UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

HAWAIIAN VOLCANO OBSERVATORY

SUMMARY 13

January-March 1959

by

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Preface

The gradual improvement of instruments and techniques employed in recording events at Hawaiian volcanoes necessitates an occasional revision of the content and format of this summary. In such revision a compromise is sought between the need to summarize current data as fully as possible and the desirability of maintaining continuity in the type of data reported and the nature of its presentation.

In Summary 9 the local earthquake statistical summary was modified to eliminate its arbitrary dependence on the obsolete seismograph at the Whitney station, and the summary of tilting at Kilauea caldera was modified to permit a simpler, more useful presentation of the data. Revisions incorporated into the present summary (13) again involve local earthquakes and tilting. To permit the reporting of epicenters of local earthquakes with the added precision made possible by recent improvements in the seismograph network, epicenter locations will now be given in terms of geographic coordinates; and the map (fig. 2) has been provided with latitude and longitude guides. The pattern of tilting around Kilauea caldera delineated by the newly developed liquid-level tiltmeter bases* will also be displayed in summaries covering quarters during which measurements are made. Weekly indications of tilting at the Whitney station will be discontinued, for they have proved to be so strongly dependent on vagaries of temperature and rainfall as to be generally unreliable as an index to the swelling and shrinking of the volcano.

This summary also describes seismograph installations operated by the U.S. Geological Survey in Hawaii. Changes in the network will be reported in the summary covering the quarter during which they occur, and the entire network will be redescribed in the summary covering the first quarter of each year.

Chronological summary

Measurements made during the first week of February at tilt bases around Kilauea caldera revealed that the ground surface had tilted outward from the south edge of the caldera since October 1958. From a maximum rate of about 3 microradians per month at Uwekahuna and Summer Camp, tilting decreased rapidly at greater distances from the caldera.

*J. P. Eaton, A portable water-tube tiltmeter, Seism. Soc. Amer. Bull., v. 49, no. 4, p. 301-316, October 1959.

Tilting at Uwekahuna vault during the first quarter of 1959 was rather erratic and did not reflect the gentle swelling of the Kilauea summit indicated by the tilt bases around the caldera.

More than 1,000 earthquakes were recorded at Uwekahuna during January. About 400 of these originated at very shallow depths beneath Kilauea caldera. On January 5 and 6 about 600 small to moderate earthquakes and several hours of accompanying tremor from a source about 60 km deep and 10 km northeast of the caldera were registered by seismographs around the summit of Kilauea and at Hilo. Although 29 earthquakes of this swarm were of magnitude 2.5 or larger, none was felt.

The largest earthquake in the Hawaiian region during January occurred beneath the sea about 125 km south of Honolulu at 20°15' N., 157°55' W. on January 12 at 01^h05^m. Although its magnitude was 4.0, it was not felt.

An earthquake with a magnitude of only 1.6 which originated at a very shallow depth beneath Kilauea caldera was felt at the caldera at 16^h11^m on January 29. A magnitude 2.9 earthquake from an epicenter about 12 km east-northeast of Apua Point was felt in Hilo at 05^h33^m on January 30.

Only 175 earthquakes were recorded at Uwekahuna during February, marking a sharp decline in the number of shallow earthquakes beneath the caldera.

At 23^h29^m on February 9 a magnitude 3.5 earthquake from a source about 5 km south of the caldera and 10 km deep was felt at Kilauea caldera and at Hilo.

On the evening of February 19 three earthquakes from an origin about 12 km northeast of Apua Point and 5 km deep were felt at scattered points over most of the island of Hawaii. The first of these earthquakes, with a magnitude of 4.0, occurred at 19^h58^m. It was followed, at 20^h00^m, by a magnitude 4.5 earthquake, the largest earthquake in the Hawaiian region during February, which was felt at least as far away as Honokaa. The third earthquake, with a magnitude of 3.5, occurred at 20^h35^m.

The number of earthquakes recorded at Uwekahuna declined to 130 for March. Five of these were felt.

At 05^h32^m on March 5 a magnitude 3.5 earthquake from a focus 5 km deep and 10 km north-northwest of Apua Point was felt from the vicinity of the Desert seismograph station to Hilo.

The earthquake felt in Capt. Cook at 16^h45^m on March 6 originated beneath the ocean about 15 km west of Keahole Point. Its magnitude was 4.0.

An earthquake with a magnitude of 3.5 from a source 5 km southeast of Waikii and 15 km deep was felt at Pohakuloa at 04^h26^m on March 9. At 07^h45^m on March 12 a magnitude 4.0 earthquake with an epicenter 10 km southeast of Honokaa and a focal depth of about 15 km was felt at Kukuihaele (10 km northwest of Honakaa).

The earthquake which was felt at Kilauea caldera and Capt. Cook at 07^h49^m on March 17 emanated from a focus 10 km southeast of Mokuaweoweo and 5 km deep. Its magnitude was 3.5.

Briefly, this quarter may be summarized as a period of continuing, slow inflation of the summit of Kilauea. The swarm of tiny shallow earthquakes beneath Kilauea caldera which was so pronounced in January declined greatly during February and March.

Tilting of the ground around Kilauea caldera

Tilting of the ground around the summit of Kilauea is monitored daily by a short-base water-tube tiltmeter in Uwekahuna vault, and at irregular intervals it is measured on a regional scale by means of a network of field tilt bases and a portable water-tube tiltmeter (tables 1 and 2). The attitude of the ground surface at each tilt base is reported in terms of north-south and east-west tilt coordinates. Both coordinates at each station were arbitrarily set equal to 500 when measurements at that station were bugun. Increasing tilt coordinates correspond to northward and eastward tilting of the earth's surface, that is, to a relative subsidence toward the north and east. A 1-unit change in coordinate corresponds to a 1-microradian (1 mm per km) tilt in the direction indicated.

Seismic summary

Events recorded by the U.S. Geological Survey seismograph network in Hawaii fall into two categories: local earthquakes and tremor originating in the region of the Hawaiian Islands, usually within 100 km of the Observatory, and distant earthquakes originating farther than 3,000 km from Hawaii. As an index of seismic activity at Hawaiian volcanoes, weekly totals of earthquakes with magnitudes of 2.5 or greater, earthquakes with magnitudes less than 2.5, and minutes of continuous tremor, all recorded on the HVO-1 seismograph at Uwekahuna, are reported in table 3. Earthquakes of magnitude 2.5 or greater are generally sufficiently well recorded to be located; they are listed individually in table 4. Data on identifiable phases from distant earthquakes are listed in table 5.

Locations of the seismograph stations are shown on figure 2, and essential data on the stations are given in table 6.

Table 1.--Tilt coordinates at Uwekahuna vault, January-March 1959

Date	N-S	E-W	Date	N-S	E-W
Jan. 4	511	455	Feb. 22	506	456
11	513	457	Mar. 1	504	458
18	508	457	8	505	459
25	504	458	15	507	460
Feb. 1	506	456	22	507	464
8	504	457	29	511	466
15	504	458			

Table 2.--Tilt coordinates and changes at tilt bases around Kilauea caldera (see fig. 1)

Tilt base (location)	Date (1959)	Tilt coordinates		Direction and rate of tilting since last reading (10^{-6} rad/mo)		Date of last reading (1958)
		N-S	E-W			
Uwekahuna (19°25.5' N., 155°17.4' W.)	Feb. 2	543.9	472.7	3.3	N. 33° W.	Oct. 2
Tree Molds (19°26.3' N., 155°17.3' W.)	Feb. 5	508.6	499.0	2.2	N. 7° W.	Oct. 9
Summer Camp (19°24.6' N., 155°15.6' W.)	Feb. 8	508.4	427.1	3.1	N. 77° E.	Oct. 7
Sand Spit (19°24.1' N., 155°16.8' W.)	Feb. 8	505.1	494.1	2.4	N. 49° W.	Oct. 31
Kalihipaa (19°21.4' N., 155°15.3' W.)	Feb. 9	495.9	503.3	0.9	S. 42° E.	Oct. 6
Keamoku (19°25.1' N., 155°19.0' W.)	Mar. 2	500.0	500.0	---	---------	-------
Kamokukolau (19°22.7' N., 155°16.6' W.)	Mar. 4	500.0	500.0	---	---------	-------

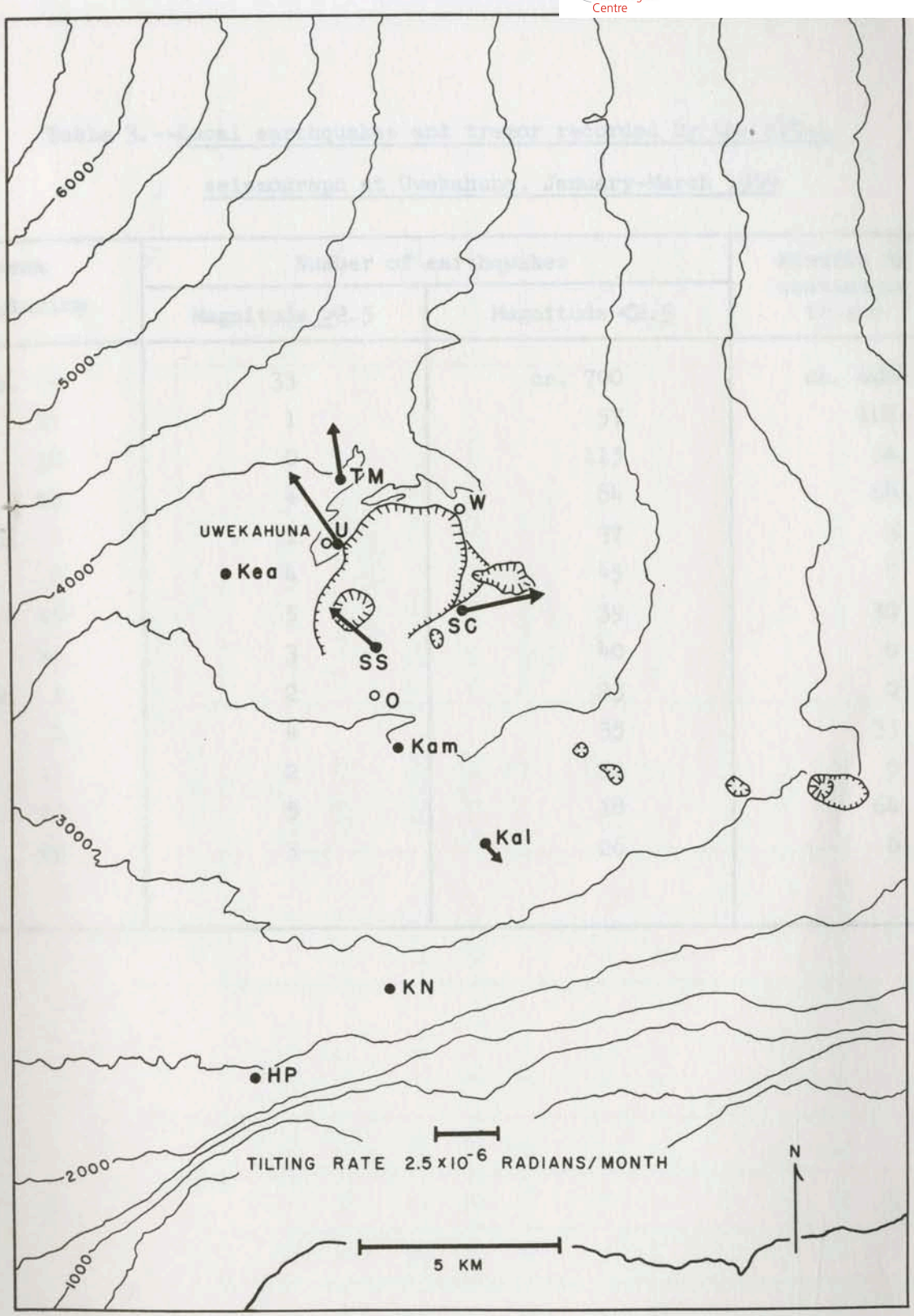

Figure 1.--Tilting of the ground around Kilauea caldera, Oct. 6, 1958, to Feb. 6, 1959. The vector depicting tilting at a given tilt base points in the direction of maximum relative subsidence and has a length proportional to the rate of tilting during the measurement interval. Closed circles represent field tilt bases; open circles, short-base water-tube tiltmeters.

Table 3.--Local earthquakes and tremor recorded by the HVO-1 seismograph at Uwekahuna, January-March 1959

Week beginning	Number of earthquakes		Minutes of continuous tremor
	Magnitude ≥2.5	Magnitude <2.5	
Jan. 4	33	ca. 700	ca. 400
11	1	57	106
18	0	115	14
25	4	84	68
Feb. 1	1	37	3
8	4	45	0
15	5	39	30
22	3	40	0
Mar. 1	2	23	0
8	4	35	33
15	2	32	0
22	5	18	64
29	3	26	0

Table 4.--Local earthquakes recorded by seismographs of the U.S. Geological Survey, January-March 1959

[Except for smaller earthquakes of special interest, only earthquakes with magnitudes of 2.5 or greater are listed. Time is Hawaiian standard]

Date	Time			Magnitude	Epicenter			Remarks
	h	m	s		Latitude	Longitude	Description	
					N	W		
Jan. 1	18	36	00	2.5	19°21'	155°56'	5 km SW of Hookena-------	Depth about 15 km.
2	00	19	39	2.8	19°25'	155°26'	10 km NW of Desert seismograph.	Depth about 5 km.
2	04	15	08	2.8	19°29'	155°56'	5 km SSW of Kealakekua---	Do.
3	03	04	35	2.5	19°26'	155°56'	4 km WNW of Honaunau-----	Depth about 10 km.
3	18	25	38	2.9	19°26'	155°16'	Beneath NE rim of Kilauea caldera.	30 km deep.
5	07	35	17	2.6	19°33'	155°39'	10 km NW of Mokuaweoweo--	At shallow depth.
5	15	41	34	2.5	19°29'	155°13'	10 km NE of Uwekahuna----	Depth about 60 km. One of several hundred small earthquakes from this source Jan. 5-6.
5	16	25	26	2.9	--do---	---do---	-----do-----------	Do.
5	16	35	31	2.5	--do---	---do---	-----do-----------	Do.
5	18	00	10	2.5	--do---	---do---	-----do-----------	Do.

Table 4.--Local earthquakes recorded by seismographs of the U.S. Geological Survey, January-March 1959--Continued

Date	Time			Magnitude	Epicenter			Remarks
	h	m	s		Latitude	Longitude	Description	
					N	W		
Jan. 5	18	07	22	2.6	19°29'	155°13'	10 km NE of Uwekahuna----	Depth about 60 km. One of several hundred small earthquakes from this source Jan. 5-6.
5	19	30	42	3.2	--do---	---do---	-----do----------	Do.
5	20	55	13	2.7	--do---	---do---	-----do----------	Do.
5	21	13	04	2.8	--do---	---do---	-----do----------	Do.
5	22	03	46	2.5	--do---	---do---	-----do----------	Do.
5	22	09	04	2.5	--do---	---do---	-----do----------	Do.
5	22	33	17	2.5	--do---	---do---	-----do----------	Do.
5	22	34	03	2.5	--do---	---do---	-----do----------	Do.
5	22	54	53	2.9	--do---	---do---	-----do----------	Do.
5	23	01	02	2.9	--do---	---do---	-----do----------	Do.
6	00	21	24	2.5	--do---	---do---	-----do----------	Do.
6	02	39	24	3.0	--do---	---do---	-----do----------	Do.
6	04	01	32	2.7	--do---	---do---	-----do----------	Do.

Table 4.--Local earthquakes recorded by seismographs of the U.S. Geological Survey,

January-March 1959--Continued

Date	Time			Magnitude	Epicenter			Remarks
	h	m	s		Latitude	Longitude	Description	
					N	W		
Jan. 6	04	09	21	2.9	19°29'	155°13'	10 km NE of Uwekahuna---	Depth about 60 km. One of several hundred small earthquakes from this source Jan. 5-6.
6	04	25	13	2.5	---do---	---do---	-----do-----------	Do.
6	04	35	18	2.5	---do---	---do---	-----do-----------	Do.
6	05	13	03	2.8	---do---	---do---	-----do-----------	Do.
6	05	46	49	2.9	---do---	---do---	-----do-----------	Do.
6	06	36	26	2.8	---do---	---do---	-----do-----------	Do.
6	06	42	17	2.5	---do---	---do---	-----do-----------	Do.
6	10	38	20	2.5	---do---	---do---	-----do-----------	Do.
6	11	50	24	2.8	---do---	---do---	-----do-----------	Do.
6	12	08	35	3.6	20°45'	155°32'	120 km east of Hana, Maui.	Depth about 15 km.

Table 4.--Local earthquakes recorded by seismographs of the U.S. Geological Survey,

January-March 1959--Continued

Date	Time			Magnitude	Epicenter			Remarks
	h	m	s		Latitude	Longitude	Description	
					N	W		
Jan. 6	13	20	54	2.5	19°29'	155°13'	12 km NE of Uwekahuna---	Depth about 60 km.
6	14	51	12	2.7	---do---	---do----	-----do----------	Do.
6	19	03	14	2.7	---do---	---do----	-----do----------	Do.
7	17	37	43	2.5	19°26'	155°28'	10 km SW of Mauna Loa seismograph.	Depth about 5 km.
10	08	58	32	3.2	19°19'	155°10'	7 km NNE of Apua Point--	At shallow depth.
12	01	05	15	4.0	20°15'	157°55'	125 km south of Honolulu.	Depth about 15 km.
26	00	36	43	2.6	19°24'	155°29'	13 km NW of Desert seismograph.	Depth about 5 km.
29	16	10	45	1.6	19°25'	155°17'	Felt at Kilauea caldera-	At shallow depth.
30	01	16	17	2.7	19°22'	155°25'	5 km NW of Desert seismograph.	Depth about 10 km.

Table 4.--Local earthquakes recorded by seismographs of the U.S. Geological Survey,

January-March 1959--Continued

Date	Time			Magnitude	Epicenter			Remarks
	h	m	s		Latitude	Longitude	Description	
					N	W		
Jan. 30	05	32	41	2.9	19°19'	155°07'	12 km ENE of Apua Point. Felt in Hilo.	Depth about 10 km.
Feb. 5	13	28	12	2.7	20°00'	155°34'	10 km east of Kamuela---	Depth about 15 km.
9	23	28	51	3.5	19°21;	155°17'	5 km south of Outlet seismograph. Felt at Kilauea caldera and Hilo.	Depth about 10 km.
10	14	01	44	2.6	19°23'	155°25'	7 km NW of Desert seismograph.	Depth about 5 km.
10	19	10	27	2.5	19°13'	155°13'	5 km SW of Apua Point---	Do.
13	02	30	40	2.5	19°22'	155°19'	5 km SW of Outlet seismograph.	Do.

Table 4.--Local earthquakes recorded by seismographs of the U.S. Geological Survey,

January-March 1959--Continued

Date	Time			Magnitude	Epicenter			Remarks
	h	m	s		Latitude	Longitude	Description	
					N	W		
Feb. 17	19	50	53	3.0	19°45'	156°12'	15 km west of Keahole Point.	Depth about 15 km.
19	19	58	01	4.0	19°21'	155°09'	12 km NE of Apua Point. Felt at scattered points over the Island of Hawaii (Capt. Cook, Honokaa, Hilo, Hawaii National Park).	Depth about 5 km.
19	20	00	28	4.5	--do---	---do---	-----do----------	Do.
19	20	35	04	3.5	--do---	---do---	-----do----------	Do.
20	16	04	08	3.4	19°13'	156°23'	50 km west of Milolii--	Depth about 10 km.
26	00	10	27	3.4	19°29'	156°28'	60 km west of Kealakekua Bay.	Depth about 15 km.
28	00	24	17	3.2	19°13'	155°32'	7 km west of Pahala----	At shallow depth.
28	06	54	54	3.2	19°26'	155°29'	20 km west of Uwekahuna	Depth about 5 km.

Table 4.--Local earthquakes recorded by seismographs of the U.S. Geological Survey.

January-March 1959--Continued

Date	Time			Magnitude	Epicenter			Remarks
	h	m	s		Latitude	Longitude	Description	
					N	W		
Mar. 5	05	32	10	3.5	19°20'	155°13'	10 km NNW of Apua Point. Felt from Kapapala (10 km SW of Desert seismograph) to Hilo.	Depth about 5 km.
6	16	45	15	4.0	19°44'	156°12'	15 km west of Keahole Point. Felt at Capt. Cook.	Depth about 15 km.
9	04	25	42	3.5	19°50'	155°38'	5 km SE of Waikii. Felt at Pohakuloa.	Do.
9	10	16	33	2.8	19°22'	155°26'	7 km NW of Desert seismograph.	Depth about 10 km.
10	21	08	58	2.5	19°23'	155°20'	7 km SW of Uwekahuna on SW rift zone of Kilauea.	Do.
12	07	44	55	4.0	20°01'	155°25'	10 km SE of Honokaa. Felt at Kukuihaele (10 km NW of Honokaa).	Depth about 15 km.
17	07	49	07	3.5	19°24'	155°32'	10 km SE of Mokuaweoweo caldera. Felt at Kilauea caldera and Capt. Cook.	Depth about 5 km.

Table 4.--Local earthquakes recorded by seismographs of the U.S. Geological Survey,

January-March 1959--Continued

Date	Time			Magnitude	Epicenter			Remarks
	h	m	s		Latitude	Longitude	Description	
					N	W		
Mar. 21	05	37	31	2.7	19°26'	155°33'	7 km SE of Mokuaweoweo caldera.	Depth about 15 km.
22	00	40	19	3.0	19°26'	155°16'	Beneath NE rim of Kilauea caldera.	35 km deep.
22	00	58	01	2.6	19°26'	155°30'	20 km west of Uwekahuna-	At shallow depth.
24	01	16	52	2.6	19°23'	155°16'	2 km east of Outlet seismograph.	Depth about 10 km.
25	07	27	14	2.7	20°02'	155°25'	8 km SE of Honokaa------	Depth about 15 km.
25	12	51	13	3.0	19°14'	155°11'	3 km south of Apua Point.	Do.
29	10	52	31	2.6	19°23'	155°18'	2 km west of Outlet seismograph.	Depth about 10 km.
30	01	39	01	3.2	19°12'	155°33'	15 km north of Naalehu--	At shallow depth.

Table 5.--Distant earthquakes

[Times are reported in Greenwich civil time, which is 10 hours faster than Hawaiian standard time. A "c" following the time of P indicates that the first motion was a compression; a "d", that it was a dilatation. Station symbols, locations, and instrumentation are presented in table 6. Locations of epicenters, origin times, focal depths, and magnitudes are from the notices of Preliminary Determination of Epicenters published by the U.S. Coast and Geodetic Survey.]

Jan. 5				
M	Z	iP	09:56:03.1	c
O	Z	iP	09:56:02.5	c
D	Z	iP	09:56:01.6	c
U	Z	iP	09:56:02.5	c
U	PEZ	eS	10:03:35	
U	PEZ	eR	10:11:07	
171-1/2° E., 22° S., 09:46:42 Loyalty Is. region Magnitude 6-1/2 to 6-3/4				
Jan. 13				
U	PEZ	eR	01:41:16	
13-1/2° N., 146° E., 01:15:25 Mariana Is. Magnitude 6-3/4				
Jan. 13				
O	Z	eP	08:45:20.7	
9° N., 33-1/2° W., 08:34:08 Costa Rica region h = 100				
Jan. 15				
M	Z	iP	21:28:45.3	c
O	Z	eP	21:28:45.6	c
D	Z	eP	21:28:44.7	c
U	Z	iP	21:28:44.7	c
Hi	Z	iP	21:28:47.6	c
25-1/2° S., 180° South of Fiji Is. h = 500 Magnitude 6-1/2				
Jan. 16				
M	Z	eP	01:38:16.4	
D	Z	e	01:38:16.7	
U	Z	eP	01:38:20.6	
U	PEZ	eS	01:43:29	
U	PEZ	eR	01:47:36	
52° N., 171° W., 01:31:25 Fox Is. Aleutian Is. h = 60				

Table 5.--Distant earthquakes--Continued

Jan. 16

M	Z	T	17:37	
O	Z	T	17:37	
D	Z	T	17:37	
U	Z	T	17:37	
Hi	Z	T	17:37	
Ha	Z	T	17:36	

52° N., 131-1/2° W.
Queen Charlotte Is.

Jan. 22

M	Z	eP	05:20:11.3	
O	Z	e	05:20:15.9	
D	Z	e	05:20:10.9	
U	Z	eP	05:20:13.7	c
U	PEZ	iP	05:20:13.5	d
U	PEZ	iS	05:28:06	
U	PEN	eQ	05:33:36	
U	PEZ	iR	05:36:02	
Hi	Z	eP	05:21:04.8	d
Ha	Z	e	05:21:04.8	

34° N., 142° E., 05:10:25
Coast of Honshu, Japan
Magnitude 6-3/4 to 7

Jan. 24

M	Z	iP	05:18:23.6	
O	Z	e	05:18:23.3	
D	Z	e	05:18:23.8	
Hi	Z	eP	05:18:23.1	
Hi	Z	ipP	05:18:46.9	

37-1/2° N., 141° E., 05:08:35
Coast of Honshu, Japan
h = 100

Jan. 24

O	Z	eP	19:52:28.9	
D	Z	e	19:52:29.4	

15° N., 92-1/2° W., 19:42:20
Mexico-Guatemala border
Magnitude 6-1/4

Jan. 26

U	Z	iP	05:55:42.9	

16-1/2° S., 174-1/2° W., 05:48:27
Samoa Is. region
H = 300

Jan. 29

U	Z	eP	20:28:18.7	
U	PEZ	eR	20:37:26	

52° N., 174° W., 20:21:27
Andreanof Is. Aleutian Is.
Magnitude 5-3/4 to 6

Table 5.--Distant earthquakes--Continued

Jan. 30

M	Z	iP	00:28:38.5	c
O	Z	iP	00:28:37.6	c
D	Z	iP	00:28:38.5	c
U	Z	iP	00:28:38.3	c
U	PEZ	eR	00:42:52	
Hi	Z	iP	00:28:38.6	c
Ha	Z	iP	00:28:38.6	c

10° S., 161° E., 00:19:25
Solomon Is.
Magnitude 6-3/4

Jan. 30

M	Z	iP	18:18:49.6	d
O	Z	iP	18:18:49.2	d
D	Z	iP	18:18:48.3	d
U	Z	iP	18:18:49.5	d
Hi	Z	iP	18:18:51.9	d
Ha	Z	iP	18:18:55.0	d

31° S., 179° W., 18:09:02
Kermadec Is.

Jan. 30

U	PEZ	eR	21:04:17

44° N., 144° E., 20:38:58
Hokkaido, Japan
Magnitude 5-3/4 to 6

Jan. 30

M	Z	iP	22:26:27.6
U	PEE	iS	22:34:19
U	PEZ	iR	22:41:59

44° N., 144° E., 22:16:47
Hokkaido, Japan
Magnitude 6-1/4

Feb. 2

M	Z	iP	04:08:18.1	d
O	Z	iP	04:08:18.5	d

6-1/2° S., 126° E., 03:56:12
Banda Sea
h = 150

Feb. 5

M	Z	iP	01:12:01.9
O	Z	iP	01:12:02.4
D	Z	iP	01:12:02.7
Hi	Z	iP	01:12

57-1/2° N., 157-1/2° W., 01:40:50
Alaska Peninsula
h = 100

Table 5.--Distant earthquakes--Continued

		Feb. 6		
M	Z	iP	14:40:03.1	c
O	Z	iP	14:40:03.6	c
D	Z	iP	14:40:03.7	c
U	Z	iP	14:40:03.1	d
U	Z	i	14:40:18.0	
U	Z	Tmax	15:18:42	
U	PEZ	eS	14:45:49	
U	PEZ	eR	14:48:48	
Hi	Z	eP	14:40:02.2	c
Hi	Z	i	14:40:16.6	
Ha	Z	eP	14:39:49.1	c
Ha	Z	i	14:40:04.8	
Ha	Z	Tmax	15:16:25	

51-1/2° N., 175-1/2° W., 14:33:02
Andreanof Is. Aleutian Is.
Magnitude 6

		Feb. 7		
M	Z	iP	09:48:43.8	c
M	Z	i	09:48:57.8	
O	Z	iP	09:48:43.0	c
O	Z	i	09:48:57.1	
D	Z	iP	09:48:43.6	c
D	Z	i	09:48:57.5	
U	Z	eP	09:48:42.8	d
U	Z	i	09:48:56.7	
U	PEZ	iP	09:48:42.0	c
U	PEE	iS	09:58:23.8	
U	PEN	iS	09:58:26.6	
U	PEZ	iS	09:58:27.8	
U	PEN	iG	10:08:29	
U	PEZ	iR	10:11:11	
Hi	Z	iP	09:48:42.2	d
Ha	Z	eP	09:48:52.1	c

4° S., 81-1/2° W., 09:36:51
Coast of Peru
Magnitude 7-1/4

Table 5.--Distant earthquakes--Continued

Feb. 7

M	Z	iP	10:21:22.0	d
O	Z	iP	10:21:22.6	d
D	Z	iP	10:21:22.0	d
U	Z	iP	10:21:24.1	d
Hi	Z	iP	10:21:24.1	
Ha	Z	iP	10:21:15.9	d

16° N., 146° E., 10:11:39
Mariana Is.

Feb. 8

M	Z	iP	05:54:13.2	c
O	Z	iP	05:54:13.0	c
U	Z	iP	05:54:13.5	c
Hi	Z	iP	05:54:16.7	c
Ha	Z	iP	05:53:19.8	c

23° S., 180°, 05:46:15
South of Fiji
h = 600

Feb. 9

M	Z	eP	04:49:28.9
O	Z	eP	04:49:33.3
D	Z	e	04:49:34.3
U	Z	iP	04:49:33.2
Hi	Z	eP	04:49:28.0

50-1/2° N., 177-1/2° W., 04:42:33
Andreanof Is. Aleutian Is.

Feb. 9

M	Z	eP	21:22:55.9
O	Z	e	21:22:55.6
D	Z	e	21:22:55.5
U	PEZ	eR	21:38:37
Hi	Z	iP	21:22:57.6
Hi	Z	epP	21:23:18.1
Ha	Z	eP	21:22:53.5

5° S., 154° E., 21:13:18
Solomon Is.
h = 100

Table 5.--Distant earthquakes--Continued

Feb. 11

M Z iP 14:16:50.4 c

O Z iP 14:16:49.5 c

16° N., 97° W., 13:52:13
Coast of Oaxaca, Mexico
Magnitude 6

Feb. 11

U PEZ eR 21:53:39

15° S., 173-1/2° W., 21:36:46
Samoa Is. region

Feb. 15

U PEZ eR 04:59:12

59-1/2° S., 26° W., 04:42:35
Sandwich Is.
Magnitude 6-3/4

Feb. 17

M Z iP 12:09:52.1 c

O Z iP 12:09:53.0 c

D Z iP 12:09:53.1 c

U Z eP 12:09:52.7 d

U PEZ iS 12:15:21

U PEE iQ 12:16:59

U PEZ iR 12:17:08

51-1/2° N., 171° W., 12:03:05
Fox Is., Aleutian Is.
Magnitude 6 to 6-1/4

Feb. 23

U PEZ eR 02:26:05

5-1/2° S., 150° E., 01:58:38
New Britain

Feb. 23

M Z iP 10:39:53.6

53-1/2° N., 159° E., 10:31:14
Kamchatka
h = 100

Feb. 27

M Z eP 21:07:43.1

U PEZ eR 21:28:13

27-1/2° N., 129° E., 20:56:30
Ryukyu Is.

Mar. 1

M Z eP 17:00:33.6

U Z iP 17:00:35.2

U PEZ eP 17:00:38

U PEN eS 17:10:00

U PEN iQ 17:18:44

U PEZ iR 17:21:55

Hi Z iP 17:00:39.5

Ha Z iP 17:00:33.7

1/2° S., 134-1/2° E., 16:49:13
Coast of New Guinea
Magnitude 7
h = 100

Table 5.--Distant earthquakes--Continued

Mar. 3

Ha Z Tmax 00:09:41

37-1/2° N., 122° W., 23:27:15
Coast of California
Magnitude 4.9

Mar. 12

U PEZ eS 01:47:32

U PEN eQ 01:53:10

U PEZ iR 01:56:20

7° N., 145° E., 01:29:07
Caroline Is.
Magnitude 6

Mar. 17

M Z eP 08:36:27.8

O Z iP 08:36:26.2 d

D Z iP 08:36:25.5 d

U Z eP 08:36:26 d

U PEZ eP 08:36:27 d

U PEZ eR 09:01:37

Hi Z eP 08:36:27.4 c

27-1/2° N., 130° E., 08:25:22
Ryuku Is.
Magnitude 5-3/4 to 6

Mar. 19

U PEZ eR 09:13:20

35° N., 36° W., 08:25:32
North Atlantic
Magnitude 6-1/4

Mar. 23

U PEN eQ 07:26:43

40° N., 118° W., 07:10:22
Western Nevada
Magnitude 6-1/4

Mar. 24

U PEZ eR 17:45:17

34° N., 142° E., 17:18:24
Coast of Honshu, Japan

Mar. 28

Hi Z iP 19:54:40.2

20° S., 178-1/2° W., 19:47:07
Fiji Is.
Magnitude 5-3/4 to 6
h = 600

Mar. 31

U PEE eQ 07:38:45

15° S., 173° W., 07:20:45

Samoa Is.
Magnitude 6

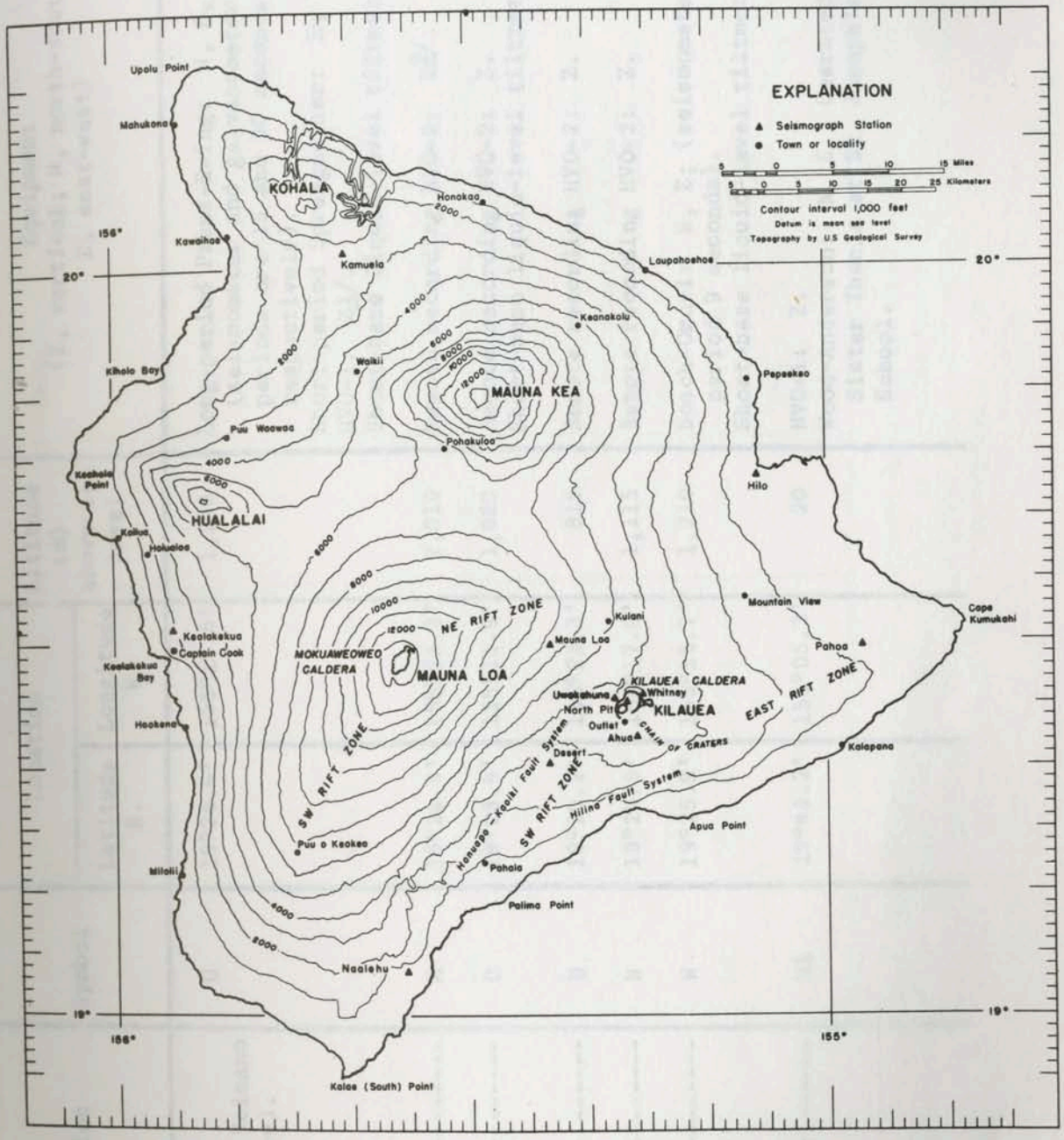

Figure 2.--Map of the Island of Hawaii showing seismograph stations operated by the Geological Survey and localities mentioned in the text. Epicenters of local earthquakes are given in terms of geographic coordinates, which are indicated at the edges of the map.

Table 6.--U.S. Geological Survey seismograph stations in Hawaii

Station	Symbol	Location		Altitude (m) above sea level	Equipment (Z, vertical; N, north-south; E, east-west)
		Latitude N.	Longitude W.		
Uwekahuna (Hawaiian Volcano Observatory).	U	19°25.4'	155°17.6'	1,240	Long-period Press-Ewing: N, E, Z; (seismometer and galvanometer periods are 15 and 90 seconds, respectively). Short-period Sprengnether: E, Z. HVO-1: Z[1/]. Short-base liquid-level tiltmeter.
Mauna Loa----------	M	19°29.8'	155°23.3'	2,010	Remote recording HVO-2: Z[2/].
Outlet----------	O	19°23.4'	155°16.9'	1,080	Remote recording HVO-2: Z. Short-base liquid-level tiltmeter.
Desert----------	D	19°20.2'	155°23.3'	815	Remote recording HVO-2: Z.
North Pit----------	N	19°24.9'	155°17.0'	1,115	Remote recording HVO-2: Z.
Whitney----------	W	19°25.9'	155°15.7'	1,210	Bosch-Omori: N, E; (seismometer period 9 seconds). Short-base liquid-level tiltmeter.
Hilo----------	Hi	19°43.2'	155°05.3'	20	HVO-1: Z. Wood-Anderson: N, E. Operated by Sister Thecla at St. Joseph's School.

Table 6.--U.S. Geological Survey seismograph stations in Hawaii--Continued

Station	Symbol	Location		Altitude (m) above sea level	Equipment (Z, vertical; N, north-south; E, east-west)
		Latitude N.	Longitude W.		
Naalehu----------	Na	19°03.8'	155°35.2'	205	Loucks-Omori: N, E; (seismometer period 3 seconds). Operated by Mr. Alfred Kahakua at Naalehu School.
Pahoa----------	Pa	19°29.7'	154°56.8'	205	Loucks-Omori: N, E; (seismometer period 3 seconds). Operated by Mr. Kongo Kimura at Pahoa School.
Kamuela----------	Ka	20°01.3'	155°40.3'	815	Loucks-Omori: N, E; (seismometer period 3 seconds). Operated by Mr. T. C. Mills at Waimea School.
Konawaena----------	Ko	19°30.8'	155°55.1'	495	Hawaiian-type seismograph: N, E; (seismometer period 9 seconds). Operated by Mr. Howard Tatsuno at Konawaena School.
Haleakala, Maui----	Ha	20°46.0'	156°15.0'	2,090	HVO-1: Z. Wood-Anderson: N, E. Operated by the staff of Hawaii National Park at Haleakala, Maui.

1/ HVO-1 is a moving-coil, hinged, vertical-component seismograph with seismometer and galvanometer periods of 0.5 second. Overdamping of both seismometer and galvanometer is used to control the strong galvanometer reaction. This seismograph has a peak magnification of about 20,000 at a period of 0.25 second. Recording is optical, on photographic paper.

Table 6.--U.S. Geological Survey seismograph stations in Hawaii--Continued

2/ HVO-2 is a moving-coil, vertical-component seismograph with a seismometer period of 0.8 second. Its signal is transmitted over telephone wires to the Hawaiian Volcano Observatory, where it is recorded on smoked paper. The response of this seismograph is similar to that of HVO-1. Records from these seismographs at the M, O, and D stations are recorded on a 3-component drum to permit an accurate comparison of arrival times at these stations.

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SUMMARY 14

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HAWAIIAN VOLCANO OBSERVATORY SUMMARY 14

By J. P. Eaton and H. L. Krivoy

Chronological summary

Releveling of tilt bases around Kilauea caldera in late April and early May disclosed that the pattern of tilting around the caldera during February, March, and April was somewhat more complicated than during the preceding few months. Tilting rates were moderate at all stations, averaging about 4 microradians per month, with a maximum of 10.3 at Sand Spit and a minimum of 1.1 at Uwekahuna. All stations except Uwekahuna and Tree Molds, both on the northwest rim of the caldera, tilted away from an east-northeast to west-southwest axis just southeast of the caldera. Moderate tumescence along this axis and a slight relative collapse along the northwest rim of the caldera are suggested by the tilt pattern.

During April, 138 earthquakes were recorded at Uwekahuna. Three of these, with magnitudes between 2 and 2.5, occurred beneath the summit of Kilauea at depths of 10 to 30 km.

The largest earthquake in the Hawaiian region during April came from a focus 35 km deep and 20 km east of the summit of Haleakala volcano on Maui at 17^h34^m on April 24. It has a magnitude of 3.5.

No earthquakes were reported felt during April.

Only 137 earthquakes were recorded at Uwekahuna during May, and none was reported felt.

On May 5 a small swarm of tiny, deep earthquakes accompanied by about 4 hours of very weak spasmodic tremor stemmed from a zone about 10 km north of Kilauea caldera and 65 km deep. The largest of these earthquakes occurred at 17^h51^m and had a magnitude of only 2.2. About 60 distinct earthquakes from this swarm appeared on the Mauna Loa seismograph.

At 14^h28^m on May 7 a magnitude 3.1 earthquake originated about 5 km southwest of Halemaumau at a depth of about 30 km. The largest earthquake in Hawaii during May originated about 3 km southwest of Halemaumau at a depth of about 30 km at 06^h35^m on the 20th. Although it had a magnitude of 3.5, it was not reported felt.

The number of earthquakes recorded at Uwekahuna declined to 95 during June. Five of these, with magnitudes between 2 and 2.5, occurred beneath the summit region of Kilauea at depths ranging from 15 to 30 km.

Four earthquakes were felt in Hawaii during June. The earthquake felt on Maui at 04^h31^m on June 3 originated beneath the sea about 5 km east of Huelo Point. Its magnitude was 3.3. A magnitude 2.8 earthquake that occurred about 5 km northwest of the Desert seismograph at 21^h26^m on June 9 was felt at Kilauea caldera. An earthquake from a focus 15 km deep beneath the southwest end of Mokuaweoweo caldera at 20^h01^m on June 24 was felt from Kilauea caldera to Capt. Cook. It had a magnitude of 3.7.

The largest earthquake in the Hawaiian region during June originated beneath the sea about 50 km west of Mililii at 12^h17^m on the 26th. It had a magnitude of 4.2 and was felt in Capt. Cook.

Tilting of the ground around Kilauea caldera

Tilting of the ground around the summit of Kilauea is monitored daily by a short-base water-tube tiltmeter in Uwekahuna vault, and at irregular intervals it is measured on a regional scale by means of a network of field tilt bases and a portable water-tube tiltmeter (tables 1 and 2). The attitude of the ground surface at each tilt base is reported in terms of north-south and east-west tilt coordinates. Both coordinates at each station were arbitrarily set equal to 500 when measurements at that station were begun. Increasing tilt coordinates correspond to northward and eastward tilting of the earth's surface, that is, to a relative subsidence toward the north and east. A 1-unit change in coordinate corresponds to a 1 microradian (1 mm per km) tilt in the direction indicated.

Seismic summary

Events recorded by the U.S. Geological Survey seismograph network in Hawaii fall into two categories: local earthquakes and tremor originating in the region of the Hawaiian Islands, usually within 100 km of the Observatory, and distant earthquakes originating farther than 3,000 km from Hawaii. As an index of seismic activity at Hawaiian volcanoes, weekly totals of earthquakes with magnitudes of 2.5 or greater, earthquakes with magnitudes less than 2.5, and minutes of continuous tremor, all recorded on the HVO-1 seismograph at Uwekahuna, are reported in table 3. Earthquakes of magnitude 2.5 or greater are generally sufficiently well recorded to be located; they are listed individually in table 4. Data on identifiable phases from distant earthquakes are listed in table 5.

Locations of the seismograph stations are shown on figure 2; and essential data on the stations were given in Summary 13, table 6.

Table 1.--Tilt coordinates at Uwekahuna vault, April-June 1959

Date	N-S	E-W	Date	N-S	E-W
Apr. 5	512	464	May 24	515	470
12	512	466	31	515	469
19	513	468	June 7	515	466
26	513	469	14	515	470
May 3	513	471	21	515	474
10	515	469	28	518	474
17	514	471			

Table 2.--Tilt coordinates and changes at tilt bases around Kilauea caldera (see fig. 1)

Tilt base (location)	Date (1959)	Tilt coordinates		Rate and direction of tilting since last reading (10^{-6} rad/mo)		Date of last reading (1959)
		N-S	E-W			
Uwekahuna (19°25.5' N., 155°17.4' W.)	Apr. 27	544.2	469.8	1.1	N. 84° W.	Feb. 2
Tree Molds (19°26.3' N., 155°17.3' W.)	Apr. 28	502.1	498.7	2.4	S. 2° W.	Feb. 5
Summer Camp (19°24.6' N., 155°15.6' W.)	May 4	517.7	528.0	3.3	N. 5° E.	Feb. 8
Sand Spit (19°24.1' N., 155°16.8' W.)	May 4	531.1	482.8	10.0	N. 23° W.	Feb. 8
Kalihipaa (19°21.4' N., 155°15.3' W.)	Apr. 28	487.3	502.4	3.4	S. 6° W.	Feb. 9
Keamoku (19°25.1' N., 155°19.0' W.)	May 12	512.8	498.6	5.4	N. 6° W.	Mar. 2
Kamokukolau (19°22.7' N., 155°16.6' W.)	May 5	489.2	506.5	6.1	S. 31° E.	Mar. 4

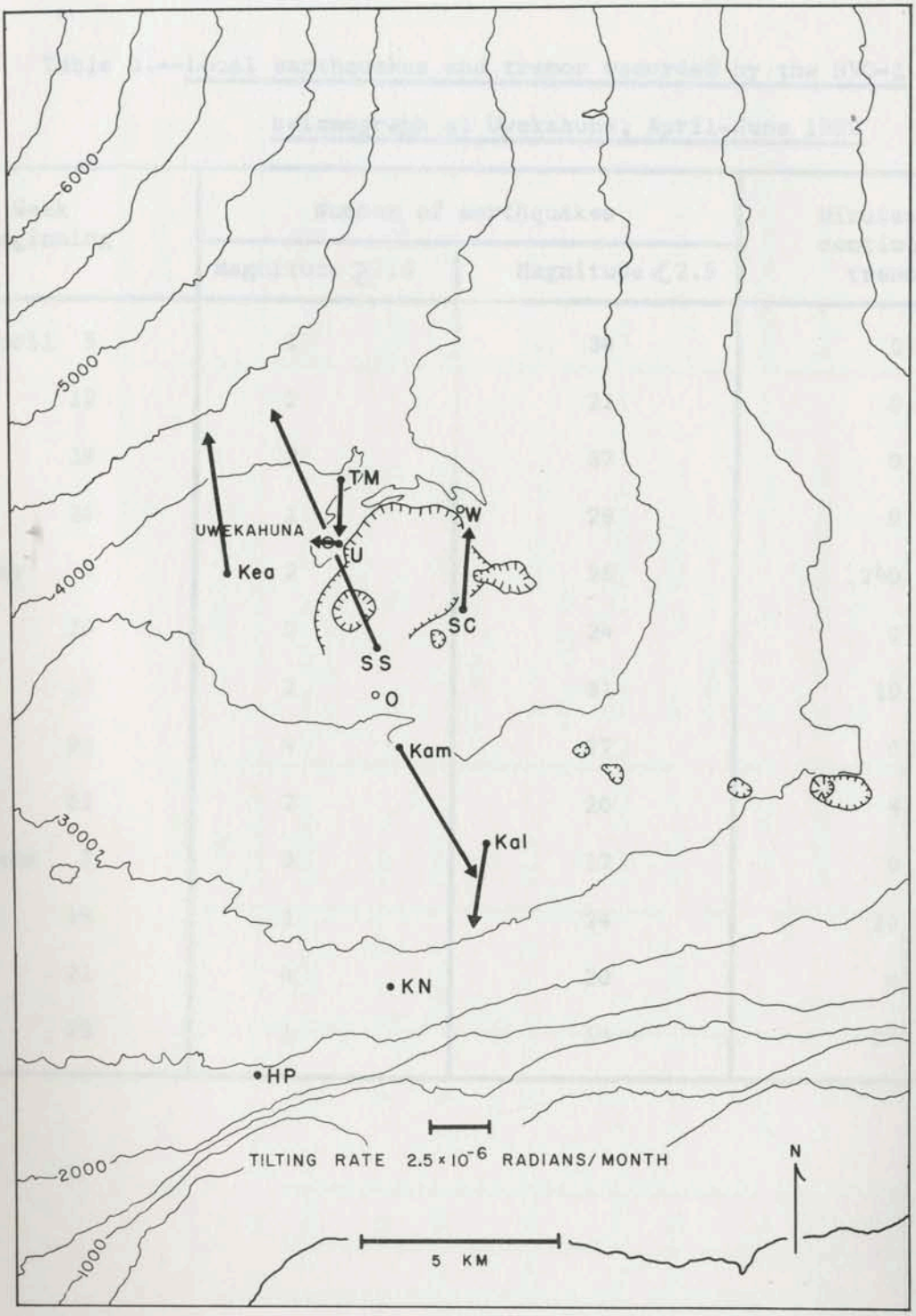

Figure 1.--Tilting of the ground around Kilauea caldera, Feb. 6, 1959, to May 5, 1959. The vector depicting tilting at a given tilt base points in the direction of maximum relative subsidence and has a length proportional to the rate of tilting during the measurement interval. Closed circles represent field tilt bases; open circles, short-base water-tube tiltmeters.

Table 3.--Local earthquakes and tremor recorded by the HVO-1 seismograph at Uwekahuna, April-June 1959

Week beginning	Number of earthquakes		Minutes of continuous tremor
	Magnitude $\geq$2.5	Magnitude $<$2.5	
April 5	1	30	0
12	2	21	0
19	2	37	0
26	1	29	9
May 3	2	35	240
10	0	24	0
17	2	31	10
24	4	27	0
31	2	20	4
June 7	3	17	0
14	1	24	10
21	4	20	0
28	1	14	25

Table 4.--Local earthquakes recorded by seismographs of the U.S. Geological Survey, April-June 1959

[Except for smaller earthquakes of special interest, only earthquakes with magnitudes of 2.5 or greater are listed. Time is Hawaiian standard]

Date	Time			Magnitude	Epicenter			Remarks
	h	m	s		Lat. N.	Long. W.	Description	
Apr. 4	07	23	18	2.8	19°26'	155°27'	10 km SW. of Mauna Loa seismograph.	Depth about 5 km.
Apr. 5	00	10	09	3.3	20°54'	154°57'	About 130 km N. of Hilo---	Depth about 15 km.
Apr. 12	23	49	28	2.8	19°20'	155°14'	8 km SE. of the Outlet seismograph.	Depth about 3 km.
Apr. 13	17	38	30	2.5	19°27'	155°26'	7 km SW. of Mauna Loa seismograph.	Depth about 8 km.
Apr. 20	10	31	42	2.7	19°59'	155°27'	12 km S. of Honokaa-------	Depth about 10 km.
Apr. 24	17	33	50	3.5	20°43'	156°03'	20 km E. of summit of Haleakala, Maui.	Depth about 35 km.
Apr. 28	15	19	55	3.1	20°02'	155°30'	8 km SSW. of Honokaa------	Depth about 10 km.
May 7	14	21	37	3.1	19°22'	155°18'	3 km SW. of the Outlet seismograph.	Depth about 30 km.
May 7	15	16	38	2.5	19°44;	155°23'	15 km E. of Pohakuloa-----	Depth about 15 km.
May 20	06	35	00	3.5	19°23'	155°19'	3 km SW. of Halemaumau----	30 km deep.

Table 4.--Local earthquakes recorded by seismographs of the U.S. Geological Survey, April-June 1959--Continued

Date	Time			Magnitude	Epicenter			Remarks
	h	m	s		Lat. N.	Long. W.	Description	
May 23	11	35	03	2.8	19°20'	155°50'	West flank of Mauna Loa about 25 km SW. of Mokuaweoweo.	Depth about 5 km.
May 24	15	28	27	3.0	19°10'	156°20'	About 45 km W. of Milolii-	Depth about 15 km.
May 24	19	59	25	2.7	19°21'	155°34'	13 km. S. of Mokuaweoweo--	Depth about 5 km.
May 26	08	41	03	3.0	19°59'	155°40'	5 km S. of Kamuela--------	Depth about 30 km.
May 26	08	41	02	2.6	20°11'	155°31'	20 km NE. of Kamuela------	Depth about 15 km.
June 3	04	31	29	3.3	20°55'	156°10'	5 km E. of Huelo Point, Maui. Felt on the island of Maui.	Depth about 15 km.
June 6	05	08	28	3.4	20°03'	155°40'	5 km N. of Kamuela beneath the summit region of Kohala Mountain.	35 km deep.
June 7	20	41	01	2.5	19°05'	155°24'	Beneath sea 20 km E. of Naalehu.	Depth about 10 km.
June 7	21	21	05	2.7	19°26'	155°28'	10 km SW. of Mauna Loa seismograph.	Depth about 5 km.
June 9	21	25	50	2.8	19°23'	155°25'	5 km NW. of Desert seismo- graph. Felt at Kilauea caldera.	Depth about 5 km.

Table 4.--Local earthquakes recorded by seismographs of the U.S. Geological Survey, April-June 1959--Continued

Date	Time			Magnitude	Epicenter			Remarks
	h	m	s		Lat. N.	Long. W.	Description	
June 16	09	06	15	3.3	19°24'	155°28'	10 km NW. of Desert seismograph.	Depth about 5 km.
June 22	14	28	09	3.0	19°19'	155°45'	10 km N. of Puu o Keokeo--	At shallow depth.
June 24	20	01	18	3.7	19°26'	155°36'	At SW. end of Mokuaweoweo caldera. Felt from Kilauea caldera to Capt. Cook.	Depth about 15 km.
June 25	16	11	30	2.6	19°15'	155°31'	7 km NW. of Pahala--------	Depth about 5 km.
June 26	12	16	34	4.2	19°13'	156°22'	50 km W. of Milolii. Felt in Capt. Cook.	Depth about 15 km.
June 28	02	52	57	2.6	19°29'	155°56'	Kealakekua fault at Kealakekua Bay.	At shallow depth.

Table 5.--Distant earthquakes

[Times are reported in Greenwich civil time, which is 10 hours faster than Hawaiian standard time. A "c" following the time of P indicates that the first motion was a compression; a "d," that it was a dilatation. Station symbols, locations, and instrumentation were presented in Summary 13, table 6. Locations of epicenters, origin times, focal depths, and magnitudes are from the notices of Preliminary Determination of Epicenters published by the U.S. Coast and Geodetic Survey]

Apr. 1

Hi	Z	iP	14:57:29.0	

18-1/2° S., 169° W.
14:48:34.
New Hebrides Is.
h about 200 km.

Apr. 1

Hi	Z	iP	23:43:20.0	

6° S., 154° E.
23:33:45.
Solomon Is.
h about 100 km.

Apr. 5

M	Z	eP	21:14:44.1	
O	Z	eP	21:14:44.1	
U	Z	eP	21:14:43.4	

15-1/2° S., 167-1/2° E.
21:05:54.
New Hebrides Is.
h about 100 km.

Apr. 5

Hi	Z	iP	23:39:56.8	
U	PEN	eQ	23:54:30	
U	PEZ	eR	23:58:00	

5-1/2° S., 146° E.
23:29:25.
Near north coast of New Guinea.

Apr. 6

M	Z	iP	14:25:33.9	
O	Z	iP	14:25:33.7	
D	Z	iP	14:25:33.1	
U	Z	iP	14:25:32.5	
U	PEN	iS	14:36:14	
U	PEN	eSS	14:42:00	
U	PEN	eQ	14:48:40	
U	PEZ	eR	14:53:46	
Hi	Z	eP	14:25:35.1	
Ha	Z	iP	14:25:22.2	

10° S., 120-1/2° E.
14:12:36.
Sumba Is.
Magnitude 6-1/4.

Apr. 8

M	Z	iP	01:32:38.3	d
O	Z	iP	01:32:37.8	d
D	Z	eP	01:32:36.5	d
U	Z	iP	01:32:38.1	d
Hi	Z	iP	01:32:40.5	c
Ha	Z	eP	01:32:42.8	d

Table 5.--Distant earthquakes--Continued

Apr. 8--Continued

32-1/2° S., 179-1/2° E.
01:23:26.
Kermadec Is. region.
h about 400 km.
Magnitude 6 to 6-1/4.

Apr. 9

U	PEZ	eR	07:20:20

36° S., 77° E.
08:18:34.
Kerguelen Is. region.

Apr. 9

U	PEN	eQ	18:06:18
U	PEZ	eR	18:08:23

7° N., 82° W.
17:36:10.
South of Panama.
Magnitude 6-1/4 to 6-1/2.

Apr. 10

M	Z	iP	05:55:53.1	d
O	Z	iP	05:55:53.0	d
D	Z	iP	05:55:52.1	d
U	Z	iP	05:55:53.1	d
Hi	Z	iP	05:55:56.6	d

25° S., 178-1/2° E.
05:47:34.
South of Fiji Is.
h about 600 km.

Apr. 11

M	Z	iP	11:40:51.4
O	Z	iP	11:40:51.4
D	Z	eP	11:40:50.5

1° S., 128° E.
11:28:50
Spice Is.

Apr. 12

M	Z	iP	10:04:30.9
U	Z	eP	10:04:28.6
U	PEZ	eS	10:12:56
U	PEZ	eR	10:20:30
Hi	Z	iP	10:04:28.2

17-1/2° N., 95° W.
09:54:51.
Mexico. Damage at Cordoba.
h about 100 km.
Magnitude 6-1/4.

Apr. 12

M	Z	iP	15:34:09.8
U	Z	eP	15:34:09.7
U	PEE	eS	15:44:26
U	PEZ	eR	15:56:38
Hi	Z	eP	15:34:10.5

4-1/2° S., 134° E.
15:22:33.
Near coast of New Guinea.
h about 100 km.

Table 5.--Distant earthquakes--Continued

Apr. 12

M	Z	eP	21:01:30.3
O	Z	eP	21:01:29.8
D	Z	eP	21:01:29.9
U	Z	iP	21:01:30.7
U	PEZ	eS	21:07:27
U	PEZ	iR	21:11:09
Hi	Z	iP	21:01:35.1

15-1/2° S., 173° W.
20:54:00.
Samoa Is. region. Felt at Apia.
Magnitude 6 to 6-1/4.

Apr. 14

U	PEZ	eR	03:12:07

24° N., 109-1/2° W.
02:53:04.
Gulf of California.
Magnitude 5-1/4 to 5-1/2.

Apr. 14

M	Z	iP	07:27:48.1
O	Z	iP	07:27:48.7
D	Z	iP	07:27:49.3
U	Z	iP	07:27:48.0
Hi	Z	iP	07:27:45.6

57-1/2° N., 155° W.
07:20:28.
Alaska Peninsula.
h about 60 km.

Apr. 15

U	PEZ	eR	00:40:52

41-1/2° N., 143° E.
00:15:21.
Near south coast of Hokkaido, Japan.

Apr. 16

M	Z	iP	07:35:36.1	d
O	Z	iP	07:35:35.8	d
D	Z	e	07:35:35.1	
U	Z	iP	07:35:35.9	d
Hi	Z	iP	07:35:38.4	d

23-1/2° S., 179° E.
07:27:27.
South of Fiji Is.
h about 550 km.

Apr. 16

M	Z	iP	16:23:53.9
O	Z	iP	16:23:54.2
D	Z	e	16:23:53.3
U	Z	eP	16:23:53.7
U	PEZ	eR	16:40:31
Hi	PEZ	eP	16:23:54.8

12-1/2° N., 143° E.
15:13:56.
Mariana Is. region.
h about 100 km.
Magnitude 6-1/2.

Table 5.--Distant earthquakes--Continued

Apr. 18

Hi	Z	iP	06:27:37.1

4-1/2° S., 153-1/2° E.
06:18:00.
New Ireland region. Felt at Londolovit and Rabaul.
h about 100 km.

Apr. 19

U	PEZ	eR	08:09:30

45° S., 82° W.
07:26:15.
Pacific Ocean.
Magnitude 6.

Apr. 19

M	Z	iP	15:10:52.8
O	Z	iP	15:10:52.9
D	Z	iP	15:10:53.7
U	Z	eP	15:10:52.3
U	PEZ	eR	15:20:59

58° N., 152-1/2° W.
15:03:26.
Near Kodiak Is., Alaska.
Magnitude 6-1/4.

Apr. 20

Hi		eP	03:28:02.4
U	PEE	eS	03:46:15
U	PEZ	eSS	03:50:25
U	PEN	eG	03:50:01
U	PEZ	eR	03:55:37

Apr. 20--Continued

6° S., 149-1/2° E.
03:27:52.
New Britain. Felt at Kandrian and Walindi.
h about 100 km.
Magnitude 6.

Apr. 21

M	Z	iP	12:50:00.8
D	Z	iP	12:50:02.0

56° N., 162-1/2° W.
12:42:50.
Bristol Bay.

Apr. 22

M	Z	iPn	11:03:21.1
O	Z	iPn	11:03:22.7
D	Z	iPn	11:03:23.1
U	Z	eP	11:02:06.3
U	Z	iPn	11:03:21.5
U	Z	Tmax	11:39:22
Hi	Z	e	11:02:19
Hi	Z	iPn	11:03:19.8
Hi	Z	Tmax	11:39:13
Ha	Z	iPn	11:03:02.2
Ha	Z	Tmax	11:37:29

54° N., 167° W.
10:55:05.
Fox Is., Aleutian Is.
Magnitude 6.

Table 5.--Distant earthquakes--Continued

Apr. 22

U	PEZ	eR	21:02:38	

36-1/2° S., 97-1/2° W.
20:26:46.
Pacific Ocean.
Magnitude 5-3/4 to 6.

Apr. 24

U	PEZ	eR	10:02:21	

11-1/2° N., 86-1/2° W.
09:31:33.
Near coast of Nicaragua.
Magnitude 6-1/4 to 6-1/2.

Apr. 24

M	Z	iP	18:07:39.3	d
O	Z	iP	18:07:38.6	d
D	Z	iP	18:07:37.5	d
U	Z	iP	18:07:38.2	c
U	PEZ	iP	18:07:38.5	c
U	PEN	iS	18:15:24.2	
U	PEZ	eSS	18:19:03	
U	PEZ	iR	18:29:05	
Hi	Z	eP	18:07:40.2	c
Ha	Z	eP	18:07:44.5	c

31° S., 178° W.
17:57:58.
Kermadec Is.
Magnitude 6-3/4 to 7.

Apr. 26

O	Z	iP	20:52:09.9	c
D	Z	iP	20:52:09.4	c
U	Z	iP	20:52:09.5	d
U	PEZ	iP	20:52:09.3	c
U	PEZ	ipP	20:52:37	
U	PEZ	isP	20:52:46	
U	PEZ	ePP	20:54:44	
U	PEZ	iS	21:01:44	
U	PEZ	iPS	21:02:22	
U	PEZ	eSS	21:06:02	
U	PEN	iG	21:09:40	
U	PEZ	iR	21:14:50	
Hi	Z	iP	20:52:09.8	c
Hi	N	eS	21:01:40	
Ha	Z	iP	20:52:03.0	c
Ha	N	eS	21:01:31	

25° N., 122-1/2° E.
20:40:38.
Near northeast coast of Formosa.
Two killed and minor damage at Taipei.
h about 150 km.
Magnitude 7-1/2 to 7-3/4.

Apr. 27

M	Z	eP	10:00:17.0	
O	Z	eP	10:00:17.5	

Table 5.--Distant earthquakes--Continued

Apr. 27--Continued

D	Z	eP	10:00:14.7	
U	Z	eP	10:00:17.4	
Hi	Z	eP	10:00:19.2	

7° S., 129° E.
09:48:09.
Banda Sea.

Apr. 27

M	Z	iP	12:59:29.7	
O	Z	iP	12:59:29.7	
U	Z	eP	12:59:26.9	

1/2° S., 124° E.
12:47:27.
Celebes region.
h about 200 km.

Apr. 28

M	Z	iP	11:19:39.0	d
O	Z	iP	11:19:38.1	d
D	Z	iP	11:19:38.7	d
U	Z	iP	11:19:38.3	d
U	PEZ	iP	11:19:37.5	c
U	PEZ	iS	11:27:52.0	
U	PEZ	eSS	11:31:46	
U	PEN	eG	11:34:24	
U	PEZ	iR	11:36:49	
Hi	Z	iP	11:19:36.8	d
Ha	Z	iP	11:19:47.9	d

Apr. 28--Continued

15° N., 93° W.
11:09:30.
Mexico-Guatemala border.
Magnitude 6-1/2 to 6-3/4.

May 1

Hi	Z	iP	15:06:57.4	

5° S., 154° E.
14:56:57.
Solomon Is. region. Felt at Londolovit and Rabaul.
h about 60 km.

May 3

U	PEZ	eR	05:11:33	

12-1/2° N., 87-1/2° W.
04:41:24.
Near coast of Nicaragua. Felt at San Vicente, El Salvador.
h about 100 km.

May 4

M	Z	iP	07:24:21.6	d
O	Z	iP	07:24:22.5	d
D	Z	iP	07:24:22.9	d
U	Z	iP	07:24:22.4	d
U	PEZ	iP	07:24:22.4	d
U	Z	ePn	07:27:01.1	
U	PEN	iS	07:31:15	
U	PEN	eSS	07:34:00	
U	PEZ	iSSS	07:34:56	
U	PEE	iQ	07:35:00	

Table 5.--Distant earthquakes--Continued

May 4--Continued

U	PEZ	iR	07:36:49	
U	Z	Tmax	08:17:24	
Hi	Z	iP	07:24:21.0	d
Hi	Z	ePn	07:27:07	
Hi	E	eS	07:31:26	
Hi	E	eQ	07:35:40	
Hi	N	iR	07:37:36	
Hi	Z	Tmax	08:16:42	
Ha	Z	iP	07:24:10.2	d
Ha	Z	iPP	07:26:09.6	
Ha	Z	ePn	07:26:43	
Ha	Z	ePPP	07:26:47	
Ha	N	eS	07:31:05	
Ha	E	eQ	07:35:12	
Ha	N	iR	07:36:51	
Ha	Z	Tmax	08:22:02	

52-1/2° N., 159-1/2° E.
07:15:42.
Near east coast of Kamchatka;
1 killed and 13 injured.
h about 60 km.
Magnitude 8.

May 5

M	Z	eP	19:13:04.4
D	Z	eP	19:13:05.0
U	Z	eP	19:13:07.2
U	PEZ	eS	19:20:23
U	PEZ	eR	19:26:14

53° N., 159° E.
19:04:16.
Kamchatka aftershock.
Magnitude 6.

May 5

M	Z	iP	17:36:45.3
O	Z	iP	17:36:44.7
Hi	Z	iP	17:36:48.8

18° S., 179° W.
17:29:26
Fiji Is.
h about 600 km.

May 7

U	PEZ	eS	00:21:50
U	PEZ	iR	00:30:27

3-1/2° S. 148-1/2° E.
00:03:24.
Bismarck Sea.
Magnitude 6 to 6-1/4.

May 7

U	PEZ	eR	11:44:15

3-1/2° S., 150° E.
11:17:16.
Bismarck Sea.

Table 5.--Distant earthquakes--Continued

May 7

M	Z	iP	20:35:18.1

8-1/2° S., 123-1/2° E.
20:22:41.
Flores Is.

May 8

M	Z	eP	11:43:30.8
O	Z	eP	11:43:30.0
D	Z	eP	11:43:31.6
U	PEZ	eS	11:50:35
U	PEZ	iR	11:56:37

53-1/2° N., 160-1/2° E.
11:34:50.
Near east coast of Kamchatka.
h about 60 km.
Magnitude 6.

May 10

U	PEZ	eR	00:24:35

45° N., 149° E.
23:57:09 (May 9).
Kurile Is.

May 12

M	Z	eP	05:05:55.4
O	Z	eP	05:05:54.9
D	Z	eP	05:05:53.7
U	PEZ	eP	05:05:49
U	PEN	iS	05:12:36
U	PEE	iQ	05:15:51
U	PEZ	iR	05:17:56

May 12--Continued

Hi	N	eR	05:17:42

54-1/2° N., 168° E.
04:57:35.
Komandorskie Is.
Magnitude 6-1/2.

May 12

U	PEZ	eS	21:53:05
U	PEZ	iR	21:56:34
Ha	Z	Tmax	22:24:15

51-1/2° N., 177° W.
21:40:22.
Andreanof Is., Aleutian Is.

May 12

M	Z	eP	22:07:10.7
O	Z	eP	22:07:10.9
D	Z	eP	22:07:11.8
U	PEZ	iS	22:12:36
U	PEZ	iR	22:16:12
Ha	Z	Tmax	22:43:45

51-1/2° N., 177° W.
21:59:56.
Andreanof Is., Aleutian Is.
Magnitude 6.

May 14

U	PEZ	eR	07:39:06

35-1/2° N., 24-1/2° E.
06:36:57.
Crete.
Magnitude 6-1/2.

Table 5.--Distant earthquakes--Continued

May 14

U	PEZ	eS	09:49:52
U	PEZ	iR	09:56:46

19° S., 170° E.
09:33:22.
New Hebrides Is.

May 14

U	PEZ	eS	12:05:45
U	PEZ	iR	12:12:37

19° S., 170° E.
11:49:20.
New Hebrides Is.

May 14

U	PEZ	eS	13:35:51
U	PEZ	iR	13:42:47

19° S., 170° E.
13:19:32.
New Hebrides Is.

May 16

M	Z	eP	06:26:01.0
O	Z	eP	06:26:01.3
D	Z	eP	06:26:0018
U	PEZ	eP	06:25:58
U	PEE	iS	06:33:50
U	PEZ	eSS	06:37:11
U	PEN	iQ	06:39:46
U	PEZ	iSSS	06:40:11

May 16--Continued

U	PEZ	iR	06:41:35
U	Z	Tmax	07:25:37
Hi	Z	iP	06:26:01.5
Ha	Z	eP	06:26:00
Ha	Z	Tmax	07:25:26

4-1/2° S., 153-1/2° E.
06:16:23.
New Britain. Felt at Karoola, Taliligap and Rabaul.
h about 60 km.
Magnitude 6-3/4.

May 20

M	Z	eP	01:00:05.1
O	Z	eP	01:00:03.6

23° S., 114° W.
00:50:03.
South Pacific Ocean.

May 20

M	Z	iP	11:36:05.0
O	Z	eP	11:36:05.8
D	Z	iP	11:36:05.4

32-1/2° N., 136-1/2° E.
11:26:28.
South of Honshu, Japan.
h about 450 km.

May 20

M	Z	iP	19:44:32.5	c
O	Z	iP	19:44:33.1	c

Table 5.--Distant earthquakes--Continued

May 20--Continued

D	Z	iP	19:44:32.7	c
U	Z	eP	19:44:33.0	c
U	PEZ	eR	19:59:07	
Hi	Z	iP	19:44:32.7	c

44-1/2° N., 149° E.
19:35:03.
Kurile Is.

May 21

U	PEZ	eR	07:07:42	

52-1/2° N., 170-1/2° W.
06:51:40.
Fox Is., Aleutian Is.

May 21

Hi	Z	eP	11:47:47.1	
U	PEZ	ePS	12:00:11	
U	PEZ	eSS	12:05:17	
U	PEZ	eR	12:17:23	

28° S., 69° W.
11:34:23.
Northern Chile - Argentina border.
h about 60 km.
Magnitude 6.

May 24

M	Z	iP	19:27:06.9	d
O	Z	iP	19:27:06.2	d
D	Z	iP	19:27:06.9	d

May 24--Continued

U	Z	iP	19:27:06.2	d
U	PEZ	iP	19:27:07	d
U	PEZ	ipP	19:27:35	
U	PEN	iS	19:34:48	
U	PEN	isS	19:35:24	
U	PEZ	eSS	19:38:28	
U	PEN	iG	19:40:35	
U	PEZ	iSSS	19:40:48	
U	PEZ	iR	19:42:57	
Hi	Z	iP	19:27:04.4	d
Ha	Z	eP	19:27:13.2	c

17-1/2° N., 97° W.
19:17:40.
Oaxaca, Mexico; 5 killed, 10 injured, and minor property damage. Felt also in Mexico City.
h about 100 km.
Magnitude 6-3/4 to 7.

May 26

U	Z	eP	04:24:10.2
U	PEZ	eR	04:44:48
Hi	Z	eP	04:24:09.9
Ha	Z	eP	04:24:01.7

27-1/2° N., 126-1/2° E.
04:13:01.
Ryukyu Is. region.
h about 100 km.
Magnitude 6-1/2 to 6-3/4.

Table 5.--Distant earthquakes--Continued

May 29

M	Z	iP	10:51:53.6	c
O	Z	iP	10:51:53.2	c
D	Z	eP	10:51:52.4	c
U	Z	iP	10:51:53.3	c
U	PEZ	iP	10:51:54.3	c
U	PEZ	ipP	10:52:16.8	
U	PEZ	iS	10:59:42	
U	PEN	eQ	11:03:26	
U	PEZ	iSSS	11:05:01	
U	PEZ	iR	11:07:40	
Hi	Z	iP	10:51:56.3	c
Ha	Z	iP	10:51:55.9	c
Ha	Z	epP	10:52:22	

19° S., 169-1/2° E.
10:42:48.
New Hebrides Is.
h about 60 km.
Magnitude 6-1/2.

May 31

O	Z	eP	09:37:39.7
D	Z	eP	09:37:38.9
U	PEZ	iP	09:37:41
U	PEZ	iS	09:45:16
U	PEZ	eSS	09:49:06
U	PEZ	iR	09:52:37
U	PEE	eQ	09:54:37

May 31--Continued

6-1/2° S., 155° E.
09:28:09.
Solomon Is.
Magnitude 6-1/2.

June 1

U	PEZ	eP	17:16:45
U	PEZ	eS	17:24:25
U	PEZ	eSS	17:28:09
U	PEZ	iR	17:31:39

6-1/2° S., 155-1/2° E.
17:07:23.
Solomon Is.
h about 100 km.

June 2

U	PEZ	eR	01:17

31-1/2° N., 131-1/2° E.
00:47:17.
Near coast of Kyushu, Japan.

June 2

U	PEZ	eR	03:44:49

25° S., 176° W.
03:23:12.
Tongo Is. region.

June 2

U	PEZ	eR	05:19:29

21° N., 121-1/2° E.
04:57:18.
Baton Is. region.

Table 5.--Distant earthquakes--Continued

June 3

U	PEZ	eR	05:59:09	

52-1/2° N., 170° W.
05:43:28.
Fox Is., Aleutian Is.

June 5

U	PEZ	eR	21:07:35	

12° N., 86-1/2° W.
20:37:15.
Near coast of Nicaragua.
h about 100 km.

June 14

M	Z	iP	00:25:09.8	c
O	Z	iP	00:25:09.1	c
D	Z	iP	00:25:09.4	c
U	Z	iP	00:25:10.0	c
U	PEZ	iP	00:25:10	d
U	PEZ	ipP	00:25:38	
U	PEZ	iPP	00:28:34	
U	PEZ	iPPP	00:29:34	
U	PEE	iS	00:35:38	
U	PEE	isS	00:36:40	
U	PEZ	eSP	00:42:29	
U	PEN	eQ	00:48:59	
U	PEZ	iSSS	00:49:41	
U	PEZ	iR	00:54:36	

June 14--Continued

Hi	Z	iP	00:25:06.5	c
Hi	Z	ipP	00:25:38.4	
Hi	Z	Tmax	02:08:00	
Ha	Z	iP	00:25:17.4	d
Ha	Z	epP	00:25:49.9	
Ha	Z	Tmax	02:09:29	

20-1/2° S., 68° W.
00:11:57.
Southwestern Bolivia; 1 killed and minor property damage in northern Chile.
h about 100 km.
Magnitude 7-1/4 to 7-1/2.

June 14

M	Z	eP	21:10:57.1
O	Z	eP	21:10:56.6

23-1/2° S., 179-1/2° W.
21:02:32.
Tonga Is. region.
h about 300 km.

June 15

M	Z	iP	02:50:34.7
O	Z	iP	02:50:35.0
D	Z	iP	02:50:34.6

25° N., 122-1/2° E.
02:38:48.
Near northeast coast of Formosa.

Table 5.--Distant earthquakes--Continued

June 18

U PEZ eR 07:26:09

55° S., 129° W.
06:50:45.
Pacific Ocean.

June 18

M Z iP 15:40:10.9

O Z iP 15:40:11.8

D Z iP 15:40:11.7

U Z eP 15:40:11.0

U PEZ eP 15:40:12.5

U PEN ePcS 15:46:49

U PEZ iS 15:47:18

U PEE iQ 15:51:29

U PEZ iR 15:53:23

Hi Z iP 15:40:10.3

54° N., 161° E.
15:31:25.
Near east coast of Kamchatka.
Magnitude 6-1/4 to 6-1/2 (sic).

June 18

M Z iP 16:07:23.8

O Z iP 16:07:24.9

D Z iP 16:07:24.8

U PEZ iR 16:20:09

Hi Z eP 16:07:20.9

June 18--Continued

54° N., 161° E.
15:58:38.
Near east coast of Kamchatka.
Magnitude 6-1/2 to 6-3/4 (sic).

June 19

Hi Z eP 20:42:20.6

U PEZ eR 20:52:53

27-1/2° N., 111° W.
20:34:40.
Gulf of California.

June 21

U PEZ eR 22:34:08

11-1/2° S., 167° E.
22:11:51.
Santa Cruz Is.

June 22

Hi Z eP 14:15:04.1

17° S., 177° W.
14:06:50.
Fiji Is.

June 23

U PEN eQ 14:50:53

39° N., 119° W.
14:35:02.
Western Nevada. Felt in Nevada and eastern California.
Magnitude 6-1/4.

Table 5.--Distant earthquakes--Continued

June 25

U	PEZ	eR	07:31:48	

62° N., 27-1/2° W.
06:46:55.
South of Iceland.

June 27

M	Z	iP	19:14:15.0	d
O	Z	iP	19:14:14.6	d
D	Z	iP	19:14:13.8	d
U	Z	iP	19:14:14.7	d
U	PEZ	iP	19:14:14.7	d
U	PEZ	epP	19:14:49	
U	PEZ	esP	19:15:11	
U	PEN	iS	19:22:04	
U	PEN	isS	19:23:04	
U	PEZ	eSS	19:25:52	
U	PEN	eQ	19:27:48	
U	PEZ	eR	19:30:48	
Hi	Z	iP	19:14:17.4	c
Ha	Z	iP	19:14:20.8	c

33° S., 179° W.
19:04:27.
South of Kermadec Is.
h about 100 km.
Magnitude 6-3/4.

June 28

M	Z	iP	19:56:07.4	
O	Z	iP	19:56:07.8	
D	Z	iP	19:56:07.2	
U	Z	iP	19:56:08.4	
U	PEZ	iS	20:06:27	
U	PEZ	eR	20:23:34	
Hi	Z	iP	19:56:09.3	
Ha	Z	iP	19:56:05.5	

9-1/2° S., 122-1/2° E.
19:43:22.
Sawoe Sea.

June 29

U	PEZ	eP	07:25:44	
U	PEE	eS	07:33:41	
U	PEZ	eR	07:41:20	

7° S., 155-1/2° E.
07:16:07.
Solomon Is.
Magnitude 6 to 6-1/4.

June 29

M	Z	iP	13:31:31.5	d
O	Z	iP	13:31:31.6	d
D	Z	iP	13:31:30.6	d
U	Z	iP	13:31:31.7	d

Table 5.--Distant earthquakes--Continued

June 29--Continued	June 30
6° N. 126-1/2° E. 13:19:47. Near south coast of Mindanao. Philippine Is. h about 150 km.	M Z eP 10:33:12.1 O Z iP 10:33:11.5 34° S., 179° W. 10:23:17 South of Kermadec Is.

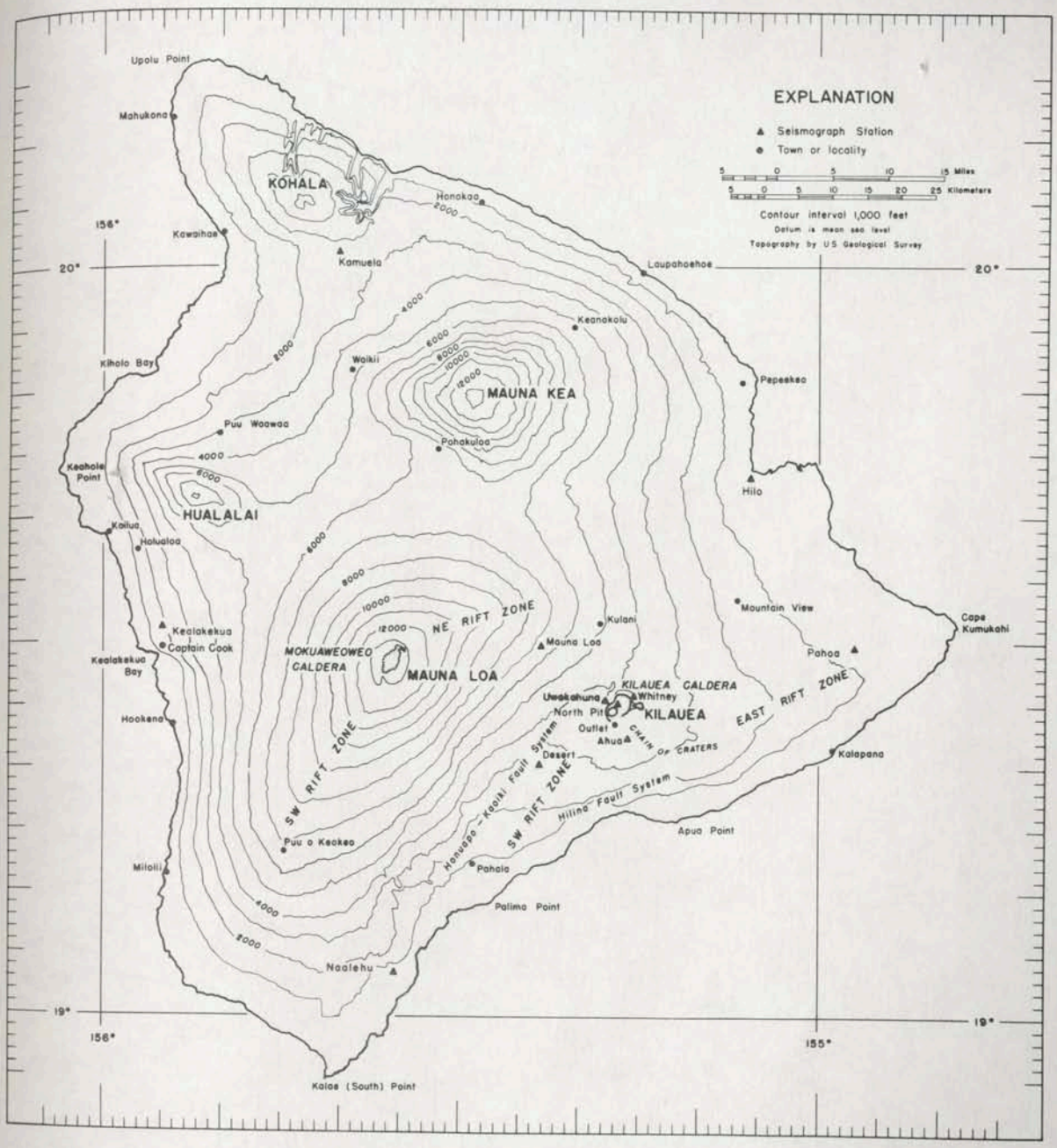

Figure 2.--Map of the Island of Hawaii showing seismograph stations operated by the Geological Survey and localities mentioned in the text. Epicenters of local earthquakes are given in terms of geographic coordinates, which are indicated at the edges of the map.

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HAWAIIAN VOLCANO OBSERVATORY SUMMARY 15

By J. P. Eaton and H. L. Krivoy

Chronological summary

Tilt bases around the Kilauea summit tilted generally inward toward the south rim of Kilauea caldera between early May and mid-August. Rates of tilting were quite small at all stations, averaging slightly less than 1 microradian per month, with a maximum of 1.4 microradians per month at Sand Spit and Kamokukolau and a minimum of 0.5 microradian per month at Kalihipaa. Comparison of the present pattern of tilting (fig. 1) with that from October 1958 to February 1959 (Summary 13) reveals a striking contrast. The present tilt vectors are almost exactly reversed with respect to corresponding vectors of the earlier epoch; and present tilting rates average only about 1/3 those of the earlier epoch. Even Sand Spit, which appeared to be anomalous during the October to February epoch because it tilted toward the caldera while other stations tilted away, reversed. From May to August it tilted outward from the caldera while other stations tilted toward the caldera.

Gentle subsidence of the summit of Kilauea in response to a slow escape of magma from a reservoir beneath the south rim of the caldera is suggested by the present tilt pattern. Keamoku, a new tilt base, failed to conform to the pattern set by the rest of the stations and tilted northward away from the southwest rift zone adjacent to the caldera. Possibly, magma moving from the sub-summit reservoir into the southwest rift zone is responsible for this apparent anomaly.

Of the 107 earthquakes recorded at Uwekahuna during July, 3 were reported felt. The first of these occurred near Kealakekua at 02^h19^m on July 10 and was felt in Capt. Cook. Its magnitude was only 2.0. The second was somewhat larger, with a magnitude of 3.0, and it was also felt in Capt. Cook. It originated at a shallow depth near Hookena at 15^h27^m on July 29. The magnitude 3.5 earthquake which was felt at Kilauea caldera on July 31 at 18^h44^m was the largest Hawaiian earthquake of the month. It originated at a focus 5 km south of Mokuaweoweo caldera and 30 km deep.

An interesting group of moderately deep earthquakes with magnitudes of 2.6 to 3.5 occurred at scattered points on a broad ring around Kilauea volcano at an average distance of about 35 km from Kilauea caldera. In order of occurrence these earthquakes were:

July 7, $15^h41^m21^s$, 8 km south of Hilo and 40 km deep;
July 13, $09^h52^m01^s$, 27 km south of Cape Kumukahi and 15 km deep;
July 13, $22^h21^m00^s$, 22 km east of Naalehu and 25 km deep;
July 28, $16^h51^m01^s$, 10 km southeast of Kalapana and 10 km deep;
July 31, $18^h43^m55^s$, 5 km south of Mokuaweoweo and 30 km deep.

On June 30, 1959, D. H. Richter arrived from Denver to join the Observatory staff as Geologist to replace G. D. Fraser, who returned to Denver on July 26, 1959.

From August 14 to August 20 a great swarm of small earthquakes and many hours of accompanying spasmodic tremor emanated from a zone a few kilometers north of Kilauea caldera and about 52 km beneath the surface of the earth. About 2,400 distinct earthquakes were recorded on the Desert seismograph, which obtained the clearest record of the swarm. Spasmodic tremor was strong enough during the first day to mask many earthquakes. After about 40 hours tremor diminished markedly, and it died out altogether during the last half of the swarm.

Earthquakes of the swarm were divided into two families: (1) those for which the first arrival at Hilo followed that at Uwekahuna by less than 1.6 seconds and (2) those for which it followed by 1.6 seconds or more. An analysis of 26 of the largest earthquakes of the first family disclosed that the P wave reached Uwekahuna first, 7.5 seconds after the earthquake occurred. Arrival times of P at other stations minus its arrival time at Uwekahuna were as follows: Outlet, +0.1 sec.; Desert, +0.4 sec.; Mauna Loa, +0.4 sec.; Hilo, +1.3 sec.; Haleakala, +16.4 sec. These data fixed the focus of this group of quakes at 19°29' N., 155°18' W., at a depth of 54 km. A similar analysis of 28 earthquakes of the second family indicated that P reached Uwekahuna 6.9 seconds after the origin time. Additional times required for P to reach other stations were: Outlet, +0.1 sec.; Mauna Loa, +0.4 sec.; Desert, +0.5 sec.; Hilo, +1.8 sec.; Haleakala, +16.7 sec. These data placed the focus of the second family of earthquakes at 19°28' N., 155°19' W. at a depth of 49 km, about 5 km above and 2 km southwest of the focus of the first family of quakes.

In the computation of both foci the Mauna Loa arrival times were corrected by -0.3 sec. to allow for a delay at that station revealed by a study of distant earthquake P phases.

Actually, the two families graded into one another; and the two foci should serve only to indicate the apparent dimensions of the region from which they emanated. This region is clearly distinct from that which produced a similar swarm of deep earthquakes and spasmodic tremor in January 1959, however (Summary 13). It lies about 10 km above and 10 km west of the source of the January disturbance.

As a result of the swarm of deep earthquakes the number of earthquakes recorded at Uwekahuna during August rose to 2,314; but only three were felt. The first, which had a magnitude of 3.4 and was felt in Capt. Cook and Kealakekua, originated 20 km west of Keahole Point at 16^h13^m on August 12. The second, with a magnitude of 4.0 was the largest earthquake in Hawaii during August. It occurred 8 km south of Kalapana at a depth of about 45 km at 13^h55^m on August 18 and was felt at Kilauea caldera and Hilo. The third was reported felt

only in Hilo. It originated 4 km north of Keanakolu at 03^h06^m on August 25 and had a magnitude of 3.5.

During August, seven earthquakes with magnitudes of 1.8 to 2.8 occurred at depths ranging from 20 to 32 km beneath the summit of Kilauea; none of these was felt.

The number of earthquakes recorded at Uwekahuna during September fell to 146. The magnitude 4.0 earthquake from a shallow focus 3 km west of Kalalua Crater at 14^h50^m on September 18, which was felt at Kilauea caldera and Hilo, was both the largest earthquake and the only earthquake felt in Hawaii during the month.

Two magnitude 2.0 earthquakes originated at depths of about 30 km beneath the summit region of Kilauea in early September.

One earthquake in August and four in September augmented the group of moderately deep earthquakes which occurred around Kilauea during July at a distance of about 35 km from the caldera. These earthquakes were:

Aug. 18, $13^h54^m55^s$, 8 km south of Kalapana and 45 km deep;
Sept. 1, $21^h22^m16^s$, 15 km north of Hilo and 50 km deep;
Sept. 12, $07^h44^m21^s$, 14 km south of Hilo and 25 km deep;
Sept. 13, $18^h31^m25^s$, 10 km southeast of Naalehu and 35 km deep;
Sept. 18, $11^h05^m54^s$, 10 km west-southwest of Hilo and 40 km deep.

In mid-September the North Pit seismograph began to record a swarm of tiny, shallow earthquakes originating very near the northeast rim of Halemaumau. From its commencement about September 17 until September 24, the swarm averaged about 60 earthquakes per day. From September 24 until the end of the month it averaged about 85 earthquakes per day. Earthquakes of the swarm were so small and originated so near the North Pit seismograph that no more than one earthquake in 10 recorded at that station could be detected on the Outlet seismograph less than 3 km away. For the largest quakes, amplitudes recorded at Outlet were only about 1/100th of those recorded at North Pit.

Tilting of the ground around Kilauea caldera

Tilting of the ground around the summit of Kilauea is monitored daily by a short-base water-tube tiltmeter in Uwekahuna vault, and at irregular intervals it is measured on a regional scale by means of a network of field tilt bases and a portable water-tube tiltmeter (tables 1 and 2). The attitude of the ground surface at each tilt base is reported in terms of north-south and east-west tilt coordinates. Both coordinates at each station were arbitrarily set equal to 500 when measurements at that station were begun. Increasing tilt coordinates correspond to northward and eastward tilting of the earth's surface,

Table 1.--Tilt coordinates at Uwekahuna vault, July-September 1959

Date	N-S	E-W	Date	N-S	E-W
July 5	518	469	Aug. 23	519	466
12	518	469	30	520	471
19	518	471	Sept. 6	521	467
26	518	472	13	521	467
Aug. 2	519	474	20	521	469
9	520	464	27	521	467
16	519	465			

Table 2.--Tilt coordinates and changes at tilt bases around Kilauea caldera (see fig. 1)

Tilt base (location)	Date (1959)	Tilt coordinates		Rate and direction of tilting since last reading (10^{-6} rad/mo)		Date of last reading (1959)
		N-S	E-W			
Uwekahuna (19°25.5' N., 155°17.4' W.)	Aug. 13	543.3	471.0	0.4	S. 54° E.	Apr. 27
Tree Molds (19°26.3' N., 155°17.3' W.)	Aug. 14	499.7	498.5	0.7	S. 5° W.	Apr. 28
Summer Camp (19°24.6' N., 155°15.6' W.)	Aug. 15	517.7	525.2	0.8	W.	May 4
Sand Spit (19°24.1' N., 155°16.8' W.)	Aug. 15	527.4	485.8	1.4	S. 38° E.	May 4
Kalihipaa (19°21.4' N., 155°15.3' W.)	Aug. 14	488.6	501.0	0.5	N. 44° W.	Apr. 28
Keamoku (19°25.1' N., 155°19.0' W.)	Aug. 17	516.1	497.5	1.1	N. 17° W.	May 12
Kamokukolau (19°22.7' N., 155°16.6' W.)	Aug. 16	493.9	506.1	1.4	N. 5° W.	May 12

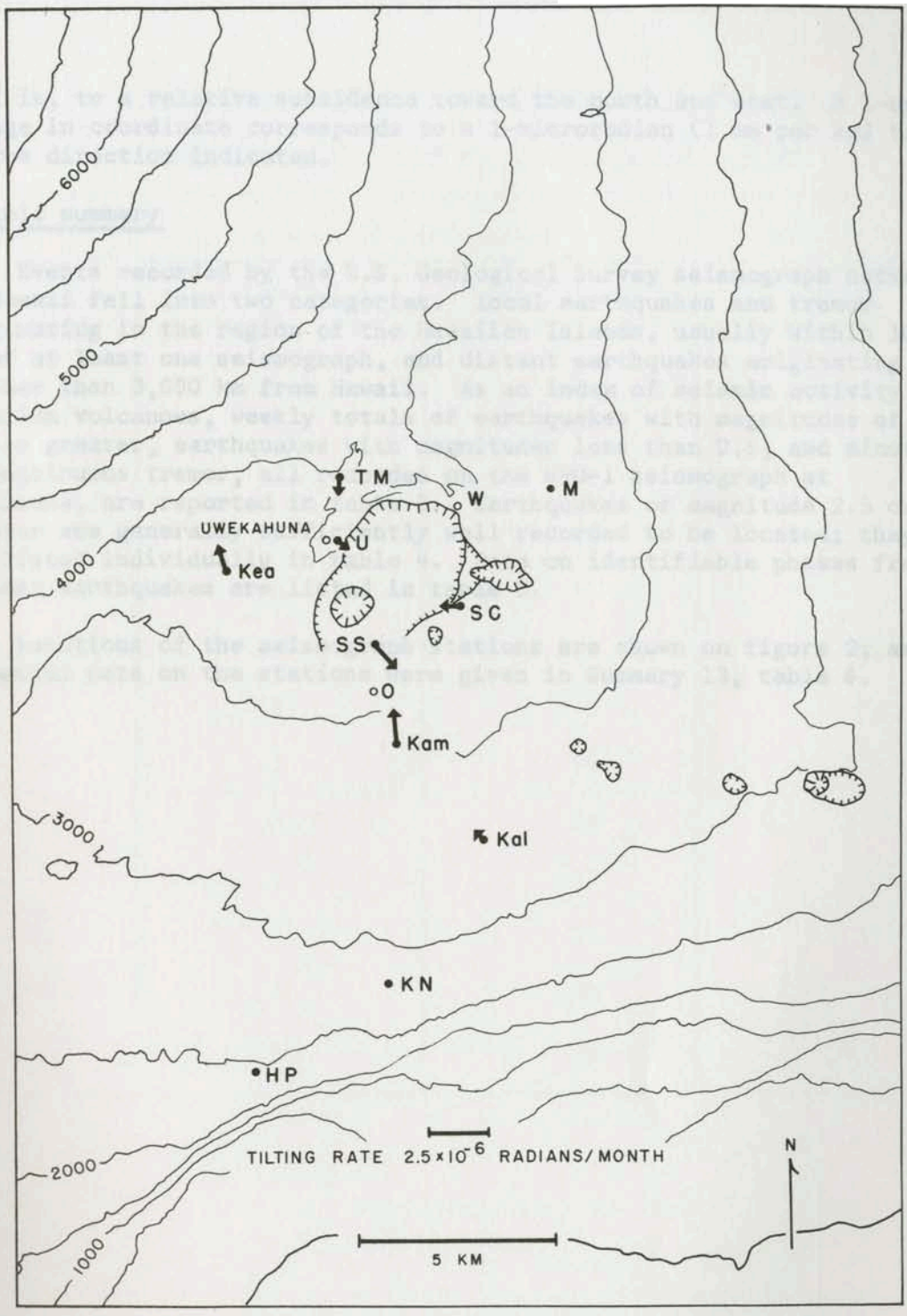

Figure 1.--Tilting of the ground around Kilauea caldera, May 5, 1959, to Aug. 15, 1959. The vector depicting tilting at a given tilt base points in the direction of maximum relative subsidence and has a length proportional to the rate of tilting during the measurement interval. Closed circles represent field tilt bases; open circles, short-base water-tube tiltmeters.

that is, to a relative subsidence toward the north and east. A 1-unit change in coordinate corresponds to a 1-microradian (1 mm per km) tilt in the direction indicated.

Seismic summary

Events recorded by the U.S. Geological Survey seismograph network in Hawaii fall into two categories: local earthquakes and tremor originating in the region of the Hawaiian Islands, usually within 100 km of at least one seismograph, and distant earthquakes originating farther than 3,000 km from Hawaii. As an index of seismic activity at Hawaiian volcanoes, weekly totals of earthquakes with magnitudes of 2.5 or greater, earthquakes with magnitudes less than 2.5, and minutes of continuous tremor, all recorded on the HVO-1 seismograph at Uwekahuna, are reported in table 3. Earthquakes of magnitude 2.5 or greater are generally sufficiently well recorded to be located; they are listed individually in table 4. Data on identifiable phases from distant earthquakes are listed in table 5.

Locations of the seismograph stations are shown on figure 2; and essential data on the stations were given in Summary 13, table 6.

Table 3.--Local earthquakes and tremor recorded by the HVO-1 seismograph at Uwekahuna, July-September 1959

Week beginning	Number of earthquakes		Minutes of continuous tremor
	Magnitude ≥2.5	Magnitude <2.5	
July 5	3	29	56
12	3	21	8
19	1	20	0
26	3	24	29
Aug. 2	0	20	0
9	35	1,345	1,815
16	13	852	555
23	1	36	4
30	3	22	0
Sept. 6	2	29	0
13	5	37	0
20	1	35	0
27	1	35	34

Table 4.--Local earthquakes recorded by seismographs of the U.S. Geological Survey, July-September 1959

[Except for smaller earthquakes of special interest, only earthquakes with magnitudes of 2.5 or greater are listed. Time is Hawaiian standard]

Date	Time			Magnitude	Epicenter			Remarks
	h	m	s		Lat. N.	Long. W.	Description	
July 7	15	41	21	2.6	19°39'	155°04'	8 km S. of Hilo----------	40 km deep.
8	12	40	55	2.5	19°22'	155°26'	7 km NW. of Desert seismograph.	Depth about 5 km.
8	14	56	36	2.7	19°27'	155°24'	5 km S. of Mauna Loa seismograph.	Depth about 5 km.
10	02	19	17	2.0			Near Kealakekua. Felt in Capt. Cook.	At shallow depth.
12	11	37	16	2.9	19°15'	155°33'	10 km NW. of Pahala-------	Depth about 5 km.
13	09	52	01	2.6	19°17'	154°47'	27 km S. of Cape Kumukahi-	Depth about 15 km.
13	22	21	00	3.0	19°03'	155°23'	22 km E. of Naalehu-------	Depth about 25 km.
19	21	00	49	2.5	20°03'	155°50'	Kawaihae----------	Depth about 15 km.
28	16	51	01	3.0	19°17'	155°03'	10 km SW. of Kalapana-----	Depth about 10 km.
29	15	27	29	3.0			West coast of Hawaii near Hookena. Felt in Capt. Cook.	At shallow depth.
31	18	43	54	3.5	19°25'	155°36'	5 km S. of Mokuaweoweo caldera. Felt at Kilauea caldera.	Depth about 30 km.

Table 4.--Local earthquakes recorded by seismographs of the U.S. Geological Survey, July-September 1959--Continued

Date	Time			Magnitude	Epicenter			Remarks
	h	m	s		Lat. N.	Long. W.	Description	
Aug. 9	04	08	30	2.5	19°21'	155°18'	5 km S. of Outlet seismograph.	32 km deep.
11	01	45	42	2.8	19°31'	155°29'	10 km NNE. of Mauna Loa seismograph.	Depth about 5 km.
12	16	12	51	3.4	19°44'	156°16'	20 km W. of Keahole Point. Felt in Capt. Cook and Kealakekua.	Depth about 15 km.
14	07	07	41	2.5	19°26'	155°17'	30 km deep beneath N. rim of Kilauea caldera.	
14	23	44	54	2.5	19°29'	155°18'	7 km N. of Uwekahuna. (This focus will be designated by KM 54 in rest of this list.)	54 km deep.
14	23	51	54	2.5			KM 54.	
15	00	55	00	3.1			KM 54.	
15	01	30	38	3.4	19°28'	155°19'	5 km NNW. of Uwekahuna. (This focus will be designated by KM 49 in rest of this list.)	Depth about 49 km.
15	01	49	55	2.8			KM 54.	

Table 4.--Local earthquakes recorded by seismographs of the U.S. Geological Survey, July-September 1959--Continued

Date	Time			Magnitude	Epicenter			Remarks
	h	m	s		Lat. N.	Long. W.	Description	
Aug. 15	02	04	14	2.9			KM 54.	
15	02	05	50	2.8			KM 54.	
15	03	18	10	2.7			KM 49.	
15	03	44	31	2.7			KM 49.	
15	05	09	38	2.7			KM 49.	
15	05	48	21	3.4			KM 54.	
15	06	05	56	3.0			KM 49.	
15	06	08	59	3.1			KM 54.	
15	06	11	11	3.1			KM 54.	
15	06	29	27	3.4			KM 49.	
15	06	42	17	2.5			KM 49.	
15	08	05	22	2.5			KM 49.	
15	08	38	36	2.7			KM 49	
15	08	41	52	2.7			KM 49.	

Table 4.--Local earthquakes recorded by seismographs of the U.S. Geological Survey, July-September 1959--Continued

Date	Time			Magnitude	Epicenter			Remarks
	h	m	s		Lat. N.	Long. W.	Description	
Aug. 15	09	08	39	2.5			KM 49.	
15	09	19	06	2.8			KM 54.	
15	17	01	56	2.5			KM 49.	
15	17	22	16	2.8			KM 49.	
15	19	31	52	3.0			KM 49.	
15	19	35	59	2.9			KM 54.	
15	19	58	14	2.8			KM 54.	
15	20	42	09	3.2			KM 49.	
15	20	48	56	2.8			KM 49.	
15	21	39	11	2.5			KM 49.	
15	22	25	38	2.5			KM 49.	
15	23	52	39	2.5			KM 49.	
16	01	34	31	2.8			KM 54.	
16	01	56	19	2.5			KM 54.	
16	03	34	41	2.5			KM 54.	

Table 4.--Local earthquakes recorded by seismographs of the U.S. Geological Survey, July-September 1959--Continued

Date	Time			Magnitude	Epicenter			Remarks
	h	m	s		Lat. N.	Long. W.	Description	
Aug. 16	07	05	42	2.5			KM 54.	
16	08	29	30	2.5			KM 49.	
16	10	47	46	2.6	19°22'	155°16'	5 km SE. of Outlet seismograph.	20 km deep.
17	00	46	39	2.5			KM 54.	
17	02	02	34	2.5			KM 54.	
17	02	13	56	2.7			KM 54.	
17	02	33	48	2.8			KM 54.	
17	22	04	45	2.9			KM 54.	
18	04	34	38	2.5			KM 49.	
18	13	54	50	4.0	19°17'	154°57'	8 km S. of Kalapana. Felt at Kilauea caldera and Hilo.	Depth about 45 km.
25	03	06	16	3.5	19°57'	155°21'	4 km N. of Keanakolu. Felt in Hilo.	Depth about 10 km.
Sept. 1	21	22	16	2.8	19°51'	155°04'	15 km N. of Hilo---------	50 km deep.
2	06	08	48	2.5	19°00'	155°41'	10 km N. of South Point on the Kahuku fault.	Depth about 5 km.

Table 4.--Local earthquakes recorded by seismographs of the U.S. Geological Survey, July-September 1959--Continued

Date	Time			Magnitude	Epicenter			Remarks
	h	m	s		Lat. N.	Long. W.	Description	
Sept. 5	23	33	51	2.5	19°18'	155°53'	10 km S. of Hookena-------	Depth about 10 km.
11	22	55	01	3.0	18°57'	156°43'	100 km W. of South Point--	Depth about 15 km.
12	07	44	21	2.5	19°36'	155°03'	14 km S. of Hilo----------	Depth about 25 km.
13	18	31	25	2.4	18°59'	155°32'	10 km SE. of Naalehu------	Depth about 35 km.
14	07	01	27	2.6	20°06'	155°50'	7 km N. of Kawaihae-------	Depth about 15 km.
14	23	57	15	3.3	19°45'	157°59'	170 km S. of Honolulu-----	Depth about 15 km.
16	10	50	22	2.9	19°49'	155°55'	5 km S. of Kiholo Bay-----	Depth about 10 km.
18	11	05	54	3.1	19°41'	155°10'	10 km WSW. of Hilo--------	Depth about 40 km.
18	14	50	04	4.0	19°24'	155°06'	3 km W. of Kalalua Crater. Felt at Kilauea caldera and Hilo.	At shallow depth.
20	16	11	07	2.5	19°28'	155°53'	5 km SW. of Capt. Cook on Kealakekua fault.	Depth about 10 km.

Table 5.--Distant earthquakes

[Times are reported in Greenwich civil time, which is 10 hours faster than Hawaiian standard time. A "c" following the time of P indicates that the first motion was a compression; a "d," that it was a dilatation. Station symbols, locations, and instrumentation were presented in Summary 13, table 6. Locations of epicenters, origin times, focal depths, and magnitudes are from the notices of Preliminary Determination of Epicenters published by the U.S. Coast and Geodetic Survey]

July 2				
M	Z	iP	11:41:50.7	c
O	Z	iP	11:41:49.8	c
U	Z	iP	11:41:49.7	d
Hi	Z	iP	11:41:52.5	c
20° S., 178-1/2° W.				
11:34:20.				
Fiji Islands.				
h about 650 km.				
July 3				
U	PEZ	iP	18:03:51.4	
U	PEZ	iS	18:10:47	
16° S., 173° E.				
17:55:10.				
New Hebrides Islands region.				
Magnitude 6-1/2.				
July 3				
M	Z	eP	18:04:30.6	d
O	Z	eP	18:04:29.6	d
U	Z	eP	18:04:31	
U	PEZ	iP	18:04:31.1	d
U	PEZ	iS	18:11:27	
U	PEZ	iSS	18:14:54	
July 3--Continued				
U	PEE	iQ	18:15:38	
U	PEZ	iR	18:16:44	
16° S., 173° E.				
17:55:53.				
New Hebrides Islands region.				
Magnitude 6-1/2.				
July 6				
U	PEZ	e	09:22:52	
M	Z	epPP	09:29:27	
U	PEZ	esPP	09:30:24	
U	PEZ	eSP	09:35:24	
U	PEZ	esSP	09:39:26	
U	PEZ	esSS	09:44:28	
Hi	Z	e	09:23:09	
26-1/2° S., 61° W.				
09:10:17.				
Chuco Province, Argentina.				
h about 600 km.				
Magnitude 6-3/4.				
July 6				
U	PEE	ePS	09:48:38	
U	PEE	esSP	09:52:30	
U	PEZ	esSS	09:57:38	

Table 5.--Distant earthquakes--Continued

July 6--Continued

26-1/2° S., 61-1/2° W.
09:23:21.
Chuco Province, Argentina.
h about 600 km.
Magnitude 6-3/4 to 7.

July 9

M	Z	eP	16:18:29.0	
M	Z	epP	16:19:05.0	
M	Z	esP	19:19:14.5	
O	Z	eP	16:18:29.5	
O	Z	esP	16:19:15.3	
D	Z	eP	16:18:29.7	
D	Z	esP	16:19:15.7	
U	Z	eP	16:18:30.6	
U	PEZ	eP	16:18:31	
U	PEZ	isP	16:19:11	
U	PEZ	esPP	16:22:50	
U	PEZ	eS	16:29:54	
U	PEZ	esPS	16:31:18	
U	PEZ	eSS	16:35:50	
U	PEZ	iR	16:48:20	
Hi	Z	eP	16:18:28.0	
Ha	Z	eP	16:18:38.0	

20-1/2° S., 68° W.
16:05:18.
Chile-Bolivia border.
h about 100 km.
Magnitude 6-3/4.

July 11

U	PEZ	eR	05:15:29	

July 11

U	PEZ	eR	13:02:19	

37° S., 79° E.
12:01:39.
Indian Ocean.
Magnitude 6-1/4 to 6-1/2.

July 12

M	Z	eP	00:32:04.5	
O	Z	eP	00:32:02.9	
Hi	Z	iP	00:32:05.7	

19-1/2° S., 177-1/2° W.
00:24:22.
Fiji Islands region.
h about 400 km.
Magnitude 6-1/4.

July 13

M	Z	iP	12:35:39.2	c
M	Z	ipP	12:35:49.5	
O	Z	iP	12:35:39.7	c
O	Z	ipP	12:35:50.4	
D	Z	iP	12:35:40.9	
D	Z	ipP	12:35:50.8	
U	Z	iP	12:35:39.0	c
U	Z	ipP	12:35:49.5	
U	Z	ePn	12:36:54.6	
U	Z	Tmax	13:13:12	
U	PEZ	eP	12:35:39.1	d

Table 5.--Distant earthquakes--Continued

July 13--Continued

U	PEZ	ePP	12:37:00	
U	PEZ	iS	12:41:12	
U	PEE	iQ	12:42:57	
U	PEZ	iR	12:44:30	
Hi	Z	eP	12:35:37.6	c
Hi	Z	ipP	12:35:48.3	
Hi	Z	ePn	12:36:52.8	
Ha	Z	eP	12:35:25.1	c
Ha	Z	ipP	12:35:34.1	
Ha	Z	Tmax	13:11:23	

52° N., 172-1/2° W.
12:28:45.
Andreanof Islands, Aleutian Islands.
Magnitude 6-1/2.

July 14

U	PEZ	eR	08:56:31	

51-1/2° N., 172° W.
08:40:48.
Fox Islands, Aleutian Islands.

July 14

U	PEZ	eS	13:15:53	
U	PEZ	eR	13:21:25	

16-1/2° S., 173° E.
13:00:24.
New Hebrides Islands region.
h about 100 km.

July 18

U	PEN	eL	12:35	

50-1/2° N., 130° W.

July 18--Continued

12:18:35.
Off coast of Vancouver, British Columbia.

July 18

M	Z	iP	19:37:38.9	c
O	Z	iP	19:37:38.4	c
U	Z	iP	19:37:38.1	d
Hi	Z	iP	19:37:40.9	c
Ha	Z	iP	19:37:42.8	c

19:29:22.
Fiji Islands region.

July 18

M	Z	iP	20:06:54.0	d
M	Z	ipP	20:07:33.7	
M	Z	isP	20:07:47.2	
O	Z	iP	20:06:54.8	d
O	Z	ipP	20:07:33.8	
O	Z	isP	20:07:47.7	
D	Z	iP	20:06:54.9	
D	Z	ipP	20:07:34.8	
D	Z	isP	20:07:47.0	
U	Z	iP	20:06:56.6	c
U	Z	ipP	20:07:33.5	
U	PEZ	iP	20:06:55.6	d
U	PEZ	ipP	20:07:31.6	
U	PEZ	iS	20:16:48	
U	PEN	isS	20:17:49	
U	PEZ	iSS	20:21:09	

Table 5.--Distant earthquakes--Continued

July 18--Continued

U	PEN	iSSS	20:25:14	
U	PEZ	iR	20:31:27	
Hi	Z	iP	20:06:56.6	d
Hi	Z	ipP	20:07:34.2	
Ha	Z	iP	20:06:49.5	d
Ha	Z	ipP	20:07:27.8	

15-1/2° N., 120-1/2° E.
19:54:45.
Luzon, Philippine Islands. Felt.
h about 150 km.
Magnitude 6-1/2 to 6-3/4.

July 19

U	Z	eP	15:18:51	
U	PEZ	iP	15:18:52.0	
U	PEZ	epP	15:19:54	
U	PEZ	esP	15:20:07	
U	PEZ	ePP	15:22:26	
U	PEZ	epPP	15:23:17	
U	PEN	iS	15:29:30	
U	PEN	isS	15:31:04	
U	PEN	eSS	15:35:28	
U	PEN	esSS	15:36:56	
U	PEN	iG	15:42:09	
U	PEZ	iR	15:49:09	
Hi	Z	iP	15:18:54.2	
Hi	Z	epP	15:19:47.5	

July 19--Continued

Ha	Z	iP	15:19:01.9	

15° S., 70-1/2° W.
15:06:10.
Peru. Felt in Northern Chile.
h about 200 km.
Magnitude 7.

July 20

M	Z	iP	17:01:41.6	
O	Z	iP	17:01:41.2	
D	Z	iP	17:01:40.1	
U	Z	iP	17:01:40.7	
Hi	Z	iP	17:01:43.9	
Ha	Z	eP	17:01:45.8	

23-1/2° S., 179° E.
16:53:38.
Fiji Islands region.
h about 600 km.

July 21

M	Z	iP	07:52:05.7	
O	Z	eP	07:52:05.5	
U	PEZ	eP	07:52:12	
U	PEZ	iS	07:59:26	
U	PEZ	iR	08:05:32	

14-1/2° S., 167-1/2° E.
07:43:13.
New Hebrides Islands.
Magnitude 6-1/4.

Table 5.--Distant earthquakes--Continued

July 22

M	Z	iP	11:27:39.0	
O	Z	iP	11:27:39.1	
U	Z	eP	11:27:39.3	

2° N., 126-1/2° E.
11:15:33.
Molucca Passage.

July 22

M	Z	iP	19:32:31.3	c
O	Z	iP	19:32:32.0	c
D	Z	iP	19:32:31.9	c
U	Z	iP	19:32:31.7	c
U	PEZ	iP	19:32:32.1	c
U	PEN	eS	19:39:12	
Hi	Z	iP	19:32:31.6	c
Ha	Z	iP	19:32:21.0	c

53° N., 153° E.
19:24:17.
Sea of Okhotsk.
h about 650 km.
Magnitude 6-1/4.

July 22

M	Z	eP	23:12:12.6	
O	Z	eP	23:12:11.8	
D	Z	iP	23:12:12.2	
U	Z	eP	23:12:11.8	
U	PEZ	iP	23:12:11.3	

July 22--Continued

U	PEZ	iS	23:20:04	
U	PEZ	eSS	23:24:09	
U	PEN	eG	23:25:49	
U	PEZ	eR	23:29:49	
Hi	Z	eP	23:12:14.0	
Ha	Z	eP	23:12:08.9	

5° S., 152-1/2° E.
23:02:27.
New Britain. Felt.
h about 60 km.

July 23

M	Z	eP	15:05:28.6	
D	Z	eP	15:05:28.3	
U	Z	eP	15:05:27.1	
U	PEZ	eP	15:05:26.8	
U	PEZ	eS	15:12:27	
U	PEZ	eR	15:18:44	
Hi	Z	eP	15:05:19.5	
Ha	Z	eP	15:05:32.9	

24-1/2 S., 176° W.
14:56:45.
Tonga Islands region.
h about 60 km.
Magnitude 5-3/4.

July 24

U	Z	eP	01:29:51.7	
U	PEZ	eP	01:29:52.8	

Table 5.--Distant earthquakes--Continued

July 24--Continued

U	PEN	eS	01:35:13
U	PEN	iQ	01:36:54
U	PEZ	eR	01:38:09
U	Z	Tmax	02:04
Hi	Z	eP	01:29:48.2
Hi	Z	eQ	01:37:06
Hi	Z	Tmax	02:05:25
Ha	Z	eP	01:29:51.7
Ha	Z	eQ	01:36:59
Ha	Z	Tmax	02:03:49

41° N., 125-1/2° W.
01:23:09.
Off coast of Northern California.
Felt at Humboldt County.
Magnitude 5-3/4.

Aug. 4

M	Z	eP	08:09:52.1
O	Z	eP	08:09:51.5
U	Z	eP	08:09:51.1

20-1/2° S., 178° W.
08:02:17.
Fiji Islands region.
h about 600 km.

Aug. 7

U	PEZ	eS	21:08:47
U	PEZ	eR	22:02:31
U	Z	Tmax	22:31:20

Aug. 7--Continued

Hi	Z	Tmax	22:31:30
Ha	Z	Tmax	22:30:15

56-1/2° N., 154° W.
21:45:26.
Kodiak Island.
Magnitude 5.

Aug. 8

M	Z	iP	00:56:19.5	c
M	Z	ipP	00:56:29.4	
O	Z	eP	00:56:19.9	
O	Z	ipP	00:56:29.9	
D	Z	iP	00:56:20.0	c
D	Z	ipP	00:56:29.8	
U	Z	epP	00:56:29.5	
U	PEN	eS	01:03:07	
U	PEN	eQ	01:07:11	
U	PEZ	eR	01:08:41	
Hi	Z	iP	00:56:19.9	c
Ha	Z	eP	00:56:07.9	c

55° N., 162-1/2° E.
00:47:38.
Near east coast of Kamchatka.
Magnitude 6-1/2.

Aug. 8

U	PEZ	eS	09:56:47
U	PEZ	eR	10:00:37

Table 5.--Distant earthquakes--Continued

Aug. 9

M	Z	iP	20:38:36.2	
O	Z	iP	20:38:36.0	
D	Z	iP	20:38:35.1	
U	Z	eP	20:38:35.1	
U	PEZ	iS	20:46:15	
U	PEZ	eR	20:52:39	
Hi	Z	iP	20:38:38.9	

10° S., 161° E.
20:29:28.
Solomon Islands.
h about 100 km.

Aug. 12

U	Z	eP	10:06:22.2	
U	PEZ	eP	10:06:16	
U	PEN	iS	10:12:39.0	
U	PEE	eQ	10:15:11	
U	PEZ	eSS	10:15:56	
U	PEZ	iR	10:17:11	
Hi	Z	eP	10:06:16.8	
Ha	Z	eP	10:06:27.8	

16-1/2° S., 177-1/2° W.
09:58:22.
Fiji Islands region.
Magnitude 6-1/2.

Aug. 14

M	Z	iP	04:51:24.2	
O	Z	eP	04:51:24.4	

Aug. 14--Continued

0°, 125-1/2° E.
04:39:07.
Molucca Passage.

Aug. 15

M	Z	eP	09:09:00.4	c
O	Z	eP	09:09:00.6	c
D	Z	eP	09:09:00.0	c
U	Z	eP	09:09:00.2	d
U	PEZ	iP	09:08:59.5	c
U	PEE	iS	09:18:52	
U	PEE	iPPS	09:19:45	
U	PEN	iSS	09:23:25	
U	PEN	iQ	09:28:11	
U	PEZ	eR	09:32:31	
Hi	Z	iP	09:09:01.6	c
Ha	Z	iP	09:09:06.4	c

23° N., 121° E.
08:57:04.
Formosa; 16 killed, many injured and extensive property damage.
Magnitude 6-3/4 to 7.

Aug. 16

U	PEZ	eP	01:01:03.5	
U	PEZ	eS	01:08:44	
U	PEZ	eR	01:15:51	

21° S., 169° E.
00:51:40.
Loyalty Islands region.
Magnitude 6.

Table 5.--Distant earthquakes--Continued

Aug. 16

Hi	Z	iP	10:01:11.7	

18° S., 178° W.
09:53:52.
Fiji Islands.
h about 350 km.

Aug. 17

M	Z	eP	21:14:17.3	c
O	Z	eP	21:14:17.2	c
D	Z	eP	21:14:16.6	c
U	Z	iP	21:14:18.4	d
U	PEZ	iP	21:14:18.7	d
U	PEN	e	21:21:11	
U	PEE	iS	21:22:02	
U	PEZ	iSS	21:25:49	
U	PEN	iQ	21:26:58	
U	PEZ	iR	21:29:19	
Hi	Z	eP	21:14:19.1	c
Ha	Z	iP	21:14:16.1	c

7-1/2° S., 156° E.
21:04:40.
Solomon Islands.
Magnitude 7 to 7-1/4.

Aug. 18

M	Z	eP	00:45:33.8	
O	Z	eP	00:45:34.3	
D	Z	eP	00:45:33.8	

Aug. 18--Continued

22-1/2° N., 122° E.
00:34:03.
Near east coast of Formosa.
h about 200 km.

Aug. 18

M	Z	eP	06:45:31.3	
O	Z	iP	06:45:30.2	d
D	Z	iP	06:45:31.2	d
U	Z	iP	06:45:31.5	d
U	PEZ	iP	06:45:31.5	c (d)
U	PEZ	iS	06:52:13	
U	PEZ	iSS	06:55:43	
U	PEN	iG	06:56:11	
U	PEZ	iR	06:57:45	
Hi	Z	iP	06:45:29.8	d
Hi	E	eS	06:52:10	
Hi	N	eQ	06:55:16	
Ha	Z	iP	06:45:28.3	c
Ha	E	eS	06:52:06	
Ha	N	eQ	06:55:53	
Ha	N	eR	06:58:13	

44°55' N., 111°05' W.
06:37:15.0.
Hebgen Lake, Montana; many killed and injured; major property damage.
Magnitude 7.1.

Table 5.--Distant earthquakes--Continued

Aug. 18

M	Z	iP	15:34:23.0	c
O	Z	iP	15:34:23.0	c
D	Z	iP	15:34:24.1	c
U	Z	eP	15:34:22.2	d
U	PEZ	iP	15:34:22.8	d
U	PEN	iS	15:41:06	
U	PEN	iSS	15:44:21	
U	PEN	eQ	15:45:58	
U	PEZ	iR	15:46:58	
Hi	Z	eP	15:34:19.4	d
Ha	Z	iP	15:34:20.4	d

44°53' N., 110°44' W.
15:26:06.5.
Hebgen Lake aftershock.
Magnitude 6-1/2.

Aug. 19

U	PEZ	eR	04:23:51

44°54' N., 111°38' W.
04:04:03.0.
Hebgen Lake aftershock.
Magnitude 6.

Aug. 20

M	Z	eP	07:30:13.7
O	Z	eP	07:30:12.7
D	Z	eP	07:30:14.2
U	Z	eP	07:30:13.4

Aug. 20--Continued

7° S., 85° W.
07:18:34.
Off coast of Peru.

Aug. 21

U	PEN	ePPS	08:28:26
U	PEZ	eR	08:44:33

50-1/2° S., 139-1/2° E.
08:03:15.
Indian Ocean south of Australia.
Magnitude 5-3/4 to 6.

Aug. 21

U	PEZ	eR	10:19:18

50-1/2° S., 140° E.
09:37:49.
Indian Ocean south of Australia.

Aug. 24

M	Z	iP	15:50:54.8	d
O	Z	iP	15:50:54.6	d
D	Z	iP	15:50:53.8	d
U	Z	eP	15:50:54.0	c
U	PEZ	iP	15:50:54.0	c
U	PEZ	eS	15:58:29	
U	PEZ	eR	16:05:57	
Hi	Z	iP	15:50:57.2	c
Ha	Z	iP	15:50:54.6	c

10-1/2° S., 161-1/2° E.
15:41:40.
Solomon Islands foreshock.

Table 5.--Distant earthquakes--Continued

Aug. 24

M	Z	iP	21:40:01.0	c
O	Z	iP	21:40:00.7	c
D	Z	iP	21:39:59.2	
U	Z	eP	21:39:59.5	c
U	PEZ	eP	21:39:58	c
U	PEN	e	21:47:01	
U	PEN	iS	21:47:39	
U	PEZ	eSS	21:51:06	
U	PEZ	iR	21:53:59	
Hi	Z	iP	21:40:02.2	d
Ha	Z	iP	21:40:00.5	d

10-1/2° S., 161° E.
21:30:46.
Solomon Islands.
Magnitude 7.

Aug. 24

U	PEZ	eS	23:49:13
U	PEZ	eR	23:55:19

10-1/2° S., 161° E.
23:32:23.
Solomon Islands aftershock.

Aug. 26

M	Z	iP	08:35:23.9	c
M	Z	ipP	08:35:36.0	
O	Z	iP	08:35:23.3	c
O	Z	ipP	08:35:35.1	

Aug. 26--Continued

D	Z	iP	08:35:24.1	c
D	Z	ipP	08:35:35.1	
U	Z	iP	08:35:23.3	
U	Z	ipP	08:35:34.9	
U	PEZ	iP	08:35:23.7	c
U	PEZ	iS	08:43:23	
U	PEN	iG	08:50:00	
U	PEZ	iR	08:52:15	
Hi	Z	iP	08:35:21.5	c
Hi	Z	ipP	08:35:33.1	
Ha	Z	iP	08:35:28.4	d
Ha	Z	ipP	08:35:39.2	

18° N., 94-1/2° W.
08:25:30.
Vera Cruz, Mexico; 14 killed, many injured, and extensive property damage throughout Tehuantepec Isthmus.
Magnitude 6-3/4.

Aug. 26

U	PEZ	eP	10:34:45
U	PEZ	iS	10:40:43
U	PEN	iQ	10:42:41
U	PEZ	eR	10:44:18
U	Z	Tmax	11:13:31
Hi	Z	iQ	10:42:48
Hi	Z	Tmax	11:13:15

Table 5.--Distant earthquakes--Continued

Aug. 26--Continued

Ha	Z	eQ	10:42:38	
Ha	Z	Tmax	11:12:55	

51° N., 132° W.,
10:27:41.
Queen Charlotte Islands region.

Aug. 27

U	PEZ	eR	14:20:21	

45° S., 80-1/2° W.
13:36:50.
Off coast of southern Chile.

Aug. 28

U	PEZ	eR	03:01:41	

9° S., 158° E.
02:37:00
Solomon Islands.
h about 150 km.

Aug. 28

U	Z	iP	12:15:51.7	
Hi	Z	iP	12:15:49.4	

63-1/2° N., 149° W.
12:07:44.
Central Alaska. Felt at College and Fairbanks.

Aug. 28

U	Z	eP	16:01:44.3	
U	PEZ	eP	16:01:43	
U	PEZ	eS	16:09:01	
U	PEZ	eR	16:15:41	

Aug. 28--Continued

17° S., 167° E.
15:52:10.
New Hebrides Islands.

Aug. 29

U	PEZ	eR	03:45:11	

03:21:07.
Solomon Islands region.

Aug. 29

M	Z	iP	17:15:20.8	d
O	Z	iP	17:15:21.3	d
D	Z	iP	17:15:21.3	d
U	Z	iP	17:15:20.5	d
U	PEZ	iP	17:15:21.6	d
U	PEZ	iS	17:25:27	
U	PEZ	eSS	17:30:47	
U	PEN	eG	17:36:41	
U	PEZ	eR	17:40:11	
Hi	Z	iP	17:15:20.7	d
Ha	Z	iP	17:15:12.6	d

52° N., 106-1/2° E.
17:03:10.
Lake Baikal, USSR.
Magnitude 6-1/2 to 6-3/4.

Aug. 30

U	PEZ	eR	22:45:30	

36-1/2° S., 78-1/2° E.
21:45:07.
Indian Ocean.

Table 5.--Distant earthquakes--Continued

Sept. 3

M	Z	iP	06:40:06.5
O	Z	iP	06:40:06.4
D	Z	eP	06:40:06.3
U	Z	eP	06:40:06.5
U	PEZ	iP	06:40:06.3
U	PEN	eS	06:50:37
U	PEZ	eSS	06:56:03
U	PEN	eG	07:01:35
U	PEZ	eR	07:05:31

4-1/2° S., 123° E.
06:27:30.
Celebes Islands.

Sept. 3

U	PEZ	eSS	22:06:47

15° S., 175-1/2° W.
21:48:56.
Fiji Islands region.

Sept. 5

M	Z	eP	06:19:34.3
O	Z	eP	06:19:34.7
U	PEN	ePPS	06:30:03
U	PEN	eQ	06:39:05
U	PEZ	eR	06:41:36

1° N., 129° E.
06:07:38.
Halmahera Island region.

Sept. 5

U	PEZ	eR	16:08:43

1° N., 129° E.
15:34:44.
Halmahera aftershock.

Sept. 5

U	PEZ	eR	21:45:45

Sept. 5

M	Z	iP	23:12:22.7
O	Z	iP	23:12:21.7
D	Z	eP	23:12:20.8
U	Z	iP	23:12:21.4
Hi	Z	iP	23:12:24.6
Ha	Z	iP	23:12:26.7

18° S., 178-1/2° W.
23:04:00.
Fiji Islands.

Sept. 6

M	Z	iP	00:39:57.3
O	Z	eP	00:39:57.2
U	Z	eP	00:39:57.2

5-1/2° N., 126-1/2° E.
00:27:59.
Near south coast of Mindanao, Phillippine Islands.

Sept. 8

U	PEZ	eR	14:25:27

Table 5.--Distant earthquakes--Continued

Sept. 8--Continued

13:12:04.
South Atlantic Ocean about 700 miles east of Bouvet Island.

Sept. 8

U	PEZ	eR	19:44:39	

42-1/2° N., 142-1/2° E.
19:19:39.
Hokkaido, Japan; felt at Hiroo, Obihiro, Kushiro, and Urakawa.

Sept. 10

M	Z	iP	05:44:41.9	d
O	Z	iP	05:44:41.8	d
D	Z	iP	05:44:41.0	d
U	Z	eP	05:44:42.8	
U	PEZ	eS	05:52:56	
U	PEZ	eSSS	05:58:41	
U	PEZ	eR	06:00:21	
Hi	Z	iP	05:44:44.1	c
Ha	Z	iP	05:44:40.7	c

6-1/2° S., 154-1/2° E.
05:35:04.
Solomon Islands.

Sept. 10

M	Z	eP	23:05:42.0	
D	Z	eP	23:05:42.5	

47° N., 152° E.
22:56:34.
Kurile Islands.

Sept. 12

U	PEZ	eSKS	02:04:15	
U	PEZ	eSS	02:12:25	
U	PEZ	isSS	02:12:46	
U	PEZ	eSSS	02:16:11	
U	PEN	eQ	02:18:51	
U	PEZ	iR	02:21:51	

20° S., 68° W.
01:41:03.
Southern Bolivia.
h about 150 km.

Sept. 12

U	PEZ	eR	07:29:31	

3° S. 146-1/2° E.
07:01:45.
Bismarck Sea.

Sept. 12

U	PEE	iS	11:42:00	
U	PEZ	iR	11:49:39	

9-1/2° S., 156° E.
11:24:27.
Solomon Islands region.

Sept. 14

U	Z	eP	13:24:40.3	
U	PEZ	eS	13:31:35	
U	PEZ	eR	13:38:01	
Hi	Z	eP	13:24:36.7	

Table 5.--Distant earthquakes--Continued

Sept. 14--Continued

24° S., 176-1/2° W.
13:15:49.
Tonga Islands region.
Magnitude 5-3/4 to 6.

Sept. 14

M	Z	iP	14:18:56.7	d
M	Z	ipP	14:19:16.4	
O	Z	iP	14:18:56.1	d
O	Z	ipP	14:19:15.8	
D	Z	eP	14:18:55.1	d
D	Z	ipP	14:19:14.9	
U	Z	iP	14:18:56.0	d
U	Z	ipP	14:19:14.4	
U	PEZ	iP	14:18:52.9	d
U	PEZ	i	14:18:56.2	
U	PEZ	ipP	14:19:07	
U	PEN	iS	14:26:28	
U	PEE	eScS	14:28:47	
U	PEE	iG	14:30:41	
U	PEZ	iR	14:33:11	
Hi	Z	iP	14:18:58.2	c
Hi	Z	ipP	14:19:16.8	
Hi	N	eS	14:26:31	
Hi	E	eQ	14:31:35	
Hi	N	eR	14:38:45	

Sept. 14--Continued

Ha	Z	iP	14:19:02.0	c
Ha	Z	ipP	14:19:20.3	
Ha	N	eS	14:26:14	
Ha	E	eR	14:34:03	

28-1/2° S., 177° W.
14:09:39.
Kermadec Islands. Felt on Raoul.
Magnitude 7-3/4.

Sept. 14

M	Z	eP	17:15:29.8
O	Z	eP	17:15:29.4
D	Z	e	17:15:24.7
U	Z	eP	17:15:31.3
U	PEN	iS	17:23:00
U	PEZ	eR	17:30:01
Hi	Z	iP	17:15:32.9
Ha	Z	e	17:15:49.2

29° S., 176-1/2° W.
17:06:15.
Kermadec aftershock. Felt on Raoul.

Sept. 14

M	Z	eP	22:33:17.7
O	Z	eP	22:33:16.5
U	PEZ	eP	22:33:18
U	PEN	iS	22:40:39

Table 5.--Distant earthquakes--Continued

Sept. 14--Continued

U	PEZ	eR	22:47:27	

29° S., 177° W.
22:23:53.
Kermadec aftershock. Felt on Raoul.
Magnitude 6-1/2.

Sept. 15

M	Z	iP	06:08:58.3	
O	Z	iP	06:08:57.1	
U	Z	eP	06:08:53.4	
U	PEZ	iP	06:08:54.4	
U	PEE	iS	06:16:22	
U	PEE	iScS	06:18:53	
U	PEZ	iSS	06:19:55	
U	PEE	eQ	06:20:11	
U	PEZ	iR	06:23:45	
Hi	Z	eP	06:08:59.2	
Hi	E	eS	06:16:20	
Hi	E	eQ	06:24:39	
Hi	N	eR	06:28:03	
Ha	Z	iP	06:08:59.8	
Ha	N	eS	06:16:29	
Ha	N	eQ	06:22:35	

28-1/2° S., 177° W.
05:59:42.
Kermadec aftershock. Felt on Raoul.
Magnitude 6-1/2 to 6-3/4.

Sept. 15

M	Z	iP	11:13:20.2	c
M	Z	iScP	11:17:38.3	
O	Z	iP	11:13:19.6	c
O	Z	iScP	11:17:37.7	
D	Z	eP	11:13:20.1	c
U	Z	iP	11:13:19.1	c
U	PEE	iS	11:19:33	
U	PEE	iScS	11:22:18	
Hi	Z	iP	11:13:21.8	c
Ha	Z	iP	11:13:25.1	c

21-1/2° S., 179-1/2° W.
11:05:33.
Fiji Islands region.
h about 600 km.
Magnitude 6-1/2.

Sept. 16

U	PEN	iS	16:13:45	
U	PEZ	eR	16:21:11	

28-1/2° S., 176° W.
15:57:03.
Kermadec aftershock.
Magnitude 5-3/4 to 6.

Sept. 17

U	PEN	eS	14:52:47	
U	PEZ	eR	15:00:31	

28-1/2° S., 176° W.
14:36:11.
Kermadec aftershock.
Magnitude 5-3/4 to 6.

Table 5.--Distant earthquakes--Continued

Sept. 17

U	PEZ	eR	22:32:11	

30-1/2° S., 114° W.
22:14:40.
Gulf of California.
Magnitude 5-1/4.

Sept. 18

U	PEZ	eR	13:00:31	

57-1/2° S., 24° W.
12:01:11.
Sandwich Islands.

Sept. 20

U	PEZ	eS	06:25:15	
U	PEN	eQ	06:30:27	
U	PEZ	eR	06:32:35	
U	ZPEZ	Tmax	07:16:16	
Hi	EZ	eQ	06:32:49	

18-1/2° S., 11-1/2° W.
06:07:59.
Pacific Ocean north of Easter Island.

Sept. 21

U	PEZ	eR	02:37:11	

9-1/2° S., 149° E.
02:08:28.
Near coast of New Guinea. Felt on Wanigella.

Sept. 25

M	Z	eP	02:48:45.6	d
O	Z	iP	02:48:46.1	d
D	Z	iP	02:48:45.1	d
U	Z	eP	02:48:45.3	d
U	PEZ	iP	02:48:45	c
U	PEE	eS	02:58:38	
U	PEZ	eSS	03:02:51	
U	PEZ	eR	03:11:28	

22° N., 122-1/2° E.
02:36:48.
Near east coast of Formosa.

Sept. 26

M	Z	eP	08:27:42.4	
M	Z	Tmax	09:02:35	
O	Z	iP	08:27:40.6	
O	Z	Tmax	09:02:31	
D	Z	Tmax	09:02:30	
U	PEN	eS	08:32:50	
U	PEN	eQ	08:34:30	
U	PEZ	iR	08:35:40	
U	Z	Tmax	09:02:45	
Hi	Z	eP	08:27:34.4	
Hi	N	eQ	08:35:35	
Hi	Z	Tmax	09:02:11	

Table 5.--Distant earthquakes--Continued

Sept. 26--Continued

Ha	Z	iP	08:27:37.7	
Ha	Z	Tmax	09:02:08	

43-1/2° N., 128-1/2° W.
08:20:51.
Off coast of Oregon.

Sept. 29

U	Z	eP	15:41:18.0	
U	PEZ	eP	15:41:16.0	
U	PEN	iS	15:48:44	
U	PEZ	eR	15:54:50	

29° S., 176-1/2° W.
15:31:57.
Kermadec Islands.
Magnitude 6-1/2 to 6-3/4.

Sept. 30

M	Z	iP	20:35:15.3	d
O	Z	iP	20:35:15.1	d
D	Z	iP	20:35:13.9	d
U	Z	iP	20:35:14.7	c
U	PEZ	eS	20:43:55	
U	PEZ	eR	20:50:30	
Hi	Z	eP	20:35:17.4	d
Ha	Z	eP	20:35:16.6	d

18° S., 168° E.
20:25:58.
New Hebrides Islands. Felt at Port Vila and Vate.
Magnitude 6-1/2.

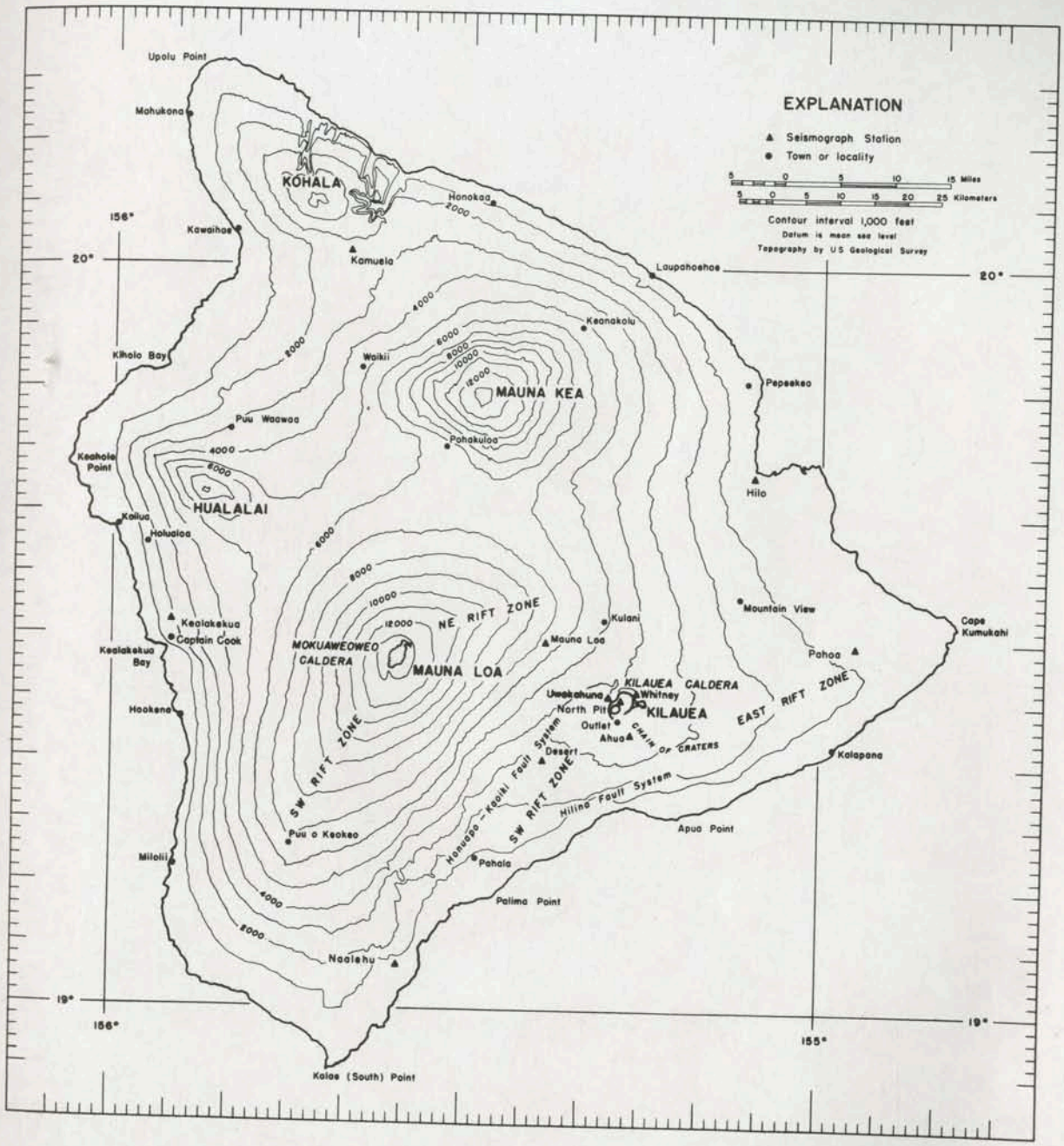

Figure 2.--Map of the Island of Hawaii showing seismograph stations operated by the Geological Survey and localities mentioned in the text. Epicenters of local earthquakes are given in terms of geographic coordinates, which are indicated at the edges of the map.