MAY 1963 EARTHQUAKES AND DEFORMATION IN THE KOAE FAULT ZONE, KILAUEA VOLCANO, HAWAII

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Abstract.—An episode of frequent earthquakes with a background of continuous harmonic tremor began at 21^h50^m on May 9, 1963. During the 4 days of this episode 3,000–4,000 earthquakes were recorded on the U.S. Geological Survey Hawaiian Volcano Observatory seismic network. The earthquakes occurred in the western half of the Koae fault system and were accompanied by abundant ground cracking. Tilt measurements on Kilauea Volcano made after the episode showed that the summit had deflated.

After 5 months of relative seismic quiescence, after the December 1962 flank eruption, seismic activity on Kilauea Volcano suddenly increased in the evening of May 9, 1963. Activity began at 21^h50^m Hawaiian standard time with a moderate ($M \approx 1.5$), shallow earthquake that occurred in the Koae fault system near the Ahua seismometer station and shallow harmonic tremor in the Kilauea summit area. More than 3,000 earthquakes were recorded in a 4-day period, and most were located around the western half of the fault system. The earthquakes were accompanied by tremor early in the episode and, in the western part of the system (fig. 1), by abundant ground cracking. All the earthquakes seemed to originate from depths shallower than 5 kilometers, and most were smaller than magnitude 0.5.

The Koae fault system is a zone of northeast-trending faults, 2 or 3 km wide and about 15 km long, that lies about 4 km south of Kilauea Caldera. It is terminated on the west by the southwest rift zone and on the east by the east rift zone of Kilauea. The Koae system is characterized by normal faults having their downthrown side commonly on the north, by open tensional cracks, and by small grabens.

Seismic episodes similar to the one of May 1963 occurred along the Koae fault system in 1938, 1950, and 1962. All these earthquake swarms were accompanied by tremor, subsidence at the summit, and

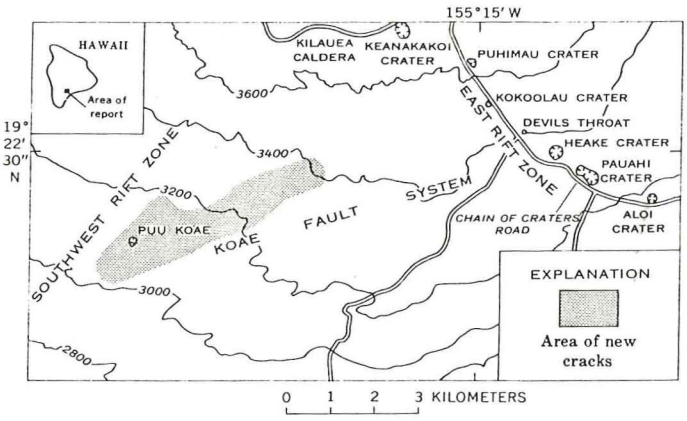

FIGURE 1.—Generalized topographic map showing Koae fault system and the upper parts of the southwest and east rift zones of Kilauea. Pattern shows area where new cracks developed during the May 1963 seismic episode. Area of new cracks mapped by James G. Moore (1963). Contour interval is 200 feet.

ground cracking along the fault system. The various episodes differed, however, in (1) the locations of the most abundant ground cracking and (2) a small eruption that accompanied the 1962 swarm.

According to Jagger (1938), the 1938 episode began on the morning of May 28 and lasted through the evening of the following day. Although he reported only 88 earthquakes and about 7 hours of tremor, his earthquake count and tremor duration are probably low because the seismographs in use at that time were low-magnification mechanical types. Jaggar described several east-west-trending cracks that were formed across Chain of Craters Road during the swarm, in an area between Pauahi and Aloi Craters. He also mentioned a hump in the same road near Devils Throat that increased in height noticeably during the seismic activity.

Finch (1950) described a seismic episode in which a very similar series of events occurred in December

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1950. Harmonic tremor, however, apparently was not as strong nor as long in duration as in the episode in 1938. He stated that the earthquakes were distributed over a linear distance of about 15 miles from Chain of Craters Road to the upper end of the 1823 lava flow on the Southwest Rift Zone. He described the episode as follows: "During the night of December 8-9, earthquakes continued to originate in the region of the early shakes (near Kokoolau Crater); others showed greater distances as though there was progressive cracking to the southwest." From December 8 to 14, a total of 656 earthquakes were recorded from this region. Finch's estimate of the depth of focus of many of the quakes was 6½–8 km.

Moore and Krivoy (1964) described a series of events in the December 1962 eruption that, except for the small eruption at Aloi Crater, are apparently similar to the other Koae seismic episodes. The ground cracking in December 1962 in the 0.8-mile zone westward from Aloi Crater is the first Koae seismic swarm that occurred since the installation of an adequately distributed high-gain seismic network.

SEISMIC ACTIVITY

Of the more than 3,000 earthquakes recorded by the U.S. Geological Survey Hawaiian Volcano Observatory seismic network during the May 1963 swarm, less than 30 were of magnitude 2.0 or greater; the greatest was 3.1. The chronological distribution of these earthquakes during the first 50 hours is shown in figure 2. These earthquake-frequency data seem to fit the formula $n=\frac{a}{t+b}$ (Bullen, 1963), where n is number of shocks per hour, t is time in hours, and the constants a and b have the values 1,462.5 and 9.2, respectively, at $t<1$ hour and $n=158$, the maximum number of shocks recorded in 1 hour. A magnitude-frequency plot (fig. 3) shows the distribution of earthquakes for increments of $M=0.5$ for the first 50 hours of the swarm. A least-square fitting of the data to the equation, $\log N=A-bm$ (Richter, 1958), gives the values $A=3.44$ and $b=0.98$. The value of b is very close to values obtained by others for earthquakes on Hawaii (Furumoto, 1965; Koyanagi and others, 1966).

The calculated total energy released by the earthquakes during this swarm is 9×10^{15} ergs, based on the formula $\log E = 9.9 + 1.9\,M_L - 0.024\,M_L^2$ (Richter, 1958), where E is ergs and M_L is magnitude determined from body-wave amplitudes of local earthquakes. About 70 percent of the total energy was released by 5 of the 150 shocks that occurred during the first hour, although there was no clear main shock.

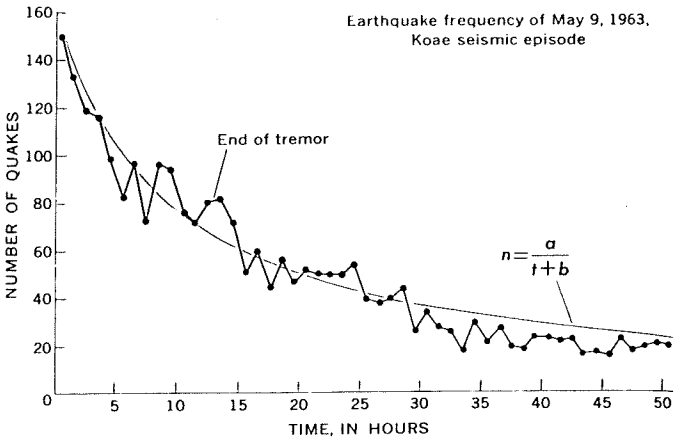

FIGURE 2.—Hourly count of earthquakes recorded at Ahua seismometer station during first 50 hours of seismic episode of May 1963.

The epicenters of the 38 largest earthquakes ($M>2$) were scattered throughout a 6-, by 6- km area near the west end of the Koae fault system. A plot of the differences in the arrival times of the P-waves at Desert seismometer and Ahua seismometer stations (figs. 4 and 5) shows a shift of earthquake epicenters toward the Desert seismometer station during the first 4–5 hours of the swarm. After about 5 hours there is more scatter in the points, but a tendency to cluster

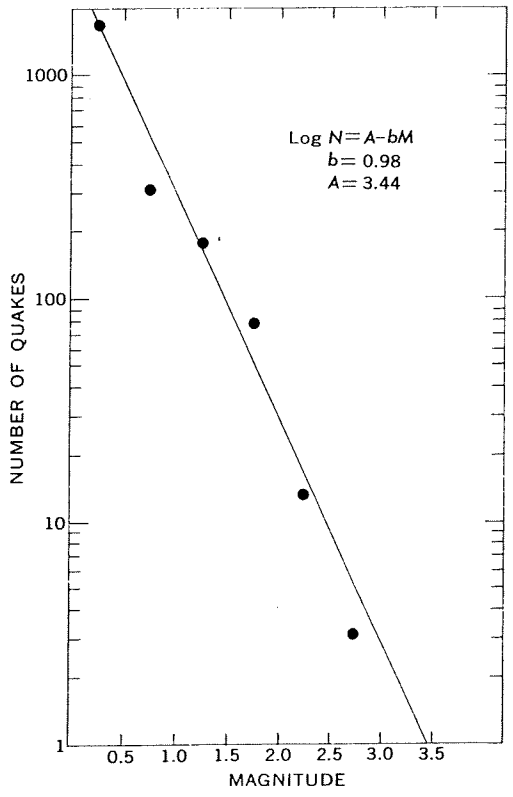

FIGURE 3.—Magnitude-frequency plot of earthquakes during first 50 hours of seismic episode of May 1963.

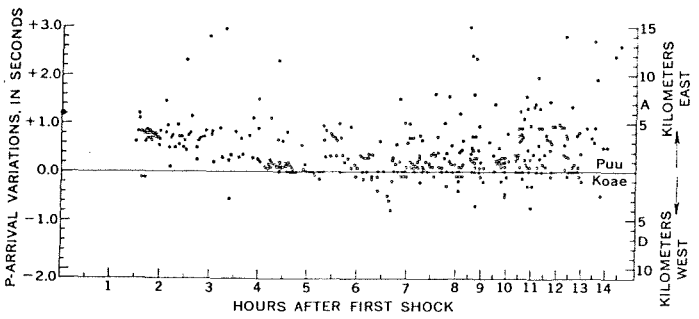

FIGURE 4.—Plot of the differences in the arrival times of the P-waves at Ahua and Desert seismometer stations versus hours after first shock. High-level tremor background obliterated seismograph records for about 1½ hours after first shock. Right ordinate is approximate distance of epicenters, along Koae fault system, from Puu Koae. *A*, Ahua, and *D*, Desert stations. Note that time scale is compressed beginning 8 hours after first shock.

near 0.0 time difference indicates that most of the earthquakes originated at nearly equal distances from both the Ahua and Desert stations. After the first shock, and for a period of about 1½ hours thereafter, the earthquake could not be located because the high-level tremor background obliterated the earthquake records. The larger earthquakes in the earlier part of the seismic activity seemed to alternate between the north and south sides of the area of new cracks.

DEFORMATION

The area of obvious deformation lies in the western half of the Koae fault system. Here several new cracks were mapped by Moore (1963) after the seismic episode. Ground tilting at other locations is shown on figure 5. Although the tilt data do not appear to be entirely consistent, in general the summit deflated moderately and the western part of the Koae fault system apparently inflated. The center of apparent inflation shown in figure 5 by the vectors from the bases *Kea*, *Kam*, *Kal*, *KN*, and *HP* almost coincides with the area of new ground cracking. Only data from *Uwe*, which is at the summit, suggest deflation and apparently are in disagreement with data from the *TM* and *SS* bases. However, this apparent disagreement can be explained by considering the daily tilt data from *Uwe*. The short-base tilt measured daily at *Uwe* showed a continued summit inflation after March 18, which was the last time the long-base tilt stations were measured previous to the seismic episode. If the amount of the additional inflation shown by the short-base tiltmeters is added to the March 18 long-base tilt data and a comparison is then made with the post-seismic-episode tilt data, the amount and direction of tilt shown by the dashed lines on figure 5 are obtained. Thus modified, the data clearly indicate a summit deflation at *Uwe* and only small changes at the *SS* and *TM* bases.

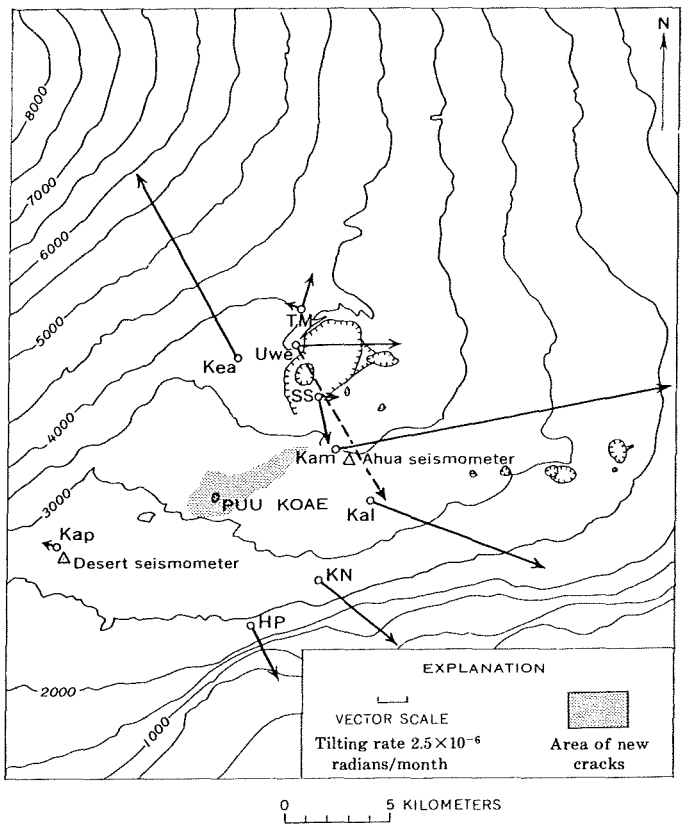

FIGURE 5.—Map showing tilting of the ground at Tree Molds (*TM*), Uwekahuna (*Uwe*), Keamoku (*Kea*), Sand Spit (*SS*), Kapapala (*Kap*), Kamokukolau (*Kam*), Kalihipaa (*Kal*), Kipuka Nene (*KN*), and Hilina Pali (*HP*) tilt bases between March 18 and May 10, 1963, location of Desert and Ahua seismometer stations, and area of new cracks (pattern) formed during episode. The vector depicting tilting at a given base shows the direction of maximum relative subsidence and has a length proportional to the rate of tilting during the measurement interval. Dashed vectors show direction and rate of tilt if probable additional inflation from March 18 to May 9 is considered. Contour interval is 500 feet.

SUMMARY

The following events all occurred during the 1938, 1950, 1962, and 1963 earthquake swarms: (1) ground cracking along the Koae fault system, (2) harmonic tremor, (3) large number of earthquakes whose focal depths were probably less than 3 km, (4) a summit deflation accompanied by an apparent upper east rift inflation, and (5) in at least two of the swarms, an apparent westward migration of the earthquake epicenters. The sequence seems to start with an earthquake, not necessarily the largest of the swarm, and shallow harmonic tremor beginning shortly before or at the same time as the earthquake. These events are followed by a rapid summit deflation and a probable inflation in the fault zone. The rate of deflation in the rift zones has not been observed, though in Decem-

ber 1962 ground cracking did not occur until a few hours after the earthquakes and the tremor began. In the May 1963 seismic episode, apparently a slow summit deflation began a few hours before the first earthquake of the swarm followed by rapid deflation after the beginning of the swarm.

Whether these swarms are characterized by only 70 percent of the total energy being released in the first hour is not known. In any case the energy being released is much lower than that released in the first hour of normal tectonic earthquake swarms. The largest quake occurred in the first 2 minutes of the swarm, but it only accounted for about 30 percent of the total energy released, compared to a release of more than 87 percent calculated for other tectonic earthquake swarms (Benioff, 1951).

Both seismic and deformation evidence indicate that these earthquake swarms are intimately associated with volcanic activity, but only one small eruption has occurred during these swarms. Very few eruptions have occurred on the Koae fault system, and no historic eruptions, except near the intersections with the southwest and east rift zones. This lack of eruptions seems peculiar because underground magmatic movement has occurred during each swarm.

REFERENCES

Benioff, Hugo, 1951, Earthquakes and rock creep, pt. 1, Creep characteristics of rocks and the origin of aftershocks: Seismol. Soc. America Bull., v. 41, no. 1, p. 60.

Bullen, K. E., 1963, An introduction the the theory of sei ogy: Cambridge, Cambridge Univ. Press. 381 p.

Finch, R. H., 1950, The December 1950 subsidence at Ki The Volcano Letter, no. 510, Oct.–Dec., 1950, p. 1–3.

Furumoto, A. S., 1965, Seismicity of Hawaii: Hawaii Univ. Inst. Geophysics Tech. Rept., p. 14.

Jaggar, T. A., 1938, Hawaiian Volcano Observatory report f May 1938: no. 459, May 1938, p. 2–5.

Koyanagi, R. Y., Krivoy, H. L., Okamura, A. T., 1966, Th Kaoiki, Hawaii, earthquake and its aftershocks: Seismol. Soc. America Bull., v. 56, no. 6, p. 1317–1335.

Moore, J. G., 1963, Hawaiian Volcano Observatory summary: U.S. Geol. Survey Hawaiian Volcano Observatory Summary 31. (July, Aug., and Sept., 1963) 40 p.

Moore, J. G., and Krivoy, H. L., 1964, The 1962 flank eruption of Kilauea Volcano and structure of the east rift zone: Jour. Geophys. Research, v. 69, p. 2033–2041.

Richter, C. F., 1958, Elementary seismology: San Francisco, W. H. Freeman and Co., 768 p.