeble	Slight	Local Seismicity*	Teleseisms
October 6	4	0	0	0	1.00	0
13	10	3	0	1	4.00	0
20	8	4	0	0	4.00	0
27	7	4	0	0	3.75	0
November 3	4	2	0	0	2.00	1
10	8	2	1	1	6.00	0
17	16	3	2	0	7.50	1
24	5	2	0	0	2.25	0
December 1	9	0	0	1	4.25	0
8	9	1	1	0	3.75	0
15	9	1	3	0	5.75	0
22	13	0	2	0	5.25	2
29	9	4	0	0	4.25	0

* For definition of local seismicity, see VOLCANO LETTER No. 371.

The data of the following local disturbances were determined from seismograph stations operated on the island of Hawaii by the Hawaiian Volcano Observatory of the Hawaii National Park. Time is Hawaiian Standard, 10 hours and 30 minutes slower than Greenwich. The number preceding each earthquake is the serial number of the quake for the current year.

104. October 8, 16:34, very feeble. Kilauea shake.
105. October 8, 23:56, slight. Felt locally and in Hilo. About 10 miles deep. NE slope of Mauna Loa, 1 mile east of seismograph.
106. October 10, 05:59, very feeble. Felt in Kona and on Maui. Deep under NW coast of Hualalai.
107. October 12, 12:59, very feeble. Kilauea shake.
108. October 14, 03:25, very feeble. Shallow focus near N end of Mokuaweoweo.
109. October 16, 10:09, very feeble.
110. October 16, 23:02, very feeble. Mauna Loa shake.
111. October 18, 01:04, very feeble.
112. October 25, 07:13, very feeble. Mauna Loa, NE rift.
113. October 25, 09:35, very feeble.
114. October 26, 05:52, very feeble.
115. October 27, 00:14, very feeble.
116. October 28, 06:53, very feeble. Mauna Loa, E slope.
117. October 29, 18:43, slight. Mauna Loa, E slope.
118. October 29, 21:00, very feeble.
119. October 29, 23:58, very feeble.
120. November 3, 19:04, very feeble.
121. November 4, 10:03, very feeble. Mauna Loa shake.
122. November 5, 08:37, feeble.
123. November 7, 00:59, very feeble. Mauna Loa shake.
124. November 11, 13:37, very feeble. Kilauea shake.
125. November 12, 13:24, feeble. Kilauea shake.
126. November 13, 05:41, very feeble. Kilauea shake.
127. November 13, 22:10, very feeble. Mauna Loa shake.
128. November 17, 01:14, very feeble. Mauna Loa, E slope.
129. November 20, 02:09, very feeble. Kilauea shake.
130. November 23, 10:15, very feeble. Mauna Loa shake.
131. November 30, 01:54, slight. Deep under E slope of Mauna Loa.
132. December 3, 12:56, feeble.
133. December 5, 11:33, very feeble. Mauna Loa, NE slope.
134. December 11, 13:53, very feeble. Kilauea shake.
135. December 12, 23:28, feeble. Kilauea shake.
136. December 13, 17:10, feeble. 5 to 10 miles under NE slope of Mauna Loa.
137. December 15, 02:36, feeble. Felt locally. Kilauea shake.
138. December 22, 07:02, feeble. Felt in eastern Hawaii. 15 miles deep, S of Hilo.
139. December 22, 11:53, feeble. Felt locally. Deep under Glenwood.
140. December 23, 00:10, very feeble.
141. December 24, 20:09, very feeble.
142. December 27, 12:05, very feeble. Kilauea shake.
143. December 28, 22:24, very feeble. Mauna Loa shake.

TELESEISMS

November 1, 00:50. slight.

November 11, 07:04. Slight.

December 20, 08:58. Moderate. Japan shake.

December 21, 00:17. Slight.

MICROSEISMS

Microseisms were moderate to strong throughout the quarter except on December 31 when they became very strong.

CRACK MEASUREMENTS

A few of the cracks around Halemaumau opened slightly in October. In November and December the cracks were stationary.

TILTING OF THE GROUND

Seasonal southerly tilt set in November 3, or a little earlier than usual. There was less than normal northerly tilt in 1946. Westerly tilt started on December 9, or about the usual time for change from easterly to westerly. There was no accumulation of tilt either east or west in 1946.

R.H.F.

Table of Tilt at Observatory on Northeast Rim of Kilauea

Week Ended		Amount	Direction
October	6	1.14″	S 71° E
	13	2.20″	N 80° E
	20	0.84″	N 45° E
	27	0.48″	N
November	3	0.80″	N 27° E
	10	0.31″	S 45° W
	17	1.32″	S 27° E
	24	0.10″	N 45° W
December	1	0.70″	S 31° E
	8	1.48″	N 76° E
	15	1.44″	S 42° W
	22	0.24″	N
	29	1.84″	S 11° W

HAWAIIAN VOLCANO RESEARCH ASSOCIATION

in cooperation with UNIVERSITY OF HAWAII

The **Hawaiian Volcano Research Association** was founded in 1911 for record of volcanoes in the Hawaiian Islands and around the Pacific Ocean. Its equipment at Kilauea Volcano, Hawaii Island, has been transferred to the United States Government, Department of the Interior, National Park Service.

The **University of Hawaii** cooperates in maintaining a research laboratory at Hawaii National Park. The **Association** and the **University** supplement the work of the government with research associates, instrumental plants and special investigation. Dr. T. A. Jaggar is their geophysicist resident in the National Park.

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UNIVERSITY OF HAWAII: T. A. Jaggar, Geophysicist

ANNUAL TILT PATTERN
AT THE HAWAIIAN VOLCANO OBSERVATORY

By H. A. POWERS

Seismologist, Hawaii National Park

The 22 years following the 1924 "collapse" of the Kilauea lava column have been relatively free of lava activity in Kilauea. Thus the tilt records from the Bosch-Omori seismograph on the northeast rim of Kilauea for this span of years offer a particularly valuable series from which to study the annual tilt pattern which is developed by forces other than visible eruptions.

As a starting point, tilt curves for a "standard" year have been computed (Figure 1, curves A and B, and columns A and B in Table 1). First an average north-south and east-west coordinate value was computed for each calendar month of the years 1925 through 1946 by adding the daily coordinates[1] of each month and dividing by the appropriate number of days. Then an arithmetic average was computed for all Januarys, Februarys, etc. The plotting of these average monthly coordinates was then compared in detail with the plotting of the actual monthly coordinates for each year in the series. Several of the actual annual "loops" departed radically from the computed average "loop" both in shape and dimension. In most of these, the departure was of a nature to be expected from volcanic events known to have occurred. A second computation of averages was made, using only the 7 years which showed the most symmetrical annual loop. This computation yielded an average loop which is remarkably comparable to the loop representing the average of all 22 years. Apparently the most radical deviations canceled themselves out in the larger average. The coordinates used to express the "standard" year were then derived by "smoothing" the 22-year averages in the direction of the values obtained in the selected 7-year average. The tilt loops for the years 1931 and 1944 most closely approach the "standard" loop. Admittedly this standard loop is not real, and perhaps never would be duplicated in nature, but it does give a quantitative picture of trends which are very real in the actual annual loops.

As the first step in the attempt to analyze the "standard" loop, the plotted curves of actual daily tilt were carefully searched for indications of dominant directions of tilt. Periods of time were chosen in which tilt continued for several consecutive days on the same azimuth. The most common direction in which tilt accumulated is N 45 E or S 45 W, associated in many instances with decided changes in air temperature. This direction also seems to have a significant structural expression, in that the Waldron Ledge segment of the rim of Kilauea Crater (the block upon which the tilt has been measured) strikes in general N 45 W, and is bounded to some extent by radial fault cracks trending N 45 E. This direction has been adopted in this study to express the direction of yielding to superficial causes of tilt. The direction N 20 E or S 20 W, which was discussed in VOLCANO LETTER No. 492, 1946, is used to express the direction of yielding to deep-seated forces affecting the Kilauea dome-structure. The most remarkable appearance of this Kilauea azimuth was in the extreme tilt to the southwest at the time of the collapse of the lava column and the explosive eruption in 1924. It has not appeared frequently in the daily tilt since 1924, but it does show up as a major direction in smoothed curves of daily and monthly tilt. These facts of occurrence are compatible with the concept that it is a direction of yielding to deeply acting forces, and that movements along it would be often interrupted by superficial movements of shorter duration. A third direction of facile movement, almost due east and west, appears occasionally. The swings of this azimuth, though rather infrequent, are of important amplitude and occur in many instances prior to a Mauna Loa eruption.

Other azimuths of tilt can be selected from the daily records, particularly from the smoothed curves. Some or all of them may have a significance which is being overlooked, but

[1] The daily coordinates refer to an arbitrary zero point, and state, in millimeters, the lateral migration of the writing pens of the instrument induced by tilting of the pendulum support. The constants are such that 10 mm. of lateral movement is induced by 1.21 seconds of tilt. Increase of ordinate and abcissa numbers indicate, respectively, north and east tilt.

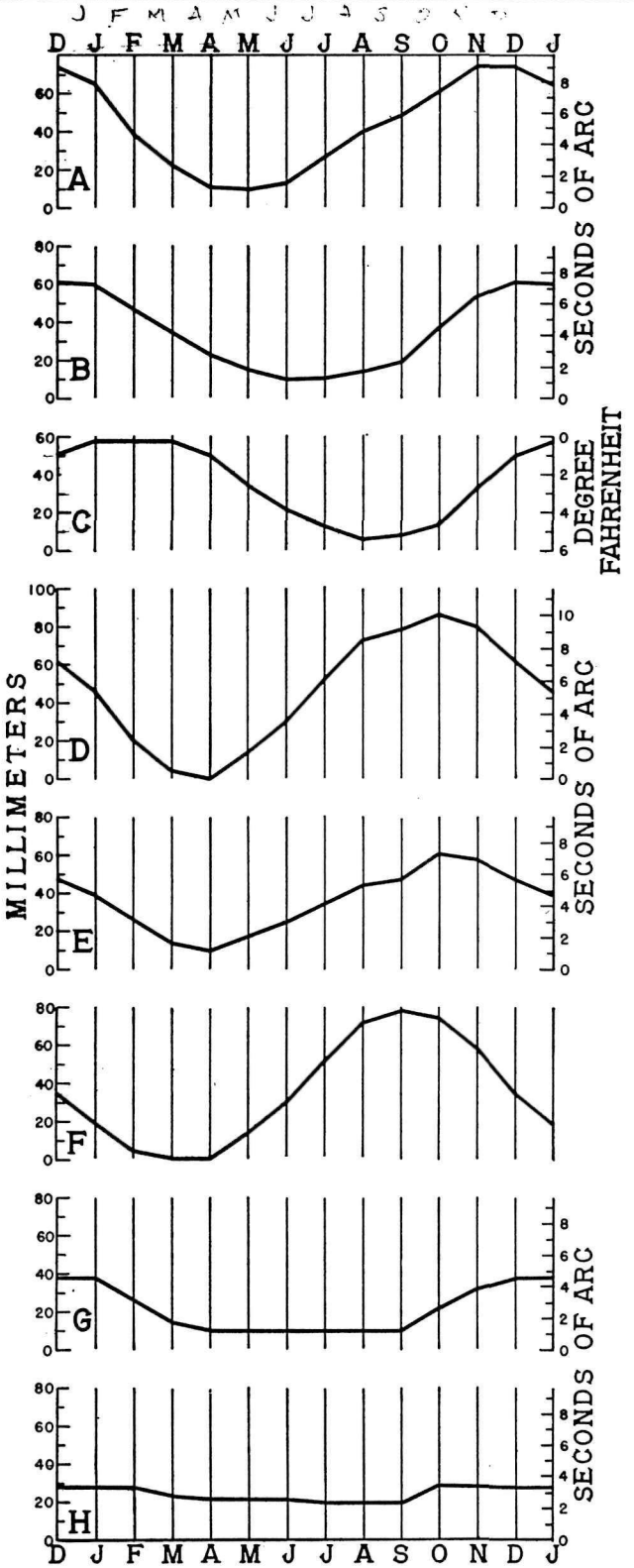

Figure 1.—*A* and *B*, respectively, N–S and E–W components of the "standard" annual tilt loop, computed from 22 years of tilt recorded by the Bosch-Omori seismograph on the northeast rim of Kilauea. North and east are up on the graph, and south and west are down. *C*, changes in mean monthly air temperature (slightly modified) on scale comparable to that of *A* and *B*. Lower temperature is up on the graph, equivalent to north or east tilt. *D* and *E*, respectively, residual N–S and E–W tilt obtained by subtracting curve *C* equally from curves *A* and *B*. *F*, postulated curve of effect of cumulative angular pull of sun. North pull is up on the graph. Scale is proportional to curve *D*. *G* and *H*, respectively, Kilauea and Mauna Loa azimuth residuals of tilt, computed from residuals remaining after subtracting *F* from *D* and *E* in proportions appropriate to tilting on direction N 20 – S 20 W. Upward pressure under the domes is up on the graphs.

this study to date seems to indicate that they are resultants of simultaneous movement on two or even three of the first-mentioned directions. Attention in this study will therefore be concentrated on the three directions postulated above: the N 45 E superficial block movement, the N 20 E Kilauea deep movement, and the east–west Mauna Loa deep movement.

Previous work[2, 3] has shown the influence of temperature change on tilt for periods of time ranging from one day, or of several consecutive days, to a year, in which increases in temperature compared with south and west tilt. A curve (not inverted) showing mean monthly range of air temperature at the Observatory was compared with the curves showing the N–S and E–W components of the "standard" tilt loop. A suggestion of similarity was observed if the temperature change was assumed to have either a three- or four-month lag in its effect on the tilt with increase in temperature correlating with north and east tilt. Study of actual annual loops versus their corresponding temperature curves showed a great lack of correspondence. It also posed the question of why the great lag in temperature effect "on the average," in the face of measured responses of daily tilt to daily temperature with at most a few hours' lag. Accordingly the mean monthly temperature curve was inverted so that decrease of temperature was associated with north and east tilt as originally advocated. Curves showing mean monthly maximum and mean monthly minimum temperature range were also introduced. It was obvious that perfect correlation of any one of the temperature curves with the tilt curves was not possible. However, studies of the daily curves show beyond a doubt that tilt is affected by temperature changes, and by presence or absence of strong insolation. Several consecutive cold cloudy days are associated with the greatest amounts of pure northeast tilt; warm cloudy days, with lesser amounts of northeast tilt; while days with extremely low minima but high insolation may show no northeast tilt at all. For the present analysis of the "standard" tilt loop, a curve intended to express a quantitative approximation of the monthly weather change which affects tilt was constructed by modifying the curve of monthly minima so as to give some weight to the factor of insolation (Figure 1, curve C). The changes of temperature are assumed to cause tilt of the superficial block in the direction N 45 E – S 45 W. The values from the temperature curve were subtracted from the values of the NS and EW components of the "standard" loop, and the residual values thus obtained give curves (Figure 1, curves D and E, and Table 1, columns D and E) which, surprisingly enough, suggest the possible tilt effect of another seasonal force, *i.e.*, the cumulated north–south component of the sun's gravitational pull.

H. O. Wood[4] outlines a theory of the possible influence of forced nutation strains on the rise and fall of lava in Kilauea. He says "These nutations (forced solar and lunar) are produced by the integration of this effect of inclined attraction upon each and every particle in the earth. If the earth were strictly rigid in the mathematical sense this action would produce only nutation and precession. But the earth is only quasi-rigid and, therefore, in addition to the tilting tendency, a tendency to the reconstitution, or readjustment, of the internal configuration of the earth particles may be expected." He evaluated the proportional influence of solar nutation and lunar nutation, and built up a time curve of strain which exhibits semi-annual maxima and minima at time of solstice and equinox, and fortnightly arches of smaller magnitude reflecting lunar influence.

[2] JAGGAR, T. A. SEISMOMETRIC INVESTIGATIONS OF THE HAWAIIAN LAVA COLUMN. Seismol. Soc. Amer. Bul. 10(4): 155-275, 1920.

[3] JAGGAR, T. A., and FINCH, R. H. TILT RECORDS FOR THIRTEEN YEARS AT THE HAWAIIAN VOLCANO OBSERVATORY. Seismol. Soc. Amer. Bul. 19(1): 38-51, 1929.

[4] WOOD, H. O. SECOND REPORT OF THE HAWAIIAN VOLCANO OBSERVATORY. Mass. Inst. Tech., 1917.

Table 1.—Tilt Values, Postulated Causal Components, and Progressive Residuals at Hawaiian Volcano Observatory

Month	A*	B*	C†		D‡	E‡	F§		G‖		H‖
	N–S	E–W	N–W	E–W	N–S	E–W	N–S	E–W	N–S	E–W	E–W
January	— 9	— 1	7	7	—16	— 8	—16	— 8	0	0	0
February	—26	—13	0	0	—26	—13	—14	— 7	—12	— 6	0
March	—16	—12	0	0	—16	—12	— 4	— 2	—12	— 6	— 4
April	—12	—12	— 8	— 8	— 4	— 4	0	0	— 4	— 2	— 2
May	— 1	— 8	—15	—15	14	7	14	7	0	0	0
June	3	— 5	—13	—13	16	8	16	8	0	0	0
July	14	1	— 8	— 8	22	9	22	11	0	0	— 2
August	13	3	— 7	— 7	20	10	20	10	0	0	0
September	8	5	2	2	6	3	6	3	0	0	0
October	13	18	5	5	8	13	— 4	— 2	12	6	9
November	13	16	19	19	— 6	— 3	—16	— 8	10	5	0
December	0	8	18	18	—18	—10	—24	—12	6	3	— 1

* Columns A and B. Coordinates of the "standard" tilt loop, stating change from preceding month, expressed in millimeters as measured on the Bosch-Omori seismograph. Negative coordinates represent south and west tilt. 10 mm. is equivalent to a tilt of 1.21 seconds of arc.

† Column C. Fractional part of tilt attributed to changes in mean monthly air temperature. 10 mm. postulated to be equivalent to a change of 1° F. Warmer temperatures postulated to cause south and west tilt. Total range of tilt on northeast–southwest direction is 8.7 seconds.

‡ Columns D and E. Residuals obtained by algebraically subtracting column C from A and B.

§ Column F. Fractional part of tilt attributed to cumulative warping of the equatorial bulge by seasonal changes in the angle of the sun's pull. Total tilt on direction N 20 E – S 20 equals 10.6 seconds.

‖ Columns G and H. Residual tilt not accounted for by columns C and F, divided onto "Kilauea" and "Mauna Loa" azimuths, respectively. This tilt may possibly represent a seasonally recurring "squeeze up" of lava pressure, followed by collapse, under the two volcanic domes, possibly associated with the kneading effect postulated in curve *F*.

Jaggar and Finch[5] suggest the possibility that the semi-annual solar tidal maxima and minima may warp the excess of mass of the earth's crust at the equator and in the Hawaiian ridge.

If Wood's strain is applied as a directional force on the equatorial bulge, and the application of the force is considered as cumulative in effect, the maximum accelerations would appear at solstice, but the points of flexure would occur at equinox. If the cumulative application of these strains actually caused a bulging to the north in summer and to the south in winter, the probable curve of bulge would be skewed somewhat in its shape from a pure sine curve. In the northern hemisphere, the north bulge might possibly show a lag because the yielding to the force would have to be a positive bulging against the elastic strength of the crust and against gravity; whereas, after the flexure from northward to southward application of the strain (at fall equinox), elastic rebound and gravity would be coupled in the same sense with the application of strain which might allow the greatest acceleration of the southing curve to appear rapidly after the point of flexure.

Curve F in Figure 1 is a crude concept of the possible cumulative north–south angular pull of the sun, skewed in accord with the discussion above. The amplitude of the curve was arbitrarily chosen to be of the same order of magnitude as that of the residual N–S tilt pictured in curve D. While the curve is not a precise mathematical computation, sufficient scientific honesty was employed in its construction to satisfy the writer that the resemblance between curves D and F is not solely due to "wishful thinking."

The residuals obtained by subtracting curve F from curves D and E are the algebraic sum of (1) the cumulative errors introduced in the analysis to this point, (2) any rhythmic tilt factors which may possibly exist but have not been considered, and (3) the average of any tilt effect caused by strictly volcanic pressure fluctuations during the period studied. These residuals have been computed to two curves, G and H, showing the residual tilt changes on the direction N 20 E to S 20 W (Kilauea) and the direction due E to W (Mauna Loa), respectively. These curves show pressure increase in the winter season and pressure decrease in the summer, which may be entirely coincidental, but also may fit with the observed fact that Hawaiian volcanic eruptions show a tendency to begin more frequently in winter than in summer.

As an approach toward a testing of the possible reality of these hypotheses, the curves of monthly tilt for the years 1930 to 1946 inclusive have been adjusted, factoring out the postulated tilt effect of the accumulated sun strain and the postulated effect of monthly changes of temperature. In the first step, monthly tilt, assumed to be caused by accumulated sun strain, was algebraically subtracted from the actual monthly tilt curves, in proper proportion from the north–south and the east–west curve to express the assumption that this tilt is effective on the Kilauea or N 20 E – S 20 W azimuth. From the residuals thus obtained, monthly tilt, assumed to be caused by the recorded changes in mean air temperature from month to month during this period, was algebraically subtracted in proper proportion to express the assumption that this tilt is superficial and affects the N 45 E – S 45 W azimuth. No attempt was here made to give a quantitative correction for changes in insolation. The residuals were then factored into tilt changes on the Kilauea azimuth (N 20 E) and the Mauna Loa azimuth (E–W).

The monthly residuals obtained from these computations are arranged in Table 2, *A* and *B*. It is apparent in the tabula-

[5] Jaggar, T. A., and Finch, R. H., *Op. cit.*

Table 2.—Monthly Residuals on Kilauea and Mauna Loa Azimuths

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
A. *Monthly residuals on Kilauea azimuth (N 20 E – S 20 W)*												
Positive residuals (NE tilt) greater than 0.6 sec.	6	4	0	5	5	4	7	4	6	11	9	11
Neutral residuals between plus 0.5 sec. and minus 0.5 sec.	5	2	6	6	7	8	6	10	7	6	6	3
Negative residuals (SW tilt) greater than 0.6 sec.	6	11	11	6	5	5	4	3	4	0	2	3
B. *Monthly residuals on Mauna Loa azimuth (E – W)*												
Positive residuals (E tilt) greater than 0.6 sec.	4	5	5	2	8	5	3	3	2	9	5	3
Neutral residuals between plus 0.5 sec. and minus 0.5 sec.	8	7	7	11	6	10	10	9	14	8	6	10
Negative residuals (W tilt) greater than 0.6 sec.	5	5	5	4	3	2	4	5	1	0	6	4

Table 3.—Adjusted Monthly Residuals on Kilauea and Mauna Loa Azimuths

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
A. *Monthly residuals on Kilauea azimuth after subtracting curve G*												
Positive residuals (NE tilt) greater than 0.6 sec.	6	5	6	7	5	4	7	4	6	3	5	6
Neutral residuals between plus 0.5 sec. and minus 0.5 sec.	5	7	5	5	7	8	6	10	7	13	7	7
Negative residuals (SW tilt) greater than 0.6 sec.	6	5	6	5	5	5	4	3	4	1	5	4
B. *Monthly residuals on Mauna Loa azimuth after subtracting curves G and H*												
Positive residuals (E tilt) greater than 0.6 sec.	3	8	9	4	8	5	3	4	1	1	2	1
Neutral residuals between plus 0.5 sec. and minus 0.5 sec.	9	7	6	11	6	10	12	9	12	8	7	9
Negative residuals (W tilt) greater than 0.6 sec.	5	2	2	2	3	2	2	4	4	8	8	7

tion for the Kilauea azimuth residuals, and less so for Mauna Loa, that there is remaining an annual curve which has not been factored out. On the Kilauea azimuth, a majority of the months show pressure increase tilt in October, November, and December, and a pressure decrease tilt in February and March. On the Mauna Loa azimuth, a majority of the months show pressure increase in October, but there are no outstanding months of pressure decrease. In view of this evidence, it is assumed that curves G and H (the residuals from the breakdown of the "standard" loop) may represent a third annually recurring tilt pattern. These curves were accordingly factored out from the actual monthly record and the residuals obtained are again grouped in Table 3, *A* and *B*. Approximately half of the residuals now show a neutral change of tilt, slightly more than one fourth show pressure increase, and one fourth show pressure decrease. This distribution might be expected from a random group of numbers. However, the plot of the 204 residuals in their respective order in the 17-year record shows pressure trend groupings. Of the 117 months on the Kilauea azimuth which show an appreciable tilt residual, only 31 occur as zigzag months, *i.e.*, isolated months flanked by residuals of opposite sign, and the rest occur in groups of 2 to 7 consecutive months with the same pressure sign. On the Mauna Loa azimuth, of 98 months, only 25 occur as zigzag months. This grouping in patterns suggests that the residuals may represent real tilt fluctuations caused by changes of volcanic pressure, and not merely accidental random values produced by the manipulation of a set of numbers.

SUMMARY

A "standard" annual tilt loop is derived from study of the tilt of a block of the northeast rim of Kilauea Crater recorded on the Bosch-Omori seismograph during the years 1924 to 1946, inclusive. From patterns of tilt developed during short periods of several days' duration, the hypothesis is advanced that the recorded tilting of this block is the resultant of tilting from three principal causes: (1) a superficial tilting in a northeast–southwest direction stimulated by surface forces, chiefly changes in air temperature and insolation; (2) a deep-seated tilting in the direction N 20 E – S 20 W, stimulated by changes of pressure under the dome of Kilauea; and (3) a deep-seated tilting in the direction approximately east–west, stimulated by changes of pressure under the dome of Mauna Loa.

The quantitative effect of seasonal changes of temperature is estimated to be a 12 second of arc tilt to the northeast for each drop of 1° F. in the mean monthly air temperature, and vice versa. The average annual effect is postulated to be a tilt to the southwest of about 8 seconds from April to September, and a northeast recovery of equivalent amount from October to February.

The hypothesis is advanced that two cyclical forces of annual period also affect the tilt. The first is postulated to be an annual swelling and deflation due to the cumulative effect of the angular pull of the sun on the equatorial bulge and the Hawaiian ridge. The effect of this cause is postulated to be a tilt in the direction N 20 E (at the site of the Bosch-Omori seismograph) of approximately 10.5 seconds of arc from April to September, and a recovery of equal amount and opposite direction from October to March. The second is postulated to be an annual swelling of about 5 seconds of arc in the direction N 20 E during October, November, and December, offset by an equivalent subsidence to the S 20 W in February, March, and April. A similar swelling to the east of less than 1 second of arc occurs in October, with the recovery spread over several spring and summer months. The thought is tentatively advanced that this short tilt loop expresses an actual annual "squeeze up" of lava pressure within the two volcanic domes which is an aftermath of the kneading of the equatorial bulge by the annual change in angular pull of the sun. Some slight support to this thought is offered by the fact that more eruptions of both Mauna Loa and Kilauea in historic time have started during the winter months than during the rest of the year.

The 204-month tilt record from the Bosch-Omori seismograph for the years 1930 to 1946 inclusive, has been adjusted by algebraically subtracting the postulated temperature effect and the three postulated deep-seated tilt effects. The residual tilt curves express the algebraic sum of (1) errors in the hypotheses and (2) true tilt due to increase and decrease of volcanic pressure. The fact that the residual curves show patterns of increase and decrease of pressure of several months' duration encourages the thought that the latter outweighs the former. A critical analysis of these residual monthly curves will be reported in a future VOLCANO LETTER.

Hawaiian Volcano Observatory Report for January–March 1947

VOLCANOLOGY

January

The year opened with both Kilauea and Mauna Loa inactive. Unusually heavy steaming from Mokuaweoweo was observed from January 19–22 inclusive. On January 21 the steam ascended as distinct columns a few hundred feet above the rim of Mokuaweoweo.

Tilt to the southwest was in about the usual amount for January. Tilt records indicate a slight decrease in pressure under Kilauea during 1946.

Sixty-three earthquakes were recorded on the Mauna Loa seismograph and 55 at Kilauea.

February

The number of earthquakes recorded during February, 35 at Kilauea and 42 at Mauna Loa, was the lowest since last September. Earthquakes originating from the southwestern part of Mauna Loa were more numerous than in the preceding several months.

There was a distinct accumulation of southerly tilt and a slight easterly tilt during the month. Such a southerly tilt is normal for February. The slight easterly tilt, instead of the normal westerly, may indicate an increase of pressure under Mauna Loa.

March

There was an increase in seismicity for the month because of an increase both in the total number of earthquakes and in the number of perceptible shakes. Fifty-three earthquakes were recorded at Kilauea and 62 at Mauna Loa.

The southwest tilt usual for this season of the year ceased about the last of February and was not resumed in March. The lack of southwest tilt may be explained partially by the fact that the mean temperature for March was lower than that for February.

R.H.F.

SEISMOLOGY

Earthquake Data, January–March 1947

Week Ended		Minutes of Tremor	Very Feeble	Feeble	Slight	Moderate	Local Seismicity*	Teleseisms
January	5	3	1	0	0	0	1.25	0
	12	8	2	0	0	0	3.00	0
	19	6	3	0	1	0	5.00	0
	26	20	2	1	0	0	7.00	2
February	2	12	2	0	0	0	4.00	0
	9	6	0	0	1	0	3.50	0
	16	5	3	0	0	0	2.75	0
	23	10	3	0	0	0	4.00	0
March	2	5	0	1	0	0	2.25	1
	9	12	3	0	0	0	4.50	0
	16	8	0	2	0	0	4.00	0
	23	5	2	1	0	1	6.25	0
	30	9	2	1	2	0	8.25	0

* *For definition of local seismicity, see* VOLCANO LETTER *No. 371.*

The data of the following local disturbances were determined from seismograph stations operated on the island of Hawaii by the Hawaiian Volcano Observatory of the Hawaii National Park. Time is Hawaiian Standard, 10 hours and 30 minutes slower than Greenwich. The number preceding each earthquake is the serial number of the quake for the current year.

1. January 2, 04:16, very feeble. Kilauea shake.
2. January 9, 07:16, very feeble. Mauna Loa shake.
3. January 11, 02:52, very feeble. Mauna Loa.
4. January 13, 01:43, very feeble. Mauna Loa.
5. January 15, 09:47, slight. NE rift Mauna Loa.
6. January 16, 14:03, very feeble. Mauna Loa.
7. January 19, 07:42, very feeble.
8. January 22, 22:46, feeble. Kilauea.
9. January 25, 18:16, very feeble.
10. January 26, 17:34, very feeble. Kilauea.
11. January 28, 16:22, very feeble. Near Mokuaweoweo.
12. January 29, 20:46, very feeble. Mauna Loa.
13. February 5, 22:53, slight. Kilauea.
14. February 11, 05:15, very feeble. W slope Mauna Loa.
15. February 13, 02:37, very feeble. Kilauea.
16. February 13, 09:44, very feeble. Mauna Loa.
17. February 17, 02:39, very feeble. Kilauea.
18. February 19, 15:19, very feeble. Felt in Kona.
19. February 21, 18:06, very feeble. Mauna Loa.
20. February 26, 18:54, feeble. NE rift Mauna Loa. Felt generally in eastern Hawaii.
21. March 5, 23:08, very feeble. Kilauea.
22. March 8, 21:40, very feeble.
23. March 8, 23:03, very feeble.
24. March 13, 03:52, feeble. Felt locally.
25. March 15, 16:14, feeble. Kilauea. Felt locally.
26. March 19, 23:06, moderate. Widely felt on island of Hawaii. Deep under Mauna Loa. Mauna Loa instruments dismantled.
27. March 20, 11:41, very feeble.
28. March 21, 17:37, feeble. Keahole Point, Kona.
29. March 22, 14:29, very feeble.
30. March 28, 09:57, feeble.
31. March 28, 09:59, very feeble.
32. March 28, 11:56, slight. Mauna Loa.
33. March 29, 20:11, slight. NE slope Mauna Loa. Felt locally and at Hilo.
34. March 30, 15:50, very feeble.
35. March 31, 00:37, very feeble. NE slope Mauna Loa.

TELESEISMS

January 24, 06:17, slight.
January 25, 23:50, slight.
February 25, 21:25, slight.

MICROSEISMS

Microseisms were moderate to strong throughout the quarter except for light spells on January 16; February 16, 21–23; and March 2–5, 27–31.

CRACK MEASUREMENTS

Cracks that were measured around Halemaumau and along the Chain of Craters Road showed practically no movement.

TILTING OF THE GROUND

Normal southwesterly tilt obtained until February 25. From this date until the end of the quarter there was no tilt accumulation.

R.H.F.

Table of Tilt at Observatory on Northeast Rim of Kilauea

Week Ended	Amount	Direction
January 5	1.50″	S 29° W
12	0.60″	S 35° W
19	1.70″	S 21° W
26	2.04″	S 69° W
February 2	0.17″	S
9	2.04″	S 45° W
16	0.26″	S 64° E
23	0.50″	S 45° W
March 2	0.17″	N 45° E
9	0.36″	N 72° E
16	1.37″	S 45° W
23	0.95″	N 40° E
30	0.38″	S 19° E

HAWAIIAN VOLCANO RESEARCH ASSOCIATION
in cooperation with UNIVERSITY OF HAWAII

The Hawaiian Volcano Research Association was founded in 1911 for record of volcanoes in the Hawaiian Islands and around the Pacific Ocean. Its equipment at Kilauea Volcano, Hawaii Island, has been transferred to the United States Government, Department of the Interior, National Park Service.

The University of Hawaii cooperates in maintaining a research laboratory at Hawaii National Park. The Association and the University supplement the work of the government with research associates, instrumental plants and special investigation. Dr. T. A. Jaggar is their geophysicist resident in the National Park.

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KILAUEA IN 1790 AND 1823

By R. H. FINCH

Volcanologist, Hawaii National Park

The object of this paper is to review the accounts dealing with the activity of Kilauea in 1790 and the lava flow of 1823 and to discuss probable events between these years.

There are several versions of the 1790 explosive eruptions of Kilauea based largely on accounts given by Ellis[1] and Dibble.[2] Accounts and interpretations by various authors were reveiwed by T. A. Jaggar[3] in 1921. Facts of the 1924 explosive eruption make it possible to give a different interpretation to some of the details.

The explosive eruption of 1790 was an important event in Hawaiian history as it occasioned the destruction of a portion of the army of Keoua, a chief of Hawaii, that was engaged in a civil war. The army had come to the volcano by the trail through Olaa from Hilo and had camped at the northern end of the crater. Hitchcock[4] assumed that the army passed to the south of Kilauea crater on the upper Puna-Kau trail across the Kau Desert. In view of the fact that the army camped for 3 nights and 2 days at Kilauea, the trail by the northern rim of the crater where water was available seems a more logical route. Bloxam[5] in 1825 was shown the place to the north of Kilauea Iki where some of Keoua's troops had encamped. The distribution of the 1790 ash also indicates that the northern route was the one used. An explosion took place shortly after the arrival of the army at Kilauea, and other explosions occurred during the next 2 days. On the third day the army continued on its way in three different companies. Shortly after getting under way a more violent explosion occurred and totally destroyed the middle company of about 80 people. The probable position of the middle company was at an elevation of about 3,800 feet on the Kapapala-Uwekahuna trail near the outer rim of Kilauea. The greatest thickness of the 1790 ash is found on the west-southwest inner rim of Kilauea crater and as the thickness diminishes rapidly both to the northwest and to the southeast, it appears that the greater thickness here is due to one or more directed blasts. The middle section of the army may have been passing at the time of a directed blast.

All native accounts agree that incandescent material was present in the explosion clouds. Some have interpreted the native accounts as indicating that spouting columns of molten lava were present. The absence of pumice and the relatively few bombs in the explosion debris make this idea improbable. The incandescence of an appreciable amount of material thrown out and numerous lightning flashes could account for all the glow reported. Many of the night explosions in 1924 produced a brilliant glow, and the sand and dust of some explosions was hot enough to scorch vegetation 1,800 feet from the Halemaumau rim. The deaths in the middle section of Keoua's army can easily be accounted for by hot sand and dust. The amount and distribution of the 1790 ash indicate that the explosions of that

[1] ELLIS, WILLIAM. NARRATIVE OF A TOUR THROUGH HAWAII . . . (Honolulu, 1917), p. 187.

[2] DIBBLE, SHELDON. HISTORY OF THE SANDWICH ISLANDS (Lahainaluna, 1843), p. 65.

[3] [JAGGAR, T. A.] *in* Hawaii. Volcano Observ. Monthly Bul., 9 (7): 114-118, July, 1921.

[4] HITCHCOCK, CHARLES H. HAWAII AND ITS VOLCANOES (2nd ed.; Honolulu, 1911), p. 165.

[5] BLOXAM, ANDREW. DIARY OF ANDREW BLOXAM, NATURALIST OF THE "BLONDE," . . . Bernice P. Bishop Mus. Spec. Pub. 10 (Honolulu, 1925), p. 10.

year were larger than in 1924. It may be assumed then, that in some of the larger explosions in 1790 the ash was still hot at a distance of 1½ miles from the explosion vent. The 1½ miles is a possible distance of the middle company. A temperature below the charring point of dry grass, about 400° F., could easily cause death and yet show no signs of severe burns.

The 1790 explosions were essentially phreatic in that they were produced by ground water gaining access to the conduit from which molten lava had recently withdrawn. The molten lava that was present as evidenced by cored bombs was not essential to the mechanics of the explosions. The bombs found in the ash may have been produced from a trapped pocket of lava that was left behind in the retreat of the lava column.

The 1790 ash represents the topmost layer, except for a small amount of 1924 ash, of the rather coarse material of the ash deposits around Kilauea. The greatest depth on the rim is 45 inches at the west-southwest. On the southwest rim it is about 12 inches thick. To the east of Cone Peaks, 9 inches of the 1790 ash are still in place. The time required to produce the widespread erosional unconformity that is found between the upper layer of coarse material and the next layer under it definitely indicates that the two topmost layers are not the product of one explosive period.

There had been one, perhaps two, lava flows in eastern Puna previous to the 1790 explosions. It is reasonable to suppose that the 1790 eruptions followed a collapse in the crater accompanying an eastern Puna lava flow. Ellis (p. 214) tells of a lava flow in the Malama district of eastern Puna about 30 years prior to his visit, or about 1790. On page 218 he tells of a lava flow in about the same area, which occurred in the time of Taraiopu. Fornander[6] shows that Taraiopu is another name for Kalaniopuu, who died about 1782. It is doubtful if these two accounts refer to the same flow. The description of the Kalaniopuu flow fits well the southern portion of what Macdonald[7] has called the lava flow of 1793 [1790]. The Macdonald map shows two flows essentially parallel and two separate fissure sources. The separate fissures are merely a further indication and not a proof that there were two flows. Thrum in the Fornander collection[8] lists a great eruption of Kilauea in 1783. As Hawaiian dates at this time were not exact, one wonders if the older of these eastern Puna flows was the great eruption of 1783.

The condition of Kilauea following 1790 is not known. On January 11, 1794, (Hitchcock, p. 161) Vancouver passed to the south of Kilauea and reported columns of smoke arising. This may have been due to short-lived activity such as has occurred several times since 1924 or it may have been due to a dust cloud in the Kau Desert. Menzies, on February 12, 1794, (Hitchcock, p. 72) reported an eruption from Kilauea in terms suggesting that he had merely encountered a dust cloud from the Kau Desert.

Sometime in the period between 1790 and 1823—the year of a great collapse in Kilauea and a lava flow from the southwest rift —a considerable quantity of pumice was deposited over the upper Kau Desert. The pumice is 44 inches thick near the southwest rim of Kilauea and can be found in place 1½ miles from the rim. It probably came from a vent near the southern end of Kilauea while trade winds were blowing. It may well be that Kilauea showed but little or no activity for several years following 1790 and that the pumice eruption occurred about the time that continuous activity commenced.

The sinking of the lava column in 1823 left a relatively flat floor about 1,000 feet below Uwekahuna.[9] The flat floor indicated the drainage of a lava lake involving nearly all of Kilauea crater. The drainage must have been through a crack leading to the southwest rift system that was about 700 to 800 feet below the Kilauea rim on that side. Widespread activity prior to the 1823 lava flow and collapse is evidenced by the presence of several spatter cones on the black ledge as shown by a sketch in Ellis, page 176. The black ledge which represented the level reached by molten lava prior to the 1823 flow resulted from contact cooling with the crater walls. The flatness of the floor after the collapse of 1823 is a good indication that the crates had been filled with molten lava and that the fill must have been made in a short time.

The infilling of the crater prior to the collapse in 1832 affords a clue as to the possible time involved in the infilling prior to 1823. The volume of the infilling prior to the 1823 collapse is not known, but it must have exceeded the amount engulfed in 1823 plus the volume of the black ledge. The 1790 explosive episode must have left a pit or some portion of the crater with a depth much greater than the 1,000 feet below Uwekahuna found by Ellis. Such a pit may have been partially filled by short-lived activities prior to the commencement of continuous activity. As there is no way of estimating the volume of such a pit it will be ignored in what follows. A crude approximation of the volume of the pre-1823 infilling may be had by taking the amount engulfed in 1823, 19,052,000,000 cu. ft. (Volcano Letter 470 and 471), and adding an estimate for the volume of the black ledge, 120,000,000 cu. ft., thus obtaining a total of 19,172,000,000 cu. ft. The fill in Kilauea crater between 1825 and 1832 was estimated to have been 23,850,000,000 cu. ft. (Volcano Letter 471) or at a rate of 3,400,000,000 cu. ft. a year. Applying this rate to the 19,172,000,000 cu. ft., we obtain 5.6 years as the time required to make the pre-1823 fill. Now the fill may have been considerably greater than the amount given above but the rate of fill may have been greater than that between 1825 and 1832, so that an estimate of 6 or 7 years as the time required to complete the fill prior to the 1823 collapse seems reasonable. This would seem to indicate the possibility that Kilauea was rather quiet or inactive for about 25 years after the 1790 explosions.

[6] FORNANDER, ABRAHAM. AN ACCOUNT OF THE POLYNESIAN RACE (London, 1880), Vol. 2, p. 204.

[7] MACDONALD, GORDON A. LAVA FLOWS IN EASTERN PUNA. Volcano Letter 474, 1941, p. 1.

[8] FORNANDER, ABRAHAM. FORNANDER COLLECTION OF HAWAIIAN ANTIQUITIES AND FOLK-LORE. Bernice P. Bishop Mus. Mem. (Honolulu, 1919), Vol. 6, Part 2, p. 317.

[9] FINCH, R. H. ENGULFMENT AT KILAUEA. Volcano Letter 470, 1940, p. 1.

Hawaiian Volcano Observatory Report for April–June 1947

VOLCANOLOGY

April

The numbers of earthquakes recorded at Kilauea and Mauna Loa during April, 41 and 49 respectively, were less than in March. Six earthquakes, two of which were felt at Kapapala, were recorded in an interval of 1 hour and 40 minutes on the morning of April 12. The shakes originated at three different places and thus have but little volcanic significance. The majority of the earthquakes recorded in April appear to have originated under the eastern half of Manua Loa.

May

The total number of shakes recorded in May, as in the past 8 months, was greater at Mauna Loa than at Kilauea, or 54 and 43 respectively. During the latter part of the month there was a slight increase in the number of shakes originating under Kilauea.

Seasonal westerly tilt continued throughout the month. There was no tilt in the north-south direction.

June

The numbers of earthquakes recorded during the month were: Mauna Loa, 48, and Kilauea, 45. Earthquake No. 79, which occurred at 05:04 on June 19, had unusually long periods for all phases. This long period was also shown on the Mauna Loa and Hilo seismographs. The quake had a shallow focus under Kilauea.

A conspicuous fume cloud was observed over Mauna Loa about sundown on June 11.

R.H.F.

SEISMOLOGY

Earthquake Data, April–June, 1947

Week Ended		Minutes of Tremor	Very Feeble	Feeble	Slight	Moderate	Local Seismicity*	Teleseisms
April	6	7	2	0	0	0	2.75	0
	13	2	4	2	3	0	10.50	2
	20	2	2	3	0	0	4.50	0
	27	6	3	1	0	0	4.00	0
May	4	10	5	1	0	0	6.00	0
	11	9	3	0	1	0	5.75	0
	18	5	2	0	0	0	2.25	0
	25	5	0	1	0	0	2.25	0
June	1	6	6	0	0	0	4.50	0
	8	16	0	0	0	0	4.00	0
	15	6	1	0	0	1	5.00	0
	22	10	2	0	0	1	6.50	0
	29	5	0	0	1	0	3.25	0

* For definition of local seismicity, see VOLCANO LETTER No. 371.

The data of the following local disturbances were determined from seismograph stations operated on the island of Hawaii by the Hawaiian Volcano Observatory of the Hawaii National Park. Time is Hawaiian Standard, 10 hours and 30 minutes slower than Greenwich until June 8 then 10 hours slower. The number preceding each earthquake is the serial number of the quake for the current year.

36. April 2, 23:57, very feeble.
37. April 8, 05:10, very feeble.
38. April 10, 05:57, very feeble. Mauna Loa shake.
39. April 12, 01:07, feeble. Probably Mauna Loa.
40. April 12, 01:10, feeble.
41. April 12, 01:46, slight. Felt at Kapapala.
42. April 12, 02:28, slight.
43. April 12, 02:29, slight. Felt at Kapapala.
44. April 12, 02:49, very feeble.
45. April 12, 18:27, feeble. Kilauea shake.
46. April 13, 06:05, very feeble.
47. April 13, 06:21, very feeble.
48. April 15, 16:15, feeble.
49. April 17, 01:27, very feeble.
50. April 20, 03:27, very feeble.
51. April 20, 12:17, feeble.
52. April 20, 23:27, feeble.
53. April 21, 23:58, very feeble.
54. April 22, 14:40, feeble. NE slope Mauna Loa.
55. April 23, 20:07, very feeble.
56. April 24, 03:14, very feeble.
57. April 28, 07:34, feeble.
58. April 28, 22:30, very feeble.
59. April 29, 06:17, feeble. Mauna Loa.
60. April 29, 23:18, very feeble.
61. April 30, 04:24, very feeble.
62. May 2, 10:44, very feeble. Mauna Loa.
63. May 3, 03:58, very feeble.
64. May 5, 19:58, slight.
65. May 9, 06:07, very feeble.
66. May 9, 17:10, very feeble.
67. May 11, 05:09, very feeble.
68. May 15, 21:18, very feeble.
69. May 17, 09:38, very feeble. Kilauea.
70. May 21, 09:44, feeble. SW rift Kilauea.
71. May 27, 03:31, very feeble. Kilauea.
72. May 27, 17:09, very feeble.
73. May 29, 17:12, very feeble. Kilauea.
74. May 31, 03:05, very feeble. Kilauea.
75. May 31, 17:37, very feeble.
76. June 1, 05:48, very feeble. Mauna Loa.
77. June 9, 14:53, very feeble.
78. June 14, 23:00, moderate. Felt locally and as far as Papaikou. Moderate depth under Kilauea. Mauna Loa instrument dismantled.
79. June 19, 05:24, moderate. EW dismantled. Felt locally. Shallow under Kilauea.
80. June 19, 05:36, very feeble.
81. June 21, 11:01, very feeble. Mauna Loa.
82. June 26, 14:23, slight. Felt locally, Naalehu, and Hilo. 15 miles under E slope Mauna Loa.

TELESEISMS

April 10, 05:43, slight. Southern California.

April 13, 21:14, slight. Japan.

MICROSEISMS

Microseisms were strong from April 6th to the 9th and light to moderate during the rest of the month. They were moderate during the entire month of May. In June they were light to moderate from the 1st to the 11th and then moderate for the rest of the month.

CRACK MEASUREMENTS

A few of the cracks around Halemaumau opened slightly in April. No appreciable movement of any of the cracks measured was detected in May and June.

TILTING OF THE GROUND

Seasonal southerly tilt ceased during the latter part of March and there was a very slight accumulation of northerly tilt during the quarter. Westerly tilt continued throughout the quarter.

R.H.F.

Table of Tilt at Observatory on Northeast Rim of Kilauea

Weed Ended		Amount	Direction
April	6	1.09″	N 84° W
	13	0.43″	N 34° E
	20	1.68″	S 86° W
	27	0.38″	S 20° W
May	4	0.54″	N 63° W
	11	0.26″	N 28° E
	18	0.76″	N 71° E
	25	0.96″	N 83° W
June	1	0.80″	S 64° W
	8	0.86″	N 56° W
	15	0.12″	N
	22	0.43″	N 34° E
	29	0.73″	S 80° W

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The University of Hawaii cooperates in maintaining a research laboratory at Hawaii National Park. The Association and the University supplement the work of the government with research associates, instrumental plants and special investigation. Dr. T. A. Jaggar is their geophysicist resident in the National Park.

The Volcano Letter, a quarterly record of Hawaiian volcano laboratories and published by the University of Hawaii, is issued by authority of the Department of the Interior and supplied to a restricted membership and exchange list of the above establishments.

THE VOLCANO LETTER

No. 497 **Department of Interior** **National Park Service** **July–September 1947**

PUBLISHED BY THE UNIVERSITY OF HAWAII

HAWAII NATIONAL PARK: Frank R. Oberhansley, Superintendent; R. H. Finch, Volcanologist

UNIVERSITY OF HAWAII: T. A. Jaggar, Geophysicist

THE INACTIVE PERIODS OF KILAUEA

By R. H. FINCH

Volcanologist, Hawaii National Park

Continuous activity of Kilauea ceased with the withdrawal of the lava column preceding the explosive eruption in May, 1924. Since then there have been seven periods of short-lived activity. The last activity was on October 9, 1934. The present period of inactivity—practically 13 years—is the longest on record. The 13-year period from 1894 to 1907 has sometimes been compared with the present. The 1894–1907 period, however, is not comparable as in those years there was much fuming and occasional glow in Halemaumau. Meager data indicate that there may have been a similar period of inactivity following the 1790 explosions.

Discrepancies in the estimates of the percentage of the time that Kilauea has been inactive since the written record began in 1823, are to be expected. Some of the discrepancies may be accounted for by differences in the definition of activity and others may be due to differences in the interpretation of the records. For the 47 years prior to the establishment of the Hawaiian Volcano Observatory in 1912, the history of Kilauea is quite faithfully given in the record books of the Volcano House, the hotel on the northeast rim of the crater. Some of the indications of lack of activity even after the hotel was established in 1865 may be due more to a lack of observations than to actual inactivity. A study of the hotel record books shows that some periods of slight activity between spells of spectacular activity have erroneously been classed as inactive.

Any period in which magmatic effervescence is indicated as at or near the surface is classed as active in this discussion. To be conservative, for periods with considerable fuming and incomplete observations (as in 1849–1851 and 1894–1907), the duration of inactivity as given in Table 1 is greater than if the above definition were strictly followed. An open vent which is fuming in appreciable volume with lava occasionally visible had best be classed as active. Periods in which high-level internal activity without fuming is indicated, as in November–December, 1944,[1] are thus not classed as active.

A list of the known inactive periods of Kilauea from 1823 to May, 1924, inclusive, is shown in Table 1.

[1] FINCH, R. H. THE NOVEMBER-DECEMBER 1944 CRISIS AT KILAUEA. Volcano Letter 486, 1944.

Table 1.—Dates and Duration of Inactive Periods at Kilauea

Year	Duration	Remarks	Year	Duration	Remarks
	Months			*Months*	
1848	1	See note *A* below	1897	7	
1849	6	See note *B*. May be less	1898	11	
1850	6	May be less	1899	10	
1851	6	May be less	1900	9	
1852	1		1901	8	
1868	1		1902	5	See note *C*
1871	2		1903	7	
1879	1		1904	9	
1886	1		1905	2	
1891	1		1906	5	
1894	1	Fuming nearly continuous 1894–1907	1907	3	
1895	8		1913	1	
1896	6		1922	1	

Note *A*. Stearns and Macdonald[1] show questioned inactive periods in 1823, 1832, and 1840. The writer's interpretation of the records makes activity continuous in these years.

Note *B*. A plug dome formed at the Halemaumau vent in 1848. Mr. Coan correctly explained its formation as being due to the "compound action of upheaving forces from beneath and of eruptions from the openings forming successive layers upon its external surface."[2] Unusually viscous lava that issued from cracks in the plug was of comparatively small volume though sufficient to give a more or less smooth outline. The dome was over 300 feet high and about 2,000 feet in diameter. The continuance of the dome through 1849, 1850, and 1851 indicates that the lava column was high during these years; otherwise the dome would have collapsed. In the spring of 1852 there was a pit in the top of the dome. This was about 100 feet in diameter with a boiling pool of lava about 100 feet below the rim. The dome gradually disappeared by engulfment. A similar elevation of the epimagma took place prior to 1846. In the earlier 1840's elevation, the area involved was much greater than in 1848. Also there was a greater volume of less viscous molten lava.

Note *C*. On February 14, 1902, it was found that there was a recent lava fill in the bottom of Halemaumau, but the activity was not observed despite a rather close watch from the hotel.

[1] STEARNS, HAROLD T. and MACDONALD, GORDON A. GEOLOGY AND GROUND-WATER RESOURCES OF THE ISLAND OF HAWAII. Hawaii Div. of Hydrography, Bul. 9. 1946.

[2] DANA, JAMES D. CHARACTERISTICS OF VOLCANOES. (New York 1891), p. 80.

Since the explosive eruption in 1924, there have been seven periods of activity at Kilauea. Prior to the commencement of the present 13-year period of inactivity in 1934, the longest period of inactivity since 1924 was the three years from July, 1924, to July, 1927. The dates and duration by days of the active periods since May, 1924, are shown in Table 2. If the duration of inactivity by months were used, as in Table 1, for the 23 plus years of this period most of the entries would be 12, or 11 and a fraction.

Table 2.—Eruptions at Kilauea Since May, 1924

Date	Duration
	Days
July 1924	12
July 1927	14
February 1929	2
July 1929	4
November–December 1930	18
December 1931–January 1932	13
September–October 1934	33

The total in the above table is 96 days. This means that Kilauea has been active but a little over 1.1 per cent of the time since May, 1924.

During the 124 years and 9 months ended September 30, 1947, Kilauea has been active about 73 per cent of the time. For the 123 years ended 1945—the period used by Stearns and Macdonald, p. 112—the writer finds that Kilauea was active about 75 per cent of the time. The Stearns and Macdonald computation makes the figure about 67 per cent. This means that they classed as inactive about 110 months which the writer called active. The statement that Kilauea was active almost continuously from 1823 to May, 1924, is correct. Computations show that Kilauea was active about 90 per cent of the time during this period.

The behavior of Kilauea before and after the 1924 explosions indicates that an explosive eruption marks a turning point in the behavior of Kilauea. During the 16 years preceding the 1924 explosions, Kilauea was active over 98 per cent of the time. During the first 16 years following the explosions, activity totaled 1.7 per cent.

In VOLCANO LETTER 496, p. 2, the writer has given some calculations to indicate that Kilauea may have become continuously active about 1816 to 1818 or 26 to 28 years after the 1790 explosions. An estimate of 25 to 30 years would probably be better than 26 to 28 as 1790 might well be given 1790± and 1816 to 1818 is derived by calculations based on assumptions. If the behavior of Kilauea after 1924 is to be similar to the behavior following 1790—analogy and suggested periodicity in the occurrence of steam blasts make this seem a possibility—then some year from 1947 onward should be the equivalent of 1816±. It should be borne in mind that there is always the possibility of another period of short-lived activity before a resumption of continuous activity.

Hawaiian Volcano Observatory Report for July–September 1947

VOLCANOLOGY

July

July, 1947, was the quietest month seismically since September, 1946. The number of earthquakes recorded at Mauna Loa and Kilauea, respectively, were 29 and 14. Many of the shakes appear to have originated along the northeast rift of Mauna Loa with shallow foci. For the year ended June 30 there was a slight accumulation of southwest tilt which may be taken as indicating a slight pressure decrease under Kilauea.

August

In August, for the first time in several months, more earthquakes were recorded at Kilauea than at Mauna Loa, or 40 and 39, respectively. A conspicuous fume cloud was observed over Mokuaweoweo on August 5. From the rim it appeared dense and bluish. Ordinary steam clouds from Mokuaweoweo were observed several times during the month.

September

During September more earthquakes of Mauna Loa than of Kilauea origin were recorded, or 33 and 20, respectively. Two earthquakes that indicate deep-seated uneasiness along the fundamental rift under Hawaii occurred during the month. The first was at 05:50 on September 21 with a depth of from 20–25 miles and the second at 04:05, September 30 with a depth of 8–10 miles.

R. H. F.

SEISMOLOGY

Earthquake Data, July-September 1947

Week Ended		Minutes of Tremor	Very Feeble	Feeble	Slight	Moderate	Local Seismicity*	Teleseisms
July	6	1	0	0	0	0	0.25	0
	13	1	1	0	0	0	0.75	0
	20	0	2	1	0	0	2.00	0
	27	2	0	3	0	0	3.50	1
August	3	1	2	0	0	0	1.25	0
	10	0	2	0	1	0	4.00	0
	17	1	3	0	0	0	1.75	1
	24	0	2	1	1	1	7.00	0
	31	4	3	0	0	0	2.50	0
September	7	3	4	1	0	0	3.75	0
	14	2	0	1	0	0	1.00	0
	21	2	0	0	1	0	2.50	0
	28	2	1	0	0	0	1.00	1

* For definition of local seismicity, see VOLCANO LETTER No. 371.

The data of the following local disturbances were determined from seismograph stations operated on the island of Hawaii by the Hawaiian Volcano Observatory of the Hawaii National Park. Time is Hawaiian Standard, 10 hours slower than Greenwich. The number preceding each earthquake is the serial number of the quake for the current year.

83. July 7, 05:59, very feeble.
84. July 14, 11:52, feeble. Kilauea shake.
85. July 15, 12:25, very feeble. Mauna Loa.
86. July 17, 15:17, very feeble.
87. July 21, 06:18, feeble. Mauna Loa.
88. July 23, 01:52, feeble. Kilauea.
89. July 23, 10:25, feeble. SW rift Mauna Loa.
90. July 26, 16:57, very feeble. NE rift Mauna Loa.
91. July 28, 15:40, very feeble.
92. July 30, 17:15, very feeble. Kilauea.
93. August 7, 05:04, very feeble. NE rift Mauna Loa.
94. August 7, 20:36 slight. Felt locally, and at Naalehu and Hilo. E slope Mauna Loa.
95. August 10, 02:16, very feeble. NE rift Mauna Loa.
96. August 11, 12:52, very feeble.
97. August 12, 07:42, very feeble. Mauna Loa.
98. August 15, 18:46, very feeble. Mauna Loa.
99. August 18, 09:52, moderate. E–W seismograph dismantled. Felt locally and at Naalehu. Deep under Kilauea.
100. August 18, 10:01, feeble. Kilauea.
101. August 18, 14:11, feeble. Mauna Loa.
102. August 19, 01:22, very feeble.
103. August 19, 06:44, slight. Felt locally and at Naalehu. Mauna Loa.
104. August 24, 02:35, very feeble. Kilauea.
105. August 28, 15:15, very feeble. Mauna Loa.
106. August 29, 21:49, very feeble. Mauna Loa.
107. August 30, 15:21, very feeble.
108. September 1, 01:33, very feeble.
109. September 2, 05:17, very feeble. Kilauea.
110. September 4, 17:49, very feeble.
111. September 6, 17:28, feeble. Kilauea.
112. September 6, 17:45, very feeble. Kilauea.
113. September 12, 04:29, feeble. Kilauea.
114. September 21, 05:50, slight. Widely felt on this island and by a few on Maui. About 20–25 miles deep below Humuula.
115. September 22, 07:41, very feeble.
116. September 30, 04:04, moderate. Generally felt from South Kona to Hilo. Instruments dismantled. 6–8 miles deep east of Kilauea.
117. September 30, 04:09, slight.

TELESEISMS

July 24, 02:24, slight. New Hebrides.
August 17, 20:23, slight.
September 23, 04:10, slight. Off North California coast.
September 26, 06:14, slight.

MICROSEISMS

Microseisms were moderate on July 8, 9, and 10 and on the last three days of September. During the rest of the quarter they were light.

CRACK MEASUREMENTS

Some of the cracks around Halemaumau opened slightly, though the majority showed but little or no movement.

TILTING OF THE GROUND

Northerly tilt was quite uniform throughout the quarter except for a strong spurt during the last week in August and a sharp southerly tilt September 8–13. Tilting in the east–west direction was about stationary until July 25 when a rather uniform east tilt set in to continue through September.

R. H. F.

Table of Tilt at Observatory on Northeast Rim of Kilauea

Week Ended		Amount	Direction
July	6	0.72″	E
	13	0.48″	N
	20	0.86″	N 56° W
	27	1.30″	N 22° E
August	3	0.97″	N 82° E
	10	0.26″	S 26° W
	17	0.50″	N 45° E
	24	1.05″	N 40° E
	31	1.87″	N 15° E
September	7	0.96″	S 83° E
	14	1.08″	S 7° W
	21	0.77″	N 52° E
	28	0.53″	N 63° E

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THE VOLCANO LETTER

No. 498 **Department of Interior** **National Park Service** **October–December 1947**

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HAWAII NATIONAL PARK: Benjamin F. Moomaw, Acting Superintendent; R. H. Finch, Volcanologist

UNIVERSITY OF HAWAII: T. A. Jaggar, Geophysicist

REVIEW OF "ORIGIN AND DEVELOPMENT OF CRATERS" BY T. A. JAGGAR

By R. H. FINCH

Volcanologist, Hawaii National Park

In the *Origin and Development of Craters,* Dr. T. A. Jaggar sets forth many of his ideas gained from a lifetime study of volcanoes. The book is memoir No. 21 of the Geological Society of America and contains 508 pages, 14 text figures, and 87 plates. The price at New York is $6.00.

Dana, in his *Characteristics of Volcanoes,*[1] generalized from Hawaiian volcanoes. Jaggar's memoir is modeled on Dana's book. It would be well for all readers of *Origin and Development of Craters* to peruse carefully the abstract and introduction. This will help in an understanding of the author's aims and prepare the reader for Part 1, which is largely the hitherto unpublished material in the record books of the Hawaiian Volcano Observatory from the second week of April, 1912, to the last of June, 1913. This section gives an excellent picture of the features and behavior of a lava lake as well as the initiation and development of observational methods. The strictly diary part probably is too detailed for most readers and might well have been included as an appendix. This comment might also apply to the diary of Part 3, Kilauea Steam Blast Eruption, 1924. The manner of treatment makes reading of the book rather difficult for all but those especially interested. It is not, however, intended as a popular book on Kilauea and Mauna Loa.

On page 267 occurs the statement: [The author] "makes no apology for introducing anywhere, if it is relevant, a geological discussion." Interpretation and definition are thus mingled with description. If there is any defect in this treatment it is largely overcome by a good index and an excellent table of contents. The table of contents merits attention as it permits those who lack time to read the book page by page to read by topics. The table of contents will also be especially helpful in using the memoir as a reference.

Part 2 gives a more or less chronological account of the activity of Kilauea and Mauna Loa from 1909 to 1935 and a condensation of 26 years of Hawaiian volcano observations and experiments. The author states that "The year 1909 is a good year to begin with because until 1913 the lava was intensely active but receding." The purely historical account of Hawaiian volcanoes given by Hitchcock[2] and Brigham[3] stops with 1908 and June, 1909, respectively. The year 1909 is thus an especially appropriate year with which to begin this part.

In the subtitle for Part 2—"The Cross of Hawaii"—the belief that Kilauea may be older than Mauna Loa is kept alive, though on page 90 there is the statement that geological mapping may demonstrate that Mauna Loa is older than Kilauea.

Mingled with the history in Part 2 are many geological discussions and the results of experiments. In 1912 a temperature of 1000° C. was found 2 feet below

[1] DANA, J. D. CHARACTERISTICS OF VOLCANOES. Dodd Mead, New York. 1891.

[2] HITCHCOCK, C. H. HAWAII AND ITS VOLCANOES. Hawaiian Gazette Co., Ltd., Honolulu. 1911.

[3] BRIGHAM, W. T. THE VOLCANOES OF KILAUEA AND MAUNA LOA. Bernice P. Bishop Mus. Mem. Vol. 2, No. 4, Honolulu, 1909.

the surface. The so-called "floating islands" were found to be but some of the epimagma, or the somewhat stiff upper portion of the lava column that normally forms the basin in which the lava lakes are located. The depth of the lava lake—40 to 50 feet—was determined both by experiment and direct observation.

On page 125 there is a discussion under the title, "Sympathy of Kilauea with Mauna Loa," wherein it is stated that there was an increase in output of a Kilauea flow attending the 1919 eruption of Mauna Loa. Collapses in Halemaumau following eruptions of Mauna Loa in 1914 and in 1916 offered definite suggestions of sympathy between the two volcanoes. There are indications of a similar collapse at Halemaumau in 1855 following an eruption of Mauna Loa in that year. These suggestions of sympathy led to the successful forecast of a collapse in Halemaumau in 1919 (p. 34).

The case for comparing the amphitheater breaches in the slag heap, Mauna Iki (p. 143), and large amphitheaters is not too good. The Mauna Iki slag heap was built up in days and the interior was composed of hot pasty material while the large amphitheater embayments occur in structures that were centuries in forming. Mohokea is cited as one such breach. Stearns and Macdonald[4] maintain that Mohokea was produced by erosion. Powers,[5] however, points out that block faulting may have played an important part in the formation of the Mohokea embayment.

The behavior of the upper end of the Kilauea lava column is quite fully treated in Part 4, Sketch Maps and Profiles of Halemaumau, 1917–1934. This method of treatment of necessity duplicates some of the history given in Part 2. Before detailed discussions of the maps and profiles are taken up there are seven pages of general statements. In reading this Part one wishes that the pertinent plates had been included as text figures instead of in an envelope containing 14 loose plates on the inside back cover. As printed, most are already of a size suitable for use as text figures.

Part 5 is a short summary of the histories of Kilauea and Mauna Loa. An excellent feature of this Part is a list of discussions bearing on crater history that appeared in the *Bulletin of the Hawaiian Volcano Observatory*. This is a helpful contribution as the *Bulletin* was never indexed. The table (p. 327) outlining Hawaiian activities is not intended as a complete listing of active years but rather to show lava culminations and lowerings. The propriety of giving probable times and amounts of lowering in such a table for the years 1800 and 1810, for which there are no records, is questioned. The dates and amounts of lowering are taken from the hypothetical portion of Plate 86.

On page 329 the author, as do Stearns and Macdonald,[6] favors a position south of the summit crater of Mauna Loa as the locus of the 1832 flow. The reviewer feels that the 1832 eruption was at the summit with a possible short flow from the northeast rim.

The idea that the north and south flanks of Mauna Loa at Humuula and Kahuku lands may be thought of as breaking down, undermined by lava flows, is given on page 333. Aside from the ancient breakdown to form the Kahuku Pali near the south point of Hawaii, there are no surface indications of such a process. If, as seems to be the case, the rise of lava at Mauna Loa is confined to the feeding conduits under Mokuaweoweo we would not expect much undermining by outflow at the places in question.

Part 6, Principles of Crater Evolution, commences with 10 pages of general statements of some of the broader aspects of volcanism. The subtitle for this part, "Earth, the Offspring of the Sun," emphasizes solar derivation. The next 40 pages treat of the work of 17 authors dealing with classification and ideas of volcanic processes. Direct quotations from many authors and comments on the work of all are given. There is evidence of a gradual increase in knowledge of volcanic processes. "Crater Physics and Chemistry" are treated in the last 20 pages of this Part. The importance of combustible gases in volcanic processes is emphasized. The three types of magma: hypomagma (profound and gas charged, rising from the earth's interior—the lava column in the depths), pyromagma, (the frothy fluid in lakes and flows), and epimagma (the stiff or pasty upper portion of the lava column) are discussed more fully here than elsewhere in the book.

Part 7, Summary and Conclusions, is a stimulating résumé with thought-provoking speculations on several subjects. The author's idea of ignisepta, "igneous partitions in earth mantle profound to the core" or "giant rift belts full of magma, leading down to the centrosphere," merits careful consideration.

The 73 plates of photographs deal mainly with Kilauea and Mauna Loa though a few are included dealing with the history of the Hawaiian Volcano Observatory. It is an excellent collection of photographs and, with the more extensive legends than usual, gives a quite comprehensive view of volcanic processes and products as exemplified by Kilauea and Mauna Loa.

The memoir is an outstanding contribution to the literature on volcanoes and will maintain this position for years to come.

[4] STEARNS, HAROLD T. and MACDONALD, GORDON A. GEOLOGY AND GROUND-WATER RESOURCES OF THE ISLAND OF HAWAII. Hawaii Div. of Hydrography, Bul. 9. 1946. P. 66.

[5] POWERS, H. A. REVIEW OF "GEOLOGY AND GROUND-WATER RESOURCES OF THE ISLAND OF HAWAII." Volcano Letter No. 494. 1946. P. 3.

[6] *Op. cit.*

Hawaiian Volcano Observatory Report for October–December 1947

VOLCANOLOGY

October

October was quiet seismically at Kilauea with but 11 earthquakes recorded. This is the smallest number recorded at Kilauea for many months. The Mauna Loa seismograph recorded a more usual number, or 30. The majority of the Mauna Loa shakes were very small with origins along the northeast rift. The strongest earthquake of the month occurred at 02:13, October 31. It dismantled the Mauna Loa and Kona seismographs. The indicated origin of the quake was at a depth of 12–15 miles below the southern end of Mokuaweoweo. There was about the usual northerly tilt during the month. The slight westerly tilt was opposite in direction to the normal for October. Tilting of the ground gave no indication of impending activity.

November

November, like October, was quiet seismically with but 18 earthquakes recorded on the Kilauea and Mauna Loa seismographs. This is the smallest number recorded at Mauna Loa for several years. The distinct earthquake of October 31 may have occasioned movement along the rift that extends from Mokuaweoweo to Kealakekua Bay. The Kona seismograph recorded two shakes from this rift on November 18 and 19. The rift was active in 1877 producing a small lava flow in Kealakekua Bay. On November 25 there were two periods of continuous tremor each lasting over 3 minutes. The tremor was more like that which accompanies an outbreak of Mauna Loa than individual earthquakes. The origin of the tremor was at Kilauea.

On November 15, following a 4-inch rainfall, heavy steam clouds developed in Halemaumau.

December

December was the third consecutive month with but few earthquakes of Kilauea origin. The Kilauea seismographs recorded but 16 shakes while the Mauna Loa instrument recorded 43. Five of the shakes were perceptible. One of these originated deep under Kilauea and four had shallow origins under various portions of Mauna Loa. The preponderance of Mauna Loa shakes, together with a distinct easterly tilt during the month, may be taken as signs of slight uneasiness under Mauna Loa. History and the scattered earthquakes give some indications that the next eruption of Mauna Loa will be at the summit. There was a slight accumulation of southeast tilt during 1947.

R. H. F.

SEISMOLOGY

Earthquake Data, October–December 1947

Week Ended		Minutes of Tremor	Very Feeble	Feeble	Slight	Moderate	Local Seismicity*	Teleseisms
October	5	3	1	0	1	1	6.25	0
	12	1	0	0	0	0	0.25	0
	19	0	0	0	1	0	2.00	1
	26	0	2	0	0	0	1.00	0
November	2	2	2	0	0	1	4.00	1
	9	1	1	1	0	0	1.75	1
	16	1	3	0	0	0	1.75	0
	23	1	1	0	0	0	0.75	2
	30	6	2	0	0	0	2.50	0
December	7	2	0	0	0	0	0.50	0
	14	1	1	1	0	1	4.75	0
	21	2	2	1	1	0	4.50	0
	28	0	0	1	1	0	3.00	0

* For definition of local seismicity, see VOLCANO LETTER No. 371.

The data of the following local disturbances were determined from seismograph stations operated on the island of Hawaii by the Hawaiian Volcano Observatory of the Hawaii National Park. Time is Hawaiian Standard, 10 hours slower than Greenwich. The number preceding each earthquake is the serial number for the current year.

118. October 3, 09:21, very feeble.
119. October 17, 00:27, slight. Generally felt on eastern part of island. Near Kapapala.
120. October 23, 09:42, very feeble.
121. October 24, 18:02, very feeble. Felt at Naalehu.
122. October 28, 22:00, very feeble.
123. October 30, 15:07, very feeble.
124. October 31, 02:13, moderate. E–W dismantled. Widely felt eastern half of island. Clocks stopped in South Kona. Origin under summit of Mauna Loa.
125. November 8, 15:53, feeble. Mauna Loa shake.
126. November 8, 16:15, very feeble. Mauna Loa.
127. November 13, 21:01, very feeble. Mauna Loa.
128. November 15, 01:43, very feeble.
129. November 16, 03:55, very feeble. Kilauea shake.
130. November 23, 01:17, very feeble. Mauna Loa.
131. November 25, 08:43, very feeble.
132. November 25, 11:31, very feeble. Kilauea.
133. December 9, 21:14, feeble.
134. December 12, 12:50, very feeble.
135. December 14, 10:10, moderate. Felt locally and at Hilo. E–W dismantled. 20 miles under Kilauea.
136. December 17, 00:01, very feeble. Felt at Kapapala. East slope of Mauna Loa.
137. December 18, 09:01, very feeble. Mauna Loa.
138. December 19, 23:07, feeble. East slope of Mauna Loa.
139. December 20, 05:18, slight. Felt eastern half of island. Near summit of Mauna Loa.
140. December 22, 02:55, feeble. East slope of Mauna Loa.
141. December 24, 06:38, slight. Felt locally, and at Hilo and Naalehu. East slope of Mauna Loa near Ainapo.
142. December 29, 16:28, very feeble.

TELESEISMS

October 15, 16:18, slight. Near Fairbanks, Alaska.
November 1, 05:12, slight. Peru.
November 3, 14:20, slight.
November 20, 18:14, slight. Mexico.
November 21, 22:26, slight.

MICROSEISMS

Microseisms were moderate to strong October 25–31 and December 11–21 and light on other days.

CRACK MEASUREMENTS

Some of the cracks near the southwest rim of Halemaumau opened slightly; other measured cracks were essentially stationary.

TILTING OF THE GROUND

The seasonal northerly tilt that continued until November was less than usual. There was a slight southerly tilt from November 7 until December 20, then a slight northerly tilt until the end of the year. There was a slight westerly tilt during the first week in October. On October 7 a distinct easterly tilt commenced that continued until December 16. During the last half of December there was a slight accumulation of westerly tilt.

R. H. F.

Table of Tilt at Observatory on Northeast Rim of Kilauea

Week Ended	Amount	Direction
October 5	0.94″	N 50° E
12	0.77″	N 19° E
19	0.60″	N 37° W
26	0.97″	N 83° W
November 2	0.86″	N 74° E
9	1.08″	E
16	1.46″	N 80° E
23	0.70″	N 59° E
30	0.12″	W
December 7	2.04″	N 62° E
14	2.70″	S 33° E
21	0.62″	S 22° W
28	1.34″	N 22° W

TRANSFER OF THE HAWAIIAN VOLCANO OBSERVATORY

On December 28, 1947, by order of the Secretary of the Interior, the Hawaiian Volcano Observatory was transferred to the United States Geological Survey. The Observatory will continue measurement and observation of volcanic behavior, and, in addition, will serve as a training station in the Geological Survey's program of volcanic studies in the Pacific and elsewhere.

It is anticipated that with the expanded program and with growing fundamental interest in study of volcanoes, a period of renewed growth and accomplishment is indicated for the 40-year-old Hawaiian Volcano Observatory.

HAWAIIAN VOLCANO RESEARCH ASSOCIATION
In cooperation with UNIVERSITY OF HAWAII

The Hawaiian Volcano Research Association was founded in 1911 for record of volcanoes in the Hawaiian Islands and around the Pacific Ocean. Its equipment at Kilauea Volcano, Hawaii Island, has been transferred to the United States Government, Department of the Interior, National Park Service.

The University of Hawaii cooperates in maintaining a research laboratory at Hawaii National Park. The Association and the University supplement the work of the government with research associates, instrumental plants and special investigation. Dr. T. A. Jaggar is their geophysicist resident in the National Park.

The Volcano Letter, a quarterly record of Hawaiian volcano laboratories and published by the University of Hawaii, is issued by authority of the Department of the Interior and supplied to a restricted membership and exchange list of the above establishments.

THE VOLCANO LETTER

No. 499 **U. S. Geological Survey** **January–March, 1948**

PUBLISHED BY THE UNIVERSITY OF HAWAII

U. S. GEOLOGICAL SURVEY: R. H. Finch, Volcanologist

UNIVERSITY OF HAWAII: T. A. Jaggar, Geophysicist

THE ACTIVE PERIODS OF MAUNA LOA

By R. H. FINCH

Volcanologist, U. S. Geological Survey

This note is intended as a companion one to the discussion of the inactive periods of Kilauea in VOLCANO LETTER No. 497. A similar study of the activity of Mauna Loa, owing to the small percentage of the time it has been active in its recorded history, is simplified if the active periods are used.

Dr. T. A. Jaggar[1,2] and Stearns and Macdonald[3] have made rather comprehensive statistical studies of Mauna Loa outbreaks. There can be but minor differences in the estimates of the small percentage of the time that Mauna Loa has been active. Differences have arisen as to whether some eruptions are to be classed as summit or flank. For example, Jaggar and the writer class the 1832 outbreak as a summit eruption while Stearns and Macdonald class it as a flank eruption. The 1851 outbreak is classed as a flank eruption by Jaggar, though by most definitions it is best classed as summit activity.

A summit eruption is one that takes place in or near the caldera and does not produce a lava flow originating in a rift outside the caldera area. A flank eruption is one that occurs on a rift outside the caldera. The records indicate that all flank eruptions start with short-lived activity at or near the summit. The duration of this preliminary activity varies from a few hours to 2 or 3 days. Such activity at the summit indicates that the ascent of lava from the depths is confined to the feeding conduits under Mokuaweoweo, the caldera of Mauna Loa. The longest dimension of the general breakdown that constitutes the caldera is more than 5 miles northeast-southwest and is roughly parallel to the southwest portion of the main rift of Mauna Loa. The southwestern limits of the caldera are not well defined, as the area has been covered by numerous lava flows some of which continued down the mountain for several miles. It is not surprising, then, that an outbreak may be placed in the caldera by one observer and on the southwest rift by another.

A list of the known eruptions of Mauna Loa and the probable duration of each is shown in Table 1.

The first eruption of Mauna Loa for which there is a definite date started on June 20, 1832. The table shows that during the 115 years and 9 months from this date to the present (March 31, 1948), Mauna Loa has been active 2,718 days, or 6.4 per cent of the time. It is interesting to note that the average duration of the 33 eruptions, starting with that of 1832, is 82 days. This large number is due mainly to four long-continuing eruptions, viz.: 1855-56, 480 days; 1859, 300 days; 1873-74, 560 days; and 1880-81, 275 days.

The first reported eruption of Mauna Loa, which is based on tradition, occurred about 1780. The exact date is not known but reports from different sources place the date definitely about 1780. The Turnbull report of activity in 1803 is quite definite and was probably a summit eruption[4]. The next reported eruption was in 1832. There may have been two or more eruptions between 1780 and 1832 instead of the one that was reported. A review of the records of the 1832 eruption rather definitely makes it a summit one, though there may have been one or more short lava flows from the caldera area. Stearns thought that a recent but un-

[1] JAGGAR, T. A. HISTORY OF MAUNA LOA. Paradise of the Pacific, Vol. 46, No. 2, Honolulu, 1934.

[2] JAGGAR, T. A. THE COMING LAVA FLOW. Volcano Letter No. 440. Oct., 1936.

[3] STEARNS, H. T., and MACDONALD, G. A. GEOLOGY AND GROUND-WATER RESOURCES OF THE ISLAND OF HAWAII. Hawaii Div. of Hydrography Bul. 9. 1946. Pp. 86-92.

[4] HITCHCOCK, CHARLES H. HAWAII AND ITS VOLCANOES. Hawaiian Gazette Co., Ltd., Honolulu, 1911. P. 80.

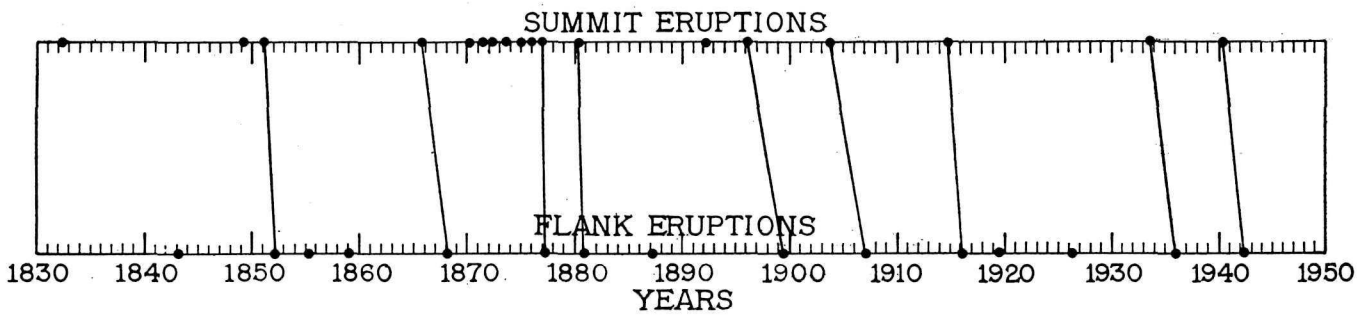

Figure 1.—Summit and flank eruptions of Mauna Loa plotted according to dates. The diagonal lines connect summit eruptions that were followed by flank eruptions without any intervening eruption.

dated lava flow from an elevation of about 8,000 feet on the southwest rift above Waiohinu occurred in 1832[5]. Aside from the freshness of the flow there is little to justify such a belief. An old map of the Hawaiian government survey shows a short flow from the east rim of Mokuaweoweo dated 1832. There is no such recent flow at the place indicated on the map. A mile or so to the north and to the southwest there are flows fresh enough to have occurred in 1832. The Goodrich[6] account of the 1832 outbreak states that it lasted from 2 or 3 weeks and that lava flowed from several vents about the summit. The records of later eruptions show that when a flank eruption starts, activity at the summit ceases. The belief that activity in 1832 was confined to the summit seems justified.

[5] STEARNS, H. T., and W. O. CLARK. GEOLOGY AND WATER RESOURCES OF THE KAU DISTRICT, HAWAII. U. S. Geological Survey, Water-Supply Paper 616, 1930. P. 71.

[6] GOODRICH, JOSEPH. VOLCANOES AND VOLCANIC PHENOMENA OF HAWAII. Amer. Jour. Sci. 1st Ser., Vol. 25, 1833. P. 199.

TABLE 1. YEAR, LOCATION, AND DURATION OF THE ACTIVE PERIODS OF MAUNA LOA.

PLACE AND YEAR OF ERUPTION		DURATION DAYS
SUMMIT	FLANK	
1780		?
1803		?
1832		21
	1843	120
1849		21
1851		12
	1852	20
	1855–56	480
	1859	300
1865		120
	1868	16
1870		14
1871		30
1872		145
1873–74		560
1875		60
1876		7
	1877	11
1880		6
	1880–81	275
	1887	15
1887–88		40
1892		3
1896		15
	1899	26
1903		61
	1907	15
1914–15		45
	1916	14
	1919	42
	1926	19
1933		17
	1935	42
1940		132
	1942	14

In studying the record books of the Volcano House, the hotel on the northeast rim of Kilauea, two different accounts of a summit eruption in 1871 were found. This eruption is not given in the list compiled by Hitchcock and subsequent writers. The first entry in the record book under the date of August 9, 1871, reads, "A great fire to be seen in the Mono Loa Crater." On August 28, the second entry reads, "Faint light at night from the outbreak on Mauna Loa." A search was then made to see if Macdonald[7] had found any reference to this outbreak. The Macdonald bibliography shows that Titus Coan had reported the outbreak in the *American Journal of Science* in 1871. Coan reported that Mauna Loa had been active for weeks prior to August 22, 1871. The record book of the Volcano House indicates that the eruption lasted about a month as there was no activity in Mokuaweoweo early in September, 1871. It seems safe to give a value of 30 days for the duration of activity in 1871.

In accordance with the definition of activity given in the discussion of the inactive periods of Kilauea in VOLCANO LETTER No. 497, the summit eruption of 1887-88 has been included in the table though no molten lava was observed. The intermittent fuming and steaming spell of November, 1943 (VOLCANO LETTER No. 482) has not been included in the list because of the very short duration, the small volume of fume involved, and the fact that it was intermittent.

There is the possibility that occasionally a short-lived summit eruption has escaped notice owing to the remoteness of the summit of Mauna Loa and the fact that it is often obscured by clouds. In 1873, Green[8] noted no glow over the summit of Mauna Loa during three clear nights prior to his ascent of the mountain on June 6, but when the crater rim was reached, a light smoke could be seen drifting away and great fountains were playing. There was insufficient fume to reveal the activity at a distance either by day or night. A characteristic tremor that is recorded on the seismographs

[7] MACDONALD, G. A. BIBLIOGRAPHY OF THE GEOLOGY AND WATER RESOURCES OF THE ISLAND OF HAWAII. Hawaii Div. of Hydrography, Bul. 10. Honolulu, 1947.

[8] GREEN, W. L. VESTIGES OF THE MOLTEN GLOBE. Honolulu, 1887. P. 167.

during Mauna Loa eruptions indicates that an outbreak can now be detected whether the mountain is visible or not.

It has often been stated that a summit eruption is usually followed by a flank eruption in about two years. Computations made from the preceding graph (Fig. 1) indicate that this relationship holds for only about 56 per cent of the time. The 1832-43 relationship has not been used in these computations as the interval between the two outbreaks was 10½ years. Activity may have been more continuous in 1870-77 than indicated in Figure 1, where seven different summit eruptions are plotted. The 56 per cent was derived by calling this group four instead of seven. The last eight summit eruptions have been followed by flank eruptions 75 per cent of the time with an average interval of 18 months. A summit eruption is thus a factor that may be considered in forecasting flank eruptions.

Hawaiian Volcano Observatory Report for January—March, 1948

VOLCANOLOGY

January

The Mauna Loa seismograph recorded 29 earthquakes during January and 26 were recorded at the Kilauea seismograph. Of the five perceptible shakes felt during the month four originated under Mauna Loa and one under Kilauea.

Landslides from the walls of Halemaumau were especially frequent from January 15 to 18, inclusive.

February

Eight more earthquakes were recorded at Mauna Loa than at Kilauea, or 28 and 20, respectively. Three perceptible shakes originated under the southwest slope of Mauna Loa and one under Kilauea Crater.

The seasonal change in direction of tilt from northeast to southwest occurred about the middle of December. There was a normal accumulation of southerly tilt during February while westerly tilt was distinctly less than normal.

March

Forty earthquakes were recorded during the month. Thirteen more shakes were recorded at Mauna Loa than at Kilauea. The strongest earthquake of the month occurred at 16:18 March 19. It originated deep under Kilauea and was generally felt over the eastern part of the island of Hawaii.

There was a slight accumulation of easterly tilt since the middle of February. As westerly tilt is usual for this season of the year, the easterly tilt gives some indication of a pressure increase under Mauna Loa. The rapid southerly tilt that started at the beginning of the year continued throughout the month.

R. H. F.

SEISMOLOGY

Earthquake Data, January—March, 1948

Week Ended		Minutes of Tremor	Very Feeble	Feeble	Slight	Moderate	Local Seismicity*	Teleseisms
January	4	2	1	1	0	0	1.00	0
	11	7	1	0	1	0	4.25	0
	18	6	0	1	1	0	4.50	1
	25	1	1	0	0	0	0.75	1
February	1	1	2	1	1	0	4.25	1
	8	1	8	0	1	0	6.25	0
	15	1	1	1	0	0	2.25	0
	22	2	0	1	1	0	3.50	0
	29	1	2	0	0	0	1.25	1
March	7	1	3	0	0	0	1.75	0
	14	3	0	1	1	0	3.75	0
	21	3	2	0	0	1	4.75	0
	28	0	2	1	0	0	2.00	0

* For definition of local seismicity, see VOLCANO LETTER No. 371.

The data of the following local disturbances were determined from seismograph stations operated on the island of Hawaii by the Hawaiian Volcano Observatory of the U. S. Geological Survey. Time is Hawaiian Standard, 10 hours slower than Greenwich. The number preceding each earthquake is the serial number for the current year.

1. January 3, 06:04, feeble. Felt locally. Under Mokuaweoweo.
2. January 8, 16:15, slight. Felt locally. East slope Mauna Loa.
3. January 10, 17:11, slight. Felt locally. East slope Mauna Loa.
4. January 11, 1:50, very feeble.
5. January 15, 6:16, slight. Felt locally and at Hilo. NE slope Mauna Loa.
6. January 17, 9:50, feeble. Near Hilina Pali.
7. January 18, 12:10, very feeble.
8. January 23, 15:04, very feeble.
9. January 26, 23:02, slight. Felt from Naalehu to Hilo. NE rift Mauna Loa.
10. January 29, 8:55, very feeble.
11. January 31, 10:32, very feeble.
12. February 1, 11:58, feeble. Felt at Naalehu. SW slope Mauna Loa.
13. February 2, 1:12, very feeble.
14. February 2, 22:31, very feeble.
15. February 6, 13:44, very feeble.
16. February 6, 16:17, very feeble.
17. February 7, 8:59, very feeble.
18. February 7, 18:04, very feeble. SW slope Mauna Loa.
19. February 8, 3:56, slight. Kilauea.
20. February 8, 4:18, very feeble. Kilauea.
21. February 8, 7:07, very feeble. Kilauea.
22. February 10, 10:40, very feeble. Mauna Loa.
23. February 12, 4:14, slight. SW slope Mauna Loa.
24. February 20, 9:30, slight. Felt locally. Kilauea.
25. February 20, 9:37, feeble. Kilauea.
26. February 26, 0:52, very feeble. Mauna Loa.
27. February 27, 21:20, very feeble.
28. March 2, 10:05, very feeble. Mauna Loa.
29. March 2, 17:07, very feeble.
30. March 5, 2:43, very feeble. Mauna Loa.
31. March 9, 8:30, very feeble. Mauna Loa.
32. March 9, 15:46, slight. Felt from Hilo to Kona. Off coast north of Hualalai.
33. March 16, 3:43, very feeble.
34. March 19, 16:18, moderate. E–W dismantled. Felt from Hilo to Naalehu. Deep under Kilauea.
35. March 19, 23:09, very feeble. Felt at Naalehu.
36. March 26, 6:08, feeble. Mauna Loa.
37. March 27, 1:03, very feeble.
38. March 27, 11:44, very feeble.
39. March 30, 0:53, very feeble.
40. March 31, 8:41, very feeble. Mauna Loa.
41. March 31, 16:44, very feeble.

TELESEISMS

January 13, 16:55, slight. 1200 km. north of Easter Island.
January 24, 8:20, slight. Philippines.
January 27, 2:06, slight.
February 29, 15:30, slight. New Guinea.

MICROSEISMS

Microseisms were moderate to strong January 23–31 and February 8–10 and moderate March 26–31. They were present though slight on other days.

CRACK MEASUREMENTS

Despite many slides from the walls of Halemaumau during the middle of January all cracks that were measured showed but little or no movement during the quarter.

TILTING OF THE GROUND

The southerly tilt that was continuous throughout the quarter was slightly greater than usual. There was about the usual accumulation of westerly tilt until February 20. From this date until March 31 there was an accumulation of one second of arc of easterly tilt. As there is normally a westerly tilt during this season of the year one second of easterly tilt may actually be greater than the figure indicates. Past records suggest that an easterly tilt is an indication of increase of pressure under Mauna Loa.

R. H. F.

Table of Tilt at Observatory on Northeast Rim of Kilauea

Week Ended		Amount	Direction
January	4	1.4″	S 49° W
	11	1.2″	S 36° W
	18	1.0″	S 35° W
	25	0.9″	S 56° E
February	1	1.5″	S 75° W
	8	0.4″	S 18° W
	15	1.5″	S 29° W
	22	1.2″	S 35° E
	29	1.5″	S 18° E
March	7	0.9″	S 50° W
	14	0.1″	E
	21	2.1″	S 30° E
	28	1.0″	S 60° W

HAWAIIAN VOLCANO RESEARCH ASSOCIATION

In cooperation with the UNIVERSITY OF HAWAII

The **Hawaiian Volcano Research Association** was founded in 1911 for the recording and study of volcanoes in the Hawaiian Islands and around the Pacific Ocean. Its equipment at Kilauea Volcano, Hawaii Island, has been transferred to the United States Geological Survey.

The **University of Hawaii** cooperates in maintaining a research laboratory at Kilauea. The Association and the University supplement the work of the government with research associates, instrumental equipment, and special investigations. Dr. T. A. Jaggar is their geophysicist resident at Kilauea.

The **Volcano Letter,** a quarterly record of Hawaiian volcano observations, is published by the University of Hawaii and supplied to members of the Research Association and to exchange lists of the above establishments.

THE VOLCANO LETTER

No. 500 **U. S. Geological Survey** **April-June, 1948**

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U. S. GEOLOGICAL SURVEY: R. H. Finch, Volcanologist

UNIVERSITY OF HAWAII: T. A. Jaggar, Geophysicist

THE TELESEISM ANNUNCIATOR AT THE HAWAIIAN VOLCANO OBSERVATORY

By BURTON J. LOUCKS

Instrument Maker, U. S. Geological Survey

The Hawaiian Volcano Observatory has issued warnings of the possibility of a tsunami or tidal wave on several occasions. The warnings were based on the seismograms of distant earthquakes and were made only when the fact that a strong shake had occurred was discovered during routine attention to the seismographs. The disastrous tidal wave of April 1, 1946,[1, 2] brought forcibly to mind the need for immediate discovery of the recording of potential tsunami-producing earthquakes regardless of the time of occurrence.

The April 1, 1946, earthquake started recording on the Observatory seismographs at 2:06 A.M. but it was not noted until the record was changed at 7:30 A.M., over half an hour after the waves reached Hilo. If the record had been seen earlier, a warning of the possibility of a tidal wave would have been issued. Experience had taught that the amplitude and distance to origin were such as to indicate the possibility of a tidal wave.[3]

In cooperation with the Hilo Chamber of Commerce, an earthquake annunciator was set up in the seismograph vault of the Hawaiian Volcano Observatory on December 16, 1946. The installation is intended to be only a stopgap to function until the U. S. Coast and Geodetic Survey station at Barbers Point, Oahu, is in operation.

[1] POWERS, H. A. THE TIDAL WAVE OF APRIL 1, 1946. Volcano Letter 491, 1946.

[2] MACDONALD, G. A., SHEPHERD, F. P., and COX, D. C. THE TSUNAMI OF APRIL 1, 1946, IN THE HAWAIIAN ISLANDS. Pacific Science, 1 (1) : 21–37, 1947.

[3] FINCH, R. H. ON THE PREDICTION OF TIDAL WAVES. Proc. 2nd Pacific Science Congress, Australia, 1923. P. 1368.

The instrument consists of a horizontal seismograph pendulum with a boom and magnifying lever (Fig. 1). Whenever a quake of appreciable amplitude occurs, the long arm of the lever makes alternate contact with two pools of mercury (Fig. 2) and closes an electrical circuit. In this circuit (Fig. 3) is a buzzer that is audible in the Observatory building and a relay that closes another circuit with buzzers located in the residences of two members of the Observatory staff. One component of the Hawaiian-type seismograph is used. The heavy mass is a 3-foot section of 8-inch steel pipe filled with sand. The pipe is bolted into a framework of steel 2 by ½ inches with about 3 inches projecting out at the back, both top and bottom. These projections are slotted and 1½-inch pieces of No. 20 music wire with retainers on the ends are inserted in the slots and corresponding ones in the adjustable back plate to suspend the heavy mass as a horizontal pendulum. An aluminum boom is secured to the pipe framework and projects forward about 4 feet from the hinge line. The forward end of the boom is coupled to the magnifying lever by a thin piece of brass with cups that fit over phonograph needles in the end of the boom and of the short arm of the lever. A piece of steel wire which projects downward about ½ inch from the end of the long arm of the magnifying lever makes contact with the mercury when the pendulum oscillates or becomes displaced by tilt. Two brass rods project up from the lever support on either side of the end of the boom to act as buffers in case of strong local shakes. The buffers are wired into the electrical circuit. If a strong local earthquake dis-

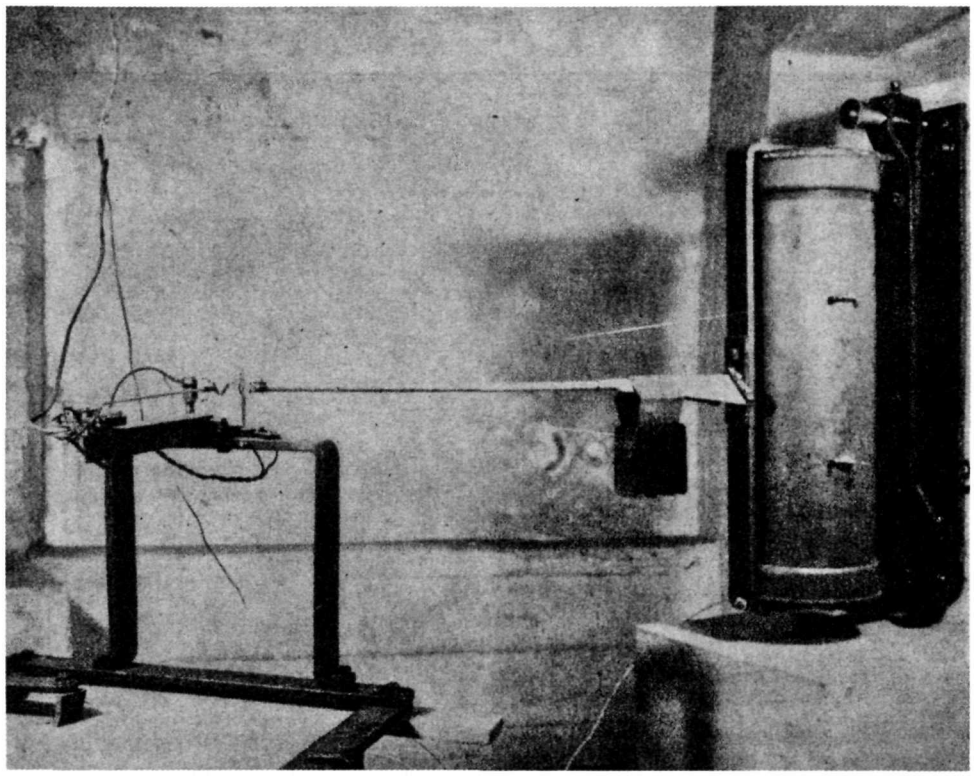

Figure 1. General view of the teleseism annunciator. The damping vanes on the boom near the heavy mass are not in use.

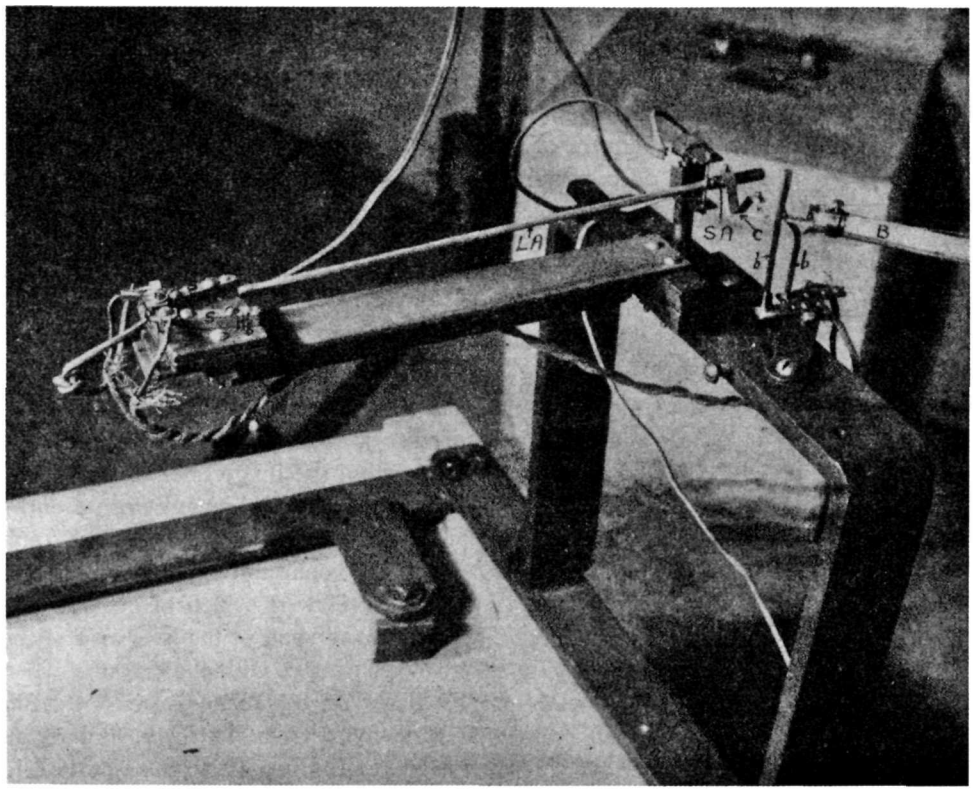

Figure 2. Details of magnifying lever and wiring. **B,** boom; **b, b,** buffers; **c** is the link that couples boom to magnifying lever; **SA** is short arm and **LA** long arm of magnifying lever; **W** is wire that contacts mercury pools; **Hg** is the mercury pool; and **s** is the steel bar that holds the mercury.

NATIONAL PARK SERVICE PHOTOGRAPHS BY DOUGLASS H. HUBBARD

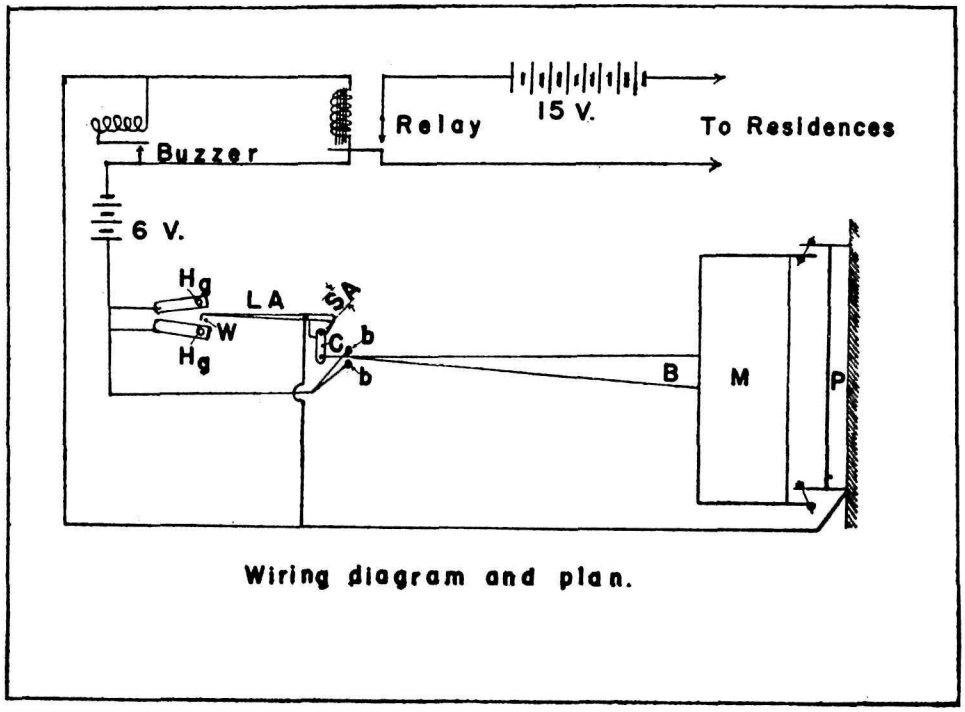

Figure 3. Wiring diagram and plan of the teleseism annunciator. Letters correspond to those in Figure 2.

mantles the instrument by throwing off the coupling mentioned above, it will still continue to function as an annunciator by means of the buffer contacts, though with diminished sensitivity.

The pools of mercury are in steel bars mounted on a piece of insulating material and are 1⅝ inches apart. When first set up they were only ¾ of an inch apart. Tilt due to daily temperature changes was so great that it was found necessary to increase the distance.

When the instrument was first installed, it was operated with a period of 12 seconds. To reduce the trouble due to tilt, the period was reduced to 7 seconds. The pendulum is undamped.

The instrument has been quite satisfactory and has announced several local earthquakes as well as a few teleseisms. It gave a good warning signal for the teleseism of May 14, 1948, which caused the tidal wave warning system in the Territory to be put into operation. This earthquake was the only one announced which was deemed to have sufficient amplitude and proper distance to justify a warning of the possibility of a tidal wave.

HAWAIIAN VOLCANO OBSERVATORY REPORT FOR APRIL-JUNE, 1948

VOLCANOLOGY

April

Forty-two earthquakes were recorded in April. Thirty-eight of the quakes were recorded on the Mauna Loa seismograph and 14 at Kilauea. The felt earthquakes which occurred at 00:25 April 26 originated near the north end of the Kilauea caldera. The facts that the shake was slight to moderate at the Observatory and was recorded as a tremor only on the Mauna Loa seismograph 10 miles away, indicate a very shallow focus.

The strong southerly tilt that set in about the first of the year continued until the last of April.

May

The earthquakes which occurred in May had widely scattered origins, as in the past several months. Twenty-eight quakes were recorded during the month, the majority of which originated under various portions of Mauna Loa. Twenty-five of the shakes were recorded on the Mauna Loa seismograph and 11 at Kilauea.

The accumulation of seasonal westerly tilt during the first 5 months of the year was the smallest for several years, and the records indicate that this may be taken as a suggestion of a slight pressure build up under Mauna Loa. The unusually sharp southerly tilt which began the first of the year ceased early in May.

A conspicuous steam cloud was observed over Mokuaweoweo at sunset on May 16 and on several other days during the month. Such observations are rather common at this season of the year.

June

Thirty local earthquakes were recorded in June. Of this number 28 were recorded on the Mauna Loa seismograph and 18 at Kilauea.

There was no accumulation of tilt during the month. The lack of westerly tilt rather than a positive easterly tilt is the only indication of a pressure build up under Mauna Loa.

R.H.F.

SEISMOLOGY

Earthquake Data, April-June 1948

Week Ended		Minutes of Tremor	Very Feeble	Feeble	Slight	Moderate	Local Seismicity*	Teleseisms
April	4	0	4	0	0	0	2.00	0
	11	0	3	0	1	0	3.50	0
	18	0	2	0	0	0	1.00	0
	25	2	1	0	1	0	1.00	0
May	2	1	2	0	0	0	1.25	0
	9	0	0	0	0	0	0	0
	16	2	0	0	0	0	0.50	1
	23	2	1	0	1	0	3.00	1
	30	1	2	1	1	0	3.75	0
June	6	1	3	2	0	0	3.75	0
	13	2	0	0	0	0	0.50	0
	20	2	1	0	1	0	3.00	1
	27	0	3	0	0	0	1.50	0

* For definition of local seismicity, see Volcano Letter No. 371.

The data of the following local disturbances were determined from seismograph stations operated on the island of Hawaii by the Hawaiian Volcano Observatory of the U. S. Geological Survey. Time is Hawaiian Standard, 10 hours slower than Greenwich. The number preceding each earthquake is the serial number for the current year.

42. April 5, 11:23, very feeble.
43. April 6, 0:25, slight. Felt locally. Shallow under northern end of Kilauea caldera.
44. April 6, 19:53, very feeble.
45. April 6, 22:12, very feeble.
46. April 14, 9:01, very feeble.
47. April 15, 3:37, very feeble. Kilauea.
48. April 24, 10:05, slight. Felt locally and at Hilo. East slope of Mauna Loa.
49. April 24, 23:59, feeble. Felt locally. Mauna Loa.
50. April 28, 20:53, very feeble.
51. April 30, 0:51, very feeble. Mauna Loa.
52. May 20, 20:04, very feeble. Under Mokuaweoweo.
53. May 22, 11:34, slight. Deep under Hualalai.
54. May 24, 23:16, slight. Felt locally. N.E. rift of Mauna Loa.
55. May 26, 0:39, feeble.
56. May 29, 16:29, very feeble. Under Mokuaweoweo.
57. May 29, 18:45, very feeble.
58. June 1, 7:34, feeble. Felt at Ainahou.
59. June 2, 21:13, very feeble.
60. June 3, 8:58, very feeble.
61. June 5, 12:08, very feeble.
62. June 6, 10:17, feeble. Kilauea.
63. June 18, 6:05, very feeble.
64. June 19, 17:06, slight, Felt locally, East slope of Mauna Loa.
65. June 24, 17:49, feeble.
66. June 25, 10:18, feeble. Kilauea.
67. June 25, 13:05, feeble. Felt locally. Mauna Loa.
68. June 26, 1:42, slight. Under Oahu; felt at Hilo.
69. June 28, 10:51, very feeble.

TELESEISMS

May 14, 12:40, moderate. Aleutians.
May 17, 7:57, slight. South of Alaska peninsula.
June 17, 3:04, slight.
June 29, 0:36, slight.

MICROSEISMS

Microseisms were moderate on April 9, 10, 24, and 25 and slight on other days.

CRACK MEASUREMENTS

A few of the cracks that were measured in the vicinity of Halemaumau rim showed slight openings.

TILTING OF THE GROUND

Seasonal southerly tilt, which was stronger than usual during the first 4 months of the year, continued until May 4, when a slight northerly tilt began. The seasonal change from westerly to easterly tilt occurred on June 9.

R.H.F.

Table of Tilt at Observatory on Northeast Rim of Kilauea

Week Ended		Amount	Direction
April	4	1.2″	S 11° E
	11	2.4″	S
	18	1.0″	N 82° W
	25	1.2″	S
May	2	0.4″	S 19° W
	9	0.8″	N 61° W
	16	0.2″	N 45° E
	23	0.8″	S 56° E
	30	1.2″	N 11° W
June	6	0.2″	S 45° E
	13	1.0″	S 55° W
	20	0.4″	N 72° E
	27	0.9″	N 9° W

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In cooperation with the UNIVERSITY OF HAWAII

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The **University of Hawaii** cooperates in maintaining a research laboratory at Kilauea. The Association and the University supplement the work of the government with research associates, instrumental equipment, and special investigations. Dr. T. A. Jaggar is their geophysicist resident at Kilauea.

The **Volcano Letter**, a quarterly record of Hawaiian volcano observations, is published by the University of Hawaii and supplied to members of the Research Association and to exchange lists of the above establishments.

THE VOLCANO LETTER

No. 501 **U. S. Geological Survey** **July–September, 1948**

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U. S. GEOLOGICAL SURVEY: R. H. Finch, Volcanologist

UNIVERSITY OF HAWAII: T. A. Jaggar, Geophysicist

THE NEW LOCATION OF THE HAWAIIAN VOLCANO OBSERVATORY

By RUY H. FINCH

Volcanologist, U. S. Geological Survey

One of the results of the transfer of the Hawaiian Volcano Observatory from the National Park Service to the U. S. Geological Survey is the establishing of the Observatory in a new location. It is being moved to the old National Park Museum and Lecture Hall buildings at Uwekahuna Bluff on the western rim of Kilauea Caldera (see figure). The buildings have been remodeled to include offices, shops, and laboratories.

The Observatory was located on the northeast rim of the Caldera from the time it was established in 1912 until 1941, when it was moved 600 feet back from the rim into the newly constructed Observatory and Naturalist Building. The vertical seismograph and a tilt meter were placed in a cellar under this building. The Bosch-Omori seismograph, the principal instrument of the Whitney Laboratory of Seismology, was left in its old location[1] under a concrete slab and 18 inches of soil.

Both the first and second locations of the Observatory were on badly fissured basalt with numerous steam cracks. Because the concrete floor was built over steam cracks, the temperature of the cellar at the original location is about 95° F. the year around. For similar reasons the cellar of the second location has a constant temperature of about 85° F. The mean annual air temperature of the area is about 61° F. A commercial highway passes about 200 feet from each cellar, and the records are marred by the frequent passing of heavy trucks.

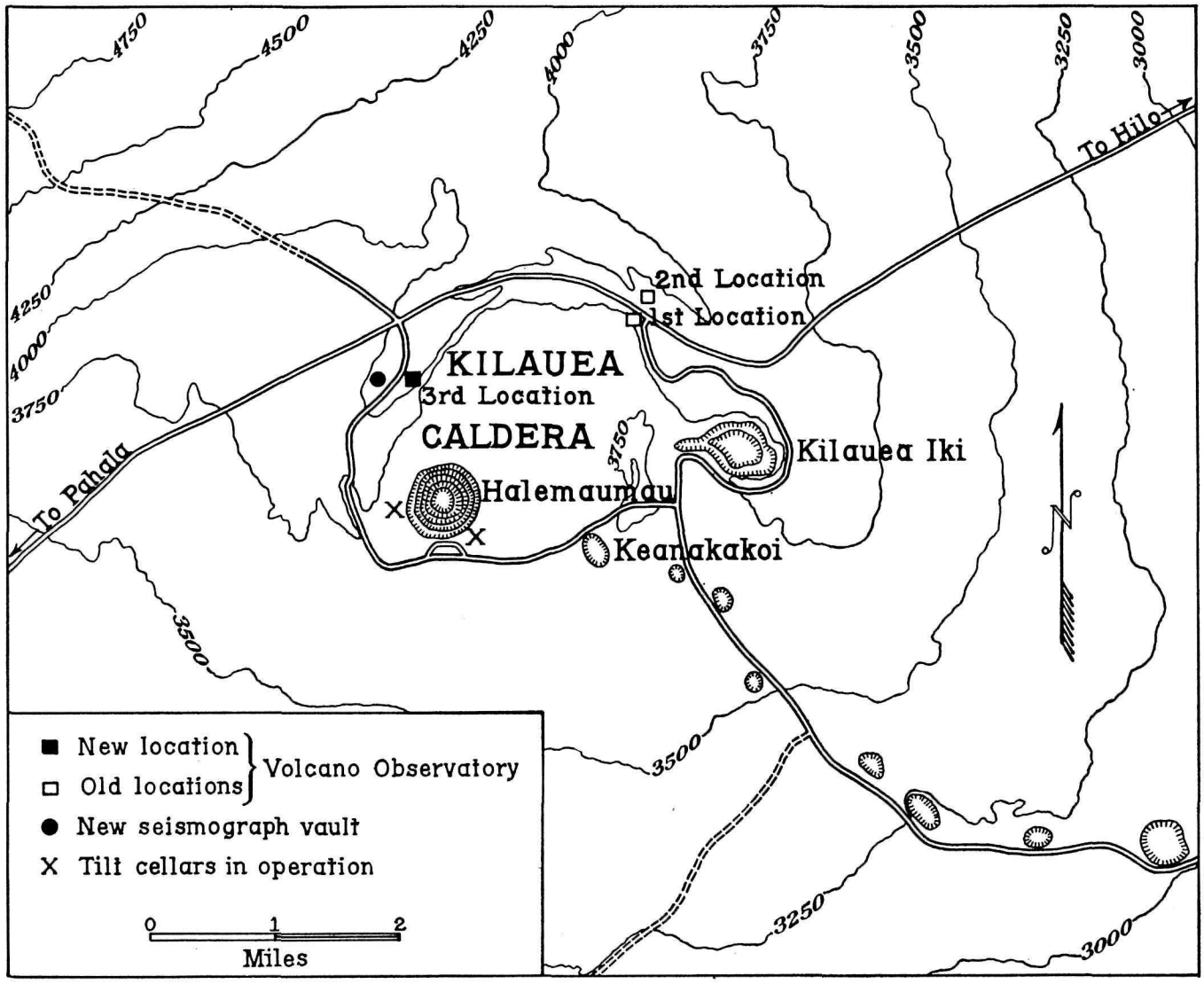
[1] Volcano Letter 475, 1942.

Tilt records have been taken from the Bosch-Omori seismograph since 1913. The instrument has been operated since 1919 with a period of about 7.7 and a magnification of about 115. It is proposed to operate this seismograph in its present location for another year before removal to the new cellar near Uwekahuna (see figure). This will afford an opportunity to correlate tilt records of the two locations, one on the northeast rim and the other on the northwest.

The Bosch-Omori seismograph tilt records do not correlate well with those obtained from a special tilt pendulum under the Observatory-Naturalist Building. When the numerous fissures of the area are considered, this is not surprising. Despite the nearly constant temperature of the second cellar, the tilt records obtained here were marred by the large tilt produced by diurnal temperature changes in the superstructure. The tilt data measured at the original location of the Observatory are real as they have been checked by leveling.[2]

The new location of the Observatory is at an elevation of 4,075 feet a short distance southerly from the highest point on Kilauea Mountain. It is 1 mile northwest from the center of Halemaumau just off the Crater Rim Road. The site affords a good view of Kilauea Caldera, the southwest rift, and part of the Puna rift as well as

[2] JAGGAR, T. A., and FINCH, R. H. TILT RECORDS FOR THIRTEEN YEARS AT THE HAWAIIAN VOLCANO OBSERVATORY. Bull. Seis. Soc. Amer. Vol. 19, No. 1, 1929. See also leveling data in T. A. Jaggar, Memoir 21, Geol. Soc. Amer., pp. 208–214, 1947.



Map showing the positions of the successive locations of the Hawaiian Volcano Observatory, the new seismograph vault, and the tilt cellars now in operation.

Mauna Loa. This was the first site selected by Dr. T. A. Jaggar for the Observatory in 1912 but was given up on account of the scarcity of water and its relative inaccessibility at that time.

A new seismograph cellar has been constructed 1,250 feet nearly due west of the Uwekahuna Bench Mark. The new cellar is 1⅛ miles from the center of Halemaumau, about 1 mile closer than the old cellar. It is 450 feet from the Crater Rim Road and about 2,000 feet from the around-the-island highway. The cellar is 12 x 20 feet with an entrance way 5 x 8 feet to serve as an air lock and processing room. The roof is a reinforced concrete slab covered with about 18 inches of volcanic ash. The foundation of the cellar is within massive basalt which lies under 20 inches of ash. There is only one visible fissure between the cellar and the Caldera rim. During the week ended September 16 a thermograph trace made in the cellar showed a drop of less than 1½° F. This record, which was obtained during a dry spell, showed a diurnal variation of about ½° F. The maximum was reached about 6:00 p.m.

The first instrument installed was a portable tilt meter oriented to measure east–west tilt. For the first 2 weeks values obtained seemed to be due largely to cellar floor and instrumental adjustments.

Two tilt meters and the vertical seismograph will shortly be installed in the new cellar. In about a year the Bosch-Omori seismograph will be moved over, and later on it is planned to install a higher-magnification instrument.

HAWAIIAN VOLCANO OBSERVATORY REPORT FOR JULY–SEPTEMBER, 1948

VOLCANOLOGY

July

Forty-one earthquakes were recorded during July. Thirty-seven of the shakes were recorded at Mauna Loa and 19 at Kilauea. Six of the seven earthquakes recorded on July 30 were perceptible. They originated at a depth of about 6 miles to the east of Kilauea Caldera. These quakes furnish the most conspicuous signs of uneasiness under Kilauea that have been noted during the last 3 years.

Seasonal northerly tilt during July was slightly greater than usual.

August

Only 27 earthquakes were recorded during August. Eleven of the shakes were recorded at Kilauea and 23 at Mauna Loa. The uneasiness at Kilauea which was quite distinct on July 30 did not continue. The only perceptible quake recorded during August (at 03:04, August 3) had a shallow origin under the northeast rift of Mauna Loa.

There was no accumulation of tilt in the east–west direction during the month. The north–south tilt curve shows an accumulation of northerly tilt greater than in 1946 or 1947. This may be taken as an indication of a slight pressure build up under Kilauea.

September

The majority of the 30 earthquakes recorded during September originated under Mauna Loa. Twenty-one of the shakes were recorded at Kilauea and 26 at Mauna Loa. The strongest of these shakes occurred at 8:20 a.m., September 13. It originated at a depth of 20–25 miles below the surface between Hilo and Mauna Kea.

The north–northeast tilt during the month of September was about normal for this season of the year.

SEISMOLOGY

Earthquake Data, July–September 1948

Week Ended	Minutes of Tremor	Very Feeble	Feeble	Slight	Moderate	Local Seismicity*	Teleseisms
July 4	4	2	0	1	0	4.00	0
11	0	0	0	0	0	0	0
18	2	2	0	0	0	1.00	3
25	0	1	1	0	0	1.50	2
August							
1	3	1	1	3	2	13.25	0
8	1	3	0	0	1	4.75	0
15	1	0	0	0	0	0.25	0
22	0	0	0	0	0	0	0
29	2	2	0	0	0	1.50	0
September							
5	1	3	1	0	0	2.75	0
12	3	0	1	0	0	1.75	2
19	0	2	0	1	1	6.00	0
26	4	0	1	0	0	2.00	0

* For definition of local seismicity, see Volcano Letter No. 371.

The data of the following local disturbances were determined from seismograph stations operated on the island of Hawaii by the Hawaiian Volcano Observatory of the U. S. Geological Survey. Time is Hawaiian Standard, 10 hours slower than Greenwich. The number preceding each earthquake is the serial number for the current year.

70. July 3, 18:14, very feeble, Mauna Loa.
71. July 12, 0:29, very feeble. Felt at Naalehu.
72. July 17, 6:11, very feeble. Felt at Naalehu.
73. July 19, 10:08, very feeble. Kilauea.
74. July 24, 13:19, feeble. Felt locally and at Hilo. Mauna Loa.
75. July 30, 2:28, moderate. Awakened some people. East of Kilauea Caldera.
76. July 30, 2:31, moderate. Same location as No. 75.
77. July 30, 2:44, slight. Same location as No. 75.
78. July 30, 12:28, feeble. Same location as No. 75.
79. July 30, 16:46, slight. Same location as No. 75.
80. July 30, 16:56, slight. Same location as No. 75.
81. August 1, 8:59, very feeble.
82. August 3, 3:04, moderate. Felt locally and at Hilo. NE rift of Mauna Loa.
83. August 4, 15:59, very feeble. Kilauea.
84. August 6, 14:23, very feeble. NE rift of Mauna Loa.
85. August 8, 5:14, very feeble. Felt locally. Mauna Loa.
86. August 10, 6:38, very feeble. Mauna Loa.
87. August 29, 17:48, very feeble. Mauna Loa.
88. August 29, 17:49, very feeble.
89. September 3, 20:31, very feeble.
90. September 4, 7:36, very feeble. Near Mokuaweoweo.
91. September 5, 8:01, feeble. Felt locally and at Hilo. NE rift of Mauna Loa.
92. September 5, 8:52, very feeble. Mauna Loa.
93. September 7, 11:05, feeble. Felt locally. Mauna Loa.
94. September 13, 8:20, moderate. Generally felt on east half of island. 20–25 miles deep, SE of Mauna Kea.
95. September 15, 9:45, slight. Near Mokuaweoweo.
96. September 18, 22:23, very feeble. Mauna Loa.
97. September 19, 14:51, very feeble. Mauna Loa.
98. September 21, 18:44, feeble. Mauna Loa.
99. September 28, 3:53, very feeble. Mauna Loa.

TELESEISMS

July 14, 12:48, slight. Near New Guinea.
July 15, 1:12, slight. Off coast of Mexico.
July 15, 20:30, slight.
July 22, 10:22, slight. Off west coast of Vancouver Island.
July 22, 11:10, slight.
September 8, 5:17, slight. Near Tonga.

MICROSEISMS

Microseisms were moderate during the latter half of September and slight on other days.

CRACK MEASUREMENTS

The cracks measured in the vicinity of Halemaumau rim were either stationary or opened only slightly.

TILTING OF THE GROUND

Easterly tilt was unusually slight but nearly continuous throughout the quarter. Northerly tilt was continuous and a little greater than in the past two years.

Table of Tilt at Observatory on Northeast Rim of Kilauea

Week Ended		Amount	Direction
July	4	0.2″	S 45° E
	11	1.2″	N 30° E
	18	0.4″	W
	25	1.0″	N 7° W
August	1	1.2″	N 53° E
	8	0.3″	N 26° E
	15	1.0″	N 30° W
	22	0.6″	N 12° E
	29	0.7″	N 45° E
September	5	1.3″	N 57° W
	12	0.6″	N 37° E
	19	0.5″	N 14° E
	26	1.4″	N 48° E

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THE VOLCANO LETTER

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U. S. GEOLOGICAL SURVEY: R. H. Finch, Volcanologist

UNIVERSITY OF HAWAII: T. A. Jaggar, Geophysicist

FLOW-PUMICE ON HAWAIIAN BASALTS

By R. H. FINCH, HOWARD A. POWERS, and GORDON A. MACDONALD

U. S. Geological Survey

Mauna Loa is a large, elongate shield volcano, built of lava flows of primitive olivine basalt to an altitude exceeding 13,600 feet above sea level and 30,000 feet above the ocean floor. Most eruptions take place from fissures in two rift zones which meet in a summit caldera. All known eruptions have started in the summit region. In some, activity is confined to the summit; in others, after brief summit action, the main eruption breaks through fissures in the flank of the mountain. In historic time, Mauna Loa has not established and maintained a lake of fluid lava comparable to the lake which has been typical of much of the historic activity of Kilauea.

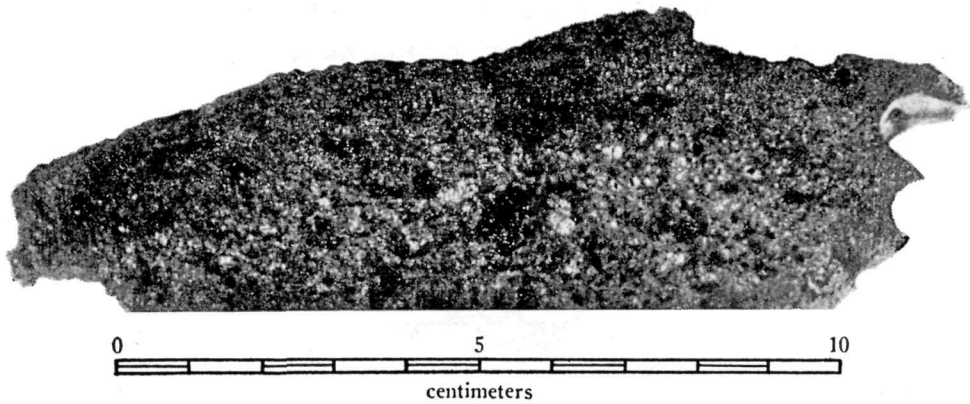
Cones of pyroclastic material have been built around Mauna Loa vents where lava fountaining has persisted for more than a few hours. Most cones contain much pumice. In addition, a skin of pumice is found on thin, short flows adjacent to eruptive fissures both in the summit area and along the rift zones. The material has previously been observed[1] and studied[2] but without regard to the process of formation.

The flow pumice, as much as an inch in thickness, is composed of basaltic glass, drawn out into thin vesicle walls, which are brown in color. Most of the vesicles are small, and only slightly elongated in the direction of flow of the lava. A few much larger elongated cavities are scattered through the pumice skin. A cube of the flow-pumice chosen to contain the least possible number of larger gas cavities has a gross density of about 0.6; the density of the glass is about 2.7. Thus, the porosity of the pumice due to gas inflation is about 75 percent. The pumice grades abruptly into a layer of vesicular black glass in which the vesicle walls are thicker and the vesicles are larger and less numerous. The layer of black glass grades into the grossly vesicular, partly crystallized rock which forms the bulk of each flow layer of lava. In this inner part, the gas cavities are so large that gross density determination is impractical; but by inspection, the gross porosity of the interior is of the same order of magnitude as that of the surface pumice.

Several details of the field occurrence of the pumice aid in interpreting the process of its formation. At the margin of many of the pumice-covered flows, the last ooze of liquid which formed the toe of the flow was quenched at its exposed surface into vesicular black glass rather than into true brown pumice. Elsewhere, the pumice-covered crust had cracked in places, allowing interior fluid to ooze upward through the cracks. Surface quenching of this residual liquid also produced the vesicular black glass rather than brown pumice. It is apparent in the field that the emplacement of these pumice-covered flows was completed in but a few minutes. During this short time, the liquid of the interior

[1] GREEN, W. L. VESTIGES OF THE MOLTEN GLOBE. Part 2, 281–282. Honolulu, 1887.

[2] MACDONALD, G. A. PETROGRAPHY OF THE ISLAND OF HAWAII. U. S. Geol. Sur. Professional Paper 214-D. In press.



Specimen of pumice-surfaced lava collected from the 1942 summit flow of Mauna Loa. The pumice is brown, nearly ½ inch in thickness, and grades abruptly into black vesicular glass. Photo by V. R. Bender, National Park Service.

part of the flow, insulated by the skin of pumice, lost enough of its dissolved volatile component but retained enough heat so that oozes of it which reached the air were quenched as black glass. In many other places, only small patches of the pumice-surfaced flows remain exposed because they have been buried by gushes of less gas-rich lava extruded later in the same eruption. These later gushes have congealed with the more common skin of black glass.

Pumice-covered pahoehoe from the 1942 summit activity is exposed throughout an area of about a quarter of a square mile; in an equally large area it is now buried. Lava flows extruded from nearly 4 miles of open fissure during less than 10 hours of eruption cover a total area of 3⅓ square miles. Flows distant from the fissure have an aa surface; the flows near the fissure have a pahoehoe surface. The pumice-surfaced pahoehoe is restricted to gushes of lava which traveled less than a quarter of a mile from their vents. The main flow of 1942 issued from a fissure in the northeast rift zone at an altitude below 9,400 feet, and began about 24 hours after the summit activity had ceased. There is very little pumice-surfaced pahoehoe at this lower fissure, though pumice is plentiful in the pyroclastic cone which was built around the persistent lava fountains. Abundant pumice-surfaced lava is associated with some of the older flank fissure vents, but the pumice was clearly formed only on the earliest gushes of lava.

These occurrences of pumice contribute some data on the time and manner of escape of volatiles from basaltic magma in the Hawaiian volcanoes. Separation of some volatiles from the liquid must have taken place during its rise in the feeding dikes, because fountaining at the vents indicates bursting of gas bubbles, and many larger gas bubbles have left cavities in the pumice formed both at the fountains and on the pahoehoe flows. However, the formation of pumice among the pyroclastic products and as a skin on lava flows indicates that the liquid reached the surface with sufficient volatiles in solution to inflate it to four times in subsurface volume. The fact that pumice does not form on lava surfaces more than a few hundred yards in distance and a few minutes in time away from the point of emission suggests that the release of volatiles involved is nearly explosive in its rapidity and occurs as soon as the magma appears at the surface. Inherently, the great bulk of the congealed products of eruption can give evidence only of the fact that volatile constituents were present and did escape; evidence of the time and manner of this escape is found only in the small amount of material which was quenched as fountain product and as the surface phase of short flows very near the vents.

HAWAIIAN VOLCANO OBSERVATORY REPORT FOR OCTOBER–DECEMBER, 1948

VOLCANOLOGY

October

Forty-nine seismic disturbances were recorded at Mauna Loa and 44 at Kilauea. Nearly all of the 76 individual earthquakes were very weak. The majority originated either under Kilauea Caldera or along the northeast rift of Mauna Loa.

North–northeast tilting of the ground on the northeast rim of Kilauea continued at a rate normal for this season of the year.

Moderate amounts of sulphurous fume were observed in the summit crater of Mauna Loa on October 5 and 6.

November

Fifty-two seismic disturbances were recorded during the month. Though the numbers recorded at Kilauea and Mauna Loa were 44 and 38 respectively, the majority of the more distinct shakes originated under Mauna Loa.

The rapid easterly tilt that marked the first half of the month ceased on November 14, and there was no accumulation of tilt in the east–west direction during the last half. There was no accumulation of north–south tilt in November.

December

There was no visible activity at any Hawaiian volcano during 1948. Tilt and earthquake data indicate that there was also a lack of any appreciable subterranean activity.

Seventy-five local earthquakes were recorded during December. Seventy-two of these were recorded at Mauna Loa and 61 at Kilauea. A majority of the earthquakes were weak and originated on the northeast rift of Mauna Loa.

The seasonal change from easterly to westerly tilt occurred on December 2, and there was a slight accumulation of westerly tilt during the month. Seasonal northerly tilt continued until December 27, when normal southerly tilt set in. There was a slight accumulation of easterly tilt during 1948.

R.H.F.

SEISMOLOGY

Earthquake Data, October–December 1948

Week Ended		Tremor	Very Feeble	Feeble	Slight	Local Seismicity*	Teleseisms
October	3	3	1	0	0	1.25	0
	10	4	4	0	0	3.00	1
	17	14	0	0	0	3.50	0
	24	10	2	0	0	3.50	0
	31	8	1	0	0	2.50	0
November	7	5	0	0	0	1.25	0
	14	10	0	1	0	3.50	0
	21	11	1	0	0	3.25	0
	28	10	4	0	0	4.50	0
December	5	10	0	0	0	2.50	2
	12	14	2	1	0	5.50	0
	19	13	1	0	1	5.75	0
	26	10	3	0	0	4.00	0

* For definition of local seismicity, see Volcano Letter No. 371.

The data of the following local disturbances were determined from seismograph stations operated on the island of Hawaii by the Hawaiian Volcano Observatory of the U. S. Geological Survey. Time is Hawaiian Standard, 10 hours slower than Greenwich. The number preceding each earthquake is the serial number for the current year.

100. October 7, 18:12, very feeble. Hualalai.
101. October 9, 00:53, very feeble. Mauna Loa.
102. October 9, 18:06, very feeble.
103. October 10, 12:06, very feeble. Mauna Loa.
104. October 18, 10:51, very feeble. NE rift Mauna Loa.
105. October 18, 17:30, very feeble. NE rift Mauna Loa.
106. October 27, 16:13, very feeble. Kilauea.
107. November 14, 03:28, feeble. NE rift Mauna Loa.
108. November 21, 09:33, very feeble.
109. November 23, 13:22, very feeble. Mauna Loa.
110. November 25, 09:55, very feeble.
111. November 28, 09:45, very feeble. Mauna Loa.
112. December 7, 20:22, very feeble. NE slope Mauna Loa.
113. December 9, 06:44, very feeble. Mauna Loa.
114. December 9, 15:05, feeble. Felt locally.
115. December 13, 07:35, slight. Mauna Loa. Record being changed.
116. December 18, 14:57, very feeble. NE rift Mauna Loa.
117. December 20, 09:01, very feeble. Mauna Loa.
118. December 23, 21:02, very feeble. Mauna Loa.
119. December 26, 03:30, very feeble.
120. December 28, 11:08, very feeble. East slope Mauna Loa.
121. December 28, 14:08, very feeble.
122. December 29, 19:58, very feeble.

TELESEISMS

October 5, 11:15, slight. Near northern Iran.
December 3, 14:32, slight. Off west coast of Mexico.
December 4, 14:01, slight. Southern California.
December 30, 14:00, slight.

MICROSEISMS

Microseisms were strong October 18–25 and November 1–12 and moderate during the rest of the quarter.

CRACK MEASUREMENTS

A few of the cracks near the Halemaumau rim showed a slight opening, though a majority of the cracks that were measured showed no appreciable movement.

TILTING OF THE GROUND

There was a rapid accumulation of easterly tilt from October 27 to November 14. The seasonal change to westerly tilt occurred on December 2. During the year of 1948 there was an accumulation of easterly tilt. Normal northerly tilt continued to December 27, when seasonal southerly tilt set in. Northerly and southerly tilt were about equal in 1948.

Table of Tilt at Observatory on Northeast Rim of Kilauea

Week Ended		Amount	Direction
October	3	0.3″	S 27° W
	10	0.4″	N 20° E
	17	0.8″	N 19° E
	24	0.9″	N 34° W
	31	1.2″	N 50° E
November	7	0.6″	N 78° E
	14	4.5″	S 11° E
	21	0.4″	N 27° W
	28	0.7″	N 9° E
December	5	0.7″	N 59° E
	12	0.5″	N 63° W
	19	0.5″	S 78° W
	26	0.6″	N

HAWAIIAN VOLCANO RESEARCH ASSOCIATION

In cooperation with the UNIVERSITY OF HAWAII

The **Hawaiian Volcano Research Association** was founded in 1911 for the recording and study of volcanoes in the Hawaiian Islands and around the Pacific Ocean. Its equipment at Kilauea Volcano, Hawaii Island, has been transferred to the United States Geological Survey.

The **University of Hawaii** cooperates in maintaining a research laboratory at Kilauea. The Association and the University supplement the work of the government with research associates, instrumental equipment, and special investigations. Dr. T. A. Jaggar is their geophysicist resident at Kilauea.

The **Volcano Letter,** a quarterly record of Hawaiian volcano observations, is published by the University of Hawaii and supplied to members of the Research Association and to exchange lists of the above establishments.

THE VOLCANO LETTER 503

No. 503 **U. S. Geological Survey** **January–March, 1949**

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U. S. GEOLOGICAL SURVEY: R. H. Finch, Volcanologist

UNIVERSITY OF HAWAII: T. A. Jaggar, Geophysicist

THE MAUNA LOA ERUPTION OF JANUARY, 1949

By GORDON A. MACDONALD and RUY H. FINCH

U. S. Geological Survey

HISTORY OF THE ERUPTION

Mauna Loa resumed eruptive activity on January 6, 1949, after a period of quiescence of 6 years and 8 months. The eruption, which was confined to the summit caldera, Mokuaweoweo, and to the uppermost part of the southwest rift zone, is to be classed as a summit eruption. Following the flank eruption of 1942 on the northeast rift, it thus continues the alternation of summit and flank eruptions which has existed since 1926.

At 4:15 p.m. on January 6 a dull rumbling was heard at the Hawaiian Volcano Observatory, apparently originating at the summit of Mauna Loa, 20 miles away. From the Observatory, the summit was hidden by a heavy cloud layer along the southeastern slope of the mountain; but from Hilo to Mountain View, on the eastern slope, the view of the summit was unobstructed. At about 4:00 p.m. B. F. Moomaw of the National Park Service saw, from the highway a short distance southeast of Olaa, a puff of fume rising from the summit. At about 3:45 or 3:50 p.m. Mrs. Walter Eklund observed fume at the summit of the mountain, from the highway in southern Kau. The registration of continuous tremor on the Bosch-Omori seismograph at Kilauea began at 3:47 p.m., indicating the movement of magma in the conduit at that time.

The precise time of beginning of the eruption thus is uncertain. It seems probable that some harmonic tremor may have preceded arrival of the magma at the surface, and therefore the probable time of beginning of surface lava activity may be placed between 3:50 and 4:15 p.m. The arrival of lava at the surface may have been preceded by an increase in the amount of fume being liberated at the summit of the mountain.

The heavy rumbling sounds, audible 20 miles away, indicate that some of the early bursts of gas liberation were of explosive violence. There is no known previous instance of such sounds, originating in summit activity of Mauna Loa, being audible at Kilauea. The audibility may have been partly the result of reflection from a high cloud layer which extended above the summit of Mauna Loa at the time. The strength of the early bursts is further indicated by the finding of pumice at 11,000 feet altitude on the northeastern flank of the mountain, 7 miles from the nearest lava fountains, and of Pele's hair at Kulani Camp, 20 miles east of the fountains.

The lava broke out along a fissure which extended south-southwesterly across the floor of Mokuaweoweo caldera from a point north of its center, up over the boundary cliff of the caldera, and about 1.7 miles down the southwestern flank of the mountain. The distribution of glow, as seen from the Volcano Observatory, indicated that lava fountaining was nearly, if not completely, continuous along this crack, a distance of about 3 miles. On the morning of January 7, D. H. Hubbard of the National Park Service observed the activity from the air and reported that two fountain areas were still active on the southwest rift. However, by the morning of January 9 aviators reported only fume along the fissures outside the caldera, except for very weak intermittent fountaining and short flows at one point. As is usual with summit eruptions of Mauna Loa, activity outside the caldera lasted only a relatively few hours. Within 24 hours it was largely over, and within 72 hours activity was entirely confined within the caldera.

The short-lived fountains, on the upper part of the southwest rift outside the crater, gave vent to a copious outpouring of lava during the first few hours of the eruption. This lava formed several short flows in addition to one long flow which moved rapidly westward just north of, and partly overlying, the lava flow of 1851. (See figure 1.) In its first 24 hours, this flow advanced about 6 miles. It was short-lived, however; with the dying of fountain activity outside the caldera the supply of lava was cut off, and by January 8 the flow appeared to be essentially dead. The lower end of the flow reached an altitude of about 8,500 feet, 6.5 miles from its source.

On the afternoon of January 7, lava fountain activity within the caldera itself had become restricted to two short lengths of the fissure. North of the 1940 cinder cone, near the middle of Mokuaweoweo, a nearly continuous line of fountains half a mile long played to an average height of about 50 feet with occasional bursts up to about 150 feet. As nearly as could be ascertained, these fountains were situated on or close to a zone of fuming fissures which had been observed by Macdonald and Powers in October 1948 (VOLCANO LETTER 502). From these fountains a small lava stream moved westward, forming a pond of lava between them and the western caldera wall; another larger flow was moving eastward.

The other active portion of the fissure was situated at and close to the base of the southwestern wall of the caldera. There a small fountain played intermittently from the fissure directly at the base of the wall, with occasional spurts from the fissure part way up the wall; a much larger and steadier fountain played a short distance out from the wall on the caldera floor. The larger fountain shot constantly to heights of 150 to 200 feet, with occasional bursts as high as 300 feet. The fountains at the southwestern edge of the caldera sent a flow northward into the caldera west of the 1940 cone joining the flow from the more northerly group of fountains, and another flow eastward. The flow to the east divided, sending one branch in the direction of South Pit and another northeastward along the base of the caldera wall. The latter branch joined the flow from the northern fountain-chain, leaving the 1940 cinder cone and part of its surrounding lava shield protruding as an island in the

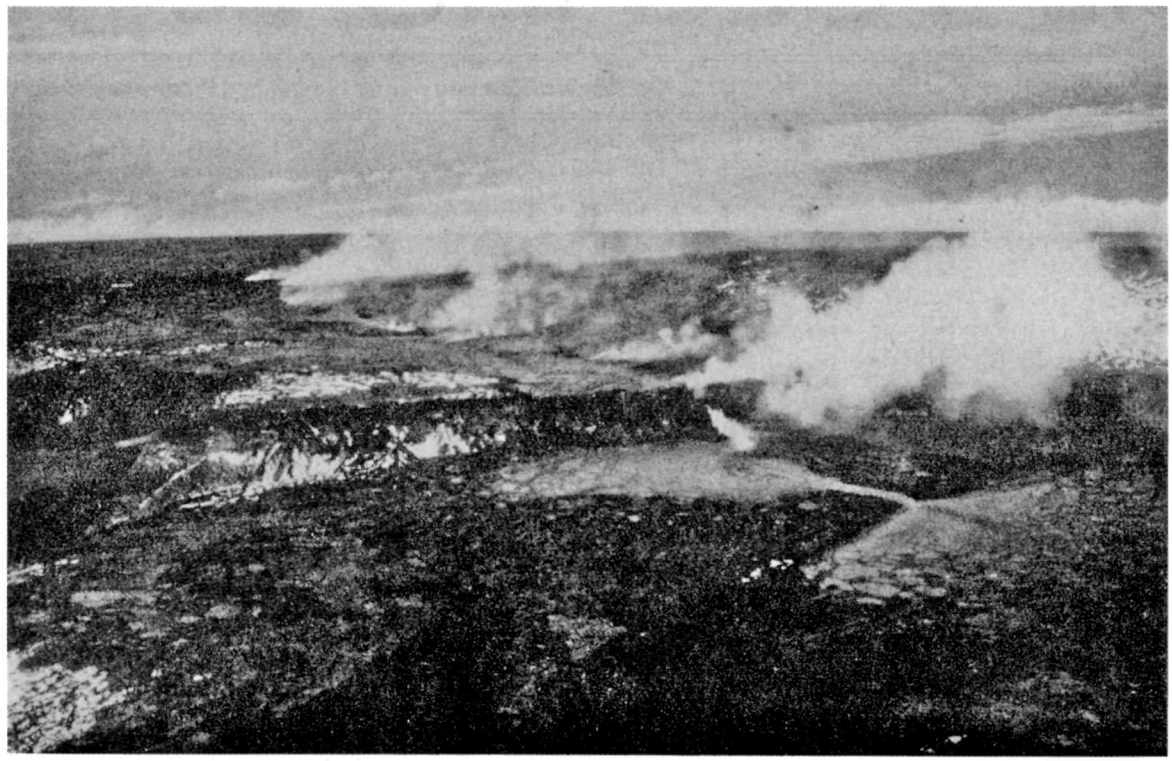

PLATE 1. Eruptive fissure extending up over the southwestern wall of Mokuaweoweo caldera and on down the southwest rift zone of Mauna Loa, on the morning of January 7, 1949. Large lava fountains are playing from the fissure at the base of the caldera wall, and smaller ones can be seen in the background along the southwest rift. In the foreground, new lava is pouring onto the caldera floor, and to the left into South Pit. OFFICIAL PHOTOGRAPH, U. S. NAVY.

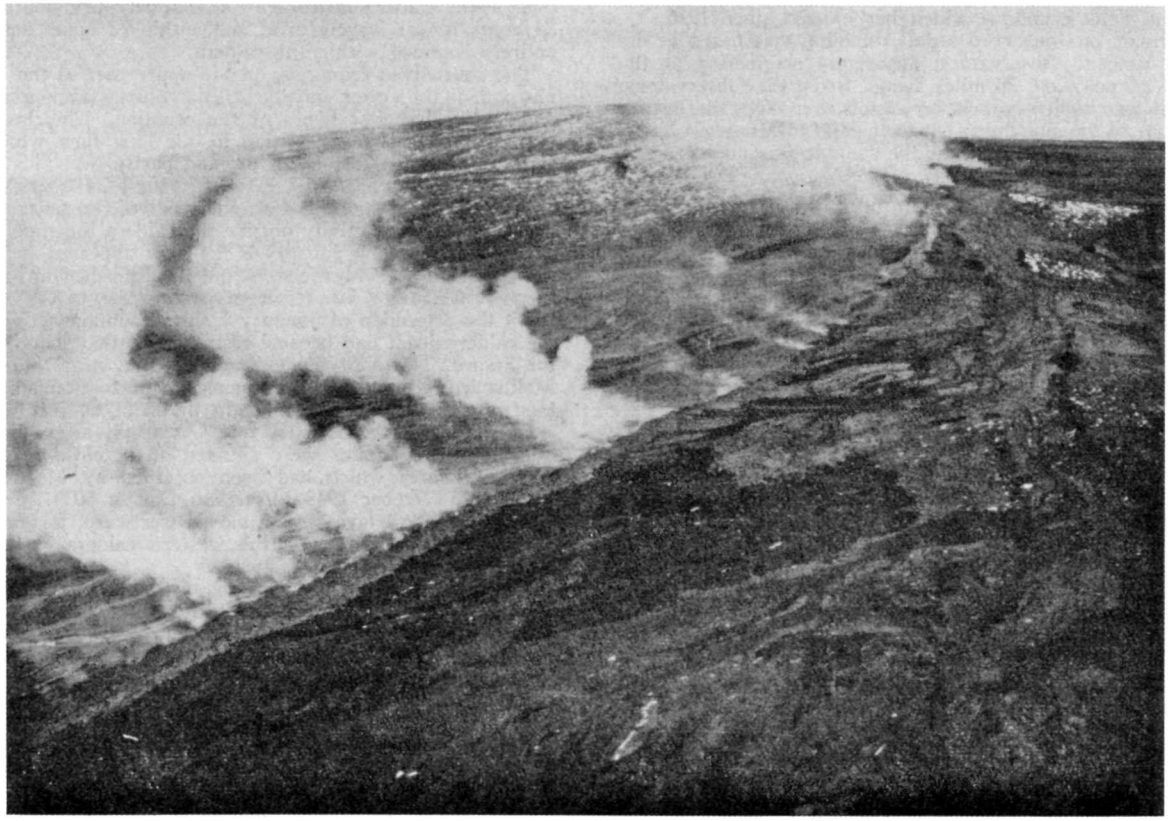

PLATE 2. Spatter rampart and small lava fountains along the fuming fissure on the upper part of the southwest rift zone on the morning of January 7, 1949. The upper part of the western lava flow is visible just left of the fissure. Mokuaweoweo caldera and the summit of Mauna Loa are in the background. OFFICIAL PHOTOGRAPH, U. S. NAVY.

new lava. The eruptive fissure split the 1940 cone and the cone was fuming strongly. During the earliest hours of the eruption a small amount of lava spilled from the fissure at the base of the cone, but by the morning of January 7 these flows were dead and had been partly buried by lava from the northern and southwestern fountains. By the afternoon of January 7 more than two-thirds of the caldera floor had been flooded with new lava, largely pahoehoe.

The fountain-chain near the center of Mokuaweoweo was as short-lived as the fountaining outside the caldera. At 2:00 p.m. on January 9 a Navy pilot reported that the fountains in the middle of the caldera had entirely stopped although the spatter rampart built by them was still fuming strongly. At that time, and for the next several days, reports from planes flying over the mountain indicated that the fountains at the base of the southwest wall were continuous but were varying greatly in the strength of their activity. Lava from them continued to pour both into the caldera and into South Pit. Fountain activity was building a cinder cone against the caldera wall.

For a week or more the southwestern fountains appear to have remained of small, although variable, size. After that, however, they greatly increased in height, ultimately becoming what may have been the highest fountains yet observed on Mauna Loa. On January 19, a United Airlines pilot reported two large fountains, 400 to 500 feet high. On January 21, Frank Hjort and James Orr of the National Park Service reported two fountains, one shooting from the fissure in the lower part of the caldera wall, and the other on the caldera floor about 100 feet from the wall. The fountains were building a compound cinder and pumice cone. The wall-fountain was the smaller of the two. The larger fountain they estimated to be 300 to 500 feet high. On January 23, Orr and D. H. Hubbard estimated the height of the large fountain to be well over 500 feet with some of the higher bursts possibly reaching more than 800 feet. These very high fountains, together with strong shifting winds, resulted in wide distribution of Pele's hair over the southern part of the island, from Napoopoo on the western coast, 21 miles from the summit of Mauna Loa, to the Kau Desert and Kilauea caldera, an equal distance southeast of the summit. The high fountains produced an exceptionally large amount of pumice. The accumulation of this pyroclastic pumice around the vent built up a pumice cone which was banked against the caldera wall and eventually overtopped it, projecting approximately 100 feet above the old rim of the caldera at that point, and resting partly on the outer slope of the mountain. (See figure 2.) West of the cone a blanket of pumice covers an area about a mile long and half a mile wide and attains a depth of as much as 20 feet near the base of the cone.

Hjort and Orr report that on the night of January 21 the two fountains were inclined somewhat toward the east and that most of the ejecta fell into a pool of lava at the eastern, breached side of the cone. Thence the lava moved eastward in a pahoehoe river about 75 feet wide, spreading into aa flows about half a mile from the vent. During the afternoon and evening there was no evidence of lava moving into South Pit. At 3:00 a.m. on January 22 there occurred a moderate earthquake, which apparently broke the rim of the pool at the east base of the cone and allowed two new flows of aa to pour into South Pit. At that time most of the early floods of pahoehoe on the caldera floor had been buried by later flows of aa. The South Lunate Platform, which in 1914 formed a conspicuous crescentic bench at the southern end of the caldera, had been almost wholly buried by new flows. Its north-facing escarpment, now totally obliterated, had been progressively lessened in height by infilling of the inner pit of the caldera in 1933 and 1940.

On January 23, Orr reports, the fountains were pulsating, the wall-fountain with a period of about 3 seconds and the larger fountain with a period of about 1 second. The temperature of the wall-fountain appeared to be a little higher than that of the larger fountain.

The lava fountaining was accompanied by the liberation of huge volumes of fume, smelling strongly of sulfur dioxide. On January 26 the pale brown fume cloud could be seen extending at least 30 miles southwest of the summit of the mountain. On February 1 and 2 sulfurous fume was noticed by residents from North Kona to Waimea, 40 miles north of the summit of the mountain.

The lava pouring into South Pit gradually filled it to the point of overflow. On January 25 Ercell Hart of the Hawaiian School of Aeronautics reported that the lava fill had reached the level of the low southeastern rim of the pit; late on the same day the pit overflowed. The lava stream moved southeasterly, and by the evening of the 26th it had attained a length of about 2 miles from South Pit, or 3 miles from its source at the fountains. On the morning of January 27 the flow was moving in three branches, and by the evening of that day the longest of these had reached a point about 3.2 miles from South Pit. Thereafter the speed of advance of the flow greatly decreased, and on the evening of January 28 transit angles from the Volcano Observatory indicated that it had advanced only about 0.2 mile in the preceding 24 hours. By the evening of January 31 the flow-front had reached a distance of about 4 miles from South Pit, but after that day it advanced very little.

On January 29 or 30 a new branch of the flow broke out near South Pit, and this new branch appears to have robbed the older one of its supply of lava. The new stream advanced downslope just east of the older one and partly overlapping it. It moved more slowly than the earlier flow and eventually attained a length of only 2 miles from South Pit. On the morning of February 7 it was still advancing very slowly. Its advance probably ended on February 8, two days after the cessation of lava fountaining at the vent. On February 7 a small amount of movement was still visible in the older flow also. This continuation of movement of the flows after the end of lava extrusion at the vent probably resulted from draining of the still-fluid lava from the feeding tubes in the flows on the upper slopes of the mountain.

During the night of February 4 the fountain activity at the southwestern edge of the caldera was still moderately strong, producing a pronounced glow on the rising fume column. By mid-morning on February 5, however, fountain activity had become very weak and irregular, only occasional small bursts of liquid lava spray being visible in the cone. Lava was moving underground through a tube almost to the wall of South Pit. There it issued in a small amphitheatral depression in slightly older 1949 aa, flowed as a pahoehoe stream to the edge of South Pit, cascaded down the wall, and spread slowly over the floor of the pit as a sluggish aa flow. The speed of movement of the liquid lava in the cascade was estimated to be generally about 10 miles an hour, reaching about 15 to 20 miles an hour in a short steep portion of the descent. On the floor of South Pit the aa flow was spreading at a rate of only a few feet an hour. About 2:00 p.m. a sudden increase in lava liberation greatly augmented the volume of the cascade and caused a brief rapid spreading of aa tongues in South Pit. Within half an hour the voluminous burst of lava was over, and by 5:00 p.m. there was no further evidence of movement of lava down the cascade into South Pit. The flows on the caldera floor also appeared to be lifeless except for many small secondary fumaroles. On the morning of February 6 the cinder cone at the southwestern edge of the caldera was visited; no further signs of activity could be detected, other than slight glow in the fountain pits and voluminous liberation of SO_2-rich fume. Even on its outer slopes, the cone was still red-hot only a few inches beneath the surface. The lava-pool and flow-channel east of the cone had been completely drained, and collapse had exposed the end of the empty lava-tube leading toward South Pit. Thus this phase of the eruption came to an end on the afternoon of February 5, having lasted just 30 days.

From February 6 to the date of writing (March 22) fume frequently has been visible at the mountain top. On several nights observers at scattered points on the southern part of the island have also reported a distinct glow at the summit. This glow may have resulted from brief weak resumptions of lava fountaining or quiet outwelling of lava, or possibly from slumping of portions of the hot cinder cone or of the cascade into South Pit, exposing glowing material. However, at no time when observers were actually present at the summit or flying over it in planes could any glow or lava movement be seen.

THE CONE

During the early hours of the eruption the "curtain of fire" which issued along the upper part of the southwest rift zone outside of the caldera built a long row of spatter ramparts and small spatter cones. These ranged up to about 20 feet in height, but were mostly less than 5 feet. A similar spatter rampart was built by the fountain-chain in the central part of the caldera.

The true cone building was restricted to the big, long-lived fountains at the southwestern edge of the caldera. The cone built there is one of the largest on Mauna Loa, rivaling in size that of the 1940 eruption. The big cone is built on a broad lava shield which overlies the former South Lunate Platform. The cone itself is compound. An outer cone, breached on the eastern side, consists largely of fine cinder and pumice and rests partly on the outer slope of the mountain and partly on the caldera floor and against the boundary cliff. (See figure 2.) The top of the outer cone is about 100 feet above the former rim

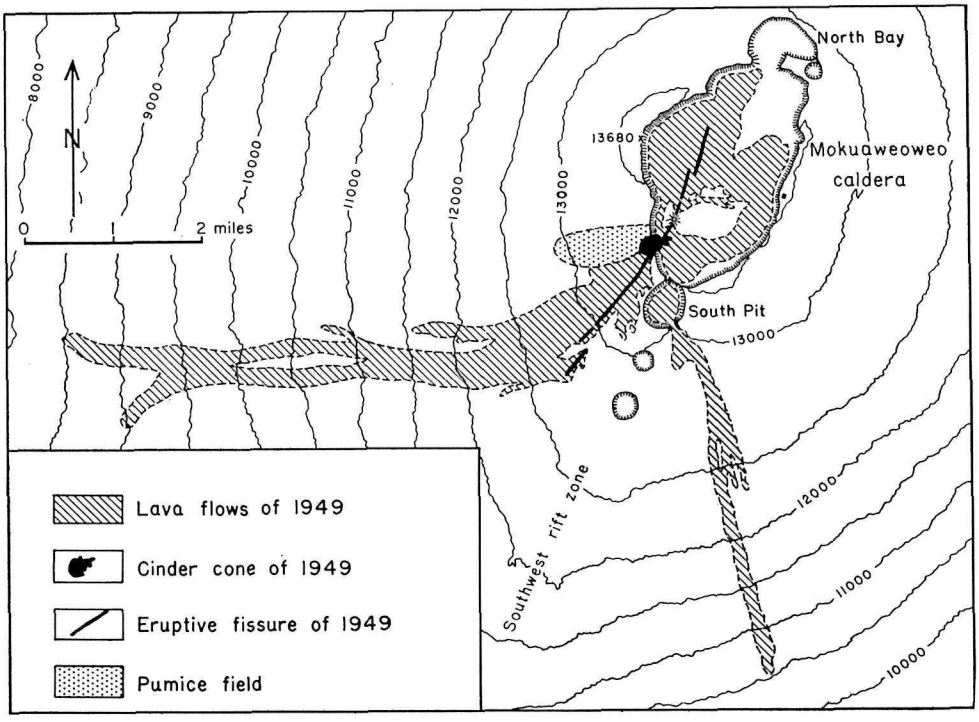

FIGURE 1. Map showing the approximate location of the 1949 lava flows and vents on Mauna Loa.

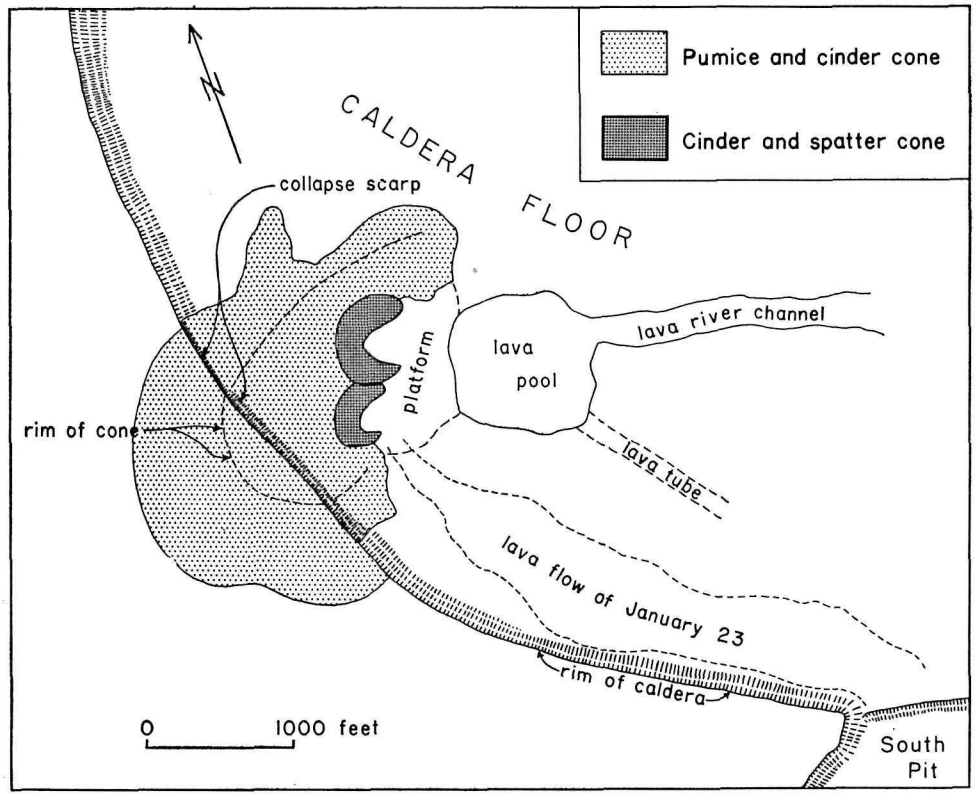

FIGURE 2. Sketch map of the cone area of the 1949 eruption.

of the caldera wall and 250 feet above the lava shield at its base. Its maximum diameter is about 1,500 feet. At the eastern edge of the large cone, and partly enclosed within it, is a small double cone of coarse cinder and spatter, built around the final sites of the two lava fountains. Each crater of the small cone also is breached on the eastern side. The inner cone probably was built during the stage of reduced gas pressure and lower fountains which directly preceded the end of the eruption. This decrease in gas content of the lava in the declining stage also resulted in the deposition of a few rather dense black "pancake" and ribbon bombs on the surface of the pale brown pumice on the southern slope of the outer cone.

The thick accumulation of ejecta against the boundary cliff of the caldera appears to have caused the northeastward migration of the smaller of the two cone-building lava fountains. On January 23, when the cone was visited by Orr and Hubbard, the fountain was situated directly against the caldera wall. By the end of the eruption, however, it had moved outward to the southernmost of the two small cinder and spatter cones, about 150 feet northeast of the base of the wall.

Lava escaping from the cone formed a pool on the lava shield just east of the cone, then drained eastward through an open lava river channel, and southeastward through tubes toward South Pit. At the end of the eruption the lava pool was drained

and its walls collapsed, exposing the mouth of a large lava tube, about 35 feet high, leading toward South Pit. (See figure 2.) The large cinder and pumice cone also partly collapsed, producing a northeast-facing scarp 10 to 15 feet high across the top of the cone. The position of the scarp was governed by the underlying caldera wall. Slumping also produced minor scarps on the outer slope of the cone.

THE LAVAS

The early lava flows in Mokuaweoweo caldera were almost entirely pahoehoe, but as the eruption progressed these were largely covered by later flows of aa. The depth of the fill in Mokuaweoweo is difficult to estimate, but probably averages about 20 feet.

The lavas erupted along the upper part of the southwest rift are pahoehoe near the vents, but as the flows moved downslope they gradually changed to aa. The average thickness of the aa in the lower part of the flow is probably about 10 to 12 feet. Near the vents the pahoehoe flows are very thin, averaging from 2 to 3 feet thick. The flows near the vents were very rich in gas and produced typical shelly pahoehoe with many open tubes and blisters covered by a crust only a few inches thick. The surface of much of this pahoehoe is a thin shell of brown pumice, similar to that formed on many pahoehoe flows in the summit region of Mauna Loa. (See VOLCANO LETTER 502.) Downslope the pahoehoe becomes denser and less shelly.

The lava spilling into South Pit was partly pahoehoe and partly aa. In cascading over the cliff which separated South Pit from Mokuaweoweo some of the pahoehoe changed into aa, probably because of the intense stirring of the liquid and loss of gas. Many exotic blocks which tumbled down from the older lava flows exposed in the walls of the pit are recognizable in the aa. The depth of the fill in South Pit is about 50 feet. At the low gap in the rim of the pit, at its southeastern side, pahoehoe issued from beneath the aa. An arcuate ridge of aa, 10 to 15 feet high, marks the underlying buried wall of the pit. This ridge appears to have been pushed up by the pahoehoe which issued from beneath it.

Just southeast of South Pit the lava is pahoehoe, much denser and more massive than that of the earlier flow from the upper end of the southwest rift. The surface of the flow near South Pit is largely a very rough "shark-skin" type; over the major tubes it shows an accumulation of sublimated sulfur and some white sulfo-salts. On the surface of the pahoehoe near the zone where it issued from beneath the aa there was formed a series of minute, tensional fault scarps, up to 8 inches high, facing down-flow. On the faces of some of these scarps there is found a moderately good development of dendritic lava. Downslope the pahoehoe gives place to aa, and most of the southern flow is aa, averaging 10 to 15 feet thick.

The approximate area and volume of the 1949 lava and of each of its principal divisions are shown in table 1. The figures are not of great accuracy, and indicate only an order of magnitude. The total volume of the lava, 71 million cubic yards, is somewhat less than the volume of the lava of the 1940 and 1942 eruptions, each of which approximated 100 million cubic yards.

TABLE 1. AREA AND VOLUME OF 1949 LAVA

DIVISION OF THE FLOW	AREA (SQ. MILES)	VOLUME (CU. YARDS)
Mokuaweoweo	1.9	40,000,000
South Pit	0.2	8,000,000
Western flow	3.1	16,000,000
Southern flow	0.6	7,000,000
Total	5.8	71,000,000

Temperature measurements with an optical pyrometer were made on the glowing interior portion of a thick aa flow in South Pit on the afternoon of February 5. The glowing portion of the flow was well exposed in a large crack. Three observations were made, all yielding readings close to 760° C. This temperature is believed accurate within 50°. The flow was essentially motionless, but was still creeping a little.

Geiger counter observations were made by D. C. Cox on the hot lava in and close to South Pit on the afternoon of February 5. The number of clicks in the earphones ranged from 38 to 45 per minute. This is of the same order of magnitude as results obtained on the nearby lavas of prehistoric age and only slightly higher than those obtained by Mrs. B. J. Loucks on lavas of Kilauea volcano ranging in date from 1921 to prehistoric. The results are of the order of magnitude to be expected from cosmic radiation, and may have been caused by that alone. Dental X-ray films were mounted on a rock monument at the summit rest-house, 1.5 miles from the lava fountains, and exposed to

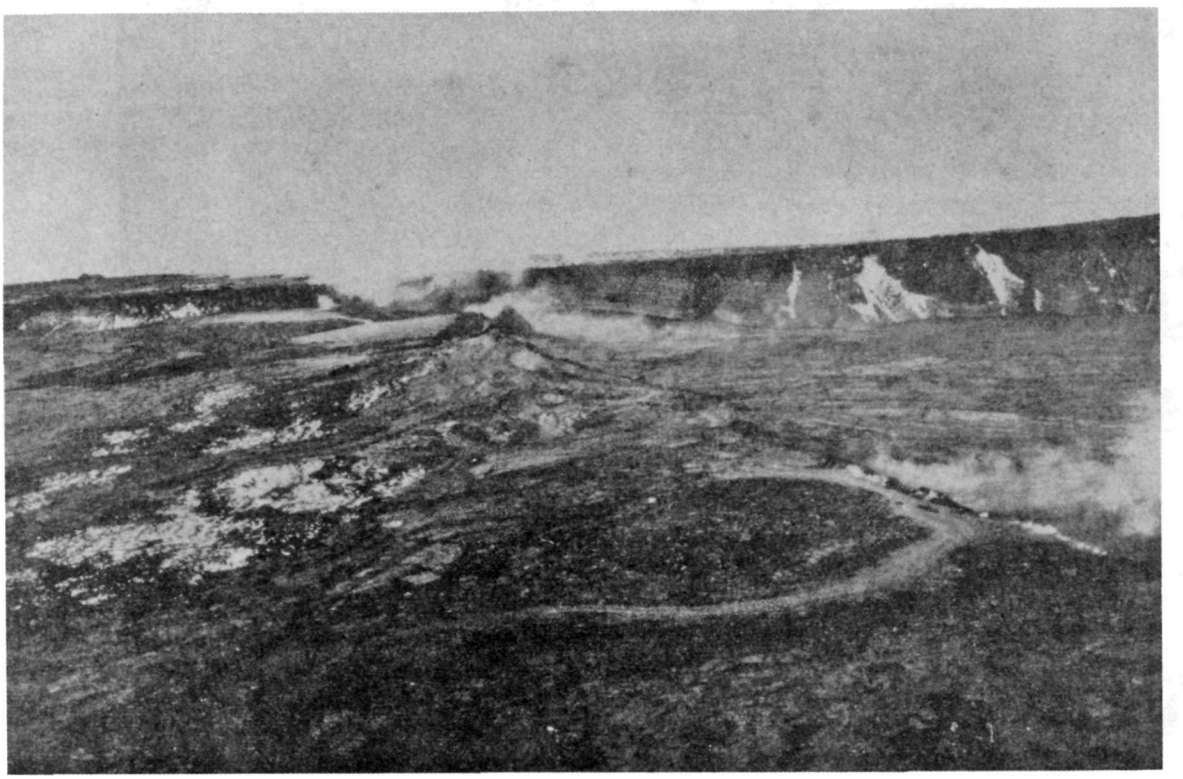

PLATE 3. Mokuaweoweo caldera, looking southwestward on the morning of January 7, 1949. In the right foreground is the northern fountain-chain and the lava flow leading eastward from it. In the middle distance the fissure can be seen cutting through the 1940 cinder cone, which is fuming strongly. OFFICIAL PHOTOGRAPH, U. S. NAVY.

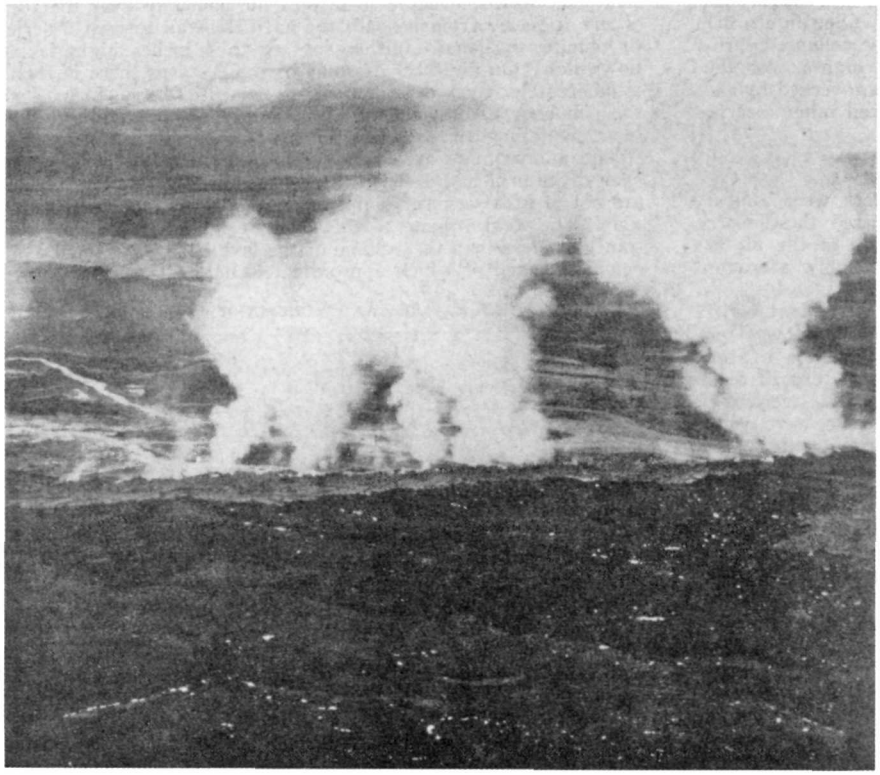

PLATE 4. Lava fountains and upper end of the western flow along the upper part of the southwest rift zone on the morning of January 7, 1949. The spatter rampart and the main lava rivers of the flow are clearly visible. Hualalai volcano is in the background. OFFICIAL PHOTOGRAPH, U. S. NAVY.

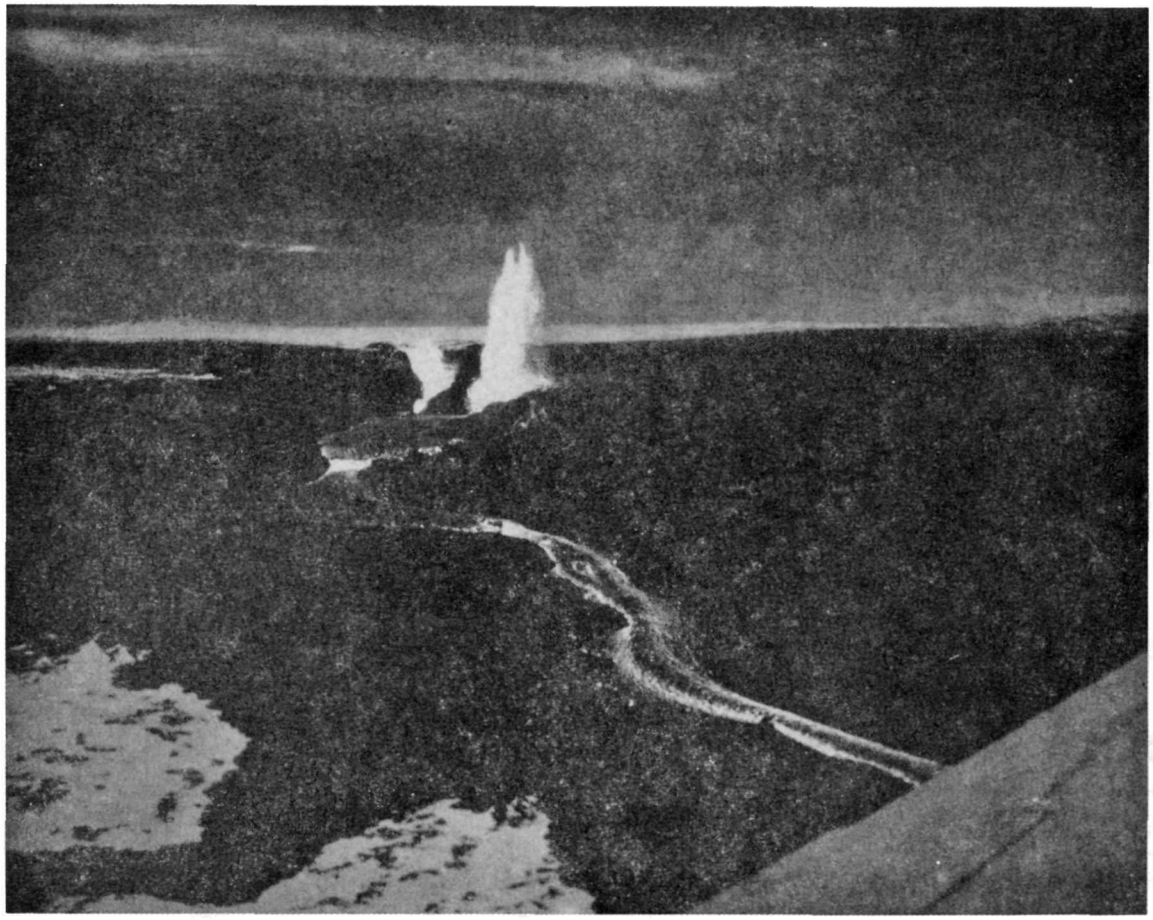

PLATE 5. Lava fountains and flow at the southwestern edge of Mokuaweoweo caldera on the evening of January 19, 1949. The smaller fountain on the left is the wall fountain. The larger fountain is about 500 feet high. PHOTOGRAPH BY K. OTAKI, ACE PORTRAIT STUDIO.

radiation from the fountains for a period of 12 days, from January 24 to February 5. These films showed practically no fogging. Samples of the early lava from Mokuaweoweo and pumice from the fountains were tested for radioactivity by Dr. Harvey White of the University of California, but no radioactivity was found.

PETROGRAPHY

The 1949 lava is a basalt containing approximately 3 per cent olivine. The rock of the more massive central portions of the southern flow, both aa and pahoehoe, is essentially crystalline, containing only a small amount of glass. It consists largely of labradorite and pigeonite (optic angle very small), with less abundant iron ore, olivine, and dark brown, interstitial glass. A roughly stellate arrangement of the feldspar microlites is present in some thin sections. A few of the olivine grains have the dimensions of phenocrysts, with lengths up to 2 mm., but the texture is seriate rather than truly porphyritic.

The rock of the upper portions of the western flow contains a larger proportion of glass, but is otherwise similar to that of the southern flow. The glass of the pumice from the fountains has a refractive index of 1.597 (± .003).

EARTHQUAKES AND GROUND TILT ASSOCIATED WITH THE ERUPTION

No distinct earthquake pattern preceded the 1949 outbreak of Mauna Loa. However, the number of earthquakes recorded in December on the Mauna Loa seismograph, at an altitude of 6,600 feet about 13 miles from the northern end of Mokuaweoweo, greatly exceeded those recorded in any of the preceding 5 months. (See table 2.)

TABLE 2. EARTHQUAKES RECORDED ON MAUNA LOA SEISMOGRAPH DURING 1948

MONTH	NUMBER OF EARTHQUAKES
December	72
November	38
October	47
September	26
August	23
July	37

Most of the quakes during December were tremors with shallow foci. Although a few of them originated under Mokuaweoweo, most of those whose origins were determined originated under the east slope of Mauna Loa or on the northeast rift. The strongest earthquake immediately preceding the eruption occurred on December 13. Its origin was at a shallow focus under the northeast rift about 2 miles from Mokuaweoweo.

Of the approximately 60 earthquakes recorded on the Mauna Loa seismograph in January 1949, 16 occurred on January 6, the day the eruption started. The number of shakes accompanying the outbreak of this summit eruption was less than during flank eruptions. This is to be expected because of the shorter distance of fissuring. During flank eruptions fissuring extends across the summit and also occurs far down the flank, whereas in summit eruptions it is restricted to the summit region. One of the strongest shakes during the eruption occurred at 3:59 p.m. on January 6 at about the time of commencement of surface activity. Its origin appears to have been at a depth of about 5 miles, approximately 2 miles northeast of Mokuaweoweo. If, as seems probable, this quake occurred at the time the fissure across Mokuaweoweo and a little way down the southwest rift was opened, the initial movement must have been at the northeastern end of the fissure.

Continuous harmonic tremor commenced on the Bosch-Omori seismograph at the northern rim of Kilauea caldera, 21 miles from the scene of eruption, at 3:47 p.m. on January 6 and ceased to be apparent at 3:00 a.m. on January 7.

During the year 1948 there was an accumulation of easterly ground-tilt at the northern rim of Kilauea caldera. The eastward tilting was especially strong during the first half of November. Records of several eruptions of Mauna Loa seem to indicate that easterly tilt is an evidence of increase of pressure under that mountain. Despite the easterly tilt and the fact that the average interval between Mauna Loa eruptions (about 4 years) had already been exceeded by more than 2 years, the earthquake pattern did not seem positive enough to justify a prediction of impending activity.

ACKNOWLEDGMENTS

We wish to express our thanks to all those many persons who have contributed information or otherwise aided in the study of the eruption. Deserving of special mention are: Superintendent Frank R. Oberhansley and Chief Ranger Frank A. Hjort of Hawaii National Park, who greatly aided us by the loan of riding horses and packing equipment up the mountain; Ranger James B. Orr, who kindly permitted the use of his field notes on the eruption; Naturalist Douglass H. Hubbard and Ranger V. R. Bender, who contributed ground and air observations; Pilot Ercell Hart, of the Hawaiian School of Aeronautics, who made repeated reports on the progress of the eruption; Harry M. Blickhahn, editor of the Hilo Tribune-Herald, who promptly passed on to the Volcano Observatory the information which came to him; Doak C. Cox, geologist for the Hawaiian Sugar Planters' Association Experiment Station, who operated the Geiger counter at the summit of the mountain; and Dr. Harvey E. White of the University of California Physics Department, who made radioactive determinations on several lava specimens.

HAWAIIAN VOLCANO OBSERVATORY REPORT FOR JANUARY–MARCH, 1949

VOLCANOLOGY

January

An eruption of Mauna Loa started on January 6 and continued through the rest of the month. History and a lack of a definite earthquake pattern had led members of the Observatory staff to believe that the next eruption would be at the summit. There was but little positive data upon which to forecast an impending eruption, however. A strong easterly tilt of seven seconds of arc near the northern end of Kilauea Caldera in November 1948 was but little greater than similar tilts in 1946 and 1947. Such a tilt could be taken only as a suggestion and not as a good indication of a pressure increase under Mauna Loa that might lead to surface activity. The November tilt and the distinct blue fumes observed in Mokuaweoweo during October 1948 do give some indications that lava was rising in Mauna Loa 3 months prior to its appearance at the surface.

Sixty-seven earthquakes were recorded during the month. Fifty-eight shakes were recorded at Kilauea and 51 at Mauna Loa. The Mauna Loa total is incomplete because the seismograph was dismantled by earthquakes on two occasions. The records of at least eight shakes were lost.

Strong southerly tilt continued throughout the month. Easterly tilt continued until January 16 and then westerly tilt a little stronger than normal set in.

February

The Mouna Loa eruption, except for fuming, came to an end on February 5.

Sixty-four earthquakes were recorded during the month. Of these 47 were recorded at Kilauea and 52 at Mauna Loa.

Strong southerly tilt was continuous in February except for distinct northerly tilt accompanying the strong earthquake on February 26. Normal easterly tilt continued throughout the month.

March

Fuming from Mokuaweoweo was continuous throughout the month.

Thirty-one earthquakes were recorded in March. Thirty of the shakes were recorded on the Mauna Loa seismograph and 16 at Kilauea.

Northerly tilt set in March 6 and continued through the end of the month. Westerly tilt was about normal for March.

CRACK MEASUREMENTS

A few of the cracks near the east rim of Halemaumau opened slightly. The other cracks that were measured showed no appreciable movement.

SEISMOLOGY

Earthquake Data, January–March 1949

Week Ended		Minutes of Tremor	Very Feeble	Feeble	Slight	Moderate	Strong	Local Seismicity*	Teleseisms
January	2	6	3	0	0	0	0	2.50	0
	9	17	2	0	1	0	0	7.25	0
	16	5	0	0	2	0	0	5.25	0
	23	5	1	1	0	0	0	2.75	0
	30	13	3	1	0	3	0	14.75	0
February	6	5	1	0	0	0	0	1.75	0
	13	1	1	0	0	0	0	0.75	0
	20	6	8	2	0	0	0	5.50	1
	27	12	3	2	0	0	1	10.50	0
March	6	0	3	2	1	0	0	5.50	0
	13	4	1	0	0	0	0	1.50	0
	20	1	0	0	0	0	0	0.25	0
	27	3	1	0	0	0	0	1.25	1

* For definition of local seismicity, see Volcano Letter 371.

The data of the following local disturbances were determined from seismograph stations operated on the island of Hawaii by the Hawaiian Volcano Observatory of the U. S. Geological Survey. Time is Hawaiian Standard, 10 hours slower than Greenwich. The number preceding each earthquake is the serial number for the current year.

1. January 4, 20:20, very feeble.
2. January 6, 15:59, moderate. Near Mokuaweoweo.
3. January 7, 03:10, very feeble.
4. January 8, 00:49, moderate. 10–15 miles deep under Alae Crater area.
5. January 15, 00:40, moderate. 20–25 miles deep above Wood Valley.
6. January 15, 11:16, slight. Under ocean west of Kohala.
7. January 16, 14:30, slight. 9 miles deep. Kau Desert near Kilauea.
8. January 20, 14:27, very feeble. Deep. 10 miles southwest of Waimea.
9. January 20, 18:09, feeble. Northeast rift Mauna Loa.
10. January 26, 13:06, feeble. Deep. 10 miles southwest of Waimea.
11. January 26, 11:45, very feeble. Deep under east slope of Mauna Loa.
12. January 26, 23:57, moderate. 5 miles deep near Ohaikea.
13. January 27, 00:04, slight. 6 miles deep, east slope of Mauna Loa.
14. January 27, 00:16, very feeble.
15. January 28, 15:50, moderate, E-W dismantled. 5 miles deep, east slope of Mauna Loa.
16. January 28, 19:45, moderate, E-W dismantled. 8 miles deep, east slope of Mauna Loa.
17. January 29, 03:29, very feeble. East slope, Mauna Loa.
18. February 4, 22:16, very feeble.
19. February 7, 18:08, very feeble. Mauna Loa.
20. February 17, 07:33, very feeble.
21. February 19, 01:13, feeble.
22. February 19, 04:34, very feeble.
23. February 19, 12:04, very feeble.
24. February 19, 14:47, very feeble.
25. February 19, 17:06, very feeble. Kilauea.
26. February 20, 08:45, very feeble. Mauna Loa.
27. February 20, 09:32, very feeble. Mauna Loa.
28. February 20, 09:46, very feeble.
29. February 20, 21:16, feeble. Kilauea.
30. February 21, 16:22, very feeble.
31. February 22, 04:48, feeble. Kilauea.
32. February 23, 23:55, very feeble.
33. February 24, 01:02, very feeble.
34. February 26, 13:20, very feeble. Felt at Kapapala.
35. February 26, 13:54, strong. Instruments dismantled. Strongly felt from Hilo to Naalehu. Shallow focus, northeast rift Mauna Loa at 7,000 feet.
36. February 27, 05:13, very feeble.
37. February 27, 10:28, slight. South slope, Kilauea.
38. February 27, 13:45, feeble. Felt at Pahala.
39. February 27, 17:18, feeble. East slope, Mauna Loa.
40. February 28, 16:58, very feeble. Northeast rift Mauna Loa.
41. March 2, 14:20, very feeble.
42. March 11, 09:31, very feeble.
43. March 23, 11:35, very feeble. Kilauea.
44. March 29, 10:58, very feeble.

TELESEISMS

February 14, 08:30, slight.
March 24, 11:11, moderate. Off north California coast.

MICROSEISMS

Microseisms were strong from January 5–7 and from February 28 to March 1. On other days they were weak to moderate.

TILTING OF THE GROUND

There was a rapid easterly tilt from January 1 to 10 when seasonal westerly tilt set in and continued until March 24. There was a slight easterly swing from March 25 to 28, then a recovery to the west. With the exception of a sharp northerly tilt accompanying the strong earthquake of February 26, southerly tilt was continuous from January 1 to March 6. From March 7 to 31 there was a slight accumulation of northerly tilt.

Table of Tilt at Observatory on Northeast Rim of Kilauea

Week Ended		Amount	Direction
January	2	1.3″	S 25° W
	9	3.1″	S 36° E
	16	2.9″	S
	23	2.4″	S 49° W
	30	4.1″	S 68° W
February	6	1.8″	S 19° E
	13	1.2″	S 62° W
	20	0.9″	S 23° E
	27	2.4″	N
March	6	1.6″	S 39° W
	13	0.6″	N 45° W
	20	1.0″	N 45° W
	27	1.4″	N 59° E

HAWAIIAN VOLCANO RESEARCH ASSOCIATION
In cooperation with the UNIVERSITY OF HAWAII

The **Hawaiian Volcano Research Association** was founded in 1911 for the recording and study of volcanoes in the Hawaiian Islands and around the Pacific Ocean. Its equipment at Kilauea Volcano, Hawaii Island, has been transferred to the United States Geological Survey.

The **University of Hawaii** cooperates in maintaining a research laboratory at Kilauea. The Association and the University supplement the work of the government with research associates, instrumental equipment, and special investigations. Dr. T. A. Jaggar is their geophysicist resident at Kilauea.

The **Volcano Letter**, a quarterly record of Hawaiian volcano observations, is published by the University of Hawaii and supplied to members of the Research Association and to exchange lists of the above establishments.

THE VOLCANO LETTER 504

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U. S. GEOLOGICAL SURVEY: R. H. Finch, Volcanologist

UNIVERSITY OF HAWAII: T. A. Jaggar, Geophysicist

ACTIVITY OF MAUNA LOA DURING APRIL, MAY, AND JUNE, 1949

By GORDON A. MACDONALD and RUY H. FINCH

The 1949 eruption of Mauna Loa commenced on January 6, and the major activity continued until February 5. This activity consisted of outpouring of lava flows on the caldera floor and down the western and southern flanks of the volcano from vents near the summit, and building of a large cinder and pumice cone at the southwestern margin of the caldera. The activity and cone have been described in VOLCANO LETTER 503.

Following the end of lava fountaining on February 5, fume rising from Mokuaweoweo was visible almost constantly during the remainder of February and March. It was obvious that the magma column must be standing at a very high level in the conduit. On several different nights a distinct glow was reported at the summit of the mountain. Thus, at 2 a.m. on February 19, Charles Hoeppel of the U. S. Coast and Geodetic Survey observed a strong reddish reflection on the fume column. However, at no time when observers were able to see into the caldera was there any sign of lava fountaining or flow. At the time, there was some doubt whether the observed glow was the result of weak resumptions of lava extrusion, or of slumping of surficial parts of the cinder cone or lava cascades, revealing hot glowing material beneath. In view of later developments, there is now little question that the glow resulted from brief quiet outwellings of lava.

The following table lists the dates on which fume or glow was reported and the place from which the observation was made. During many days the summit of the mountain was cloud-covered and invisible to persons at low altitudes. On some days when it was visible, winds at the summit may have been strong enough to dissipate small amounts of fume and make it undetectable from a distance.

OBSERVATIONS ON ACTIVITY OF MAUNA LOA FROM FEBRUARY 7 TO APRIL 7, 1949.

DATE	LOCATION OF OBSERVER	TYPE OF ACTIVITY
Feb. 15	Summit	Weak fume but no glow
17	Kilauea	Weak fume
18	Pahala and Naalehu	Weak glow and fume
19	Near Pahala	Two conspicuous puffs of fume in early morning
19	Planes over summit	Fume but no glow
21	Kilauea	Thin fume during morning
21	Kulani Camp	Glow in evening
22–27	Kilauea	No fume visible
28	Kilauea	Light fume
Mar. 1	Kilauea	Light fume during day
1	Naalehu	Distinct glow in evening
16	Kilauea	Strong fume column in evening
18	Kilauea	Strong fume column in evening
19	Kilauea	Weak fume
20–21	Kilauea	Strong fume in evening
22–23	Kilauea	Weak fume
28	Humuula	Pulsating fume cloud in morning
28	Kilauea	Glow in evening
April 1–6	Kilauea	Conspicuous fume

During late March or early April the quiet outflow of lava became essentially continuous, and was observed at close range by staff members of Hawaii National Park. The account of the activity on April 7 to 9 and May 5 to 7 is based largely on the excellent reports of Ranger James B. Orr, and the writers wish to thank Mr. Orr for making the reports available. The results of the activity were examined on the ground by Macdonald, in company with Orr, on the second and third of June, after lava extrusion again had ceased.

The precise date when lava extrusion again became fairly continuous is uncertain. On March 28 the fume column rising from Mokuaweoweo was unusually conspicuous, and on the evening of that day the glow was intense. On April 1, harmonic tremor was recorded for

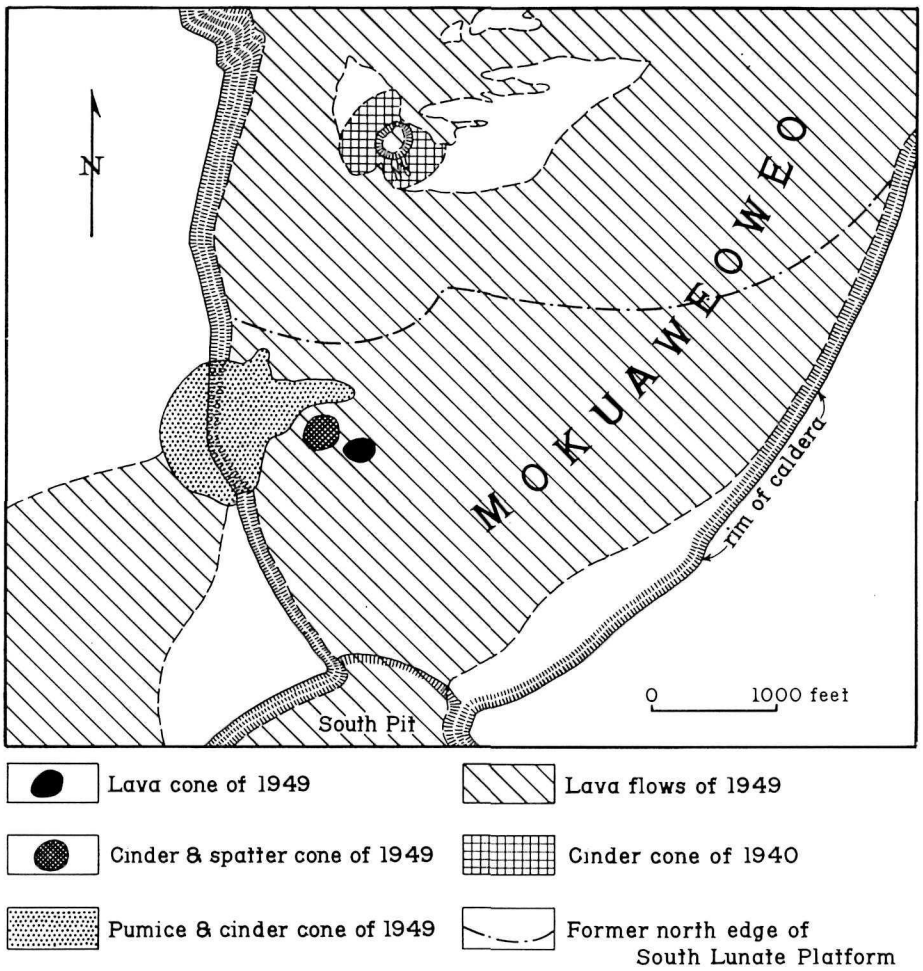

FIGURE 1. Sketch map of the southern portion of Mokuaweoweo caldera on June 3, 1949, after the end of lava extrusion.

a few minutes on both the Mauna Loa seismograph and the Bosch-Omori seismograph at Kilauea. Orr's observations at the summit on April 7 indicate that at that time lava extrusion must already have been in progress for several days. It appears probable, therefore, that fairly continuous lava extrusion was resumed sometime between March 28 and April 1.

The activity of April and May was confined entirely to the vent area on the floor of Mokuaweoweo caldera close to its southwestern wall. The large-scale lava fountaining of late January had built up a big cone of fine cinder and pumice resting against the caldera wall and on the outer slope of the mountain. (See figure 2, VOLCANO LETTER 503.) Within the breached crater of this large cone, diminished fountain activity in early February had built a smaller double cone of coarse cinder and spatter.

On April 8 the small cinder and spatter cone was rhythmically emitting voluminous puffs of fume, but no lava. About 250 feet east of the fuming cinder cone a small lava cone had been built, about 80 feet high and 150 feet across at the base, with a crater 40 feet in diameter containing a small, surging pond of molten lava. The lava composing the cone was notably denser than the highly vesicular lavas which had characterized the earlier phases of the eruption. The lava pond in the crater heaved slowly up and down, the depth from the rim to the pond surface ranging from a few inches to 15 feet during the few hours it was under observation. However, no overflow of lava occurred while Orr was there, from April 7 to 9, although the cone obviously had been built up by repeated overflows previous to April 7 and continued to grow by additional overflows later. From the vent area liquid lava moved through tubes beneath the surface, emerging about a mile east–northeast of the cones to feed two sluggishly advancing flows of aa. Another small sluggish aa flow was moving southeastward into South Pit.

On May 5 the height of the lava cone had increased to about 95 feet, as measured from its southeastern base. The lavas composing it were still relatively dense, and the pond of molten lava was still present in its crater. The cinder and spatter cone was the principal source of fume and had liberated some short flows of lava which partly veneered its flanks. Some of this lava was dense, but some was highly vesicular and shelly. A small pahoehoe flow was spreading near the base of the lava cone; another larger flow moved through tubes, issuing about a mile northeast of the cone to form a moderately active pahoehoe flow.

The activity at the cones on May 7 showed a distinctly cyclic pattern, the cycles being repeated at approximately 3½-hour intervals. Successive cycles were essentially identical, except for minor variations in the duration of the parts of the cycle. The cycle commenced with a loud hissing and roaring within the cinder and spatter cone, accompanied by copious liberation of pale brown to white fume. This lasted for 5 minutes, and was followed by rapid outpouring of gas-rich pahoehoe accompanied by a little fume. The lava effusion lasted about 45 minutes, the rapidity of extrusion gradually decreasing until all flows ceased. Within about 5 minutes after the lava ceased to flow, the hissing and roaring within the cone started again. At the summit of the cone the escaping gas tilted large slabs of partly cooled pahoehoe, lifting some of them a foot or two, then dropping them back into place. This relatively violent escape of gas continued for about 10 minutes. Immediately afterward the lava cone, which had been quiescent with its crater empty, started to fume copiously, and shortly thereafter fluid lava entered the bottom of the crater from an opening on its west–southwest side. Within 10 minutes the crater was completely filled. With the entrance of lava into the crater fuming was greatly diminished, and by the time the crater was filled fuming had practically ceased. The fluid lava bulged up above the crater rim as a broad flat dome a foot or two high, then the confining crust ruptured and the lava poured down the flanks of the cone. The crust of the bulge of lava at the summit of the cone was continually broken up, forming large irregular plates of still flexible pahoehoe which coasted down the flows on the flank of the cone, crumpling and twisting as they encountered obstacles. This phase of overflow from the lava cone continued with varying intensity for about an hour. Then the lava in the crater drained away, accompanied by liberation of large volumes of fume at the lava cone and by the renewal of the hissing and roaring in the cinder and spatter cone. This was followed by a period of quiet lasting about an hour, after which the entire cycle was repeated.

The date of final cessation of the lava extrusion is uncertain. Flows still were moving actively on the caldera floor east of the vent on May 19, when the summit was visited by H. Whitten. When Orr and Macdonald reached the summit on June 2 there was no sign of movement in any of the flows, although a weak glow still was visible on the cinder cone. The cone still was fuming copiously on June 2, but by the afternoon of June 3 the fume was very light and consisted almost entirely of steam. During the remainder of June no glow, and only weak fuming, were reported. Lava extrusion ended sometime between May 20 and June 2, probably about the end of May. The eruption appears to be over, although it is still possible that another resumption of activity may occur.

On June 3 both the cinder cone and the lava cone were climbed and examined in detail. The cinder cone was an irregular dome, about 80 feet high, with no sign of a crater. It was largely veneered with very late flows of frothy pahoehoe. (See plate 1.) The lava cone was about 110 feet high, with a crater some 30 feet across and 50 feet deep. (See plate 2.) The late lavas, erupted at the lava cone after Orr's visit on May 5, were shelly gas-rich pahoehoe, in contrast to the denser, partly degassed lavas which built most of the cone.

It is estimated that the volume of lava extruded in the late phase of the eruption after February 5 was about 4 million cubic yards, bringing the total volume for the eruption to about 75 million cubic yards. The late lavas were restricted to the southern end of Mokuaweoweo caldera, and completed the burial of the northward-facing scarp of the South Lunate Platform, which had already been partly buried by the lavas of 1933 and 1940. Only at its western end is there still visible a topographic expression of the scarp, mantled by cascades of the 1949 lavas. (See figure 1.)

It has already been pointed out that the pahoehoe lava which formed most of the lava cone was strikingly dense, as compared to the highly vesicular and shelly pahoehoe which characterized the earlier lavas of the eruption in the area close to the vents. It resembled much more closely the pahoehoe which forms in long flows which have traveled through tubes many miles from the vents. In the case of the 1949 lava, the denseness resulted from loss of gas before the lava reached the surface. The change from gas-rich to gas-poor lava as the eruption progressed might have been explained by assuming a gas-enriched "head" on the magma column which was released during the early stages of the eruption and gradually exhausted as activity continued. This explanation might be acceptable if the change in gas content had been entirely unidirectional. But it was not. The latest lavas of the eruption, instead of being as dense as or even denser than those which built the bulk of the lava cone, were again frothy and gas-rich like the earliest lavas. The change was from gas-rich to gas-poor, and then back again to gas-rich lavas.

A possible explanation of the changes in density of the erupted lavas is suggested by the time relationships of the density types to the character of the rest of the activity. The dense lavas which built most of the lava cone, and also were erupted in early May or late April at the cinder and spatter cone, were erupted following a period of nearly 2 months duration during which there was very little surface outflow of lava, but nearly continuous liberation of large volumes of fume. Possibly during this period the upper part of the magma column stood undisturbed at levels high enough to permit vesiculation, and for a period long enough for a large proportion of the gas bubbles to escape, supplying the gas for the fume cloud. However, at levels

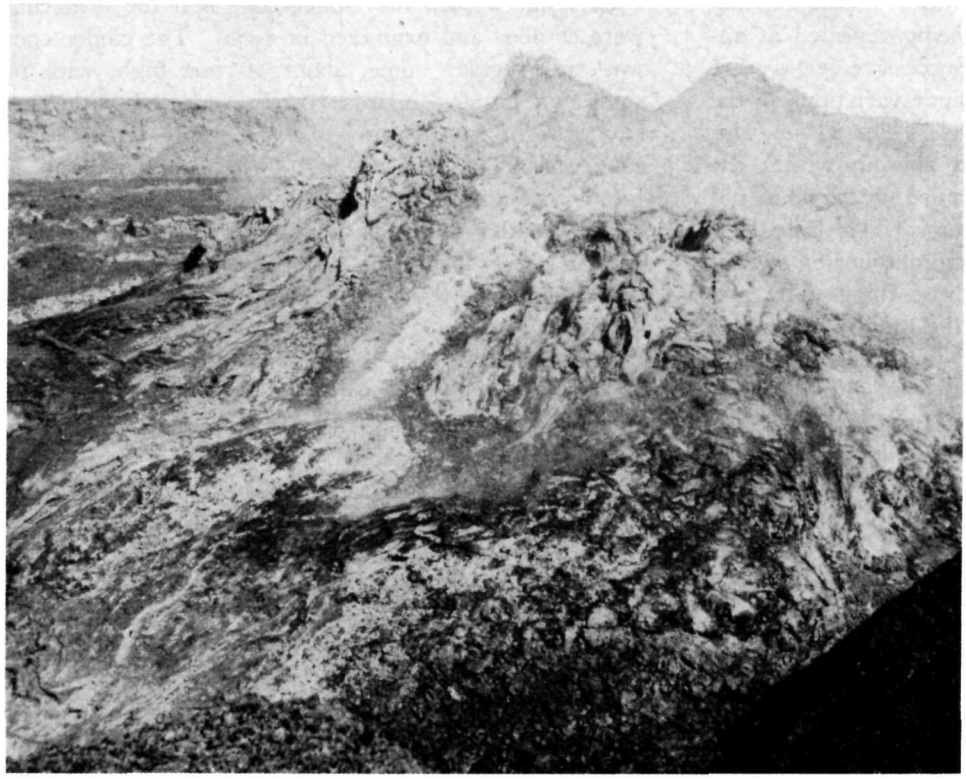

PLATE 1. The small cinder and spatter cone, largely veneered with thin lava flows, seen from the northern rim of the pumice cone, June 3, 1949. PHOTOGRAPH BY G. A. MACDONALD.

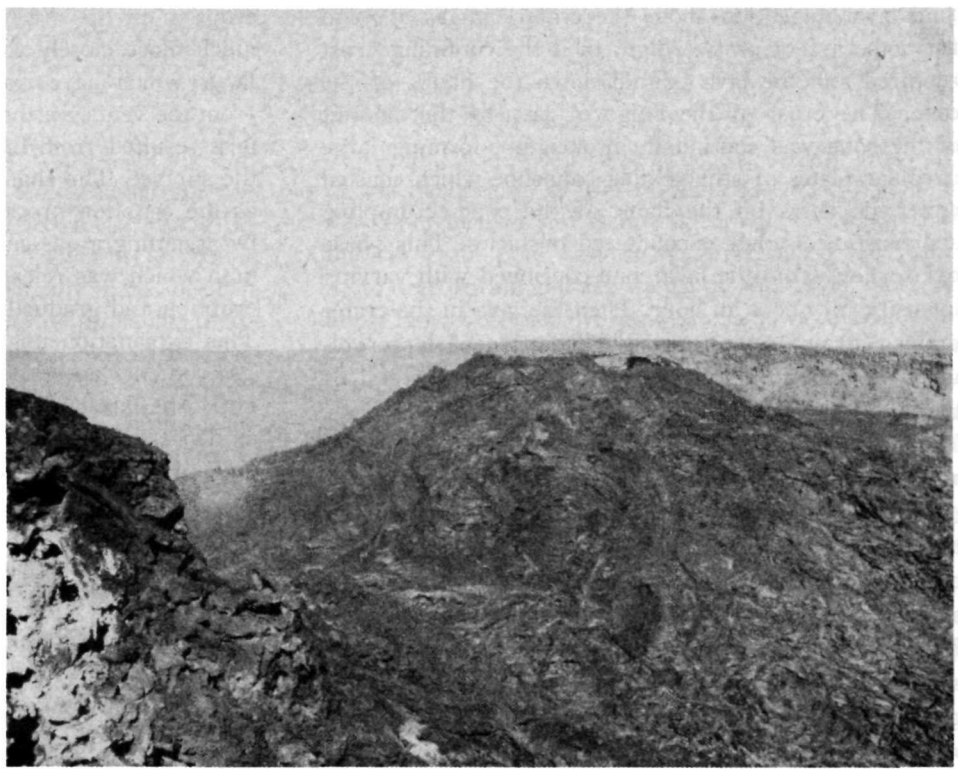

PLATE 2. Lava cone, seen from near the summit of the cinder and spatter cone, June 3, 1949. PHOTOGRAPH BY J. B. ORR, NATIONAL PARK SERVICE.

below the depth at which appreciable vesiculation could occur the magma lost only the small proportion of gas which was dissipated upward by diffusion. Convection probably would not be very effective in the narrow feeding fissure which led the lava to the surface. When lava extrusion was resumed after the 2-month period of quiet, the first erupted, upper part of the magma body was gas-poor and produced dense lavas. But as time went on the upper, partly degassed portion of the magma was exhausted, and lavas reaching the surface were again as rich in gas, or nearly so, as had been the earliest lavas of the eruption.

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HAWAIIAN VOLCANO OBSERVATORY REPORT FOR APRIL–JUNE, 1949

VOLCANOLOGY

April

About the end of March, quiet lava extrusion became fairly continuous in Mokuaweoweo, and continued through April. The activity is described in the foregoing article. Fume rising from Mokuaweoweo was visible from the Volcano Observatory on many occasions during April.

Thirty-two earthquakes were recorded in April. Sixteen of these were recorded at Kilauea and 23 at Mauna Loa.

There was a small accumulation of northwesterly tilt during April, possibly indicating a slight increase of pressure under Kilauea and a decrease under Mauna Loa.

May

Quiet lava effusion in Mokuaweoweo continued through most of May. It came to an end sometime between May 20 and June 2, probably about May 30.

Forty-three earthquakes were recorded during May. Of these 31 were recorded at Kilauea and 38 on Mauna Loa. In addition, about 225 tremors of Mauna Loa origin were recorded on the Mauna Loa seismograph on May 20 and 21. These resembled the records produced by small explosions, rather than by ordinary small earthquakes. Many of them were recorded also at Kilauea, and some on the Hilo and Kona seismographs.

Three earthquakes were felt locally during May. The strongest occurred at 5:02 a.m. on May 2. It originated in Kona, where some objects were shaken from shelves, and the seismograph at Kealakekua was broken. As in October and November, 1947, several of the larger shakes originated under the west slope of Mauna Loa, inland from Kealakekua Bay.

There was an accumulation of south tilt, and a little east tilt during May. The latter is normal for this time of year.

June

Both Mauna Loa and Kilauea remained quiet throughout June. A total of 32 earthquakes were recorded, 28 of them at Kilauea, and 27 of them on Mauna Loa. Of these, a moderate earthquake originated at a shallow depth on the northeast rift zone of Mauna Loa on June 8, and two feeble earthquakes at a depth of about 10 miles under the southern slope of Mauna Loa, near Punaluu Kahawai, on June 25.

A small accumulation of southerly tilt occurred during June, probably indicating either a slight decrease of pressure under Kilauea or a slight increase under the northeast rift of Mauna Loa. Almost no net change in tilt in an east–west direction was recorded during the month.

The average interval between summit eruptions of Mauna Loa and following flank eruptions during the past century has been 20 months. On this basis, assuming the 1949 summit eruption to have ended about the end of May, a flank eruption of Mauna Loa might be expected about the end of January, 1951. However, it is important to realize that the average interval means little. Sometimes a summit eruption of Mauna Loa is followed by another summit eruption, not by a flank outbreak. Even when a summit eruption has been followed by a flank eruption, the interval between them has ranged from 6 to 38 months. Prediction of Mauna Loa eruption entirely on the basis of historic precedent is highly uncertain, and thus far there is little else on which to base a forecast of the next eruption.

SEISMOLOGY

Earthquake Data, April–June, 1949

Week Ended		Minutes of Tremor	Very Feeble	Feeble	Slight	Moderate	Strong	Local Seismicity*	Teleseisms
April	3	15	3	0	0	0	0	5.25	0
	10	7	3	0	0	0	0	3.25	0
	17	9	0	0	0	1	0	5.25	1
	24	3	0	0	0	0	0	0.75	0
May	1	8	0	0	0	0	0	2.00	1
	8	3	0	0	0	2	0	6.75	1
	15	3	2	1	0	0	0	2.75	0
	22	266	0	4	0	0	0	70.50	0
	29	13	1	3	0	1	0	9.75	0
June	5	7	2	0	0	0	0	2.75	0
	12	3	3	0	0	1	0	5.25	0
	19	3	3	0	0	0	0	2.25	0
	26	5	1	2	1	0	0	5.75	0

* For definition of local seismicity, see Volcano Letter 371.

The data for the following local disturbances were determined from seismograph stations operated on the island of Hawaii by the Hawaiian Volcano Observatory of the U. S. Geological Survey. Time is Hawaiian Standard, 10 hours slower than Greenwich. The number preceding each earthquake is the serial number for the current year.

45. April 4, 02:59, very feeble.
46. April 7, 09:55, very feeble. Mauna Loa.
47. April 8, 16:30, very feeble. Mauna Loa.
48. April 11, 18:40, moderate, both components dismantled at Mauna Loa. Kaoiki fault. Felt at Naalehu.
49. May 2, 05:02, strong, Kona seismograph broken. West slope of Mauna Loa. Intensity about 4 on Rossi-Forrel and modified Mercalli scales. Felt in Hilo, strongly at Puu Ulaula, and generally from Holualoa to Naalehu. Many sleepers wakened, some rushed out doors. Some objects thrown from shelves in the area from Honaunau to Kealakekua.
50. May 2, 12:55, feeble. Mauna Loa. Felt at Kapapala.
51. May 7, 23:26, strong, both components dismantled at Mauna Loa. Focus at about 12 miles depth beneath Mokuaweoweo. Felt at Holualoa, Kealakekua, Naalehu.
52. May 9, 03:26, very feeble.
53. May 9, 17:02, very feeble.
54. May 14, 10:54, very feeble.
55. May 21, 01:06, feeble. West slope of Mauna Loa. Felt at Holualoa.
56. May 21, 02:25, feeble. West slope Mauna Loa.
57. May 21, 08:38, feeble.
58. May 21, 10:01, feeble.
59. May 23, 10:24, moderate, both components dismantled at Mauna Loa. South slope Mauna Loa near Kapapala. Felt at Kilauea and Hookena, strongly at Pahala.
60. May 25, 15:10, very feeble.
61. May 26, 14:44, very feeble.
62. May 28, 17:30, feeble. West slope Mauna Loa. Felt at Holualoa.
63. May 29, 01:04, feeble. Kaoiki fault near Ainapo.
64. May 30, 04:18, feeble.
65. June 3, 04:05, very feeble.
66. June 8, 14:12, moderate, both components dismantled at Mauna Loa. Northeast rift of Mauna Loa, shallow.
67. June 9, 18:07, very feeble.
68. June 11, 05:41, very feeble. Northeast rift of Mauna Loa.
69. June 11, 08:05, very feeble.
70. June 17, 05:49, very feeble.
71. June 19, 05:05, very feeble. Mauna Loa.
72. June 19, 12:53, very feeble. Mauna Loa, northeast rift.
73. June 23, 15:34, feeble.
74. June 25, 15:45, feeble. Focus at about 10 miles depth under south slope of Mauna Loa near Punaluu Kahawai.
75. June 25, 19:27, slight. Location same as number 74.
76. June 26, 08:43, very feeble.
77. June 27, 01:57, feeble. Mauna Loa.
78. June 28, 04:53, very feeble. Mauna Loa.
79. June 30, 07:03, very feeble. Kilauea northeast rift, shallow.

TELESEISMS

April 13, 10:03, slight. Between Olympia and Tacoma, Washington.

April 29, 15:36, slight. South coast of Mindanao, Philippine Islands.

May 2, 20:05, slight. Kurile Islands.

MICROSEISMS

Microseisms were slight from April 1 to 9, moderate on April 10 and 11, slight from April 12 to 19, moderate from April 20 to 28, and slight from April 29 to June 30.

CRACK MEASUREMENTS

Most of the cracks measured showed no appreciable movement. However, the crack at the observation area at the east rim of Halemaumau opened 2 millimeters at its northern end during the interval from March 31 to June 30. During the interval since August 31, 1948, it has opened 12 millimeters. The amount of opening decreased southward, reaching essentially zero at the southern end of the crack.

TILTING OF THE GROUND

From April 1 to 22 there was very little tilting of the ground surface in a north–south azimuth. From April 22 to May 4 there was a slight northerly tilting, from May 4 to 29 a distinct southerly tilting, from May 29 to 31 a small northerly tilting, and from May 31 to June 30 a small accumulation of southerly tilting. In the east–west azimuth, there was a small accumulation of westerly tilt between April 1 and 29, a nearly equal accumulation of easterly tilt between April 29 and May 27, and a slight accumulation of westerly tilt from May 27 to June 30. The net westerly tilting is normal for this quarter of the year, although the tilting during June is normally slightly to the east instead of slightly westward. The accumulation of southerly tilt during May and June is abnormal, tilting during these two months generally being distinctly northward.

Table of Tilt at Observatory on Northeast Rim of Kilauea

Week Ended		Amount	Direction
April	3	0.9″	N 45° W
	10	0.7″	S 83° W
	17	0.0	——
	24	0.7″	N 39° W
May	1	0.6″	N 80° W
	8	0.7″	S 56° E
	15	0.6″	S 19° W
	22	0.5″	S 45° E
	29	0.4″	S 34° E
June	5	1.0″	N 19° W
	12	0.5″	S 45° W
	19	0.6″	N 22° W
	26	1.1″	S 56° E

HAWAIIAN VOLCANO RESEARCH ASSOCIATION
In cooperation with the UNIVERSITY OF HAWAII

The **Hawaiian Volcano Research Association** was founded in 1911 for the recording and study of volcanoes in the Hawaiian Islands and around the Pacific Ocean. Its equipment at Kilauea Volcano, Hawaii Island, has been transferred to the United States Geological Survey.

The **University of Hawaii** cooperates in maintaining a research laboratory at Kilauea. The Association and the University supplement the work of the government with research associates, instrumental equipment, and special investigations. Dr. T. A. Jaggar is their geophysicist resident at Kilauea.

The **Volcano Letter**, a quarterly record of Hawaiian volcano observations, is published by the University of Hawaii and supplied to members of the Research Association and to exchange lists of the above establishments.

THE VOLCANO LETTER 505

No. 505 **U. S. Geological Survey** **July–September, 1949**

PUBLISHED BY THE UNIVERSITY OF HAWAII

REPORT ON PRELIMINARY WORK FOR RADIATION SURVEY

By RUTH C. LOUCKS

INTRODUCTION

In August, 1948, a series of experiments was initiated to determine to what extent available materials could be used to make a survey of radiation from volcanic sources. At that time available materials consisted of X-ray film and a small spectrograph. Later a Geiger type survey meter was made available to the Hawaiian Volcano Observatory.

X-RAY FILM

Since X-ray film registers radiation both longer and shorter than the X-ray range, it appeared to be a possible medium for recording any short-wave radiation that might be present. No X-rays are expected because of their nature, but ultraviolet radiation and gamma radiation may be recorded on X-ray film. Dental pack film was selected for this work because of the ease of handling.

The first series of films, exposed for 10 weeks at Red Hill (10,000 feet) and the rim of Mokuaweoweo, showed heavy fogging of unshielded films and no fogging of slightly shielded films. By accident two films were exposed back to back. The front one was fogged, while the one which was shielded by the two lead foil backing sheets was unfogged. The fact that even masking tape, with which the films were taped to rocks, produced a shadow on the films indicated that the radiation recorded was of relatively long wavelength. Temperature changes from below freezing to above 70° F. apparently did no damage. One film was left for a year deep in a crevice in the roofed cave near the rim of North Bay known as Hotel de Jaggar. It showed slight darkening, possibly due to the small amount of radioactivity in Hawaiian lavas. Film exposed to Hawaiian lava for 12 weeks showed no darkening, but the longer exposure of a year may have recorded the slight amount of radioactivity present (Piggot: Amer. Jour. Sci., 5th Ser., 22(127) : 1931).

The second series was tested at the Kilauea region to determine whether the film pack was actually light tight (for visible light) and whether any of the darkening could be attributed to cosmic rays. The film tested for light tightness was unfogged. Cosmic rays produced no measurable darkening on any of the films tested. The only darkening was due to radioactive lead in the masses of the tiltmeter in the Uwekahuna vault. The radioactivity of the lead was later checked with the Geiger counter. The exposure of 5 weeks produced slight darkening on the film at a distance of 12 to 15 feet from the radioactive lead. This darkening served as a check of the sensitivity of the film to gamma radiation.

The third series of tests was made at Red Hill using unshielded film and film shielded by aluminum foil and various thicknesses of lead. Film was placed in four slots of a lead-covered box. One film was uncovered, one covered by 0.11 mm. of aluminum foil, one by 3.5 mm. of lead, and one by laminations so arranged that one third was uncovered, one third covered by 1.75 mm. of lead, and one third by 3.5 mm. of lead. These were exposed nearly 6 months. The unshielded film was darkened, while the film shielded by aluminum foil and the lead was undarkened. Thus it appears that the darkening encountered was due to ultraviolet radiation and may be eliminated by encasing the film in aluminum foil. The writer wishes to acknowledge the assistance given by the dispensary of Kilauea Military Camp in developing all X-ray films.

SPECTROGRAPH

The spectrograph (Gaertner, Model L 250-W) was checked and calibrated in the laboratory by Harvey E. White of the University of California Physics Department, during a visit to the Volcano Observatory. This is a low-dispersion instrument mounted so as to be used with a tripod in the field. It appeared that an easy way to record the exact object, toward which the spectrograph slit was pointed, would be by the use of a small camera mounted on the tripod with the spectrograph. D. C. Cox donated a camera for this purpose.

GEIGER COUNTER

A Geiger-Mueller counter (El-Tronics, Inc., Survey Meter SGM-18A) was received by the Observatory early in 1949. A few tests were made to determine what might be expected in the way of background radiation (cosmic rays).

1949 ERUPTION

Two series of X-ray films were exposed at the summit of Mauna Loa during the 1949 eruption. Both were exposed near the rest house, about 1 mile or more from the nearest activity. Twice during January, 1949, film was taped to the stone monument in front of the rest house and exposed for periods ranging from 17 hours to 17 days. Since the films were unshielded, there was no noticeable darkening other than that which might be expected from ultraviolet light. At that distance one could not expect to record gamma radiation.

G. A. Macdonald and D. C. Cox took the Geiger counter to the summit of Mauna Loa and made some observations. Their readings were no higher on new lava than on the old lava. However, when they attempted to make readings in a hot crack, they got no reading because the counter does not register correctly above 125° F.

The field conditions were such that it seemed best not to take the spectrograph to the summit.

CONCLUSIONS

It appears that none of the work done during the 1949 eruption constitutes a conclusive test of radiation associated with volcanic activity, particularly the possible presence of short-lived radioactive substances in the gases liberated in the big lava fountains. The films exposed were too far from activity to be significant, and the Geiger counter readings were not complete enough to be conclusive. However, the work done so far serves to point out what should be done to make such tests valid. The year's work shows that among the three recording devices the radiation spectrum from cosmic rays down through the visible range is covered.

THE HOLLOW CINDER CONE OF THE 1949 ERUPTION OF MAUNA LOA

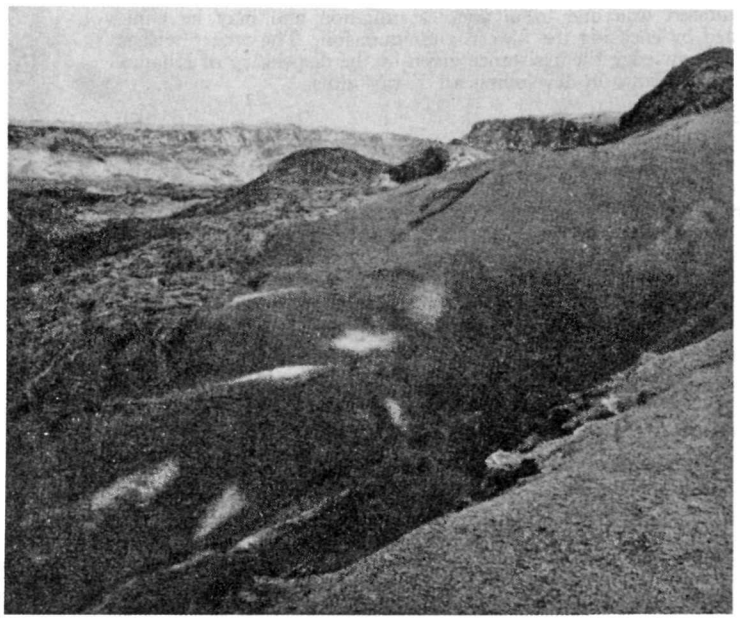
By GORDON A. MACDONALD

The small cinder and spatter cone, which developed within the breached crater of the larger cinder and pumice cone during the late stages of the 1949 eruption of Mauna Loa, has been described in previous issues of the VOLCANO LETTER. Previous to mid-April the cone had consisted entirely of coarse cinder and spatter. Between April 9 and May 6 the cone started to erupt short thin lava flows, which by early June had almost entirely covered its slopes, hiding the cinder core.

Mokuaweoweo caldera was again visited by the writer on July 26, in company with Ranger J. B. Orr of Hawaii National Park, and Tad Nichols, photographer. It was then found that the cinder and spatter cone had partly caved in, revealing a large cavity in its center. The hole formed by the collapse was on the northeastern side of the cone, and its walls clearly displayed a cross section of the cone. At the surface was the veneer of lava, averaging 6 to 8 feet thick, and consisting of a complex of many thin pahoehoe flows lying parallel to the surface of the buried cinder cone. Many of the flows showed cross sections of filled or partly filled pahoehoe tubes. Beneath the lava veneer the cone consisted of coarse cinder and spatter, largely welded together, and crudely bedded. The fragments ranged up to about 2 feet in length, although most were less than 1 foot. Most were irregular, although some were fairly regular Hawaiian type ("cow-dung") bombs.

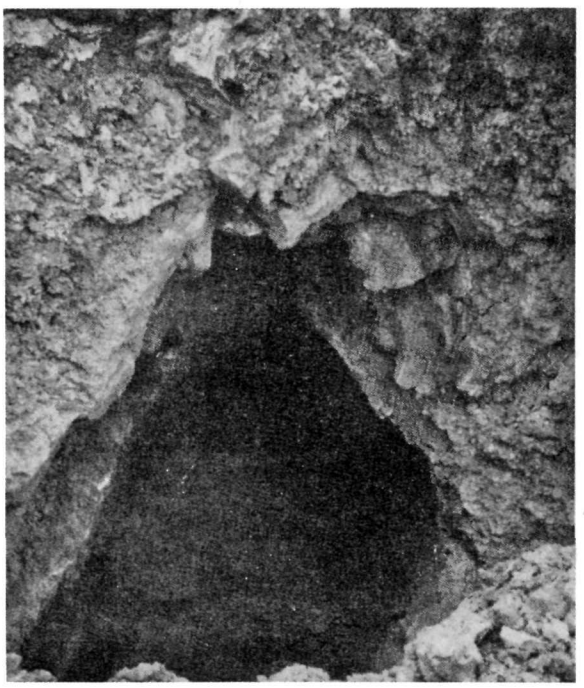
By far the most interesting feature of the cone was the open chamber at its center. The chamber was roughly the shape of an artillery projectile, about 25 feet across, with nearly vertical walls which arched inward to a point at the top. The opening was about 40 feet high, but had been higher, as the visible floor was formed of loose rubble which resulted from the collapse of the cone. The walls of the chamber were lined with a layer of pahoehoe 2 to 4 feet thick, in which the flow-lines and flow-planes were disposed parallel to the walls of the chamber and nearly vertical. At the apex of the chamber the pahoehoe lining was continued upward as a 3-foot dike which led to the two small spatter conelets at the summit of the cone.

Apparently the lava rose into the cone, making room for itself by removing the material which in earlier stages formed the core of the cone. There is no evidence whether the removal was by stoping or by redissolving the hot cinder, or both. At the end of the eruption the magma column withdrew, leaving the center of the cone empty, but the walls of the cavity veneered with a thin layer of lava.



LEFT

PLATE 1. View of the cone area of the 1949 eruption, from the top of the caldera wall to the north. In the foreground and on the right can be seen the big pumice cone built on and against the caldera rim during early stages of the eruption. The fissures are the result of partial collapse of the cone, and the white areas are the result of alteration and deposition by escaping gases. In the middle distance can be seen the hollow cinder and spatter cone, and to its left the lava cone. PHOTO BY G. A. MACDONALD.



RIGHT

PLATE 2. The open chamber in the center of the small cinder and spatter cone. The chamber is lined with a thin layer of pahoehoe lava, and on the right the nearly vertical flow-banding in the pahoehoe lining is clearly visible. At the top a flow-banded dike leads upward through the cinder. The chamber is approximately 20 feet across. PHOTO BY G. A. MACDONALD.

HAWAIIAN VOLCANO OBSERVATORY REPORT FOR JULY–SEPTEMBER, 1949

VOLCANOLOGY

July

Since the end of lava extrusion about the end of May, Mauna Loa has remained quiet. Mokuaweoweo was visited on July 26. No signs of lava activity could be detected although the new cone built during the early months of 1949 was still hot and fuming weakly and a faint pall of bluish fume hung over the crater of the 1940 cone. The small cinder and spatter cone within the crater of the larger cinder and pumice cone of the 1949 eruption had partly collapsed, and the center of the cone was seen to be occupied by an open chamber lined with a thin layer of pahoehoe.

Forty-six local earthquakes were recorded on the seismographs of the Volcano Observatory during the month of July. Of these, 31 were recorded at Kilauea and 34 at the seismograph on the eastern slope of Mauna Loa. (The total is not the same as the sum of those recorded at each of the stations, because many earthquakes were recorded at both stations.) On July 5 a moderately strong earthquake occurred at a depth of 10 to 15 miles on the east rift zone of Kilauea volcano, in the vicinity of Kapoho. At 8:52 p.m. on July 29 a strong shallow earthquake occurred on the northeast rift of Mauna Loa near the summit of the mountain. This earthquake, which dismantled both components of the Mauna Loa seismograph, was felt strongly at Kapapala and much less strongly by many persons in the area from Kilauea crater to Hilo.

On July 23, at 12:35 a.m., the Bosch-Omori seismograph recorded the long waves of a heavy earthquake with its origin near the New Hebrides Islands.

During the month of July the tiltmeter at the northeastern edge of Kilauea caldera accumulated a small amount of northerly tilt of the ground surface, but there was little change in tilt in the east–west direction. There is generally weak but pronounced easterly tilting and moderately strong northerly tilting at this season of the year. Hence the absence of appreciable easterly tilting and less than normal northerly tilting probably result from a slight decrease in pressure beneath Mauna Loa and Kilauea.

August

Mauna Loa and Kilauea remained quiet during August, although light fume was observed at the summit of Mauna Loa late on the afternoon of August 30.

Forty-seven local earthquakes were recorded on the seismographs during the month of August. Of these, 33 were recorded at Kilauea and 44 at the station on the eastern slope of Mauna Loa. A moderately strong earthquake which was felt in the area east of Kilauea crater at 2:26 p.m. on August 30 had its origin at a depth of 20 to 25 miles, about 8 miles south-southeast of Apua Point. An earthquake, which originated at a depth of about 30 miles under the southwest rift of Mauna Loa at 7:22 p.m. on August 31, was felt weakly in Kona.

On August 5 the seismographs recorded the great earthquake which caused tremendous damage and several thousand deaths in the region around Ambato, in Ecuador. On August 21 they recorded the great earthquake in British Columbia. This earthquake was of considerably greater magnitude than that of August 5 in Ecuador, and the smaller amount of damage must be attributed to its occurrence in an unpopulated area. It was so violent that it dismantled the seismographs, of comparatively low sensitivity, at the Volcano Observatory, 3,000 miles from its origin. It probably is the strongest distant earthquake thus far recorded at the Volcano Observatory. Aftershocks of the British Columbia earthquake were recorded until August 23.

During August the tiltmeter at the northeastern edge of Kilauea caldera recorded moderately strong northerly tilting of the ground, which is normal for this season of the year. There was almost no tilting in the east–west direction. Because there is normally an easterly tilting during this season, the lack of tilt in the east–west direction probably indicates a decrease of volcanic pressure under Mauna Loa.

September

The Hawaiian volcanoes remained quiet during September. The morning of September 6 marked the anniversary of the beginning of the last eruption of Kilauea. The 15 years since that eruption constitute the longest quiet period in historic record. The 13 years from 1894 to 1907 saw little lava activity, but fuming was almost continuous, and glow in Halemaumau was frequent, and one brief period of lava extrusion in Halemaumau appears to have occurred in 1902 (see VOLCANO LETTER 497, 1947). There is no indication that the end of the quiet period is near. Neither ground tilting nor earthquakes appear to indicate activity of Kilauea or Mauna Loa in the close future.

Forty-seven local earthquakes were recorded on the seismographs of the Hawaiian Volcano Observatory during September. Of these, 40 were recorded at Kilauea and 41 at the Mauna Loa station. On September 1 a sharp earthquake was felt strongly from Kapapala to Naalehu, and weakly in Kona and from Hawaii National Park to Hilo. It originated 3 to 4 miles northeast of the Kapapala Ranch headquarters, on the Kaoiki fault zone. A smaller earthquake, less generally felt, originated a little farther northeast on the same zone of faulting on September 14. An earthquake felt by a few persons in South Kona on September 16 had its origin near the coast about 5 miles south of Hookena, possibly on the Kiholo Pali fault.

On September 27, the seismographs recorded a distant earthquake which occurred in or near southern Alaska.

During the month of September the tiltmeter at the northeastern edge of Kilauea caldera recorded a slight easterly and a moderate northerly tilting of the ground surface which is normal for this season of the year.

G. A. MACDONALD

SEISMOLOGY

Earthquake Data, July–September, 1949

(Based on Bosch-Omori seismograph on rim of Kilauea caldera.)

Week Ended		Minutes of Tremor	Very Feeble	Feeble	Slight	Moderate	Strong	Local Seismicity*	Teleseisms
July	2	6	1	0	0	0	0	2.0	0
	9	13	2	0	0	1	0	7.25	0
	16	3	0	0	0	0	0	0.75	0
	23	5	1	0	0	0	0	1.75	1
	30	3	1	0	0	1	0	4.25	0
August	6	6	1	0	0	0	0	2.0	1
	13	7	2	0	0	0	0	2.75	0
	20	2	4	0	0	0	0	2.5	0
	27	9	2	1	0	0	0	3.25	2
September	3	1	2	0	1	0	1	7.25	0
	10	11	0	0	0	0	0	2.75	0
	17	4	2	1	0	0	0	3.0	0
	24	9	3	0	0	0	0	2.75	0
October	1	6	2	0	0	0	0	2.5	1

* For definition of local seismicity, see Volcano Letter 371.

The data for the following local disturbances were determined from seismograph stations operated on the island of Hawaii by the Hawaiian Volcano Observatory of the U. S. Geological Survey. Time is Hawaiian Standard, 10 hours slower than Greenwich. The number preceding each earthquake is the serial number for the current year.

80. July 5, 00:44, moderate. East rift of Kilauea near Kapoho, about 12 miles deep. Not reported as felt.
81. July 5, 17:13, very feeble.
82. July 8, 12:42, very feeble.
83. July 19, 09:55, very feeble.
84. July 28, 17:36, very feeble.
85. July 29, 20:52, moderate. Both components of Mauna Loa instrument dismantled. Felt strongly at Kapapala, weakly from Hawaii National Park to Hilo. Focus about 6 miles deep about 3 miles ENE of Mokuaweoweo.
86. August 5, 14:49, very feeble.
87. August 8, 18:35, very feeble. On west flank of Mauna Loa near Kaunene, 12 to 15 miles deep.
88. August 12, 19:05, very feeble. Southeast slope of Mauna Loa between Ainapo and Ohaikea, shallow.
89. August 16, 02:20, very feeble. Southeast slope of Mauna Loa about 7 miles northwest of Pahala.
90. August 16, 16:23, very feeble. About 2 miles south of Poliokeawe Pali, south of Kilauea caldera.
91. August 19, 07:15, very feeble. About 10 miles deep, near the shore northwest of Huehue Ranch.
92. August 19, 19:24, very feeble. Northeast rift of Mauna Loa at about 7,500 feet.
93. August 21, 18:49, feeble. Felt by a few persons in Volcano district. Offshore, southeast of Kilauea caldera.

94. August 24, 06:03, very feeble.
95. August 24, 14:18, very feeble.
96. August 30, 14:27, slight. Beneath ocean, about 8 miles SSE of Apua Point, 20 to 25 miles deep. Felt in Volcano district.
97. August 31, 19:23, very feeble. Felt at Holualoa. Under southwest rift of Mauna Loa, about 30 miles deep.
98. Sept. 1, 12:53, moderate. Both components of Mauna Loa instrument dismantled. Felt strongly from Kapapala to Naalehu, weakly from Volcano district to Hilo and in Kona from Pahoehoe to Holualoa. Origin on Kaoiki fault, about 3 to 4 miles northeast of Kapapala Ranch headquarters.
99. Sept. 2, 02:31, very feeble.
100. Sept. 12, 03:46, very feeble.
101. Sept. 14, 16:47, feeble. About 6 miles deep, on Kaoiki fault about 3 miles west of Uwekahuna. Felt in Hilo.
102. Sept. 16, 14:08, very feeble. Felt in South Kona. Origin near coast, about 5 miles south of Hookena.
103. Sept. 18, 20:38, very feeble.
104. Sept. 22, 01:31, very feeble. Under southwest edge of Kilauea caldera, about 8 miles deep.
105. Sept. 23, 21:08, very feeble.
106. Sept. 26, 08:27, very feeble.
107. Sept. 28, 12:13, very feeble.

TELESEISMS

July 23, 00:35, slight. New Hebrides Islands; provisional epicenter.

August 5, 14:43, moderate. Central Ecuador, centering around Ambato.

August 21, 18:09, very large. Both components of Bosch–Omori seismograph at Kilauea, and the north–south component of the Mauna Loa seismograph were dismantled. Queen Charlotte Islands, off coast of British Columbia. Caused 2-foot tidal wave at Ketchikan, Alaska.

August 23, 10:38, slight. Probably an aftershock of the British Columbia earthquake.

Sept. 27, 05:38, slight. Origin probably near Juneau, in southern Alaska.

MICROSEISMS

Microseisms were slight from July 1 to 10, moderate from July 11 to 22, slight from July 23 to 29, moderate from July 30 to August 6, slight from August 7 to 20, moderate from August 21 to 27, slight from August 28 to September 1, moderate from September 2 to 10, strong from the afternoon of September 10 through September 14, and moderate for the remainder of the month of September.

CRACK MEASUREMENTS

Most of the cracks measured showed no appreciable movement. However, the crack at the observation area on the east rim of Halemaumau continued to open slightly. During the interval from June 30 to September 30, stations near the northern end of this crack showed opening of 2 to 3.5 millimeters, and stations near the southern end showed opening of about 0.5 millimeter.

TILTING OF THE GROUND

There was a net northerly tilting of the ground surface of 3.5 seconds of arc at the northeastern rim of Kilauea caldera between July 1 and August 21. Minor reversals to southerly tilt occurred during the periods July 9 to 12, 25 to 30, and August 9 to 10. There was slight southerly tilting from August 21 to 23, slight northerly tilting from August 23 to September 17, and slight southerly tilting from September 17 to October 1. The net change from July 1 to October 1 was a northerly tilt of 3.4 seconds of arc. In the east–west azimuth, there was an accumulation of 0.5 second of easterly tilt from July 1 to July 5. From July 5 to September 1 there were minor oscillations from easterly to westerly tilt, but no net accumulation of either. From September 1 to 4 there was a sharp westerly tilting, followed by a moderate easterly tilting during the remainder of the month. The net accumulation of easterly tilt from July 1 to October 1 was 0.9 second of arc.

Table of Tilt at Seismograph Vault on Northeast Rim of Kilauea Caldera

Week Ended		Amount	Direction
July	2	1.4″	N 40° W
	9	0.6″	N 12° W
	16	0.4″	S 64° E
	23	0.9″	N 32° E
	30	0.7″	S 16° W
Aug.	6	1.1″	N 16° W
	13	0.1″	N 45° W
	20	1.1″	N
	27	0.3″	S 70° E
Sept.	3	0.2″	N
	10	0.1″	E
	17	0.4″	N 32° E
	24	0.6″	S 18° W
Oct.	1	0.8″	N 76° E

TEMPERATURE MEASUREMENTS

Weekly measurements of the temperature at the steam well at Sulfur Bank were resumed on September 10. The following uniform procedure has been adopted. The ½-inch plug at the top of the casing of the more easterly of the two drill-holes is removed, and the well is allowed to blow freely for 10 minutes. A maximum thermometer is then completely inserted into the aperture and allowed to remain 5 minutes. To date, the measured temperature has been uniformly 206° F.

Measurements at steaming cracks at Sulfur Bank have ranged from 203° to 208°, probably because of non-uniform exposure. Changes in the amount and direction of the wind appear particularly effective in altering the measured temperature.

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THE VOLCANO LETTER

506

No. 506 **U. S. Geological Survey** **October–December, 1949**

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BOMBING TO DIVERT LAVA FLOWS

By RUY H. FINCH and GORDON A. MACDONALD

Probably the first attempt to alter the course of a lava flow by artificial means occurred during the 1669 eruption of Etna volcano. The flow was advancing toward the city of Catania and seemed likely to destroy it. In an attempt to save the city, several dozen men covered themselves with wet cowhides for protection against the heat and dug a channel through the wall of hot lava at one edge of the flow. The operation was initially successful. A stream of lava escaped through the gap thus created and moved away at a high angle to the direction of the original flow, partly relieving the pressure on the stream moving toward Catania. Unfortunately, however, the new flow moved toward the town of Paterno, and some 500 irate citizens of that town descended upon the men of Catania and drove them away from the newly dug lava channel. Left unattended, the gap in the flow wall soon clogged up with cooled lava, and the main branch of the flow continued toward Catania, partly destroying it (Rittmann, 1929, pp. 95–96). This early attempt, although it ended in failure, demonstrated the possibility of diverting part or all of a lava flow to a new course by artificially breaking down the confining wall of the flow.

Digging away of the edge of the flow, by hand or by machine, is a difficult and possibly dangerous procedure. It is easier and quicker to blast away the lava by means of explosives. The late Lorrin A. Thurston suggested orally in the early 1920's that in the case of pahoehoe lava flows descending gentle slopes, high explosives might be thrust out over the flow on long poles and dropped through windows in the feeding tube near the flow source, shattering the tube, forcing the lava to spread out again near the source, and removing the supply of lava from the advancing lower end of the flow (Thurston, 1929). Similar methods had been under discussion for several years by members of the staff of the Hawaiian Volcano Observatory. Thurston's suggestion was accepted and advocated by Jaggar (1931), and during the Mauna Loa eruption of 1935 Jaggar introduced the method of emplacing the explosive by dropping military bombs from airplanes (Jaggar, 1936). This is generally the most practical way of transporting and emplacing the explosive. In some instances shells from nearby big guns might be more effective because of the greater accuracy with which they can be directed; but for the most part potential diversion sites are too inaccessible to be conveniently or quickly reached by artillery.

There are three principal ways in which bombing can bring about diversion of the fluid lava, thereby robbing the older flow below the point of diversion of its supply of lava and causing stagnation of the lower end of the flow. These are: (1) bombing of the natural levees along the open lava river of an aa flow or a young pahoehoe flow in which tubes have not yet formed; (2) bombing of the main feeding channel of a mature pahoehoe flow in which tubes have become well developed; and (3) bombing of the walls of the cinder cone at the source of the flow.

In well-established lava flows on little-dissected terrane the liquid lava of the main feeding channels commonly is confined within tubes or between natural levees and is at a level several feet higher than that of the land surface adjacent to the flow. Where the lava river is still open and confined between levees, breaking down of the levee therefore will allow the liquid lava to escape to one side and form a new flow, robbing the old flow of part or all of its supply of liquid lava. If topographic conditions are favorable, the new flow may move off at a high angle to the direction of the older flow, and reach some entirely different destination. More commonly, however, because the older flow was guided by

the direction of steepest slope or pre-existing topographic depressions, the new flow follows the same direction and moves downslope along the edge of the older one. If it does so, it may eventually reach the same place at which the older flow terminated. However, the advance of the lava as a whole is greatly delayed, because the diverted flow may take days, or even weeks, to reach the point attained previously by the older flow. When the second flow has reached the danger point, it also can be bombed, thus still further delaying the advance of the lava front.

A long stretch of the flow, or several separate points on the flow, may be suitable for bombing. If so, in general it appears advisable to select the lowest suitable site for bombing first. If it then becomes necessary to bomb the flow again at a later date the higher sites are still available. On the other hand, if the higher sites are bombed first the new lava streams advancing along the edges of the older one may so alter conditions that the lower sites are no longer suitable. In general, it appears desirable to wait as long as is safely possible before bombing the flow. Every day which bombing is delayed brings the eruption that much closer to an end, and, in general, sees the rate of extravasation diminished. Premature bombing may result in the process having to be repeated, whereas a single bombing might have sufficed had it been delayed a little longer. Care must be taken, however, to allow a sufficient margin of time to cover the possibility of periods of bad weather with low visibility (when bombing is impossible) and rapid forward spurts of the flow.

The practicability of breaking down the levee of an open lava stream by aerial bombing was demonstrated during the 1942 eruption of Mauna Loa (Finch, 1942, p. 4). Disruption of the levee by bombs resulted in at least one new lava stream which poured out through the break in the wall. Topography was not favorable to direct the new flow away from the course of the older one, and consequently it flowed along the edge of the older one for a short distance and then rejoined it. Even such a brief diversion may have some effect in retarding the advance of the front of the major flow, owing to the rapid cooling of the channel of the main flow below the point of diversion, and consequent chilling of the next lava to enter it, with the accompanying tendency to clog the channel.

The method of bombing the main tubes of a pahoehoe flow was tried during the 1935 eruption of Mauna Loa (Jaggar, 1936). Bombs dropped on the roof of the tube may break in the roof and cause the tube to become clogged with solid fragments. Or bombs dropped into the liquid lava within the tubes through the roof or through windows in the roof may cause sufficiently violent stirring of the liquid to transform it from pahoehoe to aa, with increase in viscosity or even local congelation. If it is not swept away with the current, this mass may cause a plugging of the tube. If in either way the tube becomes clogged, the result is an overflow of liquid lava from the tube at the point of clogging and a partial or total removal of the supply of liquid from the tube farther downslope. The lava which overflows at the break forms new tongues which advance downslope on top of, or alongside of, the older flow. If the eruption continues long enough these tongues may develop new major tubes, and may in time reach or pass the terminus of the older flow, but the advance of the lava as a whole will have been delayed and the end of the eruption will be that much closer. It may be possible to repeat the bombing if necessary.

The cinder and spatter cones formed at the source of lava flows commonly contain pools of lava which are held at levels several feet above the surrounding land surface. Likewise, the liquid surface of a mature lava flow issuing from the cone is generally several feet above the adjacent terrane. Breaking down of the cone walls, either naturally or induced by bombing, therefore will allow the liquid in the cone to escape over the surrounding ground, robbing the established lava flow of part or all of its supply of new lava. Many of the cones on the rifts of Mauna Loa have a form especially favorable for bombing. They are built by rows of lava fountains spurting from fissures, and are long and narrow, with relatively thin walls which probably would be quite easy to break down by bombing. Bombing of the walls of the source cone has been suggested (Finch, 1942, p. 6; Macdonald, 1943, p. 255), but has not yet been tried. However, during the 1942 eruption of Mauna Loa there occurred a natural breakdown of the cone walls liberating floods of pahoehoe. A new flow advanced seaward parallel to the older channel. A day later, forward movement at the front of the older flow had practically ceased.

Successful diversion of lava flows by bombing depends upon a combination of several favorable circumstances, including: a lava river flowing in a channel or lava held in the source cone at a level higher than the adjacent land surface; narrow levees, thin cone walls, or thinly roofed tubes which can be broken open by bombs; and favorable topography. The first two conditions are commonly present during eruptions of basaltic lava, but favorable topography is not so general. On the slopes of volcanoes which have been appreciably dissected by erosion, flows may be confined within valleys and diversion may be difficult or impossible. Even under those conditions, however, it may be possible to delay greatly the advance of the flow front by repeated bombing and spreading of the lava in the upper reaches of the valley. On the undissected or little-dissected slopes of young volcanoes, where erosion has not yet cut valleys, bombing to divert the flow is both possible and practical.

It must be pointed out that successful diversion is only possible where the flow has continued long enough to establish well-defined channels, or build at least moderate-sized cones. Probably little can be done with the voluminous bursts which occur during the early hours of Mauna Loa eruptions when the flows are spreading rapidly in several directions and moving through many shifting and anastomosing channels. Fortunately, these early floods are generally high on the mountain where they constitute no danger. Likewise, it must be realized that time is required to prepare the planes and load the bombs, as well as to select the targets and put the plan into operation. Therefore, diversion by bombing may not be possible in time to avert catastrophe where the flow is advancing rapidly down steep slopes, or where the point of outbreak of the flow is too close to the area it is desired to save. It is difficult to place any definite limit on the distance of the vent from the endangered area within which time is insufficient to permit bombing to divert the flow. This depends on the fluidity of the particular lava stream, on the slope, and on the general character of the terrane. For average Hawaiian eruptions, with average slope conditions, it may be about 7 miles. Where the distance is less than that, or where slopes are steep and flow of the lava rapid, only lava barriers such as those suggested by Jaggar (1945) can furnish protection.

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HAWAIIAN VOLCANO OBSERVATORY REPORT FOR OCTOBER–DECEMBER, 1949

VOLCANOLOGY

October

A total of 39 earthquakes was recorded in October. Of this total 31 were recorded at Kilauea and 37 at the Mauna Loa station. Two of these earthquakes, whose origins were determined, originated under Mokuaweoweo. The stronger of these two shakes was felt at Pahala at 07:55, October 22. Four shakes occurred in less than 15 minutes during the evening of October 26. Three of the shakes were plainly felt at the Kapapala ranch house. They originated along the Kaoiki fault near Kapapala.

The accumulation of northeasterly tilt at the northern end of Kilauea caldera during October was in about the usual amount for this season of the year.

November

An unusual feature of this month was a swarm of earthquakes under Mauna Kea. Sixteen shakes occurred between 09:46 and 20:31 on November 4. A few of the stronger shakes were felt by hunters who were at an elevation of 10,000 feet on Mauna Kea, and they were perceptible at scattered points on the island. An earthquake which occurred at 07:58, November 28, was felt over most of the island. It originated under the east slope of Mauna Loa near Mokuaweoweo at a depth of 20 miles and was strong enough to dismantle seismographs at Hilo, Kilauea caldera rim, and on the east slope of Mauna Loa.

There was about the usual accumulation of northeasterly tilt during the month.

A land slide from the walls of Halemaumau at 14:21, November 24, produced a large brown dust cloud.

December

A distinct feature of the month was the recording of 262 earthquakes on the Mauna Loa seismograph on December 28. Four of the shakes were registered as very feeble and the rest were small tremors. About 80 of the shakes were recorded on the Bosch-Omori seismograph under the Volcano House and 47 on the Kona instrument at Kealakekua. In at least two instances 3 distinct tremors were recorded in 30 seconds. Shortly before the shaking ceased, or at 23:02, continuous tremor started and lasted for 18 minutes.

The frequency of the tremor and the rather uniform small amplitude suggest an intrusion at moderate depth under the northeast rift of Mauna Loa at about 12,000 feet or above.

In addition to the swarm of earthquakes on December 28, 42 shakes were recorded during the month. Of this total 39 were recorded on the Mauna Loa instrument and 25 at Kilauea. Two of the earthquakes were strong enough to be perceptible and both originated under Kilauea. The first occurred at 03:06, December 11. It originated deep under Kilauea and was recorded on seismographs on Oahu. The second occurred at 15:09 also on December 11. It originated at a shallow depth under the northern end of Kilauea caldera and was accompanied by a distinct roar.

R. H. FINCH.

SEISMOLOGY

Earthquake Data, October–December, 1949

(Based on Bosch-Omori seismograph on rim of Kilauea caldera.)

Week Ended		Minutes of Tremor	Very Feeble	Feeble	Slight	Moderate	Local Seismicity*	Teleseisms
October	8	7	2	1	0	0	3.75	0
	15	5	0	0	0	0	1.25	0
	22	7	2	0	0	0	2.75	1
	29	2	3	1	0	0	2.00	0
November	5	14	6	3	0	0	9.50	0
	12	2	0	0	0	0	0.50	1
	19	0	0	0	0	0	0.00	1
	26	3	1	0	0	1	4.25	2
December	3	2	0	0	0	0	0.50	0
	10	5	0	0	0	0	1.25	0
	17	5	1	2	1	0	5.75	3
	24	3	0	0	0	0	0.75	0
	31	88	0	0	0	0	22.00	1

* For definition of local seismicity, see Volcano Letter 371.

The data for the following local disturbances were determined from seismograph stations operated on the island of Hawaii by the Hawaiian Volcano Observatory of the U. S. Geological Survey. Time is Hawaiian Standard, 10 hours slower than Greenwich. The number preceding each earthquake is the serial number for the current year.

108. Oct. 2, 01:28, very feeble. South edge Kilauea caldera.
109. Oct. 3, 08:44, very feeble. 4-5 miles deep on Hilina-Paliokeawe fault 8 miles southeast of Volcano House.
110. Oct. 3, 16:57, very feeble.
111. Oct. 22, 03:51, very feeble. East slope Mauna Loa.
112. Oct. 22, 07:55, very feeble. Felt Pahala. South end Mokuaweoweo.
113. Oct. 23, 10:14, very feeble. East slope Mauna Loa.
114. Oct. 26, 17:58, feeble. Felt at Kapapala.
115. Oct. 26, 18:12, very feeble. Felt at Kapapala.
116. Oct. 27, 03:56, very feeble.
117. Oct. 30, 10:56, very feeble.
118. Nov. 4, 10:37, very feeble.
119. Nov. 4, 10:52, very feeble.

120. Nov. 4, 11:44, very feeble.
121. Nov. 4, 12:00, very feeble. 118 to 121 probably same location as 122.
122. Nov. 4, 12:12, feeble. Felt by hunters at 10,000 feet on Mauna Kea. At a depth of 20 miles under summit of Mauna Kea.
123. Nov. 4, 13:02, feeble. Same as 122.
124. Nov. 4, 14:10, feeble. Same location as 122.
125. Nov. 5, 18:45, very feeble. Under east slope of Mauna Kea.
126. Nov. 23, 02:49, very feeble. Mauna Loa.
127. Nov. 25, 07:58, moderate. Instruments dismantled. Felt locally and from North Kona to Hilo. 20 miles under east slope of Mauna Loa near Mokuaweoweo.
128. Dec. 11, 03:06, feeble. Felt locally. Deep under Kilauea.
129. Dec. 11, 15:08, slight. Felt locally and accompanied by roar. Under north end of Kilauea caldera.
130. Dec. 12, 18:56, feeble. Kilauea.
131. Dec. 16, 07:35, very feeble.

TELESEISMS

Oct. 19, 11:11, slight. Solomon Islands.
Nov. 9, 13:32, slight. North of Easter Island.
Nov. 19, 22:29, slight. Gulf of California.
Nov. 21, 15:02, slight. Kermadec Islands.
Nov. 26, 22:52, slight. Tonga.
Dec. 16, 21:46, slight.
Dec. 16, 22:16, slight.
Dec. 17, 05:58, slight. Near southern tip of South America.
Dec. 25, 20:45, slight.

MICROSEISMS

Microseisms were slight October 26-28 and November 17-21 inclusive, strong from November 12-14, and moderate on other days.

CRACK MEASUREMENTS

The northern end of the crack at the observation area on the east rim of Halemaumau opened 2 millimeters during the 3 months ending December 31. All other cracks that were measured showed little or no movement.

TILTING OF THE GROUND

There was an accumulation of north tilt amounting to 3.3 seconds of arc between October 1 and November 21. The seasonal change to southerly tilt occurred earlier than common, and from November 22 to December 31 there was an accumulation of 2.2 seconds of south tilt. The 4.8 seconds of east tilt between October 1 and December 31 was about the usual for this season of the year.

Table of Tilt at Seismograph Vault on Northeast Rim of Kilauea Caldera

Week Ended		Amount	Direction
Oct.	8	0.7″	N 9° E
	15	2.1″	N 47° E
	22	0.3″	N 26° E
	29	0.7″	N
Nov.	5	0.4″	S 34° W
	12	1.1″	N 26° E
	19	1.5″	N 76° E
	26	0.6″	S 54° W
Dec.	3	1.0″	N 70° E
	10	1.1″	S 12° E
	17	1.3″	S 73° E
	24	1.5″	S 39° W
	31	0.6″	N 53° E

TEMPERATURE MEASUREMENTS

There was a positive decrease in the temperature of the steam well at Sulfur Bank. The decrease amounted to 2° F.—from 206° F. on October 1 to 204° on November 30. The temperature in December appeared to be nearly constant at 204° F. A vent in the Sulfur Bank showed a similar drop from 205° F. on October 1 to 203° F. on December 28. The decrease does not show a good correlation with heavy rainfall and perhaps is a regular seasonal change.

The highest temperature found in the Kokoolau steaming area on November 4, 1949, was 190° F., or a little less than was common for several years after it was noted that trees were being killed there in 1938.

At the Aloi crater steaming area the highest temperature found on November 4 was 194° F.

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THE VOLCANO LETTER

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THERMAL WATER ON KILAUEA VOLCANO

By RUY H. FINCH and GORDON A. MACDONALD

The numerous steam vents within Kilauea caldera are well known. For the most part the steam contains no other gases and appears to represent merely ground water of meteoric origin which has been heated to, or slightly above, the boiling point by contact with bodies of hot rock. At Sulphur Bank and at the nearly buried solfataric area east-southeast of Halemaumau the steam is mixed with a small proportion of sulfur gases and carbon dioxide of magmatic origin, but even there the majority of the steam probably is derived by heating of ground water.

In addition to the steam vents at Kilauea caldera, there are four known occurrences of warm water on Kilauea volcano. It has been reported in a crack near Waiwelawela Point, 12 miles east of Pahala (Stearns and Clark, 1930, p. 190), but no record of the temperature of the water at that locality is known. The warm water undoubtedly results from heating of basal ground water by contact with hot intrusive rock along the southwest rift zone of Kilauea.

The other three occurrences of warm water are all in eastern Puna, on or near the east rift zone of Kilauea. One of these is the well-known "Warm Spring" near the northern base of Puu Kukae, about 0.8 mile east-northeast of Kapoho. The water is basal ground water. It forms a pool in a crack at the foot of the small fault scarp which marks the southern edge of a small graben, or block of rock which has sunk down between two faults. Brigham (1868, p. 374) reported that in 1864 this pool (called by him the "Blue Grotto") had a temperature of 90° F. At present the temperature is only a little above the average air temperature. Measurements on January 11, 1950, gave a water temperature of 84° F. and an air temperature of 79°.

Another pool of warm water is situated half a mile northwest of that just described and within the same graben. The water is in a crack at the back of a shallow cave, the entrance of which is at the base of a low northward-facing fault scarp about 750 feet south of the higher fault scarp that marks the northern edge of the graben. The locality is about 0.6 mile north of the highway junction at Kapoho and 0.2 mile east of the Kapoho-Koae road. At one time the water was bottled for sale under the trade-mark "Volcano Water." The temperature of the water is only a little above that of the air outside the cave. On January 11, 1950, the water temperature was 83° F., and the temperature of the air in the cave was 77°.

The third occurrence of warm water is at Pohoiki, about 3 miles south of Kapoho. There basal springs issue just above sea level from a cobble beach at the head of a small bay. The springs are within the zone of splash from the ocean waves and are distinctly brackish. On January 11 the water temperature was 91° F., and the air temperature 77°.

No other warm waters are known on the island of Hawaii, although steam issues from vents in the caldera of Mauna Loa and on both rift zones. The amount of warm water, at first glance, seems surprisingly small in view of the large amount of volcanic heat undoubtedly still present beneath the surface. However, because of the high permeability of the rocks, as Stearns and Clark (1930, p. 190) have pointed out, most juvenile and meteoric hot waters probably become diluted and cooled at the basal water table and do not reach the surface.

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ORIGIN OF PUEHU CINDER CONE, KAU

By GORDON A. MACDONALD and RUY H. FINCH

Puehu cinder cone is a small but prominent cone situated just south of the main highway from Kilauea caldera to Honuapo, about 0.4 mile southwest of the junction with the road to Punaluu. It lies on the southern slope of Mauna Loa about 1.2 miles west of the boundary between the surface lavas of Mauna Loa and Kilauea and is surrounded and partly buried by aa lavas of Mauna Loa. The cone is being excavated to supply cinders for use on roads. Before the mining of cinders began, the cone was about 50 feet high above the lavas on its downhill side, and its exposed base was about 200 feet above sea level. At present a large pit on the southeastern side of the cone exposes cinder for a depth of about 100 feet and has not yet reached the base of the cone.

Stearns and Macdonald (1946, pl. 1) classified the cone as a littoral cone of the Kau volcanic series, formed by steam explosions where lavas of Mauna Loa entered the sea. The better exposures which have resulted from recent excavation indicate that interpretation to be erroneous.

Puehu cone clearly is a cone formed at a primary lava vent. The ejecta exposed in the new cuts are typical of primary cinder cones built at vents. They are moderately to highly vesicular, or even pumiceous, cinder and spatter. Moreover, several thin layers of lava are interbedded with the cinder, some of them obviously rootless flows formed by the aggregation of heavy showers of fluid spatter on the flanks of the cone. Some of these flows still show welded spatter on their surfaces. Lava extends all the way to the summit of the cone, 25 feet higher than the surface of the adjacent aa flow on the uphill side of the cone. On the northeastern side of the cone there is exposed a 15-foot thick section of thin-bedded pahoehoe, the beds ranging from 1 to 6 inches thick and averaging 2 to 3 inches. The rock is olivine basalt with sparingly to moderately abundant phenocrysts of olivine up to about 4 mm. long; much of it is highly vesicular. Such very thin-bedded, highly vesicular pahoehoe typically is found in close proximity to primary vents. Neither it nor the rootless flows would be expected to form on a littoral cone where relatively viscous aa lava enters the sea, nor have they been observed on known littoral cones.

Besides the presence of the aforementioned features typical of cones formed at primary vents, there is a complete absence of the features typical of littoral cones. The angular grains of relatively dense glass, which are characteristic of littoral cone deposits (Macdonald, 1949, p. 72), could not be found. Neither are there present any of the angular blocks of relatively dense lava which are common on the slopes of Puu Hou, the littoral cone formed by the Mauna Loa flow of 1868, and the older littoral cones farther west.

The lower slopes of Puehu cone in the new excavations are covered by as much as 15 feet of yellow Pahala ash, with one intercalated lava flow. The cinder layers in the cone were partly truncated by erosion before deposition of the ash. The Pahala ash is absent from most of the top of the cone, but 2 to 3 feet of ash are preserved in local pockets. Most of the ash appears to have been eroded off the upper slopes of the cone. The ash overlying the lower slopes appears to be the result of primary deposition, and there is no evidence that the thickness of the ash layer resting on the lower slopes of the cone was appreciably increased by secondary deposition of ash eroded from the top of the cone.

The presence of 15 feet of Pahala ash overlying the lower slopes of the cone indicates that the cone is somewhat older than previously was believed. Obviously, it must already have been in existence during the period of deposition of the Pahala ash, and therefore it is older than the rocks of the Kau volcanic series, which are younger than the Pahala ash. However, the Pahala ash has a thickness of 55 feet on Puu Enuhe, only 2.5 miles northwest of Puehu cone (Stearns and Clark, 1930, p. 66). Consequently, it is probable that only part of the total thickness of the Pahala ash overlies the Puehu cone and that the cone is of late Pahala age.

Puehu cone is situated about 12 miles east of the southwest rift zone of Mauna Loa and even farther from any other known vents of Mauna Loa. It lines up with no known Mauna Loa rifts. In contrast, it is only about 3.5 miles from the closest visible vent on the southwest rift zone of Kilauea volcano and lies directly in line with that rift. The cone itself is somewhat elongated in a direction parallel to the Kilauea rift, possibly because the vent fissure had that trend. Although it cannot be definitely proved, it appears highly probable that the cone was formed by eruption from the southwest rift of Kilauea and that it belongs to Kilauea rather than to Mauna Loa.

It is concluded that Puehu cone is a primary cinder cone formed by eruption at a lava vent during late Pahala time, and that it probably belongs in the Hilina volcanic series of Kilauea volcano and is correlative with the upper part of that series exposed in Hilina Pali. If this interpretation is correct, the southwest rift zone of Kilauea must have been in existence at least by late Hilina time, thus strengthening the conclusion of Stearns

and Macdonald (1946, pp. 135–136) that the Hilina volcanic series was derived from Kilauea, as opposed to the belief of Stone (1926, pp. 38, 49–50) and Powers (1946, p. 6) that the Hilina lavas are part of Mauna Loa.

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HAWAIIAN VOLCANO OBSERVATORY REPORT FOR JANUARY–MARCH, 1950

VOLCANOLOGY

January

The year opened with both Kilauea and Mauna Loa inactive save for the usual steam vents and solfataras.

Only 24 earthquakes were recorded during the month. This is the smallest monthly total since October, 1948. Twenty-two of the shakes were recorded on the Mauna Loa seismograph and 17 at Kilauea.

There was an accumulation of 7.8 seconds of arc tilt to the south-southwest during January. This is a little more than usual for this season of the year.

The fact that the lava fill in Halemaumau is still hot was shown by pronounced steaming following heavy rains on January 10.

February

A total of 29 earthquakes was recorded during February. Of this number, 26 were recorded on the Mauna Loa seismograph and 21 at Kilauea.

Dust clouds were especially conspicuous in the Kau Desert on February 12.

A landslide of appreciable magnitude from the walls of Halemaumau was observed at 09: 50 on February 13.

March

Northerly tilt during March indicates that there was a distinct pressure build-up at Kilauea. This increase of pressure was strong enough to overcome the southerly tilt usual for March and to show a positive northerly tilt of 6 seconds of arc. This is the strongest northerly tilt recorded here for several years.

The distribution of the earthquakes recorded during March also indicates a slight uneasiness under Kilauea volcano. Of the 37 shakes recorded during the month, 35 were registered on the Kilauea seismograph and 16 on the Mauna Loa instrument. Most of the earthquakes of Kilauea origin had shallow foci.

Mokuaweoweo was visited by G. A. Macdonald and J. B. Orr on March 28 to 30. No activity was observed other than the mild solfataras, and no changes were noted since the last visit in October, 1949, other than minor collapses in the small cones built during the 1949 eruption. Solfataras are located in the crater of the 1940 cone, on its northern slope, and on the caldera floor north of it. The gas liberated is largely steam, but contains a little sulfur dioxide and in places a small amount of sulfur is being deposited. The 1949 cones are still hot at many places, a little steam is being given off, but no sulfurous gas was detected. Pale yellow stalactites, probably of sulfates, are forming in the hollow 1949 cone. Collapse of the walls of the crater of the 1949 lava cone has reduced the depth of the crater to about 15 feet.

R. H. FINCH

CRACK MEASUREMENTS

None of the cracks that are regularly measured showed an appreciable movement during the 3 months ended March 31.

TILTING OF THE GROUND

Strong southerly tilt set in shortly after the beginning of the year and continued until February 9. The accumulation for the period amounted to 11 seconds of arc. From February 9 to March 5 there was no accumulation of tilt in the N-S direction. Strong northerly tilt commenced on March 6, or about 1 month earlier than usual. The northerly tilt from March 6 to 31 amounted to 6 seconds of arc.

Table of Tilt at Seismograph Vault on Northeast Rim of Kilauea Caldera

Week Beginning		Amount	Direction
January	1	1.4″	S 41° E
	8	2.0″	S 10° E
	15	2.2″	S 52° W
	22	2.0″	S 10° W
	29	1.4″	S 41° W
February	5	2.2″	S 45° E
	12	0.5″	S 64° W
	19	0.3″	N 61° W
	26	1.2″	S 65° W
March	5	1.2″	N 36° W
	12	0.2″	N
	19	2.2″	N 4° E
	26	2.3″	N 3° E

SEISMOLOGY

Earthquake Data, January–March, 1950

(Based on Bosch-Omori seismograph on rim of Kilauea caldera.)

Week Beginning		Minutes of Tremor	Very Feeble	Feeble	Slight	Moderate	Strong	Local Seismicity*	Teleseisms
January	1	4	0	0	0	0	0	1.00	0
	8	4	0	0	0	0	0	1.00	1
	15	3	2	0	0	0	0	1.75	0
	22	2	0	1	0	0	0	1.50	0
	29	3	0	0	0	0	0	0.75	0
February	5	4	0	0	0	0	0	1.00	0
	12	0	1	0	2	0	0	4.50	0
	19	6	1	0	0	0	0	2.00	0
	26	3	2	1	0	0	0	2.75	1
March	5	7	2	0	0	0	0	2.75	0
	12	7	2	0	1	0	0	4.75	0
	19	7	0	0	1	0	1	8.75	0
	26	11	2	0	0	0	0	3.75	0

* For definition of local seismicity, see Volcano Letter 373.

The data for the following local disturbances were determined from seismograph stations operated on the island of Hawaii by the Hawaiian Volcano Observatory of the U. S. Geological Survey. Time is Hawaiian Standard, 10 hours slower than Greenwich. The number preceding each earthquake is the serial number for the current year.

1. Jan. 13, 11: 54, very feeble. Inland from Kealakekua Bay.
2. Jan. 20, 19: 31, very feeble. Mauna Loa.
3. Jan. 21, 04: 40, very feeble. Near summit of Mauna Loa.
4. Jan. 25, 16: 26, feeble. Felt at 29 Miles and Hilo.
5. Feb. 12, 06: 09, slight. Felt locally and at Naalehu. Near Makaopuhi.
6. Feb. 13, 11: 59, slight. Felt locally and at Hilo. Eight miles deep under east slope of Mauna Loa.
7. Feb. 15, 16: 52, very feeble. Mauna Loa.
8. Feb. 19, 08: 00, very feeble.
9. Feb. 26, 14: 01, very feeble. Kilauea.
10. Feb. 28, 04: 26, very feeble. Mauna Loa.
11. Mar. 1. 08: 00, feeble. Southwest of Hilo.
12. Mar. 7, 21: 47, very feeble. Mauna Loa.
13. Mar. 11, 19: 59, very feeble. Kilauea.
14. Mar. 17, 02: 35, slight. Shallow; under Kilauea.

15. Mar. 17, 04:05, very feeble.
16. Mar. 24, 14:14, slight. Shallow; under Kilauea.
17. Mar. 25, 05:43, strong. Widely felt on island of Hawaii. Seismographs dismantled. 15-20 miles deep under 5,000-foot contour, east slope of Mauna Loa.
18. Mar. 28, 10:57, very feeble. Mauna Loa.
19. Mar. 31, 03:43, very feeble. Kilauea.

TELESEISMS

Jan. 9, 17:30, slight. Off south coast of Mexico.
Feb. 28, 00:30. North coast of Hokkaido.

MICROSEISMS

Microseisms were moderate during the first 2 weeks of January and the last few days of March and slight on other days.

TEMPERATURE MEASUREMENTS

The temperature of the steam well at the Sulfur Bank was 206° F. in October, 1949, then dropped to 204° F. in November. The 204° F. temperature continued until the latter part of March, when a temperature of 202° F. was measured.

MAGNETIC OBSERVATIONS

H. R. Joesting and J. H. Swartz of the Geophysics Branch of the Geological Survey, and R. E. Wilcox of the Volcano Investigations Unit, spent the first 3 weeks of February at the Observatory setting up procedures to be followed in a program of magnetic observations and calibrating instruments and instructing Observatory personnel in their use. The instruments to be used are two Askania-type magnetometers built by Wolfson of Toronto. A series of permanent observation stations is being established on Kilauea and the lower slopes of Mauna Loa, and periodic readings will be taken to determine the variation in the vertical component of the earth's magnetic field, particularly the changes in differences between the various stations.

The magnetic permeability of rocks is decreased by an increase of temperature, and above a certain temperature (known as the Curie point) they become entirely non-magnetic. Thus a body of hot magma rising beneath the surface of the volcano should be non-magnetic, and the rocks around and above it should become less and less magnetic as they are heated up. It is hoped that this reduction in strength of magnetism may be detectable at the surface, and that the effect may appear long enough before the magma reaches the surface to be useful in predicting eruptions.

During February and early March, 29 stations were established around and in Kilauea caldera, along the Chain of Craters road and the upper part of the Hilina Pali road, and along the road to the Mauna Loa seismograph. At each station concrete blocks were built on which to set up the tripod of the magnetometer. It is planned to occupy each of the stations at least once a month, and oftener if possible.

On March 27 to 30 a series of dip-needle measurements was made on Mauna Loa by G. A. Macdonald of the Observatory staff and J. B. Orr of Hawaii National Park as part of the general study by the Observatory of earth magnetism in the vicinity of the volcanoes. The measurements were made along the trail from Kilauea to the summit of Mauna Loa, part way around the summit caldera, and across the floor. Preliminary analysis of the results shows that in general the strength of the magnetic attraction was less along the rift zones than elsewhere on the mountain. It is to be expected that these zones would be hotter than the rest of the mountain and have a smaller magnetic attraction.

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U. S. Geological Survey:
R. H. Finch, Volcanologist, Director
G. A. Macdonald, Geologist
C. K. Wentworth, Geologist, part-time
B. J. Loucks, Instrument maker
Ruth B. Loucks, Assistant

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Seismograph Station Operators:
Hilo Station:
Brother B. T. Pleimann, Saint Joseph's School
Kealakekua Station:
H. M. Tatsuno, Konawaena School

HAWAIIAN VOLCANO RESEARCH ASSOCIATION
In cooperation with the UNIVERSITY OF HAWAII

The **Hawaiian Volcano Research Association** was founded in 1911 for the recording and study of volcanoes in the Hawaiian Islands and around the Pacific Ocean. Its equipment at Kilauea Volcano, Hawaii Island, has been transferred to the United States Geological Survey.

The **University of Hawaii** cooperates in maintaining a research laboratory at Kilauea. The Association and the University supplement the work of the government with research associates, instrumental equipment, and special investigations. Dr. T. A. Jaggar is their geophysicist resident at Kilauea.

The **Volcano Letter**, a quarterly record of Hawaiian volcano observations, is published by the University of Hawaii and supplied to members of the Research Association and to exchange lists of the above establishments.

THE VOLCANO LETTER

508

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PUBLISHED BY THE UNIVERSITY OF HAWAII

THE JUNE 1950 ERUPTION OF MAUNA LOA

By R. H. FINCH and GORDON A. MACDONALD*

Part I

NARRATIVE OF THE ERUPTION

INTRODUCTION

Following the end of the 1949 summit eruption of Mauna Loa, magma pressure remained high, and the molten lava continued to stand high in the conduit. A moderate release of fume continued in the summit caldera throughout the rest of 1949 and the spring of 1950. A normal accumulation of eastward ground tilting was recorded at the Volcano Observatory during the fall of 1949, but during the spring of 1950 westward tilting was markedly less than usual, apparently indicating a tumescence of the mountain. On the basis of past history, it was expected that the summit eruption would be followed by a flank eruption, probably within 2 years; the apparent high position of the magma column suggested that the interval might well be shorter. During May many earthquakes originated at Mauna Loa and pointed to a distinct uneasiness of the volcano. These culminated on May 29 with a strong earthquake originating on the southwest rift near the summit. In a bulletin released by the Observatory, published in newspapers on May 30, Finch called attention to the unrest of the southwest rift of Mauna Loa and stated that if the eruption came soon it would take place there. The expected eruption came on the evening of June 1, 1950.

ACKNOWLEDGMENTS

Many people gave valuable aid during the eruption by contributing information on the activity. It is impossible to list all by name, but to all of them we extend our sincere thanks. Some persons should receive special mention. Colonel L. W. Bryan, island commander of the Hawaii National Guard and island forester of the Territorial Board of Agriculture and Forestry, was exceedingly active in making observations from the air and deserves much credit for his work in keeping track of the flows and warning of danger from them during the first days of the eruption. His unsurpassed knowledge of the terrain was of very great aid. William Stearns and Donald Campbell of Murray Aircraft Agricultural Service contributed many excellent observations from the air. Sergeant Wilmot Vredenburg of the Hawaii Police Department passed on much information on the activity of the Ohia Lodge flow near the highway. Ernest Martin, manager of Kahuku Ranch, contributed information on the lava flows in the Kau District from personal observations and from those of his cowboys. Mrs. Myrtle Hansen of Naalehu was exceedingly helpful in relaying information from various sources in the Naalehu and Waiohinu area as well as in contributing her own observations on the lava flows and earthquakes.

Harry Blickhahn, editor of the *Hilo Tribune-Herald,* and Vern Hinkley, managing editor of the *Honolulu Star-Bulletin,* also were very helpful in passing on information and photographs as they received them.

Pilots of Army and Navy planes made observations from the air, and several of these, as well as observations by commercial pilots, were relayed by the staff of the Civil Aeronautics Authority at Hilo.

Members of the staff of Hawaii National Park contributed many valuable observations on the flows and vent activity. F. A. Hjort, chief ranger, and V. R. Bender, ranger, made aerial observations on the morning of June 2 and observations on the ground at the lower line of vents on June 3 and 4. F. R. Oberhansley, superintendent, I. J. Castro, assistant superintendent, and Herbert Quick, superintendent of construction and maintenance, observed the vent activity from the air on June 3.

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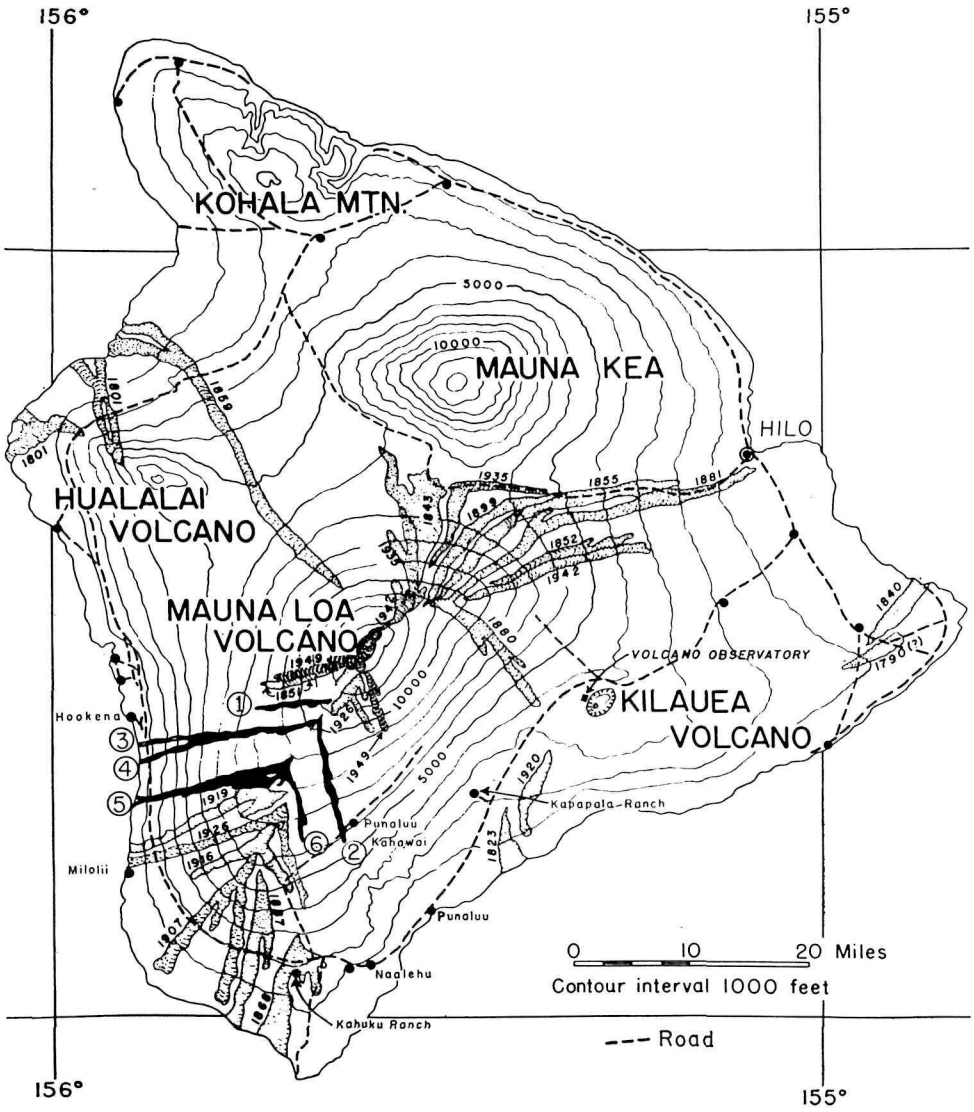

FIGURE 1. Map of the island of Hawaii, showing the approximate positions of the lava flows of June, 1950 (solid black). Numbers in circles indicate the flows referred to in the text: 1. Flow from the initial outbreak above 11,000 feet altitude; 2. Punaluu flow; 3. Hookena flow; 4. Magoon Ranch flow; 5. Ohia Lodge flow; 6. Kahuku flow. Older historic flows are stippled. Most of the flows originate along the two major rift zones.

D. H. Hubbard, naturalist, made observations from the sea and from the ground at the northern side of the Hookena flow on June 2 and 3.

D. C. Cox, geologist for the Hawaiian Sugar Planters' Association, cooperated with the Volcano Observatory staff in making observations on the lava flows and the vent activity and furnished the Observatory with a complete set of his field notes.

Several members of the U. S. Geological Survey not attached to the Observatory staff also cooperated in the investigation and were of great aid in the collection of data in the field. They include C. K. Wentworth, geologist for the Honolulu Board of Water Supply and part-time geologist for the Observatory; D. A. Davis, district geologist; M. H. Carson, district engineer; G. D. Robinson, assistant chief of the General Geology Branch; and Arnold Mason, geologist with the Pacific Geological Surveys Section. H. R. Joesting and J. R. Swartz of the Geophysics Branch carried on magnetometer observations during the eruption.

NARRATIVE

On the evening of June 1, 1950, Mauna Loa volcano erupted from its southwest rift. Glow was first seen from the Volcano House at Kilauea at about 9:25 P.M., but harmonic tremor started registering on the seismograph at 9:04 and it is probable that the eruption actually started then or very shortly afterward. About 9:10 Mr. and Mrs. Alfred Hansen, in Naalehu, heard a deep rumbling from the direction of the top of the mountain.

The first outbreak was high on the rift. At first two narrow illuminated columns of fume were visible, but these rapidly expanded down the mountain slope. A fissure 2.5 miles long opened from about 12,600 to 11,250 feet altitude, the upper end being close to the small pit crater Lua Hou and the lower end near Sulphur Cone. From this fissure poured great volumes of fume rising in a relatively narrow column about 2 miles into the air then spreading laterally to form a mushroom-shaped cloud brightly illuminated by the glare of the incandescent lava beneath. A flood of fluid gas-rich

lava poured from the fissure and down the mountainside, most of it going westward toward the Kona District. Many short flows were formed, and one long flow (flow 1, Fig. 1) extended downslope about 5 miles to an altitude of about 9,000 feet. Robert Duncan of Pahala reported hearing the roar of the lava fountains about 15.5 miles away, at the junction of the Kapapala Ranch road with the highway.

The outbreak at the upper source lasted only a few hours. By 12:30 A.M. on June 2, the glow at the upper source was distinctly less, and by 1:30 A.M. it was feeble. At that time the activity at the upper source had diminished greatly and may already have been finished.

At 10:15 P.M. on June 1, observers at the Volcano Observatory and along the Kau-Volcano highway noticed a small puff of fume rising from a point on the rift at about 8,250 feet altitude approximately 8 miles southwest of the lower end of the glowing fume column at the upper source. At 10:23 bright glow appeared on the fume cloud, indicating that fluid lava had reached the surface. The illuminated fume column rapidly spread as the length of the erupting fissure increased. Margaret Finch, watching from the Volcano Observatory, observed the glow expanding up the mountain, indicating that the fissure opened upslope. The glow from this lower source continued to increase rapidly until 10:45, when it was obscured by clouds. Lava fountain activity was very strong. At 11:40 Finch and Macdonald could hear the roar of the lower fountains distinctly at the point where the highway crosses the western branch of the 1907 lava flow, nearly 15 miles from the site of the eruption.

Early on the morning of June 2 the activity was observed from the air by Frank Hjort. He reported lava fountaining from a line of fissures about 7 miles long extending from about 10,500 down to 8,000 feet altitude. Between the main line of fissuring and the shorter westerly line a broad pond of molten lava had accumulated. Floods of very fluid lava were pouring westward toward Kona, in a series of anastomosing streams. Lava from the principal fissure was pouring over the shorter westerly fissure, partly drowning it. Sulfur dioxide fumes were very strong. About noon Ross Bender flew over the source area. He reported two principal lines of lava fountains playing along fissures at approximately 10,000 and 8,500 feet altitude. The source at 10,000 feet was largely obscured by fume, but no lava movement was observed there or in the flows originating there. From the source at 8,500 feet great floods of lava were pouring westward. At the time of his first observations lava fountains were playing from several isolated stretches of the fissure below 9,000 feet, but while he watched the activity increased and fountains developed along the intervening portions of the fissure, making the curtain of fountains essentially continuous. Some of the fountains he estimated to be about 300 feet high.

A similar condition was reported on the afternoon of June 3, when Frank Oberhansley, I. J. Castro, and Herbert Quick flew over the scene of activity. The lava fountains formed an almost continuous "curtain of fire," averaging 150 to 200 feet high, with some of the bursts reaching 300 feet or even more.

The line of fissures forming the lower source was not continuous. Over a stretch of about 2.5 miles, between 8,950 feet and 9,750 feet altitude, there appears to have been no lava liberation. Between 9,750 and 10,500 feet altitude there was a line of active fountains 1.6 miles long. Below 8,950 feet altitude there was a series of nearly aligned fissures, en echelon and commonly slightly overlapping.

During the first few hours of the eruption two very rapid flows were poured out from the vent area centering at 10,000 feet altitude. One of these (flow 2, Fig. 1) advanced south-southeastward in the general direction of Punaluu. By daybreak on June 2 it had passed the ranch road a short distance west of Punaluu Kahawai. On the morning of June 2 it was examined from the air by L. W. Bryan. At that time it had reached an altitude of about 5,500 feet, approximately 10 miles from its source, but its advance appeared to be essentially over.

The other flow (flow 3, Fig. 1) from the 10,000-foot source moved rapidly westward into the Kona District. At 12:20 it was less than a mile above the highway, and Ruth Macdonald reported that the roar and explosions caused by the lava advancing through the forest were clearly audible and the glare from hot lava and burning vegetation was strong. The flow crossed the highway at about 12:30, destroying Hookena Post Office, several houses, and a filling station. There was a light but steady fall of fine black ash and some Pele's hair mixed with rain. The flow reached the sea, 0.8 mile below the highway, at about 1:05 A.M. on June 2, having covered its 15-mile course down the mountainside at an average rate of 5.8 miles an hour. Where the hot lava entered the sea, a great billowing column of steam arose. However, observers reported no apparent increase in the amount of ash in the air. This first flow to reach the ocean is termed hereafter the Hookena flow.

By daylight lava movement in the Hookena flow had greatly diminished. By 11:00 A.M. it had practically ceased, and very little steam was rising where the flow entered the ocean.

Early on the morning of June 2 another flow branched off from the Hookena flow. The new flow (flow 4, Fig. 1) diverged southward from the older one, and at about 5:00 A.M. it crossed the highway at the Magoon Ranch house, 1.2 miles south of the earlier flow. The ranch house was destroyed, as also were two or three other

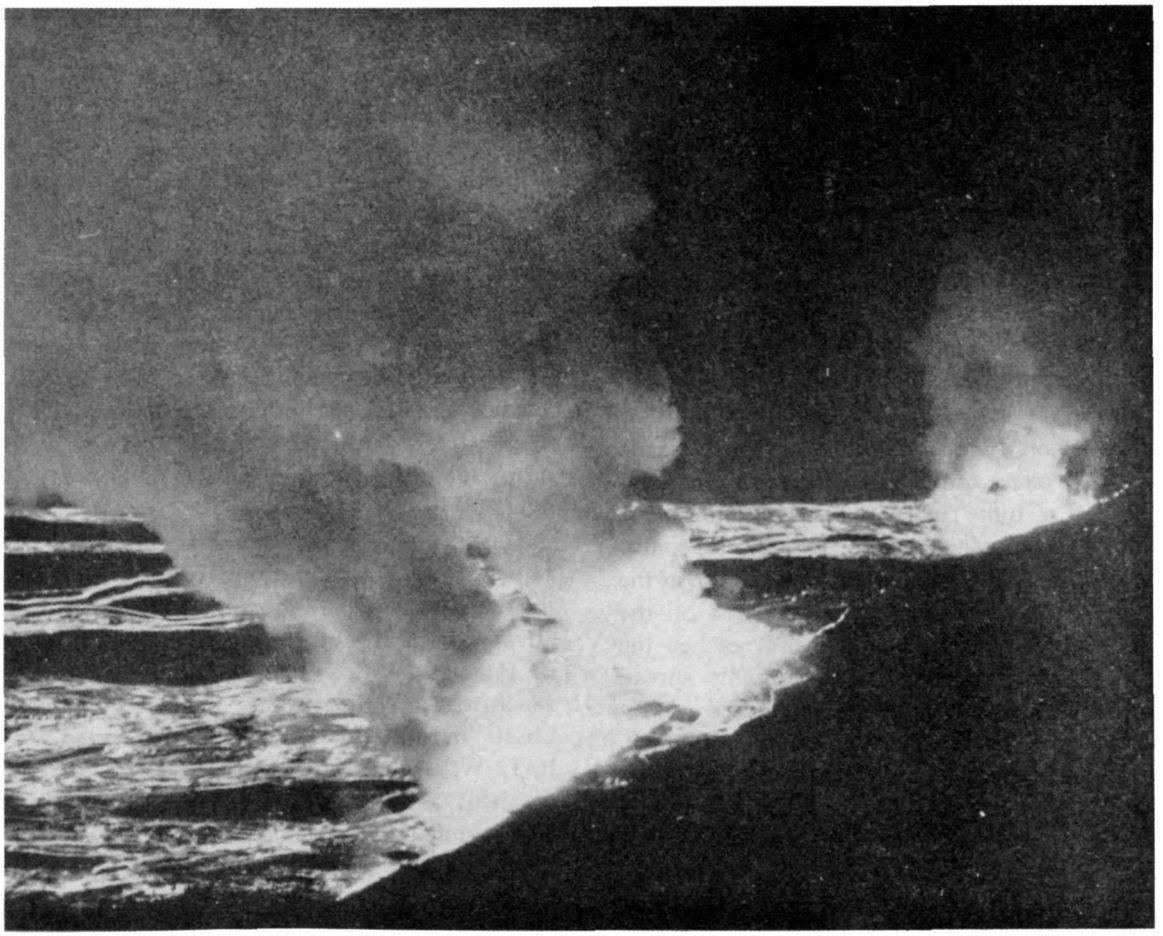

PLATE 1. Floods of lava and clouds of fume issuing from the eruptive fissure at 3:00 A.M. on June 2, 1950. The lava is flowing westward toward Kona. PHOTO BY HONOLULU STAR-BULLETIN.

houses. The flow was aa in character. Along the highway just south of the main ranch house, the advance of the lava was checked by a loose stone wall, about 3 feet high. The lava eventually piled up enough to spill over the wall, but it does not appear to have seriously damaged the wall, and for a distance of about 250 feet it spread only 15 to 20 feet beyond the wall. Farther north the flow continued unchecked on down the mountainside. It entered the sea at 12:04 P.M., destroying another house and part of a coconut grove.

For about an hour and a half before it reached the ocean, the advance of the flow was observed by Macdonald and B. J. Loucks. By that time the lava had lost its initial great fluidity and was creeping ahead at a rate of only about 750 feet an hour. The flow was descending a steep slope half a mile inland and spreading out as a broad fan over the flat sparsely vegetated terrane near the coast. As the edge of the flow engulfed the few large trees there were minor explosions, with flashes of flame. Occasionally similar roars and flashes came from the central part of the flow, probably from tree trunks buried in the flow. Many tree trunks were carried down with the flow from farther upslope. Some of these rode along on the flow surface or projected upward from it, flaming like torches.

At 11:30 A.M. the volume of lava in the flow suddenly increased, and a new flood of lava moved out over the older still-moving flow on the steep slope below the highway. At the base of the slope the new aa front spread out fanwise over the older lava, flowing at about twice the speed of the earlier front, which itself was still advancing. At 12:04 the first front entered the ocean, and a huge column of steam arose in great billows with a cork-screw motion rotating counterclockwise. No sign of ash being thrown up where the flow entered the sea could be seen. At 12:10 the second gush of lava reached the sea. The steam column increased, but there was no evidence of any strong explosive action or any appreciable amount of ash being thrown up. In the meantime the constant light fall of fine black ash, with some Pele's hair, continued as it had all morning.

By the afternoon of June 3 movement in the Magoon Ranch flow appeared to have largely or wholly ceased although the column of steam rising where the flow entered the ocean appeared strong.

Another flow appears to have started late on the night

PLATE 2. Lava fountains as much as 250 feet high playing along part of the fissure on the morning of June 2, 1950. OFFICIAL PHOTOGRAPH, FLEET AIR PHOTOGRAPHIC LABORATORY UTILITY SQUADRON 7, U. S. NAVY.

PLATE 3. Braided lava streams flowing westward near the active rift on the morning of June 2, 1950. OFFICIAL PHOTOGRAPH, FLEET AIR PHOTOGRAPHIC LABORATORY UTILITY SQUADRON 7, U. S. NAVY.

of June 1, advancing westward south of the Magoon Ranch flow. Because it later destroyed the Ohia Lodge, this flow (flow 5, Fig. 1) may be called the Ohia Lodge flow. The earlier flows started at the erupting fissure at about 10,000 feet altitude, but the Ohia Lodge flow originated at the lower line of fissures between 8,000 and 9,000 feet altitude. At 12:20 P.M. on June 2, Macdonald and Loucks were with a police detail and a small group of refugees at Ohia Lodge waiting developments from this new flow which was known to be advancing through the forest a short distance above the road. Because of the large amount of smoke and fume, combined with a low cloud cover, visibility was very poor and the exact location of the flow front was unknown. About 12:30 a patroling National Guard plane flew over at very low altitude and dropped two Mae West life jackets to which were attached warnings to leave immediately for the southward. These instructions were carried out.

At approximately 2:00 P.M. the Ohia Lodge flow reached the highway about a quarter of a mile south of Ohia Lodge and 4 miles south of the Magoon Ranch flow. At about 3:30 P.M. it entered the ocean just north of Heku Point, having taken an hour and a half to cover the 1.3 miles from the road to the sea. Again a great billowing cloud of steam arose with a counterclockwise rotational movement, but again there was no sign of violent explosion or of the formation of any appreciable amount of ash where the lava entered the sea.

By 5:00 P.M. a line of steaming water, marking the sub-sea course of the flow, extended out to sea for about half a mile from the point where the Ohia Lodge flow entered the ocean. Close to the shore and directly over the submerged flow, the water was boiling, and a semicircular area of hot turbulent water extended for a mile offshore. Many fish were killed and were seen drifting or were washed up on the shore during succeeding days. The prevailing currents drifted the area of hot water southward. Off Milolii, 5 miles south of the flow, many charred logs were seen floating in the water. These were the remains of tree trunks carried down on the top of the flows and dumped into the sea.

At 4:00 P.M. the Ohia Lodge flow was about 750 feet wide and 10 feet thick at the highway. Its outer edges were slowly moving fields of aa, creeping along at a rate of only a few feet an hour. Near its center there appeared to be a narrow, more rapidly moving, lava river, but visibility was very poor and the edge of the flow was still too hot to climb. The flow was still spreading a little laterally. Occasionally trees were pushed over at the edge of the flow. Others burst into flame while they were still standing as the heat from the lava dried out the foliage and raised it to kindling point. Minor explosions were heard from time to time as trees were engulfed in hot lava and the water in their tissues suddenly transformed into steam.

The odor of hydrocarbon gas, probably largely methane, was strong, and the flow smelled much like a leaking gas stove. Yellow flames were common along the edges and top of the flow, issuing from the lava, and there were also many blue flames resembling the flame of a well-adjusted gas burner. These gases undoubtedly were derived from the destructive distillation of the vegetation buried and engulfed by the lava. Many flames burned at cracks in the old lava—commonly 10 to 15 feet and rarely as much as 50 feet or even more from the edge of the new flow. Some of these flames were quite steady, but many went out periodically at the surface only to re-ignite within the crack and burst out again at the surface with a loud "whoomp"! Some of these gas ignitions were explosively violent, throwing rock fragments several feet.

Along the edge of the flow the vegetation was partly broken, leaves were partly blown off trees, and leaves of ti plants were shredded and broken off. Most of the breaking appeared to have been by blasts from the direction of the flow. These were probably in part marginal explosions caused by ignition of hydrocarbon gases, but some of the damage was observed to be caused by the small but strong whirlwinds which formed over the flow and moved across it.

At 6:00 P.M. it was possible to climb the edge of the flow and go out onto it about 150 feet. Beyond that point the gas and heat were unbearable. From the vantage point on the top of the flow, the central lava river could be seen clearly. It was about 25 feet wide. At highway level it was flowing at an estimated rate of 15 miles per hour, but about half a mile upslope from the highway there was a broad double lava cascade on a steeper slope where the speed was estimated to be 25 miles an hour. Temperature measurements on the river ranged from 880° to 900° C. A spectacular feature of the lava river was the many large blocks which it carried along. The blocks were as much as 20 feet high and 30 feet long, although most of them were much smaller. Most were largely incandescent, though a few were largely dark. Occasionally large blocks became wedged sideways in the channel, causing local overflows. The blocks appeared to have been dragged along by a lower, less rapidly moving and probably more viscous stratum in the river. Some could be seen to be moving distinctly less rapidly than the surficial part of the river around them.

Condensation of water in the steam cloud which rose where the lava entered the sea caused a continuous rain beneath the cloud. That the rain was caused largely by the cloud is shown by the fact that just south of the edge of the cloud there was no rain and the night was

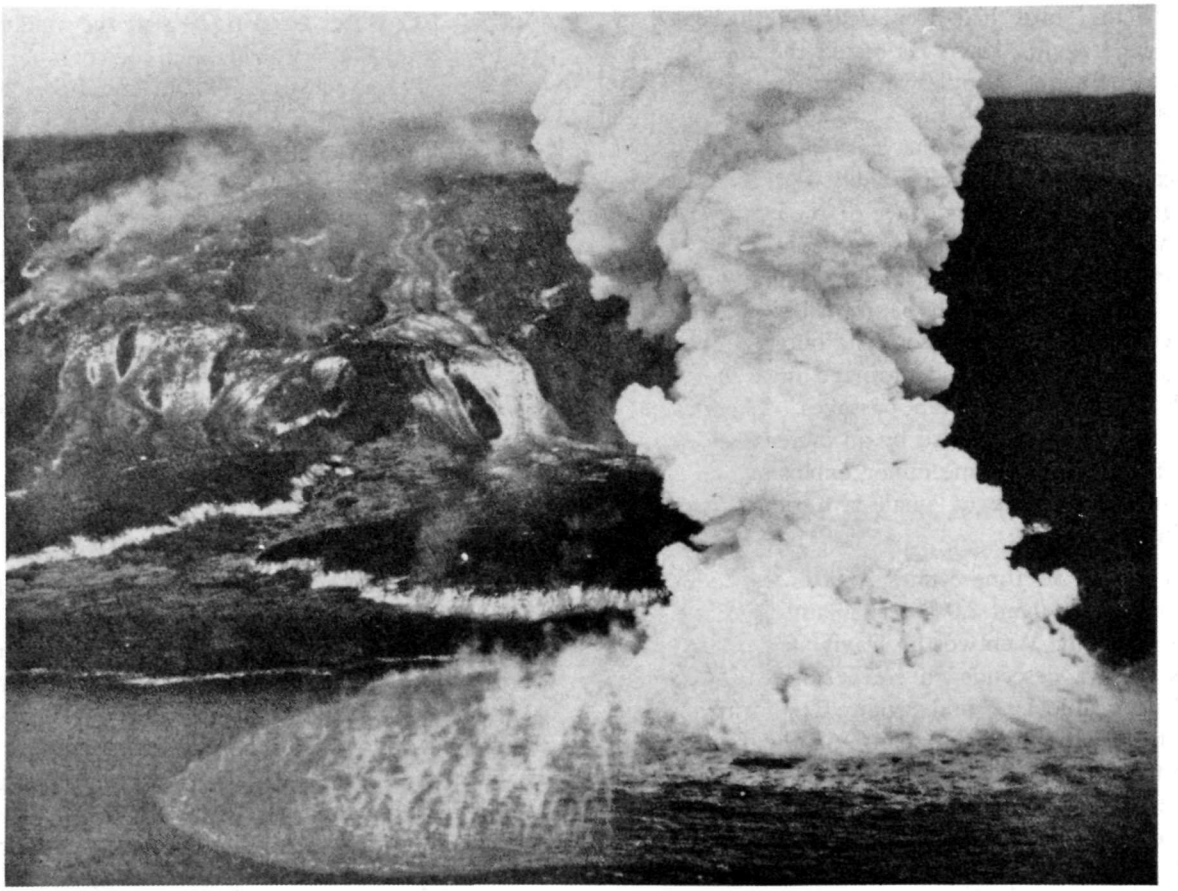

PLATE 4. Ohia Lodge flow pouring into the ocean at about 4:00 P.M., June 2, 1950. In the foreground a high column of steam is rising where the southernmost tongue reaches the ocean. Boiling and steaming water is visible off shore. In the background the flow is descending the mountainside, with smoke rising from the burning forest. Two large, brightly glowing fronts of aa are visible near the left side of the picture. OFFICIAL PHOTOGRAPH, AIR NATIONAL GUARD, 199 FIGHTER SQUADRON.

fairly clear. There was enough salt in the rain beneath the steam cloud to cause the drops to sting the face and eyes and to form a peculiar thin glaze on cars. This glaze was very difficult to remove, even by washing.

At 12:20 A.M. on June 3, Macdonald and Loucks started down the southern side of the flow from the highway. About half a mile from the ocean the flow reached the top of a steep slope formed by a buried fault scarp. There it divided into three branches. At a point just above the steepening of slope the speed of the lava in the river was estimated to be about 15 miles an hour, but as it cascaded down the buried scarp the lava reached a speed estimated at 25 to 30 miles an hour. Temperatures on the cascade were as high as 930° C. On the flatter ground below the scarp the flow slowed and spread out to form a broad fan about three quarters of a mile wide. The central lava river was the most active, and the steam column caused by it was the largest. The river appeared as a bright orange-red streak with long dark streaks paralleling the edge of the river. The southern river was moving less rapidly, and its surface was largely covered with dark blocks between which could be seen red glow.

There was a light but continuous fall of black ash of sand and silt sizes. Some of this ash may have been formed by steam explosions where the lava entered the sea, but much of it appeared to be fine debris picked up from the flow by the numerous small whirlwinds which swept over its surface.

Just above the big cascade blue or greenish-blue flames were common in the slow-moving margin of the flow, and yellow flames even more common. Dancing pale blue flames, resembling will-o-the-wisps, occasionally were seen for a few moments over the main lava river, as much as 35 to 50 feet above the river, and isolated from it by clear air. Some of these appeared to be nearly formless, but others looked like fire-balls.

The Ohia Lodge flow below the highway was examined on the morning of June 3 by D. C. Cox, D. A. Davis, and C. K. Wentworth. At 10:30 A.M. the condition was much like that of the previous night. At 10:35 a sudden increase in the volume of lava in the flow was observed. The speed of the lava in the big cascade between the highway and the shore increased notably, and a sheet of more rapidly moving lava appeared to override the older, less-rapidly flowing sheet.

By 11:15 the surge had decreased and the speed of flow lessened again. Davis estimated the speed in the cascade to be about 20 miles an hour during the peak of the surge and 5 to 6 miles an hour as the surge abated. During the surge the lava fan at the foot of the cascade had built up appreciably. At 11:30, after the surge had ceased, the surface of the central part of the fan was seen to be subsiding as the fluid lava underneath drained away, leaving higher ridges around its edges. The observers on the landward side of the fan could see no lava spilling from the outer edge of the fan into the sea, hence the drainage must have been through hidden subterranean passages. The drainage into the sea was accompanied by an increase in the size of the steam column, some minor explosions along the shore, and pushing up of small lava ridges from the water just offshore.

From 1:00 P.M. June 3 until 7:00 A.M. June 4, the Ohia Lodge flow about 2,000 feet inland from the road was observed by Wentworth, Davis, and Cox. Two streams of lava descended a steep slope in a cascade about half a mile long and reunited to form a single stream before reaching the road. At the foot of the cascade the flow was about 1,000 feet wide. Just north of this main flow another tongue of lava was advancing slowly seaward, burning trees and knocking them over. Optical pyrometer measurements made by Davis and Cox on the surface of the lava river indicated temperatures ranging from 850° to 980° C. About 2:00 P.M. the volume and velocity of the main flow commenced to increase. This surge reached its maximum about 2:30, after which the volume again decreased. Wentworth estimated the volume of actively moving lava in the flow during the surge to be five to ten times as great as that before and after the surge. Similar surges were observed in both channels of the flow at intervals of 65 to 85 minutes during the rest of the afternoon and night. Davis estimated the speed of flow in the main rivers to range from 5 to 20 miles an hour, and angular measurements by Wentworth and Cox during a surge at 11:25 P.M. demonstrated speeds of 7.8 to 8 miles an hour. The front of each surge advanced down the lava river channel, as an aa front 10 to 25 feet high, with loud clinking and crunching sounds. During the larger surges new lava spread from the river over much of the surface of the flow and, directly preceding and during some of the surges, there appeared to be a definite, though small, heating up and inflation of the stationary aa fields at the edge of the flow.

During the afternoon of June 4 the Ohia Lodge flow was watched by Arnold Mason of the U. S. Geological Survey. Conditions remained much as on the preceding day. Several surges of lava were observed, the last three at approximately 5:30, 6:00, and 6:30 P.M. When Finch and Cox arrived at 6:30 P.M. they found that at the road level the flow had been considerably widened by a new tongue which had come down parallel to the older one on its northern side, destroying Ohia Lodge. A sluggish lava river in the new tongue was feeding a slow-moving aa front just below the road. The entire flow at road level was about a quarter of a mile wide. Another tongue still farther north was advancing slowly through the forest about half a mile above the road. Its presence was revealed by occasional glimpses of glowing lava and by a bright glow from burning vegetation.

Davis returned to the Ohia Lodge flow above the road about noon on June 5. The width of the flow had increased to approximately 1,500 feet, and the active channels were entirely in the northern part of the flow. The lava was moving much more slowly than on the two preceding days, and the surges were smaller and of shorter duration. The maximum speeds in the lava rivers were estimated at 4 to 5 miles an hour. The new tongue north of the main flow was still advancing. Cox and Macdonald returned to the flow at 2:00 P.M. and went out onto the flow about 250 feet. The southern edge of the flow was still hot, but essentially motionless. The northern edge, beyond the river, was moving slowly. The flow as a whole had increased in thickness to an average of 20 to 25 feet. On the flat near the coast the flow had spread about 750 feet farther south than on June 3. The coastline had been transformed from a shallow embayment to a slight promontory.

Late in the evening of June 2, or early on June 3, another flow (flow 6, Fig. 1) started from the vent area at 8,300 feet altitude and moved southward down the mountain slope toward the main buildings of the Kahuku Ranch. This has been named the Kahuku flow. The upper portion of the flow was narrow, from 0.1 to 0.15 mile wide. On June 3 the flow was very active, with a narrow bright red lava river in the middle of a dark streak of aa. On June 4 the flow was still very active but was spreading out to form a front nearly half a mile broad at about 7,200 feet altitude, 3½ miles from its source. The lava river was reported to be on the order of 100 feet wide. On June 5 Don Campbell, from aerial observations, reported that the Kahuku flow was still advancing but appeared to have slowed. On the morning of June 6, James Beatty reported that the front had reached an altitude of about 6,500 feet. Movement continued through June 6 and the early hours of June 7, bringing the lower end of the flow to approximately 6,300 feet altitude, 5.8 miles from its source. On the afternoon of June 7 the lower portion of the flow appeared dead, but there was still some movement in the flow near the vents. By the morning of June 8 the flow was completely dead.

Frank Hjort and Ross Bender reached the vent area

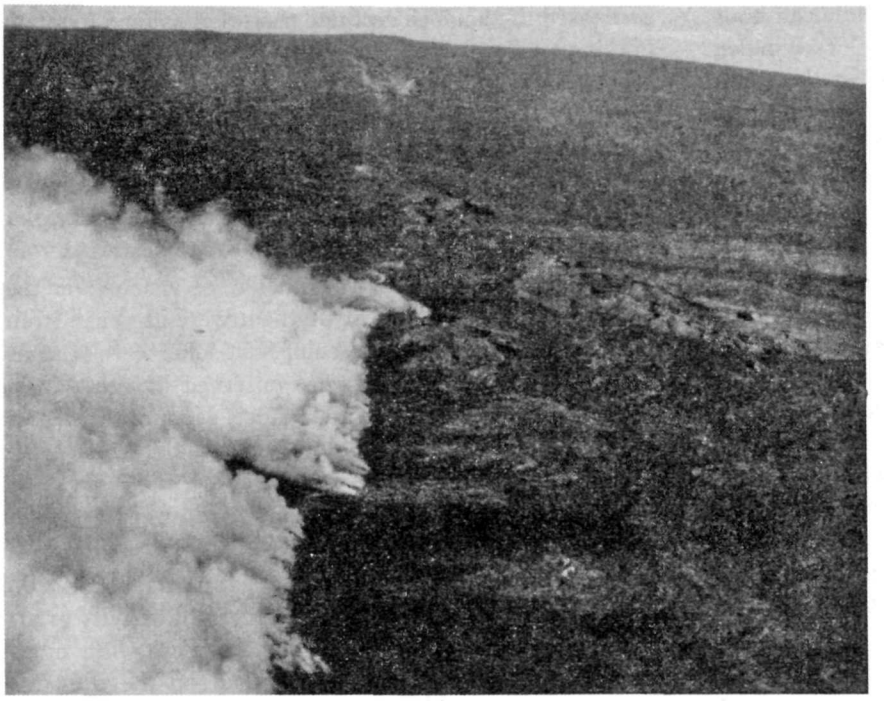

PLATE 5. Heavy fume clouds rising from the rift between 9,000 and 10,000 feet altitude, June 9, 1950. The heads of the Punaluu and Hookena flows are visible in the middle distance, and behind them fainter fume rises in the vicinity of Sulphur Cone. PHOTO BY WERNER STOY, CAMERA HAWAII.

on the afternoon of June 3 and camped at 8,700 feet altitude near the upper end of the lower line of vents. The fissure near 10,000 feet altitude was fountaining sporadically, but most of the activity was concentrated along the lower fissures below 8,900 feet altitude. From 4:30 to 8:00 P.M. activity on the lower fissures was continuous but varied rhythmically in intensity and character. Approximately once an hour an upsurge of activity commenced near the upper end of the fissure and migrated down along the fissure. Each revival of activity commenced at a large spatter cone at about 8,800 feet altitude with a loud roaring noise much like the exhaust from a steam boiler. This rush of gas was followed by a spray of lava droplets and red-hot cinder. The roaring release of gas migrated downhill along the rift, at some places giving rise to noises like thunder or heavy artillery. As the gas release ceased, the fountain activity and amount of lava liberation increased progressively along the rift until it was essentially continuous along the 2 miles of fissure which was in view. The fountains were lower than earlier in the eruption, playing to heights of about 50 feet. This activity gradually abated, and there was a lull of 20 minutes to a half-hour duration before the violent gas release started again at the upper end of the fissure and the cycle was repeated.

Most of the liberated lava was pouring westward toward Kona and feeding the Ohia Lodge flow. A front of hot lava 0.7 mile long had accumulated on the east side of the rift and was spilling southeastward to feed the Kahuku flow. At the head of the Kahuku flow the lava plunged over the steep slope of a buried cinder cone making a spectacular double cascade some 500 feet long and 200 feet wide. The rate of flow in the cascade was probably of the order of 35 miles an hour. Near the base of the cascade the highly fluid lava struck a bump on the channel floor, and the liquid was directed upward and outward into the air. At first view, from a distance, it appeared to Bender to be a fountain in the river, but on closer inspection its true nature was obvious.

A party composed of Geological Survey and National Park personnel reached the vent area on the afternoon of June 6. The cascade at the head of the Kahuku flow was still active, but the speed of flow had greatly decreased, not exceeding 10 miles an hour on the steepest slope. Fluctuations in the volume of flowing lava were obvious and occurred at approximately half-hour intervals. During the night of June 6 the lava fountains along the rift were low and sporadic. Increases in activity continued to occur about every half hour and progressed downslope along the rift. Only once was the increase in lava output preceded by a loud blowing noise and shower of incandescent cinder from the large spatter cone at 8,800 feet altitude.

On the morning of June 7 activity along the rift was still weak. Above 8,600 feet altitude the vents were fuming strongly, but no lava was being poured out. Below that altitude fountaining continued, but none of the fountains was more than 25 feet high, and most were only a few feet.

About 3:00 P.M. Davis, Cox, and Macdonald crossed the still hot pond of shelly pahoehoe which had fed the Kahuku flow and approached within 15 feet of the lava river. At 8,440 feet altitude two branches of the river plunged over a 25-foot cascade and joined at its foot.

Most of the river was moving only 3 or 4 miles an hour and was largely crusted over with a skin of wrinkled and ropy pahoehoe. In the cascade, however, the speed of flow was estimated at 30 miles an hour, and the crust was broken up to reveal the incandescent liquid beneath. Measurements with an optical pyrometer on the hot lava in the cascade yielded temperatures from 1030° to 1040° C.

Below the cascade the lava river flowed directly along the eruptive fissure, burying several lava fountains which occasionally shot through the river. Near the foot of the cascade there was a dome-shaped fountain which averaged about 10 feet across at its base and 5 feet high. This fountain resembled the dome of water which forms over the mouth of some artesian wells. Its bright orange hemisphere looked like half an orange set on the lava river. Just downstream from the dome fountain the rush of the liquid lava leaving the cascade gave rise to a hydraulic jump, with a standing wave 4 to 8 feet high.

About 500 feet down the rift from the cascade a small lava fountain was shooting 10 to 25 feet high. It was not a continuous jet, but consisted of repeated spurts of lava which separated in the air into large blobs. This fountain was typical of many which could be seen on down the rift. At the base of the fountain lava was flowing out pulsatingly, the pulses coming every 1 to 2 seconds, giving rise to a heaving motion much like that commonly observed in a pot of boiling thick porridge. A small lava shield was building up around the vent, but most of the lava was flowing down the slope of the shield to join the main river. The latter closely paralleled the erupting fissure for about a quarter of a mile then joined a large stream of lava flowing toward Kona.

Fluctuations in the amount of lava output came at roughly half-hour intervals. Following surges, the level of the lava in the river dropped, exposing along the banks rows of hot flexible lava stalactites which swayed back and forth in the blasts of gas or as their ends touched the flowing liquid much like willow roots along a creek. Many of them eventually were broken off, probably as they became more brittle with cooling, and floated away in the stream.

About 4:30 P.M. on June 7 there commenced a revival of activity along the entire rift. By 7:00 P.M. sporadic lava fountaining could be seen at a distance along the fissure near 10,000 feet altitude, and a little red lava could be seen moving in the head of the Hookena-Magoon Ranch flow. Along the fissure below 8,900 feet altitude the amount of fountaining and lava outpouring had increased. The surges in the lava river grew in size until, during peaks, the river channel was filled to the brim and locally overflowed sending tongues of pahoehoe rolling toward the observers. The height of the standing wave of the hydraulic jump below the cascade increased to about 12 feet and that of the dome fountain to about 8 feet. The temperature of the lava appeared to increase with the activity, and at 7:20 P.M. pyrometer measurements on both the cascade and the dome fountain gave temperatures of 1070° C. Some of the lava spilled eastward and formed a stream across the lower end of the former lava pond to the head of the Kahuku flow. Most of it, however, continued to westward.

As darkness came, many flames were visible over the vents along the rift. Most of them were at vents from which lava was no longer issuing, but some were at spattering vents. No flames were observed at vents from which lava was flowing in abundance. Most of the flames were greenish-yellow, but some were pale greenish-blue. The average length of the flames above the mouths of the conelets was about 5 feet, but some were as much as 20 feet long.

The revival of activity continued until about 2:00 A.M. on June 8. After that the strength of activity gradually decreased. At 6:00 A.M. the rift was still moderately active, but much less so than on the previous evening. A roaring gas vent was heard occasionally at about 8,400 feet altitude. The cascade at the head of the Kahuku flow was no longer active, and crossings of the flow itself at two places revealed it to be completely dead.

G. D. Robinson and B. J. Loucks reached the Ohia Lodge flow on the afternoon of June 6 and spent most of the night observing it in the area between the highway and the sea. About half a mile below the highway the channel divided into two branches, the southernmost of which was the more active. A short distance farther downslope the southerly channel again divided, so that there were three channels. Surges in activity were observed at approximately half-hour intervals. During lulls in the activity the lava movement was largely restricted to the central channel, but during the larger surges all three channels became very active. Will-o-the-wisps were again observed over the flow. On June 7 the Ohia Lodge flow was still very active, the principal movement at the highway being in a lava river which was flowing in a channel about 15 feet deep near the northern edge of the flow. William Stearns reported that a new spur on the southern side of the flow, about 5 or 6 miles long, was advancing slowly.

On June 8 a small overflow occurred on the southern side of the Ohia Lodge flow about a quarter of a mile above the highway. The tongue advanced only a few hundred yards before rejoining the main flow. On June 9 the flow appeared to have become distinctly more sluggish. The flow was again visited on June 10 by Robinson and Wentworth, in company with H. R. Joesting and J. H. Swartz of the Geological Survey and Juliette Wentworth. Conditions were much the same as they

had been when last seen by Robinson on the morning of June 8. However, in the interim, lava had been newly added, by repeated overflows of the channel, to the surface of much of the flow in the vicinity of the road. Several surges of activity were observed during the evening, the intervals between surges ranging from 13 to 45 minutes. Pyrometer measurements by Robinson on large glowing blocks in the river and on the surface of the river itself yielded temperatures ranging from 840° to 940° C. Cherry-red lava exposed in a cave in the older stationary aa margin of the flow gave a temperature of 675° C.

On June 11 Macdonald and D. H. Hubbard examined the flow where it entered the sea. No movement could be detected in the major part of the flow on the coastal flat, and the volume of steam being formed at the ocean was small. Lava was still pouring over the escarpment a quarter of a mile inland, but it was rather dull red in color and appeared much more viscous than during earlier observations. The speed of the lava on the steep cascade was only about half a mile an hour. Two strong surges of lava at the cascade were observed, one at 2:30 and the other at 4:30 P.M. At the foot of the cascade the lava turned southward and spread out to form a big aa flow which was advancing seaward along the southern edge of the older flow at a rate of approximately 1,000 feet an hour. The front of this flow was the largest the writers have observed in Hawaii. It was about 1,000 feet wide, at least 50 feet high, and very active. One after another, blocks up to 10 feet in diameter became detached from the front of the flow and rolled to the base. The blocks were accompanied and followed by trains of finer incandescent debris, and patches of incandescent lava were revealed as the blocks broke away from the front. Clouds of pale brown dust arose from the pulverization of the fragments rolling down the flow front. A hundred yards from the active front the radiant heat was so great that the observers' faces were scorched, and cameras became so hot they were difficult to hold.

At 3:00 to 4:00 A.M. on the morning of June 12 there was widespread overflowing of the channel of the Ohia Lodge flow at the level of the highway. Later in the morning and during the afternoon the glow in the flow was dull and lava movement was small. Shortly after 9:00 P.M. a bright glow was seen inland from the road, and by 10:15 a new surge of lava was producing flooding on the northern side of the flow. This appears to have been the last big surge. Movement in the flow at the highway stopped on June 13, although on June 14 cowboys of the C. Q. Yee Hop Ranch reported lava still moving in the flow 6 miles above the highway. At about noon on June 15 the pilot of a Navy plane reported lava bubbling from the lower 200 yards of the source fissure and fume being liberated along about 3 miles of fissure. From that time on, glow at the source area was observed nearly every night until June 22. On the afternoon of June 22, John Peoples of the U. S. Coast Guard flew over the source area and reported hot bubbling lava and a large amount of fume along the rift.

The last well-authenticated observation of glow at the source was by Finch, at 1:00 A.M. on June 23, and the eruption is believed to have come to an end on that date. Aerial observations on later days revealed much fume along the fissures but no signs of moving lava. Fume liberation continued abundant through the remainder of June.

A further discussion of special features of the eruption will appear in the next VOLCANO LETTER.

HAWAIIAN VOLCANO OBSERVATORY REPORT FOR APRIL–JUNE, 1950

VOLCANOLOGY

April

The northward tilt that started early in March continued through April. The northward tilt of 3.2 seconds of arc in April, when coupled with the 6 seconds in the same direction in March, indicates a distinct pressure increase under Kilauea Volcano.

Seasonal westward tilt ceased on March 14 and an eastward tilt set in to continue until the last of April. If an eastward tilt indicates a pressure increase under Mauna Loa then there has been a simultaneous increase of pressure under Kilauea and Mauna Loa.

Of the 77 earthquakes recorded during April, 61 were recorded at Kilauea and 56 on the Mauna Loa seismograph. The Kilauea total is larger than usual and points to uneasiness at Kilauea. However, the foci of most of the shakes were shallow and many were under the northern end of the caldera. The shallowness and location of foci far from the volcanic axis at Halemaumau appear to decrease their significance as an indication of impending activity.

Some of the cracks in the vicinity of the Halemaumau rim opened slightly. A more-or-less expected accompaniment of the continued pressure build-up was the spreading of some of the cracks on the caldera floor that are connected with the rift system of Kilauea.

May

The monthly total of earthquakes for May was 102. During the first half of the month more of the earthquakes originated under Kilauea than Mauna Loa, but during the latter half Mauna Loa quakes predominated. As far as earthquakes were concerned it appeared as though uneasiness had shifted from Kilauea to Mauna Loa. Many of the shakes originated under the upper end of the southwest rift of Mauna Loa.

During the first 2 weeks of May there was a slight east-southeast tilt. Then a distinct north-northeast tilt set in to continue until May 29. Following the strong earthquakes of May 29 there was a tilt of 2.4 seconds of arc to the southwest, or opposite the usual direction for the latter part of May.

June

A total of 279 earthquakes was recorded on the Kilauea seismograph during June. Owing to the frequent dismantling of the Mauna Loa seismograph during the progress of the flank eruption the total for that instrument is unknown but probably about the same as for Kilauea. Most of the earthquakes originated along the southwest rift of Mauna Loa.

There was an accumulation of 6.4 seconds of arc tilt to the northeast during the first 14 days of June, then a slight northwest tilt for the rest of the month. It is interesting to note that a marked decrease in the rate of output of lava from the southwest rift of Mauna Loa coincided roughly with the cessation of rapid northeast tilt.

SEISMOLOGY

Earthquake Data, April–June, 1950

(Based on Bosch-Omori seismograph on rim of Kilauea caldera)

Week Beginning	Minutes of Tremor	Very Feeble	Feeble	Slight	Moderate	Strong	Local Seismicity*	Teleseisms
April 2	10	0	2	0	0	0	4.50	0
9	7	0	0	0	0	0	1.75	0
16	12	0	0	0	0	0	3.00	1
23	17	4	1	0	0	0	7.25	0
30	20	8	1	1	0	0	10.00	1
May 7	16	5	1	0	0	0	7.50	0
14	13	4	1	0	0	0	6.25	0
21	7	2	0	0	0	0	2.75	1
28	29	17	2	2	0	1	25.75	0
June 4	86	44	12	8	8	0	95.50	0
11	34	15	4	2	3	1	37.00	0
18	7	3	0	0	1	0	7.25	1
25	5	1	1	0	0	0	2.75	0

* For definition of local seismicity, see Volcano Letter 371.

The data for the following local disturbances were determined from seismograph stations operated on the island of Hawaii by the Hawaiian Volcano Observatory of the U. S. Geological Survey. Time is Hawaiian Standard, 10 hours slower than Greenwich. The number preceding each earthquake is the serial number for the current year.

20. April 5, 04:50, feeble. Felt locally. Kilauea quake.
21. April 8, 00:35, feeble. Mauna Loa shake.
22. April 23, 01:15, very feeble. Kilauea.
23. April 25, 10:09, very feeble. Mauna Loa.
24. April 27, 23:53, very feeble. Kilauea.
25. April 28, 02:26, feeble. Kilauea.
26. April 29, 21:11, very feeble. Mauna Loa.
27. May 3, 03:48, very feeble.
28. May 3, 12:08, very feeble. Mauna Loa.
29. May 3, 22:19, very feeble. Kilauea.
30. May 4, 01:01, very feeble.
31. May 4, 04:35, feeble.
32. May 4, 05:51, slight. Felt at Kapapala.
33. May 4, 05:54, very feeble. Felt at Kapapala.
34. May 4, 06:02, very feeble. Felt at Kapapala.
35. May 4, 07:31, very feeble.
36. May 6, 03:47, very feeble.
37. May 7, 03:10, very feeble. Mauna Loa.
38. May 8, 12:01, very feeble.
39. May 8, 12:41, very feeble. Mauna Loa.
40. May 11, 13:06, very feeble.
41. May 11, 19:38, feeble. Mauna Loa.
42. May 13, 09:27, very feeble. Mauna Loa.
43. May 14, 18:39, feeble. Mauna Loa.
44. May 18, 10:47, very feeble. Mauna Loa.
45. May 18, 14:44, very feeble. Mauna Loa.
46. May 19, 00:02, very feeble. Mauna Loa.
47. May 20, 01:57, very feeble. Mauna Loa.
48. May 26, 01:45, very feeble. Mauna Loa.
49. May 27, 11:33, very feeble. Kilauea.
50. May 28, 08:27, very feeble. Mauna Loa.
51. May 29, 15:17, strong. Upper southwest rift of Mauna Loa. Widely felt. All instruments dismantled. Damage to water tanks, stone walls, etc., in Kona.
52. May 30, 14:37, very feeble. Mauna Loa.
53. May 30, 17:28, slight. Mauna Loa.
54. June 1, 13:59, very feeble. Mauna Loa.
June 1, 21:04, harmonic tremor of Mauna Loa eruption starts. Recorded continuously through June 3, then with lesser amplitude and intermittently until afternoon June 13.

Earthquakes accompanying the first 13 days of the Mauna Loa eruption.

Most of the quakes originated on the southwest rift of Mauna Loa.

Serial Numbers	Date	Number of Shakes
55– 58, inclusive	June 2	4
59– 73, inclusive	3	39
74– 91, inclusive	4	39
92–107, inclusive	5	28
108–115, inclusive	6	23
116–126, inclusive	7	15
127–133, inclusive	8	7
134–143, inclusive	9	10
144–146, inclusive	10	3
147–158, inclusive	11	23
159	12	6
160–164, inclusive	13	7
165–168, inclusive	14	13

169. June 15, 10:14, slight.
170. June 16, 16:03, very feeble.
171. June 16, 23:13, very feeble.
172. June 17, 06:31, very feeble.
173. June 19, 09:22, very feeble. Felt locally. 7 miles deep, east slope of Mauna Loa near Ohaikea.
174. June 21, 07:06, moderate. Felt locally. Kilauea.
175. June 21, 08:03, very feeble.
176. June 21, 08:29, very feeble.
177. June 26, 19:56, feeble. Felt at Naalehu.

TELESEISMS

April 18, 05:00, slight. Southwest of Galapagos.
April 30, 01:00, slight. North of Easter Island.
May 25, 15:27, slight. New Hebrides.
June 24, 12:34, slight. New Hebrides.

MICROSEISMS

Microseisms were moderate on April 4–5, 29–30, and May 10–11. They were present though slight on other days throughout the quarter.

CRACK MEASUREMENTS

Accompanying the rapid northward tilt during March, April, and May there was a distinct opening of some of the cracks on the caldera floor that are roughly aligned with the southwest rift of Kilauea. At one station there was an opening of 4 millimeters and at another the opening amounted to 9 millimeters. Such an opening is an expected accompaniment of the doming indicated by tilt. A portion of the crack at the tourist station on the east rim of Halemaumau opened 8 millimeters between March 31 and June 30.

TILTING OF THE GROUND

The strong northward tilt which started in March continued until May 29 and amounted to 11.4 seconds of arc. A distinct southerly tilt followed the large earthquake of May 29. Northward tilt was resumed on June 5. Between June 5 and June 17 there was a rapid northward tilt amounting to 3.8 seconds. From June 17 to the end of the month, northward tilt was about normal for this season of the year.

The lack of normal westerly tilt that was noted in March continued until April 10 when a positive eastward tilt commenced that continued until June 14 except for some rapid fluctuations from May 29 until June 8. There was an unusually rapid eastward tilt of 5.9 seconds between June 7 and June 14. From June 14 to June 30 there was a slight westward tilt, which is opposite to the normal direction for this season of the year.

Table of Tilt at Seismograph Vault on Northeast Rim of Kilauea Caldera

Week Beginning	Amount	Direction
April 2	0.2″	N 45° E
9	0.3″	N 45° E
16	1.0″	N
23	1.4″	N 60° E
30	1.8″	N 16° E
May 7	0.5″	W
14	1.2″	N 37° E
21	1.0″	N 7° E
28	1.7″	S 40° W
June 4	3.5″	N 70° E
11	3.0″	N 51° E
18	0.3″	N 27° E
25	0.1″	E

TEMPERATURE MEASUREMENTS

The temperature of the steam well at the Sulfur Bank was constant at 204° F. in April, May, and June.

MAGNETIC OBSERVATIONS

Routine magnetometer measurements were continued at intervals of approximately 1 month. H. R. Joesting and J. H. Swartz of the Geological Survey's Geophysics Branch spent a week at the Observatory during the eruption of Mauna Loa in June, making additional measurements and calibrating instruments.

Until May 9 most of the stations on the line along the Mauna Loa truck trail showed a decrease in vertical magnetic intensity with respect to the base station near the rim of Kilauea caldera at Uwekahuna. The next measurements, on June 9 and 12, showed a marked increase in the strength of attraction at most of the stations. Several of the stations showed a very rapid rise between June 9 and 12. It is possible that the beginning of this rise may have coincided roughly with the beginning of the Mauna Loa eruption.

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THE JUNE 1950 ERUPTION OF MAUNA LOA

By GORDON A. MACDONALD and R. H. FINCH

Part II

SPECIAL FEATURES

LAVA FLOWS

The lava of the 1950 eruption of Mauna Loa ranges from basalt to olivine basalt. The first lava erupted along the upper part of the rift contains very few olivine phenocrysts, and no dunite inclusions were observed. In contrast, the lavas erupted later from the portion of the rift below 11,000 feet altitude contain many phenocrysts of olivine up to about 5 millimeters long. Angular inclusions of dunite, up to about 3 centimeters across, are fairly common in the lavas from the lower vents. It appears probable that the marked difference in abundance of olivine phenocrysts in the early and late lavas is the result of sinking of olivine crystals in the magma column before the eruption. The first lavas liberated at the upper vents were derived from the upper part of the magma column, which had been impoverished in olivine. Later the lava was derived from a lower level in the magma column, in which the abundance of olivine phenocrysts had been increased by sinking of crystals from higher levels. A similar, but even more marked, difference has been found between the early and later lavas of the 1840 eruption of Kilauea (Macdonald, 1944).

Figure 1 is a map showing the distribution of the lava flows. All of the flows except the upper flow (no. 2) and the Kahuku flow (no. 7) have been plotted from vertical air photos taken at the request of the Volcano Observatory by Richard O. Mahan for the R. M. Towill engineering firm in Honolulu.

The accompanying table shows the approximate area and volume above sea level of each of the major lava flows of the 1950 eruption and the estimated average thickness of each flow. The areas were scaled from the map of the flows. The average thickness of several separate segments of each flow was estimated from ground observations at several points along the flows and from the appearance in the aerial photographs, then the average thickness of the whole flow was calculated from these values. The volumes were calculated by using the scaled areas and the estimates for average thickness of successive portions of the flows. It is believed that any error in thickness and volume is on the conservative side. The total area of the flows above sea level is 35.6 square miles, and the volume is on the order of 514 million cubic yards. It is estimated that more than 100 million cubic yards of lava flowed out under the ocean and is now lost to view. The total volume of lava erupted, therefore, was very probably more than 600 million cubic yards, or somewhat more than the estimated volume (600 million cubic yards) of the largest previous historic eruption, the 1859 lava flow of Mauna Loa (Stearns and Macdonald, 1946, p. 79). It is estimated that between one-half and two-thirds of the total volume of lava was poured out during the first 36 hours of the 1950 eruption.

AREA, THICKNESS, AND VOLUME OF 1950 LAVA FLOWS ABOVE SEA LEVEL

NAME OF FLOW	NUMBER ON MAP (FIG. 1)	AREA	AVERAGE THICKNESS	VOLUME
		Sq. miles	*Feet*	*Cu. yds.*
Upper rift . . .	1	3.74	4.5	17,000,000
Upper west flank	2	1.25	7.6	11,000,000
Hookena	3	6.73	8.3	59,000,000
Magoon Ranch	4	5.74	9.3	55,000,000
Punaluu	5	7.25	13.5	101,000,000
Ohia Lodge . .	6	8.47	27.6	241,000,000
Kahuku	7	1.44	12.0	18,000,000
Keokeo	8	1.00	12.0	12,000,000

TEMPERATURE MEASUREMENTS

Approximately 75 readings were made with an optical pyrometer during the eruption. Of these, about one-third were made during daylight hours and are of little value. Comparison of readings made during daylight with those made at night indicates that the extraneous illumination during daytime results in readings which are consistently too high. Most daylight readings appear to be between 50° and 100° C. higher than read-

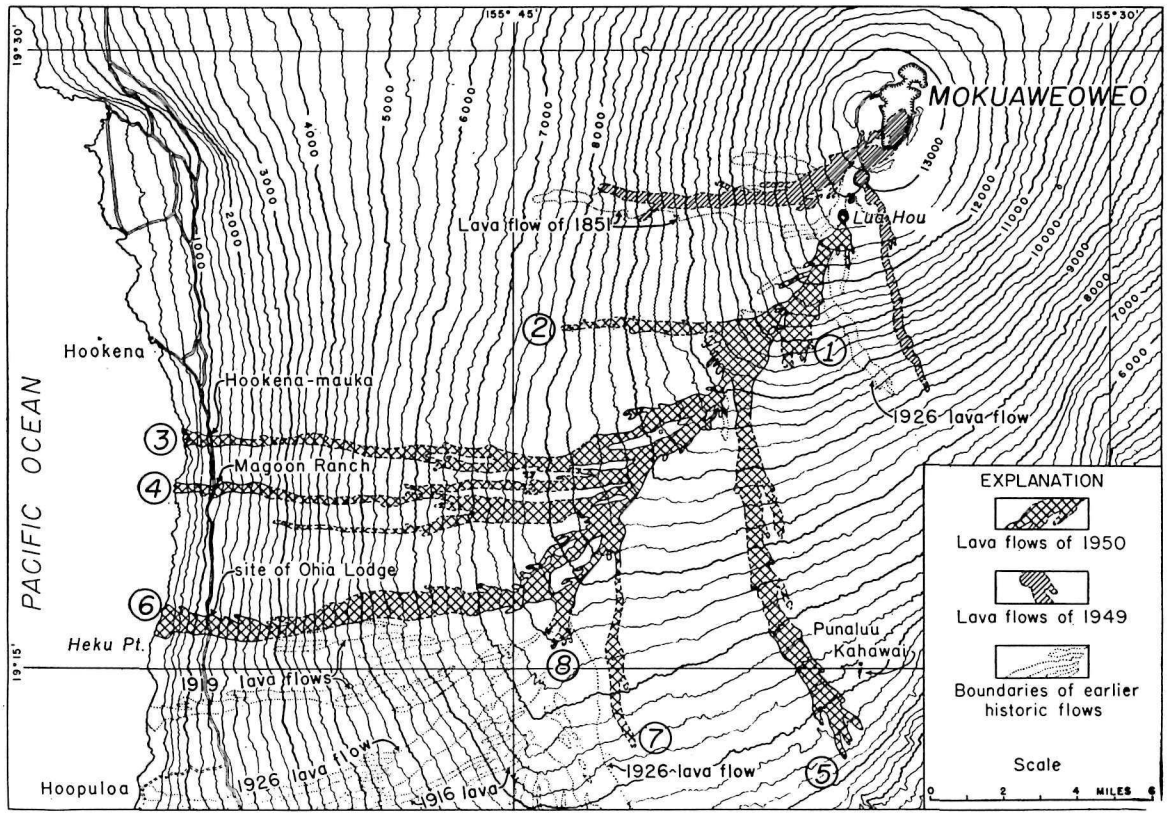

FIGURE 1. Map of a portion of the southwest rift of Mauna Loa showing the 1950 and some earlier historic lava flows.

ings on the same object at night. The values cannot, however, be successfully corrected, because the amount of extraneous light was variable and undetermined. Only the night readings have been used. The values obtained at night were quite consistent. Repeated readings on the same near-by object at intervals of a few seconds showed variations of only a few degrees. On the other hand, readings on the surface of the lava river showed a range of approximately 100°, owing at least in part to variations in the amount and thickness of crust on it.

Only a few of the pyrometer readings were made under close approximations to "black body" conditions. Therefore a small correction for the coefficient of light absorption of gray bodies should be applied. The amount of the correction has not been determined, but, for leucite basanite of Nyamuragira, Verhoogen (1948, p. 131) found it to be about 20° at 1,000° C. It is probable, therefore, that the observed temperatures given in the accompanying table should be increased by about 20°.

It is noteworthy that the temperatures of the dome fountain and of the river at the vents are of the same order of magnitude as those obtained by Verhoogen (1948, pp. 133–136) at Nyamuragira. In comparison, the temperature at the surface of the Kilauea lava lake in 1916 was about 1,000°, that at a depth of 1 meter was about 860°, and that at a depth of 13 meters was about 1,170°. The latter temperature was believed to be higher than that of the magma rising through the conduits (Jaggar, 1917). The high temperature of 1,100° measured in the throat of the inactive spatter cone on June 7, 1950, probably was partly the result of gas heating.

There probably was very little lowering of apparent temperature by crust on the very turbulent lava in the river at the vents, and the actual temperature of emission of the lava may be taken as close to 1,070°. On the other hand most of the readings on the lava river at the highway probably were to some degree affected by the presence of crust on the river. The actual internal temperature of the river at the highway was probably near the upper end of the range of observed temperatures—in the vicinity of 950°. Thus the lava of the Ohia Lodge flow cooled about 100° in traversing the 10 miles from the vents to the highway. At 950° it was still fluid and free-flowing. At 675° it had become immobile. The temperatures of 850° to 870° measured in cracks in the stagnant aa on June 2 may have been appreciably higher than the internal temperatures because of surficial heating by burning gases. During the 1949 eruption of Mauna Loa, lava with a temperature of about 760° was found to be still capable of a little movement (Macdonald and Finch, 1949, p. 5).

TEMPERATURE MEASUREMENTS

OBJECT MEASURED	NUMBER OF READINGS	TEMPERATURE °C. RANGE	TEMPERATURE °C. AVERAGE	DATE
Cascade in lava river at vents . . .	5	1030–1070	1050	June 7
Dome fountain in river at vents . .	3	1060–1080	1070	June 7
Lava river of Ohia Lodge flow near highway	16	850–980	916	June 2–4
Lava river of Ohia Lodge flow about ½ mi. from ocean	3	910–930	920	June 3
Lava river of Ohia Lodge flow near highway	15	840–940	898	June 10
Glowing lava in flaming crack in aa at nearly motionless edge of flow at highway (flow had crossed highway about 6 hours earlier) .	3	850–870	860	June 2
Glowing lava in crack in aa at stationary margin of flow at highway (flame absent) .	Several	.....	675	June 10
Glowing throat of spatter cone at vents (not active when readings were taken, but active a few hours earlier, and still emitting gas) . .	3	1090–1110	1100	June 7

RADIATION STUDIES

Two series of counts with a Geiger-Muller counter were made on June 2 and 5 at 11 stations along the highway at and near the Ohia Lodge flow. The number of clicks per minute varied considerably, but the averages close to the flow and on the flow are a little less than those at a distance from the flow. The averages are as follows:

500 to 1,000 feet from flow . . . . . 21 clicks per minute
10 to 300 feet from flow . . . . . 20 clicks per minute
On flow 75 to 250 feet from edge . 17 clicks per minute

It is possible that the higher temperature on and near the flow affected the sensitivity of the instrument, reducing the count. However, at no time was the temperature of the wand holding the tube high enough to be unbearable, or even particularly uncomfortable, to the unprotected hand of the operator. The evidence appears to indicate that there was no marked increase in radiation as the flow was approached, and, therefore, that the lava was not appreciably radioactive at the level of the highway. No counter readings were made at the vents.

Samples of lava collected where the flow crossed the road showed no radioactivity when tested by Dr. Harvey E. White of the University of California.

TILTING OF THE GROUND

Indications of a pressure build-up under both Kilauea and Mauna Loa volcanoes in February, March, April, and May were given by the tilt curves obtained at the Whitney Laboratory of Seismology on the northeast rim of Kilauea Caldera. Normally there is a seasonal southwest tilt during the first 5 months of the year (Powers, 1947, p. 2). In 1950, however, seasonal tilt was exceeded by oppositely directed volcanic tilt so that south tilt ceased on February 9 and west tilt on March 19.

A rapid northward tilt started on March 6 and continued until the end of June, except for a southward tilt of 2.2 seconds of arc from May 29 to June 5. Over half of this southward tilt, or 1.2 seconds, accompanied a strong earthquake on May 29. The northward tilt from March 6 until May 29 amounted to 11.5 seconds of arc. The 77 earthquakes recorded in April, a majority of which originated at Kilauea, together with the strong north tilt, indicated a distinct uneasiness of Kilauea Volcano.

A positive easterly tilt which followed the cessation of seasonal west tilt on March 19 continued through May 28. The 102 earthquakes recorded during May, a majority of which originated under Mauna Loa, together with the easterly tilt, indicated that Mauna Loa had become more uneasy than Kilauea. There was a sharp westerly tilt on May 29 and 30 following the strong quake on May 29. Despite some fluctuations there was an accumulation of 6.0 seconds of arc of east tilt from May 31 to June 14. It is interesting to note that strong east tilt accompanied the outbreak of Mauna Loa and continued until there was a noticeable decrease in lava output. Evidence is accumulating that there is a correlation between east tilt and Mauna Loa eruptions. In 1950 east tilt set in 2 months and 12 days prior to the outbreak of Mauna Loa. Distinct east tilt preceded the 1949 eruption by 2 months and 8 days.

HARMONIC TREMOR

Very conspicuous harmonic tremor (Finch, 1944) was recorded on the seismographs at Kilauea, on the east slope of Mauna Loa, and at Kealakekua in Kona for over an hour after the eruption began. In the following discussion the records from the Kilauea seismograph on the northeast rim of Kilauea Caldera only are used. During the summit eruptions in 1940 and 1949 the Kilauea instrument, 22 miles from the site of the eruption, recorded harmonic tremor for 5 and 12 hours, respectively. The tremor was recorded for a similar number of hours during earlier eruptions. Though the upper eruption source of the 1950 outbreak was at a distance of 24 miles, or a little greater than in 1940 and 1949, the maximum double amplitude recorded in 1950—5 millimeters—was several times that of earlier years. The period of this large-amplitude early tremor was 0.5 seconds.

Instead of the tremor slowly dying out after a few hours, as it usually does, in 1950 it continued to be recorded intermittently until June 13, although about 4 hours after the initial outbreak at 12,600 to 11,250 feet altitude most of the lava was issuing from vents between 10,500 and 8,000 feet, about 30 miles from the Kilauea seismograph.

After the first few hours the amplitude of the tremor decreased greatly, but the double amplitude still ranged

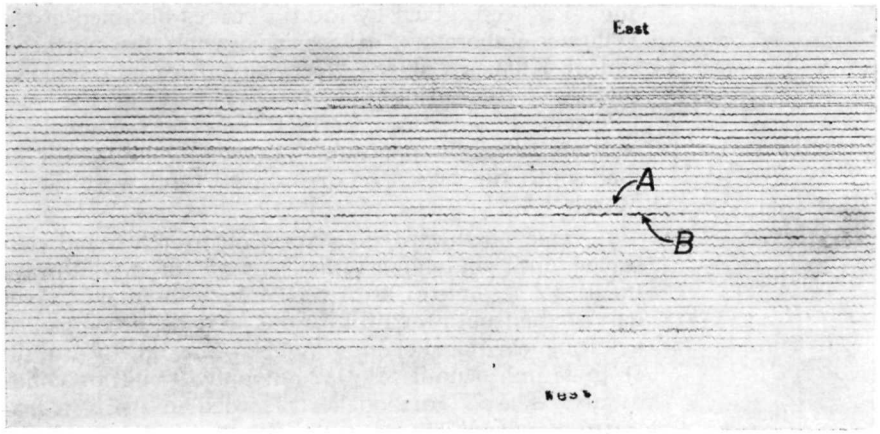

FIGURE 2. Harmonic tremor as recorded 30 miles from eruption source on June 2, 1950. A is the record of an earthquake, and B is due to an artificial disturbance.

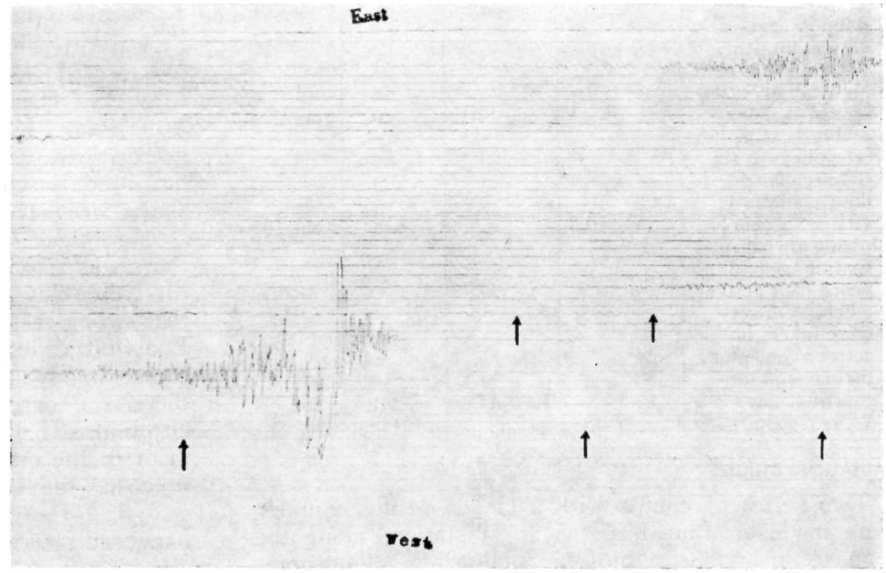

FIGURE 3. From the record of June 3, showing five spells of unusual harmonic tremor with a period of about 2 seconds. Arrows point to the beginning of each spell.

up to 0.7 millimeter (Fig. 2), which is equal to or larger than recordings in 1940 and 1949. The period of the tremor ranged up to 1.5 seconds.

The large amplitudes of the harmonic tremor at the onset of the eruption, and the fact that tremors continued after the distance to the source increased from 24 to 30 miles, indicated that the rate of output of lava was greater than usual.

On June 3 it was noticed that the harmonic tremor was not continuous, indicating fluctuations in the volume of lava being emitted. Direct observations both at the source and where the lava crossed the road showed fluctuations in volume.

Whether the harmonic tremor is produced by movements of lava in the primary conduits under Mokuaweoweo, the summit crater of Mauna Loa, or in the eruption fissures is not known, though evidence favors the latter. As noted above, in most eruptions harmonic tremor is recorded for a few hours only. In the 1942 flank eruption, harmonic tremor was recorded for a few hours during the preliminary activity at the summit (distance 22 miles) and then for 7 days after the lava broke out along the northeast rift at a distance of only 14 miles from the recording instrument. The facts that the tremor ceased being recorded a little before activity at the summit stopped and resumed, to continue for 7 days, after the lava broke out at a distance of 14 miles, indicate that the tremor originates in the eruption fissures.

On June 2 another type of harmonic tremor, apparently not previously recorded at the Hawaiian Volcano Observatory, was noticed (Fig. 3). The most frequent period of this type of tremor is roughly 2 seconds. Fourteen spells of this type of tremor were recorded on June 3, and 13 on June 4. Smaller numbers were recorded on other days, with the last on June 12.

EARTHQUAKES

Earthquakes and tilting of the ground surface during March and April caused speculation as to the possibility of an eruption at Kilauea. In May, however, quakes of Kilauea origin became less numerous and the number with Mauna Loa origin predominated. Many of the Mauna Loa quakes originated under the upper end of the southwest rift.

The following table shows the number of earthquakes per week recorded at the northeastern rim of Kilauea Caldera during May and June:

Week Beginning	No. of Quakes
April 30	30
May 7	21
14	18
21	9
28	58
June 4	158
11	60
18	11
25	7

A larger number of earthquakes during the early part of a flank eruption than during a summit eruption is to be expected because of the greater length of fissuring. In 1950 there was a progressive fissuring of the southwest rift for a distance of 13 miles. Normally, when both Mauna Loa and Kilauea are quiet, only five or six earthquakes per week are recorded.

LACK OF LITTORAL EXPLOSION

The absence of large littoral explosions or the formation of much ash where the lava entered the ocean was a striking feature of the 1950 eruption. Many aa flows entering the sea cause violent steam explosions which throw into the air large amounts of ash and which build littoral cones of ash and cinder (Macdonald, 1944). This happened in 1840, 1868, 1919, and 1926 (Jaggar, 1919, 1926). Many pahoehoe flows enter the water quietly, with only moderate evolution of steam, because the quickly formed pahoehoe skin provides an insulation which separates the very hot lava inside from the water. Aa flows, on the other hand, typically have a much broken and discontinuous surficial layer which permits the water easy access to the hot interior, with resultant strong explosions. A minor amount of such activity apparently did occur during the 1950 eruption. On June 3, D. C. Cox, going down the southern edge of the Ohia Lodge flow with D. A. Davis and C. K. Wentworth, noticed an increase in the amount of falling ash as they approached the coast and came under the steam cloud. Also, some of the moving pictures taken from the sea show small puffs of dark cloud, almost certainly ash, mixed with the white steam. However, littoral explosion and ash-making were very minor, certainly not nearly comparable with those in 1919 and 1926. Probably this was because the main lava rivers entering the sea were hotter and had a more unbroken surface than those of the 1919 and 1926 flows, thus preventing such rapid and easy entrance of the water to the hot interior. Once the flow into the ocean was well established a continuous crust may have formed over the lava river, acting as an insulator in

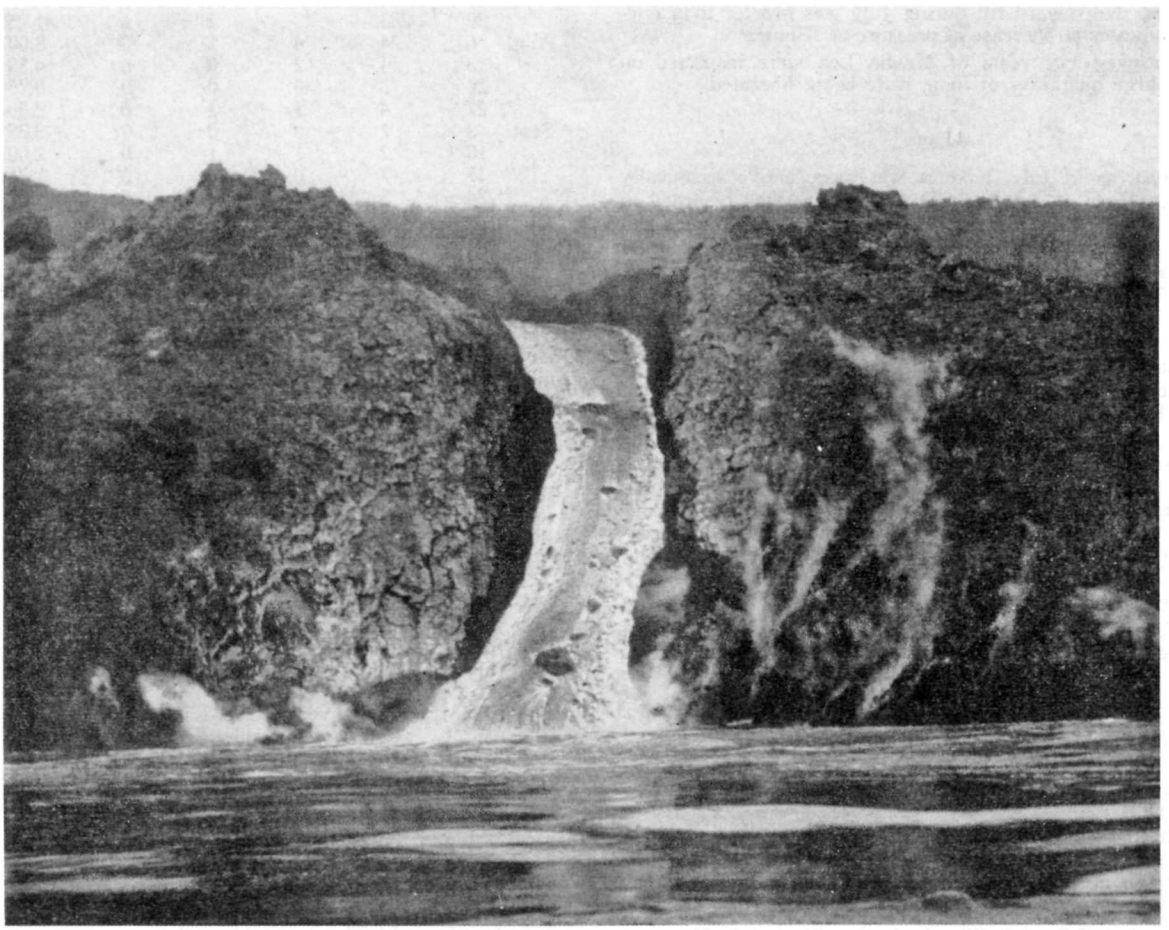

Figure 4. A lava river of the Ohia Lodge flow entering the sea. When such a river with practically unbroken surface entered the ocean, it produced but little steam. Bursts of steam were produced whenever blocks projecting above the surface of the river struck the water.—Photo by T. Matsumoto: courtesy Trans-Pacific Airlines.

much the same way as does the pahoehoe skin. Figure 4 shows such a lava river entering the sea and producing but very little steam. Whenever a block of appreciable size (some appear as dark objects in Figure 4) that was carried along by the lava river entered the water, it did produce a large burst of steam.

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HAWAIIAN VOLCANO OBSERVATORY REPORT FOR JULY–SEPTEMBER, 1950

VOLCANOLOGY

July

The southwest rift vents of Mauna Loa emitted conspicuous amounts of fume during July.

A total of 69 earthquakes was recorded in July. Of these 59 were recorded at Kilauea and 25 at Mauna Loa. A majority of the earthquakes were of Kilauea origin, and they originated at shallow depths near the northern edge of Kilauea Caldera.

A slight westward tilting, or opposite in direction normal for this season of the year, indicates a pressure decrease under Mauna Loa. Northward tilt during July was greater than normal and indicates an increase of pressure at Kilauea.

The southwest rift vents of Mauna Loa were inspected on July 11. Large quantities of fume were being liberated.

August

In August, as in July, Kilauea was more active seismically than Mauna Loa. A total of 320 earthquakes was recorded in August. Of these, 312 were on the seismograph at Kilauea and 30 on the seismograph on the east slope of Mauna Loa. Most of the quakes originated at shallow foci under the northern end of Kilauea Caldera. Shaking was nearly continuous on August 2, when 241 quakes were recorded. Only three of these 241 quakes were felt. An earthquake accompanied by a roar was felt at Naalehu at 10:58 A.M., August 11. Another perceptible quake with epicenter low down under the northeast slope of Mauna Loa was felt in Hilo and at Kilauea at 12:18 P.M., August 27.

Tilt in the east–west direction during August was of the usual seasonal value. Rapid north tilt which started on July 15 continued until August 16. From August 17 to the end of the month there was a slight accumulation of south tilt. The accumulation of northward tilting since the first of the year, 9 seconds of arc, indicates a pressure increase preceding, during, and after the June eruption of Mauna Loa.

Fume was observed over the southwest rift of Mauna Loa on several days during the month.

Landslides from the Halemaumau rim were observed on August 29.

September

A total of 25 earthquakes was recorded in September. Of this number, 21 were recorded at Kilauea and 13 on the Mauna Loa seismograph.

East tilt was less than usual for September and may be taken as an indication of a slight pressure decrease under Mauna Loa. North tilt was normal for this season of the year.

Fume was observed over the southwest rift of Mauna Loa several times during the month. Following heavy rains on Mauna Loa on September 29 and 30 large fume clouds developed over the June, 1950, eruption source. The mixed steam and fume clouds started reports that Mauna Loa was erupting.

SEISMOLOGY

Earthquake Data, July–September, 1950

(Based on Bosch-Omori seismograph on rim of Kilauea Caldera)

Week Beginning		Minutes of Tremor	Very Feeble	Feeble	Slight	Local Seismicity*	Teleseisms
July	2	5	0	0	0	1.25	1
	9	2	2	0	0	1.50	1
	16	6	3	0	0	3.00	0
	23	23	3	2	0	7.25	2
	30	223	43	2	1	81.25	0
Aug.	6	24	4	1	0	8.00	1
	13	14	2	0	0	4.50	1
	20	3	0	0	0	0.75	0
	27	4	1	1	0	2.50	0
Sept.	3	7	0	0	0	3.25	0
	10	2	1	1	0	2.00	1
	17	7	0	0	0	1.75	0
	24	3	1	0	0	1.25	1

* For definition of local seismicity, see Volcano Letter 371.

The data for the following local disturbances were determined from seismograph stations operated on the island of Hawaii by the Hawaiian Volcano Observatory of the U. S. Geological Survey. Time is Hawaiian Standard, 10 hours slower than Greenwich. The number preceding each earthquake is the serial number for the current year.

178. July 1, 12:55, very feeble. Mauna Loa.
179. July 12, 03:12, very feeble. Kilauea.
180. July 12, 20:46, very feeble. East slope Mauna Loa.
181. July 19, 20:48, very feeble. Southwest slope Mauna Loa.
182. July 20, 03:45, very feeble. West slope Mauna Loa.
183. July 21, 15:29, very feeble. Kilauea.
184. July 23, 13:11, very feeble. Kilauea.
185. July 24, 15:42, feeble. Felt locally. North end Kilauea Caldera.
186. July 25, 19:30, very feeble. Kilauea.
187. July 26, 12:14, feeble. Mauna Loa.
188. July 29, 18:56, very feeble. Kilauea.
189. July 31, 04:29, slight. Felt locally. North end Kilauea Caldera.
190. July 31, 15:18, very feeble. Kilauea.
191. Aug. 1, 02:57, very feeble. Kilauea.
192. Aug. 1, 20:43, very feeble. Kilauea.
193–231 inclusive, Aug. 2, 39 quakes originating under north end of Kilauea Caldera.
232. Aug. 3, 02:15, very feeble.
233. Aug. 3, 04:43, very feeble.
234. Aug. 8, 06:04, very feeble. Kilauea.
235. Aug. 8, 10:21, very feeble. Kilauea.
236. Aug. 9, 14:27, very feeble. Kilauea.
237. Aug. 10, 07:35, very feeble.
238. Aug. 11, 10:58, feeble. Felt at Naalehu.
239. Aug. 13, 05:15, very feeble. Kilauea.

240. Aug. 19, 05:12, very feeble. Felt locally. Kilauea.
241. Aug. 27, 12:18, feeble. Felt locally and at Hilo. North slope Mauna Loa.
242. Aug. 28, 10:25, very feeble. Upper northeast rift Mauna Loa.
243. Sept. 15, 07:42, very feeble. Kilauea.
244. Sept. 16, 21:51, feeble. Felt locally and at Hilo. Northeast rift Mauna Loa.
245. Sept. 30, 17:06, very feeble. Mauna Loa.

TELESEISMS

July 8, 16:09, slight. Near Easter Island.
July 12, 01:27, slight. Aleutians.
July 29, 06:58, slight. Molucca Passage.
July 29, 13:58, slight. Solomon Islands.
Aug. 6, 16:57, slight. Mindanao, P. I.
Aug. 15, 04:24, strong. Burma border.
Sept. 10, 05:25, slight. New Hebrides.
Sept. 28, 20:36, moderate.

MICROSEISMS

Microseisms were strong on August 13, 14, and 15, and moderate on August 16 and from September 11 to 19. On other days they were slight.

CRACK MEASUREMENTS

One end of the crack near the tourist station on the east rim of Halemaumau opened 1 centimeter from June 30 to September 30. At a greater distance from the end of the crack the opening was 2 millimeters. Other cracks measured showed but very little movement.

TILTING OF THE GROUND

A slight westerly tilt in July may be taken as an indication of a pressure decrease under Mauna Loa. Normally there is an east tilt in July. During August and September usual seasonal tilt obtained.

Except for a south tilt August 17 to 21, north tilt was continuous and in a little greater amount than normal for this season of the year.

Table of Tilt at Seismograph Vault on Northeast Rim of Kilauea Caldera

Week Beginning		Amount	Direction
July	2	0.9″	N 15° W
	9	0.5″	S 64° W
	16	1.0″	N 6° E
	23	1.0″	N 20° W
	30	2.4″	N 17° E
August	6	1.4″	N
	13	2.6″	S 82° E
	20	0.8″	W
	27	0.5″	N 14° E
September	3	0.8″	N 18° W
	10	0.9″	N 57° E
	17	0.5″	N 45° E
	24	0.6″	S 53° W

TEMPERATURE MEASUREMENTS

The temperature of the steam well at the Sulfur Bank was constant at 204° F. in July, August, and September.

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THE VOLCANO LETTER

No. 510 **U. S. Geological Survey** **October–December, 1950**

PUBLISHED BY THE UNIVERSITY OF HAWAII

THE DECEMBER 1950 SUBSIDENCE AT KILAUEA

By R. H. FINCH

At noon on December 8, 1950, after several weeks of generally normal seismic conditions, the frequency of occurrence of earthquakes recorded by the seismographs suddenly increased. Simultaneously a rapid southwesterly tilt started at the Whitney Station on the northeast rim of Kilauea.

The origins of the early earthquakes were in the vicinity of Kokoolau Crater (Fig. 1), 4 miles from the Whitney Station, under the upper end of the system of fissures between the east and southwest rifts of Kilauea. During the night of December 8–9, earthquakes continued to originate in the region of the early shakes; others showed greater distances as though there was a progressive cracking to the southwest. By early morning on December 9 many of the quakes were being plainly felt at Kapapala (Fig. 1). The indicated origin of some of the stronger shakes on this date was a little to the east of Kamakaia Hills. The strongest quake of the series occurred at 21:25, December 10, with an indicated origin also a little to the east of Kamakaia Hills, and was generally felt over the eastern half of Hawaii.

The epicenters of the quakes were distributed over a linear extent of 15 miles, from the Chain of Craters Road to the upper end of the 1823 lava flow. The indicated depth of focus of many of the earthquakes was 4–5 miles.

The total number of earthquakes recorded during the period of rapid subsidence, December 8–14, was at least 656. The maximum number of quakes in any one day was more than 200 on December 10. For several hours each day on December 8, 9, and 10 quaking was so nearly continuance that it was impossible to separate the records of numerous small quakes. The following table shows the number of earthquakes by day:

DATE	NUMBER OF QUAKES
Dec. 8	133+
9	149+
10	200+
11	112
12	33
13	17
14	12

On December 11 a small crack trending NNE–SSW with a few millimeters downthrow on the Kilauea Caldera side was noted on the road near Kokoolau Crater. Two small cracks trending NE–SW were later observed about 2 miles to the southwest of Kokoolau Crater.

The fact that the earthquakes accompanied a rapid subsidence of the entire top of Kilauea was shown by tilt records. A seasonal northeasterly tilt usually continues until the latter part of December, when a seasonal change to the southwest usually occurs. A rapid southwesterly tilt at the Whitney Station started on December 8 and continued for 4 days with a cumulative total of 14.5 seconds of arc. During the same 4 days the cumulative total at the Uwekahuna Station (Fig. 1) was 22.1 seconds of arc to the east-southeast. In both cases tilting was much more rapid than normal seasonal tilting. These values place the maximum subsidence a little to the northeast of Halemaumau, about the same position as that of the maximum subsidence of 1920–24 determined by Wilson[1] on the basis of leveling. Calculations indicate that the maximum subsidence in 1950 was in excess of 1 foot. Figure 2 shows the tilt curves obtained at the Whitney Station. The

[1] WILSON, R. M. GROUND SURFACE MOVEMENTS AT KILAUEA VOLCANO HAWAII. Hawaii Univ. Res. Pub. No. 10. 1935.

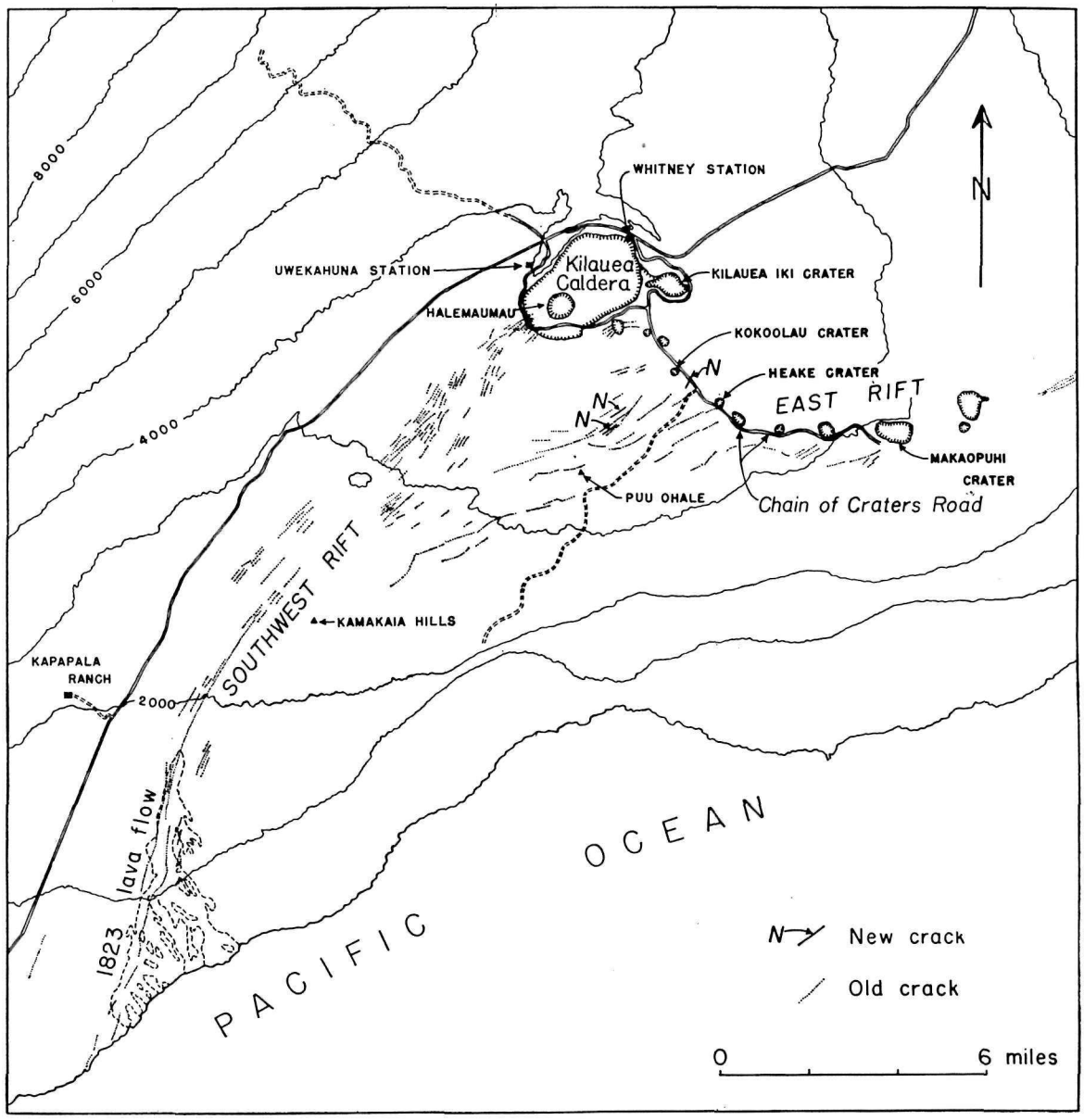

FIGURE 1. Map of Kilauea Caldera and vicinity. The 656 earthquakes recorded during the December, 1950, subsidence originated along the rift zone extending from Kokoolau Crater to beyond the Kamakaia Hills. New cracks were observed at places marked N.

sinking implied by the 14.5 seconds of arc south–southwest tilt is less than the implied tumescence during the 5 months from March to July, 1950, when there was a tilt of 21 seconds to the north–northeast.

Tilting, earthquakes, and cracks at the surface indicate that a considerable area, probably several miles in diameter around Kilauea Caldera, subsided. The location of the earthquakes and the new cracks indicate that a triangular block bounded by the east and southwest rifts and a line from Kokoolau Crater to the upper end of the 1823 lava flow underwent a greater movement than adjacent areas.

Several short spells of harmonic tremor recorded on December 10 and 11 indicate that there was some movement of magma at a depth of 4 or more miles (the depth of focus of many of the earthquakes). Tilt records indicate that pressure continued to build up under Kilauea for nearly 2 months after Mauna Loa ceased to erupt in June, 1950. Whether the rapid pressure decrease in December was accompanied by a retreat of the lava into the depths or by a more or less horizontal drainage into the southwest rift or elsewhere is not known. The writer favors the possibility of retreat of the lava column to depth.

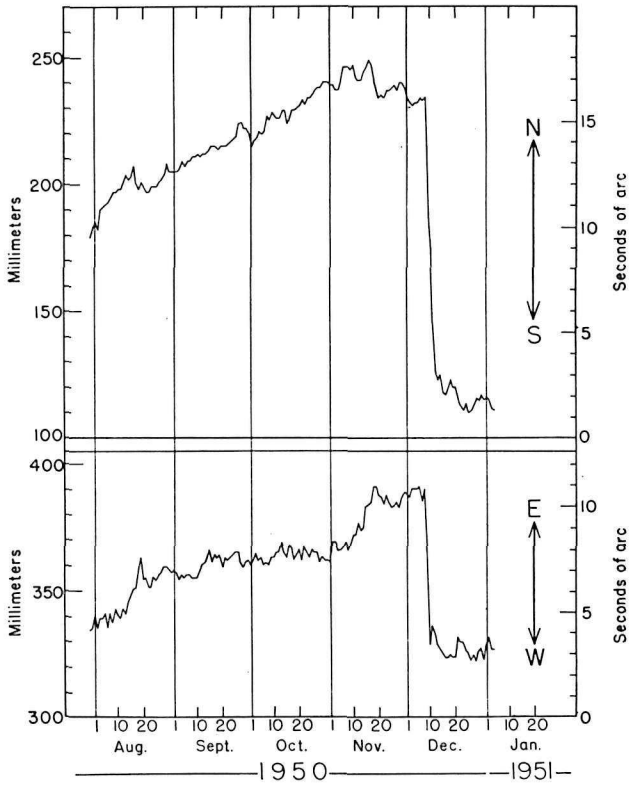

FIGURE 2. Graph of ground tilting at the Whitney Laboratory of Seismology at the northeast rim of Kilauea Caldera from August to December, 1950, showing the rapid south and west tilt on December 8 to 12. The resultant tilt for these 4 days was 14.5 seconds of arc to the south–southwest. Tilting at normal rates preceded and followed the rapid tilting.

HAWAIIAN VOLCANO OBSERVATORY REPORT FOR OCTOBER–DECEMBER, 1950

VOLCANOLOGY

October

Only 25 earthquakes were recorded in October. Of these, 24 were recorded at Kilauea and 19 on the Mauna Loa seismograph. A slight earthquake that was felt all over the island of Hawaii on October 11 originated at a depth of about 25 miles under the east slope of Mauna Loa.

Northward tilting of the ground was about normal for this season of the year and eastward tilting was less than usual.

The vents of the 1950 lava flows on the southwest rift of Mauna Loa continue to liberate fume. The fume was especially conspicuous on October 19.

November

Both Mauna Loa and Kilauea continued quiet during November. Kilauea has had no surface manifestation of activity in more than 16 years. There have been two spells of subterranean activity during these 16 years with sufficient magnitude to be easily detected by seismographs and tiltmeters. One was in November–December, 1944, and the other in April, 1950.

Forty earthquakes were recorded in November. Of these, 38 were recorded at Kilauea and 20 on the Mauna Loa instrument. Many of the quakes originated at shallow depths under the northern end of Kilauea Caldera. A continuous tremor was recorded on all seismographs on the island from 13:17 to 13:37 on November 17.

Northeastward tilting of the ground was about normal until November 16. Following heavy rains on November 15, 16, and 17 there was a slight southwest tilt. For the month as a whole there was a slight eastward tilt.

Landslides from the Halemaumau rim were common in November. The heavy rains of November 15, 16, and 17 produced conspicuous steam clouds in Halemaumau.

A conspicuous cloud was observed over the 1950 flow vents from Mauna Loa on November 15.

December

The total number of earthquakes recorded in December was 701. Of this total, 656 were recorded during 7 days—December 8–14. Owing to the frequent dismantling of the Mauna Loa seismograph no total can be given for that station.

A total of 1,702 earthquakes was recorded during 1950.

The rapid subsidence of Kilauea that began on December 8 may be taken as an indication of a sinking of the lava column under Kilauea. There had been a definite increase of magmatic pressure under Kilauea for 2½ months prior to the outbreak of Mauna Loa on June 1. The pressure build-up, as indicated by north tilt, continued definitely until the middle of August and probably until November 19. The rapid subsidence began, then, about 3 weeks after the cessation of the pressure build-up.

Tilting of the ground was slight in December except for the 14.5 seconds of arc south–southwest tilt accompanying the December 8–14 subsidence.

Conspicuous clouds were observed over the southwest rift of Mauna Loa on December 12 and less conspicuous ones on several other days.

Several landslides from the Halemaumau rim were observed.

During strong winds on December 26 most of the Kau Desert was obscured by dust clouds.

SEISMOLOGY

Earthquake Data, October–December, 1950

(Based on Bosch-Omori seismograph on rim of Kilauea Caldera)

Week Beginning	Minutes of Tremor	Very Feeble	Feeble	Slight	Moderate	Strong	Local Seismicity*	Teleseisms
Oct. 1	6	0	0	0	0	0	1.50	2
8	6	2	0	1	0	0	4.50	0
15	5	0	0	0	0	0	1.25	1
22	3	0	0	0	0	0	0.75	1
29	4	3	0	0	0	0	2.50	1
Nov. 5	9	1	0	0	0	0	2.75	3
12	8	1	0	0	0	0	2.50	0
19	7	1	0	0	0	0	2.25	0
26	3	4	0	0	0	0	2.75	1
Dec. 3	220	46	7	13	3	0	120.00	2
10	250	62	39	24	6	1	202.50	1
17	11	3	2	1	0	0	8.25	0
24	6	1	0	0	1	0	5.00	0

* For definition of local seismicity, see Volcano Letter 371.

The data for the following local disturbances were determined from seismograph stations operated on the island of Hawaii by the Hawaiian Volcano Observatory of the U. S. Geological Survey. Time is Hawaiian Standard, 10 hours slower than Greenwich. The number preceding each earthquake is the serial number for the current year.

246. Oct. 8, 05:49, very feeble.
247. Oct. 11, 20:06, slight. Felt over most of Hawaii. 20–25 miles deep under east slope of Mauna Loa.
248. Oct. 12, 07:33, very feeble.
249. Oct. 31, 02:53, very feeble.
250. Nov. 1, 15:28, very feeble. Kilauea.
251. Nov. 4, 03:02, very feeble. Kilauea.
252. Nov. 11, 23:34, very feeble. Kilauea.
253. Nov. 13, 18:22, very feeble. Kilauea.
254. Nov. 19, 23:23, very feeble. Kilauea.
255. Nov. 26, 19:53, very feeble. West slope, Mauna Loa.
256. Nov. 30, 14:18, very feeble. Mauna Loa.
257. Dec. 1, 01:37, very feeble. Kilauea.
258. Dec. 2, 20:54, very feeble. Southwest slope, Mauna Loa.
259. Dec. 7, 00:27, very feeble.
260. Dec. 7, 05:40, very feeble. Southwest slope, Mauna Loa.

Earthquakes accompanying the subsidence at Kilauea. Moderate or stronger quakes only are listed separately.

SERIAL NUMBER	DATE
261–278	Dec. 8
279–327	Dec. 9
328–398	Dec. 10
399–430	Dec. 11
431–437	Dec. 12
438–442	Dec. 13
443–447	Dec. 14

290. Dec. 9, 05:43, moderate. Widely felt. East of Mauna Iki. 4–5 miles deep.
323. Dec. 9, 20:45, widely felt. Instruments dismantled. Near Kamakaia Hills.
325. Dec. 10, 05:57, moderate. 4–5 miles deep, near Kamakaia Hills.
326. Dec. 10, 08:23, moderate. Below Kamakaia Hills.
369. Dec. 10, 17:29, moderate. Kamakaia Hills.
370. Dec. 10, 17:57, moderate. Near Puu Ohale.
379. Dec. 10, 21:25, strong. Widely felt. Instruments dismantled. Kamakaia Hills.
421. Dec. 11, 12:53, moderate. 4–5 miles deep below upper end 1823 lava flow.
431. Dec. 12, 06:28, moderate. Depth shallower than preceding quakes.
448. Dec. 15, 02:13, very feeble. Kilauea.
449. Dec. 16, 07:17, feeble.
450. Dec. 18, 05:54, very feeble. Felt plainly at Naalehu. Above South Point.
451. Dec. 20, 23:19, feeble.
452. Dec. 21, 20:00, very feeble.
453. Dec. 21, 21:17, feeble.
454. Dec. 22, 03:07, slight. Felt locally. Mauna Loa.
455. Dec. 22, 04:07, very feeble. Kilauea.
456. Dec. 26, 02:55, moderate. 8 miles deep south of Kilauea Iki. Widely felt.
457. Dec. 27, 18:58, very feeble.

TELESEISMS

Oct. 5, 06:21, moderate. Costa Rica.
Oct. 7, 17:34, slight. Moluccas.
Oct. 21, 00:04, slight. West coast of Mexico.
Oct. 23, 06:24, slight. Guatemala.
Nov. 2, 05:40, moderate. Felt at Darwin, Australia.
Nov. 7, 16:28, moderate. Solomon Islands.
Nov. 9, 16:36, very slight.
Nov. 11, 00:04, very slight.
Dec. 2, 10:01, moderate. New Hebrides.
Dec. 4, 06:38, slight. New Britain.
Dec. 9, 12:26, slight.
Dec. 13, 16:00, slight.
Dec. 14, 04:40, very slight.

MICROSEISMS

Microseisms were strong on November 3, December 2–13, and December 26–31. They were of slight or moderate amplitude on other days.

CRACK MEASUREMENTS

A majority of the cracks that were measured around the rim of Halemaumau showed distinct openings. Quite likely some of the openings were due to earthquakes. Cracks on the crater floor that are more or less aligned with the southwest rift closed slightly during the sinking spell of December 8–14. During this same spell some of the old cracks by Kokoolau Crater, near where new cracks appeared at the surface, showed distinct openings.

TILTING OF THE GROUND

Seasonal northeast tilt continued until November 17 when a southwest tilt set in. This change in direction came about 1 month earlier than usual and was probably due to unusually heavy rains on November 15, 16, and 17. Seasonal southwest tilt continued through the end of the year, except for the rapid southwest tilt December 8–12.

Table of Tilt at Seismograph Vault on Northeast Rim of Kilauea Caldera.

Week Beginning	Amount Seconds	Direction
October 1	1.21	N 5° E
8	0.54	N 63° E
15	0.60	N 36° W
22	0.86	N 8° W
29	0.60	N 79° E
November 5	0.95	N 50° E
12	2.28	E
19	1.02	S 70° W
26	0.86	S 34° E
December 3	6.24	S 37° W
10	9.48	S 25° W
17	1.02	S 45° E
24	0.76	N 18° W

TEMPERATURE MEASUREMENTS

The temperature of the steam well at the Sulfur Bank varied from 204° to 204.5° F.

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