Hawaiian Volcanoes During 1953

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HAWAIIAN VOLCANOES DURING 1953

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ABSTRACT

Hawaiian volcanoes remained dormant during 1953, although both Mauna Loa and Kilauea showed some indications of subsurface restlessness. Volcanic pressure appears to have remained high at Kilauea after the close of the 1952 eruption. There was more than normal seismic activity throughout the year. A swarm of small earthquakes originated in the Kilauea caldera region in mid-May, and during October a small swarm came from foci in the caldera region and along the southwest rift zone. In late November and early December more than 700 small quakes originated at shallow foci along the northeast rift zone of Mauna Loa.

Chemical analyses of the 1940, 1949, and 1950 lavas of Mauna Loa are presented, together with new analyses of a prehistoric flow of Mauna Loa and three historic lavas of Kilauea. Data on the abundance of trace elements in Hawaiian lavas also are given.

INTRODUCTION

This report continues the systematic account of conditions at Hawaiian volcanoes begun in earlier reports of this series (Finch and Macdonald, 1951, 1953; Macdonald and Wentworth, 1954; Macdonald, 1955).

The year 1953 opened with Hawaiian volcanoes quiet. The eruption of Kilauea that began on June 27, 1952, had come to an end on November 10 (Macdonald, 1955). Mauna Loa had been quiescent since the end of the 1950 eruption, on June 23 of that year (Finch and Macdonald, 1953, p. 72). Throughout most of the year the volcanoes remained fairly quiet, and at no time was there any eruptive activity. However, several short periods of abnormal tilting of the ground surface and seismic activity indicated uneasiness of Kilauea and Mauna Loa.

Following the 1952 eruption of Kilauea there was little or no indication, from ground tilting or earthquakes, of any relaxation of pressure or withdrawal of the magma column beneath the volcano. During late May and June 1953, marked northward ground tilting at the northeastern rim of Kilauea caldera suggested tumescence of the volcano, and by inference a further increase of magmatic pressure beneath the caldera. It was accompanied by a large number of small

earthquakes. The northward tilting continued at a rate slightly greater than normal until October, and was accompanied by slight opening of cracks on the floor of the caldera. During February and March seismographs at Kilauea recorded three short periods of continuous volcanic tremor, of the sort believed to accompany subterranean movement of magma.

Slight westward tilting at Kilauea caldera during March, and more marked westward tilting in late July and August, suggested detumescence of Mauna Loa, probably resulting from decrease of magmatic pressure beneath that mountain. A large swarm of small earthquakes during late November and early December indicated movement on the northeast rift zone of Mauna Loa, possibly accompanied by some increase of pressure beneath that volcano.

The scientific program of the Hawaiian Volcano Observatory remained essentially the same as during 1952. Owing to the relationship between local earthquakes and volcanic activity, seismometry occupied a major place in the program. J. P. Eaton arrived in September to assume the duties of seismologist, a post left vacant since the retirement of R. H. Finch in February 1951. The magnetometric program continued to be carried out by C. K. Wentworth. In January, LaVieve G. Forbes was succeeded as secretary of the Hawaiian Volcano Observatory by Elizabeth G. Eklund.

ACKNOWLEDGMENTS

The staff of the Hawaiian Volcano Observatory wishes to express its thanks to the persons on the islands of Hawaii and Maui who have reported the occurrence of earthquakes during the year. These persons include: Miss Amy Greenwell, Mrs. Alfred E. Hansen, Miss Beth Hartig, Niss Nancy R. Wallace, Mrs. Howard Farrar, Mr. and Mrs. J. H. Midkiff, Jr., Allan P. Johnston, Robert I. Baldwin, David Fraser, Edward W. Broadbent, Troy Osborn, Harold R. Warner, and Eugene Barton.

The staff of Hawaii National Park has continued to be most cooperative and helpful throughout the year. Special thanks are due Eugene Barton, assistant superintendent of the Haleakala section of the Park, and his staff, for operating the Haleakala seismograph station.

SEISMOGRAPHS AND TILTMETERS

Most of the seismograph stations of the Hawaiian Volcano Observatory continued in operation throughout 1953 without any important changes from the condition at the end of 1952 (Macdonald, 1955, pp. 17–19). During the early part of the year the Sprengnether vertical and Wood–Anderson seismographs in the Uwekahuna station operated only during hours when the generating plant at the observa-

tory was running. On November 1, commercial electric power became available at the observatory, and the Sprengnether vertical seismograph began operation on a full 24-hour schedule. The Wood–Anderson seismograph was temporarily removed from the Uwekahuna station.

The old Hawaiian-type seismograph was removed from the Mauna Loa station early in June, and after remodeling of the vault a new Loucks–Omori seismograph was installed on June 26. The static magnification of the new instrument is 200, and the free period of the pendulums is 3 seconds.

The seismograph station on the western slope of Haleakala volcano, on the island of Maui, had been out of operation for about 10 years.

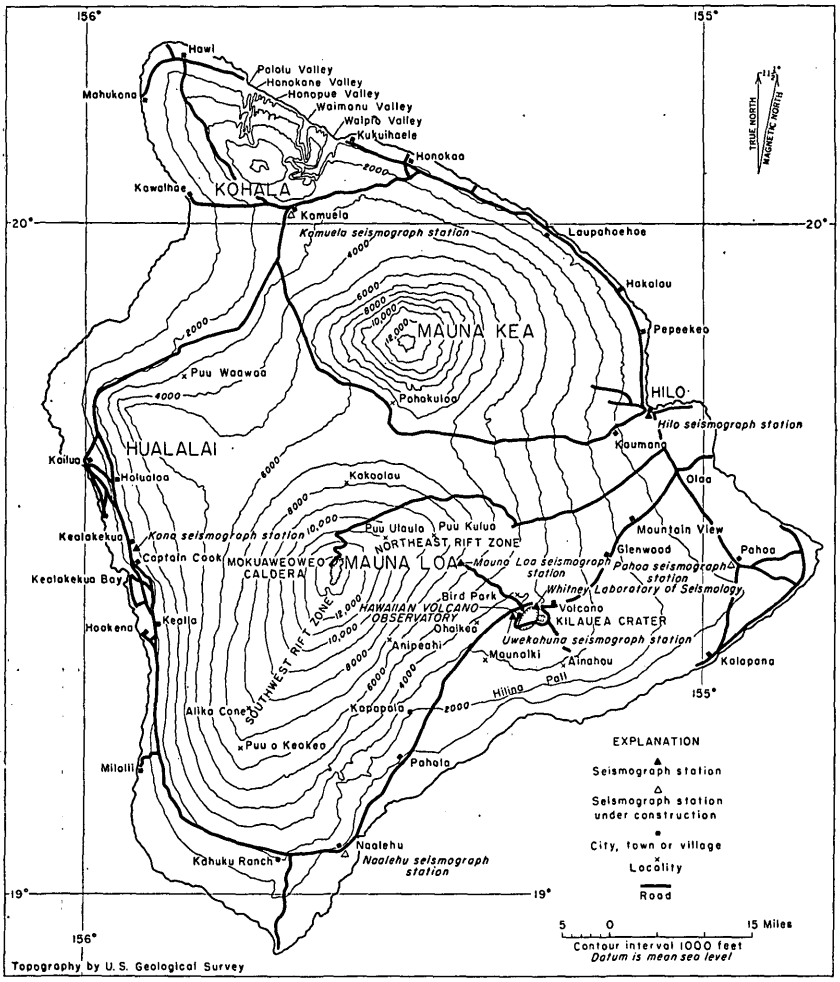

FIGURE 33.—Map of the island of Hawaii, showing location of the Hawaiian Volcano Observatory, seismograph stations operated by the observatory, and localities mentioned in the text.

On August 20, a Loucks–Omori seismograph was installed in the Haleakala vault, and the station reactivated. The instrument is identical to the seismograph in the Mauna Loa station. Time control is supplied by a Howard pendulum clock, corrected to the Bureau of Standards radio time signal. The Haleakala station is tended by personnel of the Haleakala section of Hawaii National Park and the records are sent to the Hawaiian Volcano Observatory for interpretation.

During the year construction began on three new seismograph stations on the island of Hawaii. One is located at Pahoa, near the east rift zone of Kilauea volcano; one is in Naalehu, near the southwest rift zone of Mauna Loa volcano; and one is in Kamuela, on the northern part of the island. These new stations are designed to give better coverage on local earthquakes. Construction of the shelters was completed in July, and it is hoped that internal construction will be finished and the seismographs installed during the early part of 1954.

Table 1 shows the location and characteristics of the seismographs and tiltmeters operated by the Hawaiian Volcano Observatory during 1953. Location of the stations is shown in figures 33 and 34.

TABLE 1.—*Seismographs and tiltmeters operated by the Hawaiian Volcano Observatory during 1953*

Station	Latitude (north)	Longitude (west)	Instrument	Period of pendulum (sec)	Magnification (approximate)	Sensitivity to tilt (sec of arc per mm)
Whitney Laboratory of Seismology (northeastern rim of Kilauea caldera).	19° 25′ 53″	155° 15′ 40″	Bosch–Omori seismograph and tiltmeter.	7.7	115	0.12
Mauna Loa (altitude of 6,600 feet, on eastern slope of Mauna Loa).	19° 29′ 32″	155° 23′ 29″	Hawaiian-type seismograph.	7.1	115	.14
Do	19° 29′ 32″	155° 23′ 29″	Loucks–Omori seismograph.	3.0	200	.46
Uwekahuna (1,000 feet west of western rim of Kilauea caldera).	19° 25′ 26″	155° 17′ 36″	Jaggar vertical seismograph.	.4	250	None
Do	19° 25′ 26″	155° 17′ 36″	Sprengnether vertical seismograph.	.5	1,750	None
Do	19° 25′ 26″	155° 17′ 36″	North-south and east-west horizontal pendulum tiltmeters.	20.0	7	.32
Do	19° 25′ 26″	155° 17′ 36″	Wood–Anderson seismograph.	1.0	600	----
Hawaiian Volcano Observatory (western rim of Kilauea caldera).	19° 25′ 21″	155° 17′ 23″	Imamura seismograph	3.0	15	----
Hilo (St. Joseph's School)	19° 43′ 11″	155° 05′ 20″	Loucks–Omori seismograph.	3.0	175	.48
Kona (Konawaena School, Kealakekua).	19° 30′ 47″	155° 55′ 07″	Hawaiian-type seismograph.	7.3	115	.13
Southeast tilt cellar (floor of Kilauea caldera southeast of Halemaumau).	19° 24′ 20″	155° 16′ 59″	Normal pendulum tiltmeter.	3.0	100	1.3
West tilt cellar (floor of Kilauea caldera west of Halemaumau.	19° 24′ 32″	155° 17′ 33″	do	3.0	100	1.3
Haleakala (Island of Maui)	20° 45′ 57″	156° 14′ 58″	Loucks–Omori seismograph.	3.0	200	.46

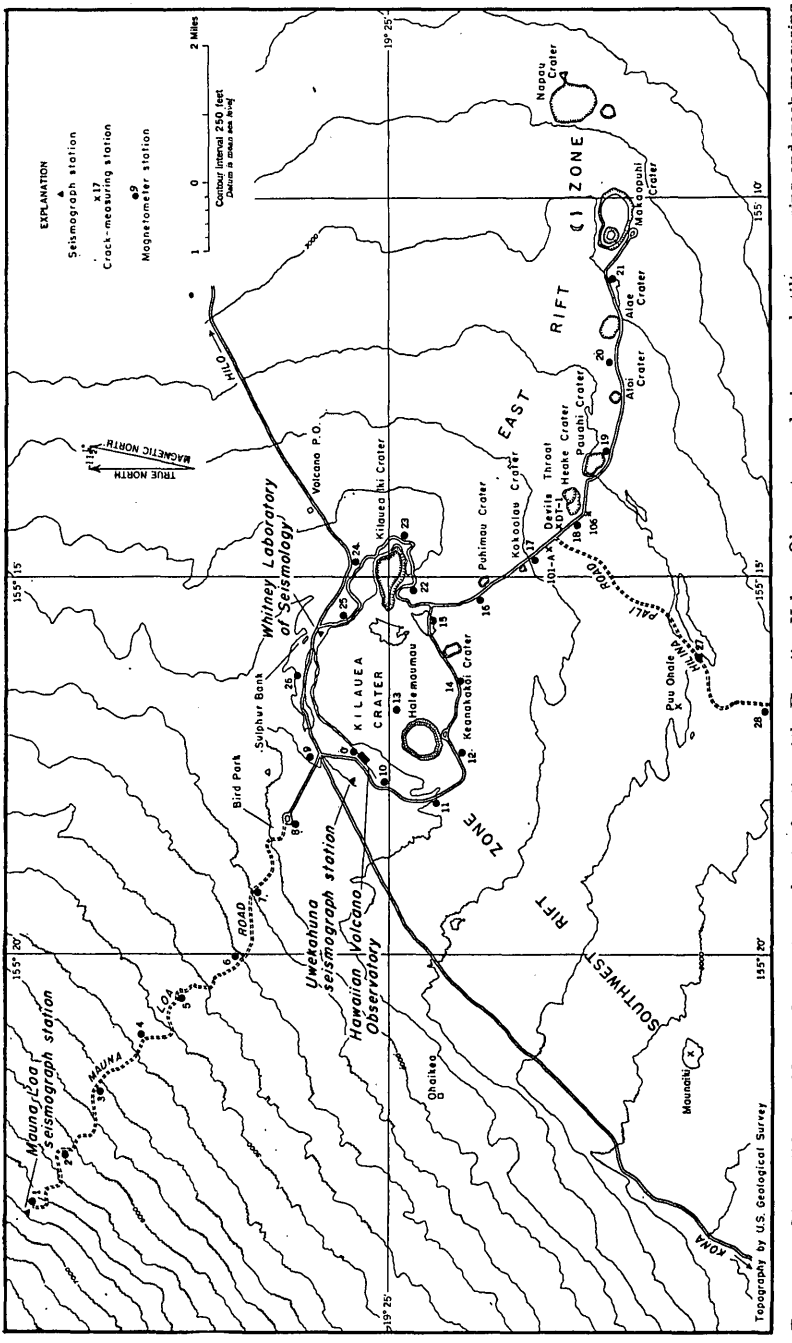

FIGURE 34.—Map of Kilauea caldera and its environs, showing location of the Hawaiian Volcano Observatory and seismograph, tilt-measuring, and crack-measuring stations on the east rift zone of Kilauea volcano.

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RECORDS AND INVESTIGATIONS

EARTHQUAKE STATISTICS

Seismographs of the Hawaiian Volcano Observatory recorded nearly 2,000 earthquakes during 1953. The number of quakes recorded per week at the Whitney Laboratory of Seismology and the Mauna Loa station ranged from 0 to 763. If the earthquake swarms of mid-May, late October, and late November are excluded, the average number of quakes per week recorded at those stations is 14.8, as compared with 8.9 per week during 1951 (Macdonald and Wentworth, 1954, p. 146). The number of quakes recorded each week on the Bosch-Omori seismograph at the Whitney Laboratory of Seismology is shown in table 2.

Table 3 lists all earthquakes larger than tremors recorded by the Hawaiian Volcano Observatory seismographs during the year, together with the date and time, the intensity of the quake at the Whitney Laboratory, the approximate position of the epicenter, and other information. If the intensity was greater at one of the other stations than at the Whitney Laboratory the name of that station and the intensity are given in the column headed "Remarks." The data on the earthquakes were determined from seismographs on the islands of Hawaii and Maui. The table lists the arrival time at the Whitney Laboratory, stated to the nearest minute in Hawaiian standard time, which is 10 hours behind Greenwich civil time. A serial number is listed for each earthquake for the year 1953.

TABLE 2.—*Number of earthquakes recorded per week and weekly seismicity at the Hawaiian Volcano Observatory during 1953*

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

Week beginning	Number of earthquakes	Seismicity	Week beginning	Number of earthquakes	Seismicity	Week beginning	Number of earthquakes	Seismicity
Jan. 4	10	7.25	May 3	11	2.75	Sept. 6	5	2.0
11	15	6.75	10	18	6.75	13	5	1.75
18	6	2.5	17	73	18.25	20	35	9.25
25	4	1.75	24	155	45.75	27	10	3.0
			31	44	12.5			
Feb. 1	0	.0	June 7	34	11.0	Oct. 4	22	11.0
8	7	3.0	14	50	13.5	11	27	8.75
15	6	2.0	21	61	18.5	18	23	8.0
22	5	3.75	28	17	4.75	25	70	46.5
Mar. 1	11	4.5	July 5	15	4.5	Nov. 1	16	7.5
8	10	3.5	12	9	2.75	8	23	7.25
15	5	2.0	19	7	2.0	15	36	11.5
22	12	6.5	26	11	4.0	22	53	23.25
29	12	3.25				[1] 29	[1] 24	[1] 14.75
			Aug. 2	17	6.5			
Apr. 5	7	2.5	9	11	4.25	Dec. 6	34	16.5
12	6	1.75	16	5	3.25	13	51	15.0
19	13	4.0	23	7	5.5	20	9	3.5
26	20	9.25	30	8	2.75	27	16	5.75

[1] On the week of November 29, 763 very small earthquakes were recorded at the Mauna Loa station, giving a weekly seismicity of 206.0 at that station.

TABLE 3.—*Local earthquakes larger than tremors recorded at Hawaiian Volcano Observatory during 1953*

Serial no.	Date	Time (Hawaiian standard)	Intensity at Whitney Laboratory of Seismology	Epicenter	Remarks
		h *m*			
1	Jan. 2	03 32	Very feeble	Near summit of Mauna Loa(?)	
2		23 34	No record	Kona	Kona, very feeble.
3	3	11 31	Feeble	On Kealakekua fault near Keei, 19°28′ N., 155°52′ W.	Kona, strong. Felt strongly throughout Kona.
4		11 34	Very feeble	Kona	Kona, slight. Kona aftershock, felt in Kona.
5	4	23 07	do	Kilauea	
6	7	15 58	Tremor	Kona	Kona, very feeble. Felt in Kona.
7		21 31	No record	Central Kona	Kona, very feeble.
8	9	09 09	Very feeble	Southwestern slope of Mauna Loa near 19°22′ N., 155°31′ W.	Felt at Kapapala and Naalehu, and in Kona.
9		09 22	do		
10		16 05	do		Felt at Kapapala.
11	9	16 42	No record	Central Kona	Kona, very feeble. Felt in Kona.
12		21 10	Strong	Southwestern slope of Mauna Loa about 4 miles southeast of South Pit, at about 19°24′ N., 155°33′ W.	Felt strongly at Kahuku and Naalehu, moderately at Kapapala, Volcano district, Hilo, and Kona, slightly at Kukuihaele. About 14 miles deep.
13	10	06 32	Tremor	Central Kona	Kona, very feeble.
14	12	03 27	do	do	Do.
15	13	04 13	Slight	Four miles S. 45° E. of Naalehu	
16	13	07 29	Very feeble		Felt quite strongly at Kapapala.
17	14	05 38	do	Southwest rift zone of Kilauea(?).	
18	15	02 05	Strong	Southeastern slope of Mauna Loa about 3 miles northnortheast of Kapapala, 19°19′ N., 155°26′ W.	Felt strongly over southern half of island from Hilo to Kona, and slightly as far away as Oahu. About 15 miles deep.
19	15	07 30	Tremor	Central Kona	Kona, slight. Felt in Kona.
20	16	13 01	Very feeble		
21		21 54	do		
22	17	05 09	do		
23		17 40	do		
24	18	09 33	Feeble	On southeastern slope of Mauna Loa near Ohaikea.	
25	21	12 58	Very feeble		
26	23	14 18	No record	Central Kona	Kona, very feeble. Felt in Kona.
27	24	11 14	do	do	Kona, very feeble.
28	25	03 17	Very feeble		
29	27	03 00	do	Kilauea	
30	29	00 17	Tremor		Do.
31	30	08 06	Very feeble		
32		10 53	Tremor		Do.
33	Feb. 3	07 28	No record	Central Kona	Mauna Loa, tremor; Kona, feeble.
34	6	20 21	do	do	Kona, very feeble.
35	8	18 48	Tremor		Do.
36	9	22 47	Very feeble	Near summit of Mauna Loa	Kona, feeble.
37	11	21 19	No record	Central Kona	Kona, very feeble.
38	12	04 38	do		Do.
39		06 45	Very feeble	Kaoiki fault near Kapapala, at about 19°17′ N., 155°27′ W.	Felt strongly at Kapapala, intensity about 4 (modified Mercalli). Shallow focus.
40		14 06	No record		Kona, very feeble.
41	13	04 49	Very feeble		
42		04 51	do		
43		04 51	do		
44	15	22 10	do		
45	16	11 21	do	Kaoiki fault, about 4.6 miles southwest of Uwekahuna station, at about 19°14′ N., 155°22′ W.	
46		20 20	No record	Central Kona	Do.
47	18	02 26	do	Western flank of Mauna Loa	Mauna Loa, tremor; Kona, very feeble.
48		02 30	do	do	Do.
49	20	06 14	do	Central Kona	Kona, very feeble.
50		06 16	do	do	Do.
51	21	22 44	do	Western slope of Mauna Loa	Do.

TABLE 3.—*Local earthquakes larger than tremors recorded at Hawaiian Volcano Observatory during 1953*—Continued

Serial no.	Date	Time (Hawaiian standard)	Intensity at Whitney Laboratory of Seismology	Epicenter	Remarks
		h m			
52	Feb. 22	02 40	Slight	Kaoiki fault between Bird Park and Ohaikea.	Felt in Volcano district.
53	25	15 30	Very feeble		
54	Mar. 1	22 42	do	Off south shore at about 19° N., 155°24′ W.	
55	3	19 32	No record	Central Kona	Kona, very feeble.
56	6	04 39	Feeble	Off south shore at about 19°04′ N., 155°25′ W.	
57		06 06	Very feeble		
58		07 48	do	Kealakekua fault, near Kealia (?).	Kona, slight. Felt in central Kona.
59		14 26	do	Beneath summit area of Hualalai volcano.	Kona, feeble. Felt in central Kona, Naalehu, and Kapapala. About 30 miles deep.
60	9	19 27	Feeble	Kilauea	
61	10	06 31	Very feeble	Northern slope of Mauna Loa about 3 miles northwest of Kokoolau cone, at about 19°39′ N., 155°37′ W.	
62	12	18 58	Tremor	Kilauea	Uwekahuna, very feeble.
63	17	03 20	No record	Central Kona	Kona, very feeble.
64	18	11 12	Very feeble		
65	18	23 40	do		Moderate distance.
66	19	06 45	No record	Central Kona	Kona, very feeble.
67		20 01	Very feeble		
68	23	19 30	Tremor		Mauna Loa and Kona, very feeble.
69		21 19	Very feeble	Western slope of Mauna Loa	Felt in south Kona.
70	25	10 50	do	Near summit of Mauna Loa, probably on northeast rift zone.	Mauna Loa, slight.
71		18 19	Moderate	Southern slope of Mauna Loa, at about 19°12′ N., 155°39′ W.	Felt strongly at Naalehu and Kapapala, and slightly over most of the island.
72	26	01 40	Very feeble	Southern slope of Mauna Loa, at about 19°08′ N., 155°35′ W.	Mauna Loa, feeble. Felt moderately at Naalehu and slightly as far as central Kona.
73	27	22 30	No record	Central Kona	Kona, very feeble. Felt in Kona.
74	31	03 54	Very feeble		
75	Apr. 2	02 59	No record	Central Kona	Kona, very feeble.
76	7	23 37	Tremor		Do.
77	10	11 09	Feeble	Northeastern slope of Mauna Loa.	Mauna Loa, slight. Felt in Volcano district.
78	13	18 00	No record		Kona, very feeble.
79	14	02 20	Tremor	Central Kona	Kona, very feeble. Felt in Kona.
80	16	14 36	No record		Kona, very feeble.
81	17	09 35	Very feeble	Kilauea	
82	22	15 28	do		
83	24	01 42	Feeble	Southwestern slope of Mauna Loa near 19°20′ N., 155° 47′ W.	Felt in Volcano district, south Kona, and Kohala.
84		05 44	Very feeble		
85	29	08 50	Moderate	Southwest rift zone of Kilauea(?).	
86		11 03	do	Kilauea	
87		13 00	Slight	Southwest rift zone of Kilauea(?).	
88	May 3	23 50	No record		Kona, very feeble.
89	6	17 59	Tremor		Do.
90	7	14 43	No record		Do.
91	8	01 18	do		Do.
92		16 19	Tremor		Do.
93		17 53	do		Do.
94	11	08 48	Slight	Kilauea (east rift zone?)	
95	13	08 25	Very feeble		
96		12 10	do		
97	15	13 31	do		
98	16	10 31	do		
99	17	09 30	No record		Do.
100		13 48	Very feeble		
101	18	03 05	do		
102	19	18 02	Tremor		Kona, very feeble. Felt in south Kona.

TABLE 3.—*Local earthquakes larger than tremors recorded at Hawaiian Volcano Observatory during 1953*—Continued

Serial no.	Date	Time (Hawaiian standard)	Intensity at Whitney Laboratory of Seismology	Epicenter	Remarks
		h m			
103	May 20	13 05	Very feeble		
104	21	14 12	do		
105	22	23 22	do	Kealakekua fault(?)	Kona, feeble. Felt in central Kona.
106	24	02 05	Slight	Kilauea	Felt in Volcano district.
107		02 12	Very feeble	do	
108		02 44	Moderate	Eastern slope of Mauna Loa near 19°26′ N., 155°27′ W.	Felt over much of Hawaii Island as far north as Kukuihaele.
109		13 15	Tremor		Uwekahuna, very feeble.
110	25	10 17	do		Kona, very feeble. Felt in south Kona.
111	26	06 26	Feeble		Felt at Naalehu.
112	27	19 33	Tremor		Felt at Kapapala.
113	29	04 59	Slight	Kealakekua fault at north side of Kealakekua Bay, near 19°29′ N., 155°56′ W.	Kona, strong. Felt in central and south Kona, Naalehu, and Volcano district.
114		05 08	Tremor	Central Kona	Kona, very feeble.
115		07 47	No record	do	Do.
116		10 21	do	do	Do.
117	30	05 16	Very feeble		
118	31	04 13	do		
119	June 4	01 14	do		
120		17 01	do		
121		18 48	do	Southeastern slope of Mauna Loa near Kapapala.	Felt fairly strongly at Kapapala.
122	5	11 23	do		
123	6	04 48	do	Kilauea	
124	8	16 58	do		
125	9	00 44	do		
126		00 49	Slight	Kilauea(?)	Felt in Hilo.
127	10	00 40	Very feeble	Kilauea	
128	11	21 27	No record	Central Kona	Kona, very feeble.
129	15	03 24	do	do	Kona, feeble.
130	15	20 34	Feeble	Northeastern slope of Mauna Loa about 3 miles N. 30° E. of Whitney Laboratory near 19°29′ N., 155°14′ W.	Felt in Hilo and Volcano district.
131	16	11 10	No record	Central Kona	Kona, very feeble.
132	17	02 27	do	Western slope of Mauna Loa	Do.
133	18	03 05	Very feeble		
134	20	20 55	Tremor		Do.
135	21	07 20	No record		Do.
136	23	17 50	Very feeble	Central Kona	Kona, slight.
137		17 53	No record		Kona, very feeble.
138	26	17 53	do		Do.
139		20 24	Very feeble	do	Kona, feeble.
140		20 54	Tremor		Kona, very feeble.
141	27	10 47	Moderate	Eastern slope of Mauna Loa about 3 miles S. 60° E. of Puu Kulua near 19°31′ N., 155°23′ W.	Felt in Volcano district.
142	27	23 12	Tremor		Kona, very feeble.
143	28	20 20	Very feeble		
144	30	00 45	Tremor	Central Kona	Do.
145	30	06 37	do	do	Do.
146	July 1	15 14	do	Northeast rift zone of Mauna Loa.	Mauna Loa, very feeble.
147	2	00 12	Very feeble		
148	2	05 34	No record	do	Do.
149	2	07 09	Tremor	do	Do.
150	2	11 58	No record		Do.
151	6	02 51	Very feeble	Western slope of Mauna Loa	
152	6	07 19	do	Northeast rift zone of Mauna Loa.	
153	6	15 07	Tremor		Do.
154	6	20 26	Slight	Beneath southwest edge of Kilauea caldera.	
155	6	23 55	Very feeble		
156	7	15 59	Tremor		Uwekahuna, very feeble.
157	7	17 55	Very feeble		
158	9	09 21	Tremor		Do.
159	10	10 07	do		Mauna Loa, very feeble.
160	13	15 56	Very feeble		
161	14	12 37	Tremor		Do.

TABLE 3.—*Local earthquakes larger than tremors recorded at Hawaiian Volcano Observatory during 1953*—Continued

Serial no.	Date	Time (Hawaiian standard)	Intensity at Whitney Laboratory of Seismology	Epicenter	Remarks
		h *m*			
162	July 15	04 59	Very feeble		Felt at Kapapala.
163	19	13 24	Tremor		Mauna Loa, very feeble.
164	20	18 07	Very feeble	Eastern slope of Mauna Loa	Mauna Loa, feeble.
165	21	17 30	Tremor		Mauna Loa, very feeble.
166	24	02 29	do		Uwekahuna, very feeble.
167	26	10 18	No record		Kona, very feeble. Felt in central Kona.
168	26	13 52	Tremor		Kona, very feeble. Felt in central Kona and at Hawi.
169	26	21 47	do		Mauna Loa, very feeble.
170	26	22 44	Very feeble		
171	28	22 24	Tremor	Central Kona	Kona, feeble. Felt in central Kona.
172	30	14 30	do	Probably Kaoiki fault	Mauna Loa, very feeble.
173	31	13 07	Very feeble		
174	31	23 44	do		
175	Aug. 1	06 48	do	Southwest rift zone of Kilauea near 19°20′N., 155°21′W.	Mauna Loa, feeble. Felt at Pahala.
176	1	08 13	Tremor		Mauna Loa, very feeble.
177	1	23 39	Very feeble		
178	2	02 31	do		
179	4	11 10	do		
180	4	17 20	do	Southwest rift zone of Kilauea near 19°20′ N., 155°23′ W.	Mauna Loa, feeble. Felt at Kapapala, strong; Volcano, Naalehu, slight.
181	5	02 46	Tremor	Mauna Loa, northeast rift zone	Mauna Loa, very feeble.
182	6	00 47	Very feeble	Southwest rift zone of Kilauea near 19°22′ N., 155°21′ W.	Mauna Loa, slight. Felt at Kapapala.
183	6	14 39	do		
184	6	18 47	do		
185	6	21 08	Tremor		Mauna Loa, very feeble.
186	7	02 17	Very feeble		
187	7	05 53	do		
188	8	00 37	Tremor		Do.
189	8	03 00	Very feeble		Felt strongly in central Kona.
190	11	07 12	do		
191	11	09 16	do	Kilauea	
192	11	12 39	do	do	
193	12	08 38	do		
194	13	05 55	do		Uwekahuna, feeble.
195	14	18 20	Tremor		Mauna Loa, very feeble.
196	14	22 14	Very feeble		
197	15	10 33	Tremor		Do.
198	15	12 04	do		Do.
199	15	16 27	No record	Kona	Kona, very feeble.
200	16	20 53	do	Central Kona	Do.
201	18	17 47	do		Mauna Loa, very feeble.
202	20	12 56	Tremor		Do.
203	21	19 47	Slight	Northern slope of Hualalai near Puu Waawaa.	Mauna Loa, Kona, and Hilo, strong. Felt over all the island of Hawaii and as far away as Honolulu. Felt on Maui, generally weakly, but strong in Haleakala Crater.
204	21	21 07	Very feeble		Felt in Kona.
205	23	00 53	Strong	Beneath southwestern slope of Hualalai about 3 miles east of Holualoa.	Felt: Kona, strong; Naalehu and Kapapala, moderate; Volcano, slight.
206	24	23 05	No record	Central Kona	Kona, very feeble. Felt slightly in central Kona.
207	25	14 54	Tremor		Mauna Loa, very feeble.
208	27	09 44	do		Do.
209	27	10 49	Tremor		Do.
210	29	06 16	do		Do.
211	Sept. 1	04 07	Very feeble		
212	1	15 31	do		Do.
213	1	15 36	Tremor		Do.
214	2	06 24	do		Do.
215	3	04 42	Very feeble	Kilauea	Felt at Hawaii National Park.
216	4	05 58	No record		Kona, very feeble.
217	4	15 40	do		Mauna Loa, very feeble.
218	10	07 00	Tremor		Do.
219	10	20 02	No record		Do.
220	12	01 58	Very feeble		
221	12	06 57	do		
222	13	07 16	do		

TABLE 3.—*Local earthquakes larger than tremors recorded at Hawaiian Volcano Observatory during 1953*—Continued

Serial no.	Date	Time (Hawaiian standard)		Intensity at Whitney Laboratory of Seismology	Epicenter	Remarks
		h	*m*			
223	Sept. 13	16	35	Tremor		Mauna Loa, very feeble.
224	14	14	03	do		Do.
225	15	02	37	No record	Kona	Kona, very feeble.
226	15	10	57	Tremor		Mauna Loa, very feeble.
227	16	04	22	do		Do.
228	17	19	34	Very feeble		
229	23	07	50	Tremor		Do.
230	23	14	50	Very feeble	Central Kona	Kona, slight. Felt in central Kona.
231	24	02	09	No record		Mauna Loa, very feeble.
232	25	09	40	Tremor		Do.
233	25	11	46	do		Do.
234	25	12	00	do		Do.
235	25	12	19	do		Do.
236	25	13	10	do		Do.
237	25	16	33	do		Do.
238	25	17	13	do		Do.
239	26	11	04	No record		Do.
240	26	12	16	do		Do.
241	26	12	57	do		Do.
242	26	13	02	do		Do.
243	26	13	43	Tremor		Do.
244	26	17	25	No record		Do.
245	26	20	11	do		Do.
246	27	06	08	Very feeble	Probably Kaoiki fault	
247	27	13	20	No record		Kona, feeble. Felt in central Kona.
248	Oct. 1	09	23	Tremor	Kaoiki fault	Mauna Loa, slight.
249	1	22	02	Very feeble		
250	2	20	18	Tremor	Southwest rift zone of Kilauea 2 miles east of Kapapala.	Mauna Loa, very feeble.
251	2	20	36	do	Kaoiki fault	Do.
252	2	22	06	No record	Central Kona	Kona, very feeble. Felt in Captain Cook.
253	4	22	27	Tremor		Mauna Loa, very feeble.
254	5	01	20	Very feeble		
255	5	11	21	do	Kilauea	
256	8	09	22	Feeble	Nine miles east of summit of Hualalai.	Mauna Loa, moderate. Felt in central Kona.
257	9	06	16	Very feeble	Kohala	Felt at Kukuihaele.
258	9	16	26	No record		Mauna Loa, very feeble.
259	9	16	28	do		Do.
260	9	19	03	do	Central Kona	Kona, very feeble.
261	9	21	11	Tremor		Mauna Loa, very feeble.
262	9	21	53	do	Mauna Loa	Mauna Loa, very feeble. Felt at Pahala.
263	10	02	04	do		Mauna Loa, very feeble.
264	10	02	51	Very feeble	East rift zone of Kilauea at Alae Crater.	
265	14	17	23	Tremor	Kaoiki fault	Do.
266	14	18	28	do	Five miles east of summit of Hualalai.	Do.
267	15	07	11	Very feeble	Kilauea	
268	15	17	10	do	Central Kona	Kona, feeble. Felt in Captain Cook.
269	16	00	33	do	Southern flank of Mauna Loa near Anipeahi.	
270	17	18	09	do	Southern flank of Mauna Loa	
271	18	00	57	do	Kilauea	
272	18	15	16	do	East rift zone of Kilauea	
273	19	02	33	No record	Central Kona	Mauna Loa, very feeble.
274	20	06	15	Tremor	Kaoiki fault	Do.
275	22	14	00	No record		Kona, very feeble.
276	22	14	02	Very feeble	Eastern flank of Mauna Kea	Mauna Loa, feeble. Felt at Pepeekeo.
277	23	14	49	No record		Mauna Loa, very feeble.
278	25	00	53	do		Do.
279	25	01	23	Very feeble		
280	25	04	17	do	Makaopuhi Crater	
281	25	10	42	Tremor	East rift zone of Kilauea near Napau Crater.	Uwekahuna, very feeble.
282	26	14	13	Very feeble	do	
283	26	17	46	Slight	East rift zone of Kilauea south of Alae Crater.	
284	26	17	50	do	do	

TABLE 3.—*Local earthquakes larger than tremors recorded at Hawaiian Volcano Observatory during 1953*—Continued

Serial no.	Date	Time (Hawaiian standard)	Intensity at Whitney Laboratory of Seismology	Epicenter	Remarks
		h *m*			
285	Oct. 26	17 51	Slight	East rift zone of Kilauea	
286	26	17 53	Very feeble	----------	
287	27	00 22	Feeble	----------	
288	27	01 07	Strong	East rift zone of Kilauea south of Aloi Crater near Ainahou.	Felt at Volcano.
289	27	01 10	Very feeble	----------	
290	27	01 38	Slight	----------	
291	27	03 37	Strong	East rift zone of Kilauea south of Makaopuhi Crater.	Do.
292	27	04 30	do	East rift zone of Kilauea near Alae Crater.	Do.
293	27	06 20	do	East rift zone of Kilauea south of Napau Crater.	
294	27	08 02	Very feeble	Southwest rift zone of Mauna Loa near Alika Cone.	Felt at Naalehu.
295	27	23 56	Tremor	----------	Uwekahuna, very feeble.
296	28	06 44	do	Kaoiki fault near Halfway House.	Do.
297	28	07 21	Very feeble	do	
298	28	15 50	do	Hilina Pali	Felt at Kapapala.
299	28	17 03	do	Southwest rift zone of Kilauea about 4 miles southwest of Maunaika.	Do.
300	28	21 15	do	Southern flank of Mauna Loa	Do.
301	28	22 58	do	East rift zone of Kilauea near Aloi Crater.	Felt at Volcano.
302	29	04 47	do	Southwestern flank of Kilauea	
303	29	05 40	do	----------	
304	30	08 16	Tremor	Kilauea caldera	Uwekahuna, very feeble.
305	31	06 08	do	Northern flank of Hualalai	Kona, feeble. Felt in North Kona and North Kohala.
306	31	12 26	Very feeble	Southwestern flank of Kilauea	
307	31	13 22	do	do	
308	Nov. 1	03 22	No record	----------	Uwekahuna, very feeble.
309		14 42	Very feeble	Southwestern flank of Kilauea near Maunaiki.	
310	3	10 14	Tremor	Southwest rift zone of Kilauea	Do.
311	5	00 16	do	----------	Mauna Loa, very feeble.
312	5	07 55	do	Mauna Loa	Do.
313	5	23 47	Very feeble	Southwest rift zone of Mauna Loa.	
314	6	02 30	Feeble	Mauna Loa, 3 miles south of the Mauna Loa seismograph.	Mauna Loa, slight.
315	6	11 24	Tremor	----------	Mauna Loa, very feeble.
316	8	18 14	Very feeble	----------	
317	8	20 37	do	Coast south of Kilauea	
318	10	13 48	Tremor	----------	Uwekahuna, very feeble.
319	12	09 37	do	----------	Mauna Loa, very feeble.
320	14	04 55	Very feeble	do	
321	14	05 12	do	do	
322	19	03 20	No record	----------	Do.
323	19	05 30	Tremor	----------	Uwekahuna, very feeble.
324	20	05 10	do	----------	Do.
325	21	11 26	Very feeble	Puu Ulaula, on northeast rift zone of Mauna Loa.	Mauna Loa, feeble.
326	21	15 23	do	Kilauea	Uwekahuna, feeble.
327	21	16 11	do	Mauna Loa	
328	22	21 32	Moderate	Kilauea caldera	Felt in Hawaii National Park and at Volcano.
329	23	17 26	Very feeble	Near Kilauea caldera	
330	25	07 07	No record	----------	Uwekahuna, very feeble.
331	25	12 42	Tremor	----------	Do.
332	26	02 09	No record	----------	Mauna Loa, very feeble.
333	26	03 09	Very feeble	----------	
334	26	05 52	do	Puu Ulaula	Mauna Loa, feeble.
335	26	13 54	do	Near Kilauea caldera	Uwekahuna, feeble.
336	26	13 55	do	do	Do.
337	26	16 58	do	do	
338	27	19 25	do	Kilauea	
339	28	08 11	do	do	
340	28	15 38	Moderate	Near Kilauea caldera	Felt in Hawaii National Park.
341	28	20 46	No record	----------	Mauna Loa, very feeble.
342	29	03 05	Very feeble	do	

TABLE 3.—*Local earthquakes larger than tremors recorded at Hawaiian Volcano Observatory during 1953*—Continued

Serial no.	Date	Time (Hawaiian standard)	Intensity at Whitney Laboratory of Seismology	Epicenter	Remarks
		h *m*			
343	Nov. 29	03 49	No record	Kona	Kona, very feeble.
344	29	07 36	Tremor	Near Kilauea caldera	Uwekahuna, very feeble.
345	29	19 44	Moderate	do	Felt in Hawaii National Park.
346	29	20 43	Strong	East rift zone of Kilauea near Napau Crater.	Felt from Hawaii National Park to Hilo.
347	29	21 18	Very feeble		
348	29	23 18	No record		Uwekahuna, very feeble.
349	30	13 02	Tremor		Do.
350	30	13 04	Slight	Near Kilauea caldera	Felt in Hawaii National Park.
351	30	13 30	No record		Uwekahuna, very feeble.
352	Dec. 1	01 56	Tremor	Northeast rift zone of Mauna Loa.	Mauna Loa, very feeble. Felt in Hilo.
353	1	02 01	No record		Mauna Loa, very feeble.
354	1	03 20	do		Do.
355	1	03 21	do		Do.
356	1	04 17	do		Do.
357	1	04 20	Tremor		Do.
358	1	04 24	do		Do.
359	1	08 46	No record		Do.
360	1	09 09	Tremor		Do.
361	1	10 54	do		Do.
362	1	12 34	No record		Do.
363	1	12 43	Tremor		Do.
364	1	12 45	do		Do.
365	1	13 13	do		Do.
366	1	13 20	No record		Do.
367	1	14 12	Tremor		Uwekahuna, very feeble.
368	1	16 27	do		Mauna Loa, very feeble.
369	1	21 23	No record		Do.
370	2	23 19	Tremor		Do.
371	3	01 54	No record		Do.
372	3	01 59	Tremor		Do.
373	6	21 02	Feeble	Kaoiki fault(?), about 3 miles southwest of Ohaikea, on the southern flank of Mauna Loa.	
374	8	03 29	No record	Near Kilauea caldera	Uwekahuna, very feeble.
375	8	14 00	Very feeble	Kilauea caldera	
376	8	23 59	do	do	
377	9	01 13	Slight	do	Felt in Hawaii National Park.
378	9	01 18	do	do	
379	9	01 56	do	do	
380	9	10 03	Very feeble	do	
381	9	10 43	do	do	
382	11	12 27	No record		Kona, very feeble.
383	12	08 56	Very feeble	Southwest rift zone of Kilauea about 4 miles southwest of Maunaiki.	
384	12	15 15	Tremor	Near the coast south of Kilauea.	Uwekahuna, very feeble.
385	13	02 53	Very feeble		
386	14	04 08	do		
387	14	08 15	do		
388	14	12 39	do	Kilauea caldera	
389	14	14 54	do		
390	15	21 08	No record		Kona, very feeble.
391	16	13 00	do		Kona, very feeble. Felt in Captain Cook, Kona.
392	16	17 01	Very feeble		
393	17	19 11	do	Kohala	
394	20	04 11	do	Southeastern flank of Kilauea near Kalapana.	Uwekahuna, feeble.
395	21	12 24	Tremor	East rift zone of Kilauea	Mauna Loa, very feeble.
396	21	12 40	do	Kilauea caldera	Uwekahuna, very feeble.
397	28	22 24	No record	do	Do.
398	29	06 01	Tremor	do	Do.
399	30	08 05	do		Do.
400	31	16 53	Very feeble	do	
401	31	19 54	do		
402	31	20 50	No record	Kona	Kona, very feeble.
403	31	22 55	Very feeble		

An arbitrary scale of seismicity is used at the Hawaiian Volcano Observatory to give a rough quantitative comparison of the amounts of energy released by local earthquakes during specified periods. The seismicity value of each earthquake is derived by assigning it a numerical value depending on its intensity. The values for all individual earthquakes in the specified period are then totaled to obtain the seismicity figure for the period. The intensity assigned to the earthquake depends on the amplitude of the record produced by the quake on the seismographs, taking into consideration the magnification of the different instruments. The maximum displacement produced on the Bosch-Omori seismograph is shown below.

Intensity of earthquake	*Double amplitude of motion on Bosch-Omori seismograph (millimeters)*	*Seismicity value*
Tremor	<0. 5	0. 25
Very feeble	0. 5–4	. 5
Feeble	4–11	1. 0
Slight	11–25	2. 0
Moderate	25–60	3. 0
Strong	More than 60	4. 0

Table 2 lists weekly seismicity values for the year 1953, based on the record of the Whitney Laboratory of Seismology. Weekly seismicity ranged from 0 to 46.5. Excluding the same swarms omitted in calculating the average number of earthquakes per week, the average weekly seismicity was 5.6. During the week beginning November 29, the very large number of small earthquakes from the northeast rift zone of Mauna Loa resulted in a weekly seismicity value of 206 at the Mauna Loa station.

Figure 35 contains frequency-distribution curves for the total number of earthquakes per week, the number of earthquakes greater than tremors, and the weekly seismicity, for the 20-year period, 1934–53. The very few weeks having more than 106 earthquakes, or seismicity greater than 26.5, lie to the right of the graph and are omitted. Five- and seven-unit moving averages are shown in the peak part of the curves for total earthquakes and seismicity, to smooth the curves. It is apparent by inspection that the mode of the curve for total earthquakes per week falls at about 4 to 7, and that of the curve for earthquakes greater than tremors at 2. The mode of the weekly seismicity curve falls at 2.0 to 2.75. Thus it is obvious, on the basis of the number of earthquakes per week and the weekly seismicity, that the year 1953 was considerably more active seismically than normal.

Table 4 lists the earthquakes of distant origin recorded on seismographs of the Hawaiian Volcano Observatory during the year. The location given for the epicenters are taken from the notices of Preliminary Determinations of Epicenters published by the U. S. Coast and

Geodetic Survey. The time given is that of the first detectable emergence of the quake on the Bosch-Omori horizontal or Sprengnether vertical seismograms, in Hawaiian standard time.

TABLE 4.—*Distant earthquakes recorded by seismographs of the Hawaiian Volcano Observatory during 1953*

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

Date	Time (Hawaiian standard)		Intensity at Whitney Laboratory of Seismology	Epicenter (from Preliminary determinations of epicenters published by U. S. Coast and Geodetic Survey)
	h	*m*		
Feb. 26	01	59	Slight	Santa Cruz Islands region, 650 miles north of New Caledonia, lat, 11° S., long, 164½° E.
Apr. 5	14	48	do	Banda Sea, lat, 7° S., long, 132° E.
18	13	48	do	Off south coast of Mexico, lat, 10° N., long, 102° W.
23	06	34	do	New Britain region, lat, 4° S., long, 154° E.
June 15	08	05	do	Near south coast of Kodiak Island, Alaska, lat, 56½° N., long., 154° W.
July 1	21	05	do	New Hebrides Islands, lat, 18½° S., long 169° E.
Sept. 13	14	46	do	Fiji Islands, lat, 18½° S., long, 178½° E. Accompanied by a tsunami. Several persons killed, and extensive property damage.
28	15	46	do	Origin probably within a few hundred miles.
30	13	23	Moderate	
Nov. 3	17	59	Slight	New Hebrides Islands, lat, 12½° S., long, 166½° E.
17	03	55	do	Near coast of Guatemala, lat, 14° N., long, 92° W.
25	07	59	Moderate	Near south coast of Honshu, Japan, lat, 34° N., long, 141° E. Felt at Honshu and Hokkaido. Seismic sea wave.
Dec. 4	05	11	Strong	Off coast of Vancouver Island, lat, 49½° N., long, 129° W.
12	07	53	Feeble	Near coast of Peru, lat, 3½° S., long, 81° W. Several persons killed and extensive property damage in Tumbes and Conales.

TILTING OF THE GROUND

Tilting of the ground surface is measured at the Whitney Laboratory of Seismology, on the northeastern rim of Kilauea caldera; the Uwekahuna seismograph station, near the western rim of Kilauea caldera; the Mauna Loa seismograph station, on the southeastern flank of Mauna Lao; and at stations on the floor of Kilauea caldera just southeast and west of Halemaumau crater. The location of these stations is shown in figures 33, 34, and 36.

Tilt is measured at the Whitney Laboratory by the Bosch-Omori seismograph, at the Mauna Loa seismograph station by the Loucks-Omori seismograph, and at the Uwekahuna seismograph station by a pair of horizontal pendulums (table 1). Table 5 shows the amount and direction of ground tilting at those stations during each week of 1953. The stations on the floor of Kilauea caldera are equipped with normal pendulums.

Figure 37 shows the ground tilting measured at the Whitney Laboratory of Seismology during the year 1953. Also shown are the approximate average annual tilt curves determined for years in which there was no eruptive activity of either Kilauea or Mauna Loa. Any marked variation of the curves of actual measured tilt from those of the average annual tilt probably is the result of variations in volcanic conditions, presumably largely subsurface magmatic pressure.

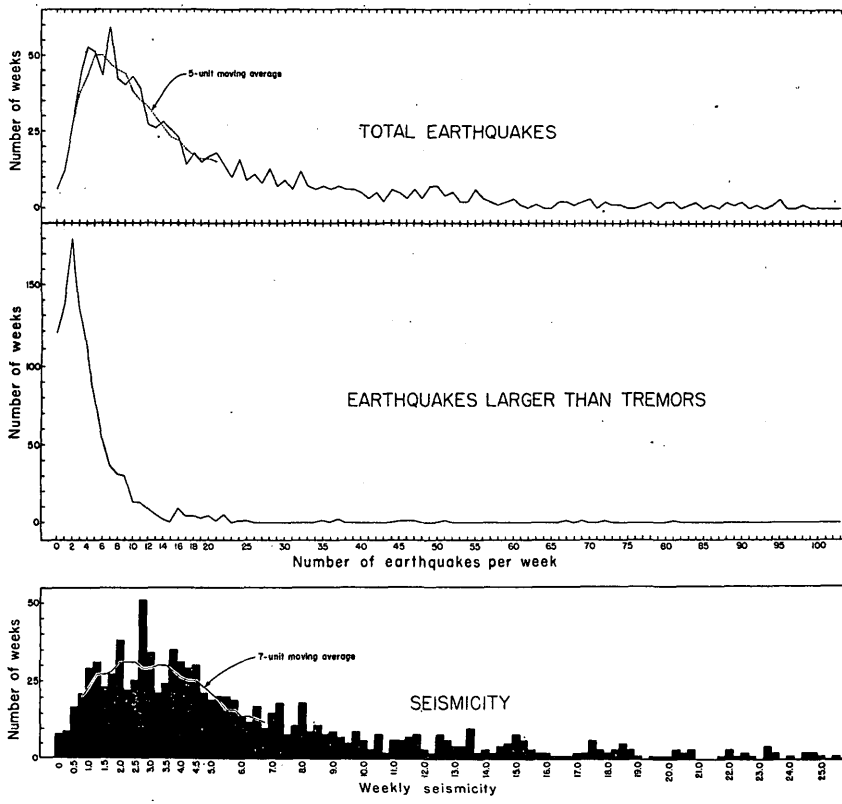

FIGURE 35.—Frequency-distribution curves of the number of earthquakes per week, and weekly seismicity, at the Whitney Laboratory of Siesmology during the 20-year period, 1934–53.

Many years ago it was shown that rise of the magma level in the open vent of Halemaumau was accompanied by tumescence of the volcano, producing northeastward tilting at the Whitney Laboratory, on the northeastern rim of Kilauea caldera, and that fall of the magma level was accompanied by detumescence, and southwestward tilting at the Whitney Laboratory (Jaggar and Finch, 1928). Similar tumescence precedes at least some eruptions of Kilauea, and probably also eruptions of Mauna Loa. However, because of the great distance (22 miles) between the tilt-measuring stations and the summit area of Mauna Loa, the effects of pressure changes beneath Mauna Loa are much less conspicuous in the tilt measurements than are those beneath Kilauea. Because the Whitney Laboratory lies almost due east of the summit of Mauna Loa, the effects of tumescence centered in the summit region of Mauna Loa appear almost entirely in the east-west component of tilt measured at the Whitney Laboratory. Tumescence of Kilauea affects both tilt components at the Whitney Laboratory, but the north-south component more than the east-west.

Throughout the early months of 1953, the average slope of the north-south tilt curve (fig. 37) is slightly less than the slope of the average annual curve, and following the reversal to northward tilting in mid-May the curve of measured tilt rises more rapidly than the average curve until mid-October. This suggests, though is not sufficiently definite to prove, an increase of pressure beneath Kilauea and a slight tumescence of the volcano. Because there was no evidence of any appreciable detumescence of Kilauea following the 1952 eruption, it further suggests that the magma column may, at the end of 1953, still have been standing at a high level beneath the surface. Under such conditions, eruption might come with very little forewarning.

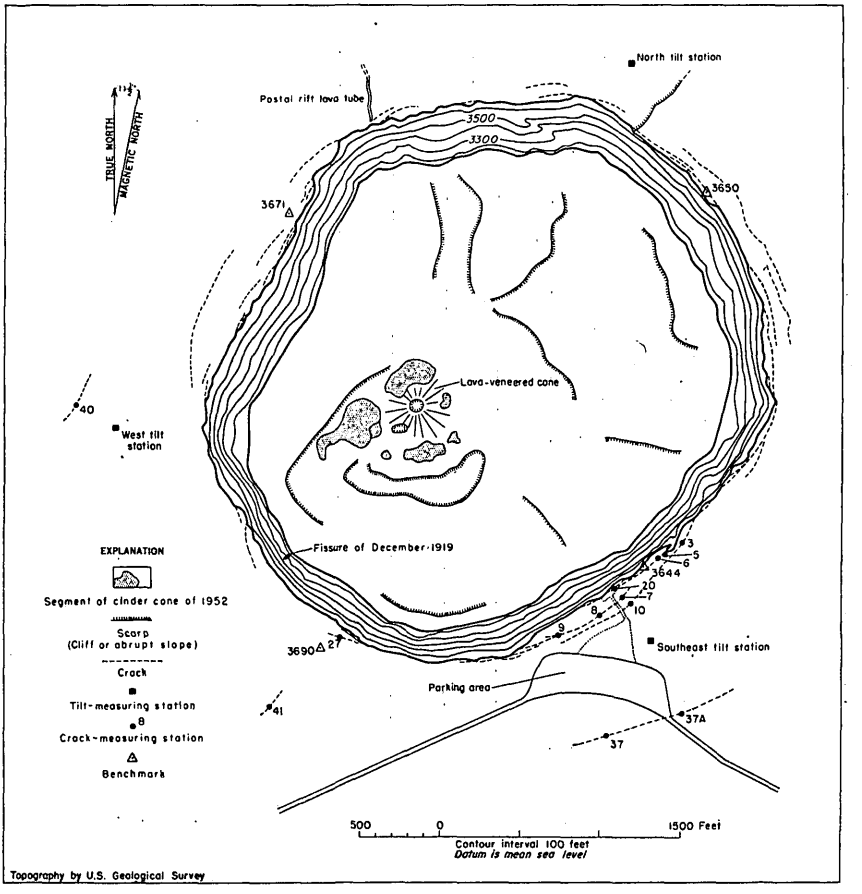

FIGURE 36.—Map of Halemaumau crater during 1953, showing location of tilt- and crack-measuring stations near the rim.

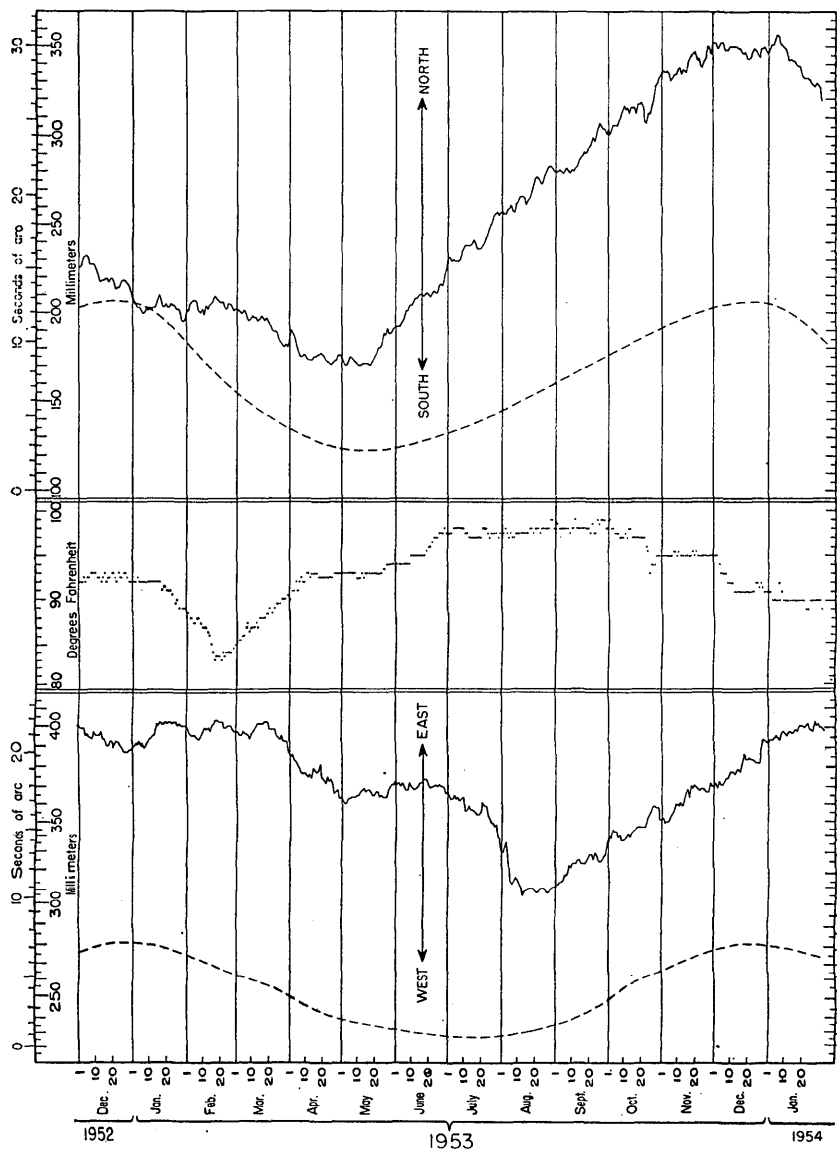

FIGURE 37.—Graph showing tilting of the ground surface at the Whitney Laboratory of Seismology, on the northeastern rim of Kilauea caldera, during 1953. The solid line shows the tilt as measured during the year. The dashed line is the approximate normal annual curve for years in which there is no volcanic disturbance. The dotted line shows the variation in air temperature in the vault during 1953.

From mid-October to late December the curve of measured tilt approximately parallels the trend of the average annual curve, suggesting that no further increase of volcanic pressure occurred during that interval. From early May to mid-June a hump on the curve of measured tilt in the east-west direction marks a conspicuous departure from the average, suggesting a tumescence of Mauna Loa. During late July and early August, however, rapid westward tilting appears to indicate relief of the pressure and detumescence of Mauna Loa. Throughout the rest of the year tilting in the east-west azimuth was essentially normal.

The period of abnormal ground tilting during the late spring coincides in part with the construction of a new wing of the Volcano House, centered about 150 feet north-northeast of the Whitney Laboratory of Seismology. It is possible that some of the tilting resulted from loading of the surface by the new structure. However, the abnormal tilting began about 3 months before the first construction, and during May and June the tilting was in a direction slightly west of north, whereas loading by the new structure should have produced tilting in an azimuth slightly east of north. Furthermore, the introduction and removal of heavy construction equipment,

TABLE 5.—*Ground tilting at seismograph stations on the rim of Kilauea caldera during 1953*

Week beginning	Whitney station (northeastern rim)		Uwekahuna station (western rim)		Week beginning	Whitney station (northeastern rim)		Uwekahuna station (western rim)	
	Direction	Amount (sec of arc)	Direction	Amount (sec of arc)		Direction	Amount (sec of arc)	Direction	Amount (sec of arc)
Jan. 4	E.	0.2	N. 45° W.	0.3	July 5	N. 42° W.	1.4	S. 8° E.	4.8
11	S. 82° E.	1.0	N. 21° E.	2.7	12	S. 45° W.	.3	N. 12° E.	1.6
18	E.	.1	S. 11° W.	1.6	19	N. 9° W.	1.6	S. 45° W.	.4
25	N. 34° W.	.4	N. 11° E.	1.6	26	N. 69° W.	2.7	N. 12° W.	1.6
Feb. 1	W.	1.2	E.	.6	Aug. 2	W.	1.8	N. 27° W.	2.9
8	S. 60° E.	1.0	S. 9° W.	1.8	9	N. 64° W.	1.1	S. 34° E.	1.1
15	S. 79° E.	.6	S. 27 W.	.7	16	N. 4° W.	1.8	S. 12° E.	3.4
22	N. 52° W.	.8	S. 11° W.	1.6	23	N. 16° E.	.9	S. 12° E.	3.4
					30	S. 61° E.	1.0	N. 72° E.	1.0
Mar. 1	N. 9° W.	.7	S. 9° W.	1.8					
8	E.	.6	S. 19° W.	4.0	Sept. 6	N. 70° E.	1.0	N.	.3
15	N. 27° W.	.8	N. 27° W.	.7	13	N. 5° E.	1.2	N. 7° W.	2.6
22	S. 31° W.	1.4	S. 14° E.	2.6	20	N. 4° E.	1.8	S. 27° E.	1.4
29	N. 88° W.	1.2	S. 16° E.	2.3	27	S. 85° E.	1.4	N. 22° W.	3.5
Apr. 5	S. 38° W.	1.4	N.	.6	Oct. 4	N. °41 W.	1.3	S. 20° E.	4.8
12	N. 56° E.	.9	S. 37° E.	1.3	11	N. 72° W.	1.1	N. 72° E.	1.0
19	S. 63° W.	1.3	N. 45° E.	.4	18	S. 54° E.	1.0	N. 14° W.	1.3
26	S. 80° W.	1.3	N. 27° W.	.7	25	N. 7° W.	2.9	S. 18° E.	3.0
May 3	N. 79° E.	.6	N. 12° W.	1.6	Nov. 1	S. 67° E.	.6	N.	2.2
10	S. 72° E.	.4	S. 14° E.	2.6	8	N. 84° E.	1.2	S. 23° E.	2.4
17	N. 14° W.	1.5	S.	2.2	15	N. 21° E.	1.0	N. 24° W.	3.9
24	N. 34° E.	1.3	N. 23° W.	2.4	22	N. 45° E.	.5	N. 45° W.	1.8
31	N. 17° W.	1.2	S. 14° W.	1.3	29	N. 9° W.	.7	N. 14° W.	2.6
June 7	N. 7° E.	1.0	----------	0	Dec. 6	S. 72° E.	.8	S.	.3
14	W.	.1	N. 26° E.	.7	13	S. 45° E.	1.2	S. 18° E.	1.0
21	N. 9° E.	.7	S. 27° E.	1.4	20	N. 63° W.	.3	E.	.3
28	N. 20° W.	1.8	N. 45° E.	.4	27	N. 72° E.	1.5	N. 23° W.	4.2

weighing nearly as much as the structure, caused no recognizable effect. It appears unlikely that any large part of the tilting was caused by the construction.

Figure 38 shows the measured ground tilting of the Uwekahuna seismograph station since the establishment of the station in 1949. No average annual ("normal") curve is shown, because the record is not yet long enough to permit the construction of such a curve. The most noteworthy feature on the Uwekahuna curves is the sudden large eastward tilting in December 1950. This accompanied a similar rapid southwestward tilting at the Whitney Laboratory, and was caused by a marked subsidence of the summit region of Kilauea volcano (Finch and Macdonald, 1953, p. 86).

Horizontal pendulums are notably sensitive to changes of temperature, particularly if any parts of the instrument are under tortional stress. In an effort to determine the sensitivity of the Bosch-Omori seismograph to temperature changes, and what proportion of the average annual tilting might be the result of variations of air temperature in the vault at the Whitney Laboratory, the temperature in the vault was artificially changed several times through a total range of 18°F, over a period of a week. The east-west component of the instrument showed a fairly regular response to the temperature changes, having a total amount of apparent westward tilting of 5.2 seconds for the temperature change of 18°. Daily measurements of maximum and minimum air temperature in the vault throughout 1952–53 show a total variation in temperature of 16°F. At the rate determined during the artificial changes of temperature, this change of 16° would account for an apparent tilt of 4.6 seconds, or approximately half the average annual east-west tilt. In contrast, the apparent tilting in the north-south azimuth associated with the same temperature variations was irregular, and amounted to a total of only 1.6 seconds. This corresponds with an apparent tilting of 1.4 seconds for the maximum annual temperature change of 16°, or only 14 percent of the average annual tilting in the north-south azimuth. Furthermore, the times of reversal of the north-south and east-west tilting do not correspond, and neither corresponds with the reversal in temperature trend. Figure 39 shows the average annual tilting curves, in juxtaposition to the curve of variation of air temperature in the vault during 1952–53. It is apparent that the reversal from westward to eastward tilting lags behind the reversal from rising to falling temperature by nearly a month, and the reversal from southward to northward tilting lags nearly another month. It appears, therefore, that only a small proportion of the measured annual tilting can be directly related to changes of temperature of the instrument.

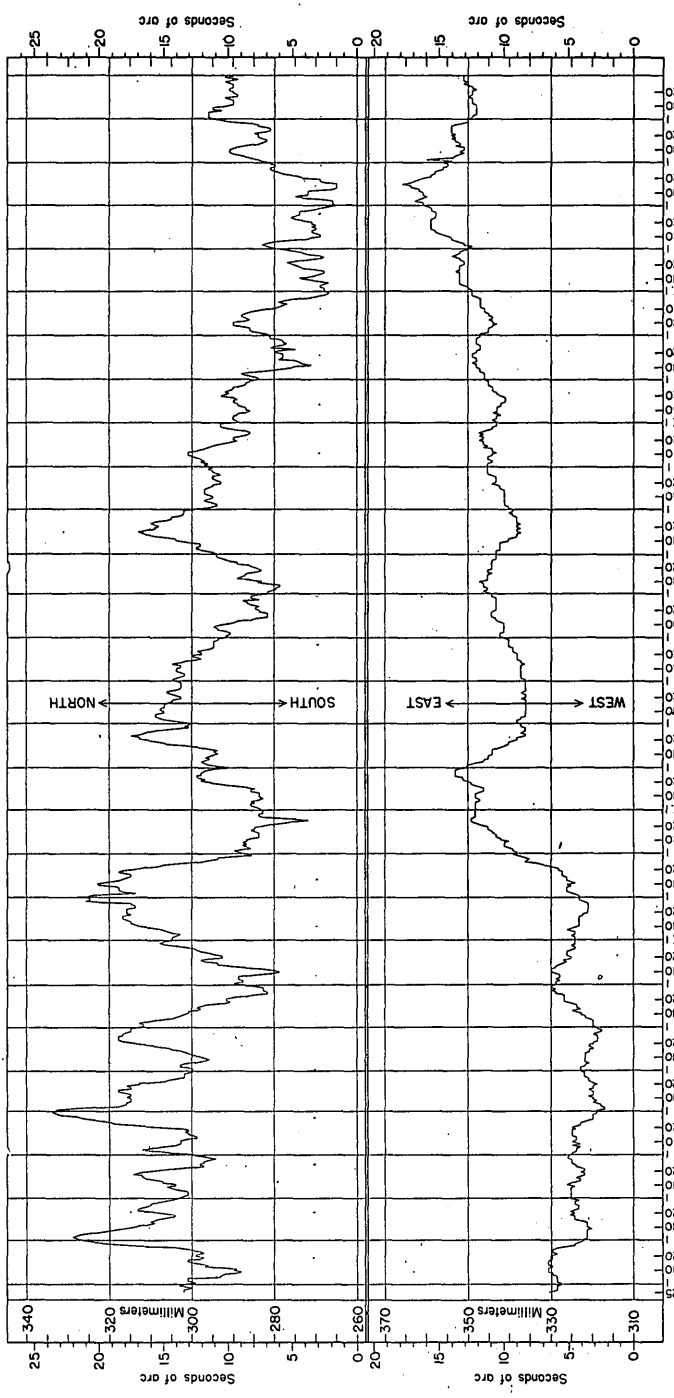

FIGURE 38.—Graph showing tilting of the ground surface at the Uwekahuna seismograph station, near the western rim of Kilauea caldera, during 1951–53.

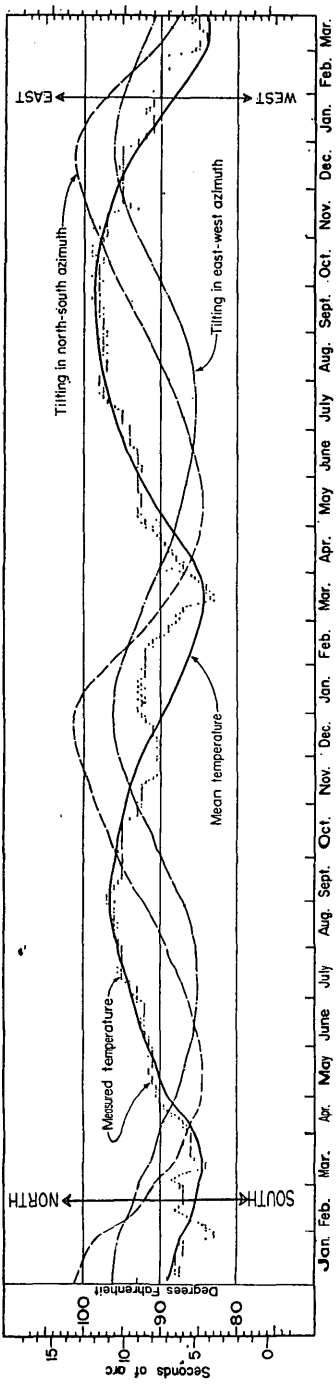

FIGURE 39.—Graph showing the average annual tilt pattern and air-temperature variation in the vault at the Whitney Laboratory of Seismology during 1952–53.

CRACK MEASUREMENTS

Measurements of crack widths were made at 15 stations on the floor of Kilauea caldera and along the east rift zone of Kilauea volcano at approximately monthly intervals throughout 1953. The location of the crack-measuring stations on the east rift zone are shown in figure 34, and those of the stations on the caldera floor in figure 36. The measurements are given in table 6.

Cracks 5, 6, and 20, near the rim of Halemaumau crater, showed consistent opening throughout the year. Other cracks near the rim of the crater showed little net change of width. Crack 9 closed slightly, possibly because of a rotational movement of the block at the southeast edge of the crater, the outward movement of which caused the opening of cracks 5 and 6. Between December 1, 1952, and December 31, 1953, crack 5 opened 3.6 centimeters, as compared with an opening of 6.8 centimeters during 1952.

Cracks 37 and 37A, on the caldera floor east of Halemaumau, opened continuously from June to the end of December. They showed similar widening at the time of the Kilauea eruption in 1952. In conjunction with the greater than normal northward tilting of the ground at the northeastern rim of the caldera during 1953, it is believed that the widening may have resulted from a slight up-bowing of the caldera floor accompanying tumescence of the volcano.

Cracks along the east rift zone of Kilauea showed no appreciable net change in width during the year, although crack 101A varied in width about 5 millimeters.

TABLE 6.—*Crack measurements, in centimeters, at Kilauea during 1953*

Date	Width of cracks for indicated station—															
	Rim of Halemaumau								On floor of caldera					On east rift zone		
									37							
	3	5	6	7	8	9	20	27	N-S	E-W	37A	40	41	101A	106	DT-1
Jan. 1	74.0	123.7	63.2	35.0	58.0	77.2	122.4	65.1	50.6	46.1	65.0	33.5	33.4	130.4	101.7	36.0
Feb. 1	74.1	124.2	63.3	35.1	58.0	77.0	122.9	65.1	50.6	46.1	65.0	33.5	33.4	-----	-----	36.0
28	74.1	124.4	63.4	35.0	58.0	77.0	122.9	65.1	50.6	46.1	65.0	33.5	33.4	130.3	101.7	36.0
Mar. 31	74.1	124.9	63.4	35.0	58.0	77.0	123.1	65.1	50.6	46.1	65.0	33.5	33.4	130.2	101.7	36.0
Apr. 29	74.1	125.4	63.8	35.0	58.0	77.1	123.1	65.1	50.6	46.1	65.1	33.5	33.4	130.2	101.6	36.0
June 1	74.1	125.9	63.9	35.0	58.0	77.1	123.1	65.1	50.6	46.1	65.1	33.5	33.4	130.3	101.6	36.0
July 1	74.1	126.3	64.1	35.0	58.0	77.0	123.4	65.1	50.8	46.3	65.3	33.6	33.4	130.5	101.6	36.0
Aug. 1	74.0	126.5	64.2	35.0	58.0	77.0	123.4	65.0	51.0	46.5	65.4	33.6	33.4	130.7	101.7	36.0
Sept. 1	74.0	126.9	64.3	35.0	58.0	77.0	123.5	65.0	51.2	46.7	65.6	33.6	33.4	130.3	101.7	36.0
30	74.0	127.1	64.5	35.0	58.0	76.9	123.5	65.0	51.4	46.9	65.7	33.6	33.4	130.4	101.7	36.0
Nov. 2	74.0	127.4	64.6	35.0	58.0	76.9	123.6	65.0	51.4	46.9	65.8	33.6	33.4	130.4	101.8	36.0
30	74.0	127.5	64.6	35.0	58.0	76.8	123.7	65.1	51.6	47.1	65.9	33.6	33.4	130.5	101.8	36.0
Dec. 31	73.9	127.9	64.8	35.0	58.0	76.8	123.7	65.1	52.0	47.5	66.1	33.7	33.4	130.5	101.7	(1)

[1] Measurements discontinued.

GEOMAGNETIC OBSERVATIONS

Measurements of the relative intensity of the vertical component of the earth's magnetic field at stations on Kilauea volcano and adjacent parts of Mauna Loa were continued by C. K. Wentworth during 1953. The method of making the measurements and the location of the stations at which the measurements were made are described in an earlier report (Macdonald and Wentworth, 1954, p. 164).

Table 7 lists the readings obtained during 1953. All readings in the table are differences (in gammas) of the vertical intensity at each of the magnetometer stations from that at station 0, near the Hawaiian Volcano Observatory, on the same date.

TEMPERATURE MEASUREMENTS

Measurements of steam temperatures at Sulphur Bank (fig. 34) were taken at approximately monthly intervals throughout 1953. The temperature of the steam escaping from the drilled well (Finch and Macdonald, 1951, p. 116) remained constant at 96°C during the early part of the year, but dropped to 95.5° in October and November. The temperature was not measured in December, but on January 7, 1954, had returned to 96°. The temperature of steam issuing from a natural vent near the east end of the solfataric area, about 50 feet east of the well, ranged from 94.5° to 95°C, apparently depending on strength and direction of the wind at the time of measurement, and on the amount of recent rainfall.

TABLE 7.—*Difference in vertical intensity of geomagnetism, in gammas, at stations on Mauna Loa and Kilauea, compared with that at station 0 during 1953*

Station no.	February 20–21	April 9–10	June 3–9	August 4–6	October 7–9	December 16
1	−709	−659	−798	−840	−854	−776
2	+8	−26	0	−160	−55	+5
3	−373	−254	−280	−431	−349	−229
4	−263	−286	−344	−564	−363	−259
5	+53	+42	+110	−14	+206	+146
6	−87	−203	−124	−128	−133	−64
7	−49	−252	−110	−115	−87	−77
8	−667	−626	−790	−955	−711	−697
9	−735	−701	−840	−821	−872	−803
10	−573	−708	−721	−762	−674	−725
11	−176	−233	−156	−197	−160	−170
12	−354	−595	−715	−711	−674	−721
13	−420	−467	−524	−537	−496	−542
14	−11	−60	−10	−32	0	−18
15	+422	+264	+472	+482	+468	+519
16	+173	+166	+161	+192	+225	+243
17	−637	−675	−762	−798	−679	−698
18	−468	−471	−487	−496	−445	−487
19	+135	+110	+371	+335	+344	+381
20	−486	−479	−459	+376	−289	−303
21	−83	+76	+330	+18	+330	+317
22	+758	+558	+867	+1,212	+900	+909
23	+1,090	+1,120	+1,331	+1,267	+1,322	+1,290
24	−128	−64	−124	−119	−46	−64
25	+2,175	+2,127	+2,565	+2,455	+2,589	+2,583
26	+268	+219	+293	+188	+285	+225
27	−727	−784	−840	−868	−863	−734
28	−750	−901	−882	−923	−877	−895

RAINFALL RECORDS

Daily readings of rainfall were continued at the gage near the Uwekahuna seismograph station throughout 1953. Gages at the Mauna Loa seismograph station and at an altitude of 5,500 feet on the Mauna Loa truck trail were read every 2 days. A rain gage 300 feet north of the southeast tilt cellar, on the floor of Kilauea caldera southeast of Halemaumau, was read at the end of each month. The monthly total for these gages are given in table 8.

TABLE 8.—*Rainfall, in inches, during 1953*

Month	Gage			
	Halemaumau	Uwekahuna seismograph station	Mauna Loa truck trail (altitude, 5,500 feet)	Mauna Loa seismograph station
January	1.23	0.92	1.17	0.83
February	7.07	2.45	5.16	5.70
March	10.78	1.98	10.56	10.26
April	.60	.24	2.19	2.14
May	1.74	1.25	1.35	2.31
June	.60	.34	.09	.27
July	.09	.05	.00	.00
August	1.88	1.03	2.21	2.86
September	.30	.15	.36	.88
October	1.43	[1].17	2.65	2.11
November	5.09	[1].34	2.92	3.70
December	5.45	[1].38	3.51	3.90
Total	36.26	9.30	32.17	34.96

[1] Figure is too low. Uwekahuna gage was leaking during October, November, and December and probably throughout the rest of the year.

HISTORY OF VOLCANIC CONDITIONS AND EARTHQUAKES

January—Hawaiian volcanoes remained fairly quiet throughout January. Seismographs at Kilauea caldera recorded 41 earthquakes during the month, and the seismograph at the Mauna Loa station recorded 33. This is about the usual number recorded during times of volcanic quiet. However, the intensity of some of the quakes was greater than usual.

Several earthquakes were felt in Kona during the month. Most of them originated locally, on the Kealakekua fault, near the north edge of Kealakekua Bay, or at sources between central Kona and the summit of Mauna Loa. A small earthquake felt at Naalehu and Kapapala at 9^h08^m on January 9 originated beneath the southeastern slope of Mauna Loa about 8 miles northwest of Kapapala, and another at 21^h10^m on the same day had its epicenter about 1.5 miles nearer the summit of the mountain. The latter quake was felt quite strongly over all the southern part of the island, and less strongly as far north as Kukuihaele.

At 2^h04^m on January 15 a strong earthquake originated beneath the southeastern slope of Mauna Loa near Kapapala. Objects were upset and knocked from shelves as far away as Hilo. Residents of the southern part of the island of Hawaii were generally awakened, and the quake was felt as far away as Oahu. In its epicentral area the intensity of the quake is estimated to have been about 5 on the modified Mercalli scale.

Tilting of the ground at the Whitney Laboratory of Seismology was slightly southward, at a rate about normal for this season. Late in January a slight northward tilting commenced. From January 1 to 15 there was an accumulation of a little more than 1 second of eastward tilting. This suggests a small increase of pressure beneath Mauna Loa, associated with the Mauna Loa earthquake activity during the early part of the month. During late January, however, the eastward tilting, and presumably also the increase of pressure beneath Mauna Loa, ceased.

February.—Seismic activity on the island of Hawaii during February was relatively slight. Seismographs at Kilauea caldera recorded only 18 earthquakes, the smallest number since January 1951. The Mauna Loa seismograph recorded 25 quakes. Some of these originated on the western slope of Mauna Loa, and others on the northeast rift zone.

At 6^h44^m on February 12 an earthquake with an intensity of 4 on the modified Mercalli intensity scale was felt strongly at Kapapala. Its origin was near Kapapala, probably on the Kaoiki fault, which parallels the highway between Kilauea caldera and Pahala. A slight earthquake was felt in the Volcano district at 2^h40^m on February 22. This quake also appears to have originated on the Kaoiki fault, between Bird Park and Ohaikea.

During February there was a small accumulation of northward tilting of the ground at the Whitney Laboratory. There was essentially no accumulation of tilt in the east-west direction. During that season tilting usually is south-southwestward. The slight northward tilting and absence of westward tilting therefore probably indicate some increase of volcanic pressure beneath Kilauea caldera, and possibly also under Mauna Loa.

Late in the afternoon of February 28, the seismographs recorded 18 minutes of continuous volcanic tremor, which is believed to have indicated movement of magma beneath the surface at Kilauea.

March.—Seismographs of the Hawaiian Volcano Observatory recorded a total of 75 earthquakes during March. Many of these were too small to be recorded at more than one station. For example, the Kona seismograph recorded four very feeble earthquakes of nearby origin that were too small to be recorded at Kilauea caldera.

During the month the seismographs at Kilauea recorded 45 earthquakes, and the Mauna Loa seismograph recorded 51. The number of earthquakes at any single station was approximately normal and, although the total was somewhat greater than normal, such a large proportion of the quakes were very small that the total seismicity also was only about normal in amount.

On March 6, at 7^h48^m, a slight earthquake was felt in central Kona. Its origin apparently was on the Kealakekua fault, probably near Kealia. At 14^h26^m on the same day an earthquake was felt throughout much of the Kona and Kau districts. Its focus lay beneath the summit area of Hualalai volcano.

At 18^h19^m on March 25 a moderately strong earthquake occurred. Its epicenter lay on the southern slope of Mauna Loa, 10 miles N. 25° W. of Naalehu. It was felt strongly at Naalehu, where the intensity was about 4 in the modified Mercalli scale. At Kapapala its intensity was 2 to 3. The quake was felt slightly over most of the island. At 1^h40^m on March 26 a smaller earthquake was felt quite strongly at Naalehu, where its intensity was estimated as about 2, and less strongly over much of the southwestern part of the island. Its epicenter also lay on the southern slope of Mauna Loa, about 5 miles north of Naalehu.

During March, tilting of the ground surface at the Whitney Laboratory of Seismology was southwestward, both the direction and the aggregate amount being approximately normal for that season. Temperatures of steam at vents in Kilauea caldera remained unchanged. General conditions at Halemaumau also remained unaltered, with no visible activity other than steam vents, and a weakly active vent liberating sulfurous fume on the floor of Halemaumau crater northwest of the large cones of the recent eruption. During late February and March there was a marked increase in the volume of steam visible at the northeast wall of Puhimau Crater, on the east rift zone of Kilauea volcano.

On March 14 continuous tremor was recorded on the seismographs for 16 minutes, apparently indicating movement of magma beneath Kilauea. Again on March 29 there was recorded 13 minutes of continuous tremor. This may have been a succession of very small earthquakes, but it was more probably volcanic tremor of the sort that accompanies magma movement. There was, however, no sign of abnormal tilting, such as would result from tumescence or collapse caused by any marked change of pressure beneath either Mauna Loa or Kilauea.

April.—The volcanoes were quiet throughout April, and seismic activity was approximately normal. Seismographs at the rim of Kilauea caldera recorded 50 earthquakes during the month, and the

Mauna Loa seismograph recorded 33. Thus Kilauea showed somewhat more activity than Mauna Loa. The Kona seismograph recorded 19 small earthquakes not recorded at any other station. These originated in central Kona near the station. Probably some or all resulted from small movements on the Kealakekua fault, which runs out to sea along the north edge of Kealakekua Bay.

A feeble earthquake felt in the vicinity of Kilauea caldera at 11^h09^m on April 10 had its origin beneath the eastern slope of Mauna Loa. A quake at 2^h20^m on April 14 was recorded as very feeble on the seismograph, but was felt by several persons in central Kona. Another feeble quake originated beneath the southwestern slope of Mauna Loa at 1^h42^m on April 24, and was felt in Kona and in the Volcano area. Moderate earthquakes at 8^h50^m and 11^h03^m on April 29 probably had their origin on the Kaoiki fault, which separates Kilauea and Mauna Loa west of Kilauea caldera.

Tilting of the ground surface at the northeastern rim of Kilauea caldera normally is toward the southwest throughout April. This year, the southward component of tilting was approximately normal, suggesting essentially no change in volcanic pressure beneath Kilauea. Westward tilting, however, was at a rate somewhat greater than normal, suggesting the possibility of some reduction of pressure beneath Mauna Loa.

May.—During early May the volcanoes were fairly quiet. From May 1 to 17 ground tilting at the Whitney Laboratory of Seismology was approximately normal, in direction and amount, for that season. The number of earthquakes recorded was nearly twice normal, but most of them were very small. On May 17 the ground surface began tilting rapidly northward, and this northward tilting continued at a rate notably greater than normal throughout the rest of May. On May 20 the number of earthquakes recorded at Kilauea caldera increased greatly, and throughout the rest of the month averaged about 20 per day, bringing the total recorded in May to 259. Of these, about 90 percent had their origin beneath or near the caldera.

Several small earthquakes were felt in Kona during the month. All except one originated in the Kona area, some of them probably on the Kealakekua fault. At 4^h59^m on May 29 a strong quake originated on the Kealakekua fault. This earthquake dismantled one component of the Kona seismograph. It was felt strongly in central Kona and weakly over much of the rest of the island.

At 2^h44^m on May 24 a moderate earthquake, originating beneath the eastern flank of Mauna Loa, was felt over much of the island. A sharp earthquake felt at Kapapala at 19^h33^m on May 27 probably had its origin on the Kaoiki fault.

A small landslide took place on the sea cliff near the mouth of Manowaiopae Stream, just south of Laupahoehoe (Hamakua coast), early on the morning of May 28. According to Joe Jose, who lives near the site of the slide, a small slip occurred at 03^h, followed by a larger one at 05^h. Seismographs on the island of Hawaii recorded no earthquakes at those times, so the slides apparently were not set off by earthquakes. At the foot of the sea cliff the slides built a small peninsula that was attacked and soon largely removed by waves.

Such landslides are not uncommon along the sea cliffs of Hawaii, especially along the windward coast of Kohala. According to William Ellis (1917, p. 284, 285), similar landslides occurred late in 1822 or early in 1823 between Pololu and Honokane Valleys, and at a locality known as Laupahoehoe, about a mile and a half northwest of Waimanu Valley. Another landslide may have occurred in this valley during the violent earthquake of April 2, 1868. A large slide occurred on the sea cliff just east of the mouth of Honopue Valley during heavy rains in January 1941 (Stearns and Macdonald, 1946, p. 51). All these slides built debris fans at the base of the cliff, but only the Laupahoehoe fan was large enough to survive the attack of waves.

June.—Kilauea volcano remained notably restless throughout June. Of the 184 earthquakes recorded by seismographs at Kilauea caldera during the month, the majority originated in Kilauea volcano. The total number of earthquakes was more than four times the usual number recorded during periods of volcanic quiet. Northward tilting of the ground surface at the northeastern rim of Kilauea caldera during June amounted to 4 seconds of arc. This rate of tilting is about five times as rapid as the average for this season. It probably indicates a distinct increase of volcanic pressure beneath Kilauea during that period.

Several earthquakes originating beneath the slopes of Mauna Loa and along its northeast rift zone indicated some uneasiness of that volcano also. However, ground tilting in the east-west azimuth at the northeastern rim of Kilauea caldera was slightly westward at a rate approximately normal for this season. This suggests a lack of any marked change of volcanic pressure beneath Mauna Loa.

A feeble earthquake felt in Hilo and near Kilauea caldera at 20^h38^m on June 15 apparently had its origin beneath the eastern flank of Mauna Loa about 3 miles north-northeast of the Whitney Laboratory of Seismology. Another, felt in the same areas at 10^h47^m on June 27, originated beneath the eastern slope of Mauna Loa about 3 miles S. 60° E. of Puu Kulua. A slight earthquake at 00^h49^m on June 9 was felt in Hilo.

The Kona seismograph recorded 17 earthquakes during June. Most of them originated in central Kona near the seismograph station, probably on the Kealakekua fault.

July.—Seismographs of the Hawaiian Volcano Observatory recorded 82 earthquakes during July. Of these, 44 were recorded at Kilauea caldera, and 58 at the Mauna Loa station. Many were recorded at both stations, but the majority were too small to be recorded at any but the nearest station. The number of earthquakes was slightly greater than usual, but only two were strong enough to be felt. On July 26, at 13^h52^m, a moderate quake was felt from central Kona to the north end of the island. It apparently originated in the vicinity of Hualalai volcano. At 22^h24^m on July 28 a quake felt lightly in central Kona probably was of nearby origin.

During July tilting of the ground at the northeastern rim of Kilauea caldera continued northward at a rate slightly greater than normal. There appears to have been little change of volcanic pressure at Kilauea. From July 22 to 31 there was a marked westward tilting. This, together with northwestward tilting at the Mauna Loa station, suggests a decrease of pressure beneath Mauna Loa, accompanied by some subsidence of the mountain.

August.—Hawaiian volcanoes continued moderately uneasy throughout August. Seismographs at the observatory recorded 79 earthquakes during the month. Of these, 47 were recorded at the stations on the rim of Kilauea caldera, and 58 at the Mauna Loa station. Most of the quakes came from shallow foci on the northeast rift zone of Mauna Loa, or in the vicinity of Kilauea caldera.

Earthquakes felt strongly at Kapapala, and slightly from Naalehu to Kilauea caldera, at 6^h48^m on August 1, 17^h20^m on August 4, and 00^h46^m on August 6, originated on the southwest rift zone of Kilauea a short distance southwest of Mauna Iki. A quake felt strongly in central Kona at 03^h on August 8 originated nearby, probably on the Kealakekua fault.

An earthquake felt over the island of Hawaii, and by many persons on Maui and Oahu, at 19^h46^m on August 21 apparently originated beneath the northern slope of Hualalai volcano in the vicinity of Puu Waawaa. This is the area from which more than 6,000 earthquakes were recorded during September and October, 1929. Another earthquake, felt strongly in Kona and lightly over most of the rest of the island at 00^h53^m on August 23, originated beneath the southwestern slope of Hualalai, east of Holualoa.

Throughout August the ground surface at the northeastern rim of Kilauea caldera tilted northward at a rate somewhat greater than normal, and westward in place of the eastward tilting normal during that season. Some of this abnormal tilting may have been caused by the load imposed on the ground by the weight of the new addition to the Volcano House. It appears probable, however, that much of it was of volcanic origin, resulting from a decrease of volcanic pressure beneath Mauna Loa and an increase beneath Kilauea.

September.—The volcanoes continued to be seismically restless during September. A large number of very small earthquakes was recorded. Many of them apparently originated on or near the zone just south of the island from which the great number of quakes originated during March and April, 1952, preceding the eruption of Kilauea (Macdonald, 1955, p. 35–44). Several other quakes had their origins along the Kaoiki fault zone near Ainapo, and in central Kona. Two of these quakes, at 15^h on September 23 and 13^h20^m on September 27, were felt in Kona.

The ground surface at the northeastern rim of Kilauea caldera tilted northward throughout September at a rate slightly greater than normal for that season. Eastward tilting was at approximately the normal seasonal rate. The possible small increase of volcanic pressure under Kilauea, suggested by the northward tilting, was confirmed to some extent by the slight opening of cracks on the crater floor.

October.—Seismic unrest at Mauna Loa and Kilauea continued throughout October. A series of sharp earthquakes on October 26, 27, and 28 originated in Kilauea volcano. Four of these quakes, which had foci on the east rift zone of Kilauea, were felt in the Volcano area at 1^h07^m, 3^h36^m, and 4^h30^m on the 27th, and at 22^h58^m on the 28th. A continuous watch was maintained at Halemaumau crater from 4^h30^m on October 27 until late in the afternoon of the same day, when it appeared that the seismic crisis had passed.

Of about 20 small to moderate earthquakes originating along the southwest rift zone of Kilauea and the Kaoiki fault, 1 was felt at Pahala on October 9 at 6^h15^m, 1 at Naalehu on October 27 at 8^h02^m, and 3 were felt at the Kapapala Ranch headquarters on October 28 at 15^h50^m, 17^h03^m, and 21^h15^m.

Thirteen earthquakes were centered in Kona. Of these, 5 were felt. They occurred on October 2 at 22^h06^m, October 8 at 9^h22^m, October 15 at 17^h10^m, October 19 at 2^h33^m, and October 31 at 6^h15^m. In addition, earthquakes felt at Pepeekeo on October 23 at 14^h02^m and at Kukuihaele, in Kohala, on October 9 at 6^h15^m were recorded by the seismographs of the Hawaiian Volcano Observatory.

Although the number of earthquakes recorded during October was not unusually large, a surprising number of them were felt.

Northward tilting of the earth's surface at the Whitney Laboratory of Seismology on the northeast rim of Kilauea caldera continued at a rate slightly greater than normal for that season. Eastward tilting was at the normal seasonal rate. Increase of pressure under Kilauea possibly indicated by this excessive northward tilting was not confirmed by the further opening of cracks in the floor of the caldera.

November.—Seismic activity centered at Kilauea volcano during November. Of the 44 earthquakes rated as very feeble or stronger which were recorded during November, 21 originated at Kilauea, 8 originated at Mauna Loa, and 15 were recorded too weakly to be located.

Twelve of the Kilauean earthquakes centered very near the Hawaiian Volcano Observatory. Four of these were felt weakly in the Volcano area at 21^h32^m on November 22, 15^h38^m on November 28, 19^h44^m on November 29, and 13^h04^m on November 30.

The largest earthquake was felt quite generally over the southeastern part of the island and weakly as far as Kealakekua in Kona, and Kukuihaele in the northern part of the island. It occurred on November 29 at 20^h43^m, and originated on the east rift zone of Kilauea 10 miles from the Hawaiian Volcano Observatory, at a depth of about 10 miles.

A feeble earthquake recorded at 20^h37^m on November 8 was felt at Naalehu and probably centered along the coast south of Kilauea. Slight earthquakes were felt in Kealakekua at 20^h35^m on November 4 and in Kamuela at 9^h45^m on November 16, but neither was recorded at the Hawaiian Volcano Observatory.

Northward tilting of the ground at the northeastern rim of Kilauea caldera continued at a rate slightly greater than normal for that season, suggesting continued slight increase of pressure under Kilauea volcano.

December.—Many small earthquakes originating under Kilauea and Mauna Loa during December indicated that the Hawaiian volcanoes remained in a state of unrest. Of 51 quakes rated as very feeble or larger, which were recorded by the observatory's seismographs during the month, 17 originated at Kilauea.

Two quakes originated on the southeastern flank of Mauna Loa between its summit and the Kaoiki fault. Two of five quakes originating under the western slope of Mauna Loa were felt; one in Kalahiki (10.5 miles south of Kaelakekua) at 16^h16^m on December 14, the other in Captain Cook (1.5 miles south of Kealakekua) at 13^h on December 16.

Seismic activity at Kilauea continued to center around the caldera. Twelve of the 17 quakes at Kilauea originated within a few miles of the observatory. In addition, two quakes proceeded from epicenters on the southwest rift zone of Kilauea, and two others from epicenters along the coast south of Kilauea.

Earthquakes were felt in the Kohala district at 19^h42^m on December 11, 2^h53^m on December 12, and 19^h11^m on December 17. The second of these was not recorded on any of the observatory's seismographs.

The rate of northward tilting of the earth's surface at the northeastern rim of Kilauea caldera decreased, as is usual at that time of the year. Eastward tilting, however, proceeded at the same moderate rate which had prevailed since mid-August. Tilting generally slackens and changes to a westward direction during December, and its failure to do so this year suggests the possibility of some increase of pressure beneath Mauna Loa.

Between November 29 and December 5 the seismograph at the Mauna Loa station recorded a total of 735 earthquakes. Of these, 658 occurred on December 1. Most were very small, 713 were rated as tremors, 21 as very feeble earthquakes, and 1 as slight. The tremors had the characteristics of very small earthquakes, not of the so-called harmonic tremor that appears to accompany magma movement at depth. Most were recorded only at the Mauna Loa station, and their foci could not be located with certainty. However, one of the larger quakes, at 1^h56^m on December 1, was felt in Hilo, and its focus was located deep under the northeast rift zone of Mauna Loa. It is highly probable that the smaller quakes also had their origins on the northeast rift zone, and resulted from shifting along that zone. Thus both slightly abnormal eastward tilting and movement along its northeast rift zone suggest uneasiness of Mauna Loa volcano during December. Nevertheless, at the end of 1953 there were as yet no indications of imminent eruption.

NEW CHEMICAL ANALYSES

Chemical analyses of the lavas of three recent eruptions of Mauna Loa have been completed in the laboratory of the Geological Survey. These are listed in table 9, together with re-analyses of a prehistoric flow of Mauna Loa and three historic lavas of Kilauea. Earlier analyses of the last four rocks (Powers, 1931; Macdonald, 1949) were suspected of being erroneous because of lack of agreement with the mineralogical composition of the rocks (Powers, H. A., written communication). The new chemical analyses are in close agreement with the modal analyses, and consequently are regarded as probably more nearly correct than the previously published analyses.

The abundance of trace elements also was determined in the samples of the 1940 and 1949 flows of Mauna Loa, in the laboratory of the Geological Survey. These are listed in table 10, together with the percentages of trace elements in other Hawaiian rocks recently published by Wager and Mitchell (1953, p. 218).

TABLE 9.—*Chemical analyses of lavas of Mauna Loa and Kilauea*

[Analyst, L. N. Tarrant, unless otherwise noted]

1. Olivine basalt, Kaapuna flow of the 1950 eruption of Mauna Loa, at the highway. Analyst, Lucile M. Kehl.
2. Basalt, lava of 1940, Mokuaweoweo caldera near the gap into North Bay, Mauna Loa. Analyst, Lois D. Trumbull.
3. Basalt, lava of 1949, 100 feet southwest of the southwest edge of South Pit, on southwest rift zone of Mauna Loa. Analyst, Lois D. Trumbull.
4. Olivine basalt, lava of 1921, near south edge of Kilauea caldera. (Powers, 1931, p. 2, analysis 7; Macdonald, 1949, p. 74, analysis 14.)
5. Lava of 1917, splash from lava lake at Halemaumau, Kilauea. (Powers, 1931, p. 2, analysis 4; Macdonald, 1949, p. 74, analysis 8.)
6. Olivine basalt, lava of 1919, near northeast edge of Kilauea caldera. (Powers, 1931, p. 2, analysis 6; Macdonald, 1949, p. 74, analysis 12.)
7. Olivine basalt, prehistoric flow of Mauna Loa, at highway at southern boundary of Waiakea forest reserve, 1.65 miles northwest of the mill at Olaa. (Powers, 1931, p. 2, analysis 1; Macdonald, 1949, p. 63, analysis 5.)

	New analyses			Re-analyses			
	1	2	3	4	5	6	7
SiO_2	51.40	52.01	52.04	50.04	50.08	50.20	50.94
Al_2O_3	13.27	14.09	13.94	13.68	13.73	14.04	12.97
Fe_2O_3	2.72	1.46	1.58	2.29	1.32	1.83	1.95
FeO	8.66	9.77	9.69	9.05	9.79	9.50	8.96
MgO	9.14	7.04	7.14	7.61	7.89	7.03	10.68
CaO	10.04	10.74	10.63	11.38	11.50	11.49	9.88
Na_2O	2.13	2.23	2.25	2.24	2.18	2.25	1.99
K_2O	.31	.35	.33	.57	.56	.57	.37
H_2O+	.00	.02	.01	.00	.00	.01	.12
H_2O-	.04	.00	.02	.02	.02	.02	.04
TiO_2	1.91	2.08	2.05	2.76	2.60	2.74	1.78
CO_2	.00	.00	.00	.06	.01	.02	.04
P_2O_5	.22	.24	.26	.27	.26	.27	.21
SO_3	----	.01	.01	----	----	----	----
Cl	----	.00	.00	----	----	----	----
MnO	.17	.18	.18	.17	.17	.17	.17
Total	100.01	100.22	100.13	100.14	100.11	100.14	100.10

TABLE 10.—*Abundance of trace elements in Hawaiian lavas, in parts per million*

[Analyst, R. L. Mitchell (Wager and Mitchell, 1953, p. 218), unless otherwise noted]

1. Picrite basalt, lava flow of 1840 at Nanawale Bay Kilauea.
2. Picrite basalt, lava flow of 1868 at highway, Mauna Loa.
3. Olivine basalt, lava flow of 1919 at northeast edge of caldera floor, Kilauea (same rock as analysis 6, table 9, this report).
4. Basalt, lava flow of 1859 at highway, Mauna Loa.
5. Basalt, lava of 1940, Mokuaweoweo caldera near the gap into North Bay, Mauna Loa.
6. Basalt, lava of 1949, 100 feet southwest of southwest edge of South Pit on the southwest rift zone of Mauna Loa.
7. Basalt, lava flow of 1926 at highway, Mauna Loa.
8. Andesine andesite, western slope of Mauna Kea, on highway 6 miles south of Nohonaohae cone.
9. Andesine andesite, Laupahoehoe peninsula, Mauna Kea.
10. Oligoclase andesite, at an altitude of 2,900 feet in Moumoualoa Gulch, Kohala Mountain.
11. Oligoclase andesite, Puu Makea, Kohala Mountain.
12. Trachyte, Puu Anahulu, Hualalai.

	1	2	3	4	[1] 5	[1] 6	7	8	9	10	11	12
Ba	150	70	150	100	80	80	100	600	600	1,000	1,000	800
Be	----	----	----	----	----	----	----	----	----	----	----	8
Co	70	80	30	40	40	40	30	12	16	7	4	2
Cr	1,000	2,500	400	500	200	200	500	----	----	----	----	20
Cu	150	150	200	100	300	300	200	10	10	10	10	<10
Ga	15	20	25	25	5	5	20	20	20	25	20	25
La	----	----	----	----	----	----	----	30	20	70	150	100
Li	1	1	1	1	----	----	3	20	10	15	25	30
Mo	1	2	----	1	----	----	----	----	----	----	----	4
Ni	400	1,500	80	100	100	100	70	6	7	10	15	15
Rb	----	----	----	----	----	----	----	40	30	70	40	300
Sc	----	----	10	10	20	20	10	----	----	----	----	----
Sr	400	200	800	600	500	500	1,000	2,000	3,000	4,000	3,000	100
V	300	200	400	250	300	300	200	70	70	30	8	----
Y	20	20	20	25	60	60	20	60	50	150	100	150
Yb	----	----	----	----	20	20	----	----	----	----	----	----
Zr	100	50	100	50	800	800	150	300	400	1,000	1,500	1,500

[1] Elements looked for but not found: Ag, As, Au, B, Be, Bi, Cd, Ge, In, La, Mo, Nb, Pb, Pt, Sb, Sn, Ta, Th, Tl, U, W, and Zn. Analyst, P. R. Barnett.

PUBLICATIONS OF THE HAWAIIAN VOLCANO OBSERVATORY

In addition to the annual reports of the observatory, published as Bulletins of the Geological Survey, reports by staff members on volcanic conditions and features in Hawaii and elsewhere appear in several other publications. A report on earthquakes and ground tilting, and a summary of volcanic conditions, appears quarterly in the Volcano Letter, published by the University of Hawaii. Technical papers appear as the lead article in the Volcano Letter, and in other technical journals. The latter form a series known as Contributions of the Hawaiian Volcano Observatory. For the convenience of persons interested in Hawaiian volcanoes, there are listed below the technical papers published by members of the observatory staff since March 1947. Publications previous to that date are listed in the Bibliography of the Geology and Water Resources of the Island of Hawaii (Macdonald, 1947). The few papers by staff members dealing with areas other than Hawaii are included in the list.

The papers are listed chronologically, and for convenience are divided into those published in the Volcano Letter, and those published in the Contributions of the Hawaiian Volcano Observatory. The annual reports of the observatory are not included in the list, but are listed under the heading "Literature cited."

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