



THE 1972-1974 MAUNA ULU ERUPTION, KILAUEA VOLCANO: AN EXAMPLE OF QUASI-STEADY-STATE MAGMA TRANSFER

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ABSTRACT

The eruption at Mauna Ulu from February 3, 1972, to July 22, 1974, renewed the sustained activity on Kilauea's east rift zone that had previously ceased in October 1971. During 901 days of virtually continuous activity, about 162×10^6 m³ of basaltic lava was erupted. Vent activity was confined to the Mauna Ulu-Alae area except for two short-lived outbreaks near Pauahi and Hiiaka Craters in May and November 1973. The minimum average magma production rate through April 1973 was 8×10^6 m³/mo, comparable to rates for other periods of sustained eruptive activity at Kilauea.

The 1972-74 lava (1) covered an area of about 46 km²; (2) raised the summit of the shield built at Mauna Ulu during the 1969-71 eruptions to a maximum height of 121 m above the pre-1969 ground surface; (3) greatly increased the size and height of the complex shield at Alae, which attained a maximum height of nearly 90 m above the pre-1969 ground surface; (4) filled the west pit of Makaopuhi Crater; and (5) entered the sea in August-October 1972 and February-May 1973 after traveling more than 12 km through well-developed lava-tube systems.

The 1972-74 eruption was dominated by active lava lakes at Mauna Ulu and Alae, their vents linked by an efficient tube system. The lava lakes exhibited a wide range of behavior, including (1) complex circulation patterns of the lake surface and low-level fountaining at drainback areas; (2) cyclic fluctuations of as much as a few tens of meters in the level of the lava column, accompanied by violent degassing during column collapse (the so-called gas-piston activity); (3) complete or partial draining of the lava lakes caused by major changes in eruptive mode or lava-supply system; (4) repeated short-duration overflows and levee construction leading to shield growth; and (5) sustained overflows and the development of lava tubes to feed long flows.

Records of Kilauea summit tilt during 1972-74, as measured at Uwekahuna vault, show two periods (February 1972 to April 1973 and December 1973 to July 1974) of oscillations within a narrow range and little or no net change in tilt. Each of these periods is interpreted to reflect a quasi-steady-state regime of magma transfer from a mantle source to Kilauea's summit reservoir and to the upper east rift zone. The first period apparently was terminated by subsurface blockage in the magma-transfer system, possibly caused by a 6.2-magnitude earthquake on April 26, 1973, which also disrupted a well-established tube system and halted lava entry into the sea. The second period marked the reestablishment of a highly efficient magma-transfer system following the November-December 1973 eruption at Pauahi. Our postulated periods of quasi-steady-state regime of magma transfer are compatible with the speculation of Daniel Dzurisin and others that the sustained

eruptive activity at Mauna Ulu may be linked to increased deep magma production, as evidenced by above-average occurrence of deep harmonic tremor beneath Kilauea.

Ground deformation measured by periodic resurveying of level, ground tilt, and trilateration networks in the Kilauea summit region generally is compatible with patterns seen in continuous records of Uwekahuna tilt, seismicity, and observed eruptive activity. However, some deformation patterns during the periods of quasi-steady-state magma-transfer regime are diffuse and not amenable to simple analysis. The most coherent patterns obtained are related to the Pauahi-Hiiaka (May) and Pauahi (November) eruptions during the net inflation period of 1973; each of these was associated with a deflation at Uwekahuna of about 20 microradians. Perhaps a threshold volume or rate of change in summit magma storage must be exceeded before coherent ground-deformation patterns can be derived from geodetic surveys; the volcano may possess a characteristic yield strength, such that a finite amount of inelastic deformation must be accommodated before geodetic response can reflect elastic behavior.

INTRODUCTION

The 1969-71 Mauna Ulu eruption (figs. 16.1 and 16.2), which lasted about 2½ years and produced 185×10^6 m³ of lava, was one of the most voluminous and long-lived historical rift eruptions of Kilauea Volcano, Hawaii (Swanson and others, 1971, 1979). The waning stage of that eruption was characterized by monotonic subsidence of the surface of a lava lake in Mauna Ulu crater, accompanied by sharp summit inflation, and was punctuated by a brief eruption within the summit caldera during August 1971 and another, in the caldera and southwest rift zone, during September 1971 (Duffield and others, 1982). The end of the 1969-71 Mauna Ulu eruption was October 15, 1971, the date when lava was last seen in the vent (Swanson and others, 1979). No eruptions occurred at Kilauea for the next 3½ months, a period of steady summit inflation.

In early February 1972, lava quietly reentered the crater of Mauna Ulu, initiating a period of sustained eruption that ultimately lasted until mid-July 1974. The 1972-74 activity was confined to the Mauna Ulu-Alae area except for an outburst from vents within and near Pauahi and Hiiaka Craters on May 5, 1973, and a month-long eruption at Pauahi in November-December 1973 (fig. 16.2). For convenience of discussion, the eruptions of Mauna Ulu (which

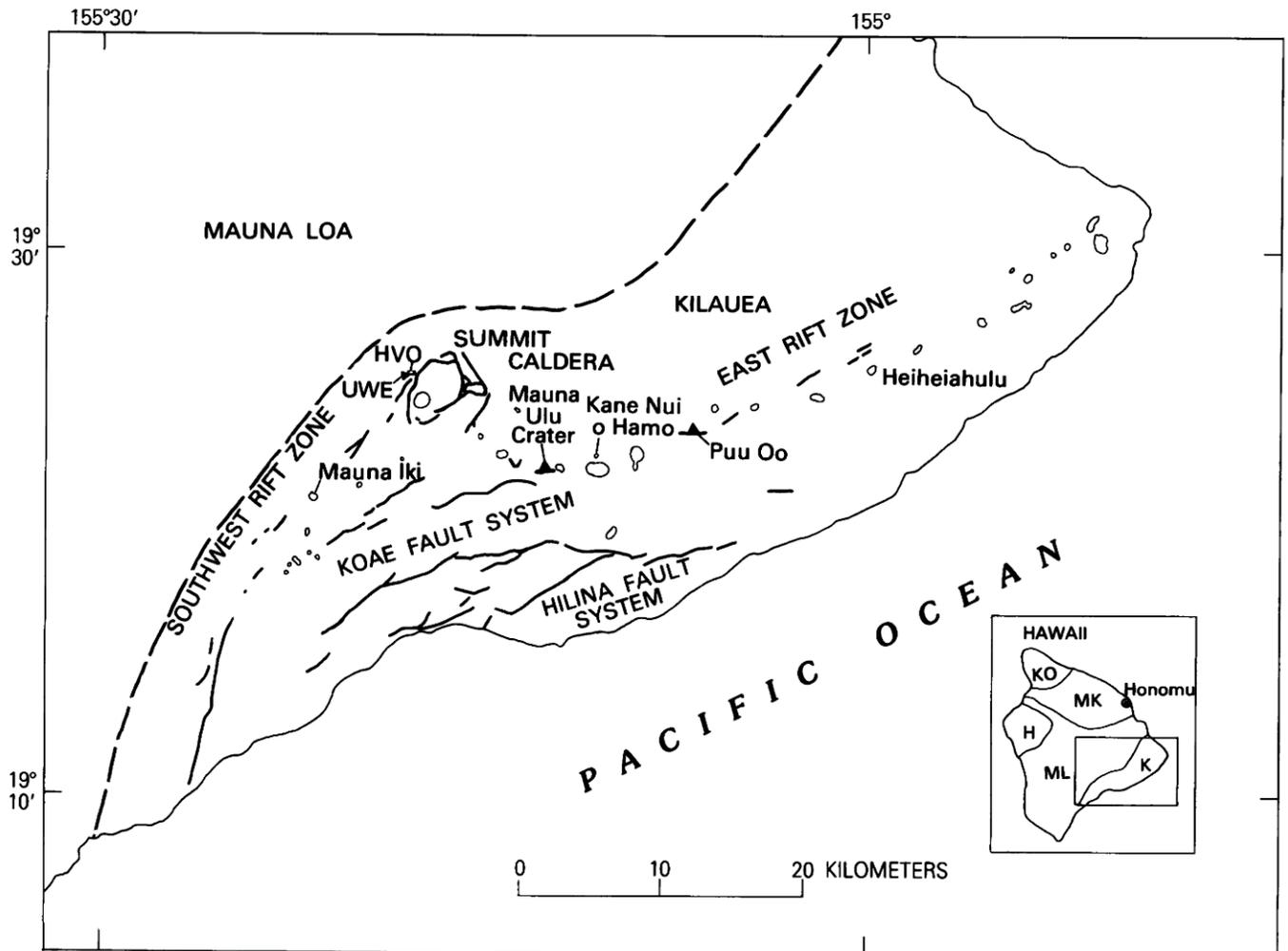


FIGURE 16.1.—Map of Kilauea Volcano showing summit caldera, rift zones, and principal fault systems; locations of the Hawaiian Volcano Observatory (HVO) and Uwekahuna vault (UWE) are also shown. Inset shows volcanoes making up Island of Hawaii: KO, Kohala; MK, Mauna Kea; H, Hualalai, ML, Mauna Loa; and K, Kilauea. Mauna Ulu eruption site (1969–1974) is on upper east rift zone, and Puu Oo eruption site (1983–present) is on middle east rift zone; these sites are indicated by solid triangles. Mauna Iki (1919–20), Heiheiahulu (1750?), and Kane Nui o Hamo (prehistoric) are volcanic shields developed on rift zones before 1969. Modified from Dzurisin and others (1984, fig. 2).

means “growing mountain” in Hawaiian), Pauahi, and Hiiaka during 1972–74 are considered collectively as the 1972–74 Mauna Ulu eruption because of their close association in space and time and the persistence of harmonic tremor throughout almost the entire period. The end of eruptive activity at Mauna Ulu is taken to be July 22, 1974, following a three-day summit eruption (Peterson and others, 1976), after which no molten lava could be observed at Mauna Ulu and harmonic tremor ceased.

Following the 1972–74 Mauna Ulu eruption, activity at Kilauea shifted to the summit region, where short-lived outbursts during July and September were followed by a brief eruption and intrusion in the southwest rift zone in December 1974 (Peterson and

others, 1976; Dzurisin and others, 1984, table 1). Following various other short-lived eruptions and intrusions at several sites on the volcano during 1975–82 (Tilling and others, 1976b; Moore and others, 1980; Dzurisin and others, 1984), the beginning of the Puu Oo eruption in the middle east rift zone in 1983 (Wolfe and others, chapter 17) marked the return to Kilauea of a long-lived, voluminous flank eruption, like the Mauna Ulu eruptions during 1969–74.

The 1972–74 activity was particularly notable for active lava lakes that occupied the summit craters of Mauna Ulu and Alae shields for long periods of time. We consider a lava lake active if it is linked, directly or indirectly, to a feeding magma column, in contrast

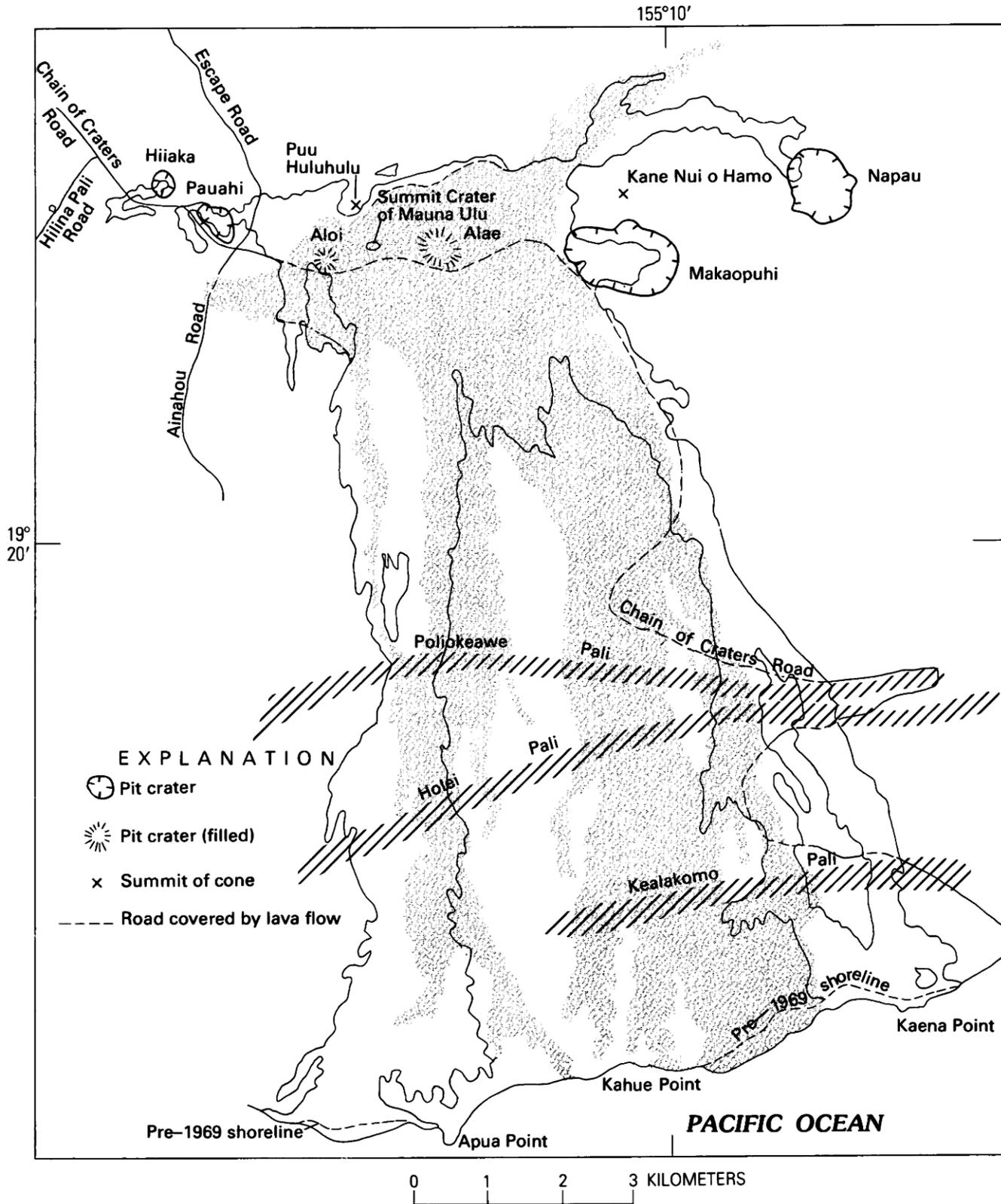


FIGURE 16.2.—Sketch map showing lava fields produced by the 1969-1971 Mauna Ulu eruption (shaded) and the 1972-74 Mauna Ulu eruption (outlined by solid line); pali means cliff in Hawaiian. Modified from Swanson and others (1979, fig. 4) and Holcomb (1976).

TABLE 16.1.—Some published topical studies on aspects of the 1972–1974 Mauna Ulu eruption and general works on Kilauea that include data relevant to processes, products, or effects of the eruptions

Topic	Reference
General summaries and field guidebooks.	Greeley (1974) Hazlett (1981) Macdonald and Hubbard (1982) Peterson and others (1976)
Geologic maps	Holcomb (1976) Holcomb (1980)
Lava chemistry	Wright and Tilling (1980)
Lava tubes	Peterson (1983)
Lava lakes, variations in depth to surface.	Tilling and others (1986)
Pahoehoe-aa transition	Peterson and Tilling (1980) Kilburn (1981)
Volcanic landforms	Tilling and others (1973) Holcomb (1973) Holcomb and others (1974) Tilling and others (1976b, c) Dzurisin (1978) Peterson (1976)
Lava deltas	
Lava movement under water and pillow formation.	Grigg (1973) Tepley (1975) Moore (1975) Tilling (1976a) Tilling and others (1975) Klein (1982)
Rockfall activity and seismicity	
Pattern of historical eruptions	
Ground deformation, including modeling.	Ryan and others (1983) Epp and others (1983) Dvorak and others (1983) Koyanagi and others (1973) Klein (1982) Dzurisin and others (1984) Dzurisin and Koyanagi (1981) Dzurisin and others (1984)
Magma intrusion into rift zones	Ryan and others (1981) Ryan and others (1983) Koyanagi and others (1976a, b) Ellesworth and Koyanagi (1977) Unger and others (1973) Unger and Ward (1979) Aki and Koyanagi (1981)
Magma budget	
Magma reservoir shape and mechanics	
Seismicity	
Geoelectrical studies of volcanic processes.	Zablocki (1976) Zablocki (1978)
Thermal studies	Casadevall and Hazlett (1983)
Gas and sublimate studies	Cadle and others (1973) Naughton and others (1973) Sicks (1975) Dzurisin (1980)
Miscellaneous	

to an inactive lava lake formed by passive ponding of magma within preexisting pit craters (see Swanson and others, 1979, p. 10). The long duration and easy accessibility of the 1972–74 Mauna Ulu eruption permitted frequent and numerous direct observations of the activities of these lava lakes, as well as of the development and evolution of volcanic shields, lava levees, flow channels, and lava tubes.

Many features of the 1972–74 Mauna Ulu eruption were virtually identical to those well described and illustrated by Swanson and others (1979) for the lava-lake-dominated activity of episodes 3 and 4 (called stages by them) of the 1969–71 Mauna Ulu eruption, and we refer where appropriate to those excellent descriptions rather than unnecessarily describing processes anew.

Many topical studies were undertaken during the course of the 1972–74 Mauna Ulu eruption, and several recent syntheses of Kilauea's magmatic behavior included data obtained in the 1972–74 period. A listing of some of these studies is given in table 16.1 to complement similar summaries for the 1969–71 Mauna Ulu

eruption (Swanson and others, 1979, tables 1 and 2). The main purposes of this paper are to describe the eruptive phenomena in 1972–74, provide a general framework for topical studies already completed, and identify directions for possible further topical research.

ACKNOWLEDGMENTS

This paper could not have been written without the enthusiastic efforts of the many present and former members of the Hawaiian Volcano Observatory (HVO) staff who contributed to the systematic observation and monitoring of the 1972–74 Mauna Ulu eruption. Particular thanks go to John C. Forbes, William H. Francis, Kenneth T. Honma, George Kojima, John P. Lockwood, Jennifer S. Nakata, Arnold T. Okamura, Reginald T. Okamura, Marie S. Onouye, Gary S. Puniwai, James C. Ratte, Maurice K. Sako, Akira Yamamoto, and Charles J. Zablocki. Our National Park Service colleagues at Hawaii Volcanoes National Park also assisted our studies by their administrative support and additional observations of the eruptive phenomena.

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TABLE 16.2.—Summary of east-rift eruptive activity of Kilauea Volcano, Hawaii, from February 1972 to July 1974 (modified from Peterson and others, 1976)

Time period	Duration (days)	Location of vents (see fig. 16.3)	Estimated lava volume ¹ (10 ⁶ m ³)	Area covered by lava (km ²)
February 3, 1972 to May 4, 1973	457	Mauna Ulu and Alae	125	2 35
May 5, 1973	1	Pauahi and Hiiaka and nearby fissures	1	.6
May 6, 1973 to November 9, 1973	188	Mauna Ulu and Alae	2.5	.9
November 10, 1973 to December 9, 1973	30	Pauahi and nearby fissures	3	1.1
December 10, 1973 to July 22, 1974	225	Mauna Ulu	30	8
Total	901		161.5	45.6

¹Includes only volume remaining on surface and excludes volume that drained back into fissures before eruption ended.

²Includes 0.47 km of new land added to south coast of Hawaii from lava entry into sea (Peterson, 1976).

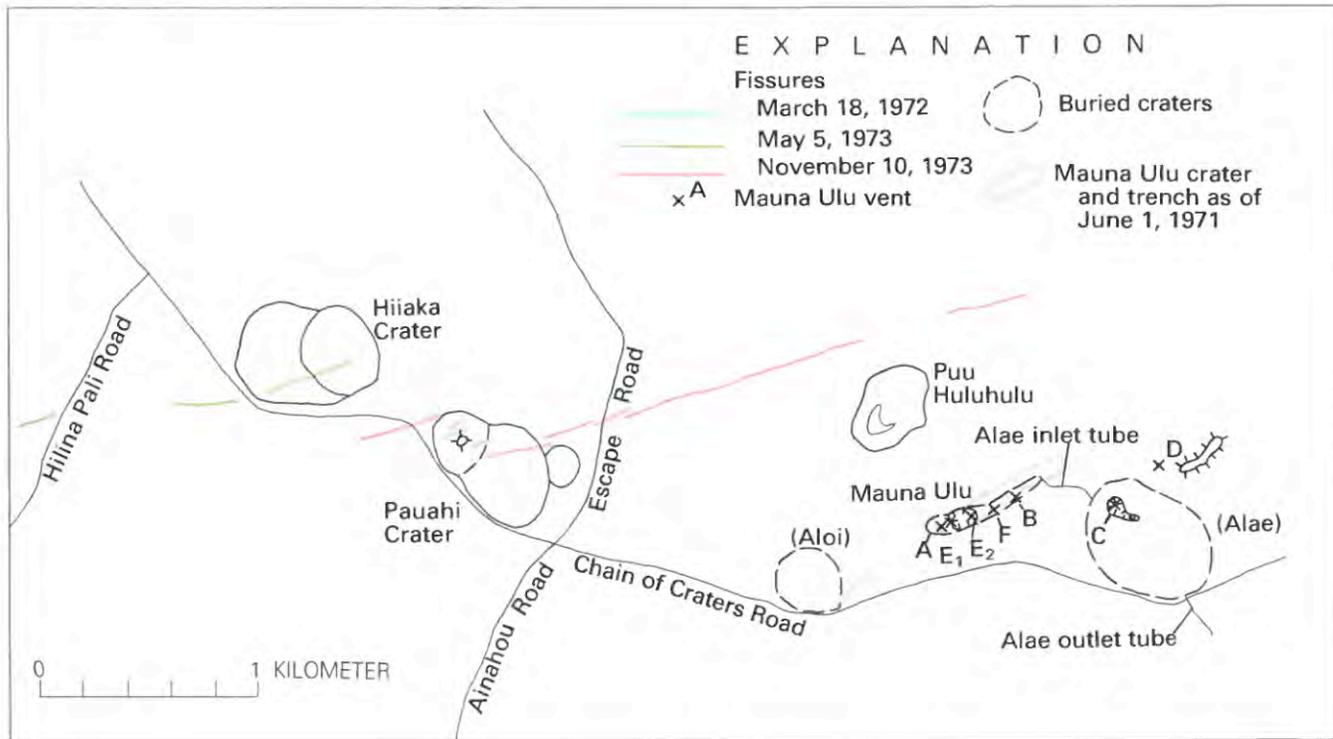


FIGURE 16.3.—Sketch map showing location of vents active during 1972–1974 eruption. The locus of 1972–74 Mauna Ulu vents (A, B, C, D, E₁, E₂, and F) essentially coincides with that of the vents active during July 1970–June 1971 (see Swanson and others, 1979, pl. 4).

OVERVIEW OF THE 1972–74 ERUPTION

Peterson and others (1976) summarized the general features of the 1972–74 eruptive activity of Kilauea Volcano; the overview given here draws on and adds to that earlier summary. The major events, locations of vents, and variation in summit tilt, as measured at Uwekahuna, throughout the 1972–74 Mauna Ulu eruption are summarized in table 16.2 and figures 16.3 and 16.4.

The eruption began in early February 1972 and was dominated through early June 1973 by active lava lakes and associated phenomena, such as overflows, lava-tube formation, and volcanic shield growth, at both Mauna Ulu and Alae (fig. 16.2). The lava lakes were clearly connected beneath the surface, but lava passageways between Mauna Ulu, Alae, and the summit reservoir are not well known. Through May 4, 1973, periodic voluminous overflows of lava from Mauna Ulu and Alae totaled $125 \times 10^6 \text{ m}^3$. An unknown additional volume drained back into vents and intruded into the east rift zone. This volume of surface eruptive products, not adjusted for lava vesicularity or ground deformation, yields a minimum average magma supply rate of approximately $8 \times 10^6 \text{ m}^3/\text{mo}$, comparable to the rates for the 1969–71 Mauna Ulu eruption (Swanson and others, 1979) and the 1971 summit eruptions (Duffield and others, 1982).

Many short-lived overflows from Alae, traveling only short distances, built a new shield, approximately 100 m high, abutting

the eastern flank of the Mauna Ulu shield (Tilling and others, 1973, fig. 2). In contrast, long-lived overflows, instead of adding to the shield, evolved into lava tubes that were able to transport the lava for great distances from the vent. Some tube-fed lava from the Alae vent cascaded into Makaopuhi Crater and entered the sea during August–October 1972 and February–April 1973 (fig. 16.2; Tilling and others, 1973; Peterson, 1976).

The 6.2-magnitude Honoumuli earthquake on April 26, 1973 (Unger and others, 1973; Unger and Ward, 1979), although centered more than 60 km away (fig. 16.1, inset), apparently disrupted the well-integrated lava-tube system from Alae to the coast, and all flow into the sea stopped by about May 1. This earthquake probably also altered the magma conduit system from the summit to Mauna Ulu, as well as the lava-tube link between Mauna Ulu and Alae. Early on the morning of May 5, strong harmonic tremor and summit deflation accompanied the complete drainage of the lava lakes at Mauna Ulu and Alae. About $3\frac{1}{2}$ hours later, lava fountained from a fissure in Pauahi Crater, 2 km uprift from Mauna Ulu (fig. 16.2), in the first historical eruption there. The Pauahi eruption began to wane after about 2 hours, and early in the afternoon new vent fissures opened within and near Hiiaka Crater. Near the closing stages of this activity, lava erupted briefly from a fissure in the eastern part of the Koa'e fault zone about 1 km west of Hiiaka, in the first historical outbreak in that area (Koyanagi and others, 1973; Duffield, 1975, p. 11–12).

By May 7, 1973, lava had quietly returned to the Mauna Ulu

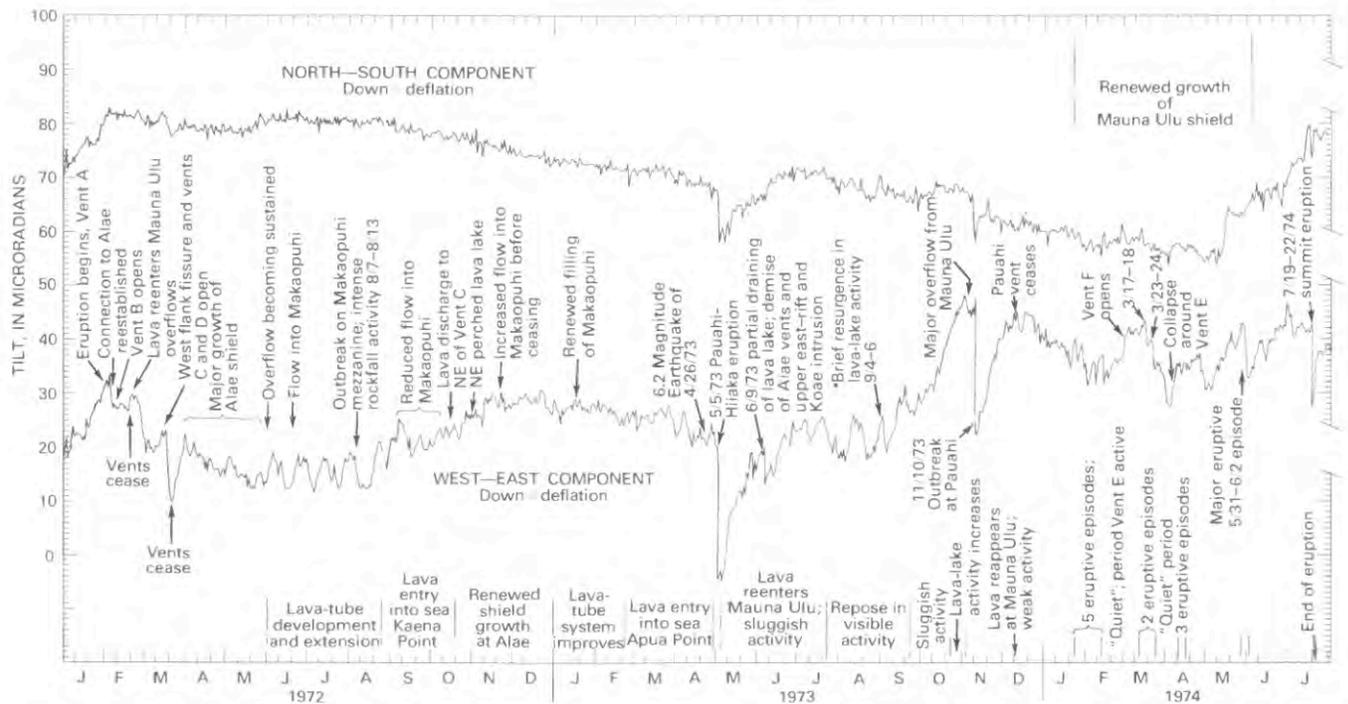


FIGURE 16.4.—Variation in Uwekahuna tilt for the period January 1972–July 1974, and its correlation with significant eruptive events (see text). Tilt data adjusted for the 18-microradian offset (east-west component) caused by the April 1973 Honomu earthquake (fig. 16.1 inset); zero point on tilt scale is arbitrary and referenced to January 1, 1972. The same data are also shown in figure 16.37 at reduced scale and not adjusted for earthquake offset.

crater. Moderate lava-lake activity had resumed at Mauna Ulu by early June, and a small lava lake reappeared at Alae. In the early hours of June 9, preceded and accompanied by harmonic tremor and abrupt summit deflation, drainage of lava partly emptied Mauna Ulu; Alae drained completely and stayed inactive for the remainder of the eruption. Almost immediately following its partial draining, Mauna Ulu lava lake began to rise again and to circulate sluggishly. Subsequent activity was summarized by Peterson and others (1976, p. 652): "Although the lava lake rose gradually with time, the surface area of the actively circulating lake steadily diminished. By mid-July the lava lake became practically stagnant, and the occasional small overflows of lava traveled only short distances on the crater floor. In late September, after nearly two months of virtual quiet, activity increased and voluminous flows flooded the crater floor."

Activity increased throughout October and early November, and Mauna Ulu lava lake rose to the crater rim, feeding voluminous overflows during November 4–8. On November 10, harmonic tremor and summit deflation again accompanied the abrupt drainage of the lake, which subsequently remained inactive for more than a month. A few hours after this sudden draining of lava from Mauna Ulu, an eruption began at Pauahi Crater (fig. 16.2) and continued vigorously for several hours, forming lava ponds in both the east and west pits fed by vents within the crater as well as by lava cascades from fissures outside Pauahi. Weak activity persisted in the west pit

of Pauahi for about a month. Then, from December 9 to 12, 1973, no visible activity occurred anywhere on Kilauea.

On December 12, the seismic station located closest to the Pauahi-Mauna Ulu area began to record bursts of barely detectable harmonic tremor. By the next day, tremor had increased and become sustained, and lava quietly reentered Mauna Ulu. For the next one and one-half months, weak to moderate activity produced several short-lived flows that flooded the crusted surface of the rising lava lake.

Mauna Ulu eruptive activity in 1974 was unlike that during 1972–73. Beginning in late January, short vigorous eruptive episodes, lasting typically less than two days, produced moderately high lava fountains (40–80 m) that fed short-lived overflows. These brief eruptive periods were separated by 3-day to 5-week intervals of only feeble activity. The pattern of alternating vigorous and weak activity mimicked, albeit on a smaller scale, the episodes of high fountaining interspersed with longer periods of low activity that characterized the first stage of the 1969–71 Mauna Ulu eruption (Swanson and others, 1979).

Some overflows during the period January–June 1974 advanced as far as 9 km from the vent, but most traveled shorter distances. Consequently, the Mauna Ulu volcanic shield grew substantially in 1974, particularly during March–June, reaching a maximum height of 121 m above its pre-1969 base (Peterson and others, 1976). After June 2, the circulation of the lava lake became

increasingly sluggish, and the crusted and rubbly lake surface gradually subsided and became largely obscured by fumes. The summit region of Kilauea remained highly inflated during this period. The waning activity at Mauna Ulu apparently was unaffected by the July 19-22 summit eruption (Peterson and others, 1976), but the small, subsiding lava pool in Mauna Ulu disappeared below the rubble-covered crater bottom soon after. Harmonic tremor in the Mauna Ulu area also ceased after July 22, the arbitrary date taken for the end of the 1972-74 Mauna Ulu eruption.

The 1972-74 Mauna Ulu eruption produced a total volume of 162×10^6 m³ of lava, 97 percent of which came from vents at Mauna Ulu and Alae, and 3 percent from vents in the Pauahi-Hiaka area (table 16.2). During the period January-June 1974, the average magma eruption rate was about 4×10^6 m³/mo, one-half that for the 1972-73 Mauna Ulu activity. This reduction in average magma eruption rate perhaps augured the eventual cessation of the eruption.

CHRONOLOGICAL NARRATIVE

FEBRUARY 3-DECEMBER 31, 1972

REBIRTH OF MAUNA ULU LAVA LAKE

The start of the 1972-74 eruption was preceded by several months of net summit inflation and of increased seismicity from shallow sources at the summit and upper east rift. About one dozen earthquakes of magnitude 2.5 were felt by local residents between 0037 and 0200 (all times given are Hawaii standard time, H.s.t.) on January 21; these earthquakes, accompanied by shallow harmonic tremor, were centered in the caldera and Keanakakoi areas.

On the morning of February 5, 1972, a ground party discovered that lava had filled about half of the summit crater of Mauna Ulu. The reactivation of the lava lake may have occurred as early as February 2. This possible starting date is based on a telephone call from a passing motorist, who reported seeing "lava fountains on Hilina Pali" around 2130 while driving northeast from Pahala. Hilina Pali lies almost directly in line between Pahala and Mauna Ulu; thus, lava fountains or glow from Mauna Ulu might appear to issue from the pali (fig. 16.2). Though fog prevented its independent confirmation, there is little reason to doubt the February 2 eruption sighting of the motorist, a longtime resident who had witnessed many eruptions. The "bright and solid" glow witnessed by him could well have represented an early stage in refilling Mauna Ulu crater. However, seismograms for February 2 and 3 showed no unusual seismic activity or detectable harmonic tremor, which typically accompanies Kilauea eruptions.

The number of small east-rift earthquakes increased gradually about 0320 on February 4, and tremor began between 0500 and 0600. A strong storm struck the Island of Hawaii during this time, however, and the tremor recorded by several seismographs was thought at the time to be caused by high winds. The instrument at Puu Huluhulu (fig. 16.2) appeared to have been affected the most by the storm, even though some other instruments were equally

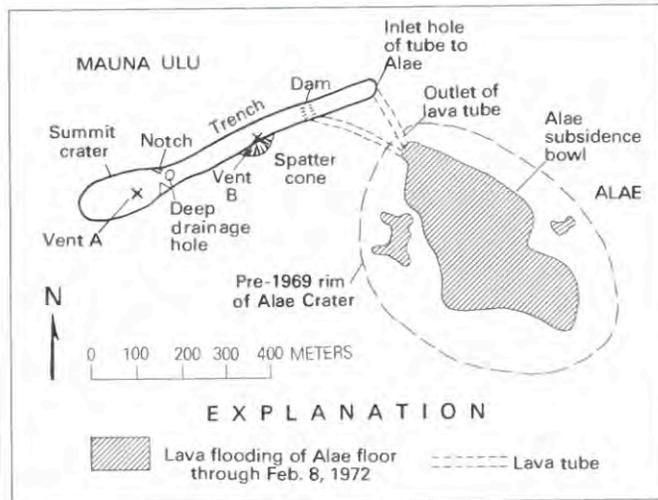


FIGURE 16.5.—Sketch map showing configuration of the summit area of Mauna Ulu shield and of Alae when the 1972-1974 eruption began in early February 1972. Summit crater, notch, trench, and lava-tube system linking Mauna Ulu and Alae had been developed by early 1971 during the 1969-71 Mauna Ulu eruption. Easternmost lava tube reopened on February 7, 1972, and fed lava onto the floor of Alae subsidence bowl, which filled to the brim by February 12.

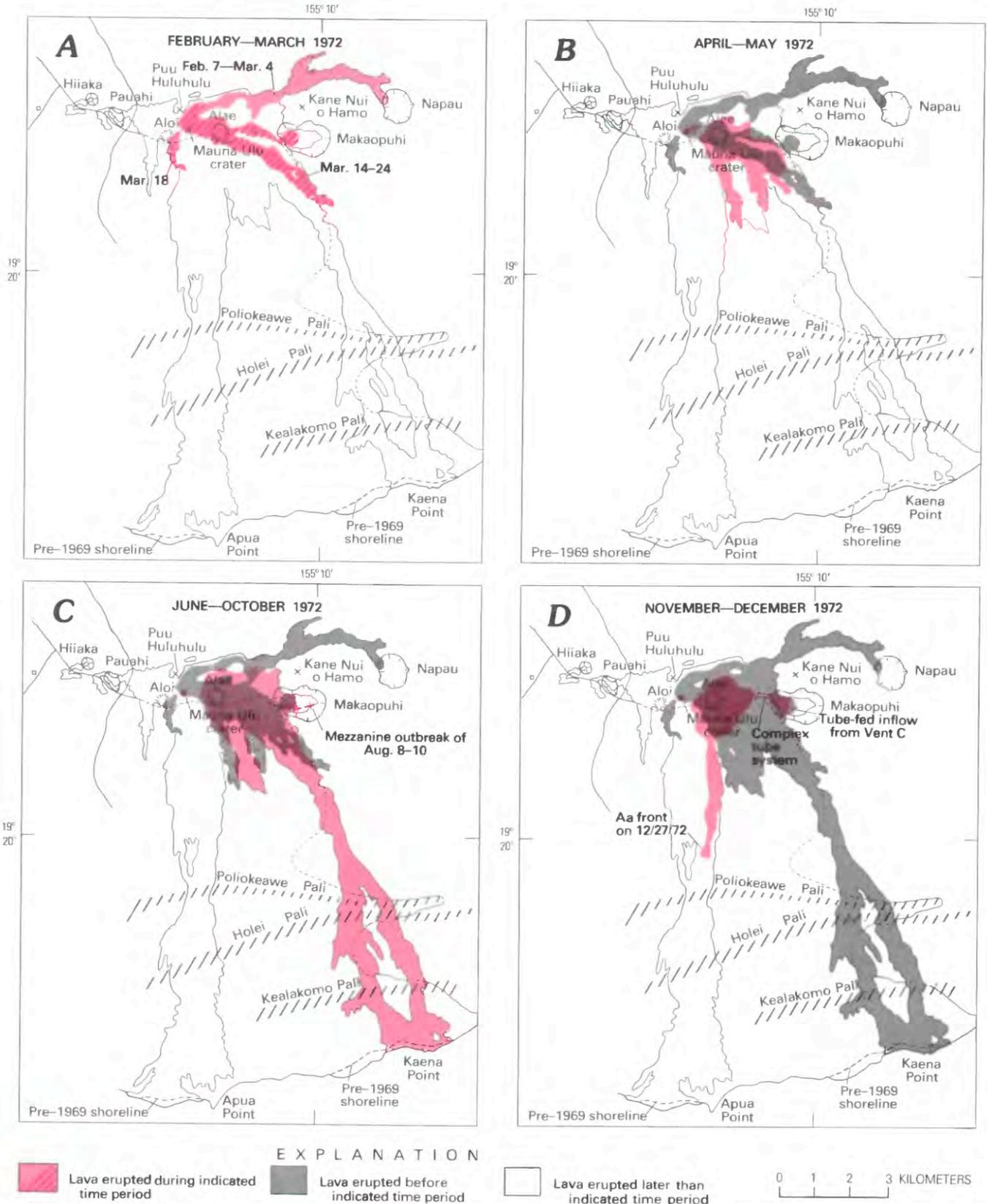
exposed to the wind. In retrospect, the recorded tremor on February 4 was probably only partly due to the storm; when the storm slackened on February 5, tremor continued.

Available evidence thus indicates that lava was almost certainly flowing into Mauna Ulu crater on the morning of February 4 and possibly as early as the night of February 2. We arbitrarily use February 3 as the starting date of the 1972-74 Mauna Ulu eruption. This date is consistent with a starting time of the eruption of about 1900 on February 3, calculated by simple backward projection of the lava's rate of rise during February 5-6 (about 1.6 m/h).

REOPENING OF THE MAUNA ULU-ALAE CONNECTION

When discovered on the morning of February 5, the new lava lake had already filled about half of Mauna Ulu Crater and was slowly rising. No fountaining or surface circulation was observed. In the afternoon, the surface of the lava lake was 78 m below the crater rim, about the same elevation as the lava pool in a 30-m-diameter hole immediately east of the notch at the east end of the crater (fig. 16.5). All activity was confined to the western part of Mauna Ulu summit.

During the next two days, harmonic tremor increased, lava gradually rose, and fountaining as high as 10 m became localized at a point in the east-central part of the crater (fig. 16.5, vent A). Vent A is located in the same part of the lava lake as one of the vents active during stages 3 and 4 of the 1969-71 Mauna Ulu eruption (Swanson and others, 1979, plate 4). By 1030 on February 7, lava had risen to about 25 m below the rim of the crater and began to cascade over the notch into the pool. It flowed eastward down the



trench, reaching the eastern end at 1200. The lava-tube system that linked Mauna Ulu and Alae during the 1969–71 eruption was still in existence, as later confirmed by thermal infra-red scanning imagery obtained during a pre-dawn flight in February 1973; lava apparently reentered this tube system and emerged at 1225 at the northwestern edge of the Alae subsidence bowl (fig. 16.5; see also Swanson and Peterson, 1972, fig. 1B). Activity in the lava lake continued steadily, and lava flowing in the trench developed a well-defined channel that fed directly into the Alae inlet tube(s).

LAVA-LAKE ACTIVITY AT MAUNA ULU AND ALAE AND PERIODIC OVERFLOWS

Activity on February 8 was similar to that the day before, except that rising lava now covered the notch between the summit crater and trench. Lava was overflowing a channel obstruction (the dam in fig. 16.5) that had developed about 165 m west of the end of the trench. Low fountaining continued at vent A, but a new fountain appeared near the south wall of the trench 130 m west of the dam (fig. 16.5, vent B). Vent B was to become the dominant vent for the remainder of the 1972–74 eruption.

For the next several days, activity remained much the same, with both vents A and B spurting lava fountains 10–20 m high, and a prominent spatter cone formed at vent B. Except for local variations around these two active vents, lava movement was generally eastward through the trench to the inlet for the tubes to Alae. By February 12, the Alae subsidence bowl had filled with a lava lake that remained intermittently active until early June 1973. Lava spilled over some low areas along the rim of the Alae lake but advanced only a few meters before levees developed.

During February 13–14, the vigor of vent A began to decline, while vent B produced a sustained overflow that advanced east-southeast about 1.1 km from Alae's rim toward Makaopuhi Crater (fig. 16.6A). Activity at vent A ceased on February 16, and the lava level at Mauna Ulu began to drop; although the fountaining at vent B temporarily increased, lava entry into Alae also ceased shortly thereafter. The surface of Alae lava lake crusted over and subsided 1–2 m, and all lava overflows stopped. For the next several days, the lava level in the summit crater continued to decline while weak fountaining persisted at vent B. By the morning of February 22, all surface activity terminated, but lava was still visible through three glowing holes at the site of vent B.

Lava reentered Mauna Ulu on February 24, and, fed by fountains 5–20 m high at vents A and B, the lake rose rapidly several tens of meters to spill over both the south and north rims of the trench. Fountains 40–75 m high at vent B were the highest observed since the eruption began. A major east-northeast-trending overflow advanced north of Kane Nui o Hamo as aa and spilled into Napau Crater on February 29 (figs. 16.6A and 16.7). For the next several days, numerous overflows raised the rim of the eastern part of the trench. Meanwhile, the spatter cone at vent B became the highest point on Mauna Ulu, more than 10 m higher than the rim of the summit crater (hereinafter the summit crater will be referred to simply as the crater). The episode of vigorous activity and overflows ended on March 5, when the lake surface subsided to more than 30 m below the rim of the crater (fig. 16.8). During the next several days, the lake surface continued to drop, and activity at vent B was reduced to sporadic low spurts.

Activity at vents A and B increased beginning on March 11, and on March 14 another overflow episode began. Periodic overflows, some lasting for several hours, alternated with drainbacks of 5–10 m accompanied by vigorous degassing. This cyclic activity resembled the so-called gas-piston described by Swanson and others (1979) but was larger in scale, involving the entire lake instead of a chimney-like vent. Virtually all parts of Mauna Ulu, except its extreme western end, were flooded by the overflows (fig. 16.9).

At 1800 on March 18, a new fissure vent, 200 m long, opened on the west flank of Mauna Ulu over the southeastern edge of the buried Aloi Crater (fig. 16.3). This fissure nearly coincided with that formed in April 1970 (Swanson and others, 1979, pls. 1, 3). The lava level in both the crater and trench rapidly dropped several tens of meters. Activity at the new fissure was short lived; after feeding a small flow (fig. 16.6A), the fountains stopped during the morning of March 19. However, accompanied by high-amplitude harmonic tremor and summit deflation, eruptive activity then shifted to the Alae area, where two new vents opened (fig. 16.11, vents C and D), each feeding fountains about 20 m high. The subsidence bowl at Alae again quickly filled; a perched lava lake soon developed by repeated overflows and levee construction, initiating the growth of a volcanic shield at Alae. During March 19–20, vents C and D fed two lava streams that advanced 2 km or more east and southeast; one of these streams poured into the deep western pit of Makaopuhi Crater (fig. 16.6A). Activity at the two vents then began to wane and ceased by March 24.

DOMINANT ACTIVITY SHIFTS TO ALAE: VOLCANIC SHIELD GROWTH

The opening of the vents during March 18–20 (the west-flank fissure at Mauna Ulu and vents C and D at Alae) ended the period of overflows from Mauna Ulu in 1972 (fig. 16.10): the next overflow was not to occur until early November 1973. For the remainder of 1972 and until mid-1973, generally weak activity continued intermittently at vent A within the crater, but vents C and D and various openings at or near vent B dominated the eruptive activity at Mauna

FIGURE 16.6.—Lava flows developed during 1972 in the Mauna Ulu region. Outlines of flows are approximate in this and subsequent similar figures tracing the development of lava flows during 1972–1974 Mauna Ulu eruption. Outline of the entire field, as well as the outlines of portions of lava flows not covered by younger flows, taken from geologic map of Holcomb (1976). See figure 16.3 for locations of vents. **A**, February–March. Lava erupted during March 14–24 indicated by hachuring. **B**, April–May. **C**, June–October. For details about lava delta at Kaena Point, see Peterson (1976). **D**, November–December. Except for late December flow and tube-fed inflow into western pit of Makaopuhi Crater, most flows were short-lived and accreted near vent, resulting in shield growth.



FIGURE 16.7.—View of 10-m-wide pahoehoe flow advancing through forest east of Puu Huluhulu on February 28, 1972, during overflow from Mauna Ulu (fig. 16.6A). Note burned vegetation adjacent to flow. Photograph taken by R.I. Tilling.

Ulu and Alae. In effect, the lava lake in Mauna Ulu's crater became mainly a passive holding tank, fluctuating in level but distinctly subordinate in activity to vents C and D, which are rootless and probably supplied from vent B through the Alae inlet tube. Whether vent B itself was a primary vent or tapped another, primary vent beneath Mauna Ulu is not known. However, we regard vent B as primary, at least for the period February 1972–April 1973 (see Tilling and others, 1973, fig. 2). All visible activity at Mauna Ulu from May 1973 on involved vents located west of vent B, and the primary vent may therefore have shifted westward at about that time.

The last week in March 1972 was marked by a lull in harmonic tremor and summit inflation; visible vent activity was restricted to weak spattering at vent A. On April 3, tremor increased and the lake in the crater rose. A new (unnamed) vent between vent B and the west end of the trench (fig. 16.3, near vent F) opened and fed a cascade of lava westward over the septum separating the trench and crater (fig. 16.11) and into the lava lake. Vent C was reactivated and began again to fill Alae lava lake.

Overflows from vent D built a 20-m-high satellitic shield on the northern flank of the growing Alae shield.

For the next several months, the eruptive activity changed little. At Mauna Ulu, low fountains spouted locally from the circulating lava lake, whose level fluctuated from 20 to 30 m (generally 22–26 m) below the rim. The circulation pattern generally involved a net east-to-west movement; however, during brief episodes lasting a few minutes to half an hour, circulation reversals occurred, accompanied by turbulent disruption of the lake surface and fountaining as high as 25 m, presumably from vent A. A number of small vents and open, glowing holes in the trench, between the septum and the vent B spatter cone, intermittently ejected spatter or spawned short lava flows that covered the trench bottom. Gas-piston activity and attendant degassing were commonly observed at these vents. The lava level was generally about the same in both the crater and the trench, suggesting the existence of hydraulic connection through the septum.

The dominant vent during this period, however, was C, which quietly pumped out a virtually uninterrupted stream of lava into the



FIGURE 16.8.—Lava from the trench fed by vent B falling approximately 20 m over the septum (fig. 16.11) into the lava lake in Mauna Ulu Crater. Photograph taken by D.W. Peterson, March 5, 1972.

perched Alae lava lake, which measured about 200 m across and perhaps 5–10 m deep. Overflows from this lake fed many short lava flows, mainly to the south and southeast (fig. 16.6B), raised the confining levees, and accreted lava to the surrounding areas. By

May, the irregular summit area of the rapidly growing volcanic shield was more than 40 m above the mid-1971 surface of the subsidence bowl at Alae.

The generally steady and quiet output of vent C was dis-



FIGURE 16.9.—Aerial view showing Mauna Ulu Crater filled with lava during March 14–24 period of overflow and shield growth. Circular structure, about 700 m across, in background is Alae subsidence bowl (fig. 16.5). Photograph taken by W.A. Duffield, March 17, 1972.

rupted, at intervals ranging from about 30 minutes to more than 2 hours, by abrupt and brief (5–30 seconds) drainbacks, causing considerable turbulence of the nearby lava-lake surface. Little or no gas was emitted during such behavior and the entire process occurred silently. Furthermore, simultaneous observations indicated that the drainback events at Alae did not correlate with gas-piston activity at Mauna Ulu.

Within Alae lava lake itself, quasi-solid but still highly mobile island-like and peninsula-like masses began to develop in late April (fig. 16.12). These islands and peninsulas eventually became fixed in position, grew, and coalesced to form a discontinuous, roughly northwest-southeast divider across the center of the lake, nearly separating it into two compartments, each of which contained lava pools (fig. 16.11). Beginning in late May, the principal inflow of lava from vent C was into the northeastern compartment; subsequent periodic overflows raised its surface about 5 m higher than that of the southwestern compartment. Spillage across the divider kept the

southwestern pool active. Voluminous overflows from both compartments of the lake built the complex Alae shield to an estimated height of 80 m above the pre-1969 southeastern rim of former Alae Crater (fig. 16.13).

SUSTAINED OVERFLOWS, LAVA TUBES, AND LAVA ENTRY INTO THE SEA

Starting in June 1972, the eruption began to depart from the mode of activity characteristic of the preceding months. The level of Mauna Ulu lava lake dropped and then fluctuated between 30 and 45 m below the crater rim. Construction of the volcanic shield continued by periodic overflows around the margin of Alae lava lake, but some of the overflows were more sustained and gradually became channelized. Consequently, an integrated system of lava channels and tubes developed and carried lava great distances from

the immediate flanks of the growing shield. At times the surface of the Alae lake fell 1–10 m below the confining levees as lava drained from the lake through the tube system and emerged at the surface as far as 2 km from Alae. By June 20, surface and tube-fed lava flows from Alae again began to spill into the deep west pit of Makaopuhi Crater (fig. 16.6C).

The activity at Mauna Ulu remained essentially unchanged for the next several months. Lava entered the lake from the vent complex between vent B and the west end of the trench; surface circulation of the lava lake was predominantly from east to west; and lava fountains 5–10 m high played sporadically from various parts of the lake margin where surface lava and crust circulated downward. Meanwhile, vent C at Alae continued to feed lava through tubes into Makaopuhi's west pit. Near-vertical tubes developed around the two dominant lava cascades down the west wall of Makaopuhi and fed lava directly into the molten pool beneath the crusted floor, gradually raising it in piston-like fashion, as also happened during the filling of Alae Crater in 1969 (Swanson and others, 1972, 1979). In addition, prominent talus-and-lava cones formed against the west wall (fig. 16.14).

By early August, inflow into Makaopuhi declined, but tube-fed Pahoe flows accumulated in the area southeast of the Alae shield and began to advance southeastward. During August 7–13, intense rockfall activity in Makaopuhi's west pit generated about 0.27×10^6 m³ of rockfall debris. Many of these rockfalls were observed and photographed as they happened; correlations of field observations and seismic data suggested that this unusually energetic flurry of rockfalls was caused by eruption-induced changes in stress patterns of the crater walls (Tilling and others, 1975). The peak rockfall activity coincided with a small-volume eruption from echelon fissures on the mezzanine of Makaopuhi observed on August 9 and 10 (Tilling and others, 1975, figs. 2, 4); this eruption began between late afternoon of August 7 and early morning of August 9. Because the mezzanine vent fissures were rootless, the cause of this outbreak is problematic. It may in part be attributed to hydrofracturing induced by the weight of the lava lake and rockfall debris in the west pit exceeding the tensile strength of the mezzanine.

By mid-August, the tube-fed southeastward-flowing lava from Alae had advanced over Paliokae Pali and Holei Pali, buried a segment of Chain of Craters Road not covered during the 1969–71 activity, and covered flows of 1970–71 and older ages along the coastal flat. On August 23, lava reached the ocean at Kaena Point, about 1.5 km east of the lava delta of March–May 1971 (fig. 16.6C), marking the fourth time that lava had entered the sea along the south coast of Hawaii since June of 1969. The processes of lava entry into the sea and formation of lava deltas were essentially identical to those described earlier for the 1969–71 eruption of Mauna Ulu (Moore and others, 1973) and have been summarized by Peterson (1976). Substantial stretches of new black-sand beaches formed along the new shoreline when molten lava shattered upon quenching by seawater and was comminuted in the surf zone. SCUBA-diving scientists observed pillow formation and the submarine movement of lava (Grigg, 1973; Moore, 1975; Tepley, 1975).

Similar activity continued at Mauna Ulu and Alae throughout September and until mid-October. The lake level at Mauna Ulu varied between 33 and 50 m below the crater rim; the lake at Alae occasionally dropped to about 20 m below the crater rim and, at other times, briefly overflowed its levees to add to the bulk and height of the Alae shield. The volume rate of inflow of tube-fed lava into Makaopuhi Crater slackened. Temperature, flow velocity, and dimensions of lava channels were measured or estimated through openings or skylights formed by local collapse of the roof in the upstream parts of the principal tube systems (figs. 16.15, 16.16). Optical pyrometer and thermocouple measurements indicated minimum temperatures ranging between 1,130 and 1,165 °C. Average flow rates were 1.5–3.0 m/s; at times of low stands of Alae lake (for example, on October 17), flow rates in the tube systems decreased to about 0.2–0.5 m/s.

Lava flowage to the sea from Alae lake through the well developed southeast-trending tube system continued until mid-October, when lava from vent C was diverted to the east and northeast, away from the tube system. By November 8, the diverted lava had accumulated to form a well-defined lava pond, in effect a much smaller version of the Alae lake. This northeast pond periodically overflowed to construct a satellitic shield on the northeastern flank of the larger and complex Alae shield.

The diversion of vent C lava to the northeast diminished the rate of lava supply to Alae lake and to the tube system between Alae and the sea. Consequently, lava entry into the sea ceased completely by about October 20, after having formed a lava delta about 8.6×10^6 m³ in volume and 0.18 km² in area (Peterson, 1976, table 1).

By early November the main lava tube draining Alae had become choked off at a point near the southeastern rim. Lava from Alae spilled into Makaopuhi again briefly in late October and more voluminously in mid-November (fig. 16.6D). The west pit of Makaopuhi was then virtually full of lava, the irregular surface of which sloped gently eastward from the west wall and averaged 2–3 m below the floor of the eastern mezzanine (fig. 16.17A).

ADDITIONAL GROWTH OF ALAE SHIELD

Activity at Mauna Ulu and Alae varied little for the remainder of 1972; the Mauna Ulu lake level fluctuated between 28 and 36 m below the crater rim, but was most commonly at about 31 m. Steady outpouring of lava from vent C through surface channels or short tubes fed numerous flows, which built the complex Alae shield higher and wider. The areas of major growth included Alae summit (around vent C) and three secondary vent areas on the southern flank of the complex shield. Accretions around these secondary vents, presumably the outlets of tubes within the shield, rose as much as 10 m above the sloping flanks of the main shield. Overflows also flooded the crusted surfaces of both compartments of the Alae lava lake, obliterating their former distinct edges.

The growth of the Alae shield was the dominant and most conspicuous activity in November–December 1972, but significant overflows to the south built a new system of lava channels and tubes,



FIGURE 16.10.—Profile of Mauna Ulu volcanic shield as seen from Alae, following February–March 1972 overflows; prominent knob is the 10-m-high

which gradually became well integrated. Toward the end of December, lava was being transported progressively greater distances from vent C through an increasingly efficient channel-tube system; as a result, shield-building processes became sporadic and subordinate. By December 27, a partly roofed, south-trending channel fed a flow that advanced to within 1 km of the edge of Poliokeawe Pali (fig. 16.6D). The continuing lava-lake activity at Mauna Ulu was not affected by the change of Alae's main activity from shield building to lava-tube development. In the months to come, shield building would be only an intermittent and minor eruptive process at Alae.

JANUARY 1–MAY 4, 1973

RENEWED OVERFLOWS, LAVA-TUBE FORMATION, AND LAVA ENTRY INTO SEA

Eruptive activity during January–April 1973 was dominated by continued voluminous lava output from vents at Alae, development of well-integrated lava-tube systems, and renewed entry of lava into the sea. Mauna Ulu's behavior during this interval remained basically the same as that during much of 1972; the lava-lake level was fairly steady, mostly fluctuating between 30 and 35 m below the crater rim (total range 24–41 m). Whereas during 1972 the surface movement of the lake was most commonly from east to west, in 1973 no net circulation direction prevailed.

Vent C remained the principal source of lava output at Alae during January–April 1973, and secondary nearby sources were intermittently active. Gas-piston activity became notable at vent C: a cycle consisted of the slow, quiet rise of the lava column for 15 minutes to one hour, followed by vigorous degassing and an abrupt

drop of 5–20 m in the level of the column. As degassing ended, the quiet rise of lava resumed and the cycle repeated.

Associated with the steady activity at Alae during January–February, two major tube systems developed, one a south-trending system that began in December 1972 and the other a rejuvenated east-northeast-trending system toward Makaopuhi (fig. 16.18A). Tube-fed lava from the south-trending system spilled over Poliokeawe Pali and Holei Pali by January 12 and began to pond at the base of Holei Pali. Extension of the east-northeast-trending system resulted in renewed filling of Makaopuhi beginning on January 24. By mid-February the west pit of Makaopuhi was filled to the mezzanine level, and soon thereafter pahoehoe lava covered more than half of the mezzanine floor (fig. 16.17B).

Pahoehoe flows fed by the south-trending tube system continued to spread slowly over the coastal flat and on February 24 reached the ocean about 1 km west of Apua Point (fig. 16.18A), marking the fifth consecutive year that lava from Mauna Ulu eruptions had entered the sea. By March 20, the subaerial part of the lava delta at Apua Point had grown to about 0.18 km². Lava entered the sea at Apua Point throughout March and April, and the lava delta attained an area of about 0.29 km² and a volume of 13.0 × 10⁶ m³ (Peterson, 1976, table 1). As in 1972, SCUBA-diving scientists were again able to observe lava movement and pillow formation beneath the sea surface.

While inflow into Makaopuhi dwindled and finally stopped in early March, numerous overflows issued from two lava-tube skylights about 100–120 m east-northeast of vent C. These overflows and several from vent C itself resulted in a brief period of shield building at Alae summit, but the rate of flow in the south-trending system showed no decrease.



spatter cone of vent B. This profile changed little through late 1973. Composite of photographs taken by R.T. Holcomb, February 6, 1973.

Activity at Mauna Ulu and Alae through April varied little from that of earlier 1973. At times during this period, Mauna Ulu and Alae lava lakes varied roughly in concert (fig. 16.19). In mid-March, part of the east wall of Mauna Ulu crater collapsed and the lava lake lengthened eastward by about 20 m into the area of the trough. However, within about a week, the collapsed part of the wall was rebuilt and the lake perimeter retreated to near its former position. Beginning in early April, the western part of the Mauna Ulu trench subsided, and lava from vent B reached the lake in the western crater by periodic surface flows across part or all of the trench floor, rather than by flow beneath it.

EFFECT OF THE APRIL 26, 1973, HONOMU EARTHQUAKE

At 1026 on April 26, an earthquake of magnitude 6.2 shook the Island of Hawaii. The hypocenter was 48 km beneath Honomu (fig. 16.1, inset) on the northeast coast of Hawaii (Unger and others, 1973; Unger and Ward, 1979). Observations from the air and on the ground showed no appreciable immediate effect of this earthquake on the eruptive activity at Mauna Ulu and Alae, but the south-trending lava-tube system feeding the flows entering the ocean near Apua Point apparently was severely disrupted by subsurface collapse-induced obstructions that impeded and ultimately halted lava transport.

The rate of lava entering the sea showed a temporary increase immediately after the earthquake but then declined rapidly. By May 1, lava entry into the sea had ceased. Blockage of the tubes above Poliokeawe Pali caused several copious overflows from upstream skylights, which in turn fed spectacular cascades down the face of

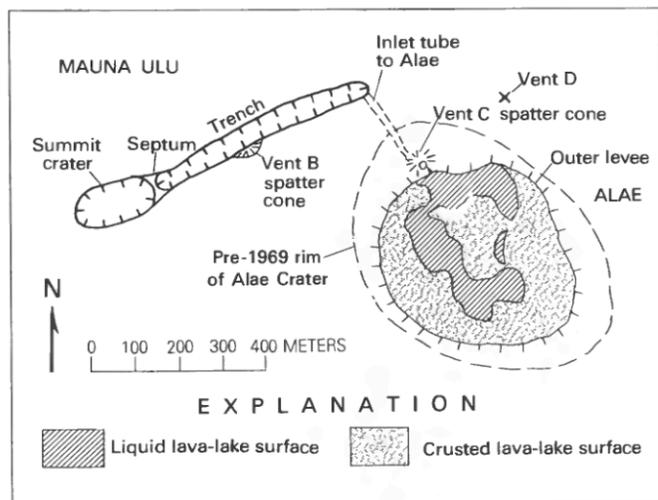


FIGURE 16.11.—Sketch map showing two compartments in lava lake at Alae and location of vents C and D. Vent C was fed through lava tubes from Mauna Ulu trench and in turn supplied vent D through surface channels and tubes. Configuration of Alae lava-lake surface varied daily, but the distinction of southwest and northeast compartments persisted for many weeks. See also Holcomb and others (1974, figs. 5-12, 5-13).



FIGURE 16.12.—View to west showing island-like masses of semisolid lava developed in Alae lava lake, which was fed by lava issuing from opening at base of fuming vent C spatter cone (center). Mauna Ulu shield, with its prominent vent B spatter cone, and Puu Huluhulu are seen in upper left. Photograph taken by D.W. Peterson, April 23, 1972.

Poliokeawe Pali and Holei Pali a few hundred meters east of the blocked tube system. These cascades continued until May 5. Tube blockage may also have caused the overflows and 5-m-high fountains on May 1 from vent C and several secondary vents on the southwest

and south rim of the crusted Alae lake. By May 3, the activity at the secondary vents had nearly ended, and the lava column in vent C dropped to about 7 m below the ground surface.

We assume but cannot prove that this rather abrupt cessation in

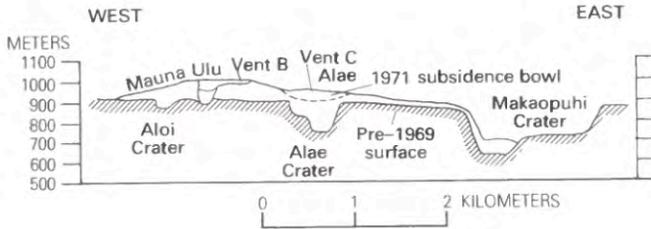


FIGURE 16.13.—Schematic cross section showing Mauna Ulu and Alae volcanic shields in late May 1972; line of section is approximately east-west but is bent at several points so as to traverse summits of Mauna Ulu and Alae, as well as Makaopuhi Crater and buried Aloi Crater. Vertical exaggeration is 2.5. Modified from Tilling and others (1973, fig. 2).

early May of the virtually continuous activity that had prevailed through April 1973 resulted from blockages in the magma conduits caused by the Honouliuli earthquake. A 7.2-magnitude earthquake in November 1975 (Tilling, 1976b; Tilling and others, 1976a) caused major changes in Kilauea's magma regime (Dzurisin and others, 1984). Yet, the 6.7-magnitude Kaoiki earthquake in November 1983 apparently produced no observable effects on the Puo Oo eruption (Wolfe and others, chapter 17; E.W. Wolfe, written commun., 1985). Though the coincidence in timing between cessation of activity and the Honouliuli earthquake may be fortuitous, we favor the working hypothesis that the disruption in magma-transfer regime perhaps was induced by the earthquake.



FIGURE 16.14.—Streams of tube-fed lava cascading down the western wall (200 m high) of Makaopuhi Crater, forming lava-and-talus cones. Photograph taken by W.A. Duffield on June 30, 1972; see Holcomb and others (1974, p. 51 and figs. 5-25, 5-26) for additional information.



FIGURE 16.15.—Geologist probing the depth of a lava stream with stainless steel pipe inserted through lava-tube skylight. Photograph taken by R.I. Tilling in January 1973.

PAUAHI-HIIAKA ERUPTION OF MAY 5, 1973

ACTIVITY WITHIN PAUAHI CRATER

At 0703 on May 5, an intense flurry of small shallow earthquakes began in the vicinity of Mauna Ulu and Alae. Subsequent smaller earthquakes were soon masked on seismograms by increasing harmonic tremor, accompanied by rapid deflation of the summit of Kilauea. Observations at 0915 showed that Mauna Ulu lava lake, whose level was 39 m below the crater rim only two days before, had completely drained to leave a very deep, rubble-choked crater, whose walls were crumbling amid thick dust clouds. The crater formerly containing the lava lake was now composed of two parts, a western pit about 180 m deep and an eastern pit about 200 m deep, both of which were entirely devoid of molten lava (figs. 16.20, 16.22A). The western pit approximately coincided with the general area of vent A. The empty crater extended eastward into the trench of Mauna Ulu as far as the area of the vent B spatter-and-pumice cone (fig. 16.20). Observations at 0945 showed that molten lava within the Alae volcanic edifice also had drained completely, as

expressed by the collapse of the area of vent C to form a rubble-filled crater about 60 m by 100 m across and 30 m deep.

A magnitude-3 earthquake occurred at 0932 near Puu Huluhulu and was followed during the next hour by several comparable and larger shocks, some of which were felt as far away as Hilo. These earthquakes prompted inspection of the Chain of Craters Road area and a recommendation to officials of Hawaii Volcanoes National Park that the road be closed to traffic. An observer arrived at Pauahi Crater (fig. 16.18B) at 1020, just in time to watch the last of a series of large rockfalls from the north crater wall. At 1023 he heard a sharp loud sound and saw a dense fume cloud beginning to issue from a new opening near the deepest part of the western pit of the composite crater. At 1025 lava spurted from that opening, marking the first historical eruption in Pauahi. Within a few minutes, lava emerged from several additional openings aligned across the northern side of Pauahi, and by 1050 lava was fountaining along a 120-m-long fissure trending about N. 85° E. (figs. 16.3, 16.18B). At 1120 the lava fountains at the first and third vents to open on the crater floor reached their maximum height of about 20 m. Fountaining then declined rapidly along the length of the fissure, except at the two sites of maximum fountaining; drain-back into the stagnant segments of the vent fissure immediately followed.

The decline of the lava fountains and increase in rate of drainback were rapid. By 1125, the remaining fountains were feeble, the level of the lava pond had dropped 17 m, and a new vent had broken out at a site a few tens of meters east-southeast of the original fissure and about 40 m above the level of the lava pond (fig. 16.18B). This new vent increased in vigor as the original fountains died about 1140. By then lava was draining at the two former vents on the original fissure much more rapidly than the new vent was supplying lava to the pond. Activity at the new vent soon began to weaken, and it ceased at about 1200. The lava surface in the crater had dropped to 20 m below its highest level by the time active drainback ended about 30 minutes later, leaving a pond of lava 20 m deep in the lowest part of the crater.

The total volume of lava erupted into Pauahi Crater during this first stage of the eruption was about $0.14 \times 10^6 \text{ m}^3$, of which $0.12 \times 10^6 \text{ m}^3$ drained back down the fissure. A few small bubbling vents were later observed to have remained intermittently active until early morning of May 6, but these contributed negligible additional volume to the lava fill within the crater.

ERUPTION SHIFTS TO HIIAKA CRATER AND NEARBY FISSURES

Earthquake activity and harmonic tremor remained high after the eruption within Pauahi. At 1255 on May 5, fountaining broke out along a set of fissures extending N. 70° E. from just east of the Chain of Craters Road to within the southeastern part of Hiiaka Crater (figs. 16.3, 16.18B). The highest fountains played along the fissure within the crater, reaching heights of nearly 50 m at times. Smaller fountains erupted from the fissures outside the crater and fed a spectacular cascade of lava down Hiiaka's southwestern wall. At



FIGURE 16.16.—Branch floating on lava stream bursts into flame as it encounters oxygen in the atmosphere at skylight (opening about 3 m wide) of principal lava tube leading from Alae. Passage of such branches is timed at successive downstream skylights by observers with stop watches who communicate by radio. Average rates of lava movement so determined are minimum rates, because the length of the meandering lava stream is greater than the length obtained by summing the linear distances measured between skylights and because cascades, pools, and eddies along the lava stream slow a branch's progress. Except at skylights, little oxygen is available in the lava tubes, so a branch can be carried hundreds of meters before being totally consumed. This method was used to estimate average flow velocities throughout the tube-fed stages of the 1969–71 and 1972–74 Mauna Ulu eruptions (Peterson and Swanson, 1974; this paper). Photograph taken by R.I. Tilling, September 19, 1972.

1307 lava broke out from a new fissure southwest of the Chain of Craters Road and initially ponded around the erupting vents and against one of the Koae fault scarps about 200 m farther south. The lava crossed the Chain of Craters Road at 1325 and added to the cascade down the crater wall, while fountaining continued at full force within Hiiaka.

The fissure southwest of the Chain of Craters Road, the latest near Hiiaka to open, was the first to die. Its decline was apparent by about 1500, and activity ended at about 1535. By that time, the fissures northeast of the road were erupting very gassy spatter in fountains no more than 3 or 4 m high, and the height of the lava fountains in Hiiaka had decreased as well. By 1700 the last (easternmost) vent in Hiiaka was virtually dead, spattering only feebly at long intervals, and slow drainback was underway (fig. 16.21).

At 1645, a dense fume cloud rose from a fissure 120 m west of the Hilina Pali Road (fig. 16.18B), 1 km southwest of its intersection with the Chain of Craters Road. Aerial observations around 1700 showed a continuous line of spattering only a few meters high along a fissure about 180 m long. A small flow was puddled around the eruptive fissure. By 1740, when this fissure was observed from the ground, it no longer was erupting lava but instead was degassing with a deafening roar and visible pale flames. The degassing gradually declined over a few hours, but the fissure fumed profusely through the next two days. This outbreak was only the second to occur within the Koae fault system in historical time, the first having been on May 24, 1969, and was much farther within the Koae system than the 1969 fissures (Koyanagi and others, 1973; Duffield, 1975; Swanson and others, 1979).

The maximum volume of the new fill in Hiiaka Crater from this



A

FIGURE 16.17.—Views of Makaopuhi Crater in early 1973. **A**, View on January 26, 1973, from the southwestern rim showing the west pit filled by tube-fed lava from vent C to within a few meters of the mezzanine surface. Part of 1965 lava on mezzanine (Wright and others, 1968) can still be seen (center left). Photograph taken by D.W. Peterson. **B**, View from nearly the same point on February 5, 1973, showing the mezzanine surface (center) more than half covered by new flow. Vegetation on mezzanine was killed earlier by fire set by the outbreak in August 1972. Photograph taken by R.T. Holcomb.

second stage of the eruption was $0.56 \times 10^6 \text{ m}^3$, of which $0.12 \times 10^6 \text{ m}^3$ drained back. In addition, flows covered about 0.37 km^2 of ground outside the crater, probably accounting for an additional volume of at least $0.5 \times 10^6 \text{ m}^3$. Together with the $0.14 \times 10^6 \text{ m}^3$ at Pauahi, these amounts make the total volume of lava erupted during the 7-hour eruption $1.2 \times 10^6 \text{ m}^3$, of which $0.2 \times 10^6 \text{ m}^3$ drained back into the vent fissures, resulting in a net

volume remaining on the surface of about $1 \times 10^6 \text{ m}^3$ (table 16.2).

MAY 6–NOVEMBER 9, 1973

The combination of the April 26 magnitude-6.2 Honouliuli earthquake and the May 5 Pauahi-Hiiaka eruption caused only a temporary disruption of the eruptive activity at Mauna Ulu.

**B**

FIGURE 16.17.—Continued.

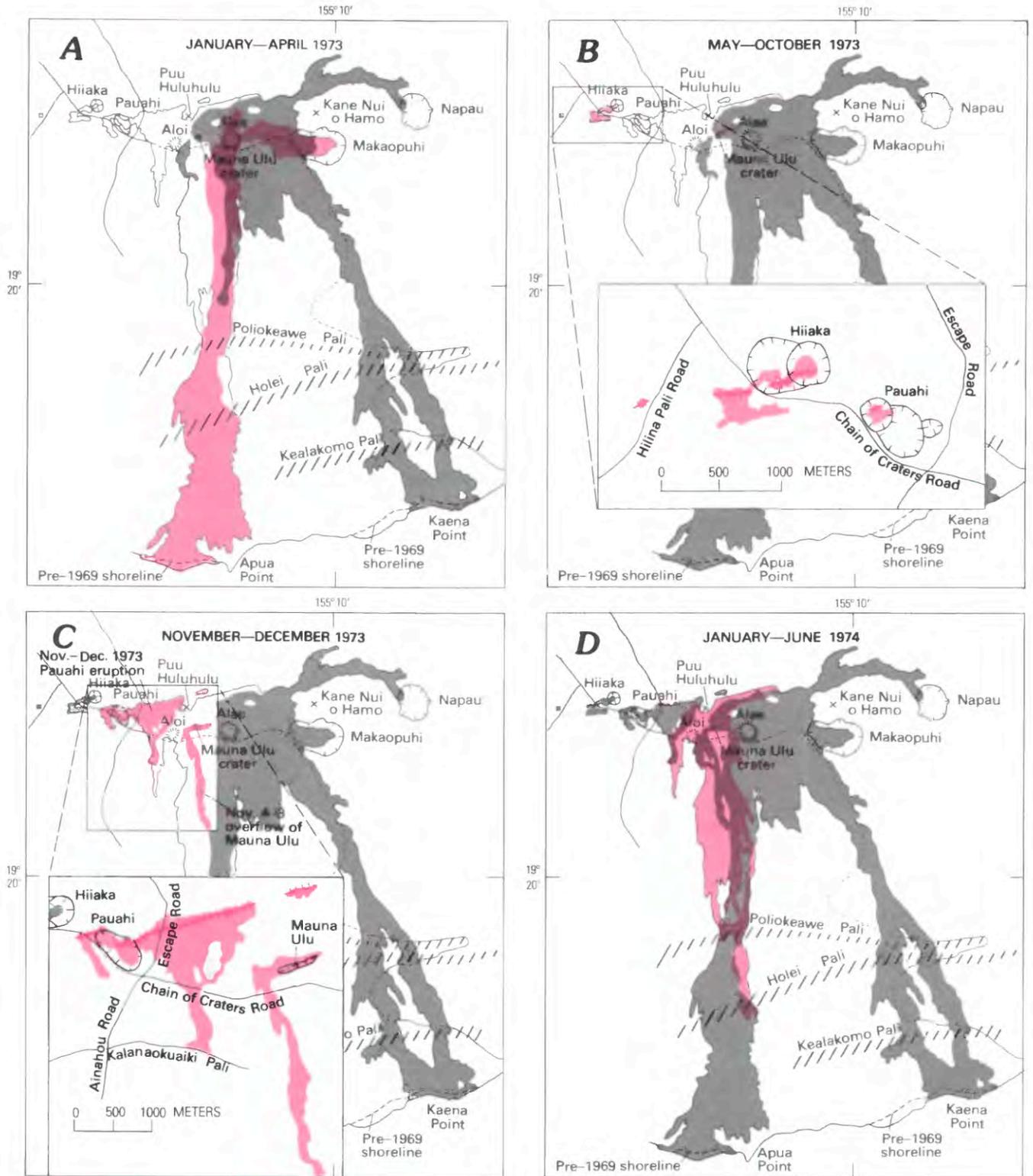
However, these events may have been sufficient to weaken, and soon sever, the magma connection between Mauna Ulu and Alae that had operated so efficiently since February 1972.

RETURN OF LAVA TO MAUNA ULU AND ALAE

Mauna Ulu's 200-m-deep crater, emptied several hours before the Pauahi-Hiiaka eruption of May 5, was highly unstable now that its walls were no longer buttressed by the lava lake. Rockfall dust

cleared sufficiently to allow the crater floor to be seen and its level measured on the morning of May 6 (fig. 16.20), but large rockfalls continued to spall from its walls for many days, generating dust clouds that rose as high as 500 m above the crater rim (see, for example, Tilling and others, 1975, fig. 9).

Harmonic tremor as recorded on the Puu Huluhulu seismograph was at a very low level from the morning of May 6 until about 1900 on the evening of May 7, when it increased noticeably. On the morning of May 8, two small pools of lava were observed in



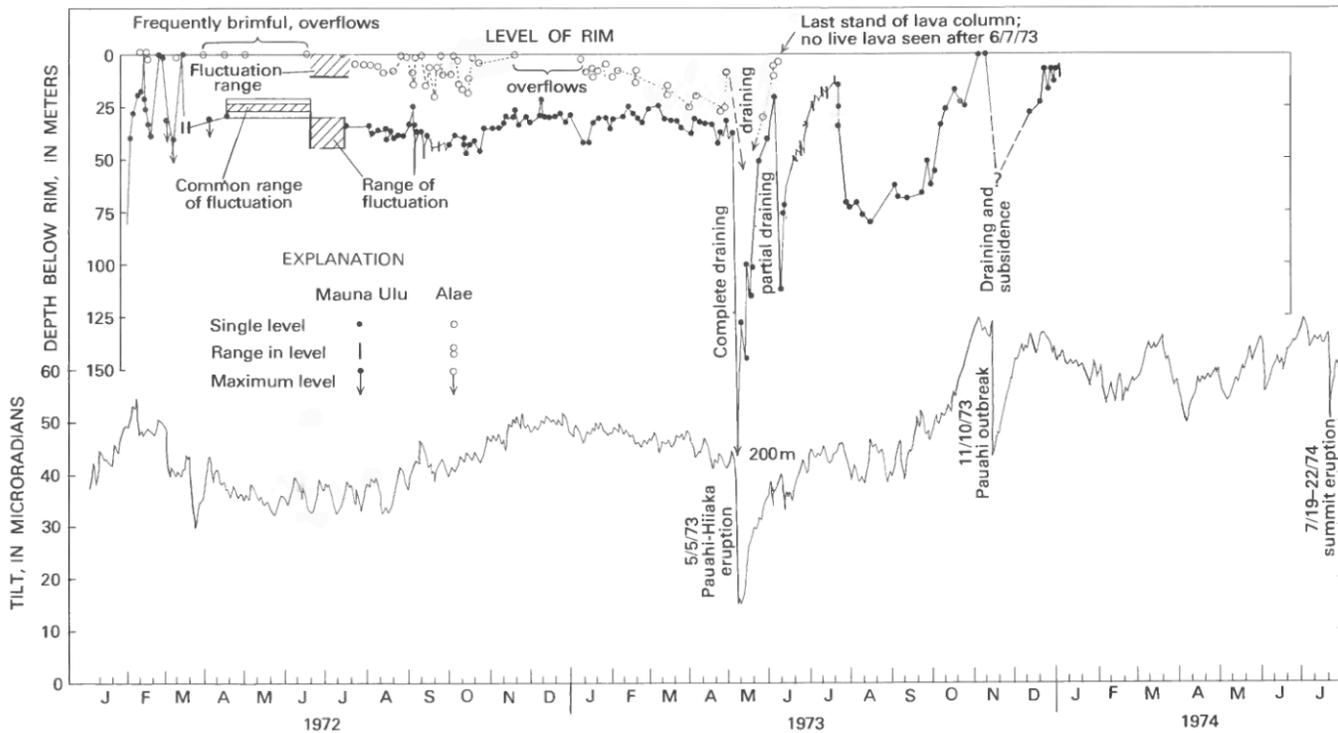


FIGURE 16.19.—Fluctuations in the depth from crater rim to the surface of lava lakes at Mauna Ulu and Alae compared with variations in the east-west component of summit tilt measured at Uwekahuna. Data plotted are from Tilling and others (1986) and figure 16.4; tilt record has been adjusted to remove the 18-microradian offset caused by the April 26, 1973 Honomu earthquake (see also figs. 16.4, 16.37).

the two deep pits of the crater; presumably lava had returned quietly during the night. Each pool rose rapidly, particularly that in the eastern deep pit. By May 15, the lava level in the eastern pit had reached as high as 97 m below the crater rim, but the level for both pits then fluctuated between 100–120 m below the rim during the next several days (fig. 16.22B). Then the level again rose rapidly and by May 25 the two pools had coalesced and the surface was 50 m below the crater rim. The level had risen another 10 m by May 30, and a small island of semisolid lava protruded above the surface of the lake (fig. 16.22C). This island, though changing somewhat in

size and position and occasionally disappearing, persisted during much of the subsequent lava-lake activity (figs. 16.22 D–F). Prior to the 1972–74 Mauna Ulu eruption, the development and movement of such semisolid masses in liquid lava had only been observed at Halemaumau Crater within Kilauea's summit caldera (see, for example, Jaggard, 1920, 1947).

The lake continued to rise and on June 5 reached a level only 18 m below the rim, the highest stand since the overflows of February–March 1972, before subsiding to a depth of 23 m by June 7. Although the recovery of the lava lake was rapid, the sluggish lava circulation that prevailed throughout this time suggests that the effective viscosity of the lake lava was greater than before the May 5 draining.

On May 30, when the lava reached the 40-m level in Mauna Ulu, fresh lava was observed about 34 m below the crater rim in vent C of Alae. As the lava rose at Mauna Ulu, the level correspondingly rose at Alae, confirming the general sympathetic variation in the levels of the two lakes noted earlier (fig. 16.19). On June 5, when Mauna Ulu was at its highest level, the 100-m-diameter crater of Alae was filled to within 5 m of the rim by an active, bubbling lava lake. On June 7 the level at Alae subsided to 12 m, simultaneously with the drop at Mauna Ulu, and the lake surface became entirely crusted over.

FIGURE 16.18.—Lava flows developed during 1973 and 1974 in the Mauna Ulu region. **A**, January–April, 1973. **B**, May–October, 1973. Flows and vents of the May 5 Pauahi-Hiaka eruption are shown in greater detail in the inset. No molten lava was seen at Alae after the June 9 draining of Mauna Ulu lava lake. **C**, November–December, 1973. Major overflow from Mauna Ulu during November 4–8 and flows and vents of the November 10–11 outbreak at and near Pauahi are shown in greater detail in the inset. The flow field of Pauahi eruption was formed in less than 9 hours of activity, but weak activity associated with the vent and perched lava pond within the west pit of Pauahi persisted through December 9 (see fig. 16.29). **D**, January–June 1974. All flows were produced in eleven relatively short-lived (no longer than 2 days) eruptive episodes: five in January–February, two in March, three in April, and one in May–June (see text). The only flow that advanced beyond Hōlei Pali in 1974 formed during the most voluminous eruptive episode (May 31–June 2).



FIGURE 16.20.—Aerial view looking east on May 6, 1973, showing dust-choked Mauna Ulu Crater and western half of trench (to vent B spatter cone, indicated by arrow), which collapsed during draining of lava lake on May 5 (see text). Contrast between February–March 1972 overflows (dark) and 1969–71 lava (light) is obvious in this photograph. Trail to left of crater leads to viewing platform established by the National Park Service for visitors to Hawaii Volcanoes National Park. Photograph taken by R.T. Holcomb.

JUNE 9 DRAINING OF LAVA LAKES: DEMISE OF ALAE VENT

At 2346 on June 8, strong harmonic tremor began abruptly, accompanied by rapid summit deflation and earthquakes in the eastern part of the Kōae fault system. This activity ended equally

abruptly at 0350 on June 9, by which time the summit had deflated by 8 microradians (fig. 16.4). When observers reached Mauna Ulu summit after daybreak, they discovered that the lava lake had fallen to about 112 m below the crater rim—a drop of 94 m from its stand



FIGURE 16.21.—Hiiaka Crater after the eruption of May 5, 1973, showing flat, crusted lava pond ringed by a lava-subsidence terrace (Holcomb, 1973), the top of which (about 6 m above pond surface) marks highest stand of lava lake during the eruption. Photograph taken by R.T. Holcomb, May 6, 1973.

just four days earlier (fig. 16.19). The large drop again triggered a rash of rockfalls from the unstable crater walls. The crusted lake at Alae also had dropped, and no molten lava could be seen anywhere on the rubble-covered floor of vent C, which was about 20 m below the crater rim. In effect, the events of June 8–9 were a smaller scale repetition of the May 5 draining of the lava lakes, but accompanied

this time by intrusion into the upper east rift zone and the eastern part of the Koaie fault system (Dzurisin and others, 1984, table 1) without a surface outbreak.

The lava lake at Alae never recovered from the June 9 draining, and all vent activity ceased there for the remainder of the eruption. However, the lava lake at Mauna Ulu immediately began

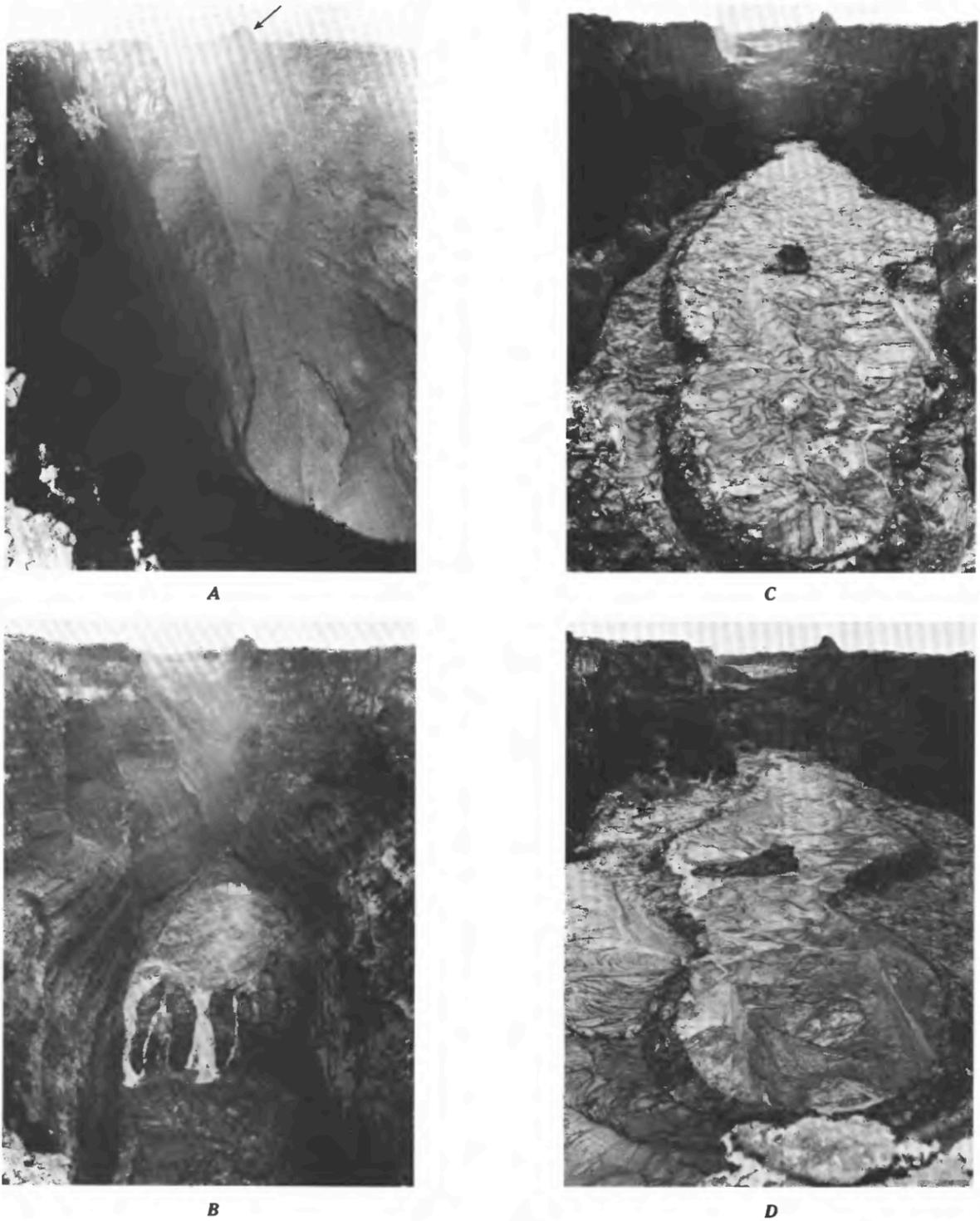


FIGURE 16.22.—Filling and draining of Mauna Ulu Crater during the period May–November 1973; all views are eastward from the western end of the crater. **A**, Summit crater one day after the lava lake drained; crater is approximately 100 m wide and 200 m deep. Vent B spatter cone (arrow) serves as reference landmark in later views. Photograph taken by R.I. Tilling, May 6, 1973. **B**, Renewed eruption has begun to fill the crater. Lava is shown here flowing over the levee of the lava lake in the eastern part of the crater and into deeper western part. Photograph

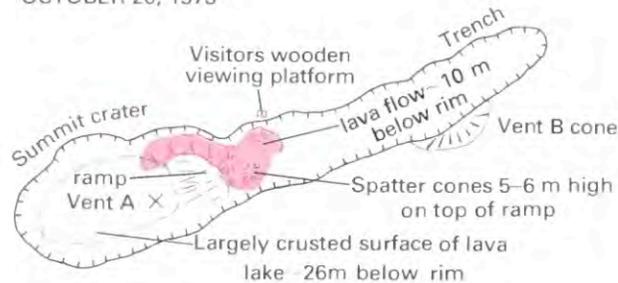
taken by R.I. Tilling, May 18, 1973. **C**, Filling of the crater resumed following draining of the lava lake on June 9. Here levees confine an active lava lake that frequently overflowed into the surrounding moat. A semisolid island in center of lake, which first formed in late May and then briefly foundered following the June 9 draining, reappeared as the lake rose. Photograph taken by R.I. Tilling, June 15, 1973. **D**, The island has grown larger, and the surface of active lake has decreased also as levees grew inward from the crater walls. Dominant flow direction of lake

**E****G****F****H**

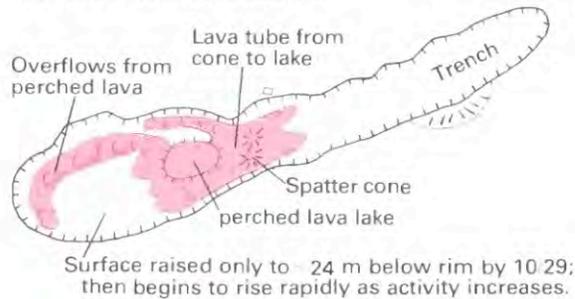
surface toward camera. Photograph taken by D.W. Peterson, June 21, 1973. **E**, As lake level rose, the surface area of active lake continued to decrease. The former island has grown to become a peninsula that nearly divides the lake into two ponds. Photograph taken by R.I. Tilling, June 24, 1973. **F**, Rise in lake surface has flooded the levees with new lava. Photograph taken by R.I. Tilling, June 28, 1973. **G**, Gradual draining of lava during July resulted in collapse of perched lake

and surrounding crust, beginning a two-month repose at Mauna Ulu (see text). Photograph taken by R.I. Tilling, July 25, 1973. **H**, Rapid filling of the crater during October and early November produced a lava lake without levees, and the lake surface reached the lowest point on Mauna Ulu's western rim. Fountain in background fed lake and built spatter cone (fig. 16.23). Photograph taken by R.I. Tilling, November 4, 1973.

A OCTOBER 20, 1973



B OCTOBER 22—NOVEMBER 3



C NOVEMBER 4-10

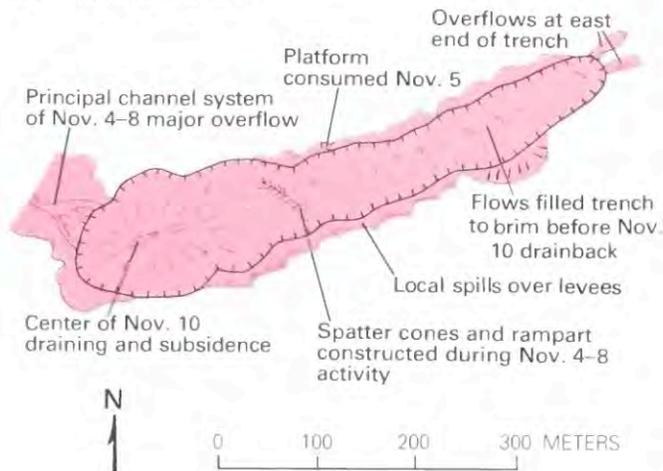


FIGURE 16.23.—Sketches showing eruptive activity at Mauna Ulu from October 20 through November 10, 1973. **A**, October 20. **B**, October 22—November 3. **C**, November 4—10. Major overflow of November 4–8 was first from Mauna Ulu since March 1972.

to rise, reaching 51 m below the rim by June 19. The island of semisolid lava that first formed in late May briefly disappeared following the June 9 draining but soon reappeared and rose together with the lake surface (fig. 16.22C–F). The lava appeared even more viscous than following the May 5 draining. As the lava lake rose gradually, the area of sluggishly circulating lava steadily decreased. Activity was confined to a central part, perched behind natural levees and separated from the crater walls by a moat 3–20 m wide and 3–4 m deep. Periodic overflows into the moat raised the



FIGURE 16.24.—Overflow of Mauna Ulu Crater in November 1973. Lake level stabilized when overflows began on November 4, and levees again developed (compare fig. 16.22H), confining a perched lake at an elevation higher than the initial crater rim. Site from which photographs of figure 16.22 were taken is in foreground where stream on right overflows levee. Photograph taken by R.I. Tilling, November 7, 1973.

confining natural levees and the perched lake, as well as the level of the moat.

Sluggish lava-lake activity continued at Mauna Ulu for the next several months; lava level rose while the area of active surface lava shrank (fig. 16.22D, E). By mid-July, active lava was restricted to two circular areas 10–15 m in diameter, one of which included the active vent. Gas-piston cycles and associated small overflows occurred at intervals of 5–20 minutes. The declining activity, coupled with concurrent inflation at Kilauea summit, indicated that the connection between the summit reservoir and Mauna Ulu was not fully reestablished. By July 24 the lava lake had become stagnant, with the crusted surface at the vent about 15 m below the rim. No molten lava was visible, and the crusted surface began to subside (fig. 16.22G), beginning the longest repose in visible activity since the eruption began in February 1972. This repose period, except for the brief reappearance of lava in early September, lasted nearly two months. Subsidence was rapid for one week, averaging 5–6 m/d, and then slackened; it continued throughout August, and the lake crust fell to about 81 m below the rim. Harmonic tremor, varying from very low to moderate in intensity, persisted throughout the repose.

RESUMPTION OF LAVA-LAKE ACTIVITY AT MAUNA ULU: A MAJOR OVERFLOW

No molten lava was visible at Mauna Ulu from July 24 to September 3. Harmonic tremor markedly increased at 0435 on September 4, and observations later that morning revealed a lava lake in Mauna Ulu Crater with a few fountains up to 5 m high. The lake surface was 62 m below the crater rim, up from its 81-m level in mid-August. About 1400, tremor abruptly decreased and the low fountaining ceased. The lake persisted through September 6, by



FIGURE 16.25.—Telephoto view (300-mm lens) from Puu Huluhulu showing slabs of crust and molten material of Mauna Ulu lava lake being lifted in vortex of thermally generated whirlwind. Photograph was taken by R.I. Tilling on January 30, 1974, but similar and more vigorous activity occurred on November 8, 1973.

which time a solid, slowly subsiding crust had again developed across its entire surface.

Lava-lake activity resumed sometime between noon of September 25 and the afternoon of September 26 with the reopening of a vent in the eastern part of Mauna Ulu Crater. Lava flooded the crater floor, and within a few days the lake level rose from 68 m to 61 m below the rim; the familiar circulation pattern with periodic crustal overturns was reestablished. During the next three weeks, lava-lake activity alternated between active circulation and stagnation with the formation of crust, and the irregular surface of the lake gradually rose to 15 m below the rim in the eastern part of the crater and to 32 m in the western part.

Sharply increased summit inflation continued during October (fig. 16.4) and by October 20 the activity at Mauna Ulu was the most vigorous for many months; lava fountains from parts of the lake surface commonly attained heights of 15 m. The principal vents, whose lava columns periodically exhibited gas-piston behavior, were localized between former vents A and B, near the position of the septum that formerly separated the crater and the trench (figs.

16.11, 16.23A). Lava mostly flowed westward from these vents down a sloping ramp, at the base of which a perched lake developed (fig. 23B). Overflows from this perched lake, together with flows fed directly by the vents, flooded much of Mauna Ulu's crater floor during the next few weeks. The area of active surface greatly increased, and the lava lake continued to rise.

Mauna Ulu's activity substantially increased during the morning of November 3, when the lava surface was about 25 m below the lowest point of the western crater rim. Voluminous flows from three closely clustered vents (fig. 16.23B) raised the lava surface to 12 m below the rim by midday. The next morning fountaining was 40 m high, and modest deflation began at Kilauea summit. At 0900 on November 4, the lava level was only 3 m below the low point of the western rim, and it continued to rise at a rate of about 0.5 m/h. Soon the perched lava lake was inundated by the rising lava, and the two-level aspect (western crater and eastern trench) that had characterized the configuration of Mauna Ulu throughout much of the 1972–73 activity was lost. Mauna Ulu now resembled the brimfull lake that existed at times during February–March 1972.

By 1445 on November 4, lava had risen to the lowest point of the western rim (fig. 16.22H), and slow outflow commenced at 1600, marking the first overflow from the crater since March 18, 1972. This overflow, however, advanced only about 35 m, because construction of confining levees nearly kept pace with the now more slowly rising Mauna Ulu lake, whose surface area was now almost 55,000 m² (fig. 16.23C). Throughout the night of November 4–5, the lava lake continued to rise, and levees, typically 1–2 m high, were built along low areas of the old crater rim.

A major overflow from the western end of the crater began early on November 5, as a lava stream several meters wide flowed across a levee 8–10 m higher than the original low point on the rim (fig. 16.24). Subsequently, two or three lava streams spilled over the levees on the northwestern rim, converged into a single stream within about 30 m of the rim, and turned southward to pass east of the buried Aloi Crater (fig. 16.18C). An irregular overflow apron formed along most of the northwest crater rim, and other smaller short-lived spills occurred elsewhere, including two at the eastern end. However, voluminous outflow was confined to the south-trending stream spilling out of the western end of the crater; this flow advanced about 2.6 km before stopping in the early morning of November 8 (fig. 16.18C).

A wooden viewing platform at Mauna Ulu (fig. 16.23) was kept open to the public by the National Park Service through the night of November 4, allowing hundreds of park visitors to view the filling lava lake and 30 to 40-m-high fountains. Heat from the rising lava and continued high fountaining forced the viewing platform to be abandoned late on the night of November 4. The platform was consumed early the next morning as lava overflowed the rim.

On November 8, observers witnessed a thermally generated whirlwind that played erratically across the Mauna Ulu lava-lake surface for about 10 minutes. The whirlwind lifted crustal slabs 2–3 meters in diameter to heights of 20–30 m, and smaller pieces went much higher (fig. 16.25). Molten lava exposed beneath the vortex also was lifted high into the air and deposited, in part, as blobs of spatter and Pele's hair beyond the crater rim.

PAUAHI ERUPTION OF NOVEMBER 10–DECEMBER 9, 1973

VIGOROUS INITIAL ACTIVITY ASSOCIATED WITH FISSURE VENTS, NOVEMBER 10–11

About 1730 on November 10, seismic stations in the vicinity of Mauna Ulu and Pauahi Crater began to record a moderate to high level of harmonic tremor accompanied by a flurry of earthquakes. At the same time, a National Park Service ranger at Puu Huluhulu radioed a report to HVO that he felt ground shaking and could see greatly increased turbulence and degassing of the still brimful lava lake at Mauna Ulu. A drainback of Mauna Ulu lava lake was underway, similar to those that had occurred on May 5 and June 9. Summit deflation commenced about 15 minutes later and, combined with intensified seismic activity localized in the Pauahi-Mauna Ulu area, suggested the possibility of another eruptive outbreak.

HVO observers arrived at Mauna Ulu about 1830, in time to watch drainback; the surface of the lake in the western part of the crater had already subsided to a level of about 40 m below the rim



FIGURE 16.26.—Draining of lava from Mauna Ulu on November 10, 1973, left a rubble-covered crater floor about 40 m deep. During draining, the levees on the rim, left unsupported, collapsed. Photograph taken by D.W. Peterson, November 12, 1973.

(fig. 16.26). By 2100 subsidence (fig. 16.23C) had largely ceased, and partially cooled lava continued to spall from the crater walls amid showers of glowing debris. Meanwhile, rockfalls were reported in Pauahi Crater. At 2135 an earthquake was felt in the Puu Huluhulu area and triggered rockfalls at Pauahi.

At 2147, gassy lava broke out in Pauahi Crater about midway up the north wall of the east pit and began to pool at the bottom of the crater. Echelon fissures opened eastward up the wall to the crater rim. A few minutes later, a fissure trending N. 70° E., aligned with the northwest corner of the western pit, cut the Chain of Craters Road west of Pauahi (fig. 16.18C); fountaining of lava from this fissure was observed at 2200, and within minutes the road was blocked by lava. At 2215, a vent opened in the north wall of the west pit, approximately midway between the two fissures of the May 5 eruption, and lava began to pool in the west pit as well as in the east pit.

At 2245, several additional fissures opened and extended about 1.5 km east-northeast toward Puu Huluhulu; pahoehoe flows fed by fountains from these fissures ultimately covered about 1.1 km² of land (fig. 16.18C). Fountaining as high as 70 m continued within and outside Pauahi Crater throughout the night of November 10–11 and fed lava pools in both the east and west pits (fig. 16.27).

Shortly after midnight, lava filled the east pit to the level of the septum that separated it from the west pit and began to cascade westward and circulate clockwise (fig. 16.28). At 0135 on November 11, new lava outbreaks occurred high on the northwest wall of the west pit. Lava from these sources poured into the pit, but the rate of drainback, presumably into the May 5 fissures, was greater; the lava level in the west pit consequently began to lower. At 0150, the fissure in the east pit stopped erupting, and by 0200 flow



FIGURE 16.27.—View from the south rim of Pauahi Crater at 0015 on November 11, 1973, showing fountains 20–30 m high along fissure that cuts the north wall of the east pit of Pauahi and supplies lava to the rising lake, which at this point is still below the septum separating east and west pits. Lava fountains from other vents in the west pit (left center, near edge) feed another lava lake in the west pit. Five minutes after this photograph was taken, lava in the eastern lake had risen to the lowest point along the septum and began to spill into the west pit (see fig. 16.28). Photograph taken by R.I. Tilling.

across the septum between the pits had stopped. Soon lava was draining back into fissures in both pits, though it continued to cascade at a decreasing rate from the northwest wall of the west pit until 0545. At 0440, fountains as high as 20 m were active near the east end of the fissure system near Puu Huluhulu, but all activity along these fissures stopped by 0600.

PERSISTENT, FEEBLE ACTIVITY AT A LOCALIZED VENT WITHIN THE WEST PIT, NOVEMBER 11–DECEMBER 9

On November 12, the level of the largely crusted lava pool in the east pit of Pauahi was about 100 m below the crater rim and about 21 m below the high lava mark established before drainback. The northwest vent on the floor of the west pit of Pauahi continued to emit lava after all other activity had ceased. Lava fountains 15–35 m high still played at the vent through November 12, but four days later only a slow upwelling of lava could be seen. By

November 19, a perched lava lake about 30 m in diameter had developed at the base of a spatter cone 5–10 m high situated near the west end of the northwest fissure vent (fig. 16.3). Lava level in the west pit slowly rose as the result of periodic overflows from the perched lava lake, and by November 21 it reached within 5 m of the lowest point on the septum between the two pits. On November 28, lava from the west pit trickled over the septum and descended into the east pit (fig. 16.29).

On about December 3, the activity in the west pit declined appreciably, and overflows from the perched lava lake ended. Vent activity virtually stopped, and during the next several days circulation became progressively more sluggish. By December 8, no circulation could be seen in the lake, and the crusted surface had subsided 7 m below the levees. Further subsidence of the lava crust occurred the next day, and fuming from the vent largely ceased. Cessation of tremor about noon on December 9 marked the end of the November–December Pauahi eruption.



FIGURE 16.28.—View from south rim of Pauahi Crater at 0050 on November 11, 1973, showing lava from lake in east pit cascading over septum into lava lake in west pit. Two smaller vents on western wall of west pit also feed lava into the lake, which here is about 150 m across and shows clockwise circulation. Photograph taken by R.I. Tilling.

DECEMBER 10, 1973–JULY 22, 1974

REAPPEARANCE OF THE LAVA LAKE AT MAUNA ULU

No eruption occurred at Kilauea between December 9 and 12. On December 10 and 11, a portable seismometer in the Pauahi-Mauna Ulu area detected no harmonic tremor above normal background noise. Then, on December 12, the permanent seismometer closest to the Pauahi-Mauna Ulu area began sensing intermittent harmonic tremor. This tremor increased in intensity and became sustained by the next day, when lava quietly reappeared at Mauna Ulu and quickly rose to 30 m below the crater rim. Thus visible activity at Mauna Ulu resumed on December 13 (not December 12 as stated by Peterson and others, 1976). Vent activity was localized a short distance west of the vigorous vents that fed the November 4–8 overflows (fig. 16.23).

Over the next few days the lake level rose to 18–20 m below the crater rim. Initially the entire surface of the lake was active, but by December 20 activity was reduced to sporadic oozing of lava,

punctuated by brief degassing bursts, from a spatter cone feeding a small perched lava lake. This low-level activity continued into mid-January 1974, and the floor of Mauna Ulu crater became irregular because of differential subsidence.

DEPARTURE FROM 1972–73 BEHAVIOR: RENEWED GROWTH OF MAUNA ULU SHIELD

Rather than the sustained lava-lake and associated eruptive behavior that generally prevailed during 1972–73, Mauna Ulu activity in 1974 was characterized by short eruptions (no more than two days) in which lava fountains 40–80 m high fed short-lived but voluminous overflows. Episodes of fountaining and overflow were separated by 3-day to 5-week periods of only feeble activity.

The voluminous overflows, augmented by spatter-cone growth during the quiet periods, resulted in renewed growth of the Mauna Ulu shield. Most overflows traveled only short distances, but several extended 5 km or more from the vent and one advanced about 9 km.



FIGURE 16.29.—View from Pauahi's west pit on December 5, 1973, toward Puu Huluhulu (arrow) and Mauna Ulu shield to right of it. Continued eruption in Pauahi's west pit through December 9 built a low lava shield, the small summit crater of which contains a perched pond of molten lava (lower left). Small amounts of lava from this perched pond have flowed across septum into the east pit. Also seen are the high mark of lava lake in east pit before drainback, and the fissure that fed the east-pit lake. Photograph taken by R.T. Holcomb.

The first of the 1974 eruptive episodes began on January 24 and was preceded by several days of heightened harmonic tremor, increased shallow summit earthquakes, and summit inflation (fig. 16.30). During the ensuing 36-hour burst of activity, a 60-m-high

lava fountain (figs. 16.31, 16.32) fed by vent E_1 (fig. 16.3) filled Mauna Ulu to the brim, built a 15-m-high spatter cone atop the shield, and fed numerous overflows, one of which advanced more than 1 km from the vent. This episode was accompanied at Kilauea

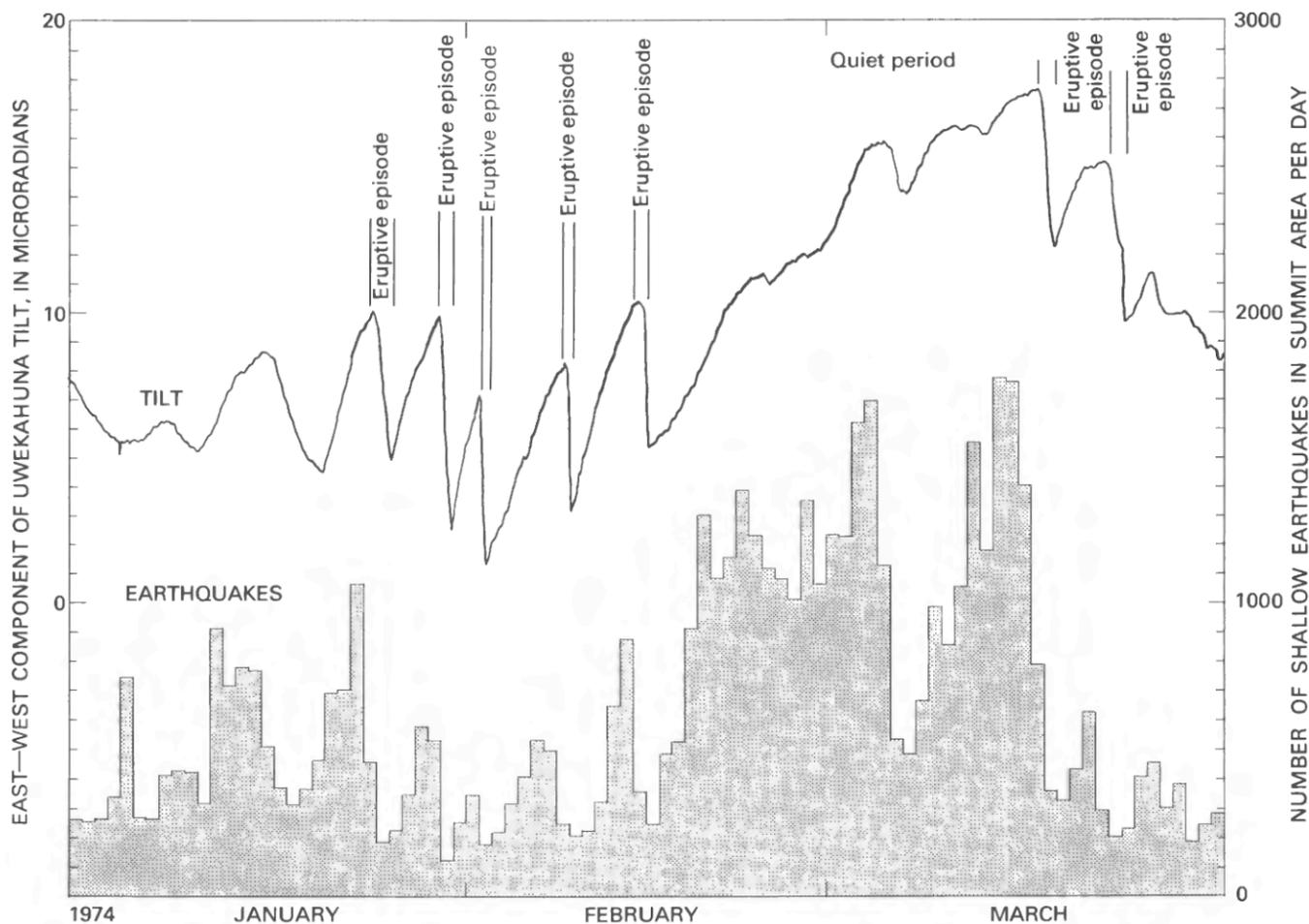


FIGURE 16.30.—Correlation of the eruptive episodes during January–March 1974, characterized by vigorous fountaining and voluminous overflows, with variations in Uwekahuna tilt and daily number of shallow (depth less than 5 km) summit earthquakes (see table 16.3 and text).

summit by abrupt but modest deflation and a decrease in seismicity. Once the episode ended, inflation began again and seismicity increased immediately, culminating in another eruptive episode on January 29. During the quiet period between the two eruptive episodes, low-level activity persisted at Mauna Ulu. The crusted lava-lake surface sagged to about 3 m below the rim, and bursts of spatter from vigorous gas-piston degassing reached heights of 20 m above the vent.

The time, duration, amount of inflation or deflation, tilt variations, and summit seismicity for five exceptionally well documented eruptive episodes during January–February 1974 are summarized in table 16.3 and figure 16.30. Lava spilled over all flanks of the Mauna Ulu shield during each episode, but the most voluminous overflows were directed northward. Much lava ponded in the saddle between Mauna Ulu and Puu Huluhulu, and a well-defined levee grew around the pond during the January 24–26 episode (fig. 16.32).

A month-long quiet period followed these January–February

eruptive episodes; during the first part of this (February 15–March 5), vent activity was restricted entirely to the vent E_1 spatter cone at Mauna Ulu summit. On March 5 a new vent (designated F) opened about 140 m east-northeast of vent E_1 (fig. 16.3), accompanied by summit deflation of about 2 microradians. Both vents E_1 and F operated until March 17, and lava output from each varied within the range 2–5 m³/s. Both vents exhibited gas-piston activity that generated spatter, enlarged their cones, and fed numerous short-lived flows. Their activities, however, could not be closely correlated in time; any connection between them was apparently complex despite their close proximity.

Two eruptive episodes occurred in March (table 16.3 and fig. 16.30). The first began in the early evening of March 17, lasted about 30 hours, and resulted in a summit deflation of about 5.5 microradians. In contrast to the January–February episodes, this one produced a maximum fountain height of only 15 m, even though lava output was equally great. South-directed overflows advanced 3 km (fig. 16.18D). The eruptive episode of March 23–24 (fig.



FIGURE 16.31.—Lava fountain and thermal plume produced during January 24–26 eruptive episode of Mauna Ulu viewed from Hawaiian Volcano Observatory more than 12 km away. Photograph taken by R.T. Holcomb, January 24, 1974.

16.30) produced copious overflows mainly directed southward and built the vent E₁ spatter cone even higher (fig. 16.33). This episode also included strong rockfall activity at Pauahi Crater. These frequent and large rockfalls, combined with high-amplitude tremor

and rapid deflation, were reminiscent of the precursors to the May 1973 and November 1973 eruptions in the Pauahi area. This time, however, the movement of magma into the Pauahi area remained entirely underground and fed a brief intrusion into Kilauea's east rift



FIGURE 16.32.—View from the summit of Puu Huluhulu on January 25, 1974, during first of a series of brief eruptive episodes that were interspersed with longer quiet periods of only feeble visible activity. The lava fountain was about 60 m high. The lava lake surrounding the vent overflowed the confining levee and fed a copious flow that ponded in the saddle between Mauna Ulu and Puu Huluhulu (middle foreground). Ponded flow developed levees and evolved into a perched lava pond. Topographic feature to the left of lava fountain is the spatter cone of vent B. Photograph taken by R. T. Holcomb.

zone (Dzurisin and others, 1984, table 1), which had no observable effect on activity at Mauna Ulu. The sharp deflation ceased at 0700 on March 24, signaling the end of the episode. However, even though vigorous vent activity and voluminous surface overflows had largely ended by the morning of March 24, lava primarily from vent F continued to feed a south-moving flow through a channel-tube system. This flow cascaded over Poliokeawe Pali on April 3 and stopped several hundred meters farther two days later. During March, the southeastern flank of Mauna Ulu became underlain by a complex maze of anastomosing lava tubes, and there were abundant opportunities to observe lava-tube processes.

During the first half of April, relatively quiet activity prevailed at Mauna Ulu. The spatter cone at vent E_1 (fig. 16.33) collapsed on April 2, and continuing collapse resulted in a small (20 m by 15 m) active lava lake, which commonly exhibited gas-piston behavior. This activity apparently was confined to the area of the Mauna Ulu vents, as it was not reflected by Kilauea summit deflation or inflation. However, three larger eruptive episodes in mid-April (April 13–14, 16–17, and 18–19) were accompanied by summit deflations of 5, 1.5, and 2 microradians, respectively. These episodes produced overflows, which moved down all sides of Mauna Ulu but did not enter the eastern part of the trench. The April 13–14 overflows continued virtually nonstop for 16 hours, and a dome fountain 5–10 m high played for many hours from an opening between vents E_1 and F (an excellent example of a dome fountain is shown by Swanson and others, 1979, fig. 28).

No well-defined eruptive episodes occurred during late April, but activity during this time was nonetheless fairly strong. All vent activity was confined to E_1 and a 2-m-wide new opening (designated E_2) 30 m farther east (fig. 16.3); vent F became inactive.

TABLE 16.3.—Date and time of beginning and end of eruptive and associated premonitory quiet periods, and duration and amplitude of Kilauea summit deflation and inflation as measured by Uwekahuna mercury-pool tiltmeter January 20 to February 15, 1974

[All times given are in Hawaii standard time]

Quiet periods					Eruptive episodes							
Inflation				Activity				Deflation				
Beginning	End	Duration (hours)	Amount (microradians)	No.	Beginning intermittent	Beginning continuous	End	Beginning	End	Duration (hours)	Amount (microradians)	
1/20, 2200	1/24, 1900	93	5.6	I	1/24, 0800	1/24, 1400	1/26, 0500	1/24, 1900	1/26, 0530	35	5.1	
1/26, 0530	1/29, 1400	90	5.0	II	1/29, 1800	1/29, 2400	1/30, 2400	1/29, 2400	1/30, 2400	24	7.3	
1/30, 2400	2/2, 0400	52	4.5	III	2/1, 1100	Not observed, but continuous by 2/2, 0545	2/2, 1607	2/2, 0400	2/2, 1600	12	5.8	
2/2, 1600	2/8, 2000	148	6.9	IV	2/8, 1900	2/9, 0100	2/9, 0600	2/8, 2000	2/9, 0700	11	5.0	
2/9, 0700	2/14, 2000	133	6.8	V	2/14, 0300	Never continuous, but intermittent fountaining became strongest on 2/14, 2200	2/15, 0830	2/14, 2000	2/15, 0900	13	4.9	



FIGURE 16.33.—View of Mauna Ulu shield from the west on March 27, 1974, showing steep-sided spatter cone of vent E_1 , which collapsed on April 2. Flank of Puu Huluhulu is seen center left; Alae shield is behind and to right of Mauna Ulu. Photograph taken by R.I. Tilling.

Many brief but copious overflows from E_1 and E_2 added to the shield, burying vent F in the process. By the end of April, the height of the Mauna Ulu shield had increased about 15 m, to 117 m above the pre-1969 base, and its width increased proportionately. During the period of rapid shield growth, a sustained flow fed by vent E_2 formed a tube system that extended southward. Lava spilled over Poliokeawe Pali on April 30, and on May 7 the flow front reached the lip of Holei Pali before stopping the next day.

Gas-piston processes dominated the behavior of the overflows: a strong overflow would issue from vent E_1 or E_2 for a period of 5 minutes to more than one hour; then a brief but spectacular burst of degassing would abruptly terminate the overflow, and the lava column would drop 10–20 m. The lava column would then rise slowly over a period of 15 minutes to several hours. When the lava reached the rim of the vent, a new overflow would begin. The gas-piston cycles of vents E_1 and E_2 apparently operated independently.

During May, the eruptive activity at Mauna Ulu progressively declined: overflows stopped, lava in channels and tubes solidified, and the lava column dropped several meters. Piecemeal wall collapse enlarged vents E_1 and E_2 ; by May 12 the two openings coalesced to form an elongate crater, which measured approximately 40 m by 90 m on May 20. The lava lake within the western part of this crater was about 15–20 m below the rim. Lava circulated from west to east and then plunged over a septum into a pit at least 50 m

deep in the eastern part of the crater.

During late May, lava-lake circulation became increasingly sluggish until the late evening of May 29, when summit deflation began and harmonic tremor increased. By the next morning the summit crater at Mauna Ulu had refilled, and low fountains were active along much of the lake margin. Lava was spilling over at two points on the southeast rim, and a flow already had advanced nearly 2 km southward. As the day progressed, the activity increased, as did the rate of summit deflation. During the night of May 30, gassy fountains at the lava lake threw spatter about 20 m high, and voluminous overflows began to cascade down all sides of the Mauna Ulu shield.

Fountains and overflows continued until June 1, when weather conditions permitted excellent aerial photography during peak activity (fig. 16.34). Most of the lava traveled southward, and the main flow poured over Poliokeawe Pali and Holei Pali (fig. 16.35). At about midnight the summit deflation stopped and inflation resumed; overflows ended about 0200 on June 2.

The May 29–June 2 eruptive episode was the largest of 1974 and was accompanied by about 10 microradians of summit deflation. It added another 4 m of lava to the Mauna Ulu shield to raise its summit to the maximum height reached during the 1972–74 eruption, 121 m above the pre-1969 ground surface (Peterson and others, 1976), and sent lava over Holei Pali for the first time in 1974

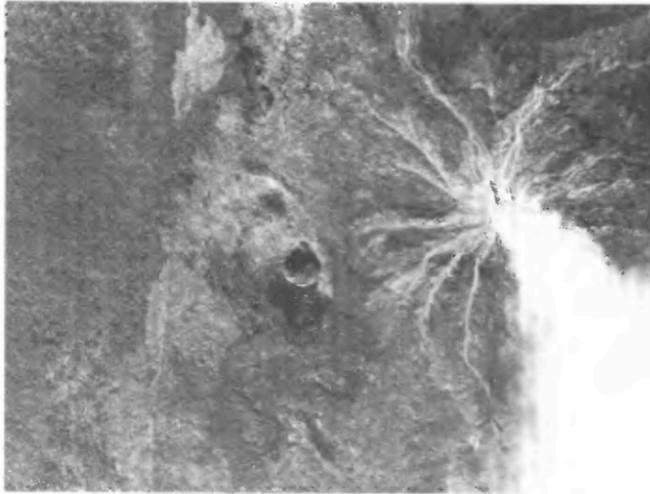


FIGURE 16.34.—Vertical aerial photograph (north is to left) taken June 1, 1974, showing active radial overflows from Mauna Ulu lava lake during the May–June eruptive episode. Also shown (center) are summit crater of Puu Huluhulu and lava pond in saddle between Mauna Ulu and Puu Huluhulu, which first formed in January 1974 (fig. 16.32) and was reactivated during several later eruptive episodes. Photograph taken by R.M. Towill Corporation.

(fig. 16.18D). This episode, as it turned out, also knelled the end of the 1972–74 Mauna Ulu eruption.

CESSATION OF THE 1972–74 MAUNA ULU ERUPTION

Soon after the May–June eruptive episode, Mauna Ulu's summit lake subsided, and lava circulated sluggishly 20–32 m below

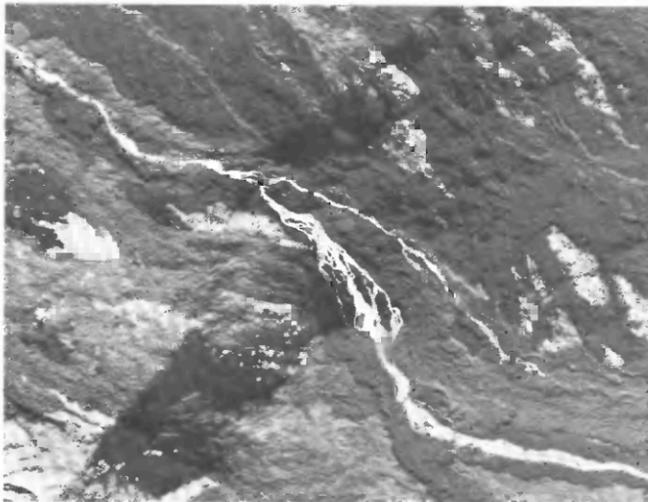


FIGURE 16.35.—Lava stream of May–June 1974 eruptive episode becomes braided during cascade over Pali (about 165 m high). Northwest is to left; lava flows from upper left to lower right. Vertical aerial photograph taken by R.M. Towill Corporation on June 1, 1974.

the crater rim. In response to the lower lake level, numerous rockfalls from steep and overhanging walls enlarged the crater at its rim from 40 m by 90 m on May 20 to 107 m by 147 m by June 20. Lava activity declined through June and much of July; the lava lake changed little in configuration and was largely obscured by fumes. Circulation became increasingly sluggish, and the crusted and rubbly lake surface continued to subside gradually, approaching about 40 m below the rim by mid-July.

As Mauna Ulu activity waned, the summit region of Kilauea remained highly inflated, the tilt at Uwekahuna fluctuating within a range of 4 microradians. A summit eruption on July 19–22 (Peterson and others, 1976) caused no observable changes in the already feeble activity at Mauna Ulu. Following the summit eruption, however, the small, subsiding lava pool disappeared beneath the rubble-covered crater bottom. After July 22, no molten lava was visible anywhere on Kilauea, and harmonic tremor in the Mauna Ulu area ceased.

Months after July 22, Mauna Ulu Crater was obscured by extremely heavy emission of fumes. Visible observations of the crater were impossible, but sounds of rockfalls were commonly heard, indicating continued piecemeal collapse of the walls and possible subsidence of its rubbly floor. During November 1974, attempts were made to determine the depth of the crater by hurling percussion-impact, noise-emitting probes into the crater and measuring the time elapsed between release and impact. These measurements yielded six depth estimates ranging from 56 m below the rim in the shallow northwestern part of the crater to 133 m in the considerably deeper eastern part. Large uncertainties are attached to these measurements, but they nevertheless suggest that the deepest parts of Mauna Ulu Crater in November 1974 (averaging perhaps 130 m) were considerably shallower than the maximum depth of 200 m measured following the complete drainage of the lake in May 1973. The decrease in depth presumably reflected solidification of residual lava and partial filling of the crater by rockfall debris. The depth of the Mauna Ulu crater at the end of the 1969–71 eruption was 145 m (Swanson and others, 1979, fig. 7).

GROUND DEFORMATION AND SEISMICITY

The general relations between eruption, intrusion, ground deformation, and seismicity at Kilauea Volcano have been well documented from systematic studies by scientists of the Hawaiian Volcano Observatory since its founding in 1912. A comprehensive model that integrates the data on subsurface structure, magma storage and transport, and eruptive processes was first described in the early 1960's (see Eaton and Murata, 1960; Eaton, 1962); many subsequent studies have refined and increasingly quantified this model (for example, Fiske and Kinoshita, 1969; Swanson, 1972; Kinoshita and others, 1974; Koyanagi and others, 1976a, b; Swanson and others, 1976b; Ryan and others, 1981, 1983; Aki and Koyanagi, 1981; Dvorak and others, 1983; Dzurisin and others, 1984). In the discussion to follow, we assume that the reader is familiar with the well-documented behavior typically observed for Kilauea rift activity: between eruptions, summit inflation occurs as

TABLE 16.4.—Dates of reoccupations of the ground-deformation networks of Kilauea summit pertinent to 1972-74 Mauna Ulu eruption

[Measurements obtained during these reoccupations provide the data for figures 16.38-16.43. Some reoccupation periods were prolonged because of inclement weather. Reoccupations of two or more types of networks during a closely bracketed time period are indicated by an asterisk (*). Data are stored on magnetic tapes at the Hawaiian Volcano Observatory]

Level	Tilt	Trilateration
Inflation period before eruption		
* 9/29-30/71	10/1-7/71 10/20-22/71 11/1-2/71 11/11-12/71 11/19-24/71	10/4-7/71
* 11/30-12/1/71	11/29-12/1/71 12/13-14/71	
*	12/27-30/71 1/10-11/72	12/20-23/71
* 1/17-20/72	1/26-28/72	1/26-28/72
During the 1972-74 Mauna Ulu eruption		
	2/7-9/72 2/22-25/72 3/7-9/72 4/3-7/72 4/17-18/72	
* 6/12-13/72	6/5-8/72	6/5-14/72
	7/17-20/72 8/21-29/72 9/27-29/72	
* 12/4-13/72	12/4-11/72 3/13-26/73	12/5-29/72
* 5/10-11-73	5/7-14/73	5/7-10/73
	5/21-6/1/73 6/26-28/73	5/29-6/1/73 (partial)
* 9/19-20/73	9/20-10/3/73	9/24-27/73
* 11/13-14/73	11/11-14/73 12/10-20/73 1/14-29/74 3/12-25/74	11/15-21/73
* 4/4-5/74	5/22-30/74	4/1-3/74
* 7/26-31/74	7/22-26/74	7/22-25/74

magma is supplied from the upper mantle to a reservoir 2-4 km deep; during flank eruptions, summit deflation occurs as magma moves into a rift zone.

Ground-deformation and seismic data for the 1972-74 Mauna Ulu eruption are summarized in table 16.4 and figures 16.4 and 16.36-16.46. In general, crustal deformation and seismicity during the 1972-74 Mauna Ulu eruption were typical for Kilauea

east-rift eruptions. Periods of weak or no vent activity generally correlated with net inflation and increased number of shallow earthquakes in the summit region, whereas vigorous eruptive activity correlated with deflation and reduced summit seismicity.

VARIATION IN SUMMIT TILT MEASURED AT UWEKAHUNA

Tilt at Kilauea summit, especially as measured daily by the 3-m-base, water-tube tiltmeters at Uwekahuna vault (fig. 16.1) to a precision of about 1 μ rad (1 microradian), provides a sensitive and continuous record of the inflation-deflation state of the shallow magma reservoir. These daily measurements are augmented by continuously recording mercury-pool capacitance tiltmeters at the same site; data from these instruments correlate well with the daily water-tube measurements. In addition to these tilt-measurement instruments, Kilauea caldera is laced by the summit electronic-distance-measurement (EDM) monitor (fig. 16.36). The five EDM lines of the summit monitor are measured on a fairly frequent basis between periodic occupations of the entire summit trilateration network of 47 lines (Kinoshita and others, 1974, fig. 9). In general, summit inflation is indicated by extensions on these EDM lines and deflation by contractions.

Summit tilt measured at Uwekahuna (figs. 16.4, 16.37) generally correlates systematically with evidence of inflation and deflation from leveling, trilateration, and gravimetric data (Dzurisin and others, 1980, 1984; Dvorak and others, 1983). Because the locus of maximum uplift most commonly lies southeast of the Uwekahuna site, northward down tilt on the north-south axis or westward-down tilt on the east-west axis almost always indicates inflation; similarly, opposite senses of relative tilt of the two components generally indicate deflation. As will be seen, however, exceptions to this general relationship sometimes occur.

For the 1972-74 Mauna Ulu eruption, the east-west component of the Uwekahuna tilt shows the variations more clearly than does the north-south component; for convenience we discuss the summit tilt in terms of change in microradians (+, apparent inflation; -, apparent deflation) only in this east-west component (fig. 16.4). Whether the apparent inflation or deflation registered by the Uwekahuna tilt corresponds to actual inflation or deflation of the entire summit region can be evaluated by comparison of level, ground tilt, and trilateration surveys. With the exception of those related to non-elastic rotation of tectonic blocks, large changes in Uwekahuna tilt indicate true summit inflation or deflation, but small changes may not be amenable to simple interpretation. Like Dzurisin and others (1984, p. 191), we assume that net summit inflation reflects increased summit storage and cumulative summit deflation reflects increased rift-zone storage, which can be manifested as eruptive activity, intrusive activity, or both.

The variation curve for Uwekahuna tilt during 1972-74 shows two plateau-like segments (fig. 16.37), each of which is characterized by variations in tilt of less than 25 μ rad during periods of at least 8 months. The first of these segments encompasses the period from the start of the eruption through April 1973, and the second period from December 1973 to the end of the eruption.

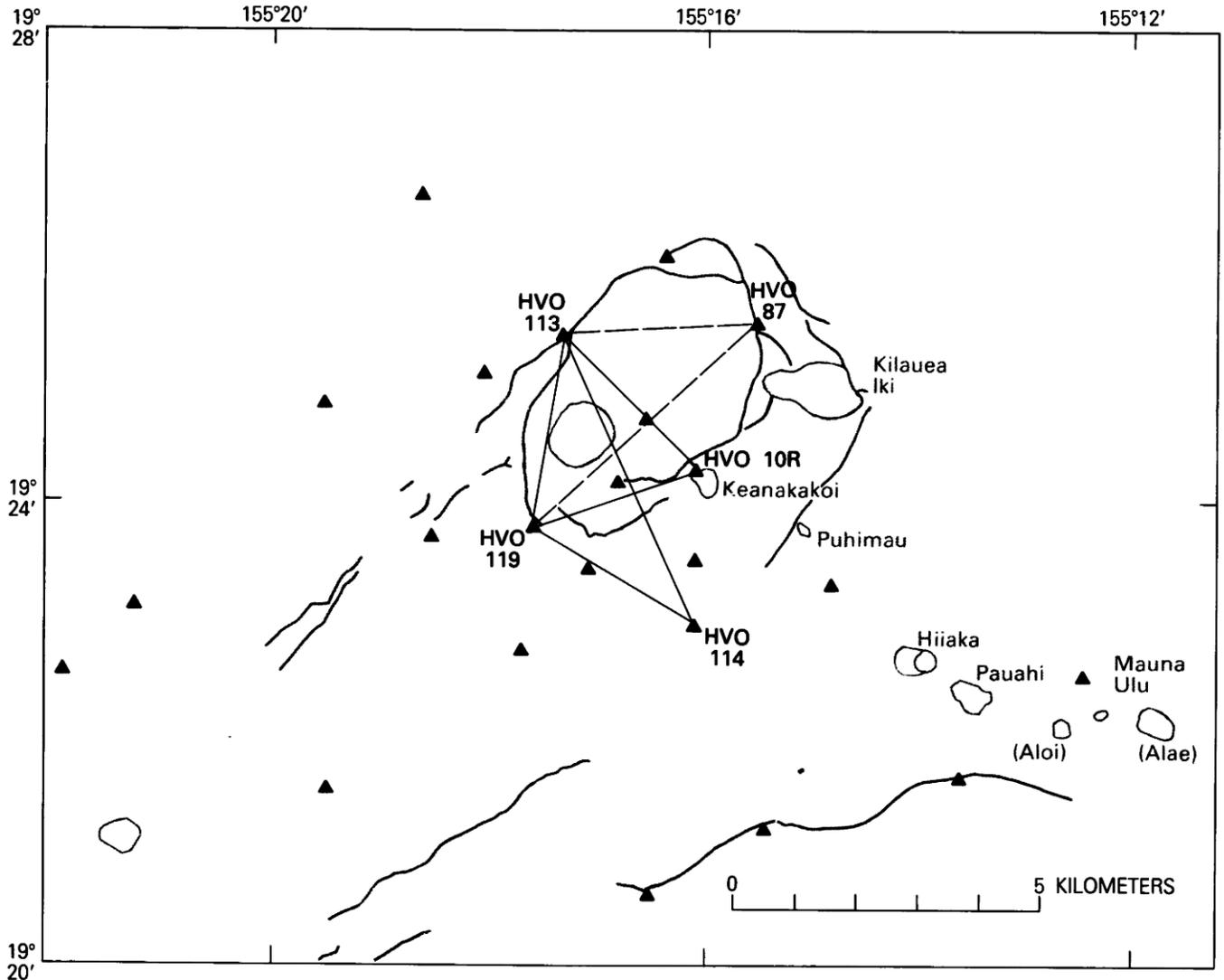


FIGURE 16.36.—Map showing location of the electronic-distance-measurement (EDM) bench marks (triangles) of the Kilauea summit trilateration network. The straight lines shown make up the so-called summit EDM monitor: solid lines are remeasured more frequently than dashed lines (see fig. 16.39). Distances between all other bench marks in the summit network (Kinoshita and others, 1974, fig. 9) are remeasured periodically depending on eruptive activity. Craters, the summit caldera, and faults in the rift zones shown for reference. HVO, Hawaiian Volcano Observatory.

These two prolonged periods of little net change in summit tilt suggest that a quasi-steady-state regime prevailed in the summit magma reservoir: supply of magma to the reservoir was counterbalanced by migration of magma into the east rift zone. This delicate balance was upset in early May 1973, possibly as a consequence of the Honouliuli earthquake (April 26, 1973), after which magma entered the reservoir faster than it was transferred to the rift zone, and net summit inflation occurred for the next seven months. December 1973 marked the reestablishment of open communication between the summit reservoir and the Pauahi-Mauna Ulu area, and the second period of quasi-steady state magma transfer began.

The amount of summit deflation during the May 1973 and November 1973 eruptions, about $20 \mu\text{rad}$ for each (fig. 16.37), is

similar to the range of tilt oscillations during the various stages of the 1972–74 Mauna Ulu eruption (variation within the shaded bands in fig. 16.37). We suggest that the gross equivalence of the ranges of tilt changes reflects transfer of magma from the summit reservoir to the rift zone in increments just sufficient to maintain a quasi-steady-state condition that prevailed during most of the eruptive period.

A more detailed plot of the Uwekahuna tilt record for the 1972–74 Mauna Ulu eruption (fig. 16.4), adjusted for the $18\text{-}\mu\text{rad}$ tectonic offset caused by the April 1973 Honouliuli earthquake, reveals interesting second-order variations. The reappearance of lava at Mauna Ulu on February 3, 1972, did not appreciably disrupt the marked trend of net inflation that began in mid-1971. On February 5, the summit tilt reached a maximum since

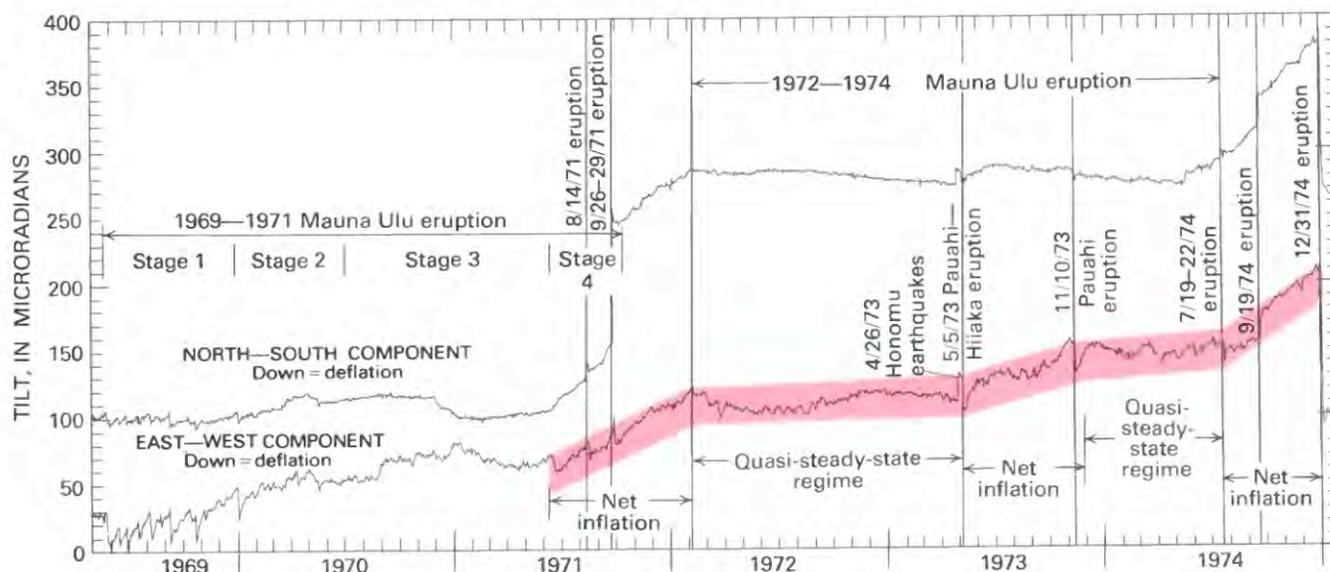


FIGURE 16.37.—Variation in Kilauea summit tilt for the period May 1969–January 1975, as measured by short-base water-tube tiltmeter at Uwekahuna vault; microradian scale arbitrary, with value at May 1, 1969, taken as zero. The magnitude-6.2 Honoumou earthquake (April 26, 1973) caused an 18-microradian offset of the east-west component of tilt. Tilt record for 1972–1974 Mauna Ulu eruption is characterized by two distinctive plateau-like segments separated by period of net inflation (see text).

daily measurements were initiated at Uwekahuna in July 1956. This inflationary trend then was terminated by a 6- μ rad deflation during the next two days as the lava lake rose rapidly in Mauna Ulu Crater. Thereafter, most of the larger variations in summit tilt can be related to significant changes in observed surface activity, the most prominent of which are annotated in figure 16.4.

Even many of the smaller tilt oscillations (5 μ rad or less) can be correlated with changes in lava-lake level or episodes of vigorous vent activity, such as above-average lava fountaining or overflows from the vent. One of the best documented examples of such correlation is associated with the five eruptive episodes during January–February 1974 (table 16.3, fig. 16.30). Other good, but less well documented, examples are evident in figure 16.4.

Parts of the summit (Uwekahuna) tilt record cannot, however, be readily correlated with eruptive behavior. Possible reasons for such lack of correlation include: (1) Diagnostic field observations are lacking. (2) The tilt reflects subsurface magma migration processes that caused no visible change in eruptive activity, such as intrusion or leakage into secondary storage reservoirs in the rift zone(s). (3) Unrecognized time lags exist between changes in summit tilt and changes at the site of eruption. Some particularly intriguing tilt oscillations, larger than usual and more periodic and cyclical in amplitude, cannot be fully accounted for by changes in visible activity. The June–August 1972 oscillations (figs. 16.4, 16.37) occurred during a quasi-steady-state period when a well-integrated tube system supplied sustained overflows. Similar oscillations in late July–September 1973 occurred during a two-month repose in visible activity (fig. 16.4) when the summit was inflating.

These cyclical oscillations have a period of 20 to 21 days and are therefore unlikely to be related to fortnightly earth tides. They

may reflect pulses of magma entry into shallow secondary reservoirs within the east rift zone, which caused localized intrusion and associated ground deformation rather than observable changes in surface activity at Mauna Ulu or Alae. Dzurisin and others (1984, fig. 4) demonstrated that similar oscillations (though more variable in amplitude), in April–August 1980 reflected periodic leakage of magma from the summit reservoir into the east rift zone. Unfortunately, the Mauna Ulu flows during 1969–74 repeatedly destroyed instrument sites and buried much of the established geodetic network in Kilauea's upper east rift zone. Periodic reoccupations that had been planned for these sites might have provided critical data on the possible existence of subsidiary magma storage reservoirs between the summit and the Mauna Ulu–Alae area or even farther downrift. Evidence for a secondary reservoir near Makaopuhi Crater before May 1969 was presented by Jackson and others (1975) and by Swanson and others (1976a).

If adjusted for the offset caused by the April 1973 Honoumou earthquake, the net change in summit tilt during the entire eruption, February 3, 1972 to July 22, 1974, was no more than +8 μ rad. Thus the 1972–74 Mauna Ulu eruption, despite the tilt excursions related to the two 1973 outbreaks near Pauahi (figs. 16.4, 16.37), resulted in negligible net inflation in terms of Uwekahuna tilt.

Throughout the eruption, the east-west component of summit tilt and the north-south component varied sympathetically, except during two intervals: August–December 1972 and June–October 1973. Individual tilt peaks during these intervals can be correlated, but the east-west component indicates apparent net inflation and the north-south component shows apparent net deflation (figs. 16.4, 16.37). Such a pattern can be produced either by an inflation center northeast of the Uwekahuna vault or by a subsidence center

southwest of it. Abundant studies of other historical Kilauea eruptions (for example, Fiske and Kinoshita, 1969; Duffield and others, 1982) provide no support for the possibility of an inflation center northeast of Uwekahuna. Although the alternative interpretation seems to be more plausible, given the well-documented and wide-ranging lateral shifts in inflation centers in the southern part of the summit, it too is unsatisfactory (see section below titled "Results of level, tilt, and trilateration surveys"). A departure from the general correspondence between the east-west and north-south components also characterized the period September 1970–April 1971 (Swanson and others, 1979, fig. 2) during stage 3 of the 1969–71 Mauna Ulu eruption, when lava-lake and associated processes were well developed and dominated the eruptive activity.

RESULTS OF LEVEL, TILT, AND TRILATERATION SURVEYS

Variations in Uwekahuna tilt provide a useful guide to the behavior of the summit magma reservoir, but they only represent measurements at a single locality and should be interpreted within the context of other geodetic data from ground-deformation networks spanning the entire summit of Kilauea.

SEPTEMBER 1971–JANUARY 1972: PRE-ERUPTION INFLATION

Ground-deformation networks in the summit region of Kilauea were reoccupied periodically before and during the 1972–74 Mauna Ulu eruption (table 16.4). Particularly useful are the results of closely bracketed surveys that included the reoccupation of the level or trilateration network in addition to the more frequently measured tilt network (tilt surveys were made by the spirit-level tilting or dry-tilt technique described by Kinoshita and others, 1974, p. 91). These data allow comparison of the geodetic response of the entire summit region with the tilt changes observed at Uwekahuna. For example, the 4-month net inflation ($+43 \mu\text{rad}$) preceding the 1972–74 Mauna Ulu eruption was clearly recorded by all three types of surveys, which delineated a well-defined center of inflation located about 1 km south-southeast of Halemaumau Crater (fig. 16.38A; Duffield and others, 1982, fig. 10B).

FEBRUARY 1972–APRIL 1973: QUASI-STEADY-STATE ACTIVITY

Only data from tilt surveys are available for the first several months of the eruption, a period of relatively small tilt changes at Uwekahuna but substantial visible activity at Mauna Ulu and Alae. The pre-eruption inflation, which during January 1972 resulted in a net Uwekahuna tilt change of about $+15 \mu\text{rad}$, is well expressed by plots of tilt vectors determined from measurements during January 26–28, about a week before resumption of activity at Mauna Ulu, and during the next survey on February 7–9 (fig. 16.38B). The period bracketed by these two surveys, though it included the start of eruption on February 3 and the tilt peak on February 5, showed virtually no net change in the east-west component of Uwekahuna tilt (figs. 16.4, 16.37). Given the measurement uncertainty of $2\text{--}3 \mu\text{rad}$, the solid line vectors in

figure 16.38B should have been essentially random in direction, if the Uwekahuna tilt was representative of the entire summit region. However, the vectors for the field surveys yield a fairly well-defined pattern consistent with slight summit inflation. Moreover, vectors calculated from the east-west and north-south components of Uwekahuna tilt are compatible with this inflation pattern (fig. 16.38B).

During the next survey period, the net Uwekahuna tilt change was negligibly small ($+3 \mu\text{rad}$), and the almost random array of vectors was not amenable to simple interpretation (fig. 16.38C). The next period, February 22–25 to March 7–9, encompassed major overflow activity at Mauna Ulu and net Uwekahuna deflation of about $9 \mu\text{rad}$. The resulting tilt vectors for this period show a weak but nevertheless coherent deflation pattern (fig. 16.38D), in agreement with tilt data from Uwekahuna.

These results indicate that the measurable geodetic response of the entire summit region may not correspond to that at Uwekahuna vault during periods of minor inflation or deflation. Indeed, these observations in turn raise intriguing questions about the magma-conduit system: Is there some threshold value in the rate or volume of magma transport that must be exceeded before surface response becomes coherent over the entire summit region? Because Kilauea does not deform purely elastically (see Davis and others, 1974) but possesses a finite yield strength, must time elapse to accommodate inelastic deformation before elastic behavior dominates and integrated geodetic response is established?

It is difficult, perhaps impossible, to answer such questions with existing data, because the tilt surveys are significantly less precise than the water-tube tilt measurements at Uwekahuna. In addition, some ground displacements considerably larger than those discussed show widely diverse geodetic responses of the summit region: the center of inflation or deflation can migrate as much as 3 km in any direction within weeks; deflation generally is not a simple reversal of the preceding inflation; and the complexity of Kilauea's overall magma reservoir system allows local behavior to be almost independent for short periods of time (Fiske and Kinoshita, 1969; Swanson and others, 1976a; Duffield and others, 1982; Ryan and others, 1983; Dzurisin and others, 1984).

No appropriately paired deformation surveys are available to evaluate the effects of the mid-March deflation ($13 \mu\text{rad}$ at Uwekahuna), the largest during 1972 (figs. 16.4, 16.37), which accompanied the opening of the west-flank fissure at Mauna Ulu and of Alae vents C and D that fed voluminous overflows. However, this deflation is reflected in the frequently measured lines of the summit EDM monitor (fig. 16.39).

Through May 1972 the eruption was characterized by a net Uwekahuna tilt change of $-20 \mu\text{rad}$, associated with a broad, kidney-shaped area of subsidence across the eastern part of the summit region (fig. 16.40A). The tilt vectors are consistent with the vertical displacements. However, similarly paired trilateration surveys (table 16.4) yield a pattern of vectors of horizontal ground displacements that is incompatible with the deflation pattern derived from tilt and level data. The reasons for this incompatibility are unknown but are under study. In addition, net summit deflations of

small magnitude, especially those involving several wider oscillations in summit tilt may in general yield less simple patterns than summit inflations.

The period June–December 1972, an interval of nearly continuous eruptive activity at Mauna Ulu and Alae, was characterized by a few months of periodic tilt oscillations (fig. 16.19) with virtually no net change in Uwekahuna tilt, followed by modest apparent net inflation of $+15 \mu\text{rad}$. However, during part of this period, the north-south component of Uwekahuna tilt indicated apparent net deflation. Perhaps these tilt data are best interpreted as indicating deflation localized south and west of Uwekahuna, as suggested by the vector calculated from the east-west and north-south tilt components (fig. 16.40*B*, vector UWE). Such deflation accords with the results of level and tilt surveys, which also suggest minor subsidence east of Pauahi (fig. 16.40*B*), but the azimuth of vector UWE appears to be incompatible with the deflation center defined by level data and vectors for other tilt sites. This incompatibility demonstrates that during the second half of 1972 Uwekahuna tilt changes were not representative of Kilauea summit as a whole. The trilateration data for the same period also yield a pattern of horizontal ground displacements that, despite being locally aberrant, can be reconciled with a model of complex net deflation (fig. 16.40*C*).

Comparing the surveys bracketing the entire period from mid-January to mid-December 1972 accumulates the effects of small changes and results in a coherent pattern of net deflation; the secondary low in the Pauahi–Mauna Ulu area is also reasonably defined (fig. 16.40*D*). The azimuth of the tilt vector for UWE, however, still appears anomalous with respect to the well-defined deflation center south of Halemaumau.

A weak trend of net deflation through April 1973 was expressed by both east-west and north-south components of Uwekahuna tilt and the summit EDM lines (figs. 16.37, 16.39). Remeasurement of the summit tilt network during mid-March 1973 yielded tilt vectors of about $15 \mu\text{rad}$ or less relative to the previous survey in mid-December 1972; these small changes yield a diffuse pattern (not shown) similar to those obtained during 1972.

Collectively, these data demonstrate the difficulty in making an internally consistent interpretation of ground displacements during a period dominated by quasi-steady-state eruptive activity and attendant subsurface magma transfer. In the absence of major shifts of magma from summit to rift, the geodetic response of the ground surface to small changes affecting the volcanic conduit system is apparently influenced by independent adjustments to local stresses. In addition, the Uwekahuna tilt changes, especially during June–December 1972, seem aberrant and permit interpretations incompatible with deformation patterns derived from tilt, level, and trilateration surveys.

The April 1973 Honomu earthquake, which perhaps caused or accelerated the termination of the quasi-steady-state activity, seemingly produced only minor dislocations of the volcano's surface. Other than the $18\text{-}\mu\text{rad}$ earthquake-induced offset of the Uwekahuna tiltmeter (fig. 16.37) and a 2-cm dilation of a crack at the rim of Mauna Ulu crater (Tilling, 1976a, fig. 3), no data exist to

suggest other measurable geodetic response to the April 26 main shock and the 57 located aftershocks.

MAY–NOVEMBER 1973: NET SUMMIT INFLATION AND CHANGE IN ERUPTIVE MODE

The May–November 1973 period was characterized by substantial net inflation at Uwekahuna ($+30 \mu\text{rad}$) and encompassed the short-lived outbreaks at Pauahi–Hiiaka in May and at Pauahi in November, as well as the partial draining of Mauna Ulu lava lake on June 9.

The May 5 Pauahi–Hiiaka eruption was accompanied by deflation of about $20 \mu\text{rad}$ at Uwekahuna. Posteruption ground-deformation surveys (table 16.4) yield a pattern typical for Kilauean east-rift eruptions or intrusions (for example, Jackson and others, 1975, figs. 13, 32; Swanson and others, 1976a, fig. 20): a distinct deflation at the summit coupled with uplift and associated local collapse at the eruption site (fig. 16.41*A*). The level data indicate maximum subsidence of 209 mm centered southeast of Halemaumau, slightly north of the center of inflation during the quasi-steady-state activity of 1972. The May 5 eruption was accompanied by intrusion in the Pauahi–Hiiaka area and into the Koaie fault system, resulting in maximum measured uplift as great as 117 mm. Geodetic control is not good, but contours of equal vertical displacement can be drawn that reflect dike intrusion into the Koaie fault system indicated by seismicity (Koyanagi and others, 1973). Within the uplifted area, graben-like collapse occurred along existing and new cracks in the vicinity of the eruptive fissures and resulted in vertical displacements as great as 250 mm (fig. 16.41*A*). Some ground cracks widened by as much as 0.5 m.

The results of tilt and trilateration surveys are consistent with the deformation pattern derived from the level data (figs. 16.41*A*, *B*). The tilts associated with the May 5 eruption are an order of magnitude greater than those recorded during 1972. The large horizontal displacements near Pauahi and Hiiaka reflect distension related to eruptive fissures and inferred intrusion into the Koaie fault system (fig. 16.41*B*). However, the displacement vectors for benchmarks in the western part of the network, which are far removed from the sites of eruption and intrusion, appear anomalous and are not understood at present.

The summit reinflated rapidly following the May 5 eruption, and by early June the Uwekahuna tilt had essentially recovered from its $20\text{-}\mu\text{rad}$ deflation. This rapid inflation is well shown by tilt surveys, which indicate a broad area of uplift east and south of Halemaumau (fig. 16.41*C*). Tilt site Escape Road No. 2 (fig. 16.41*C*), however, shows downtilting toward the eruption area; apparently this site had not fully recovered from the localized collapse and ground cracking of the May 5 eruption (figs. 16.41*A*, *B*). A few horizontal displacements (not shown) obtained from partial reoccupation of the trilateration network are compatible with the summit-inflation pattern defined by the tilt.

Partial draining of Mauna Ulu lava lake and related minor intrusion on June 9 were marked by a deflation of $7 \mu\text{rad}$ at Uwekahuna. The two tilt surveys that bracket this event (table

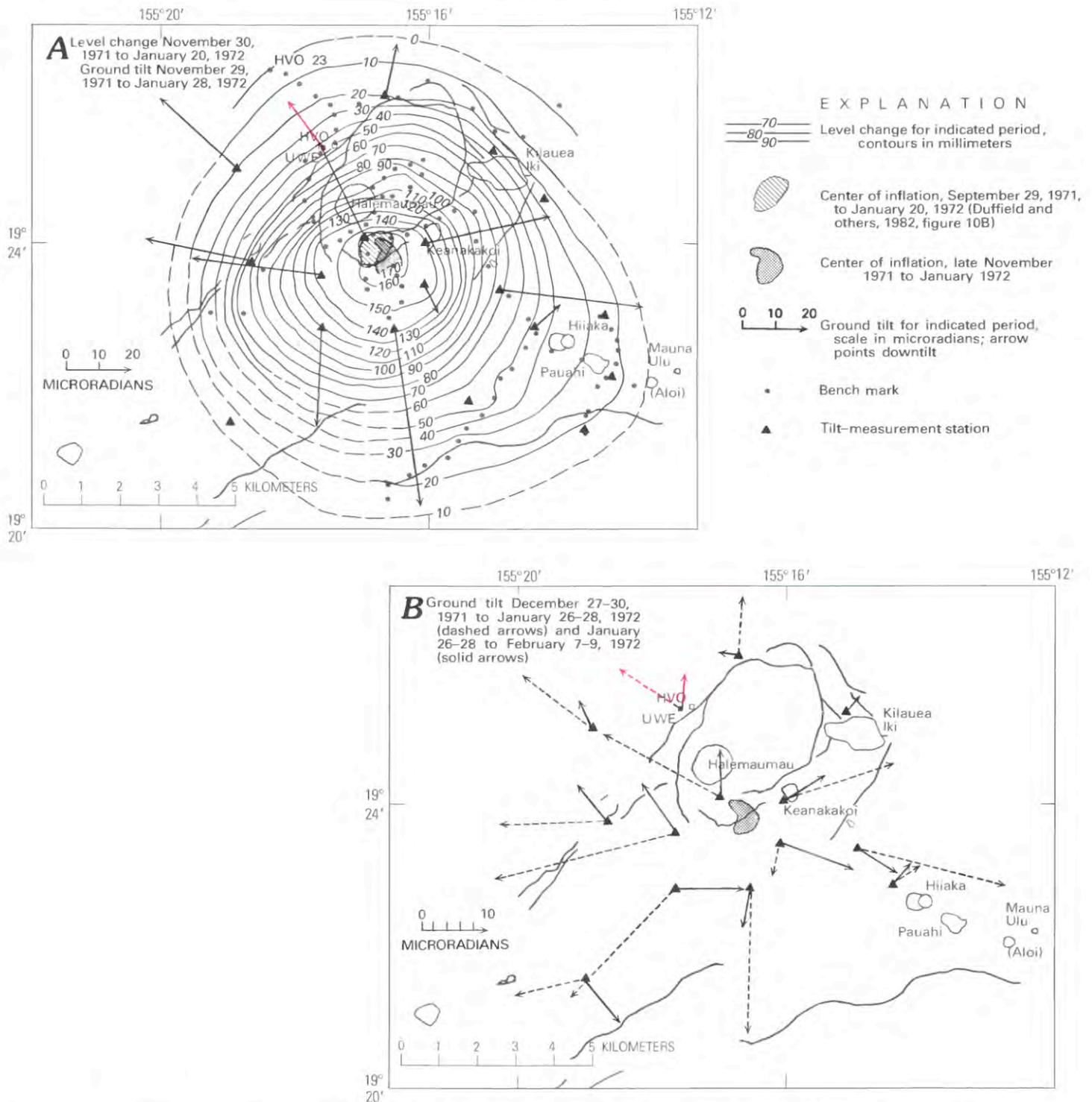


FIGURE 16.38.—Results of level and tilt surveys on Kilauea before and during first two months of the 1972–74 Mauna Ulu eruption. Vector UWE (red) calculated from east-west and north-south components of Uwekahuna tilt. Contours of level data referenced to bench mark HVO 23, assumed to be stable. **A**, Well-defined pre-eruption inflation between November 1971 and January 1972. Inflation center defined for this 2-month period is virtually coincident with that obtained by Duffield and others (1982, fig. 10) for the 4-month period building toward the 1972–1974 Mauna Ulu eruption. **B**, Tilt for periods spanning the final month of pre-eruption inflation (dashed vectors) and first days of the eruption beginning on February 3, 1972 (solid vectors). Survey period bracketing the start of eruption involved no net change in Uwekahuna tilt (see text). **C**, Tilt vectors between February 7–9 and February 22–25, 1972, an interval with only about +3 microradians net change in Uwekahuna tilt (apparent inflation). **D**, Tilt vectors between February 22–25 and March 7–9, 1972; net change in Uwekahuna tilt was about –9 microradians (apparent deflation), consistent with deflation indicated by vectors.

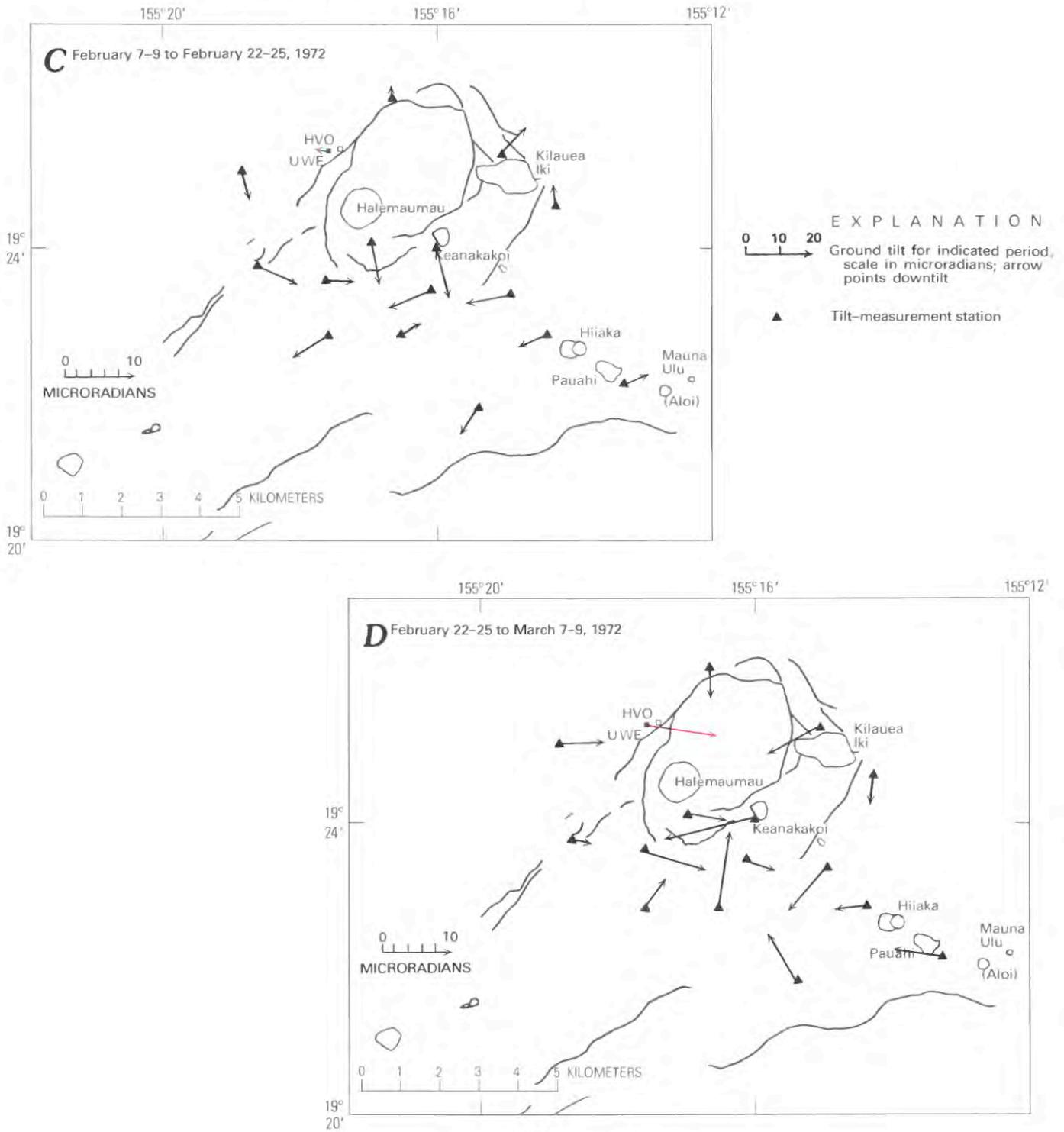


FIGURE 16.38.— Continued.

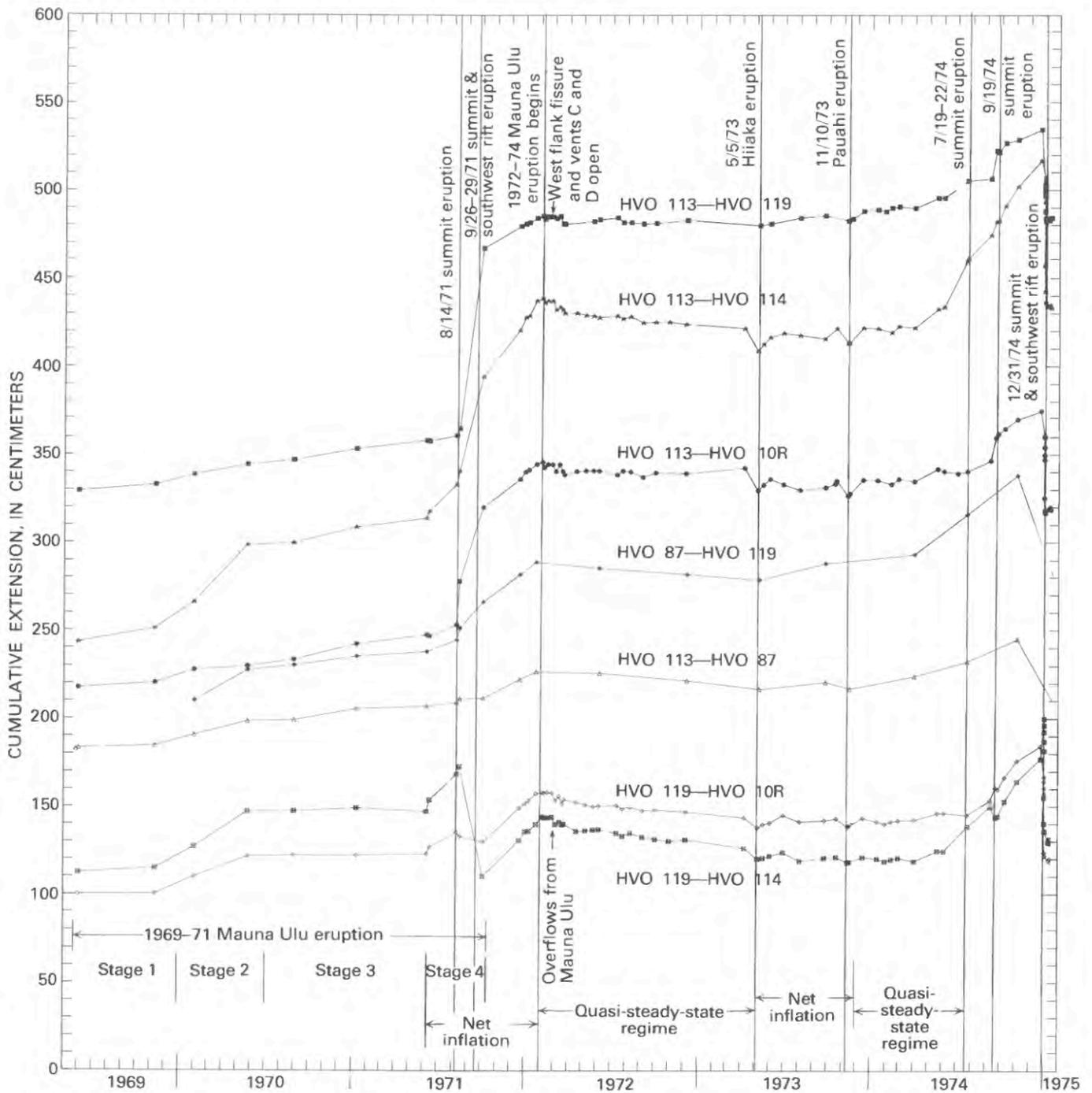


FIGURE 16.39.—Variations of distances within the summit EDM monitor between May 1969 and January 1975; locations of lines are shown in figure 16.36. Cumulative extension scale (in centimeters) is arbitrary. Frequent measurements detected small deflations in February and March 1972 related to overflows from Mauna Ulu and opening of new vents, respectively. Dotted parts of the curves for the 1973–74 period show probable variations if more frequent measurements had been made. Frequency of measurement during 1969–71 was about same as during 1972–75 (see Swanson and others, 1979, fig. 2; Duffield and others, 1982, fig. 2) but not all data plotted here.

16.4) yielded a diffuse net inflation pattern similar in shape but of slightly smaller magnitude to that obtained for the preceding survey period (see figs. 16.41C, D). Measurable geodetic response to the

events of June 9, if any, apparently was largely masked by the net inflation and continued localized adjustments to the May 5 eruption that prevailed during May and June.

The reoccupation of all summit deformation networks beginning in mid-September provided data documenting the complex re-inflation process following the May 5 eruption. Level and tilt data suggest a very broad zone of post-eruption uplift, including the southeastern sector of the caldera and the upper part of the east rift zone (fig. 16.42A). The maximum vertical displacements occurred adjacent to the periphery of the eruption site on the north and southeast. The area of least vertical displacement coincides with the eruption site, indicating incomplete recovery from the localized collapse associated with the eruption (compare figs. 16.41 and 16.42). The pattern of horizontal ground displacements for the same survey period (fig. 16.42B) is expectedly complex but reasonably compatible with that derived from ground tilt and level data.

Net inflation during the May–October 1973 period was ended by the eruption at Pauahi on November 10 and the associated Uwekahuna deflation of about $21 \mu\text{rad}$. All summit deformation networks were reoccupied in mid-November (table 16.4), when weak vent activity was continuing within Pauahi Crater. The previous reoccupation was completed on October 3, which was during the inflation (fig. 16.37). The differences between the surveys therefore record only about 25 percent of the total Uwekahuna deflation: the maximum measured subsidence in the summit deflation area barely exceeded 40 mm at two distinct centers (fig. 16.42C). Otherwise, the deformation pattern accompanying the November eruption—weak summit deflation coupled with stronger uplift and associated local collapse at the eruption site—closely resembles that for the May 1973 Pauahi–Hiiaka outbreak (see figs. 16.41, 16.42). As in May, the results of the level, tilt, and trilateration surveys bracketing the November eruption are mutually consistent.

Rapid re-inflation of the summit began as soon as the peak eruptive activity of November 10–11 had dwindled to weak vent activity that persisted for nearly a month. This inflation was expressed by a tilt survey in mid-December, which shows a relatively well-defined inflation center east of Halemaumau, as well as local tilt changes presumably reflecting weak vent activity in December (fig. 16.42D).

DECEMBER 1973–JULY 1974: RETURN TO QUASI-STEADY-STATE REGIME AND DEPARTURE FROM 1972–73 ERUPTIVE BEHAVIOR

Kilauea apparently returned to quasi-steady-state activity in December, following rapid recovery from the November 10 outbreak at Pauahi. This is inferred from variations in Uwekahuna tilt, which showed little net change for the December 1973–July 1974 period, even though the tilt oscillations were larger than those in the quasi-steady-state period in 1972–73. The existence at this time of a highly efficient hydraulic connection between the summit reservoir and Mauna Ulu is illustrated by the close correlation between minor variations in summit tilt and visible activity during the eruptive episodes, especially the well-documented episodes during January–February 1974 (fig. 16.30). However, because of inclement weather and instrument breakdown, few deformation surveys were

conducted during 1974, and we do not know whether slight shifts from equilibrium might have been detected by more frequent remeasurements.

The tilt network was remeasured in January 1974 and again in March (table 16.4). Deviations in Uwekahuna tilt were small (no more than $5 \mu\text{rad}$), and the survey periods were prolonged by bad weather and instrument problems; the results obtained do not permit good definition of patterns. Nonetheless, tilt vectors for the December 1973–January 1974 period can be interpreted as indicating weak deflation, and those for the January–March 1974 survey, as slight inflation (patterns not shown). For both survey periods the measured tilts were $15 \mu\text{rad}$ or less, and most of the larger values were at sites near Hiiaka and Pauahi, probably because of continuing adjustments to the November–December Pauahi eruption, or possibly reflecting the influence of the eruptive activity at Mauna Ulu itself.

The level and trilateration networks in the summit area were reoccupied in early April (table 16.4). The level data indicate summit inflation (fig. 16.43A), consistent with the net tilt change at Uwekahuna of about $+5 \mu\text{rad}$ for the period November 1973–April 1974. Residual effects of local uplift and associated collapse during November–December 1973 were still evident in April near Pauahi. The location of the inflation center, about 1 km northeast of Halemaumau indicates a substantial northward shift from the pre-eruption inflation center and the net 1972 deflation center (fig. 16.43A). The deformation pattern (not shown) obtained from the trilateration data is not diagnostic, but it is compatible with that shown in figure 16.43A. No tilt-survey data exist for April 1974 for comparison with level and trilateration measurements. However, tilt vectors for the period between November 1973–May 1974 also indicate net inflation with a center northeast of Halemaumau (fig. 16.43B).

Dvorak and others (1983, table 2, fig. 3) used a least-squares inversion technique and a point-source elastic model to analyze the surface displacements for the November 1973–April 1974 period. They found that: (1) the inflation centers determined separately for level and trilateration data coincide reasonably well; and (2) the model depth to the point source (summit magma reservoir) ranges from 2.2 to 2.6 km, depending on whether level data, trilateration data, or both are used.

Following the July 19–22 summit eruption, which terminated the 1972–74 Mauna Ulu eruption on the east rift, geodetic surveys were run in late July (figs. 16.43C, D). Their results reflect the prolonged inflation that preceded the July summit eruption but are complicated by the $15\text{-}\mu\text{rad}$ deflation at Uwekahuna that accompanied the eruption (Peterson and others, 1976). Level and tilt surveys were not completed until July 31 and thus bracketed part of the summit re-inflation. As is typical of Kilauea summit eruptions, the area of maximum displacement coincided with the loci of eruptive fissures in the southeastern part of the caldera and in and near Keanakakoi and Lua Manu Craters (figs. 16.43C, D). The complex area of weak subsidence along the east rift zone between Hiiaka and Mauna Ulu reflects lingering effects of the November 1973 Pauahi eruption.

VOLCANISM IN HAWAII

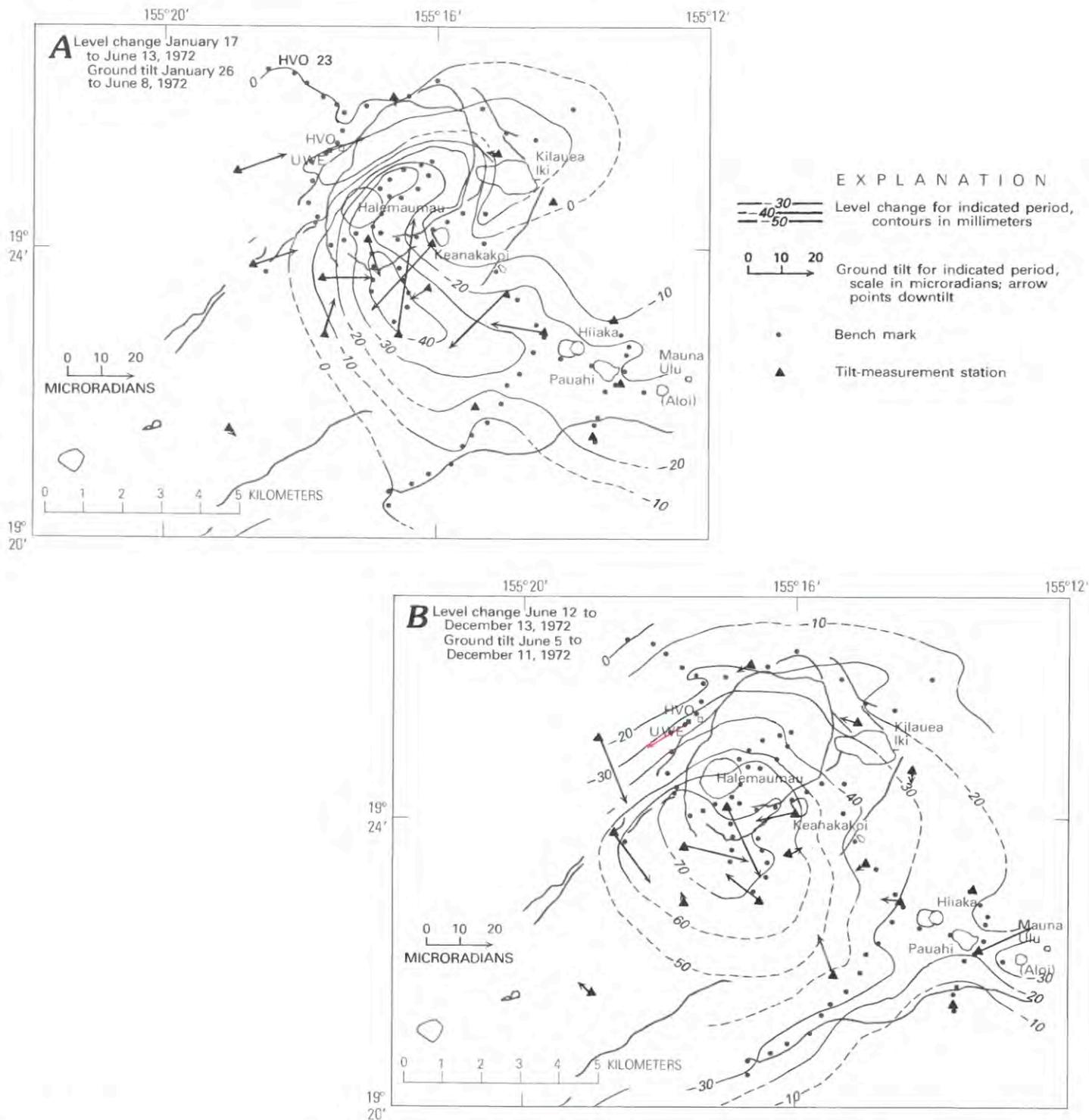


FIGURE 16.40.—Results of level, tilt, and trilateration surveys during 1972. Vector UWE (red) calculated from east-west and north-south components of Uwekahuna tilt. Contours of level data referenced to bench mark HVO 23, assumed to be stable. **A**, Changes in elevation and tilt between January and June 1972; note change in vector scale from figures 16.38B–D. **B**, Changes in elevation and tilt between June and December 1972, showing a weak but relatively well-defined pattern of net deflation; azimuth of vector UWE appears anomalous. **C**, Horizontal displacements from trilateration surveys of Kilauea summit between June and December 1972. Displacement vectors determined by reference to assumed stable bench marks on southeastern flank of Mauna Loa Volcano (see Kinoshita and others, 1974). **D**, Changes in elevation and tilt between January and December 1972. Combining the two survey periods shown in **A** and **B** yields a coherent deflation pattern; the azimuth of vector UWE is still anomalous. Note secondary area of subsidence in Pauahi–Mauna Ulu area.

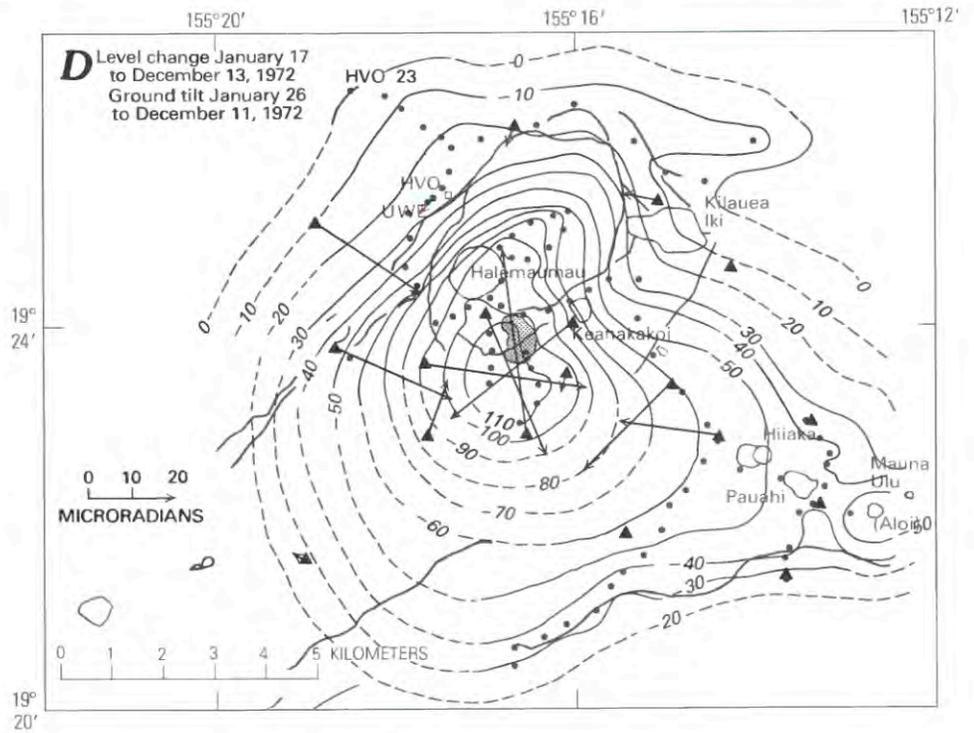
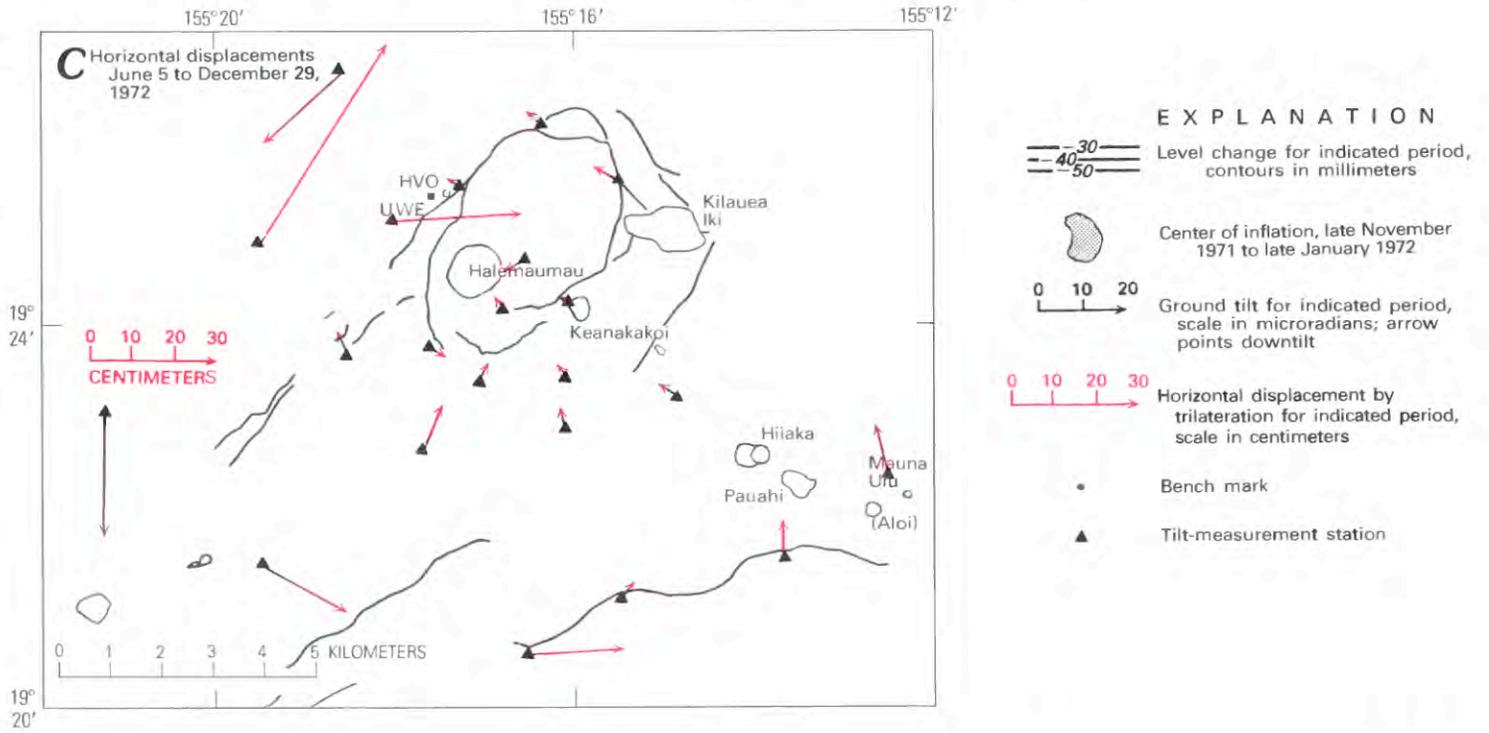


FIGURE 16.40.—Continued.

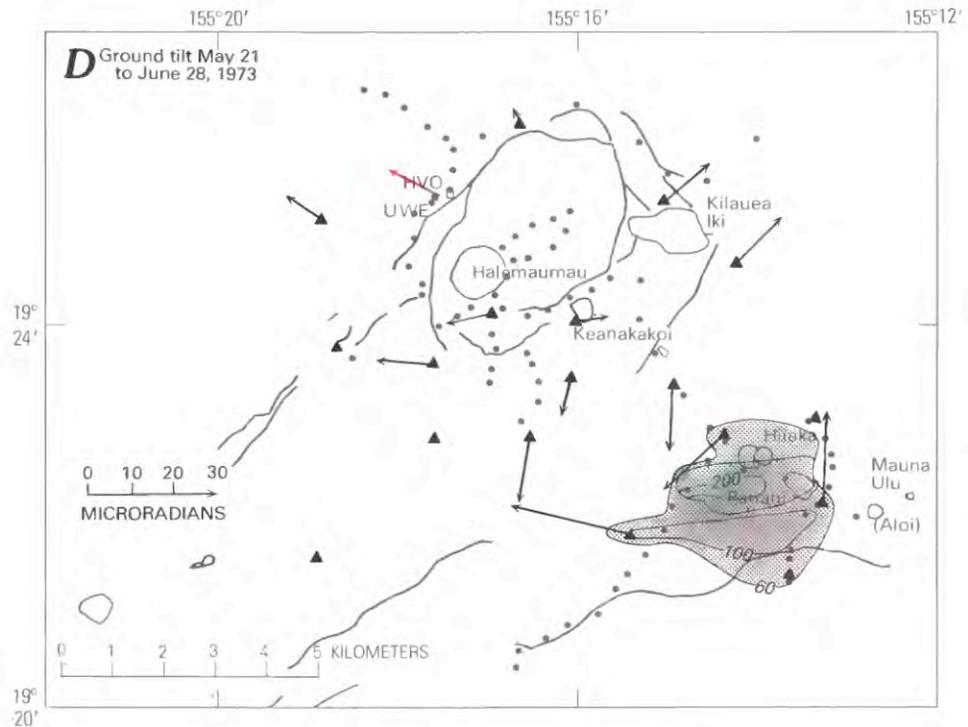
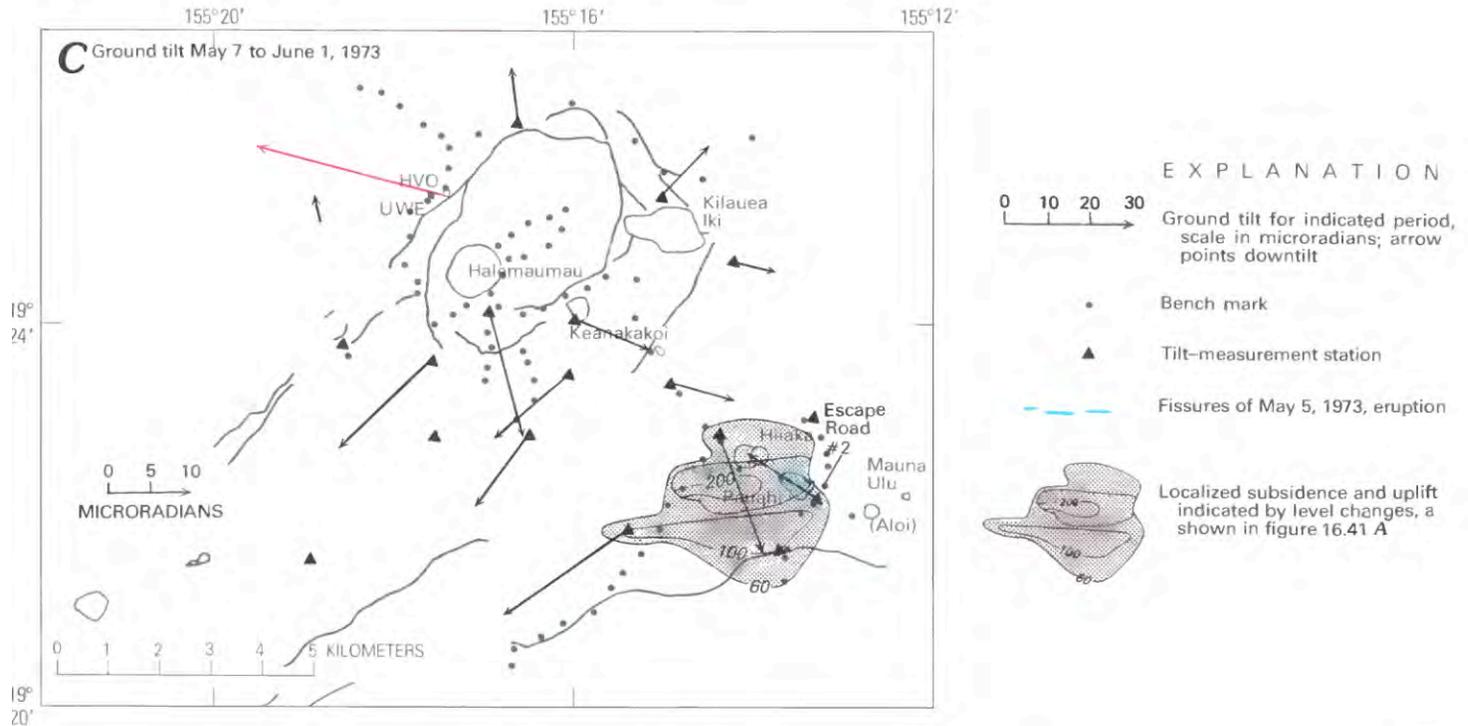


FIGURE 16.41.—Continued.

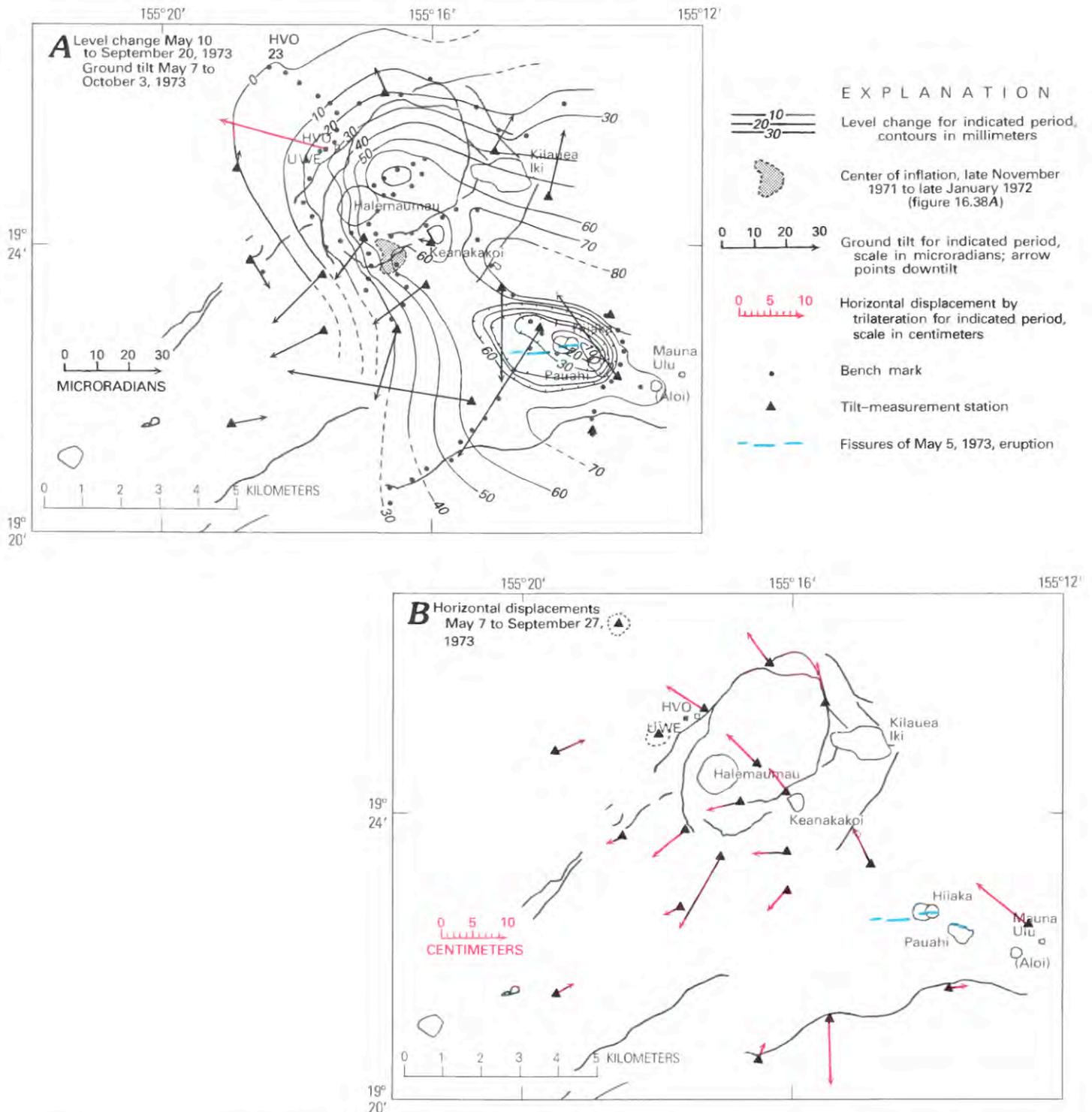


FIGURE 16.42.—Results of level, tilt, and trilateration surveys from May to December 1973. Vector UWE (red) calculated from east-west and north-south components of Uwekahuna tilt. Contours of level data referenced to bench mark HVO 23, assumed to be stable. **A**, Changes in elevation and tilt between May and September 1973. Effects of May 5 eruption and intrusion still evident. Elongate uplifted area shifted northward from previous inflation and deflation centers. **B**, Horizontal displacements from trilateration surveys between May and December 1973. Changes are relatively small and resulting pattern diffuse; bench marks in dotted circles show northerly vectors that are masked by plot symbols (triangles). **C**, Changes in elevation and tilt between September and November 1973, showing deformation associated with November 10–11 eruption at Pauahi. Deformation pattern generally similar to that for the May 5 eruption and other eruptions in Kilauea's upper east-rift zone (see text). **D**, Changes in tilt between November and December 1973, reflecting summit inflation following the November 10–11 Pauahi eruption, which persisted feebly until December 9.

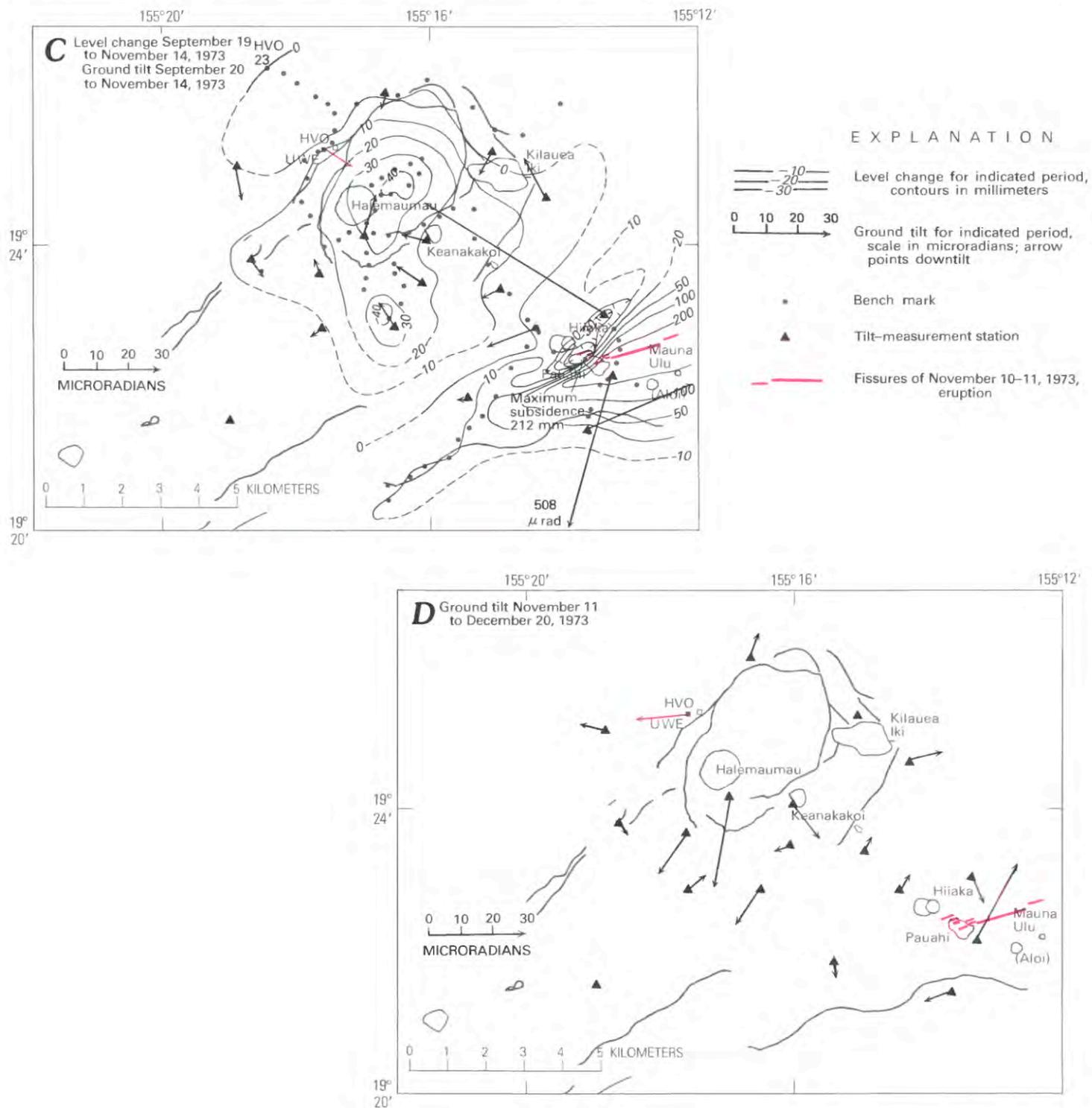


FIGURE 16.42. — Continued.

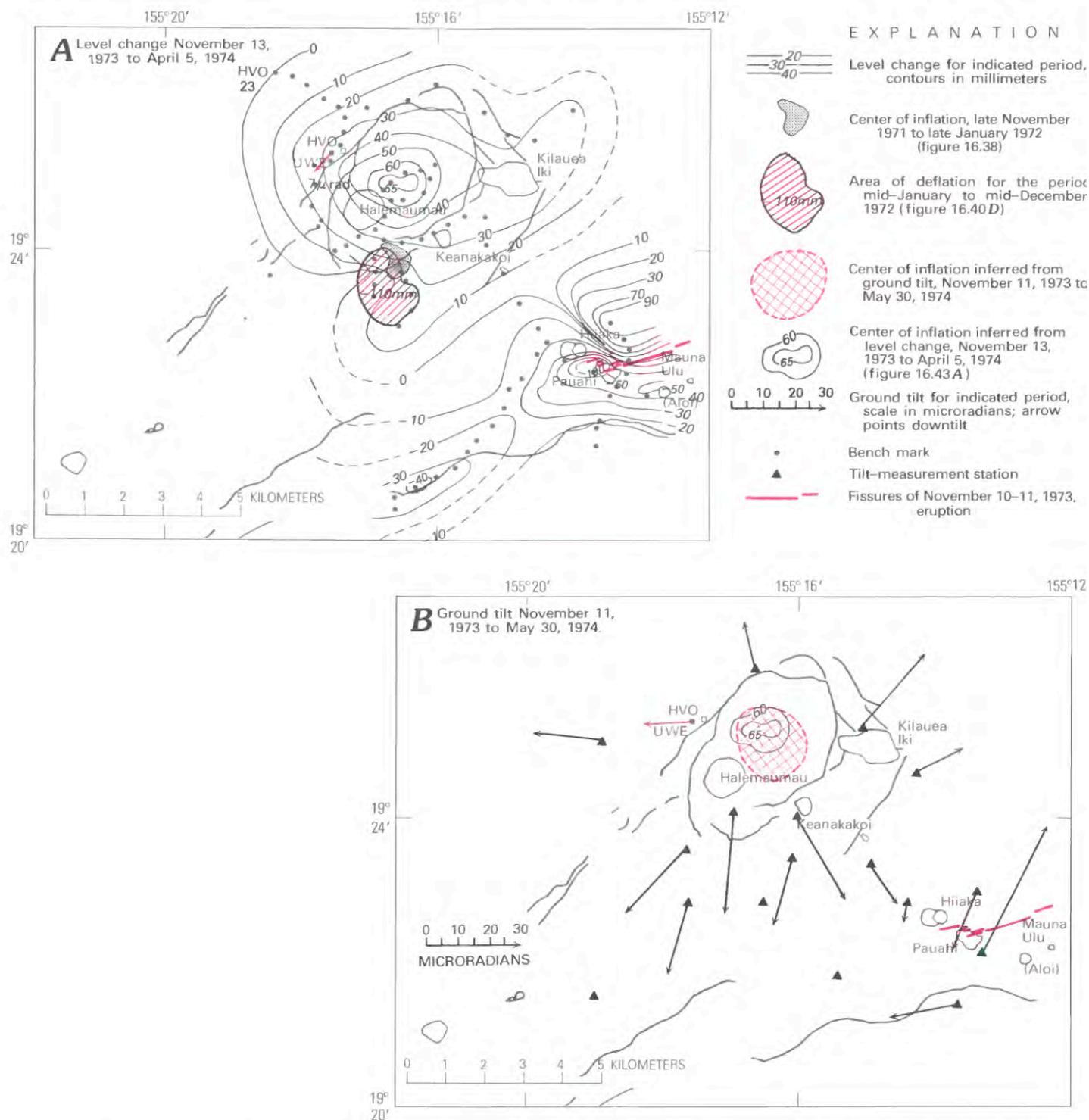


FIGURE 16.43.—Results of level, tilt, and trilateration surveys from November 1973 to July 1974. Vector UWE (red) calculated from east-west and north-south components of Uwekahuna tilt. Contours of level data referenced to bench mark HVO 23, assumed to be stable. **A**, Changes in elevation between November 1973 and April 1974. Pattern of vertical displacements is complex and shows: (a) well-defined inflation center near northern end of uplifted area shown in figure 16.42A; (b) area of greater uplift north of Pauahi that perhaps reflects continued adjustments to November–December 1972 eruption; and (c) subsidence at and east of Pauahi, as well as in the eastern part of the Koa'e fault system. No corresponding data from tilt surveys available, but see **B**; azimuth of vector UWE appears anomalous. **B**, Tilt vectors between November 1973 and May 1974. Broad inflation center corresponds well with previous centers determined from level data (see figs. 16.41, 16.42). Vector UWE is incompatible with radial pattern of vectors from tilt surveys. **C**, Changes in elevation and tilt between March and July 1974, the period that includes the July 19–22 summit eruption and the end of the 1972–74 Mauna Ulu eruption on July 22. Well-defined uplift area coincides with active fissures of eruption in southern part of caldera near Keanakakoi and Lua Manu Craters. Bench mark at rim of Lua Manu (shown in red) collapsed about 2 m and not considered in contouring of the level data. **D**, Horizontal displacements from trilateration surveys between March and July 1974. Displacement vectors point away from the eruptive fissures.

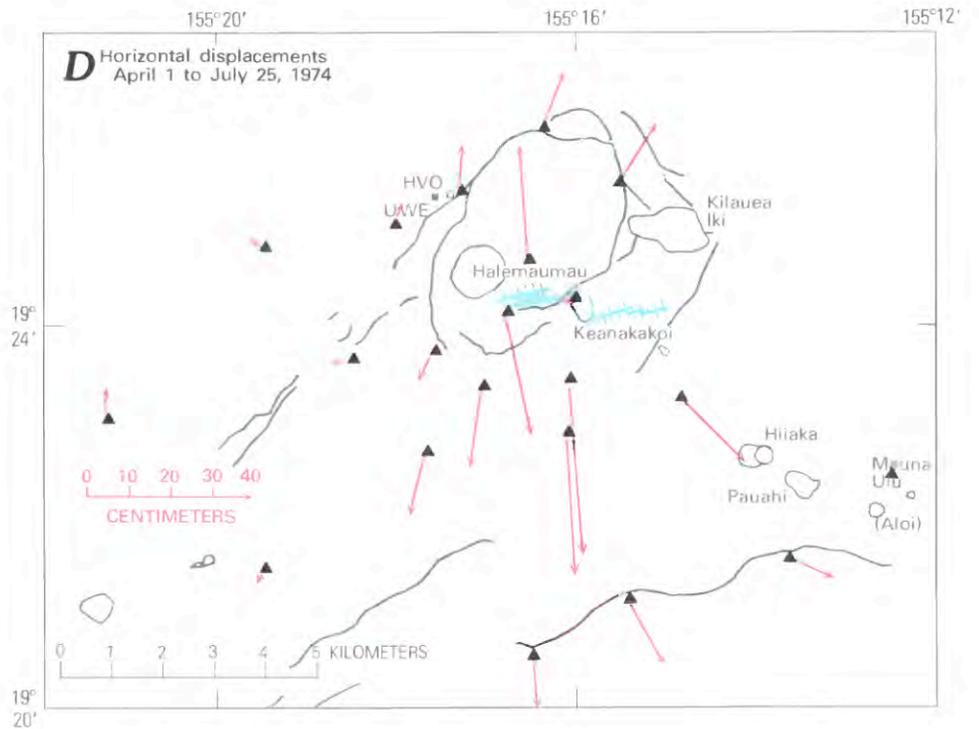
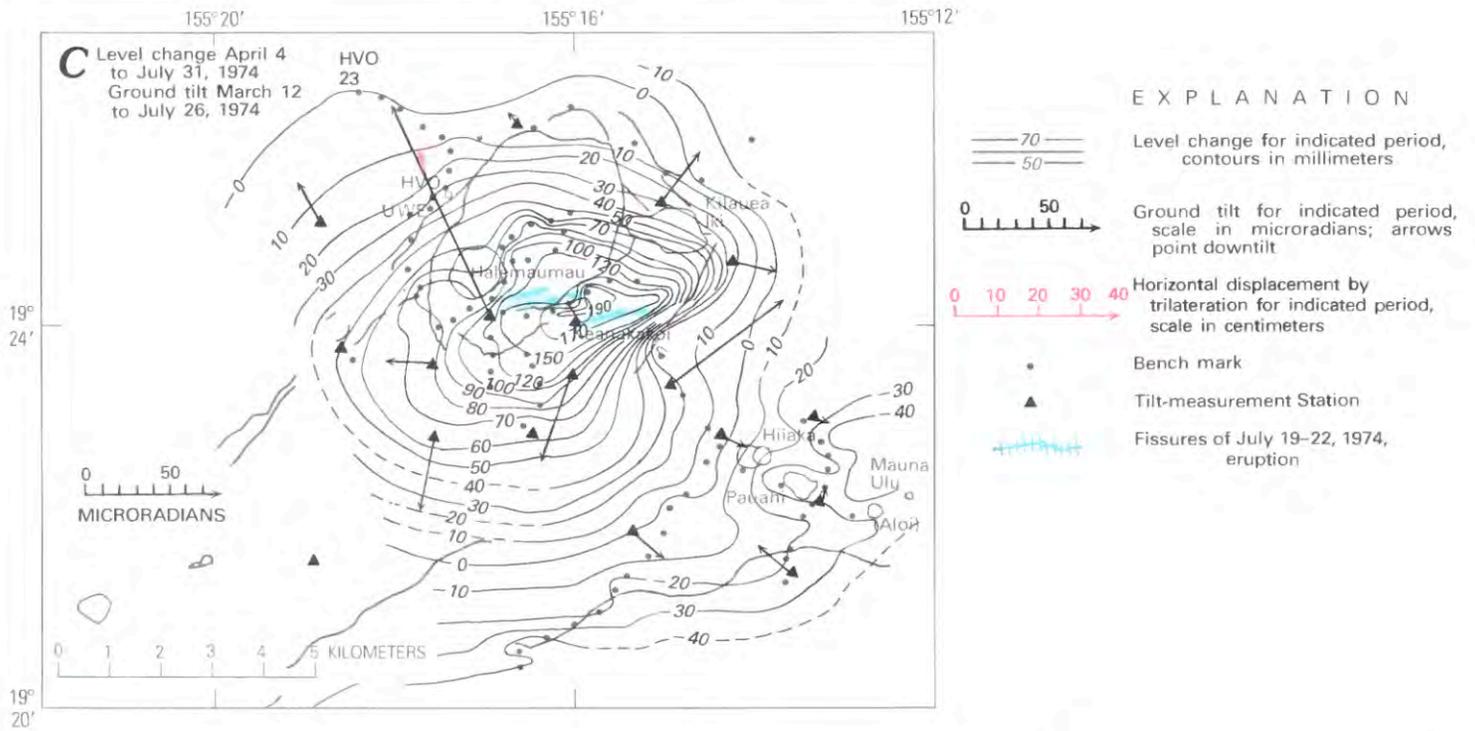


FIGURE 16.43.—Continued.

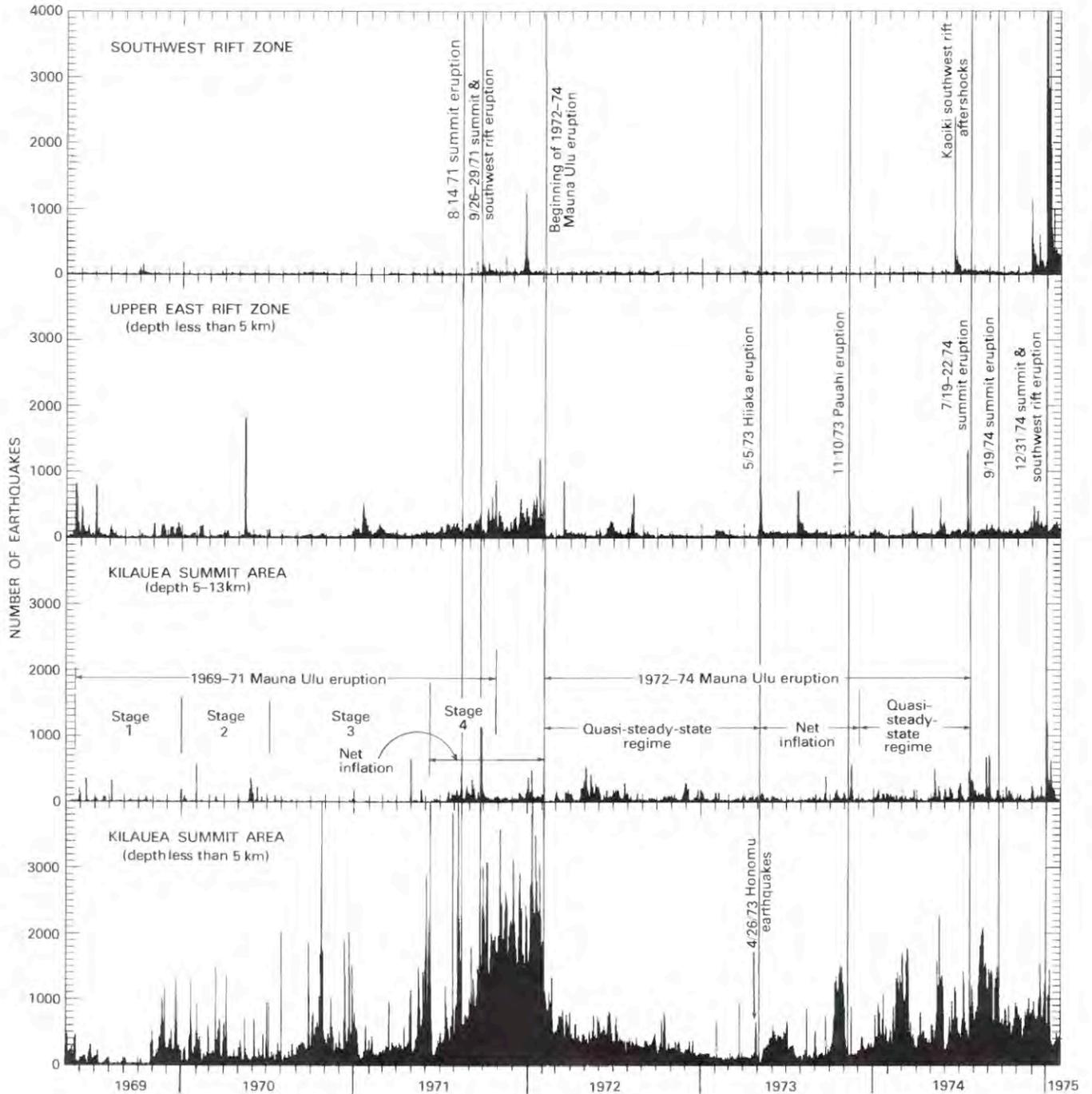


FIGURE 16.44.—Numbers of earthquakes in summit area (shallow and crustal depth), upper east rift zone, and southwest rift zone of Kilauea from May 1969 to January 1975. All events are counted, whether or not their hypocenters are well determined; counts for the southwest rift earthquakes include those in the Kaoiki fault system.

VARIATION IN SEISMICITY

Tabulations of earthquake counts and located events for 1972–74, as well as descriptions of the seismic network and instruments, have been published in summary form (Hawaiian Volcano Observatory, 1977a, 1977b, 1977c, 1977d, 1977e,

1977f, 1977g, 1977h, 1978). Some aspects of seismic activity during the 1972–74 period were discussed elsewhere (Koyanagi and others, 1973; Tilling and others, 1975; Koyanagi and others, 1976a, 1976b; Ellsworth and Koyanagi, 1977; Unger and Ward, 1979; and Aki and Koyanagi, 1981). We present in this paper a

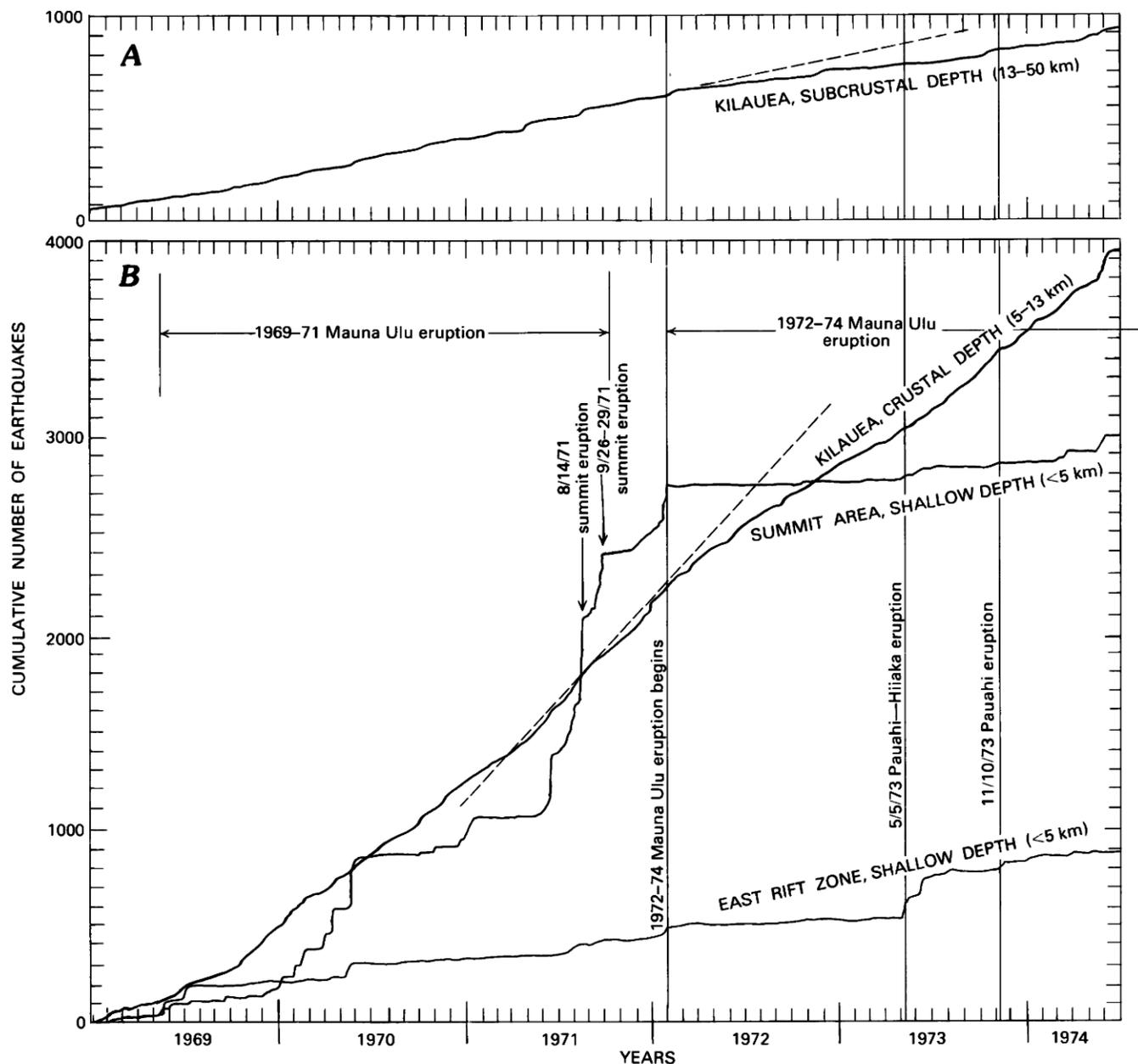


FIGURE 16.45.—Cumulative numbers of earthquakes with well-determined hypocenters, magnitude 1 or greater, at Kilauea from January 1969 to June 1974. **A**, Subcrustal earthquakes (reference area: lat $19^{\circ}11'$ to $19^{\circ}33'$ N., long $154^{\circ}48'$ to $155^{\circ}20'$ W.). Dashed line is extrapolation of slope for period before onset of 1972-74 Mauna Ulu eruption. **B**, Earthquakes of crustal depth (reference area: same as for subcrustal earthquakes) and shallow earthquakes in the summit area and east rift zone (reference areas: lat $19^{\circ}23'$ to $19^{\circ}27'$ N., long $155^{\circ}13'$ to $155^{\circ}19'$ W. and lat $19^{\circ}20'$ to $19^{\circ}23'$ N., long $155^{\circ}06'$ to $155^{\circ}15'$ W., respectively). Dashed line is extrapolation of slope of crustal-earthquake plot for pre-eruption net summit inflation beginning in mid-June 1971 (fig. 16.37); slope decreases after onset of 1972-74 eruption and then is similar to that during the 1969-71 Mauna Ulu eruption.

brief overview of the variation in seismicity (figs. 16.44-16.46) within the framework of the chronological narrative of volcanic activity. Systematic, more quantitative studies of the seismicity associated with the 1972-74 Mauna Ulu eruption are pending.

SEISMICITY BEFORE AND AFTER THE 1972-74 MAUNA ULU ERUPTION

Seismicity during the 1972-74 Mauna Ulu eruption was moderate relative to that of the preceding and subsequent periods.

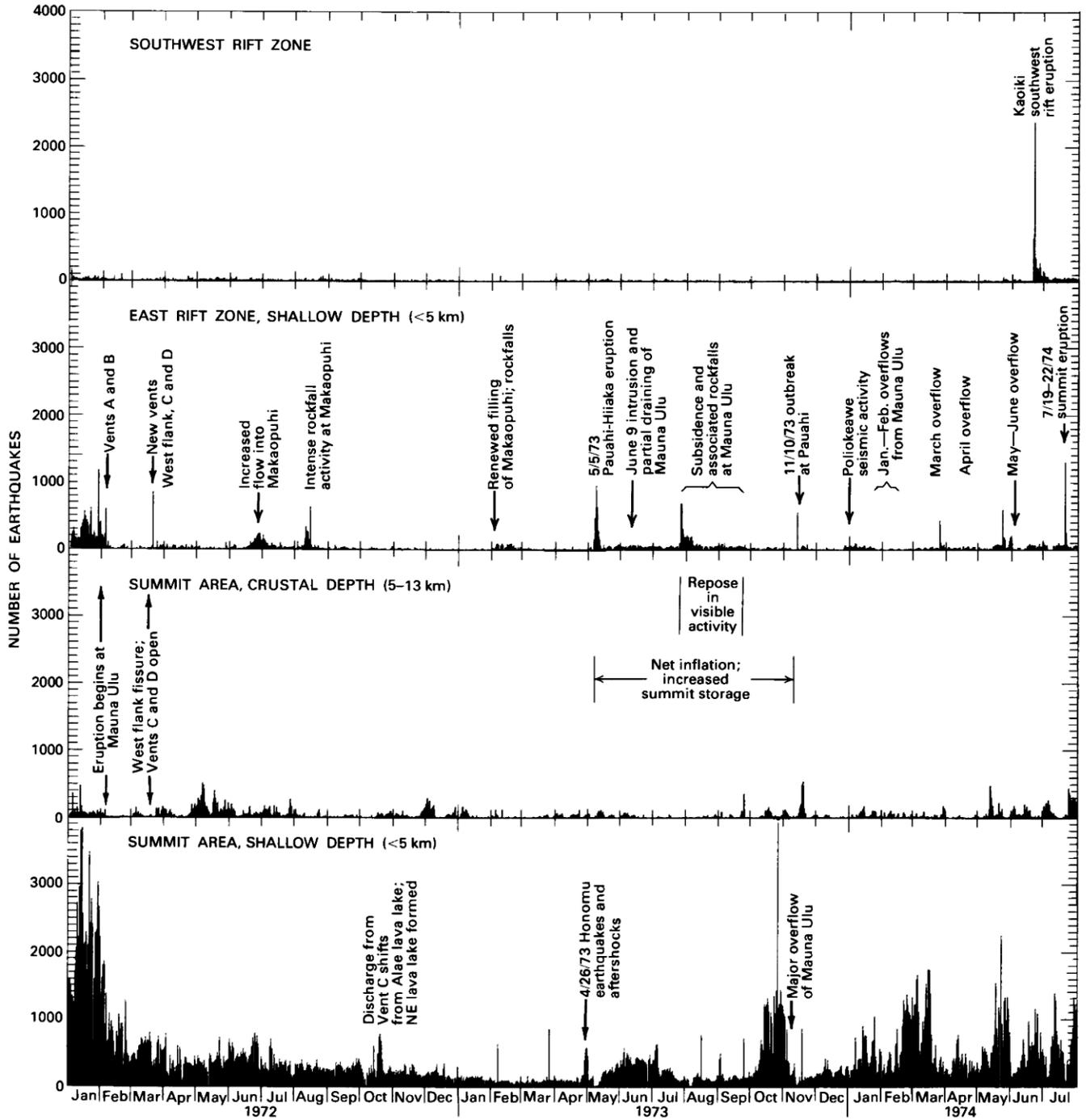


FIGURE 16.46. —Variation in seismicity during 1972–1974 Mauna Ulu eruption. Data also shown at smaller scale in figure 16.44. Significant changes in eruptive activity correlate with increased seismicity. Shallow summit-area earthquakes for the period January to March 1974 are shown in greater detail in figure 16.30.

Occurrence of long-period earthquakes at crustal depths (5–13 km) beneath Kilauea’s summit became more frequent beginning in June 1971 (figs. 16.44, 16.45B), at about the same time as summit inflation. The generally reduced level of seismicity during the 1972–74 Mauna Ulu eruption, particularly of shallow (short-

period) summit and east-rift earthquakes (depth less than 5 km), is especially evident during the first period of quasi-steady-state activity during February 1972–April 1973. Moreover, the occurrence of deeper Kilauea earthquakes (13–50 km) during the 1972–74 Mauna Ulu eruption decreased, as compared with that

during the 1969-71 Mauna Ulu eruption (fig. 16.44A).

As commonly observed at Kilauea, variations in the number of shallow summit earthquakes correlate closely with variations in tilt measured at Uwekahuna (see figs. 16.4, 16.37, 16.44-16.46). This correlation is well exhibited during the June 1971-January 1972 period, when the 1969-71 Mauna Ulu eruption gradually ended and the summit inflated in response to increased storage of magma in the summit reservoir (Duffield and others, 1982). A similar correlation exists between net inflation and incidence of upper-east-rift earthquakes during this period, implying periodic leakage of magma into the rift zone as the stressed summit reservoir failed repeatedly during reestablishment of the magma conduit system leading to Mauna Ulu. Within this context, the August 1971 summit eruption and the September 1971 southwest-rift eruption may be considered as massive and rather abrupt leakages by surface venting, inasmuch as the strong net summit inflation was only briefly interrupted by these events (Duffield and others, 1982).

SEISMICITY DURING THE ERUPTION

Sporadic bursts of low-level harmonic tremor in the summit region and upper east rift were recorded throughout the September 1971-January 1972 period of summit inflation. However, tremor increased in amplitude and became sustained in the early morning of February 4, 1972, only a day after the start of renewed eruption at Mauna Ulu. Within the next two days, as the new lava lake rose rapidly and vent activity increased, the numbers of shallow summit and upper-east-rift earthquakes decreased dramatically and thereafter remained low through April 1973 (fig. 16.46). This prolonged period of low seismicity implies the existence of a highly efficient and open system of magma transfer between the summit reservoir and the eruption site. We interpret the gradual net decline of shallow summit earthquakes during this period as reflecting a progressive improvement in the ability of the conduit system to transfer magma freely. Most of the conspicuous departures from the prevailing background of low seismicity can be correlated with changes in eruptive and associated activity and are so annotated in figure 16.46. Perhaps the most notable seismic events in 1972, however, were those associated with the continuous lava inflow into Makaopuhi in June-July and with the intense rockfall activity at Makaopuhi in August (Tilling and others, 1975), rather than with vent activity at Mauna Ulu or Alae.

An abrupt change in the magma-transfer regime, beginning in early May 1973, is clearly reflected in a seismic signature that is distinct from that for the previous 15 months (figs. 16.44, 16.46). We correlate this change with obstruction of the magma transfer conduit caused by the April 26, 1973, Honomu earthquake, although we concede that their coincidence in timing could be fortuitous. Whatever the cause, the changed magma regime was expressed initially by an immediate increase in the number of shallow summit earthquakes, followed by increased east-rift seismicity in early May that preceded and accompanied the May 5 draining of Mauna Ulu and Alae lava lakes, the Pauahi-Hi'iaka eruption, and the associated intrusion into the Koae fault system. After the

eruption, the level of earthquake activity and harmonic tremor remained high until the early morning hours of May 6. Most of the earthquakes during this time occurred in the upper east rift zone and in the middle and eastern portions of the Koae fault system, with a secondary zone of seismicity around the summit caldera. Weak tremor, fluctuating in intensity, continued for about a week afterward.

Lava returned to Mauna Ulu's crater on May 7 and to Alae on May 30. Alae was probably entirely tube fed from Mauna Ulu, although local, limited feeding by dikes could also have occurred. The posteruption reinflation and related increase in the number of shallow summit earthquakes suggest that the reestablished link between the summit reservoir and Mauna Ulu and Alae was not a good conductor of magma. Alternatively, the increase in seismicity may reflect adjustment in brittle rock of the summit region and east rift zone during reinflation of the magma reservoir. After May 5, both the east-rift and summit seismicity were characterized by higher background levels than previously (fig. 16.46). The partial draining of Mauna Ulu lava lake and the demise of the Alae vent in early June are not clearly recognizable in the record of east-rift seismicity, though they are reflected by brief deflation at Uwekahuna and associated slight decrease in summit seismicity. The next significant increase in east-rift seismicity after the May 5 eruption occurred in late July 1973 (fig. 16.46), when collapse of the Mauna Ulu Crater floor triggered a flurry of rockfalls.

The month-long dramatic increase in the number of shallow summit earthquakes during October 1973 was the most noteworthy seismic activity since late 1971 and coincided with a period of strong inflation. The heightened seismicity began to wane in late October, when renewed vigorous activity in the rapidly rising Mauna Ulu lava lake indicated increased east-rift magma storage, and returned to background levels with the onset of the overflow from Mauna Ulu during November 4-8. Curiously, the east-rift seismicity preceding and accompanying the draining of Mauna Ulu lava lake and the November 10 outbreak at Pauahi was relatively weak and short-lived compared to that for similar events in May 1973 (fig. 16.46). The reappearance of Mauna Ulu lava lake on December 13 was heralded by increased local harmonic tremor, but otherwise it was not expressed seismically, either at the summit or the east rift zone.

We have postulated a period of quasi-steady-state activity from December 1973 to July 1974, largely on the basis of the small net change in Uwekahuna tilt. However, we have shown that this period differs from the quasi-steady-state period of February 1972-April 1973 in eruptive style. It also has a different seismic signature, characterized by significantly greater variation in the number of shallow summit earthquakes, which generally can be correlated with more variable oscillations in Uwekahuna tilt. The variations in both seismicity and Uwekahuna tilt during the final 8 months of the eruption bear a crude resemblance to those during stages 2 and 3 (January 1970-June 1971) of the 1969-71 Mauna Ulu eruption (fig. 16.44; Swanson and others, 1979, pl. 2).

The irregular increase in the number of shallow summit earthquakes following the November 10, 1973, Pauahi outbreak is inferred to reflect increased summit storage, even while the conduit

system between the summit and Mauna Ulu was gradually becoming more open and efficient in magma transfer. By mid-January 1974, the magma pathway between the summit reservoir and Mauna Ulu was fully reestablished, as evidenced by the precise correlation among the bursts of high fountaining and overflows, summit seismicity, and minor changes in Uwekahuna tilt during the five closely spaced eruptive episodes during January–February 1974 (figs. 16.30, 16.46; table 16.3). We believe that such an exact correlation can be achieved only if the magma transfer system between the summit reservoir and Mauna Ulu is fully engorged in order to maintain hydraulic equilibrium.

Shallow summit earthquakes typically increased in number before observed eruptive episodes during January–June 1974, but summit seismicity dropped abruptly and summit deflation began immediately before the high lava fountaining and voluminous overflows of the eruptions. As the summit deflated and magma moved to the eruption site during most such episodes, east-rift seismicity increased and summit seismicity decreased, in a manner like that during some of the high-fountaining events in stage 1 of the 1969–71 Mauna Ulu eruption (Swanson and others, 1979, pl. 2) and the well-documented example of summit to east rift magma transfers during April–August 1980 (Dzurisin and others, 1984, fig. 4).

VARIATION IN HARMONIC TREMOR

At Kilauea and well-monitored volcanoes elsewhere in the world, harmonic tremor has been shown to be linked to magma movement, surficial as well as subterranean, and to commonly precede and accompany intrusions and eruptions (Aki and Koyanagi, 1981). As during the 1969–71 Mauna Ulu eruption, shallow harmonic tremor in the upper east rift zone and summit area occurred at varying intensities throughout the 1972–74 Mauna Ulu eruption. Harmonic tremor typically increased in intensity and (or) became sustained shortly before and during changes in loci of energetic vent activity, including the opening of new vents. When visible activity was feeble or absent, harmonic tremor typically was more sporadic and barely detectable; on rare occasions, for as long as a few days, tremor decreased to levels too low to be discerned from background with normal gain settings of the seismic instruments.

Of perhaps greater significance is the increased occurrence of the so-called deep harmonic tremor during the period 1969–75 (Dzurisin and others, 1984). Such tremor is believed to originate in Kilauea's deep magma source region at a depth of approximately 40–50 km and to reflect the production and ascent of magma supplying Kilauea's shallow summit reservoir. A marked increase in the amplitude and duration of recorded deep tremor was observed coincident with the onset of the 1969–71 Mauna Ulu eruption.

The trend of increasing deep tremor peaked at the end of 1972, but occurrence remained much above average through 1975 (Dzurisin and others, 1984, fig. 10). We suggest that the period of maximum deep tremor correlates with the February 1972–April 1973 period of quasi-steady-state activity at Mauna Ulu. However, the increased occurrence in deep tremor apparently was not accompanied by concomitant increase in deep or crustal earthquakes at

Kilauea (fig. 16.45). The foci of Kilauea crustal earthquakes (depth 5–13 km) are interpreted to define the feeding conduits from the deep magma source region to the shallow summit reservoir (Koyanagi and others, 1976a, fig. 5). Thus, our data may corroborate the speculation of Dzurisin and others (1984, p. 203) that "the rates of deep magma production and shallow supply to Kilauea may be closely linked" and that "a pulse of relatively rapid magma supply during 1968–1975 may have been responsible for the sustained eruptions at Mauna Ulu during 1969–1971 and 1972–1974." We recognize, however, that the correlation between deep tremor, magma supply, and eruptive activity is imperfect. For example, the 1967–68 Halemaumau eruption (Kinoshita and others, 1969) had the same magma supply rate as the 1969–1971 Mauna Ulu eruption (Swanson, 1972) but there was little associated deep tremor (Dzurisin and others, 1984, fig. 10).

SIGNIFICANCE OF THE 1972–74 MAUNA ULU ERUPTION

During the 1969–71 eruption, volcanic shield development was greatest during periods characterized by numerous short-distance and short-duration overflows from the main vents at Mauna Ulu. Swanson and others (1979, fig. 6) traced in detail the growth of Mauna Ulu shield, whose height grew at an average rate of about 6 m/mo and reached 80 m above the pre-eruption ground surface by the end of the major overflow activity in July 1970. At Alae, the complex filling, overflows, and draining of the lava lake between February 1969 and April 1971 resulted in net accretion of 29–40 m of lava above the rim of buried Alae Crater (Swanson and Peterson, 1972, fig. 2; Swanson and others, 1972, fig. 10). However, when activity ended in 1971, the altitude of the lowest point on the Alae lake surface, which rose or dropped by much as 19 m in response to the individual episodes of filling and subsidence, was determined in June 1971, after final settling, to be about 6 m higher than the pre-1969 datum (Swanson and Peterson, 1972, table 1).

During the 1972–74 eruption, countless overflows from vent C and subsidiary vents at Alae again filled the shallow subsidence bowl formed in 1971, and they accreted approximately another 60 m onto the complex Alae shield, increasing its height to about 100 m above the pre-1969 datum (the pre-eruption southeast rim of Alae Crater at 915 m above sea level, the same datum used by Swanson and Peterson, 1972).

At Mauna Ulu, the shield grew only slightly and irregularly from many small overflows during February–March 1972 and again during early November 1973. Vigorous growth comparable to that during 1969–70 occurred only during voluminous but short-lived eruptive episodes in 1974. By the end of April 1974, the height of the Mauna Ulu shield was 117 m above the pre-May 1969 ground surface (datum is 951 m above sea level, the same as used by Swanson and others, 1979, fig. 6) and its width increased proportionately. The final and most voluminous overflow of May 29–June 2, 1974, added another 4 m to the summit of the shield, resulting in its maximum height of 121 m above the pre-May 1969 base at the

end of the eruption. The May 1972 configuration of Mauna Ulu and Alae shields in May 1972 and of a mound filling the deep west pit of Makaopuhi Crater is schematically shown in figure 16.13. This configuration essentially persisted throughout the 1972-74 Mauna Ulu eruption, but the elevations of the landforms were modified by posteruption settling.

A comparison of the 1963 1:24,000 topographic map (based on 1954 aerial photographs) and the 1981 topographic map (based on 1977 aerial photographs) shows the following changes associated with the 1969-74 Mauna Ulu eruptions:

(1) The summit area of Mauna Ulu shield in 1977 is about 111 m above the pre-eruption ground surface, and the summit crater is deeper than 30 m.

(2) The site of buried Aloi Crater is well expressed topographically by a crudely circular area of minor subsidence (not more than 5 m) on the west flank of Mauna Ulu shield.

(3) The highest areas on the complex Alae shield, which rim the small collapse pit in the area of the (former) vent C, are nearly 90 m above the pre-1969 datum. The subsidence bowl that existed in 1971 is still reflected by a broad area of subsidence roughly coincident with the deeper compartment of the buried Alae Crater.

(4) Benchmarks not buried by 1969-74 flows have been raised or lowered a few meters, presumably in response to complex ground deformation related to eruptions during the period 1954-1977, principally the Mauna Ulu eruptions.

(5) Comparison of the maximum heights attained by Mauna Ulu and Alae during the eruption (121 m and 100 m, respectively) with their heights in 1977, as indicated by the 1981 topographic map (111 m and 90 m, respectively), demonstrates posteruption settling of about 10 m.

SUSTAINED OVERFLOWS: DEVELOPMENT OF LAVA-TUBE SYSTEMS

The 1969-74 Mauna Ulu eruptions afforded the opportunity, for the first time at Kilauea, to study the formation and evolution of lava tubes (see Greeley, 1971, 1972; Cruikshank and Wood, 1972; Peterson and Swanson, 1974; Peterson, 1983). Lava-tube and related flow processes have been described in detail by these geologists; we wish here only to outline some general observations especially pertinent to the 1972-74 eruption:

This paper is in general a sequel to the study by Swanson and others (1979) of the 1969-71 Mauna Ulu eruption. Indeed, we have presented our observations and inferences on the 1972-74 Mauna Ulu eruption in a format parallel to theirs in order to emphasize the continuity of similar eruptive processes and to facilitate the comparison of these two eruptions, separated by about 3½ months of inactivity, in the same area of Kilauea's east rift zone. Not surprisingly, much of Swanson and others' (1979) perception of the significance of the 1969-71 Mauna Ulu eruption applies also to the 1972-74 eruption.

LONG-LIVED FLANK ACTIVITY

It has previously been noted (Peterson and others, 1976;

Swanson and others, 1979) that the Mauna Ulu eruptions were the longest nearly continuous rift activity at Kilauea in historical times (that is, since about A.D. 1750): the 1969-71 eruption lasted 875 days and the 1972-74 eruption lasted 901 days. Most historical flank eruptions of Kilauea have lasted a few weeks at most and more typically a few days or less. The Mauna Ulu eruptions of 1969-74 included several prolonged periods of remarkably continuous lava-lake activity, previously observed only at Halemaumau within the summit caldera during the 19th and early 20th centuries.

CONTINUOUS LAVA-LAKE ACTIVITY

Throughout much of the 1972-74 Mauna Ulu eruption, active lava lakes operated within the summit crater of Mauna Ulu and at Alae. Mauna Ulu lava lake was apparently fed directly by the magma conduit leading from the summit reservoir, whereas Alae lava lake was supplied through a very efficient tube system connected to Mauna Ulu. Lake circulation patterns and persistent vent activity suggest that magma from Kilauea summit most likely entered the Mauna Ulu system at an intricately branched inlet located beneath the area between vents A and B (fig. 16.3). The magma was directed from there through complex branches westward to feed Mauna Ulu lava lake and eastward to supply Alae lake, generally through vent C. We speculate that from mid-March 1972 through April 1973, eastward shunting of lava from the inlet dominated and resulted in vigorous activity at or near Alae and relatively sluggish activity at Mauna Ulu lava lake. The tube system connecting Mauna Ulu and Alae never fully recovered from its disruption in early May 1973, and vent C at Alae was severed from the inlet by early June. Magma thereafter was shunted westward from the inlet area to feed activity at Mauna Ulu for the remainder of the eruption.

Gas-piston activity associated with rises and falls of lava columns at Mauna Ulu and Alae was commonly observed during the 1969-74 eruptive activity. Short-term minor fluctuations in level of Mauna Ulu and Alae lava lakes may simply be due to larger scale gas-piston activity of a magma column of greater volume and lateral extent. However, large variations in lake levels over a period of time probably reflect major changes affecting either the magma-transfer system linking the Kilauea summit reservoir and the eruption site, or possibly even changes in the reservoir itself. The levels of Mauna Ulu and Alae lava lakes often varied sympathetically (fig. 16.19); at no time during 1972 did a drop in level at Mauna Ulu correlate with a rise in level at Alae or vice versa, but this correlation was weaker in early 1973. Moreover, the variations in lake level at times exhibited an unmistakable positive correlation with summit tilt (fig. 16.19). These observations suggest that a hydrostatic balance existed between the Kilauea summit reservoir, the Mauna Ulu holding tank, and the vent at Alae, compatible with the postulated quasi-steady-state magma regime operating during two long periods of the 1972-74 eruption. Detailed study of the hydrodynamics and evolution of active lava lakes at Mauna Ulu and Alae should bear importantly on the overall magma-transfer regime of Kilauea during sustained rift activity.

SHORT-DURATION OVERFLOWS: VOLCANIC SHIELD DEVELOPMENT

Volcanic shields are built by repeated eruptions of fluid lava from centralized vents. A number of small shields dot the flanks of Kilauea Volcano; examples include Kane Nui o Hamo (pre-historic) and Heiheiahulu (circa A.D. 1750?) on the east rift zone, and Mauna Iki (1919–20) on the southwest rift zone (fig. 16.1). However, it was not until the 1969–74 Mauna Ulu eruptions that shield development at Kilauea could be systematically observed and documented.

(1) Steady lava output from the vent over a long period of time (weeks to months) is the most important prerequisite in the development of channelized flows and, ultimately, lava tubes. Short-lived or erratic vent activity, even if of high volume, does not allow the formation of lava tubes.

(2) As shown in the chronological narrative, periods of sustained overflows leading to lava-tube development and periods of frequent short-duration overflows leading to shield growth generally are not coincident. On occasion, however, these two types of eruptive activity may grade from one into the other over a transition interval of several weeks; thus, both activities may go on concurrently for short periods of time.

(3) Systematic field observations of the transition of pahoehoe to aa during the sustained overflows permitted the documentation of several modes of transition and demonstrated that moving lava flows function as natural viscometers. Peterson and Tilling (1980) proposed the concept of a transition threshold zone to portray the observed inverse critical relation between viscosity and shear rate in the transition from pahoehoe to aa; this model was refined by Kilburn (1981).

(4) Sustained overflows and development of well-integrated tube systems enabled lava to be transported as far as 12 km from vents at Mauna Ulu and Alae. Flows that filled the deep west pit of Makaopuhi Crater were tube fed, as were those that entered the sea in August–October 1972 and in February–May 1973.

(5) Lava-tube systems are efficient but fragile conductors of lava and can be easily blocked or disrupted, as evidenced by the apparent drastic effect of the April 26, 1973, Honoumuli earthquake on the tube system feeding lava into the sea. By May 1, earthquake-induced impediments and blockage caused all flow to cease.

CHEMICAL VARIATIONS (MAGMA BATCHES)

The long-lived Mauna Ulu eruptions provided a unique opportunity to study and model subtle variations in major-element chemistry during the course of a lengthy eruption. Using the chemical composition of the lava from the 1967–68 summit eruption at Halemaumau (Kinoshita and others, 1969) as the reference analysis, Wright and others (1975) identified, after adjusting for olivine control, five chemical variants (magma batches) for the 1969–71 Mauna Ulu lava. Identification of these subtly different chemical variants in turn enabled Wright and others (1975) to demonstrate that the lava from a new fissure cutting Aloi Crater and

the adjacent west flank of Mauna Ulu shield in early April 1970 was identical to that erupted by Mauna Ulu on the same date but distinct from that in preceding Mauna Ulu eruptions. Swanson and others (1979, p. 38–39) concluded that “a batch of new magma entered both the Mauna Ulu and Aloi plumbing systems just before the outbreak, implying that the systems were interconnected at some unknown depth.” Hoffman and others (1984) contend, however, that the variations in the composition of the 1969–71 Mauna Ulu lava can be interpreted in terms of a partial melting model without resort to different magma batches from the mantle.

Wright and Tilling (1980) extended such chemical studies to include lava erupted during the two 1971 summit eruptions, the 1972–74 Mauna Ulu eruption, and the eruptions of July, September, and December 1974. They recognized five new magma batches (chemical variants) and concluded that the following processes were common to all eruptions in the period 1969–1974 (Wright and Tilling, 1980, p. 786):

1. appearance of new chemically distinct batches of magma,
2. mixing of two or more of these batches prior to eruption,
3. subordinate isolation and cooling of magma followed by flow differentiation leading to eruption of differentiated compositions.”

Analysis of the distribution in time and space of the chemically distinct magma batches makes it possible to estimate the residence times and volumes of these batches. For example, on the basis of such information, Wright and Tilling (1980, p. 777) suggest that the appearance of fractionated magma in July 1974 can be related to the isolation and cooling of magma introduced into shallow storage 2½ to 4 years before.

QUASI-STEADY-STATE ACTIVITY

The small amount of net summit inflation observed, together with other evidence presented earlier in this paper, suggests that a quasi-steady-state magma-transfer regime prevailed throughout much of the 1972–74 eruption. If our concept of quasi-steady-state activity is valid, then the magma influx from the deep source region must be approximately constant, at least on a time-averaged basis, and nearly equal to the increments transferred into the rift zone.

The ground-deformation patterns derived from level, ground tilt, and trilateration surveys during the periods of quasi-steady-state magma transfer, which show little net summit inflation or deflation between surveys, are not always in good agreement with the variations in Uwekahuna tilt (see section titled “Results of level, tilt, and trilateration surveys”). In contrast, deformation patterns during the period of net summit inflation related to the 1973 eruptions in the Pauahi-Hiiaka area, are more coherent. These observations suggest that a threshold amount or rate of summit tilt change must be exceeded in order for the results of ground-deformation surveys encompassing the entire summit region to yield definitive interpretations. This in turn implies that the volcanic edifice has a yield strength and that a finite amount of inelastic deformation must be accommodated before elastic behavior sets in.

COMPARISON WITH 1969-71 MAUNA ULU ERUPTION

The 1972-74 Mauna Ulu eruption shares many characteristics with the 1969-71 eruption. It differs, however, in the following aspects:

(1) The later eruption lacked the high-fountaining episodes (maximum 540 m) and associated larger summit deflation (maximum about 30 μ rad) of the 1969 activity (stage 1 of Swanson and others, 1979). Although the behavior in 1974—brief eruptive episodes separated by longer intervals of weak vent activity—was qualitatively reminiscent of the stage 1 activity, fountain heights were smaller by an order of magnitude (40-80 m).

(2) The 1972-74 eruption occurred with practically no net summit inflation, whereas the 1969-71 activity resulted in a net summit inflation of approximately 60 μ rad, suggesting that a more efficient magma-transfer regime existed during 1972-74.

(3) The February 1972-April 1973 period of low seismicity on the summit and east rift has no counterpart in the 1969-71 Mauna Ulu eruption.

SUMMARY REMARKS

The 1969-71 and 1972-74 Mauna Ulu eruptions provided an unparalleled opportunity to conduct systematic studies of ongoing eruptive processes associated with long-lived active lava lakes. Many of these studies have already been published (table 16.1; Swanson and others, 1979, table 1), others are in progress. Long-lived lava lakes were commonly active within or near Halemaumau Crater during the 19th and early 20th centuries, but it was not until the Mauna Ulu eruptions that such lava lakes were observed in a flank eruption. As of this writing (June 1985), the current long-lived eruption at Puu Oo in Kilauea's middle east (Wolfe and others, chapter 17) resembles activity during stage 1 of the 1969-71 Mauna Ulu eruption. Will it later evolve into a subsequent stage dominated by one or more active lava lakes? Our experience at Mauna Ulu suggests that it is possible.

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