MAUNA LOA 1974–1984: A DECADE OF INTRUSIVE AND EXTRUSIVE ACTIVITY

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ABSTRACT

The 1975 and 1984 eruptions of Mauna Loa Volcano were both related to a decade-long period of seismic and geodetic unrest (inflation) that was first detected in April 1974. The 1975 eruption, the first of Mauna Loa in 25 years, began just before midnight on July 5, but lasted less than 19 hours. Eruptive vents were confined to the summit region and produced about 30 million cubic meters of uniform tholeiite, which covered nearly 14 square kilometers of the summit area and north flank. Intense seismic activity continued in a localized area along the middle northeast rift zone (NERZ) for a week following the eruption and was accompanied by extensions across the rift, which suggested the intrusion of magma into this area. This led to a forecast of renewed activity on the NERZ sometime before the summer of 1978. The forecast timing proved erroneous, but the scenario was correct as to the place and character of the subsequent eruption.

The Mauna Loa summit inflated rapidly during the first two years after the 1975 eruption, but at lesser rates after 1977. Modeling of geodetic data showed that this inflation was caused by magma accumulation in a shallow storage reservoir beneath the southern edge of the summit caldera. Seismic activity was steady, although rates of intermediate-depth earthquakes began to increase in 1980, as did rates of summit deformation, resulting in a renewed forecast (1983) for an eruption of Mauna Loa within the next two years.

The 1984 summit-flank eruption began at 0125 H.s.t., March 25 (during a fortnightly earth tidal minimum). Eruptive fissures, which initially opened in the southwest corner of Mokuaweoweo, quickly propagated down the upper southwest rift and northeast rift zones, but eruptive activity was soon limited to the NERZ. A dike propagated down the NERZ at an average rate of 1.2 km/h during the day and was marked at the surface by discontinuous echelon eruptive fissures and earth cracks. The lowest eruptive vents were 15 km from the edge of Mokuaweoweo, between 2,770 and 2,930 m elevation; activity was restricted to these vents for the last three weeks of the eruption. Eruptive temperatures throughout this period remained constant at about 1,140 °C. Lava production began to diminish by early April, and lava steadily became more viscous, blocking supply channels at higher and higher elevations. When the eruption ended on April 15, approximately 220 million cubic meters of uniform tholeiite had been erupted, covering about 48 square kilometers of the Mauna Loa surface. Aa lava flowed as far as 27 km from eruptive vents to the 900-m elevation, to within 6 km of the nearest buildings in the city of Hilo.

Repeated geodetic and gravity measurements made throughout the eruption documented a substantial deflation of the Mauna Loa summit. The maximum measured subsidence, in the southern part of the summit, was 630 mm, and typical trilateration survey lines across Mokuaweoweo contracted an average of 300 mm, after initial dike-related extensions of about 600 mm. The summit area of Mauna Loa began to re-inflate immediately after the 1984 eruption, indicating the recharge processes for the volcano's next eruption have already begun.

INTRODUCTION

Mauna Loa, the largest active volcano on Earth, is a classic basaltic shield on the Island of Hawaii and rises to 4,170 m above the north-central Pacific Ocean. Mauna Loa erupted in July 1975 for the first time in 25 years. Another much larger summit and flank eruption followed in March and April 1984. Both eruptions were clearly related to a continuum of seismicity and deformation that began in 1974. This paper documents some of the events of this decade, but is only preliminary to more detailed analyses.

At the beginning of 1974 Mauna Loa had not erupted since the large eruption of June 1950 (Macdonald, 1954). Geophysical monitoring of Mauna Loa was provided principally by Hawaiian Volcano Observatory (HVO) instruments located on Kilauea prior to 1964, when the first modern seismometer was installed at the summit. Thomas A. Jaggar had previously placed seismographs at the summit at various times, but telemetry logistics limited their utility. R.W. Decker established a single EDM (Electronic Distance Measurement) survey line across Mokuaweoweo caldera in 1964, and annual reoccupation of this line (expanded to three lines by 1973) provided the only geodetic control. These transcaldera lines showed no significant changes prior to 1974. Earthquake activity was at low levels, as it had been for the previous 24 years.

The historical record of Mauna Loa's past eruptive behavior is lamentably brief—the first specific account describes the eruption of 1832, viewed from 150 km away. From 1832 to 1950 Mauna Loa had erupted an average of once every four years; the 24 years of quiescence from 1950 to 1974 was the longest noneruptive period in the volcano's brief recorded history. At the beginning of 1974 there were no premonitory indications of the decade of volcanic unrest and eruption which was soon to begin.

ACKNOWLEDGMENTS

Data and observations presented in this report came from the

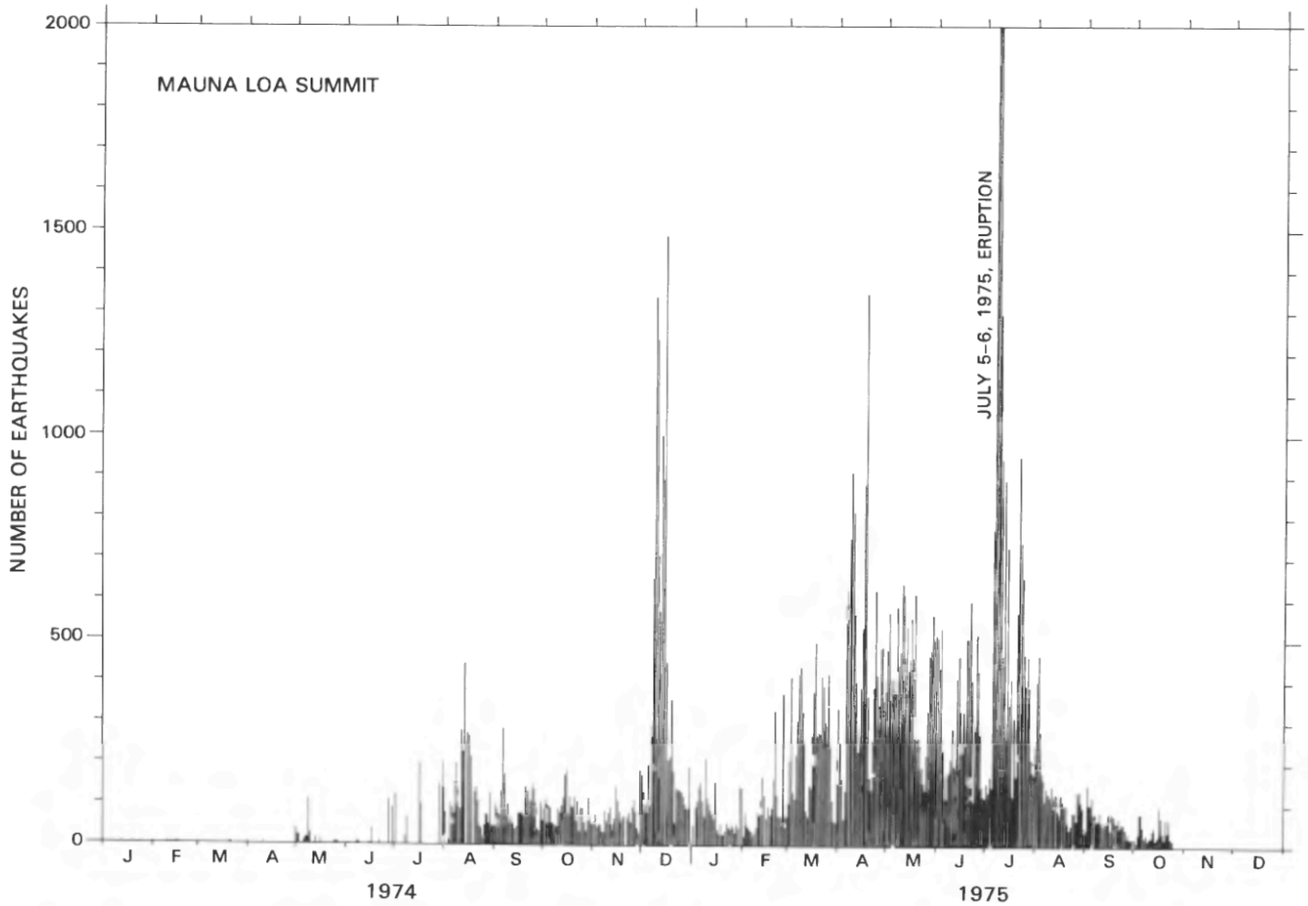


FIGURE 19.1.—Daily frequency of Mauna Loa short-period summit earthquakes (M>0.1), January 1974 to October 1975 (modified from Lockwood and others, 1976, fig. 5).

field and laboratory efforts of the entire staff of the Hawaiian Volcano Observatory from 1974 to 1984. This article incorporates previously published data of N.G. Banks, L.P. Greenland, D.B. Jackson, D.J. Johnson, K.A. McGee, Motoaki Sato, and J.M. Rhodes (see Lockwood and others, 1985). The careful review and thoughtful comments of P.W. Lipman greatly improved the manuscript as did review comments by T.L. Wright.

BEGINNING OF UNREST

An increase in the number of summit microearthquakes was detected in April 1974. The seismic activity continued to increase into the summer, and the possibility of future eruptive activity was noted (Koyanagi and others, 1975). Efforts to monitor the Mauna Loa activity more closely were frustrated by the fact that Kilauea was in near-continuous eruption at the Mauna Ulu eruptive vent during the first half of the year (Tilling and others, chapter 16), and brief Kilauea summit eruptions occurred in July, September, and December.

Trilateration measurements across Mokuaweoweo caldera in August 1974 revealed that significant dilation of the summit caldera had occurred since the previous measurements in 1973. This finding, together with continued increase in seismicity in the summit area, prompted expansion of the trilateration network to eight lines and the addition of two seismometers, placed around the rim of the caldera. Civil authorities were briefed on the situation, and through extensive news media interest, the island populace was alerted to the possibility of Mauna Loa eruptive activity. In mid-December 1974 the microearthquake rate (M>0.1) increased to 1,500 per day (fig. 19.1), and the conclusion that Mauna Loa was awakening was unescapable.

Trilateration measurements at the summit on December 14 showed significant dilation (to 4 cm) had occurred since August. On the morning of December 15, an earthquake of magnitude 4.6 below the southeastern part of the summit area was felt widely on the Island of Hawaii, and public concern was intensified.

From late December 1974 to February 1975 heavy snowfall blanketed Mauna Loa down to the 2,800-m elevation and covered all survey stations, preventing their reoccupation until early June. Aerial inspection of the summit area in April showed possibly

FIGURE 19.2.—Pit craters along upper southwest rift zone of Mauna Loa showing possibly anomalous melting of snow in April 1975. Lua Hou is in lower right corner. Photograph by J.P. Lockwood.

anomalous melting of snow in two pit craters on the upper southwest rift zone and along parts of the caldera floor (fig. 19.2).

In early spring of 1975 additional trilateration survey networks were established at lower elevations in order to measure strain across Mauna Loa's southwest rift zone (SWRZ) and northeast rift zone (NERZ). The Mokuaweoweo trilateration network was occupied on June 4 and showed as much as 10 cm of dilation of the summit since December.

Earthquakes between January 1974 and June 1975 occurred at intermediate depths (5–13 km) northwest of the summit and at shallow depths (<5 km) beneath and to the southwest of Mokuaweoweo (fig. 19.3). The number of intermediate-depth earthquakes increased first and was soon followed by an increase in the number of shallow earthquakes, commonly exceeding several hundred per day. Intense swarms occurred in August and December 1974, and again from February through June 1975.

During the week of June 30 to July 4 three borehole tiltmeters were installed on Mauna Loa's summit and north flank. One of these tiltmeters was to be destroyed by a lava flow in a few hours, before final adjustments could be made.

THE ERUPTION OF JULY 5–6, 1975

No unusual activity was noted on the Mauna Loa seismograms during the early evening of July 5; seismicity was at relatively low levels. At 2318 H.s.t. (all times given in Hawaii standard time), however, seismic alarms, signifying prolonged high-amplitude volcanic tremor, were activated in homes of HVO staff. The tremor had been first recorded by three seismometers (stations MOK,

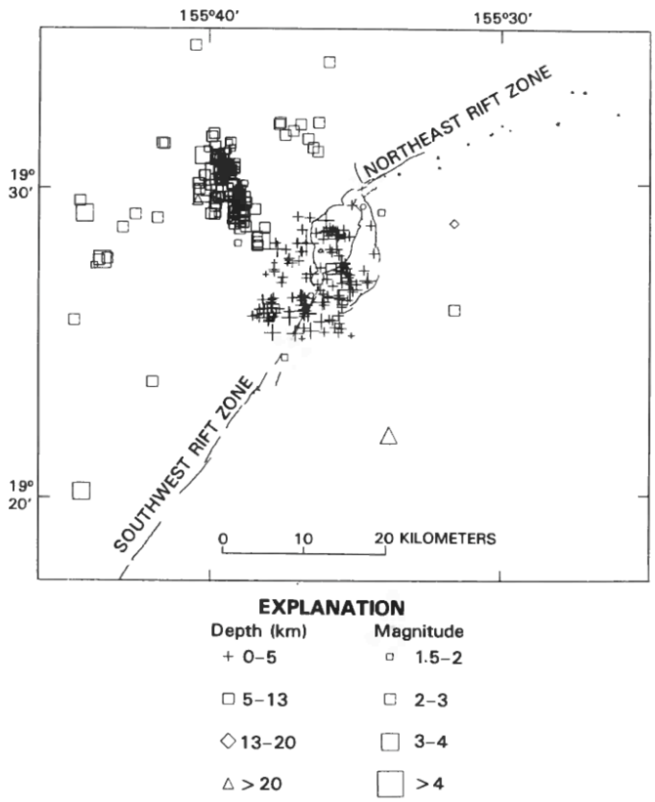


FIGURE 19.3.—Earthquake foci ($M \geq 1.5$) beneath Mauna Loa summit region in 18-month period prior to 1975 eruption (January 1, 1974, to June 30, 1975).

SWR, and WIL, see fig. 19.19) near Mokuaweoweo at 2251. Staff reached HVO at 2330 and saw that harmonic tremor was being recorded on all Mauna Loa and Kilauea seismographs. National Park and civil defense authorities were alerted to the imminent probability of a Mauna Loa eruption, and at 2342 a small glow was noted above the southwest end of Mokuaweoweo. Within one minute the glow extended across the entire summit area, and a fume cloud more than one thousand meters high was illuminated with a bright orange-red glow from the unseen lava fountains on the caldera floor.

A light airplane with two HVO staff members aboard reached the summit area at 0148; a line of fountains 20–50 m high crossed the entire floor of Mokuaweoweo at this time and extended about 1 km down the SWRZ. Lava cascades 90 m high were pouring into the three pit craters on the upper SWRZ (fig. 19.4). Flows were rapidly advancing to the west and southeast from the SWRZ vents. The eruptive fissures extended rapidly northeastward, across North Pit, and into the upper NERZ at 0225. At 0245 lava from the North Pit vents began cascading into another summit pit crater, Lua Poholo (see fig. 19.6). By 0315, the lava fountains on the SWRZ and within Mokuaweoweo were waning, and the lava flows moving to the west and southeast had stagnated. Fountains continued to migrate eastward along the NERZ, but by dawn eruptive activity was largely restricted to echelon vents near the NERZ 3,700-m level (fig. 19.5).

A voluminous aa flow moved about 2 km/h down Mauna Loa's north flank and threatened to cut the paved access road and powerlines to the Mauna Loa Observatory (an atmospheric research station operated by the National Oceanic and Atmospheric Administration, fig. 19.6). At about 0715 fountains feeding this aa flow subsided, and it soon stopped about 100 m from the Observatory road, having traveled 5.2 km. Fountaining continued at greatly diminished levels throughout the day, but ceased by nightfall. Approximately 30×10^6 m^3 of lava had been erupted, and 13.5 km^2 of the Mauna Loa summit area had been covered (fig. 19.6).

The erupted lava includes both aa and pahoehoe. This lava consists of dense pahoehoe within the caldera and mostly highly vesicular, shelly pahoehoe near eruptive vents on the rift zones. The flows are mostly blocky aa more than 500 m from eruptive vents and become more dense toward the distal ends of flows. The rock is nearly aphyric tholeiite (table 19.1), with sparse (<1 percent) olivine phenocrysts to 3 mm diameter. About 90 percent of these flows were subsequently buried by 1984 lava (see fig. 19.33).

A trilateration survey on July 7 showed that individual survey lines across Mokuaweoweo had extended by as much as 760 mm since the previous measurements in 1974, principally reflecting the July 5 intrusion of a dike across the caldera.

THE POSSIBILITY OF RENEWED ACTIVITY

July 7–12 was a period of great public concern, as an outbreak of lava lower along the NERZ seemed possible, in light of both the on-going seismicity and the numerous historical examples of brief summit eruptions followed within a few days by flank outbreaks (for example, April 1942, see Macdonald, 1954). Magma was clearly being intruded into the middle NERZ from July 6–12, as harmonic tremor continued, and several hundred small earthquakes occurred daily within the NERZ. Epicenters of these earthquakes, dozens of which were felt, were concentrated near the 2,900-m level on the NERZ, just southeast of Puu Ulaula (fig. 19.7). A trilateration network near Puu Ulaula was reoccupied on July 8 and showed significant dilation since installation of the network on May 28. On July 9, the network was again reoccupied and indicated continued dilation (as much as 4 cm extension on individual survey lines). Also on July 9, an earthquake of magnitude 4.5 near Puu Ulaula was felt throughout the island. Trilateration measurements at the summit on July 10 showed that the caldera had contracted since July 7 (as much as 5 cm of negative extension on some lines), presumably as magma drained into the NERZ. Harmonic tremor began to diminish in amplitude on July 10, and between July 9 and 12 the geodimeter lines near Puu Ulaula also contracted as much as 5 cm. With this information, the week-long 24-hour alert ended.

The historical record of Mauna Loa activity shows that isolated eruptions similar to that of July 1975 (those not followed within a few days by flank outbreaks) are nearly always followed by more voluminous flank eruptions after a period of 2–3 years (Dutton, 1882, p. 140; Stearns and Macdonald, 1946, p. 82). On

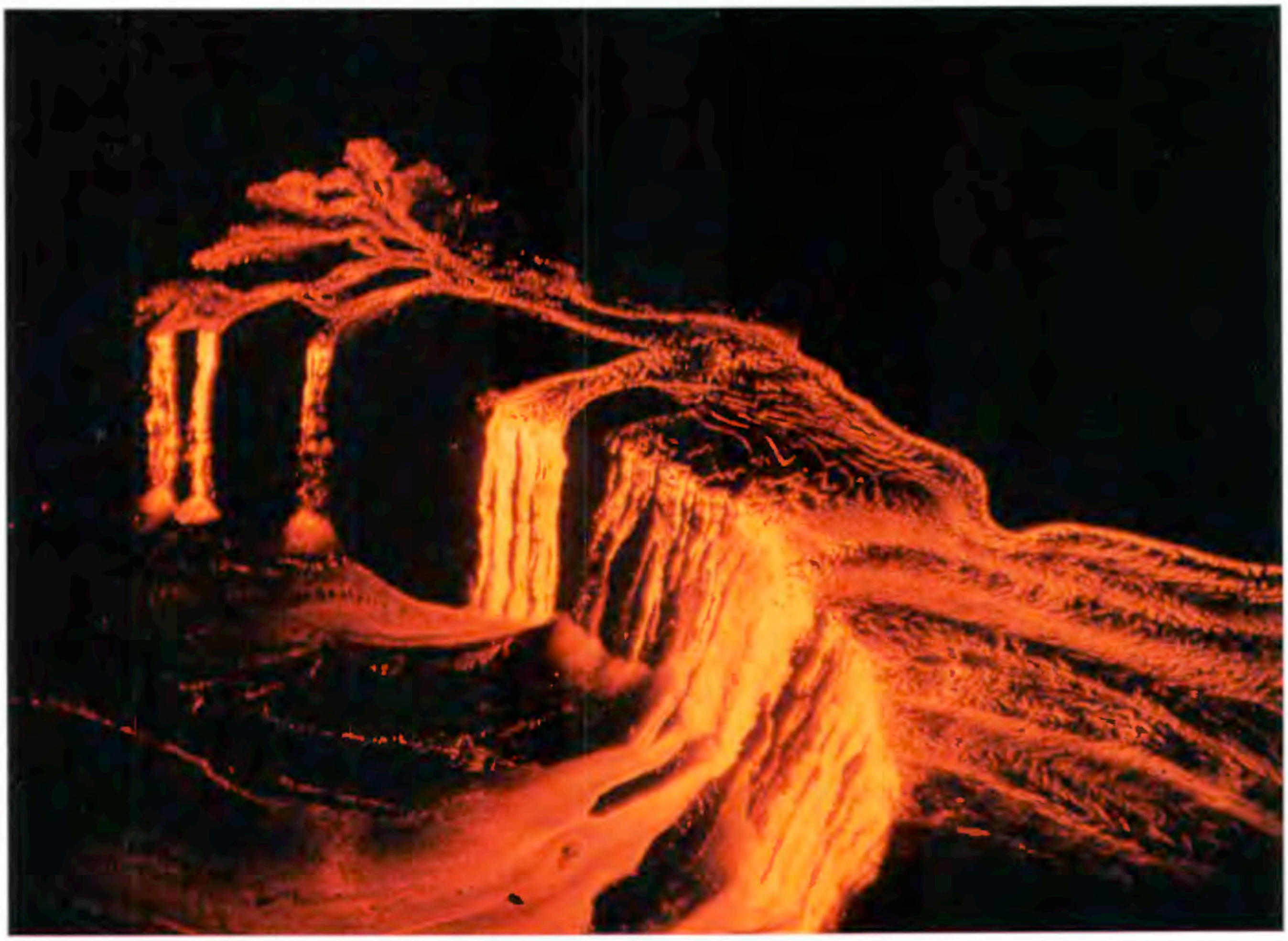


FIGURE 19.4.—Aerial view of lava cascades into Lua Hou, upper southwest rift zone, July 6, 1975, 0240 H.s.t. Cascade height about 90 m. Photograph by R.T. Holcomb.

FIGURE 19.5.—Oblique aerial view, looking west, of echelon eruptive fissures in Pohaku Hanalei area at dawn on July 6, 1975. Photograph by D.W. Peterson.

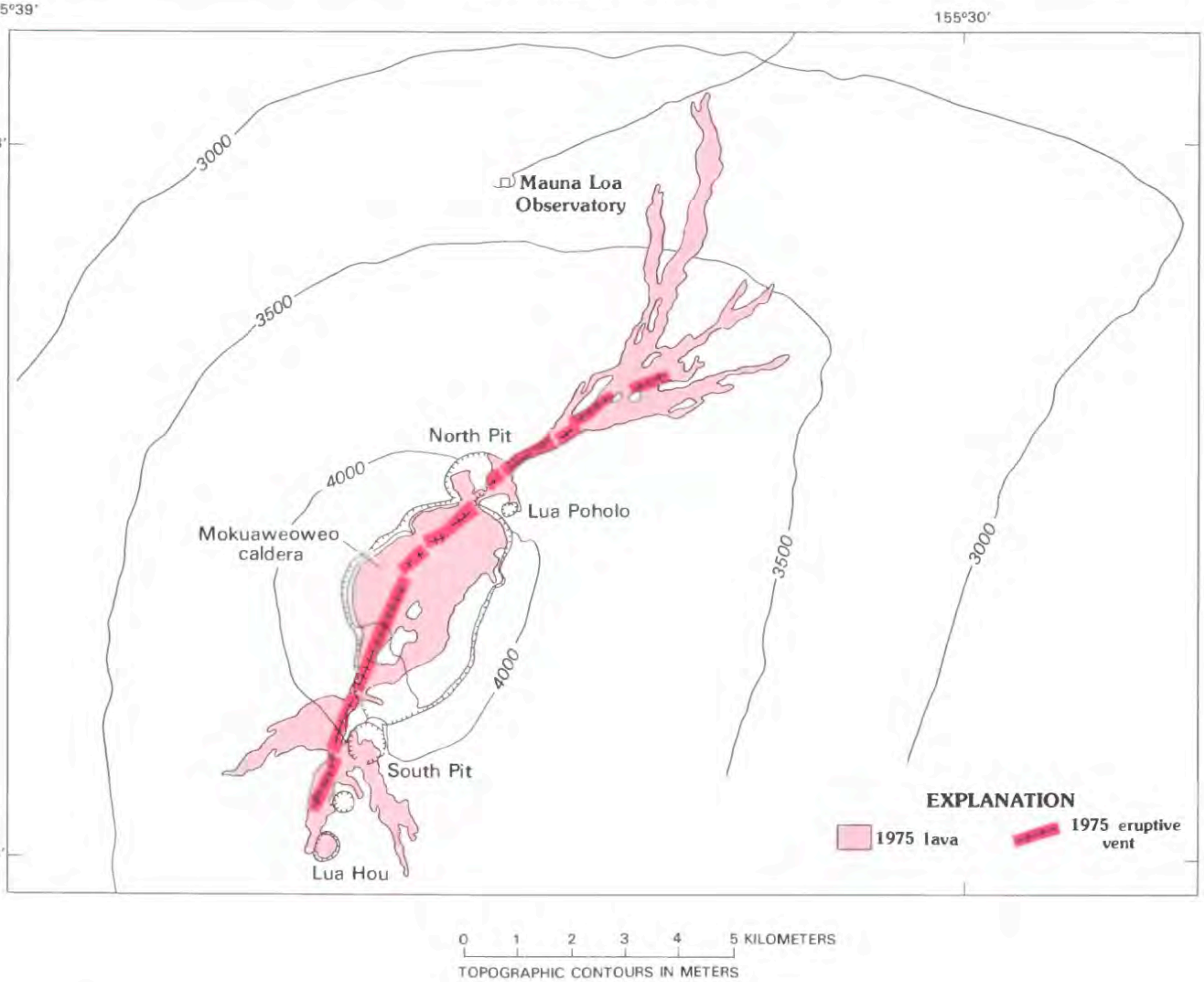


FIGURE 19.6.—Distribution of July 5–6, 1975 lava and geographic features of Mauna Loa summit area. Map by R.T. Holcomb, U.S. Geological Survey, 1975.

TABLE 19.1.—*Major-element compositions of 1975 Mauna Loa lava*

[NERZ, northeast rift zone; SWRZ, southwest rift zone; MOK, Mokuaweoweo. ML775-1 to -27, conventional rock analyses by V.C. Smith; ML-4 to -127, X-ray fluorescence analyses by J.M. Rhodes, reported on volatile-free basis, with total iron reported as Fe_2O_3. —, data not available]

Sample Location Rock	ML775-1 NERZ aa	ML775-17 MOK spatter	ML775-21 NERZ spatter	ML775-22 MOK spatter	ML775-23 SWRZ spatter	ML775-24 SWRZ pahoehoe	ML775-26 NERZ spatter	ML775-27 SWRZ aa	ML-4 MOK spatter	ML-5 NERZ spatter	ML-76 MOK spatter	ML-78 SWRZ spatter	ML-126 NERZ aa	ML-127 SWRZ spatter
SiO_2	52.04	52.01	52.13	52.31	52.13	52.15	52.11	51.93	51.76	51.64	51.81	51.54	51.87	51.58
TiO_2	2.09	2.07	2.14	2.23	2.19	2.19	2.19	2.19	2.11	2.11	2.10	2.09	2.11	2.10
Al_2O_3	14.26	14.32	14.04	13.96	14.26	14.21	14.22	14.16	13.72	13.76	13.72	13.73	13.72	13.77
Fe_2O_3	2.81	1.49	1.44	1.44	1.34	1.46	1.33	4.95	12.18	12.24	13.30	12.22	12.38	12.34
FeO	8.55	9.64	9.84	9.88	9.76	9.70	9.79	6.57	—	—	—	—	—	—
MnO	.18	.17	.17	.18	.17	.17	.17	.17	.16	.16	.17	.16	.18	.17
MgO	6.65	6.64	6.61	6.40	6.67	6.65	6.65	6.65	6.53	6.61	6.55	6.50	6.50	6.56
CaO	10.60	10.63	10.58	10.46	10.61	10.63	10.60	10.60	10.55	10.53	10.48	10.49	10.53	10.61
Na_2O	2.34	2.34	2.34	2.60	2.38	2.34	2.33	2.40	2.33	2.09	2.11	2.19	2.19	2.29
K_2O	.37	.36	.34	.40	.38	.38	.38	.38	.39	.39	.38	.39	.39	.39
P_2O_5	.23	.23	.23	.25	.23	.23	.22	.22	.26	.24	.23	.22	.24	.23
Cl	.01	0	.01	.01	0	0	.01	.01	—	—	—	—	—	—
F	.03	.03	.03	.03	.03	.03	.03	.03	—	—	—	—	—	—
S	.01	.02	.01	.02	.02	.04	.02	.01	—	—	—	—	—	—
CO_2	.01	0	.01	.01	.01	.01	.01	.01	—	—	—	—	—	—
H_2O^+	.01	0	.02	.01	.04	.04	.07	.05	—	—	—	—	—	—
H_2O^-	.07	.15	.04	.06	.01	0	0	0	—	—	—	—	—	—
Total	100.26	100.10	99.98	100.25	100.23	100.23	100.13	100.33	99.99	99.77	99.85	99.53	100.11	100.04

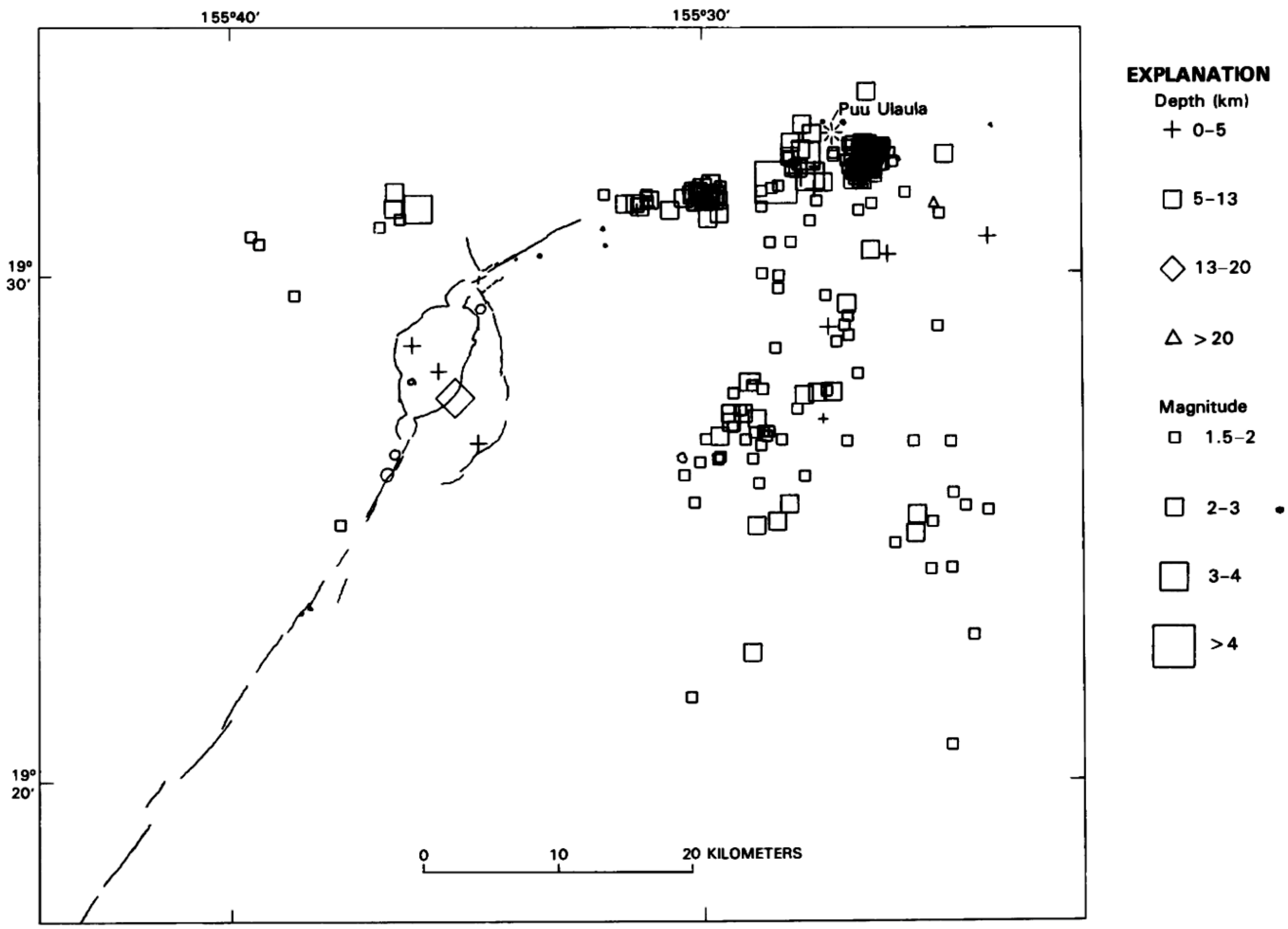


FIGURE 19.7.—Earthquake foci ($M \geq 1.5$) July 1–31, 1975. Earthquakes west of long 155° 34′ W. occurred before eruption, those to east occurred after July 5, mostly during critical period July 6–12.

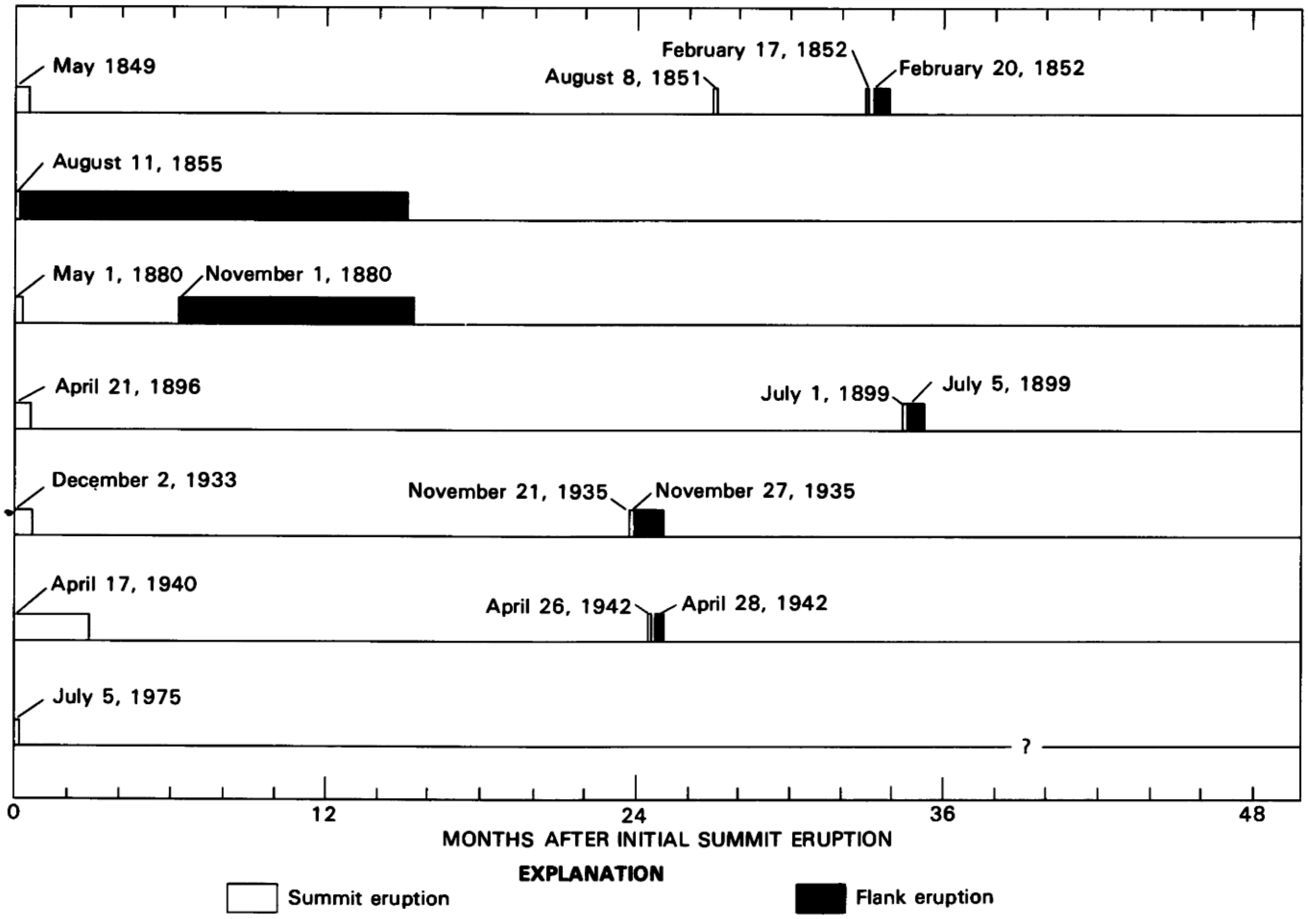


FIGURE 19.8.—Chronology of summit and northeast rift zone flank eruptions, 1849 to 1975 (modified from Lockwood and others, 1976, fig. 4).

the basis of this pattern (fig. 19.8), and the accumulating geophysical information on Mauna Loa's post-eruptive inflation, the 1975 eruption was recognized as the forerunner of future activity (Lockwood and others, 1976, p. 15):

> The historical record thus suggests that the summit eruption of July 1975 was the first phase of an eruptive sequence that will culminate with a major eruption on the flanks of Mauna Loa sometime before the summer of 1978. This flank eruption will likely be closely preceded by brief summit activity. If the Mauna Loa activity of July 6–10 is a reliable indicator, we can expect the flank vents to open between 2,800 and 3,000 m on the northeast rift zone in the vicinity of Puu Ulaula. On the basis of the historical record, we can expect relatively low fountains (50–75 m high) to form a 'curtain of fire' extending 1 to 3 km along the rift zone. The initial rate of lava production will be high, as are slope gradients high on Mauna Loa, so that lava may travel up to 10 km from eruptive vents during the first 24–48 hours. Because the rate of lava production should diminish, because the slopes of Mauna Loa become more gentle at lower elevations, and because lava will be farther from its supply vents, the flow rate will soon slow dramatically.

This scenario proved to be correct in all details, except for the timing, which was in error by almost six years (!).

THE INTERERUPTIVE PERIOD: 1975–1984

During this period the number of earthquakes beneath Mauna Loa's summit gradually increased in frequency. Geodetic monitoring showed that Mauna Loa continued to inflate at an essentially continuous, but irregular rate, reflecting the rise of magma into a shallow reservoir beneath Mokuaweoweo. The seismic and deformation data together allowed definition of the general location and depth of this reservoir (Decker and others, 1983). Civil authorities were kept apprised of Mauna Loa's inflation and the potential threat to the city of Hilo, and contingency plans were prepared for the diversion of lava flows above Hilo should that prove necessary (Lockwood and Torgerson, 1980; U.S. Army, 1980).

SEISMICITY

Over the 22-year period 1962–1984 shallow earthquakes (<5 km deep) were concentrated beneath Mokuaweoweo and the

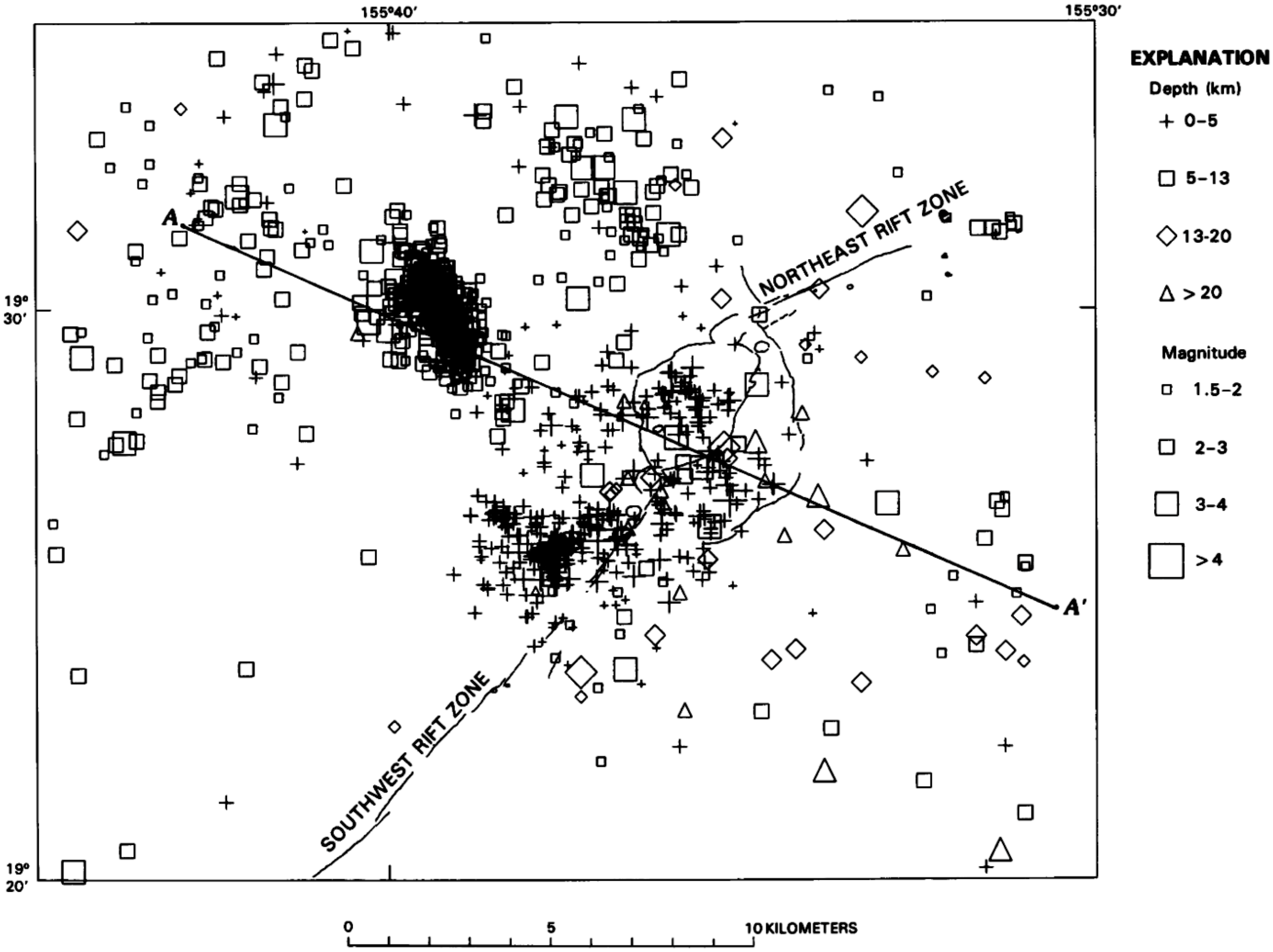


FIGURE 19.9.—Earthquake foci ($M \geq 1.5$) beneath Mauna Loa summit region from January 1, 1962, to December 31, 1984. *A–A′*, line of cross section in figure 19.10. The earthquake foci have been obtained from a network of about 50 seismic stations covering the entire Island of Hawaii. To eliminate any bias from increasing number of earthquakes processed, owing to the increased density of seismometers over this period, only earthquakes of magnitude equal to or larger than 1.5 with horizontal and vertical location uncertainties of less than 2 km are plotted.

upper SWRZ, whereas intermediate depth earthquakes (5–13 km deep) were concentrated beneath the northwest flank (figs. 19.9, 19.10). After the 1975 eruption and the posteruption swarm of intrusion-related earthquakes in the NERZ (fig. 19.7), shallow earthquakes ceased beneath the summit, but 2–3 intermediate-depth earthquakes were noted each year until 1977, when they increased to about 20 per year (fig. 19.11). The number of deeper earthquakes (>13 km) per year was unchanged over the entire inter-eruptive period. Shallow earthquakes began again in 1977, and their rate generally continued to increase until the 1984 eruption (fig. 19.12).

SEISMIC INTERPRETATION

The shallow earthquakes are believed to occur in brittle rocks capping a magma storage reservoir. The intermediate-depth earthquakes northwest of the summit are of tectonic origin (E. Endo, written commun., 1983) and may be related to stresses built up in response to the wedging effects of shallow dikes emplaced along the summit caldera and rift zones. The deeper earthquakes may be caused by the opening of deep feeder conduits between the mantle magma source and the higher magma storage reservoirs.

DEFORMATION

Following the large dike-related dilation of Mokuaweoweo on July 5, 1975, and the subsequent slight contraction, trilateration lines across the caldera continued to extend (fig. 19.13). Repeated trilateration measurements between the summits of Mauna Loa, Mauna Kea, and Hualalai revealed that the extensions across Mokuaweoweo were mostly accommodated by southeastward translation of Mauna Loa's southeast flank. The northwest flank was only slightly compressed by the Mauna Loa inflation. The summit inflation is also indicated by spirit-level (dry-tilt) measurements (fig. 19.14). Spirit-level measurements were made by precise, repeated

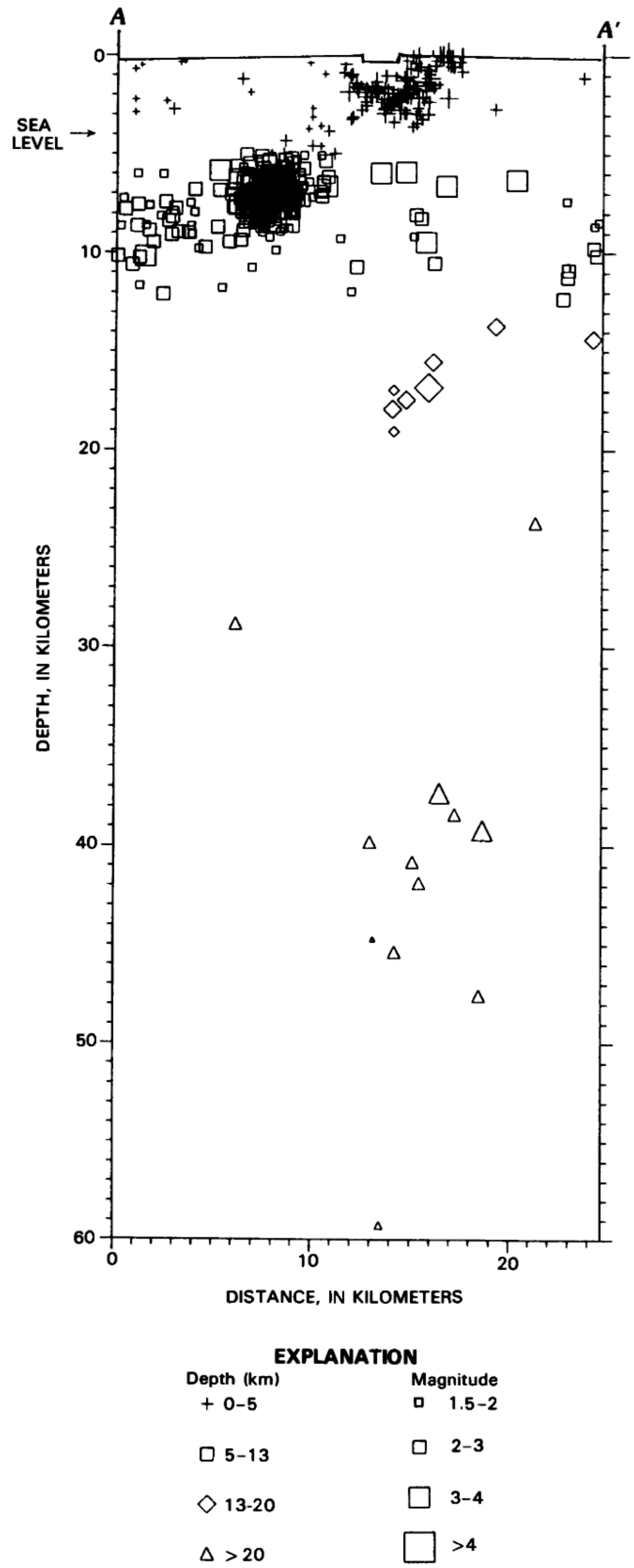


FIGURE 19.10.—Cross section of earthquake hypocenters within 2.5 km of line *A–A′* of fig. 19.9.

optical levels on stadia rods placed at bench marks arranged in a triangle with approximately 30- to 40-m base legs (Yamashita, 1981). Rapid outward tilt rates (inflation) persisted for one year after the 1975 eruption, followed by more moderate, though continuous, inflation after 1976. Level data for the summit region show greatest vertical uplift near the summit. The uplift profile (fig. 19.15) fits the theoretical uplift (Mogi, 1958) calculated for a pressure point source at 3.1 km depth.

DEFORMATION INTERPRETATION

Simultaneous inversion of horizontal, vertical, and tilt data for the period 1977–1981, using the methods of Dvorak and others (1983), further refined the location of the shallow inflation source (table 19.2; see fig. 19.19). In table 19.2 the longitude and latitude of the apex of inflation are x and y, respectively, and z is the depth to the point pressure source beneath the apex of inflation, referred to the elevation of the caldera floor. The volume values show, for each data source, the total volume of swelling, which represents the minimum volume of increased magma storage at depths of 3 to 4 km. The bulk rigidity and compressibility of the system are not known; thus magma-volume changes cannot be estimated. The base values show the amounts of theoretical uplift of the reference bench mark required to make the elastic model best fit the observations. The sigma values show the quality of fit between the least-squares model and the observations.

It is clear from all the deformation measurements that they fit a point-source elastic model reasonably well and that they define a common center of uplift and a surprisingly shallow pressure source. The similarity between the surface-deformation pattern of the summit areas of Mauna Loa and Kilauea Volcanoes is striking. On Kilauea, the pressure source is about 3 km deep (Fiske and Kinoshita, 1969; Swanson and others, 1976), and inflations and deflations of the summit area show similar patterns to those measured on Mauna Loa. Even though the lower zones of the magma chambers beneath Mauna Loa and Kilauea reach to several kilometers depth on the basis of seismic evidence (Koyanagi and others, 1975; Ryan and others, 1981), the changes in surface deformation on both volcanoes indicate that the zone of active magma input and removal is quite shallow, near the upper portion of the aseismic zones underlying both calderas.

The injection of magma into Mauna Loa's shallow storage reservoir over the 1977–1981 period caused an average surface-volume change of about 4×10^6 m^3/yr. This value is only 14 percent of the average historical Mauna Loa effusion rate of 29×10^6 m^3/yr (Lockwood and Lipman, chapter 18), and if characteristic of the entire 1975–1984 inter-eruptive period the cumulative amount intruded would account for only 16 percent of the volume erupted in 1984. For these reasons it is probable that magma was also accumulting at deeper levels within Mauna Loa during the 1975–1984 period. A schematic cross section of one possible model for the shallow magma-reservoir system beneath Mauna Loa shows the top of this shallow reservoir to be at about sea level (fig. 19.16).

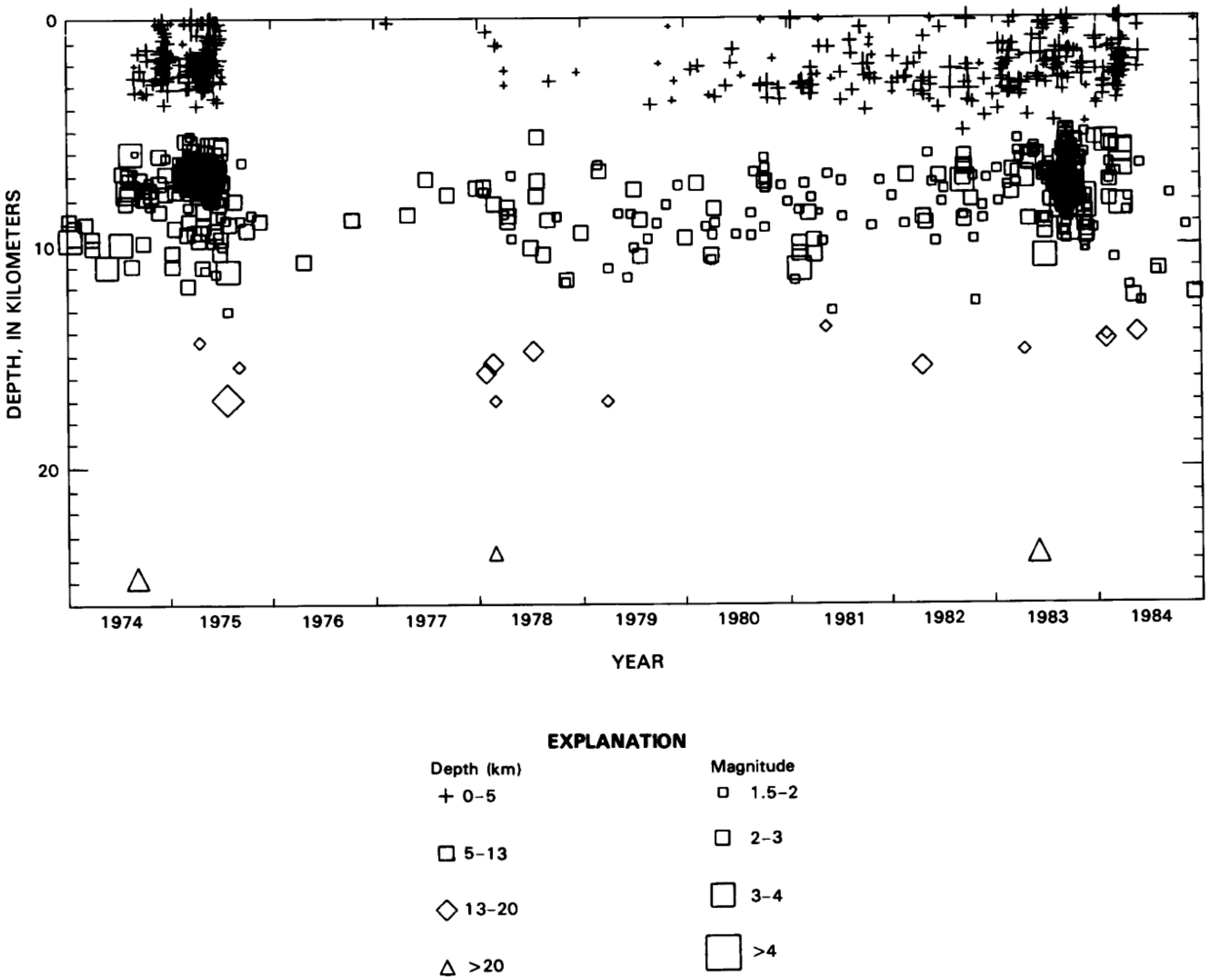


FIGURE 19.11.—Time, magnitude, and depth distribution of Mauna Loa earthquakes for period January 1, 1974, to December 31, 1984. Earthquakes plotted are those with $M>1.5$ located in area shown in fig. 19.9. Absence of earthquakes between 3 and 6 km depth suggests location of Mauna Loa's shallow magma storage reservoir.

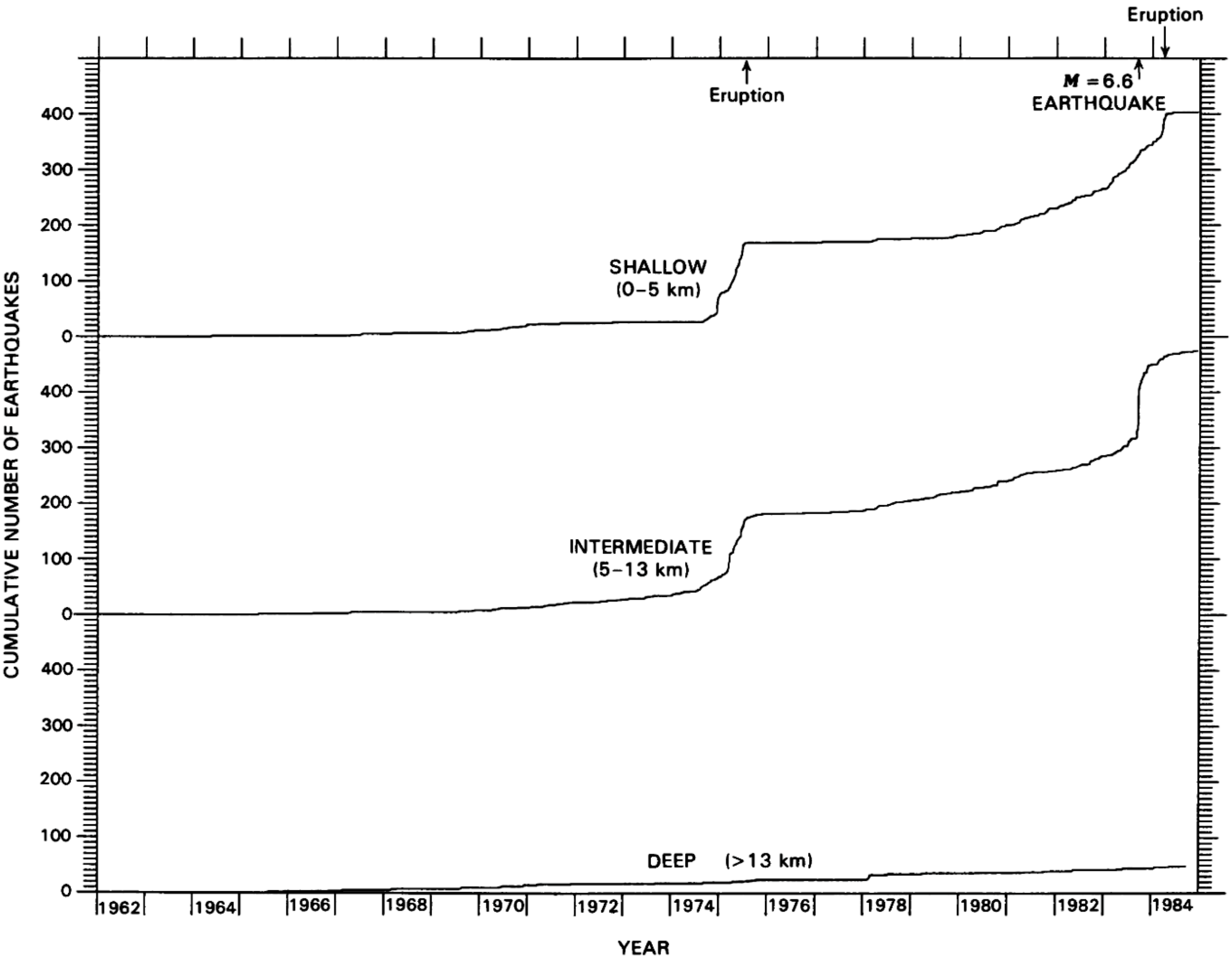


FIGURE 19.12.—Cumulative frequency plot of all earthquakes of magnitude equal to or greater than 1.5 beneath Mauna Loa summit region, from January 1, 1962, to December 31, 1984. Area included shown in figure 19.9. Note increase in intermediate depth earthquakes associated with $M = 6.6$ earthquake of November 16, 1983, and its aftershocks.

Zone A, the part of the magma-reservoir system that most influences summit geodetic changes, is probably a region that inflates slowly between eruptions and deflates rapidly during eruptive activity. Zone B may also be a region of magma storage, but is less active than zone A; it has less impact on surface deformation monitors. Both zones are inferred to be plexi of molten intrusions separated by screens of hot but more solid rock.

High-temperature (to 350 °C) fumaroles were continuously active along the central part of the 1975 eruptive fissures during the entire nine-year inter-eruptive period. These fumaroles produced visible fume (fig. 19.17) in dry as well as in humid weather and commonly produced a dense blue haze on Mauna Loa's upper north flank, especially during morning hours. This fume, mostly of atmospheric composition, contained relatively high concentrations of CO_2, which was frequently detected at the NOAA Mauna Loa Observatory during morning hours of downslope air movement (Miller and Chin, 1978). This fuming ceased immediately after cessation of the 1984 eruptive activity, and the Mauna Loa summit is now clear of visible fume (see Lockwood and Lipman, chapter 18, fig. 18.27).

Kilauea erupted more than six times during the 1975–1984 inter-eruptive period (1977, 1979, 1980, twice in 1982, and multiple episodes in 1983–1984). Mauna Loa exhibited no known sympathetic behavior with any of the Kilauea activity, suggesting the independence of their magma storage systems.

THE 1984 ERUPTION

Based on the post-1975 deformation and seismic data, Decker and others (1983) forecast an "increased probability for an eruption

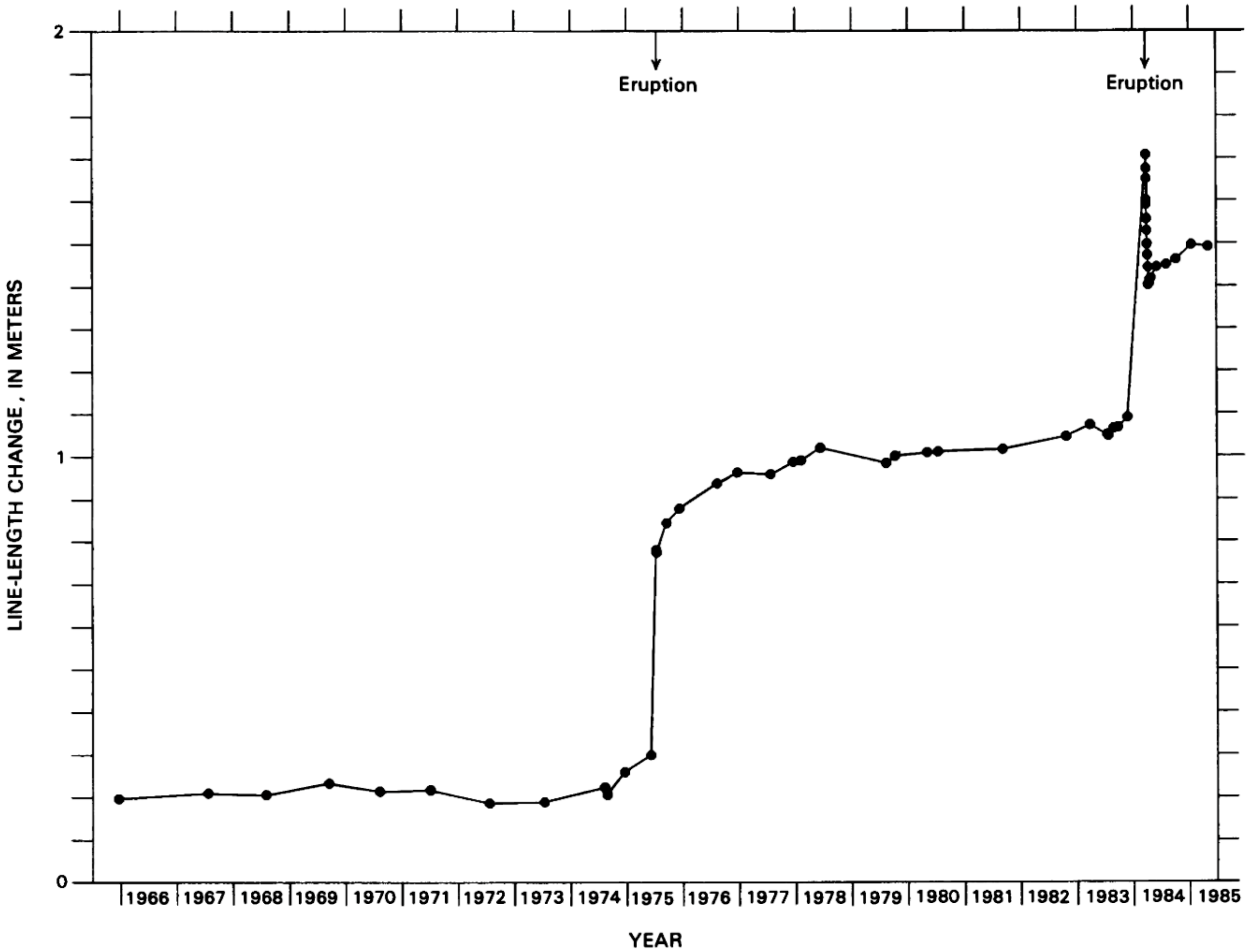


FIGURE 19.13.—Dilation of Mokuaweoweo, December 1965 to May 1985, as measured by trilateration surveys between stations HVO 92 and HVO 93 (station locations shown on fig. 19.19). Abrupt extensions on July 5, 1975, and on March 25, 1984, were associated with dike emplacement during 1975 and 1984 eruptions.

of Mauna Loa during the next two years." The inflation center was determined to underlie the south rim of Mokuaweoweo, and it was suggested that the eruption would follow historical patterns by beginning in the summit area.

PREMONITORY PHENOMENA

PREERUPTION SEISMICITY

Shallow- and intermediate-depth earthquakes increased in frequency beneath Mauna Loa from 1980 to 1983, culminating with a swarm of intermediate-depth earthquakes (5–13 km deep) beneath the northwest flank in mid-September 1983 (fig. 19.18). First-motion analyses suggest that these September earthquakes resulted from increasing lateral stresses generated in the summit and upper SWRZ, possibly as a consequence of intrusion of magma beneath the summit and upper rift zones (E. Endo, written commun., 1983).

At 0613 H.s.t. November 16, 1983, a damaging $M=6.6$ earthquake occurred beneath Mauna Loa's southeast flank (fig. 19.19). The earthquake generated an extensive aftershock sequence 20 km across, with the northern perimeter bordering Mauna Loa's NERZ. Seismicity remained high in the vicinity of Puu Ulaula until merging with eruptive seismicity on March 25, 1984.

The number of larger earthquakes ($M>1.5$) rose persistently as the time of eruption approached (figs. 19.11, 19.12). The daily frequency of smaller earthquakes ($M<1.5$) showed a more episodic increase, peaking one week before the eruption but decreasing to below average on the day before the outbreak (fig. 19.20). The overall distribution of earthquakes in the 16 months before the eruption (fig. 19.18) is remarkably similar to distribution of earthquakes in the 16 month period before the July 5, 1975, eruption (fig. 19.3).

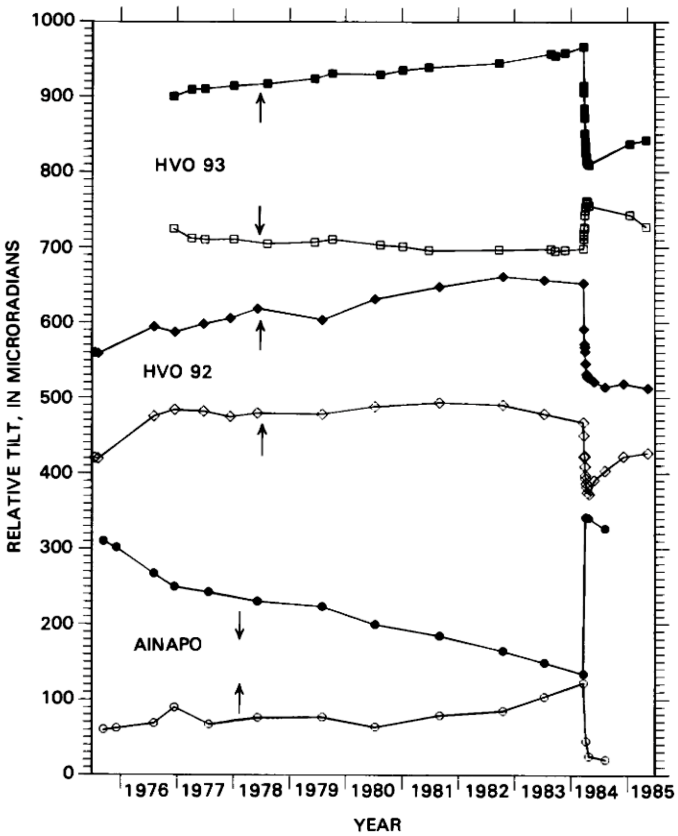


FIGURE 19.14.—Spirit-level tilt changes at three Mauna Loa summit stations, 1975 to 1985 (see fig. 19.19 for station locations). Darkened symbols are north-south component; open symbols are east-west component. Positive tilt changes indicate north or east down. Arrows show inflation direction for individual tilt components. Summit inflation is recorded at all stations prior to and after March 25 to April 15, 1984 eruption.

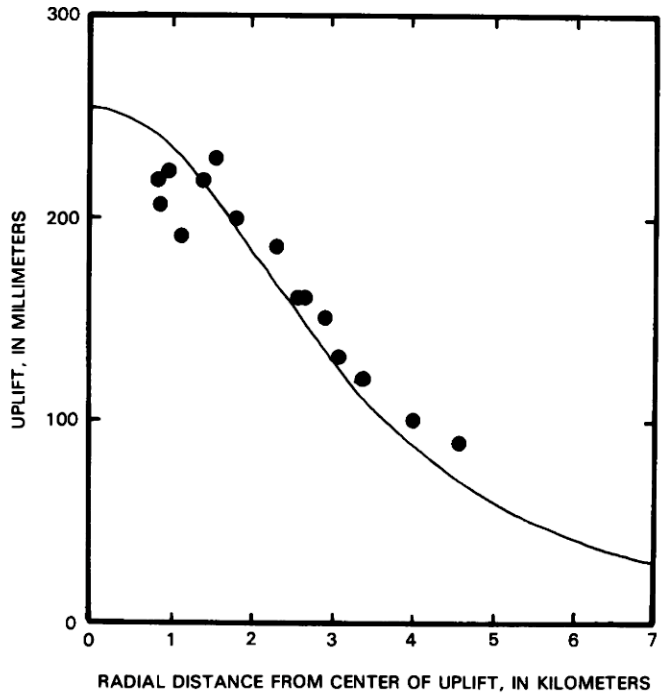


FIGURE 19.15.—Comparison of observed elevation changes in summit area (from 1977 to 1981 leveling surveys) with best-fit elastic deformation model (solid curve); see figure 19.19 for level station locations and calculated uplift center (from Decker and others, 1983, fig. 10).

TABLE 19.2.—*Mauna Loa geodetic data, 1977–1981*

[From Decker and others, 1983]

Data	x		y		z (km)	Volume (10^6 m^3)	Base (mm)	σ Level (mm)	σ EDM		σ Tilt (μrad)
	Longitude (West)	(km)	Latitude (North)	(km)					mm	μ strain	
Leveling	155°34.5′	±0.2	19°27.5′	±0.2	3.1±0.5	17±3	59±24	4	--	--	--
Tilt	155°35.2′	±0.6	19°27.5′	±0.6	2.6±1.2	8±5	--	--	--	--	27
EDM	155°35.1′	±0.7	19°27.2′	±0.4	3.2±1.2	19±8	--	--	37	25	--
All	155°35.0′	±0.4	19°27.3′	±0.3	3.9±0.8	22±6	88±50	16	40	26	30

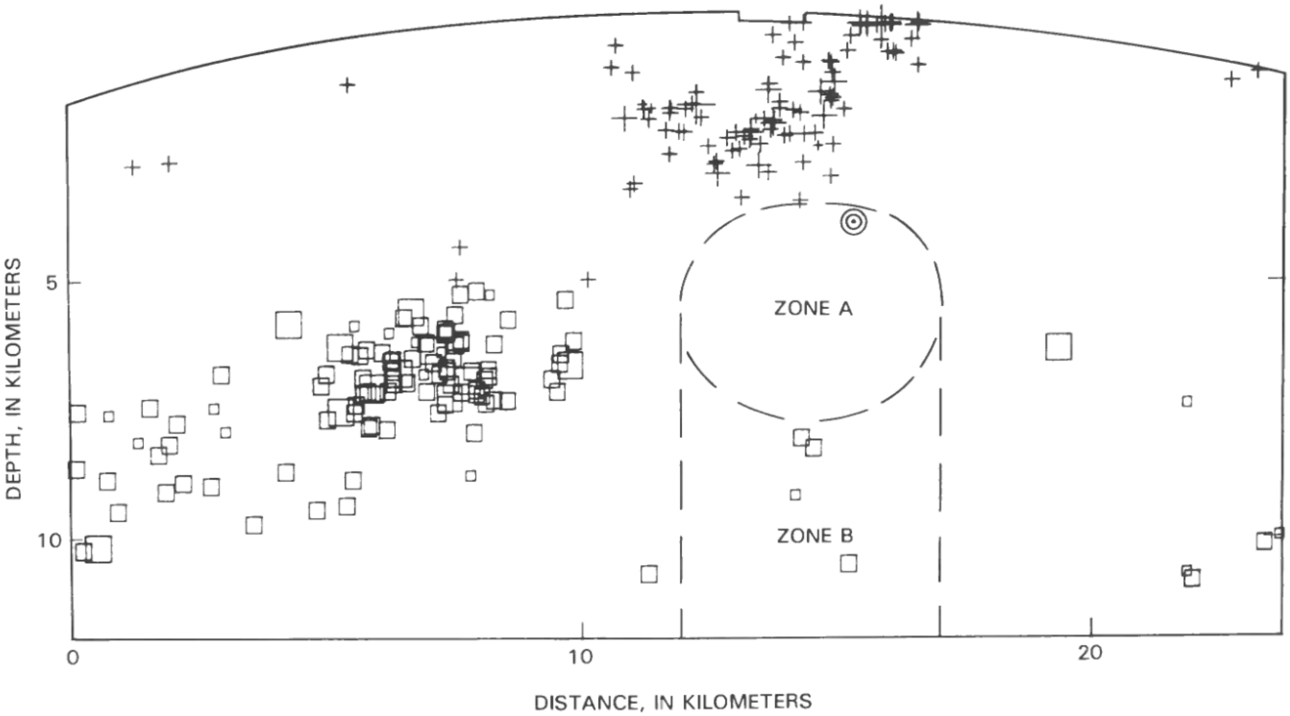


FIGURE 19.16.—Approximately true-scale schematic cross section of proposed magma reservoir system beneath Mokuaweoweo defined by an aseismic zone. Cross section and earthquake hypocenters same as in upper 12 km of figure 19.10, except earthquakes after May 1983 omitted. Double circle in zone A shows point-source inflation center calculated with 1977–81 deformation data (from Decker and others, 1983, fig. 14).

FIGURE 19.17.—Fumaroles along 1975 eruptive fissures in Mokuaweoweo caldera, view to north-northeast. 1940 cone in lower left, Mauna Kea in background. Photograph taken December 1977 by J.P. Lockwood.

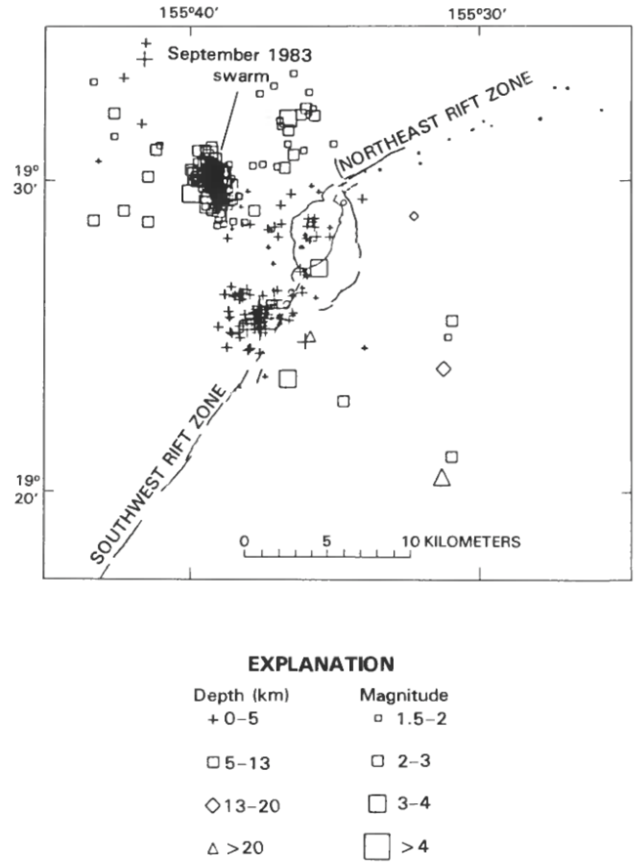


FIGURE 19.18.—Earthquake locations in summit region for 16-month period before 1984 eruption (September 24, 1982, to March 24, 1984). Compare with figure 19.3.

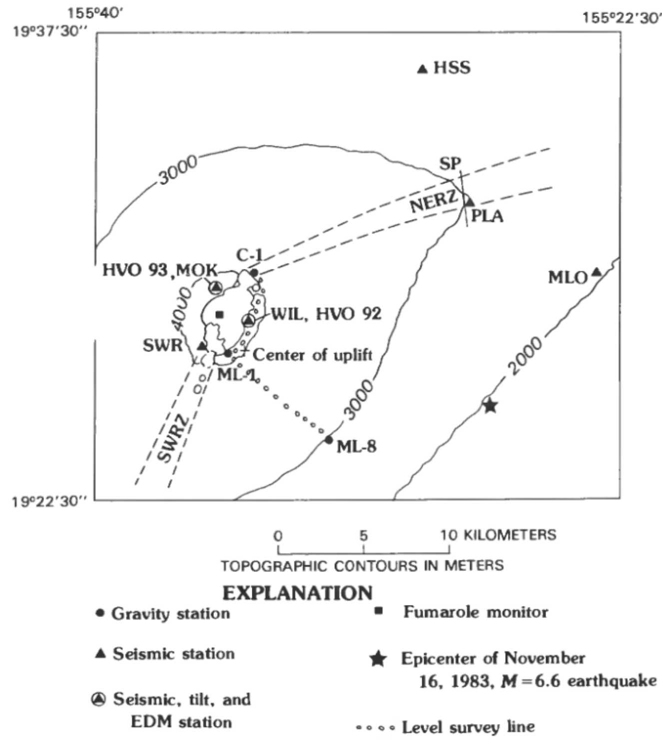


FIGURE 19.19.—Mauna Loa summit area, showing location of stations and features. NERZ, northeast rift zone; SWRZ, southwest rift zone; SP, electrical self-potential survey line.

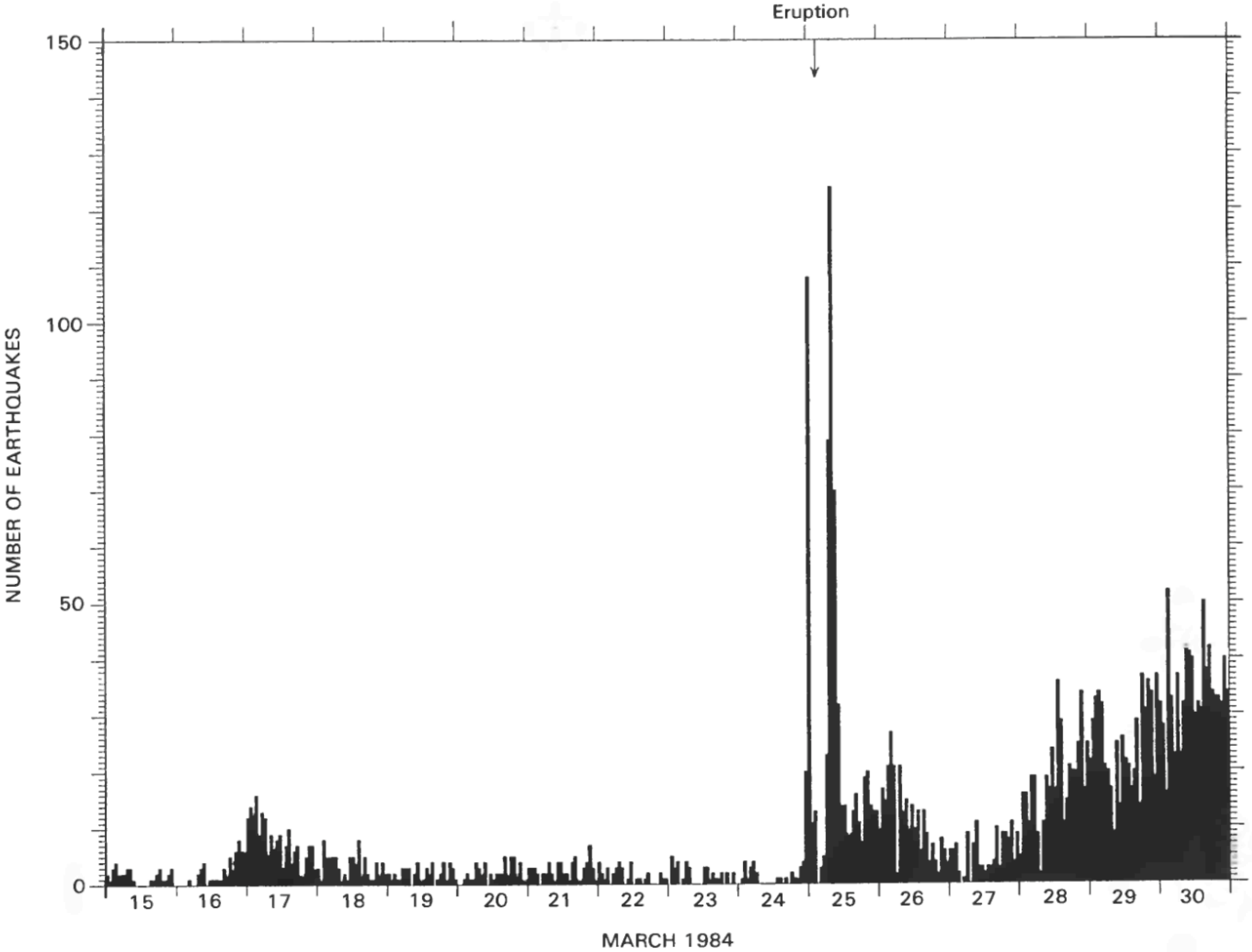


FIGURE 19.20.—Hourly counts of Mauna Loa short-period summit earthquakes for period March 15–30, 1984. Increase in earthquake frequency after March 27 accompanied deflation of Mauna Loa summit. Low counts on the morning of March 25 reflect period of masking by background of high-amplitude tremor.

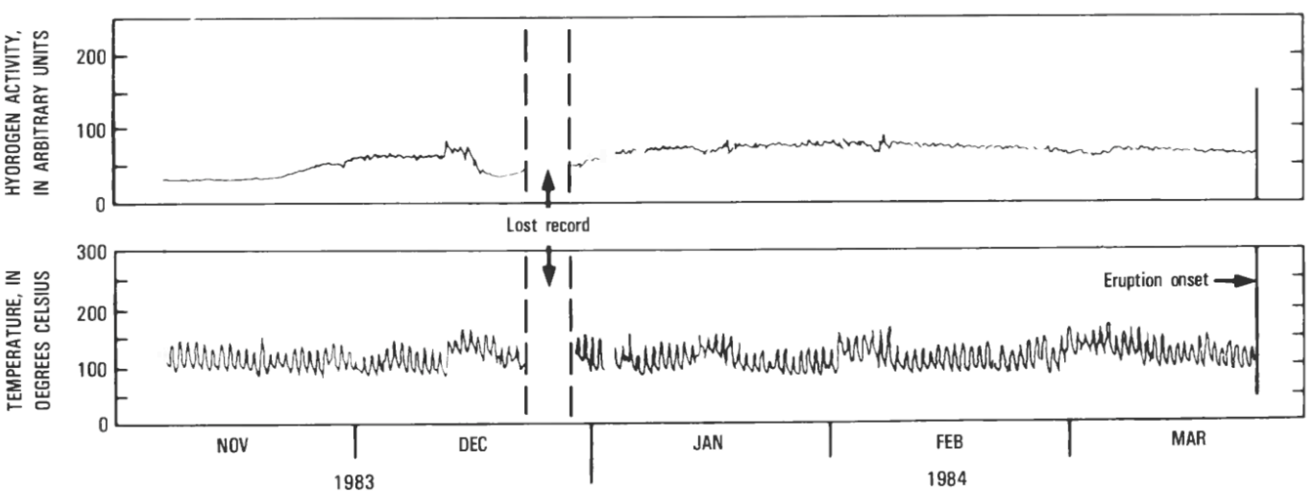


FIGURE 19.21.—Variation of temperature (t) and hydrogen (H_2) activity in a fumarole on 1975 eruptive fissure, Mokuaweoweo caldera, between November 5, 1983, and March 24, 1984. Temperature values are not field calibrated. Large diurnal temperature variations may be caused by artificial instrumental amplification. Hydrogen activity is referenced to a nonquantitative instrumental standard. Data from M. Sato and K. McGee, U.S. Geological Survey (from Lockwood and others, 1985, fig. 3).

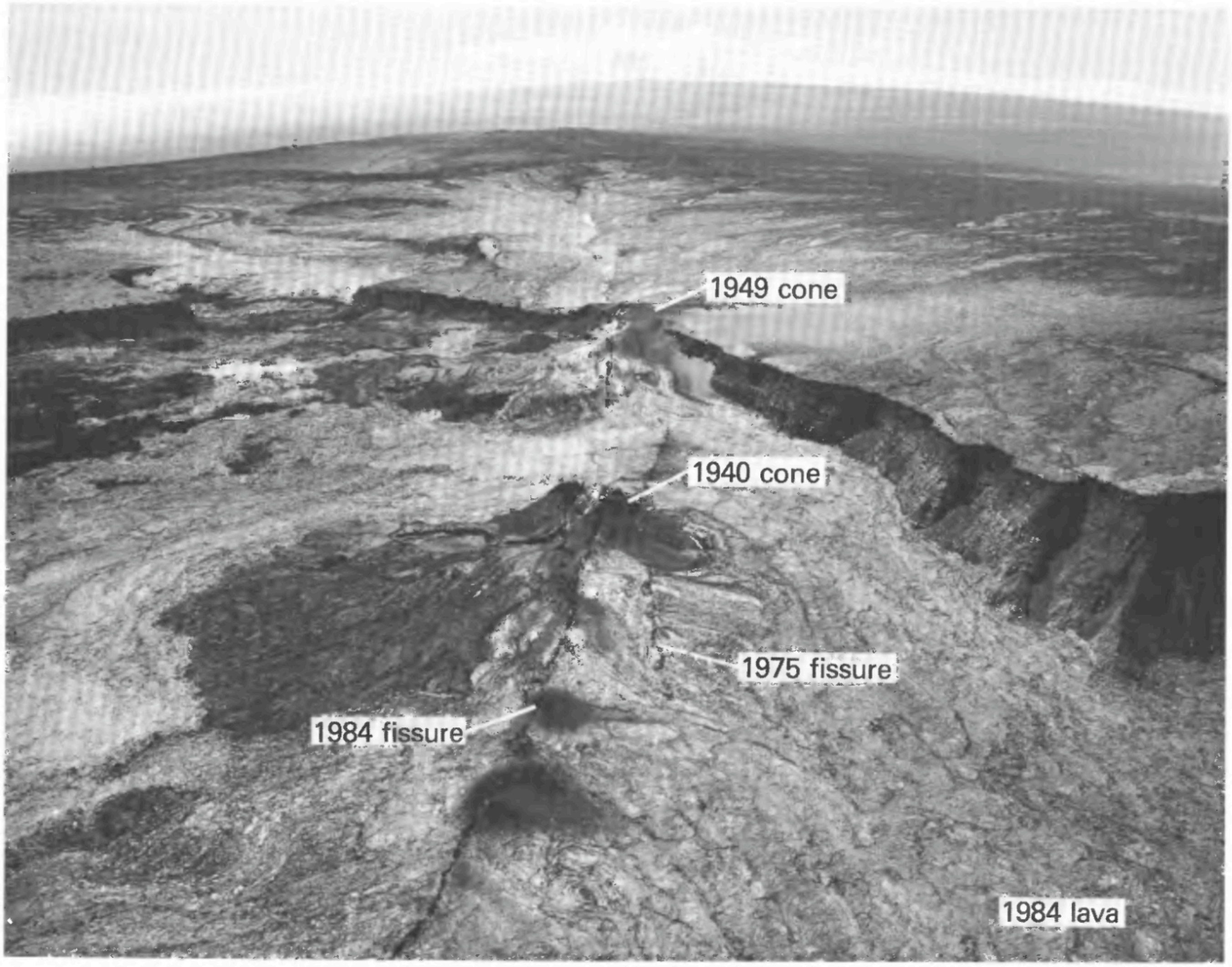


FIGURE 19.22.—Oblique aerial view, looking southwest, of 1984 eruptive fissure at southwest edge of Mokuaweoweo. Fissure extends across Mokuaweoweo, across 1940 and 1949 cones, and down the southwest rift zone. Reflective pahoehoe flows on caldera floor and down upper southwest rift were all erupted on March 25. Note 1975 eruptive fissure at northwest base of 1940 cone. Photograph by F.R. Warshauer.

PRE-ERUPTION DEFORMATION

Trilateration and tilt surveys showed that the inflation continued at a steady, but nonincreasing rate almost to the 1984 outbreak and gave no cause for alarm (figs. 19.13, 19.14).

FUMAROLE MONITORING

A remote station for monitoring H_2 activity and temperature was installed in a fumarole situated along a 1975 eruptive fissure in Mokuaweoweo on November 5, 1983 (Lockwood and others,' 1985). The first rise in temperature above the diurnal fluctuations was observed in the afternoon of November 18, 1983 (fig. 19.21).

A brief, small increase in H_2, as measured by activity of an H_2-O_2 fuel cell, was recorded concurrently with this temperature increase. The H_2 level had been stable before then, but gradually began to rise on November 21. Could these November changes have been related to the $M=6.6$ earthquake of November 16? Both temperature and H_2 increased on December 13, and on December 14 an anomalous steam cloud was seen rising to about 1 km above Mokuaweoweo. The fumaroles were visited on December 17, but temperatures and fuming were normal.

The H_2 level gradually increased again through late December and early January. Three thermal events lasted for 4 to 9 days in mid-January, early February, and early March. The H_2 levels showed concurrent changes, but the correlations were negative in 1984, contrary to the positive correlations observed in 1983. The reversal may indicate a change in the nature of emitted gases from reducing (H_2-rich) to more oxidized (H_2O, O_2-rich). The last data

FIGURE 19.23.—Echelon eruptive fissures in Pohaku Hanalei area, northeast rift zone at dawn on March 25, 1984. Compare with 1975 vent locations (fig. 19.5). View to west. Photograph by J.D. Griggs.

transmission (1 h before the sensors were destroyed at the eruption onset) showed normal background levels with no portent of the imminent events.

VISUAL OBSERVATIONS

On March 18, 1984, dull red glow was spotted along a crack (1975 fissures?) on the Mokuaweoweo floor by a hiker, but his report did not reach HVO until after the eruption began. On March 23, several observers spotted "steam clouds" rising above Mokuaweoweo. On March 24, the day before the eruption, M.M. Godchaux of Mount Holyoke College reportedly saw rocks and steam being ejected from the 1975 fissures, near the center of Mokuaweoweo, but there was no means to alert HVO.

ERUPTION NARRATIVE

Seismic stations MOK, WIL, and SWR along the rim of Mokuaweoweo (fig. 19.19) began to record an increase of shallow earthquakes at 2255 H.s.t., March 24 (fig. 19.20). Earthquakes less than $M=0.1$ were recorded at a rate of 2–3 per minute after this time. At 2330 an increase in seismic background marked the onset of harmonic tremor. The onset of tremor, which presumably recorded the beginning of magma ascent to the surface, coincided with a fortnightly earth tidal minimum. A correlation between eruptive activity and fortnightly tidal minima was also noted at a 19th century eruption of a volcano in El Salvador (Golombek and Carr, 1978), but this is not a general characteristic of Mauna Loa eruptions (Dzurisin, 1980). The earthquake swarm and tremor strengthened rapidly just before 0100, March 25. At 0056 it became impossible to stabilize astronomical telescopes on the summit of Mauna Kea, 42 km to the northwest, owing to ground oscillations, and observations were impossible for the next 2 hours.

An infrared sensor in a military satellite recorded a "strong signal" from Mauna Loa at 0125:16 on March 25; this signal indicated the first surface outbreak of the eruption. At 0130 observers at the Mauna Kea summit and at Puu Ulaula spotted a red glow reflected off fume clouds above the southwest part of Mokuaweoweo (at about 4,015 m elevation). Eruptive fissures migrated rapidly down the upper SWRZ to 3,890 m, across the 1940 cone, and to the northeast across Mokuaweoweo, a few meters southeast of the 1975 fissures (fig. 19.22). At 0357 fountains extended into the upper NERZ and migrated in a series of south-stepping echelon fissures eastward (fig. 19.23), south of the 1975 fissures (compare with fig. 19.5). At about this time the fountains died out on the SWRZ and began to wane within Mokuaweoweo. By 0700 the fountaining was restricted to a zone on the NERZ between 3,700 and 3,780 m. At 0910, however, new fountains appeared 7 km farther east, at 3,410 m. The fissure feeding this new outbreak migrated rapidly uprift and downrift, and by 0930 a 2-km-long "curtain of fire" was active between 3,400 and 3,470 m elevation. Fountains were 10–50 m high along this fissure, and lava output was estimated at $1-2\times10^{6}$ m^3/h. A narrow flow moved about 5 km down the southeast flank from these vents, southwest of the 1880 flow. At 1030, profuse steaming was noted along a 1-km-long fracture system between 3,260 and 3,170 m, but there was no further downrift migration of fountains for several hours, and lava production again waned.

At 1641 a new eruptive fissure opened below Puu Ulaula at about 2,850 m elevation, 19 km east of the original outbreak point within Mokuaweoweo. These vents opened south and slightly uprift from the principal vent of the previous NERZ eruption, that of 1942 (fig. 19.24). The dike feeding these vents had migrated down the NERZ at an average rate of 1,200 m/h (fig. 19.25). The new eruptive fissure migrated rapidly both uprift and downrift, and by 1830 a 1,700-m-long "curtain of fire" was active between 2,770 and 2,930 m elevation. All fountains farther uprift quickly waned, and for the next three weeks eruptive activity was confined to these lower vents, hereafter called the 2,900 m vents. Six principal structures eventually formed around localized vents along this fissure, including a cinder cone at the uprift end and a lava shield at the downrift end (fig. 19.26). Lava fountains were low and never exceeded 50 m in height. By daybreak on March 26, a fast-moving flow from the 2,900 m vents had traveled 9 km to the northeast, and three shorter flows moved eastward. These latter flows directly threatened two penal facilities at 1,600 m elevation—the abandoned Mauna Loa Boy's School and the Kulani Honor Camp (figs. 19.27, 19.28). Inmates were prepared for evacuation on March 26 but the flows ceased forward movement within 48 hours and never crossed the Powerline Road above these facilities (fig. 19.28). On March 28 a 100-m-long east-west steaming fissure was noted on the north side of a prehistoric spatter cone at 2,435 m elevation, 4 km east of the lowest eruptive vents. A dike may have been intruded below this area, but if so it never broke the surface. The principal flow (flow 1 on fig. 19.28) advanced as a narrow, well-channelized

A

FIGURE 19.24.—Oblique views of middle northeast rift in area of 2,900-m vents. ***A***, Area before eruptive activity; photograph taken on September 6, 1978. ***B***, Area after March 25, 1984 eruption; photograph taken on May 5, 1984. Location where 1984 eruptive fissure later opened shown by white line in *A*. Note 1984 lava shield (arrow) at left margin of *B*. Photographs by J.P. Lockwood.

aa flow on top of and between the flows of 1852 and 1942. Although flow-advance rates slowed as the lava moved farther from the 2,900 m vents, the flow had traveled 25 km by March 29, reaching the 915 m elevation and causing concern in the city of Hilo, whose nearest buildings were then 6 km away. Several square kilometers of native rainforest were destroyed, and the copious smoke from burning vegetation (fig. 19.29), as well as large explosions from accumulations of methane gas near flow margins, accentuated the apprehension of Hilo residents.

On the morning of March 29, however, a channel levee on flow 1 collapsed at the 1,740 m elevation, 13 km upstream from the flow front. Here lava was diverted to form a second flow parallel to the first, and most of the supply to the initial lava flow was cut off. The new flow (flow lA on fig. 19.28) also moved rapidly downslope, but did not overtake flow 1 until April 4. Another channel collapse and diversion occurred on April 5 at 2,070 m elevation, cut off the supply to flow lA, and started a new branch (flow lB). Lava production at the 2,900 m vents had begun to decrease in late March (Lipman and Banks, chapter 57, table 57.3) and rates of flow within the feeder channels clearly decreased (fig. 19.30). Lava in the channels became steadily more viscous (see section "Lava Petrography and Temperatures"), and channel blockages and levee

B

FIGURE 19.24.—Continued.

collapses occurred more and more frequently. These collapses restricted lava supply to the lower flow fronts, and the elevation of the lowest active flows moved steadily upslope (fig. 19.31), easing the threat to Hilo. By April 14 no active lava flows extended more than 2 km below the 2,900 m vents; the eruption ended on April 15.

On April 2 the north margin of flow IA abutted against a 40-m-long segment of a lava diversion test barrier constructed at the 1,150 m elevation in 1977. The 4- to 5-m-high barrier impeded advance of this 10- to 12-m-thick portion of flow 1A for 6 days, but was finally overtopped by a short aa tongue on April 8, as the flow, now cut off from fresh lava supply, continued to creep forward because of gravitational downslope movement of its molten core (fig. 19.32).

The 1984 lava covered an area of about 48 km^2 (figs. 19.28, 19.33), and about 220×10^6 m^3 of lava was erupted. About 90 percent of the total volume was erupted from the 2,900 m vents. Flow thicknesses ranged from less than 1 m near short-lived vents to as much as 18 m at the distal ends of major aa flows.

As the flows cooled, a thin sublimate coating of *thenardite* (Na_2SO_4), as identified by T.E.C. Keith (written commun., 1984), formed on protected surfaces, and in late April many flows at higher, dry areas looked as if they had been dusted by a light snow.

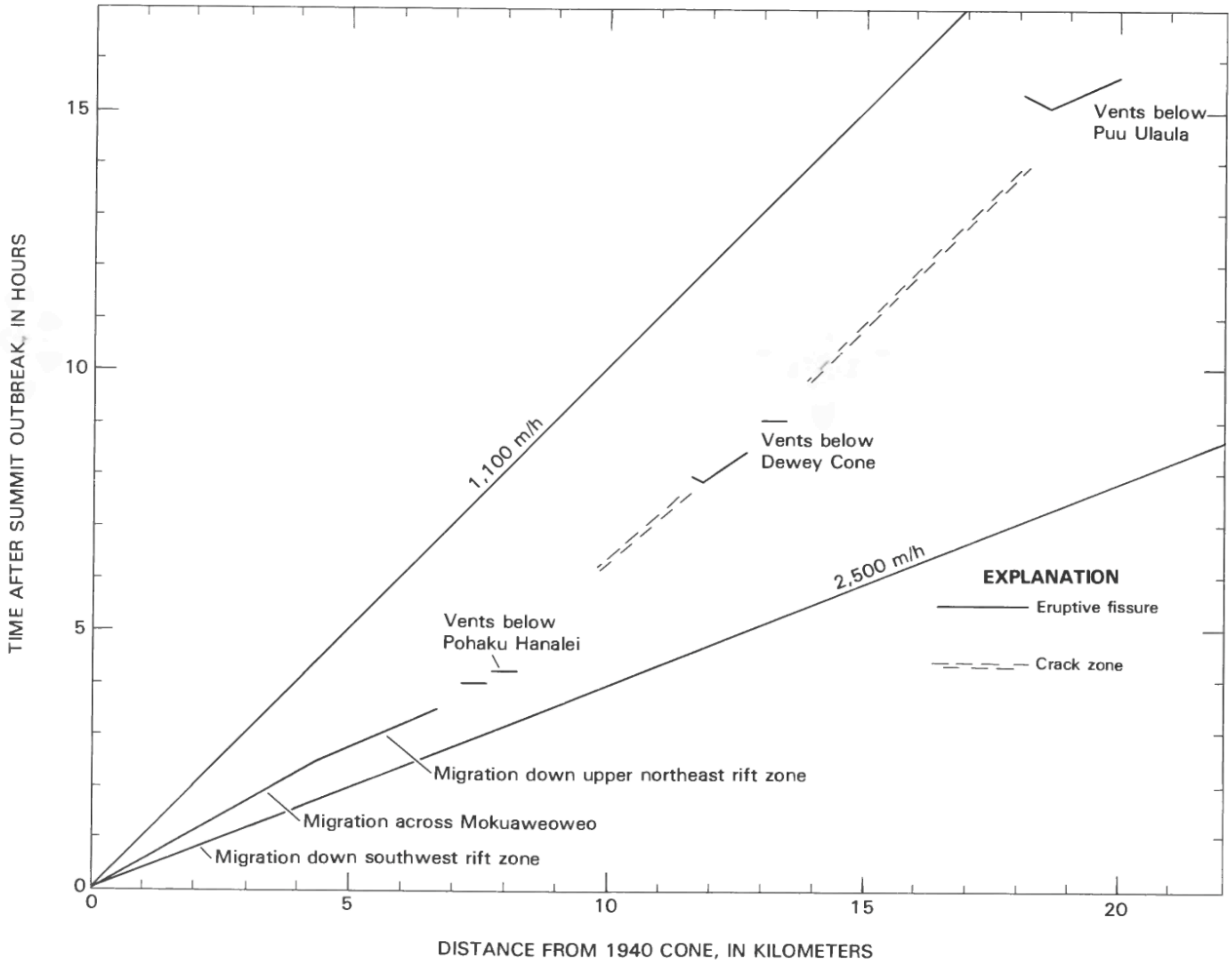


FIGURE 19.25.—Eruptive fissure (dike propagation) rates on March 25, 1984. Upside-down chevron fissure plots indicate propagation both uprift and downrift after initial surface rupture.

The thenardite was as thick as 5 mm as a mat of very fine, acicular crystals and formed after the rocks cooled below incandescence, but while still at over 100 °C. The mineral was especially common on low density (more permeable ?) aa blocks. This mineral is fragile, and water soluble, and was easily blown away by high winds; it was not seen after light rains in early May. This occurrence has apparently not been previously reported on Hawaiian lavas, although it is likely a common, but ephemeral mineral on cooling aa flows. It has also been reported as a high-temperature sublimate on the growing andesite dome of Mount St. Helens volcano (Keith and others, 1981).

A brief but spectacular eruption of Kilauea Volcano on March 30 (episode 17 of a protracted east rift zone eruption) had no effect on activity at Mauna Loa. These were the first simultaneous eruptions of Mauna Loa and Kilauea since 1919 and served to demonstrate the magmatic independence of these two volcanoes.

SEISMIC OBSERVATIONS

Although lava did not reach the surface until 0126, seismic activity had reached high levels earlier, and seven moderate earthquakes of 3.0–4.2 magnitude occurred between 0050 and 0210. This intrusion-related earthquake swarm and harmonic tremor at the summit decreased at 0215, marking the beginning of about 5 h of comparatively low seismicity (fig. 19.20), as magma migrated into the NERZ. Perhaps the elevated NERZ seismicity associated with aftershocks of the November 16, 1983, $M=6.6$ earthquake (Koyanagi and others, 1984) caused a substantial decrease in stress, which facilitated the subsequent rapid and relatively aseismic migration of magma from the summit into and along the NERZ on this morning. Or, perhaps the magma that intruded into the middle NERZ on July 6–10, 1975, was still liquid and capable of maintaining open conduits.

Between 0700 and 0915 the frequency of small earthquakes

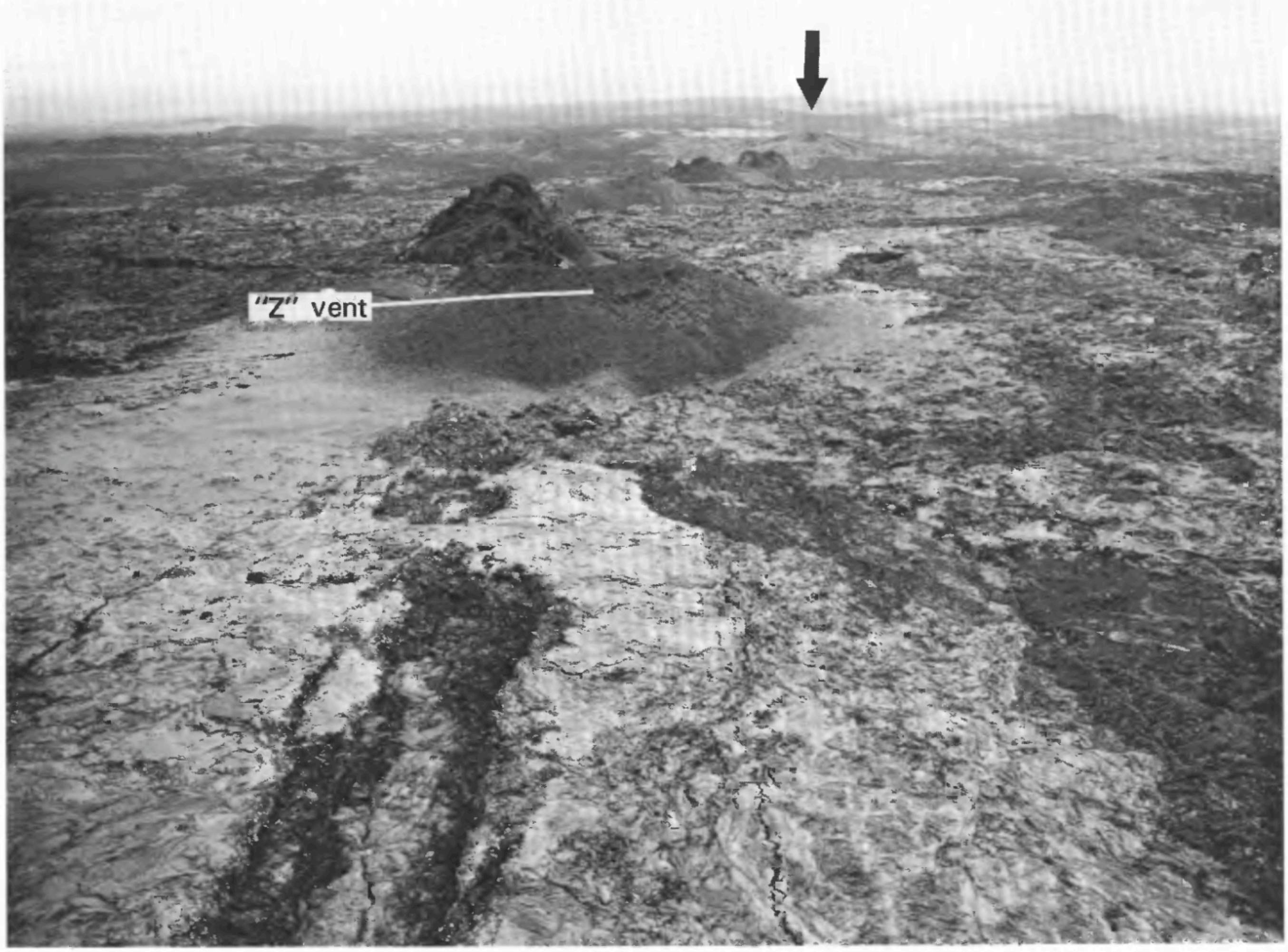


FIGURE 19.26.—Oblique view of 2,900-m vents looking downrift, with 25-m-high "Z" vent cinder cone and its tephra blanket at uprift end of vent system. This cone formed on April 8–12, and was the only vent to produce reticulite. Note lava shield at lower end of vent system (dark arrow). Cracks in foreground converge on "Z" vent and mark subsurface position of feeder dike. Note 20° bend in 1984 eruptive fissure. Photograph by J. P. Lockwood, April 30, 1985.

increased beneath the summit (fig. 19.20) and the NERZ midway between Mokuaweoweo and Puu Ulaula (fig. 19.28). At 0917 harmonic tremor increased in the NERZ, and high tremor was recorded on stations more than 30 km away. For the remainder of the vigorous eruption, tremor was centered along the NERZ and generally decreased in amplitude as a function of distance from Puu Ulaula. The dominant period of the tremor signals varied from about 0.2 to 0.7 s and also varied with recording distance from the eruption zone. Shorter period tremor dominated at stations within a few kilometers of the eruptive center. Short-period tremor was also dominant during the pre-eruptive and early eruptive stages. Tremor remained consistently strong on the seismometer nearest the eruptive site (PLA) until April 12, and after several days of low activity decayed to nearly background levels on April 15. The more distant stations MLO and HSS, located about 8 km from the center of eruption, showed highest tremor from March 25–28, followed by a lower level until April 2 and a gradual decay until the end of the eruption on April 15 (fig. 19.34).

The frequency of shallow, short-period earthquakes associated with summit subsidence started to increase on March 28. Counts peaked at 50–100 per hour on April 5–8, and they remained relatively high throughout April. These events decreased slowly thereafter and reached nearly average pre-eruption levels by mid-May. Earthquakes related to summit subsidence were mostly smaller than magnitude 1, shallower than 5 km, and centered in the caldera region. An exceptionally large earthquake on April 9, which measured $M=3.9$, was located 2 km beneath the caldera.

Numerous small, short- and long-period earthquakes near the active vents on the northeast rift followed the cessation of eruptive activity. These events (mostly $M<0.1$), which numbered many

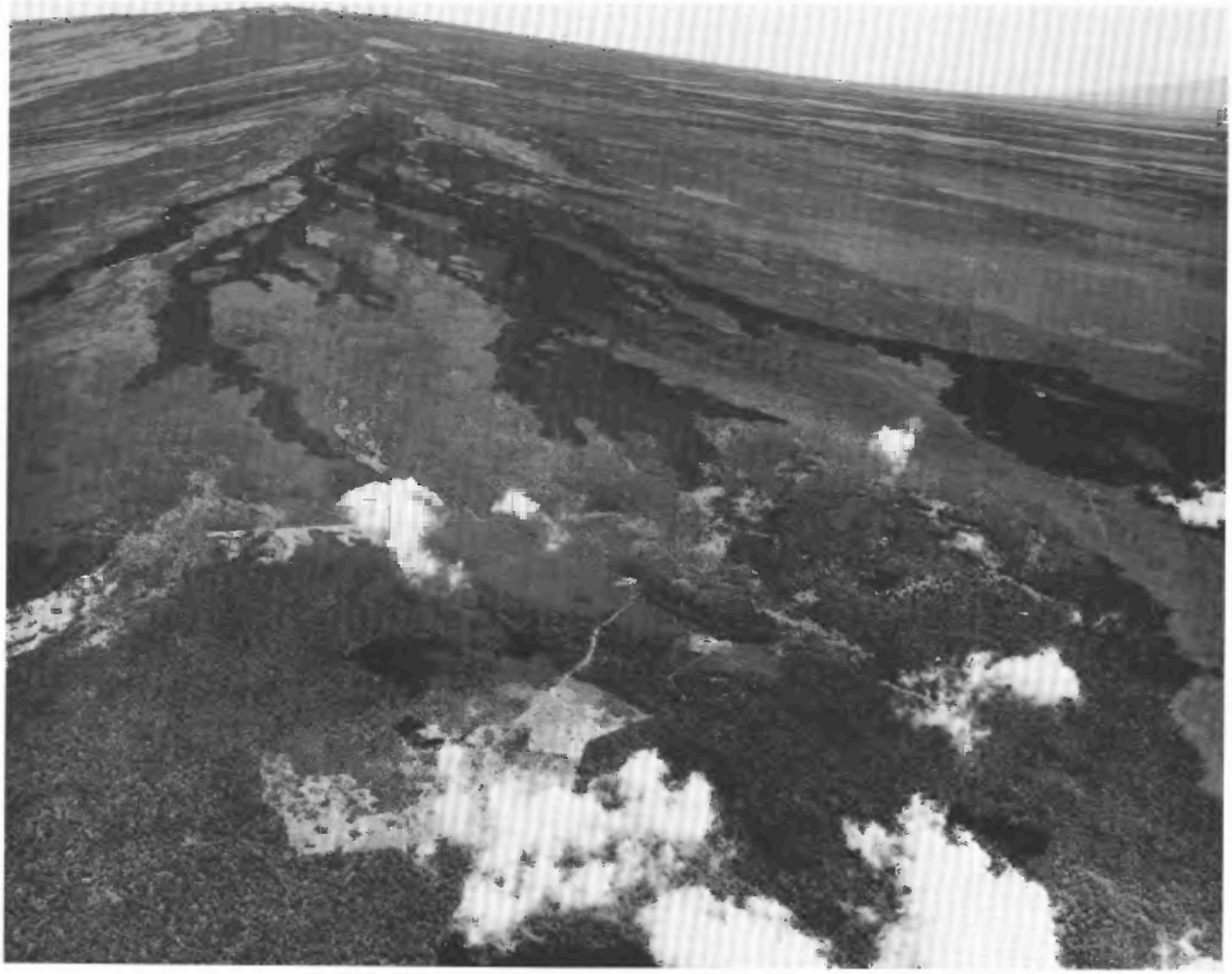


FIGURE 19.27.—Oblique aerial view of northeast rift zone showing 1984 lava (dark areas) between 2,000 and 3,000 m. Mauna Loa Boy's School is in right foreground. Kulani Honor Camp is located left of photograph margin. Lineament across center of photograph is Powerline Road. View is to west. Photograph by J.P. Lockwood.

hundreds per day in late April and throughout May 1984, were apparently caused by vent degassing activity as well as by local stresses induced by gravitational and thermal gradients; they gradually decreased to background levels (fig. 19.34).

GEODETIC OBSERVATIONS

An automatic tiltmeter located near the seismic station MOK at Mauna Loa's summit (fig. 19.19) recorded rapid surface displacements beginning at 0100 on March 25 (fig. 19.35). The initial tilt change, a sharp downward deflection to the north and west, indicated uplift of the summit region, probably caused by the sudden upward migration of magma.

A reversal in tilt direction at 0150 marked the beginning of summit subsidence and may also have corresponded to the eastward migration of eruptive vents. Subsequent spirit-level measurements at several dry tilt stations around the summit (network shown in Decker and others, 1983, fig. 13) indicated that subsidence of the summit region continued, though at a decreasing rate, for the duration of the eruption (fig. 19.36). A similar pattern of summit subsidence—contraction of several horizontal lines across the caldera—was indicated by trilateration surveys (fig. 19.37). The curves shown in figure 19.37 are similar to the decreasing lava production rate determined at the 2,900 m vents (Lipman and Banks, chapter 57, fig. 57.17). Net tilt changes between July 1983 and May 1984

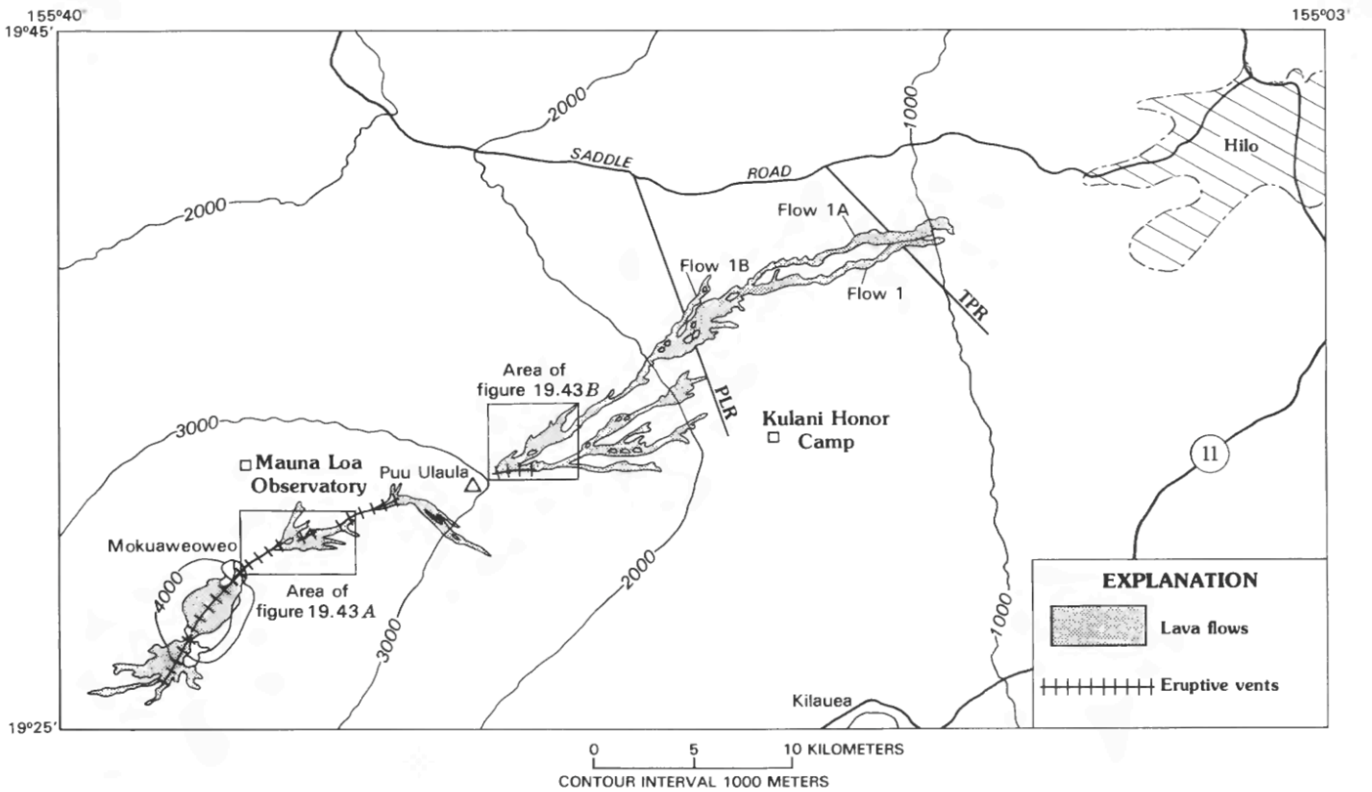


FIGURE 19.28.—Distribution of 1984 eruptive vents and lava flows and locations of figures 19.43*A*, *B*. PLR, Powerline Road; TPR, Tree-planting Road. (Modified from Lockwood and others, 1985, fig. 5.)

were 100–300 microradians at summit dry-tilt stations (fig. 19.38). The computed center of subsidence was in the southeastern area of the summit, a position identical to the center of uplift identified in 1977–1983 geodetic surveys (Decker and others, 1983). The volume of subsidence since July 1983, determined from the tilt vectors, was at least 100×10^6 m^3. Reoccupation of a 14-km-long level line that passes within 1.2 km of the subsidence center indicated that the Mauna Loa summit subsided at least 630 mm during the eruption. A resurvey of an extensive trilateration network (about 200 lines) that encompasses much of Mauna Loa indicated extension of more than 800 mm across the NERZ and compression of the adjacent flanks, which reflects dike emplacement. The dilation of the summit region was mostly accommodated by southeastward translation of the upper southeast flank, as revealed by distance measurements between the northwest summit of Mauna Loa and the summits of Mauna Kea and Hualalai Volcanoes.

GRAVITY OBSERVATIONS

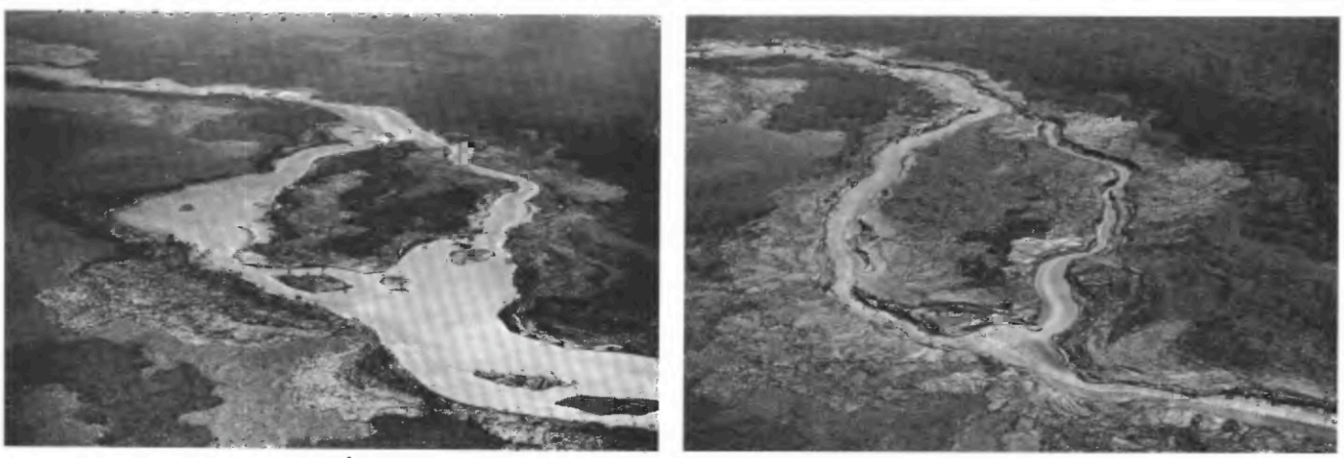
A network of gravity stations on the upper slopes and summit of Mauna Loa was partly reoccupied on February 13–14, 1984. This survey, which preceded the 1984 eruption by 40 days, provided a precise datum for subsequent major changes and showed that a gravity change of only -20 ± 10 microgals (uplift) had occurred at station C-l (fig. 19.19) in the preceding 8 years. Gravity values were determined to a precision of 10 microgals relative to a base station located 14 km distant, using two LaCoste and Romberg Model G gravimeters transported by helicopter between readings.

Reoccupation of station ML-1 (fig. 19.19) was begun within 10 h of the eruption onset and was continued on a near-daily basis. Gravity increased about 150 microgals at ML-1 during the eruption, at an exponentially decreasing rate (fig. 19.39). Because the gravity change is a function of both elevation and mass transfer changes, the exact amount of subsidence is not known.

The rate of gravity change is very similar to the exponentially diminishing rates of tilt change and horizontal strain (figs. 19.36, 19.37), which implies that the elevation change was closely tracking mass transfer changes with time. Processes such as incomplete summit collapse or extensive subaerial vesiculation are thus unlikely.

Gravity increases at C-1 (5 km from the deformation center) and ML-8 (7 km) were 61 and 19 microgals, respectively. Measurements at gravity stations on Mauna Loa's northeast flank (9, 13, and 27 km from the summit subsidence center) showed no significant changes. The rapid decay of the gravity changes with distance is consistent with a relatively shallow pressure source, as suggested by geodetic measurements.

FIGURE 19.29.—Lava flow advancing through rain forest at 950-m elevation on March 30. Flow is covering 1852 lava; more heavily forested area in lower left corner is underlain by prehistorical lava. View is to southeast. Photograph by J.P. Lockwood.



A ***B***

FIGURE 19.30.—Lava channel at 2,500 m, showing changing eruptive volumes from second to tenth day. View to east, 1852 spatter cone to left of channel. ***A***, March 26, 1984. ***B***, April 4, 1984. Photographs by J.D. Griggs.

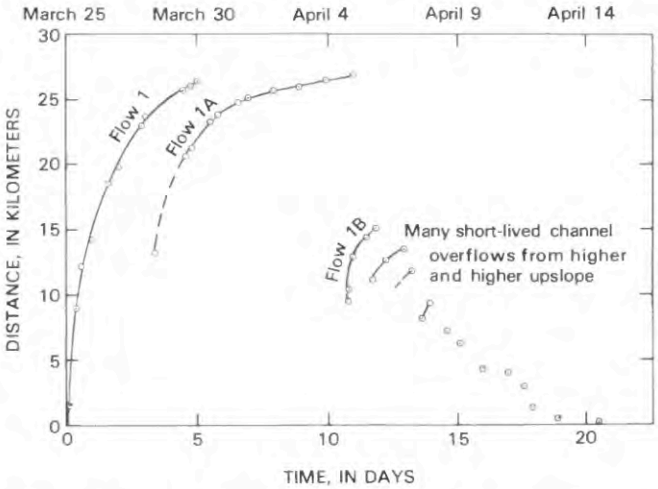


FIGURE 19.31.—Advance rates of lava flows from 2,900-m vents. Time plotted as days after initial outbreak on afternoon of March 25, 1984 (from Lockwood and others, 1985, fig. 4).

FIGURE 19.32.—Diversion of 1984 lava by U.S. Army Corps of Engineers test barriers constructed in 1977. The 4- to 5-m-high earthen barrier temporarily impeded the 1984 flows, here 14 m thick, but eventually was overtopped (arrow). View is to southeast.

GEOELECTRICAL OBSERVATIONS

A 3.8-km-long SP (electrical self-potential) line normal to the NERZ of Mauna Loa was established at about 3,000 m elevation (fig. 19.19) 9 months before the 1984 eruption. The pre-eruption SP data (fig. 19.40) show an anomaly centered over the area of the July 6–10, 1975, intrusion (Lockwood and others, 1976, p. 15). The relatively large data noise is attributed to the lack of soil or ash cover and low rainfall in this area, which produce very high electrode contact resistances.

This anomaly may indicate a zone of structural weakness that allowed upward transfer of heat. A profile along the same line on March 27, 2 days after the eruption began, shows a general increase of potentials, highest near the center of the traverse and coincident with a zone of ground cracks formed on the afternoon of March 25 (fig. 19.40).

Five days after the eruption began, VLF (very low frequency) measurements of tilt angle and ellipticity of the electromagnetic field, from a high-powered U.S. Navy radio transmitter at Lualualei, Oahu, were made along the SP profile (fig. 19.41). The steepest gradients on both the percent tilt angle and percent ellipticity curves occur approximately where they intersect at the zero crossover, a point that is nearly over the center of the anomaly-producing body.

The form of the curves suggests that the VLF anomaly is caused by a good conductor, probably with a high-angle tabular shape, directly beneath the SP high and near the center of the ground-crack zone. VLF resistivity measurements away from the conductive anomaly show high resistivity values (8,000–12,000 ohm/m); these values suggest, from an estimate of plane-wave penetration at the radio frequency used, that the depth to the top of the conductive zone is 100–150 m. The conductive body could be magma or a zone of hot, moist rocks leading to a heat source at greater depth. No emission of either steam or fume was noted from the ground cracks in this area, however, suggesting that a nonbrittle zone may have been present between the top of the shallow intrusion and the bottom of the ground cracks.

LAVA PETROGRAPHY AND TEMPERATURES

The 1984 lava consists of uniform, sparsely porphyritic tholeiitic basalt. Phenocrysts (generally less than 1 percent by volume) are euhedral to anhedral, 1- to 3-mm-diameter kinked olivine of forsteritic composition (Fo_{88-90}; M. Garcia, University of Hawaii, written commun., 1984) that is slightly to strongly resorbed, with granular pyroxene-plagioclase coronas. Similar kinked olivine in the 1959 Kilauea Iki lava has been interpreted to be of mantle origin (Helz, chapter 25). Rare clots of olivine and olivine-clinopyroxene-plagioclase intergrowths are also present. Microphenocrysts (3–30 percent) consist mostly of plagioclase laths, with slightly less abundant clinopyroxene and some olivine; all are generally less than 0.3 mm in maximum dimension. The groundmass consists of brown glass with plagioclase, granular clinopyroxene, and opaque minerals. The size and abundance of microphenocrysts increased steadily over the course of the eruption, apparently causing a concurrent increase in lava viscosity (Lipman and Banks, chapter 57; Lipman and others, 1986).

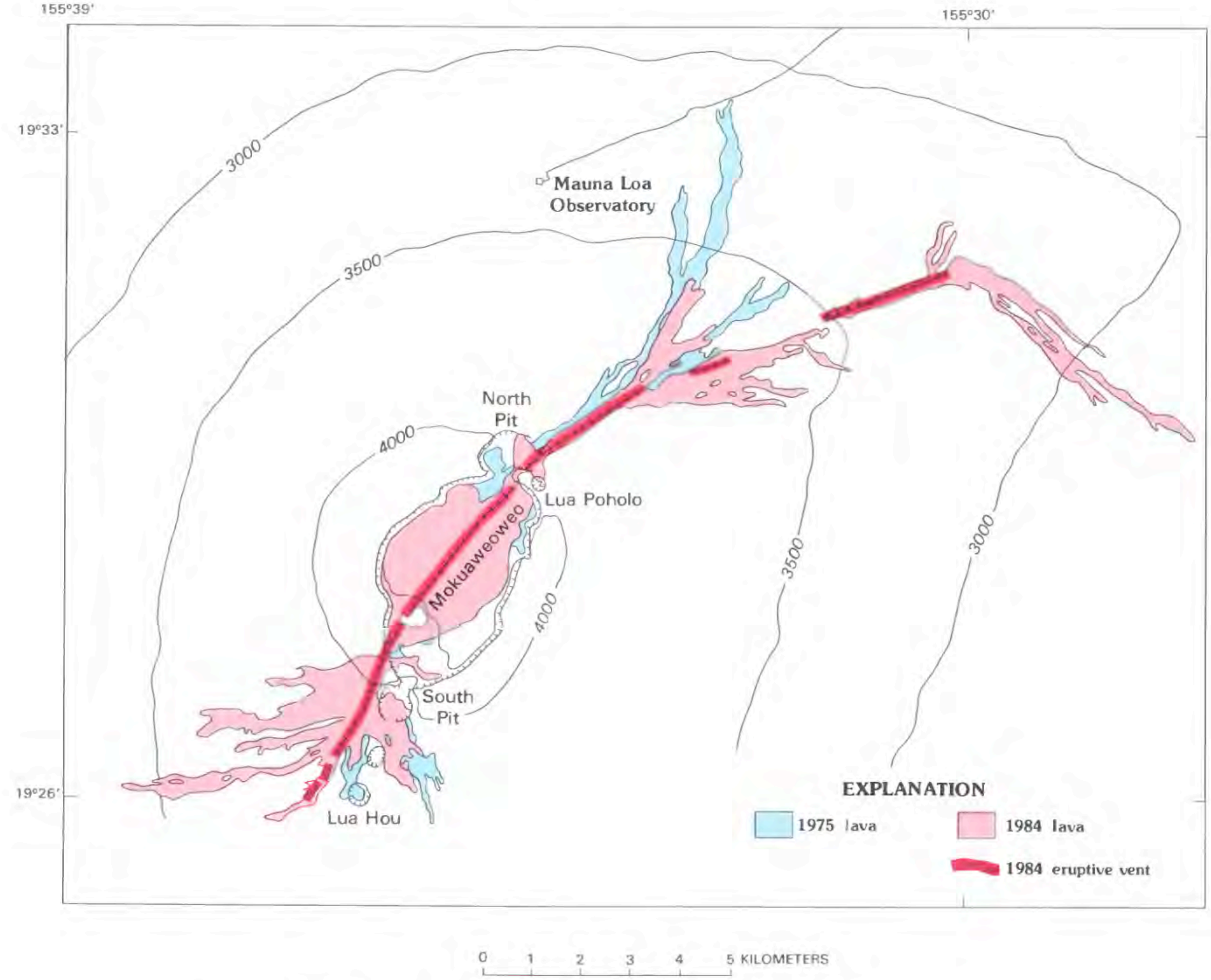


FIGURE 19.33.—Distribution of March 25, 1984, lava in summit region, showing relation to 1975 lava.

Lava temperatures were monitored throughout the eruption by Chromel/Alumel thermocouples and digital meters; the total range measured was between 1,120 °C and 1,144 °C. Fountain temperatures, measured by 2-color infrared radiometer, were generally in close agreement with the highest thermocouple temperatures obtained adjacent to the vents (Lipman and Banks, chapter 57). No changes were observed in either the fountain temperatures or in the temperatures of lava in the uppermost supply channels over the course of the eruption. The highest temperatures were obtained in lava tubes that issued from the base of spatter ramparts, although similar temperatures were obtained several kilometers downstream in the main lava channels or in overflows immediately adjacent to these channels. The lowest temperatures were obtained in thin sheet flows and in lava that appeared to have been stored for many hours or days in lava tubes. Temperatures measured in the main distributary channels decreased less than 20 °C over a total distance of 11 km downstream from the vents.

LAVA CHEMISTRY

Major-element analyses by X-ray fluorescence (table 19.3) show that the 1984 lava is remarkably uniform in composition except for one significantly more evolved sample from the SWRZ. This anomalous sample, which apparently represents contamination by older, stored magma, is not included in the analytical averages of table 19.3. With this exception, and the exception of small fluctuations in MgO content of lava erupted from the lower NERZ vents between March 25 and 30, there is little apparent difference between lava erupted along the upper SWRZ, the summit caldera, and the upper, middle, and lower segments of the NERZ. Such

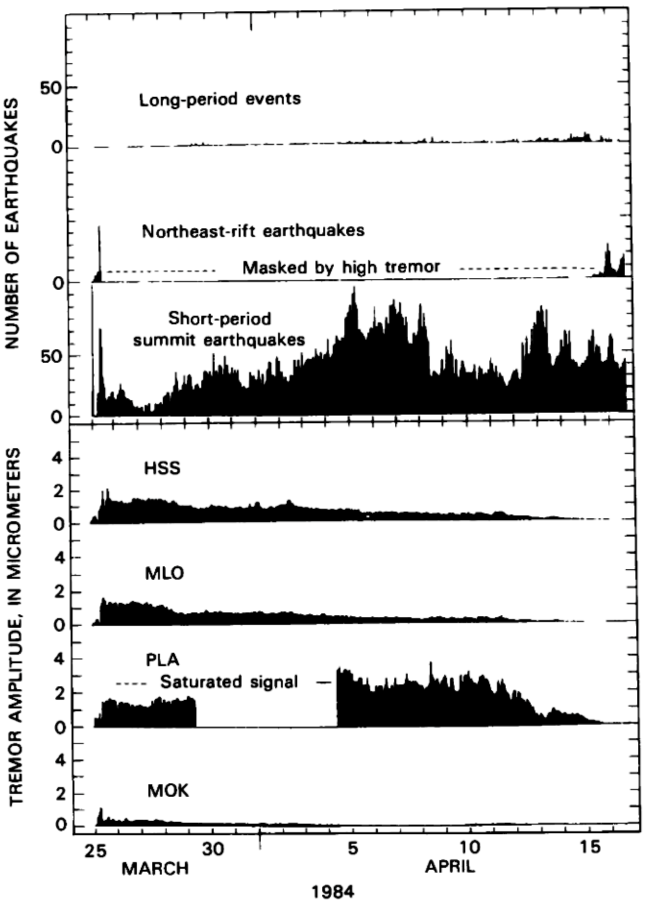


FIGURE 19.34.—Earthquake frequency (upper three plots) and tremor amplitude (lower four plots), March 25–April 16, 1984. Earthquakes as small as $M = -1$ were plotted when not masked by harmonic tremor. Harmonic tremor was read hourly at four seismic stations and plotted as micrometers of ground motion. Signals from PLA station (fig. 19.19) were saturated until April 4, when instrument sensitivity was lowered (from Lockwood and others, 1985, fig. 6).

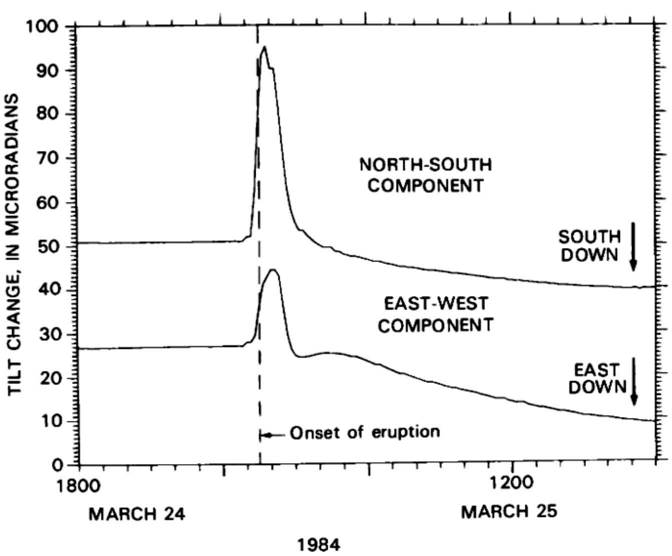


FIGURE 19.35.—Continuously recording tiltmeter record from MOK instrument for a 24-hour period beginning at 1800 H.s.t. on March 24. A positive tilt change (inflation) corresponds to a downward deflection in north and west directions (modified from Lockwood and others, 1985, fig. 7).

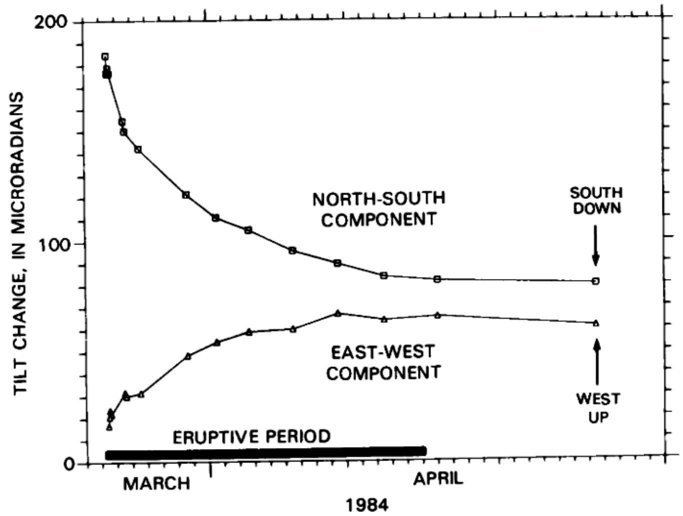


FIGURE 19.36.—Summit deflation curve determined from spirit-level (dry-tilt) measurements made near MOK station. A positive tilt change corresponds to a downward deflection in north and east directions (modified from Lockwood and others, 1985, fig. 8).

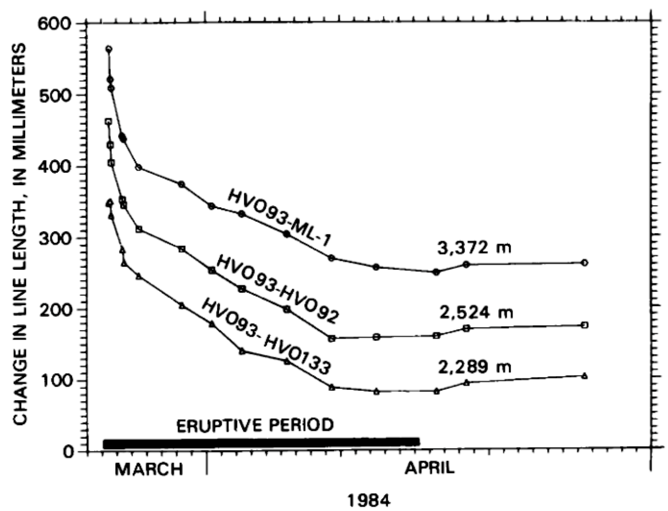


FIGURE 19.37.—Summit deflation curve determined from measurement of horizontal distances across Mokuaweoweo. Locations of survey lines are shown in Decker and others (1983, fig. 7). Line lengths from Lockwood and others (1985, fig. 9).

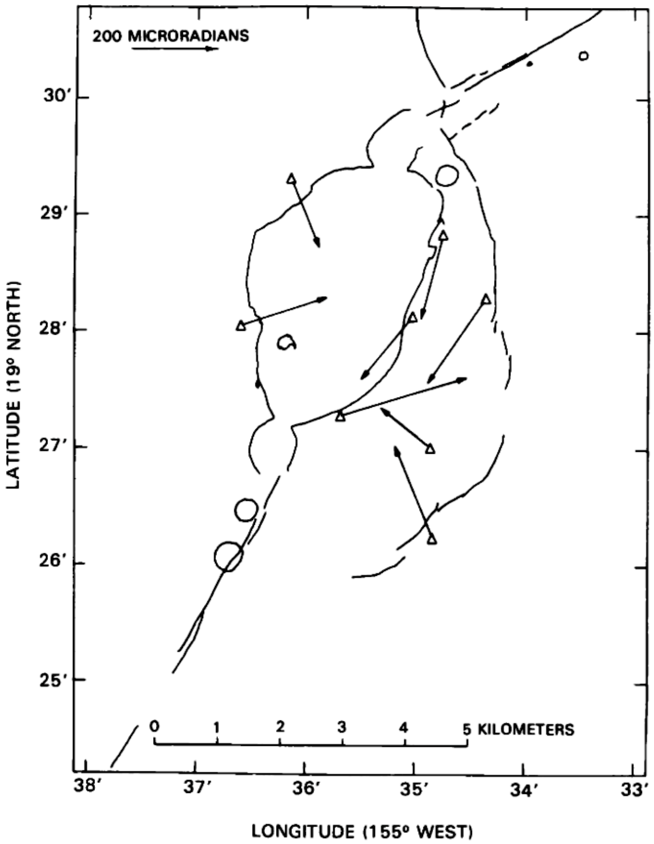


FIGURE 19.38.—Net tilt changes in summit region of Mauna Loa between June 1983 and May 1984. Triangles indicate location of spirit-level (dry tilt) stations. Vectors are drawn in direction of downward deflection of surface; length of vector shows amount of deflection (from Lockwood and others, 1985, fig. 10).

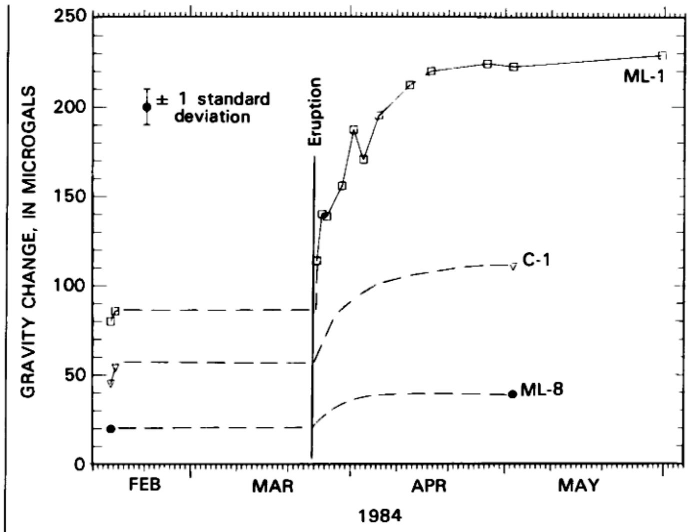


FIGURE 19.39.—Relative gravity changes at stations ML-1, C-1, and ML-8 from February 13 to May 28, 1984. Values plotted are not absolute, but only relative to February 13 datum. Dashed lines where data inferred. Data from D.J. Johnson, U.S. Geological Survey (modified from Lockwood and others, 1985, fig. 11).

homogeneity in lava composition is typical of historical Mauna Loa eruptions (Wright, 1971; Rhodes, 1983) and is consistent with the uniform lava temperature measurements.

The 1984 lava, which is slightly lower in MgO content compared with most historical Mauna Loa lava, has a composition indicative of multiple saturation with respect to olivine, clinopyroxene, and plagioclase. This lava is somewhat less evolved than the 1975 lava (table 19.1); it contains slightly less K_2O and TiO_2 and more MgO. Consequently, the 1984 lava cannot simply be residual magma remaining in shallow storage following the 1975 eruption, unless any magma stored in 1975 was less evolved than the lava erupted at that time. The combination of remarkably uniform lava composition and large eruptive volume over a 21-day period points to the ultimate derivation of this lava from a deeper reservoir of substantial size.

ERUPTIVE GASES

The 1984 eruption has yielded the first analyses ever reported for eruptive gases from Mauna Loa (Greenland, chapter 30). The gases are similar to those collected from the adjacent Kilauea Volcano, although they are lower in water and halogen content relative to sulfur (table 19.4). The low atomic C/S ratio (0.2, as at Kilauea) is attributed to pre-eruptive degassing of the magma during storage in a shallow (3–4 km deep) summit reservoir.

Thermodynamic calculations show that most samples contain excess water above that required for equilibrium with other species. Subtracting excess water from the analyses results in a calculated pO_2-temperature relation close to one directly measured in a Kilauea lava lake by Sato and Wright (1966). The excess water over that required for equilibrium in these analyses is not a meteoric contaminant but is believed to be magmatic water that has not equilibrated with the other gases because of the rapid magma rise rate.

Geographic factors had considerable influence on lava degassing. Much of the lava erupted at the 2,900 m vents was apparently partially degassed through high-temperature fumaroles along the March 25 vents between 3,400 and 3,470 m (Greenland, chapter 30). Aerial correlation spectrometer (COSPEC) monitoring showed this area of incandescent fumaroles to be a voluminous source of magmatic gas for the duration of the eruption; these fumaroles were the only source of detectable SO_2 after the end of lava production at the 2,900 m vents (J.B. Stokes, written commun., 1984). At the 2,900 m vents, high fountaining (high gas production) was most characteristic of the farthest uprift vents (including a reticulite-producing cinder cone, see fig. 19.26). At the lower end of this 1,700-m-long vent system, largely degassed pahoehoe issued continuously from a vent with almost no fountaining, constructing a 45-m-high lava shield (fig. 19.24*B*). Visible

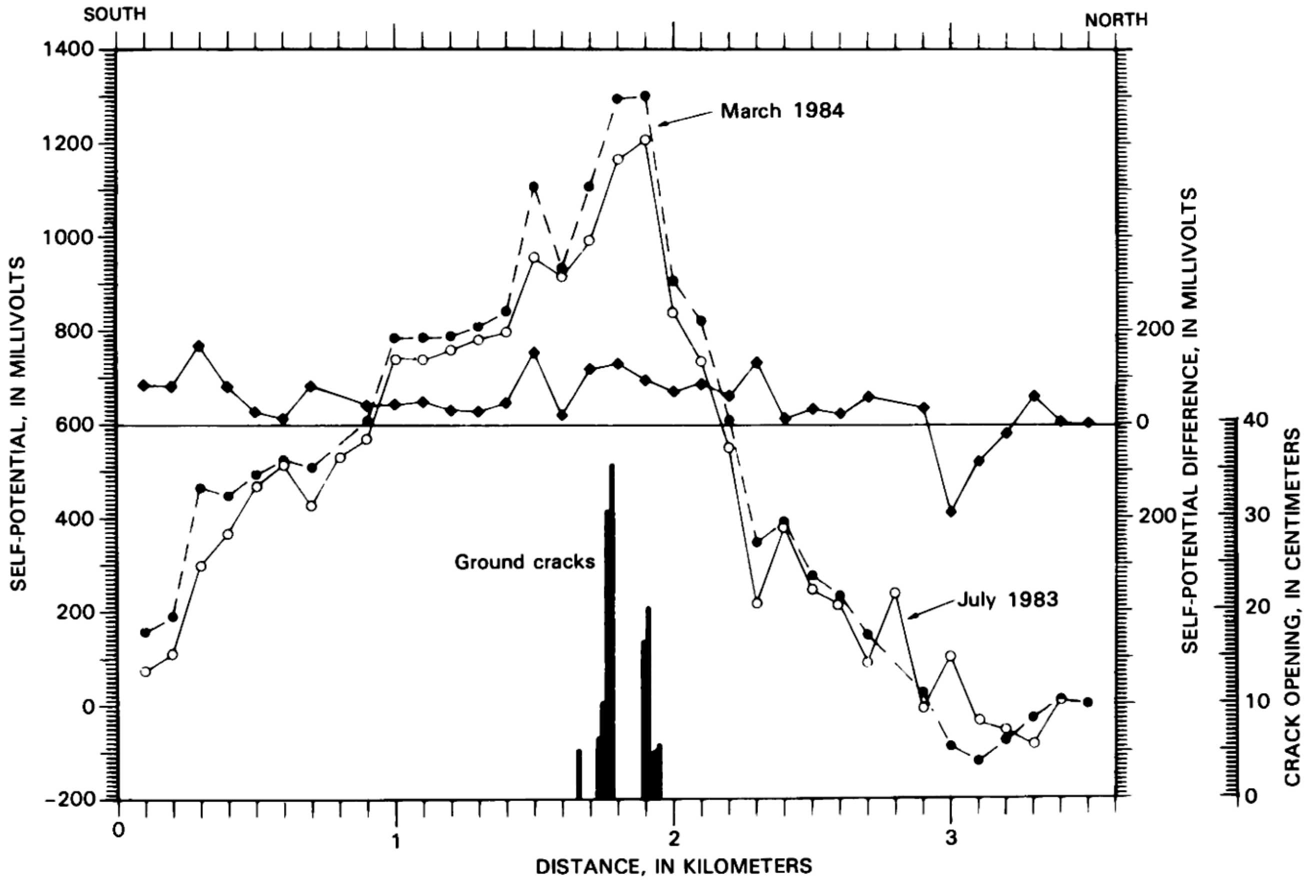


FIGURE 19.40.—Electrical self-potential (SP) profiles normal to northeast rift zone of Mauna Loa at about 3,000-m elevation, taken 9 months before 1984 eruption, and 2 days after eruption began. Locations of ground cracks that opened along profile line on March 25, 1984, are plotted on abscissa. SP data July 14, 1983 (solid lines and open circles), SP data March 27, 1984 (dashed lines and solid circles), differences between 1984 and 1983 SP data (solid lines and diamonds). Data from D.B. Jackson, U.S. Geological Survey (from Lockwood and others, 1985, fig. 12).

fume was also largely restricted to the farthest uprift of the 2,900 m vents. These circumstances may be due to vertical stratification of gas within laterally transported magma (fig. 19.42).

CONCLUSIONS: THE FUTURE

The 1975–1984 Mauna Loa eruptive sequence was the first for which extensive observations of geodetic, geoelectrical, geochemical, gravity, and temperature phenomena were possible; more has been learned about Mauna Loa inflation and eruption processes during this period than in all earlier historical eruptions.

This was Mauna Loa's first eruptive sequence since 1950 and involved the first flank eruption on the northeast rift zone since 1942. Intervals between NERZ flank eruptions have, however, been as short as 41 months (1852–1855), and posteruption geodetic measurements (figs. 19.13, 19.14) suggest inflation of Mauna Loa for her *next* eruption has already begun. As regards the volcano's long-term future behavior, we must look to the record of the past. Lava has covered the subaerial Mauna Loa surface during Holocene time at an average rate of about 40 percent per 1,000 years (Lockwood and Lipman, chapter 18, fig. 18.11). This coverage rate is likely to also characterize the long-term future, although substantial variations from this average are to be expected for shorter periods.

Most of the 32 eruptions since 1832 began with initial activity above 3,000 m elevation; 15 eruptions were limited to the summit area. The other 17 eruptions involved flank extrusion: 2 principally on the northwest flank, 7 on the southwest rift zone, and 8 primarily on the northeast rift zone. This general spatial distribution of flank eruptions will probably also characterize future activity.

Southwest rift zone eruptive loci generally migrated uprift from 1868 to 1950 (Lipman, 1980). Eruptive loci on the northeast rift zone have shown no such longitudinal distribution pattern, but have instead shown a strong tendency for southward migration with time, especially in the 20th century (fig. 19.43). The common pattern of south-stepping offset of echelon vents (fig. 19.23) is another apparent indication of this tendency for southward migration. Although

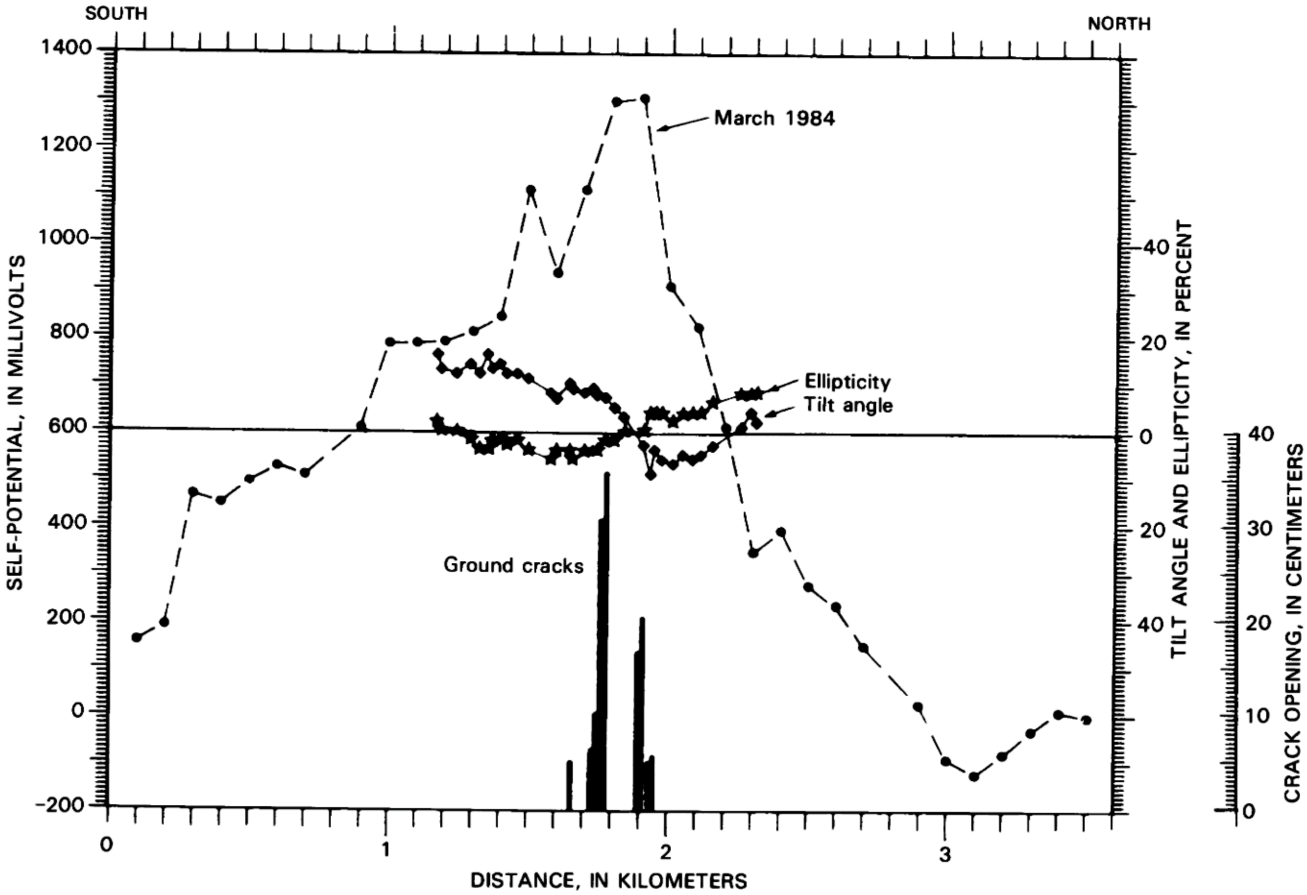


FIGURE 19.41.—Very low frequency profiles across northeast rift zone of Mauna Loa obtained on March 30, 1984. Ellipticity (stars) and tilt angle (diamonds) are shown with March 27, 1984, SP profile and ground cracks along same survey line. Data from D.B. Jackson, U.S. Geological Survey (from Lockwood and others, 1985, fig. 13).

TABLE 19.3.—*Average major-element compositions of 1984 Mauna Loa lava*

[X-ray fluorescence analyses by J.M. Rhodes. Analyses reported on volatile-free basis, with total iron reported as Fe_2O_3. *n*, sample size]

	Upper SWRZ *n*=5	Summit caldera *n*=9	Upper NERZ *n*=5	Middle NERZ *n*=5	Lower NERZ *n*=10	1975 Lava *n*=6
SiO_2	51.37	51.37	51.82	51.59	51.63	51.70
TiO_2	2.06	2.08	2.09	2.07	2.09	2.10
Al_2O_3	13.59	13.65	13.72	13.64	13.65	13.73
FeO^+	11.97	12.06	12.14	12.05	12.09	12.23
MnO	.19	.18	.18	.19	.19	.16
MgO	6.75	6.73	6.68	6.66	6.81	6.55
CaO	10.54	10.51	10.55	10.48	10.51	10.51
Na_2O	2.55	2.59	2.52	2.53	2.48	2.18
K_2O	.38	.38	.38	.38	.38	.39
P_2O_5	.24	.24	.24	.24	.24	.24
Total	99.55	99.79	100.32	99.84	100.05	99.79

TABLE 19.4.—*Relative atomic compositions of Mauna Loa and Kilauea eruptive gases*

[Values shown are the ratios of atoms of the indicated elements per atoms of sulfur. Analyses by L.P. Greenland]

	Mauna Loa	Kilauea
H	6.4	16
C	.21	.26
O	5.4	10
S	1.0	1.0
Cl	.0036	.021
F	.0035	.023

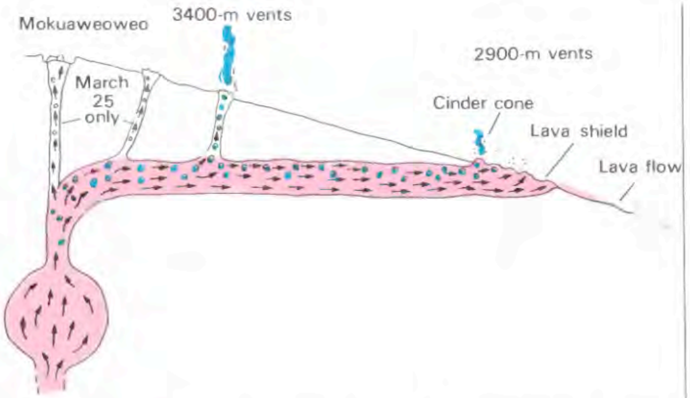


FIGURE 19.42.—Schematic longitudinal section of northeast rift zone, showing proposed degassing processes in laterally transported magma during period March 25 to April 15, 1984. Scale not internally consistent.

volumetrically more than 90 percent of historical lava flows have moved down the north side of the northeast rift zone (Lockwood and Lipman, chapter 18, fig. 18.15), future flows will preferentially flow down the south flank if the southward migration of eruptive vents continues.

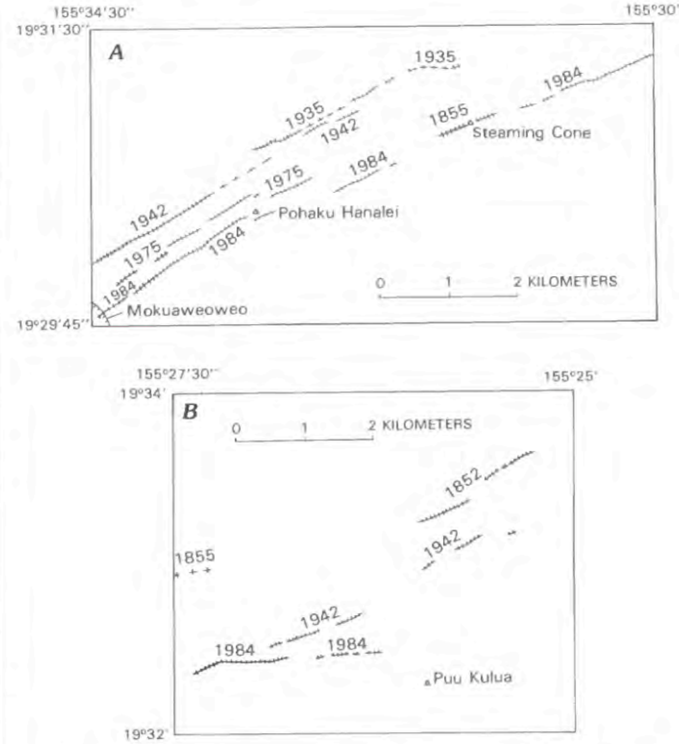


FIGURE 19.43.—Loci of historical eruptive vents at two localities on northeast rift zone. ***A***, Upper northeast rift zone, near Pohaku Hanalei. ***B***, Middle northeast rift zone, below Puu Ulaula. Figure locations shown on figure 19.28.

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