PREFACE

The Volcano Letter was an informal publication issued at irregular intervals by the Hawaiian Volcano Observatory (HVO) during the years 1925 to 1955. Individual issues contain information on volcanic activity, volcano research, and volcano monitoring in Hawaii. Information on volcanic activity at other locations is also occasionally included.

To increase accessibility of this resource, previously only available in print format, this compilation was scanned from the highest quality Volcano Letter originals in the HVO archives. Optical Character Recognition (OCR) was run on the entire file. In addition, the file size was reduced by making it compatible with only Adobe Reader v. 8 and later. The scanning was done by Jim Kauahikaua and the quality control and posting was done by Katie Mulliken, both current staff at the Hawaiian Volcano Observatory.

Originals of the first three Volcano Letters could not be found so copies plus the Title Page and Index for 1925 have been extracted from an excellent scan of Volcano Letters for 1925 to 1929 available in Books.Google.com

The Volcano Letter was published by HVO through multiple changes in administration, including the Hawaiian Volcano Research Association (1925-1932), the U.S. Geological Survey (1932-1935), the Department of the Interior (1935-1938), and the University of Hawaiʻi (1938-1955). Issues 1–262 were published weekly from January 1, 1925, to January 2, 1930, and consisted of a single page of text. Issues 263–384, also published weekly, from January 9, 1930–May 5, 1932, were generally longer—four-pages—and provided more detail on volcanic activity, including photographs, maps, and plots. Weekly issues 385–387, published May 12–26, 1932, were a single page of text due to budget reductions brought on by the Great Depression. Budget restrictions reduced the publishing frequency to monthly for issues 388–428, covering the period of June 1932 to October 1935; these issues were generally shorter, 1–2 pages, and sometimes featured figures. From November 1935 to July 1938, issues 429–461 remained monthly but increased in length (generally eight pages) and featured figures frequently. Issues 462–530, published over the period of August 1938–December 1955, varied in length from 2–15 pages, but were published quarterly, rather than monthly.

Six of the letters are misnumbered:
Jan. 21, 1926 number is 55 though it should 56
July 29, 1926 number is 82 though it should be 83
Feb. 16, 1928 number is 161 though it should be 164
May 31, 1928 number is 197 though it should be 179
Nov. 29, 1928 number is 204 though it should be 205

For background information on the Hawaiian Volcano Observatory: https://pubs.usgs.gov/gip/135/

The Volcano Letter publications are also available in print:

Fiske, R.S., Simkin, T., and Nielsen, E.A., eds.,1987, The Volcano Letter, No. 1-530. See https://www.si.edu/object/siris_sil_328087

April 2023

THE VOLCANO LETTER

No. 491 | Department of Interior | National Park Service | January-March 1946

PUBLISHED BY THE UNIVERSITY OF HAWAII

HAWAII NATIONAL PARK: Gunnar O. Fagerlund, Acting Superintendent; R. H. Finch, Volcanologist

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

320 James Campbell Building, Honolulu 48, T. H. Telephone 3834

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

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 Seis-micity*	Tele-seisms
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

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

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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

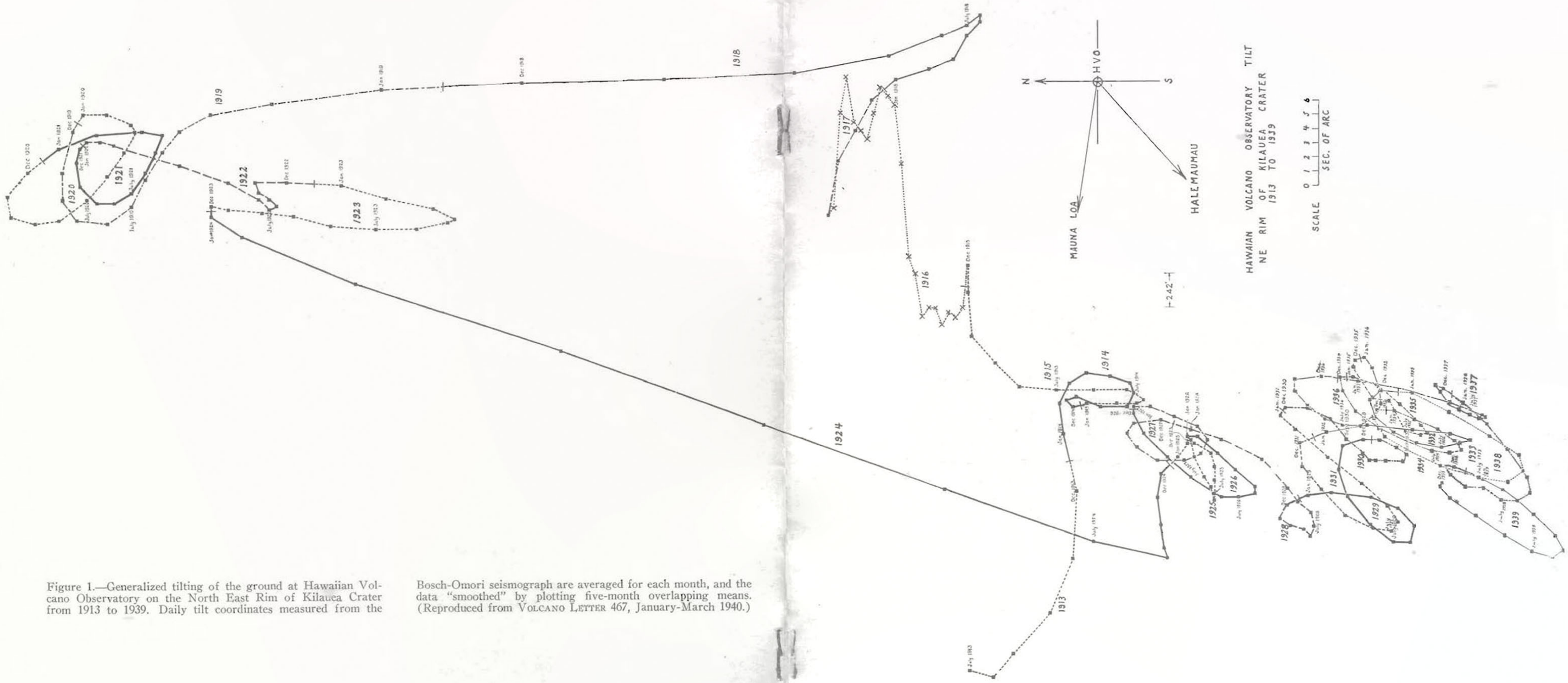


Figure 1.—Generalized tilting of the ground at Hawaiian Volcano Observatory on the North East Rim of Kilauea Crater from 1913 to 1939. Daily tilt coordinates measured from the Bosch-Omori seismograph are averaged for each month, and the data "smoothed" by plotting five-month overlapping means. (Reproduced from VOLCANO LETTER 467, January-March 1940.)

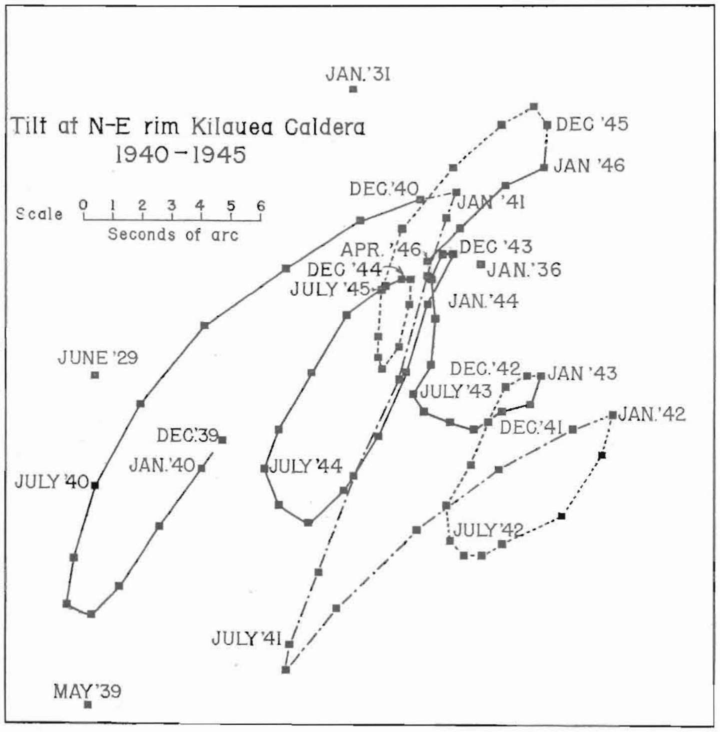
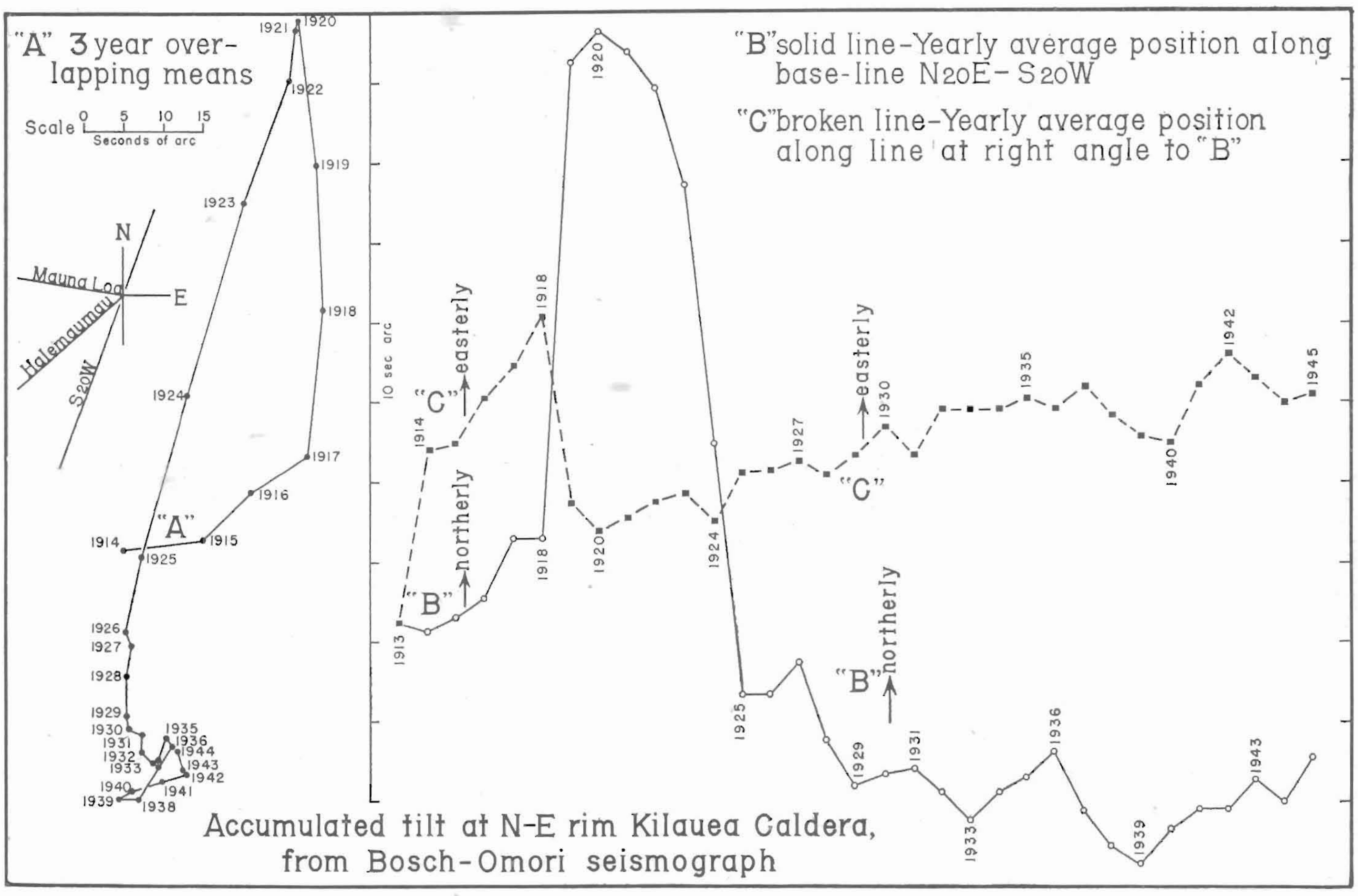


Figure 2.—A continuation of the curve of figure 1 covering the years 1940 to 1945 inclusive.

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 Seis-micity*	Tele-seisms
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

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

NE PLUS HAUSTAE AUT OBRUTAE URBES

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.

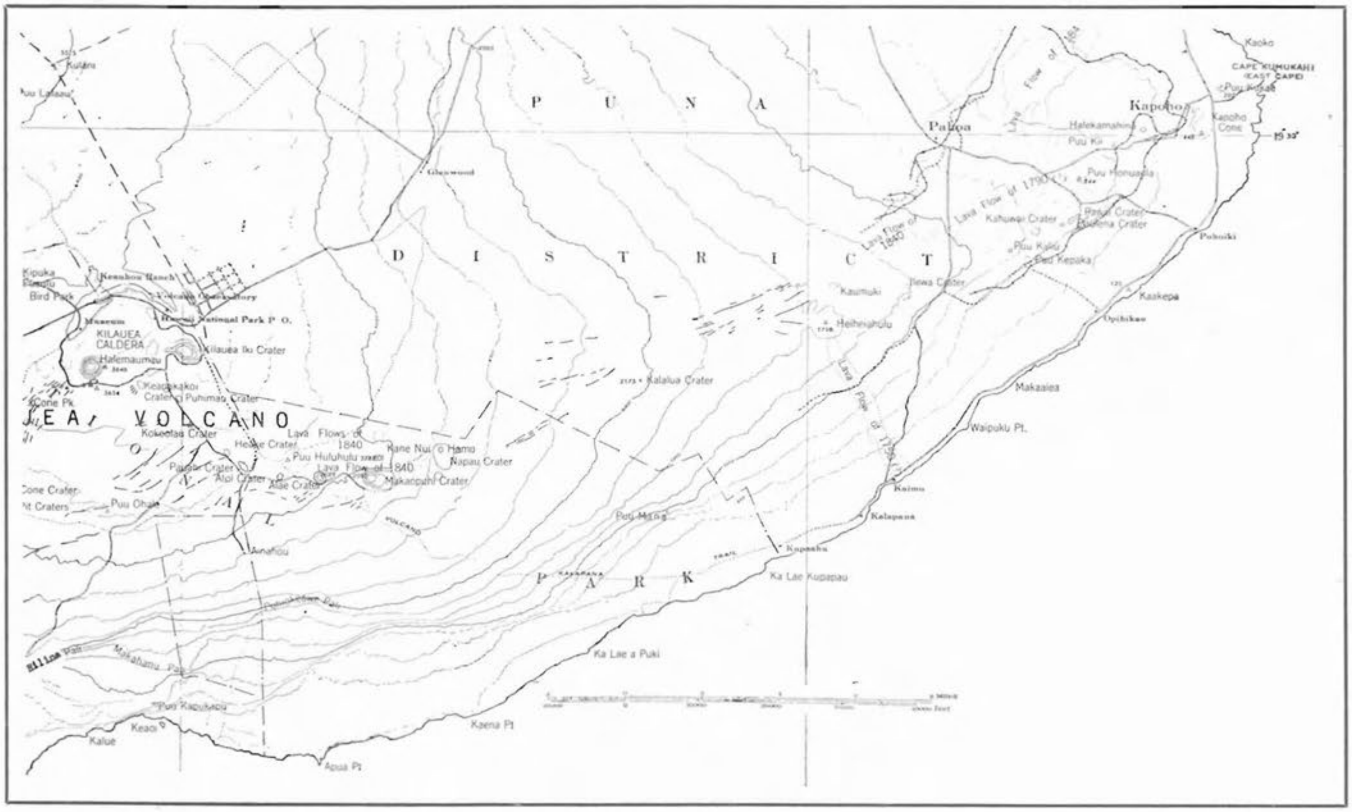

Figure 1.—Map showing the Puna rift of Kilauea and a portion of the southwest rift. Note the numerous intersections of the curved portion of the rift with NE–SW-trending fissures.

any true scarps, but the steep southeast slope indicates that the topography is still dominated by the effects of destructive forces.

Pit craters are formed by engulfment into rift tubes. Counting Keanakakoi and Lua Manu, both of which are within the general breakdown of Kilauea caldera, there are at least 18 pit craters on the Puna rift. None of the pit craters has been a source of real lava flows though lava has appeared in several of them one or more times after they were formed. Pauahi is really two pit craters of appreciable difference in age that happened to form close enough for the younger western one to break down the barrier that for a time separated it from the older eastern pit. Makaopuhi is a doublet. It is likely, though not definitely known, that its two parts formed at different ages. There are at least 14 of the pit craters in the upper portion of the Puna rift and 4 more in the vicinity of Puulena Crater, or 18 miles northeast of Napau Crater. Puulena is counted as two pits though the age difference between the two components is uncertain. Near Iilewa (Ilewa on the map) there is a distinct formation that may be a pit crater with one wall nearly buried. It was not counted to make the total of 18, however. In the southwest rift zone of Kilauea there are but two pit craters with depths of about 220 feet. The deepest one on the Puna rift is Makaopuhi with a depth of 950 feet.

The reason for the concentration of pit craters along the Puna rift is readily apparent. The upper grouping of the craters is due to the intersection of the Puna rift by a series of fissures trending NE–SW roughly parallel to the Hilina Pali breakdown series in their upper reaches and tending to an alignment with the southwest rift system in their lower. Any such intersection, even at a flat angle, would be a favorable location for the development of pit craters.

The four pit craters in the vicinity of Puulena are on the edge of the Puna rift. They are located on what appears to be a buried fault scarp of the Hilina Pali system. The slope of the country in the vicinity of these craters is 400 to 600 feet to the mile with some small ash-covered slopes that are much steeper. The ash appears to be of local origin though whether it buries Pahala ash is not certain. Large explosion blocks, definitely of local origin, are found in the vicinity of Puulena Crater.

It is conceivable that pit craters can develop at almost any place over a rift tube where appreciable stopping takes place. That they should be numerous in the upper portion of the Puna rift and non-existent or rare elsewhere, except for the four near Puulena, points to a systematic local control. A greater gas content of the lava and a resultant greater stopping near the source does not seem adequate to account for the grouping of the pit craters. The 18 pit craters are located at known or suspected places of intersection of the Puna rift by other faults.

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 Seis-micity*	Tele-seisms
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.

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.