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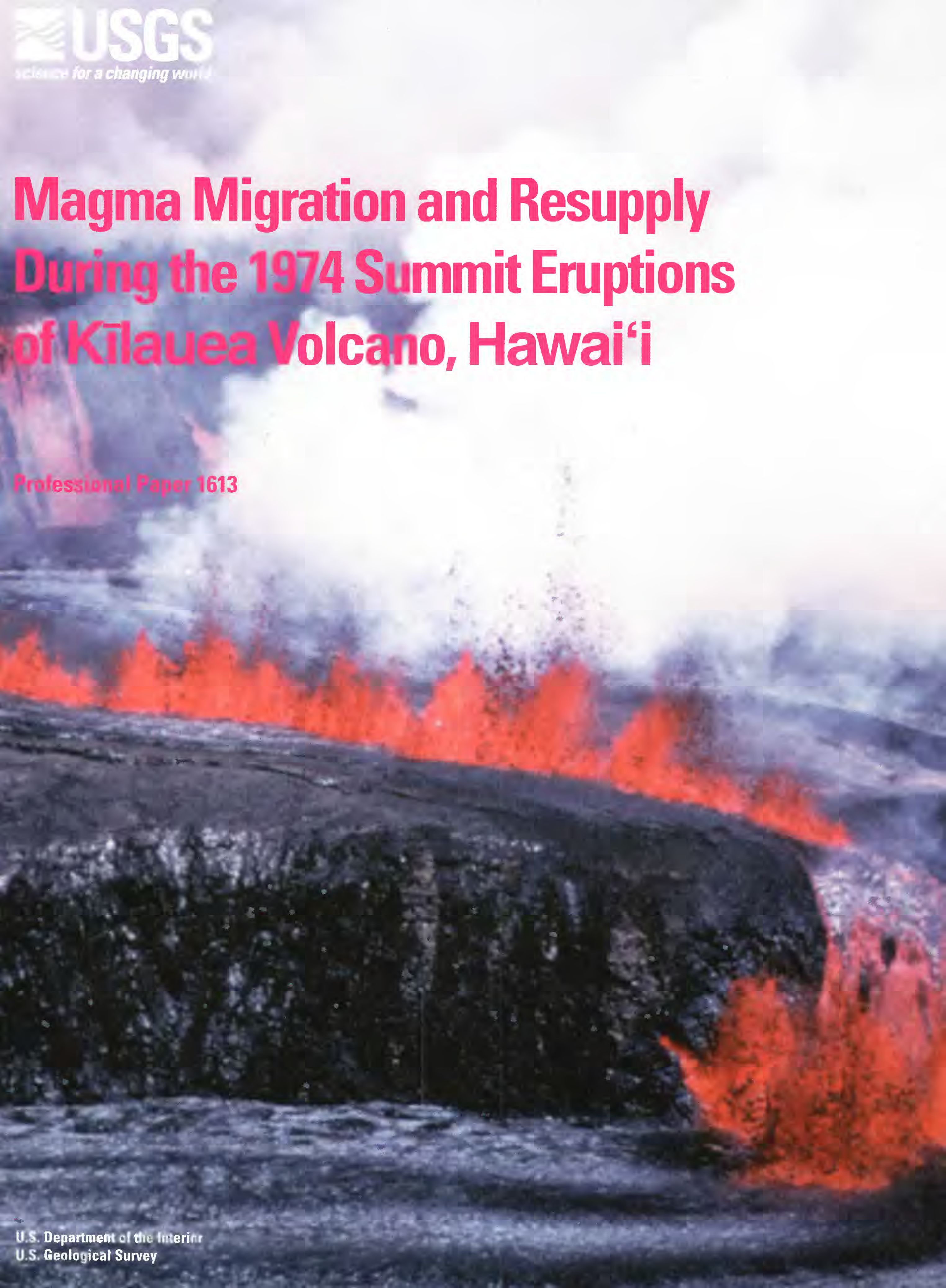
Magma Migration and Resupply During the 1974 Summit Eruptions of Kīlauea Volcano, Hawai‘i



Professional Paper 1613

U.S. Department of the Interior
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Telephoto view to the south across Kīlauea Caldera from the USGS Hawaiian Volcano Observatory, July 19, 1974, 13:25 hrs. Lava fountains up to 25 m high on the skyline south of Keanakāko'i Crater feed lava cascades into the crater. Three en echelon fissure fountains are active north of Keanakāko'i. Low fountains at the Crater's north rim feed flows that have just cut the Crater Rim Road, middle fountains feed fluid pāhoehoe lavas into a gully on the right. High fountains on the floor of Kīlauea Caldera (foreground) mark the easternmost extent of the caldera-floor fountains that extend more than a kilometer to the west of this photo. USGS photo by John C. Forbes.

Magma Migration and Resupply During the 1974 Summit Eruptions of Kīlauea Volcano, Hawai‘i

By John P. Lockwood, Robert I. Tilling, Robin T. Holcomb, Fred Klein, Arnold T. Okamura, *and* Donald W. Peterson

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There has never been a year like 1974 in historical time when three discrete yet magmatically related eruptions occurred in the summit area of Kīlauea Volcano

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Magma Migration and Resupply during the 1974 Summit Eruptions of Kīlauea Volcano, Hawai‘i

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ABSTRACT

Three brief eruptions—the longest lasting 3 days, the shortest only 6 hours—took place in the summit region of Kīlauea Volcano during the last half of 1974: July 19-22, September 19, and December 31. These eruptions followed an inferred constriction of the upper East Rift Zone (ERZ) supply conduits to the long-lived Mauna Ulu eruption in early 1974, causing magma and excess pressure to accumulate beneath Kīlauea's summit. The 1974 eruptions each shifted farther westward across Kīlauea's summit, reflecting the apparent westward migration of magmatic storage, from the upper ERZ (Mauna Ulu), across Kīlauea's summit caldera, and eventually down the volcano's southwest flank. Subsurface migration of magma storage centers across Kīlauea is documented not only by the loci of eruptive activity, but also by seismic and geodetic observations, which clearly trace the westward propagation of magma-generated seismic activity and deformation centers. These eruptions occurred during a period of increasing unrest at neighboring Mauna Loa Volcano, a factor possibly related to tectonic processes that also influenced the 1974 Kīlauea summit eruptions.

The July eruption was fed by separate, subparallel fissures that bridged the zone between the upper ERZ and the southeastern margin of the modern Kīlauea Caldera. These lavas, characterized by bimodal compositions, erupted from separate vent systems and in part represented the eruption of stored, "old" magma that was forced to the surface by an intrusion of more primitive magma from depth. The highly differentiated lavas from the southern vent system are characterized by megascopic plagioclase phenocrysts, a rarity at Kīlauea's summit. Lavas erupted in September are much more homogeneous than those erupted in July, but only slightly more mafic than the mean composition of the two groups of July lavas combined. The December lavas, however, include some of the most mafic compositions erupted at Kīlauea's summit since 1959 (12.2-15.6 percent MgO) and may include compositions little modified from a batch of "new" magma that is postulated to have entered the Kīlauea summit storage area before the July eruption.

The September eruption began within Halema‘uma‘u Crater, in the same area of the Kīlauea eruption in September, 1971. In contrast to 1971, however, 1974 caldera-floor "curtain-of-fire" fountains abruptly halted their advance when they reached the southwest wall of the caldera. In 1971, eruptive fissures extended beyond Kīlauea Caldera and down a strand of the Southwest Rift Zone (SWRZ) during earliest phases of that eruption. The SWRZ was blocked in September 1974, however, and magma was contained within Kīlauea caldera. This blockage was possibly caused by compressive stresses across the SWRZ related to the inflation of the reawakening Mauna Loa Volcano, which had begun to inflate in early 1974. We propose that the inflation state of Mauna Loa influences Kīlauea's SWRZ, and that long-term net inflation of Mauna Loa is also responsible for the paucity of SWRZ eruptive activity relative to the activity of Kīlauea's ERZ.

The December eruption took place southwest of Kīlauea Caldera in a historically noneruptive area between the Koa´e Fault System (KFS) and the SWRZ. This eruption apparently continued a geologically recent pattern of magmatic injection into the KFS, a new mode of activity first suspected in 1965 and which later included the first recorded KFS surface eruption (1973). This activity may be a new element in the tectonic evolution of Kīlauea and suggests that the Koa´e Fault System may become an increasingly important locus of magmatic injection and intrusion in the future.

The volcanic conditions that existed on Hawai‘i in the mid-1970s bears some similarities to the present situation (late 1990s). The long-lived ERZ eruption of Mauna Ulu was apparently beginning to wane in mid-1973, following several brief eruptive outbreaks and intrusions uprift, and Mauna Loa was beginning to inflate. Twenty-five years later, another long ERZ eruption has at times waned in intensity, eruptive and intrusive activity has taken place uprift of the main vent, and Mauna Loa is again slowly inflating. These parallels in eruptive history may well be coincidental, but they would merit further

study should the Pu´u ‘Ō‘ō eruption cease, eruptions return to Kīlauea’s summit, and then activity resume at Mauna Loa.

INTRODUCTION

Nearly all known eruptions of Kīlauea, one of the most active volcanoes on Earth, have taken place either within its summit region or along its two rift zones—the east-rift zone (ERZ) and the southwest-rift zone (SWRZ)–that radiate from the summit (fig. 1; Holcomb, 1987). In 1974, Kīlauea exhibited an especially wide range of eruptive behavior. During that year, the long-lived Mauna Ulu eruption in the upper ERZ (Swanson and others, 1979; Tilling and others, 1987) declined and ceased, two short-lived eruptions—one in July, another in September—occurred within Kīlauea’s summit caldera and the upper ERZ, and in December a brief, vigorous outbreak took place in an area between the upper SWRZ and the Koa´e Fault System (KFS) (fig. 1). Each of these eruptions broke out in different areas, and the lavas of each had distinctive chemical compositions; yet, seismic and ground-deformation activity associated with the eruptions suggested that each was related to a general pattern of westerly migration of a shallow magma source. Although selected aspects of the 1974 eruptions have been treated briefly (Peterson, 1976; Tilling and others, 1976; Pollard and others, 1983; Lipman and others, 1985; Klein and others, 1987; Dvorak and Okamura, 1987; Hazlett, 1993), they have never been documented in any detail.

The purpose of this paper is twofold: (1) to present a complete account of these contrasting yet related eruptions, thus filling a gap in the published narratives of recent activity of Kīlauea; and (2) to examine their significance within a broader context of regional magmatic and eruptive dynamics. In hindsight, one unanticipated benefit of the long delay in preparing this paper is that we have gained a longer term historical perspective and can view these three eruptions within a multidecade context of the eruptive behavior of not only Kīlauea, but also of the adjacent Mauna Loa.

ACKNOWLEDGMENTS

Summary reports of Hawaiian eruptive activity such as this involve the contributions of virtually the entire staff of the Hawaiian Volcano Observatory, past and present. As one reviews the rain- and sweat-soaked field notes of others or pours through the voluminous, meticulously annotated, archived HVO monitoring records largely written by the late John Forbes, a deep appreciation for the careful work of these mostly unsung heroes of the HVO “family” becomes almost overwhelming. Robert Koyanagi in particular contributed substantially to this paper; numerous ideas about the signifi-

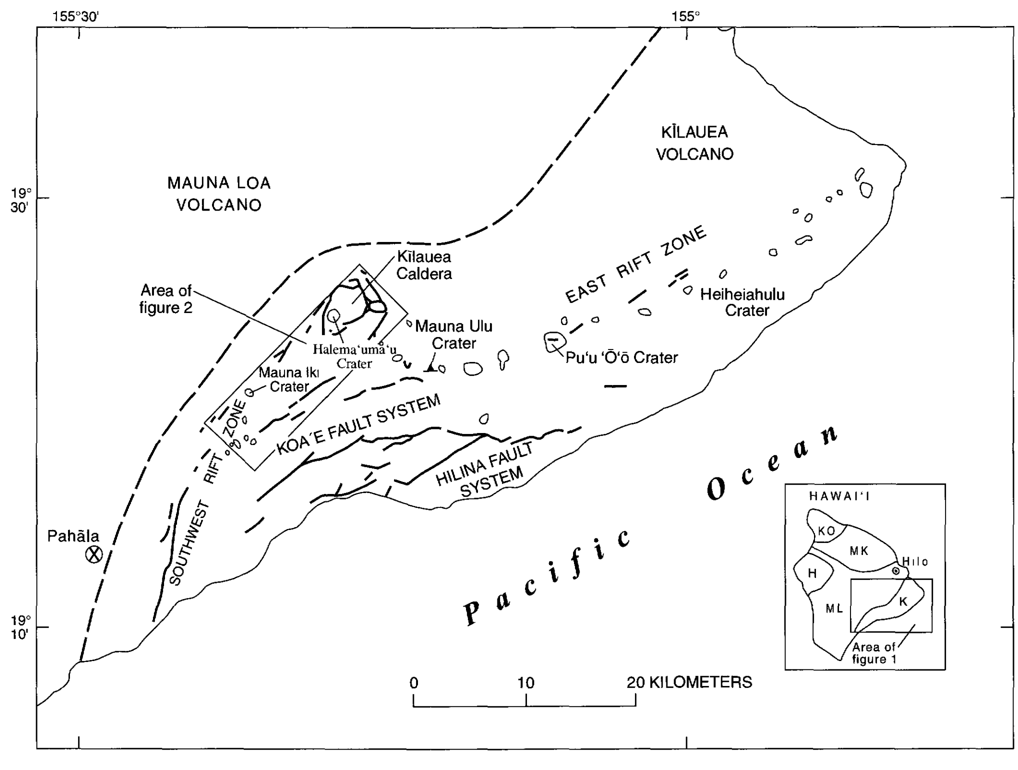

Figure 1.—Map of Kīlauea Volcano, showing principal geographic and tectonic features. Abbreviations on inset map: K, Kīlauea; ML, Mauna Loa; MK, Mauna Kea; H, Hualālai; KO, Kohala.

Table 1.—Eruptive activity at Kīlauea since the 1967-68 Halema'uma'u eruption. [Abbreviations for location of outbreak: SUM, summit; ERZ, east-rift zone; SWRZ, southwest-rift zone; and KFS, Koa'e Fault System. Table modified from Dzurisin and others (1984, Table 1)].

Location of eruption	Starting date of eruption	Duration (days)	Volume (10^6 m^3)	Descriptive account(s)
ERZ	8/22/68	5	0.01	Jackson and others (1975)
ERZ	10/07/68	16	7	Jackson and others (1975)
ERZ	2/22/69	7	17	Swanson and others (1976)
ERZ	5/24/69	875	185	Swanson and others (1979)
SUM	8/14/71	≤ 1	10	Duffield and others (1982)
SUM/SWRZ	9/24/71	5	8	Duffield and others (1982)
ERZ	2/04/72	455	125	Tilling and others (1987)
ERZ/KFS	5/05/73	≤ 1	1	Tilling and others (1987)
ERZ	5/07/73	187	2.5	Tilling and others (1987)
ERZ	11/10/73	30	3	Tilling and others (1987)
ERZ	12/12/73	222	30	Tilling and others (1987)
SUM	7/19/74	4	6.5	**This paper**
SUM	9/19/74	≤ 1	6.9	**This paper**
SUM/KFS	12/31/74	≤ 1	5.9	**This paper**
SUM	11/29/75	≤ 1	0.2	Tilling and others (1976)
ERZ	9/12/77	20	40	Moore and others (1980)
ERZ	11/16/79	≤ 1	0.4	Banks and others (1981)
ERZ[1]	3/10/80	≤ 1	0.000003	Unpublished HVO data
SUM	4/30/82	≤ 1	0.5	Banks and others (1983)
SUM	8/25/82	≤ 1	3	Banks and others (1983)
ERZ	1/03/83	> 6900	> 1,800	Wolfe (1988)
	[Eruption is continuing as of December 1999]			Heliker and Wright (1991)
				Unpublished HVO data

[1]Smallest recorded Kīlauea eruption!

cance of the three 1974 eruptions stem from his freely shared perspectives on the long-term evolution of Kīlauea. Others, including Elliot Endo, Jennifer Nakata, Reginald Okamura, Don Swanson, John Unger, and Charles Zablocki shared important observations. Christina Neal provided unpublished geologic mapping of the Kīlauea summit area as well as important insights on the eruptive record of the upper SWRZ. Dave Siems provided exceptionally rapid turn-around of chemical analyses for us in 1992, Susanne Dorn helped measure flow thicknesses, and John Luczaj provided modal analyses. Martha Lockwood provided invaluable support in the field and office. Wendell Duffield, Richard Moore, and Robert Koyanagi provided constructive reviews of the manuscript; their suggestions for improvements are greatly appreciated.

PRECEDING ACTIVITY: SETTING THE STAGE

Halema'uma'u Crater, within Kīlauea's caldera (fig. 1), was the site of nearly continuous lava-lake activity throughout most of the period 1823 to 1923; in addition to the persistently active summit lava lake, more than a dozen other eruptions, at the summit as well as both rift zones, occurred during the same interval (Macdonald and Abbott, 1970). Following the subsidence of Halema'uma'u lava lake and the ensuing series of phreatic eruptions in May 1924, the century-long continuous summit activity ceased (Jaggar and Finch, 1924). During the next 10 years, eruptive activity at Kīlauea was sporadic and feeble, entirely restricted to

Halema'uma'u. Kīlauea then was completely inactive in the period 1935 to 1951, during which time neighboring Mauna Loa Volcano erupted five times (Macdonald, 1954). After Mauna Loa's voluminous SWRZ eruption in 1950, it remained dormant and Kīlauea once again dominated Hawaiian volcanism for the next 25 years, beginning with the June 1952 eruption at Halema'uma'u. Numerous short-lived eruptions, within the summit caldera and in the upper as well as lower ERZ, took place through the mid-1960s: in 1954, 1955, 1959-60, 1961, 1962, 1963, and 1965.

The 8-month eruption within Halema'uma'u in 1967-68 (Kinoshita and others, 1969) was at the time the longest-duration activity at Kīlauea since 1924, and exhibited continuous lava-lake activity typical of that prevailing for more than a century prior to 1924. Beginning in 1969, however, eruptions in the ERZ have dominated the activity at Kīlauea (table 1). The longest-lived and most voluminous of these are the 1969-74 eruptions at Mauna Ulu (Swanson and others, 1979; Tilling and others, 1987) and the Pu'u'Ō'ō-Kupaianaha eruption (Wolfe, 1988; Heliker and Wright, 1991), which began in January 1983 and continues unabated as of December 1999. Characteristics of Kīlauea eruptive activity since the 1967-68 Halema'uma'u eruption are summarized in table 1.

LONG-LIVED RIFT ACTIVITY AT MAUNA ULU

The nearly steady-state activity that prevailed at the Mauna Ulu and Alae shields from February 1972 to July 1974 was disrupted in 1973 by several lava-lake drainings and two brief eruptive breakouts 3-4 km uprift—one in May in the vicinity of Hi'iaka and Pauahi Craters, and the other in November within and to the east of Pauahi Crater (table 1; Tilling and others, 1987, fig. 16.3). Lava-lake activity resumed at Mauna Ulu following each of these interruptions, but the activity became increasingly sluggish, less continuous, and marked by periods of repose, one lasting nearly 2 months in July-September 1973. During this repose the lake surface crusted entirely and no molten lava could be seen. The July-September 1973 repose period in part may be related to a day-long intrusion on 9 June 1973 into the KFS (Dzurisin and others, 1984, table 1; Klein and others, 1987, table 43.1); this intrusion was accompanied by a drastic lowering of Mauna Ulu lava lake but did not result in any new eruptive breakouts (Tilling, 1987).

During the first half of 1974, even though a regime of nearly steady-state magma transfer had been reestablished, a noticeable change developed in Mauna Ulu's eruptive style. Rather than exhibiting the essentially continuous lava-lake behavior typical of the 1972-73 period, the activity was now characterized by brief episodes of high lava fountaining alternating with longer periods of low-level vent activity. Following a particularly vigorous eruptive episode in May-June 1974, lava-lake activity at Mauna Ulu progressively declined through mid-July, the lake level gradually subsided, circulation became increasingly sluggish, and lava finally disappeared in late July (Tilling and others, 1987). Molten lava never again returned to the Mauna Ulu crater, as it had in February 1972 after a 4-month quiescent period following two short-lived summit and SWRZ eruptions in August and September 1971 (table 1; Swanson and others, 1979; Duffield and others, 1982).

OTHER PRECURSORY SIGNS OF RETURN TO SUMMIT ACTIVITY

The changing character and progressive decline of visible activity at Mauna Ulu were accompanied by increasing shallow summit seismicity and a net summit inflation of about 25 microradians (μrad) during the period May 5 to November 10, 1973. These observations suggested that the magmatic connection between Mauna Ulu and Kīlauea's summit reservoir was becoming less efficient (Tilling and others, 1987). Indeed, when the state of summit inflation in mid-October 1973 surpassed the previous historical high, reached in early February 1972 just before the Mauna Ulu lava lake was reactivated, staffers at the Hawaiian Volcano Observatory (HVO) wrote: "If it doesn't break out at the summit, then there is a chance that it might break out somewhere on the upper east rift" (unpublished HVO Monthly Report, September 21 to October 20, 1973). Their hunch proved correct: the November 10, 1973 Pauahi eruption (table 1) began 3 weeks later. Still another possible indicator of the pending demise of Mauna Ulu was a 3-hour intrusion into the Pauahi area that accompanied the March 23-24, 1974 eruptive episode at Mauna Ulu (Dzurisin and others, 1984, table 1; Klein and others, 1987, table 43.1).

Finally, the apparent deterioration in the nearly steady-state magma transfer from the summit region to the Mauna Ulu shield—probably underway since mid-1973—was also reflected in a halved average lava-eruption rate, from 8 x 10^6 m^3/month during 1972-73 to 4 x10^6 m^3 during 1974, prompting Tilling and others (1987, p. 411) to speculate: "This reduction * * * perhaps augured the eventual cessation of the eruption."

CHRONOLOGICAL NARRATIVES

The three spectacular, short-lived, small-volume eruptions that occurred at Kīlauea's summit following the cessation of sustained Mauna Ulu activity in 1974 are the principal focus of this paper. Figure 2 shows the vents and flow fields for each of these individual eruptions. All times given in the following narratives are in Hawaiian Standard Time (UT minus 10 hr).

JULY 19-22, 1974 ERUPTION

The seismic alarm system sounded in an HVO residence at 03:45 on July 19, triggered by a sharp and sustained flurry

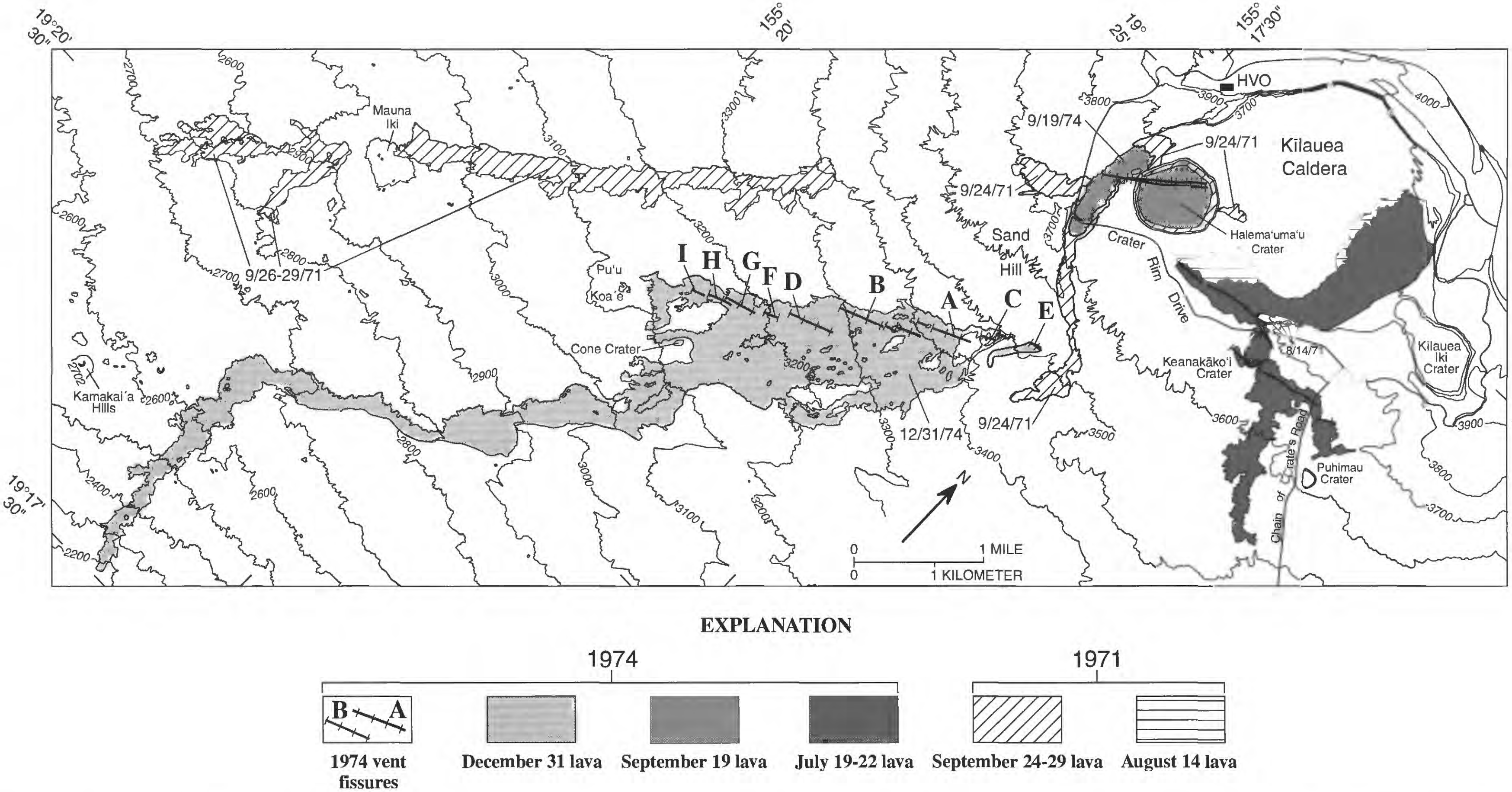

Figure 2.—Map showing the vents and flow fields of the summit and upper southwest rift eruptions of 1971 and 1974 (modified from Holcomb, 1987, Fig. 12.5). The July 19-22, 1974 lava covers much of the August 1971 lava in the southeastern part of Kīlauea Caldera; the September 19, 1974 lava covers much of the September 1971 lava in and near Halema'uma'u Crater. For the December 31, 1974 eruption, the bold letters refer to the chronological order of the opening of vent fissures (**A** = first; **I** = last). Contour elevations in feet.

of earthquakes centered near the uppermost part of the ERZ and the southern part of Kīlauea caldera. Some of these earthquakes were strong enough to be felt by local inhabitants. The first observers to HVO at 04:00 noted the normal glow above the summit of Mauna Ulu, reflecting the incandescent parts of a dwindling but still-active lava lake. A field party at Mauna Ulu later reported (~09:00) seeing molten lava during crustal overturn of the lake surface more than 40 m below the crater rim; this was the final sighting of molten lava at Mauna Ulu. The same field party also noted many new holes, or reopening of patched-over areas in the pavement of Chain of Craters Road south of Puhimau Crater (figs. 2 and 3). Volcanic tremor persisted at Mauna Ulu for three more days, before ceasing on July 22. This date (July 22) is arbitrarily taken as the end of the 1969-74 Mauna Ulu eruption (Tilling, 1987).

The onset of seismic activity on the early morning of July 19 coincided with the beginning of abrupt deflation of the summit region. As seismicity increased, strong tremor began about 10:30 and the rate of deflation also increased markedly. Magma was apparently moving towards the surface in the Keanakāko'i Crater area (fig. 3). About 12:30, lava broke out from a small fissure at the base of the south wall of Keanakāko'i, accompanied by small rockfalls from the crater wall. The lava fountains were initially about 30 m high. Within a few minutes, a second eruptive fissure, with 15-20 m-high lava fountains, formed north of Keanakāko'i (fig. 4), in the area between the Crater Rim Road and the fissures of the August 14, 1971 eruption (fig. 2; Duffield and

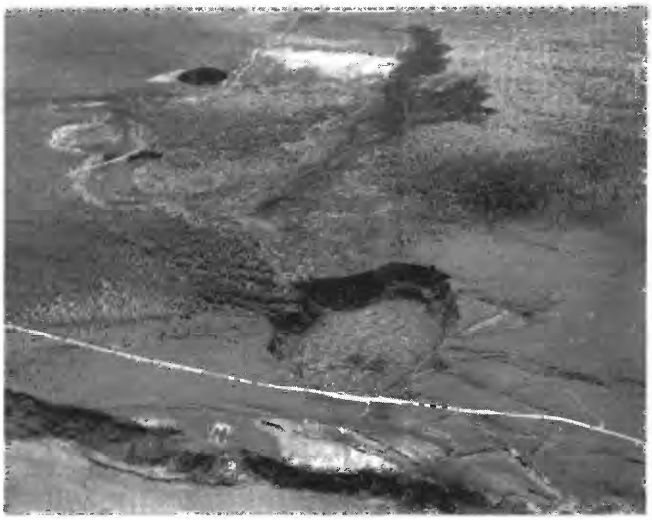

Figure 4.—Aerial view to south-southeast of eruptive vents north of Keanakāko'i Crater; Kīlauea Caldera floor in the lower left. The August 1971 fissure is closest to the caldera rim; the July 19, 1974 fissure that opened at 12:35 is just to the south; the 13:15 vents are at the rim of Keanakāko'i. USGS photo by J.P. Lockwood.

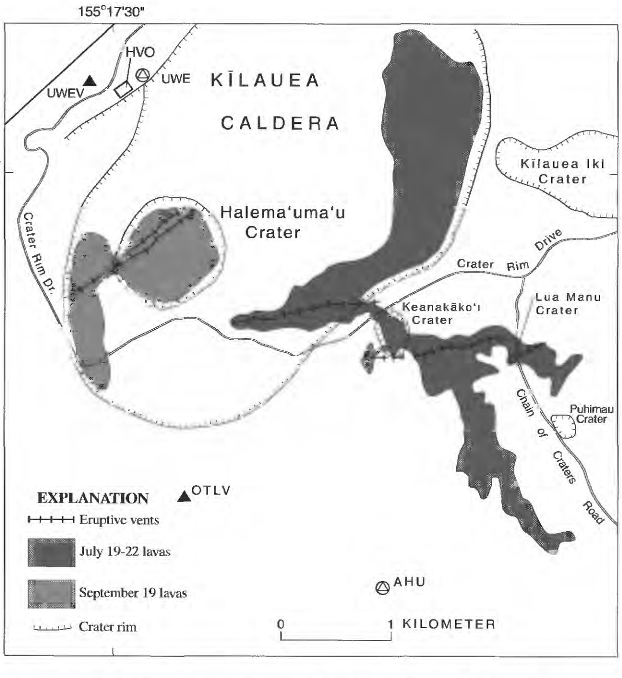

Figure 3.—Kīlauea Volcano summit area, showing location of eruptive vents and lava flows of the July and September 1974 eruptions, along with geographic features described in text. HVO, USGS Hawaiian Volcano Observatory; OTLV, Outlet Vault; UWEV, Uwēkahuna Vault; UWE, Uwēkahuna geodetic station; AHU, Ahua geodetic station.

Figure 5.—Thin pāhoehoe flow advancing across the east side of Kīlauea caldera on July 19, 1974 at about 14:00. The active flow is covering an earlier formed flow; note the fresh lava emerging from cracks in the crust of the earlier flow. USGS photo by R.T. Holcomb.

others, 1982). Lava from this fissure flowed into the August 1971 fissure as well as cascaded over the wall of the summit caldera. Shortly thereafter, two en echelon fissures broke out to the west, on the Kīlauea Caldera floor (Figs. 3, 18), and lava from all three fissures north of Crater Rim Road began to advance across the flow field of the August 1971 eruption. The advance eastward across the caldera floor was rapid, and involved complex sheet flow as new lava spread over thin crusts of slightly older flow sheets (fig. 5).

During essentially the same time interval, the activity to the south also increased, and several other new en echelon fissures extended rapidly both to the west and to the east of the initial outbreak in Keanakāko'i Crater (fig. 3). A fast-moving, fluid flow consisting of slabby pāhoehoe and loose a'a traveled quickly to the south and southeast for more than 2 km (fig. 6). These flows encased large ohia trees with chilled lava near their source vents, forming a field of "lava trees" when the fluid portions of the lava later flowed away from the encased trees (Lockwood and Williams, 1978). Moore and Kachadoorian (1980) used subsequent rheological observations of these lava trees to determine that flow velocities for this branch of the July 1974 flow varied between 5.7 km/hr (near eruptive vents) to 0.5 km/hr (near this flow's distal end).

By 13:00, lava from fissures on the southern rim of Keanakāko'i began to cascade into the crater; these spectacular lava cascades, together with lava erupted by the within-crater fissure, completely covered the crater floor to a depth of about 5 m, burying the blanket of 1959 tephra that had previously mantled lava of 1877 age. Also by 13:00, the easternmost of these "southern" fissures had extended 300 m east of Lua Manu Crater (fig. 3), cutting the Chain of Craters Road. Lava cascades poured into Lua Manu and, together with lava

Figure 6.—Aerial view to the northwest of the July 1974 lava flows, which extend south to the bottom of the photo and across the east side of Kīlauea Caldera. Mauna Loa Volcano forms the slopes beyond Kīlauea Caldera; Mauna Kea Volcano in the distant background. USGS photo by J.P. Lockwood.

derived from a fissure on this crater's east wall, partly filled the crater with about 15 m of lava. About two-thirds of this lava later drained back into the fissure, leaving a prominent "lava-subsidence terrace" (high lava mark) half way up the crater's walls.

All fissures north and south of Crater Rim Road were vigorously active when, at 13:15, two new en echelon fissures broke out north of the northern edge of Keanakāko'i Crater, in the area between the previously formed fissures (figs. 3, 4). Some lava from these latest fissures crossed Crater Rim Road about 10 minutes later and began to cascade down the north wall of Keanakāko'i Crater. However, most of the lava from the fissures north of the Crater Rim Road poured over the wall of the caldera to feed the flow spreading over the southeastern part of the caldera floor. One of these lava streams into the caldera raced down a curving gully, with lava banking up against and spraying the outside wall of several bends, much as had occurred in the same gully in 1971 (Duffield and others, 1982). This particular stream was later the topic of a detailed flow-dynamics analysis by Heslop and others (1989), who concluded that it was characterized by laminar flow, traveled at a mean velocity in excess of 8 m/s, and had low or negligible yield strength and viscosities in the range of 85-140 Pa-s.

By 13:45, lava from the westernmost of the southern line of fissures (fig. 3) also began to cascade into Keanakāko'i Crater, while the vent activity at the fissure inside the crater was decreasing. Meanwhile, within the summit caldera, the fissures remained vigorous, feeding lava that had covered about one-half of the August 1971 flow field by 14:35. Although there were momentary surges in lava-fountain heights to 45-55 m, discharge rates at all fissures gradually began to decline; by 16:15, all activity had ceased along the fissures south of Keanakāko'i. However, low fountaining from the two fissures in the caldera floor persisted until the early morning of July 20. One vent on the caldera floor continued to spatter and feed a small flow through July 21, but all eruptive activity stopped by early morning of July 22.

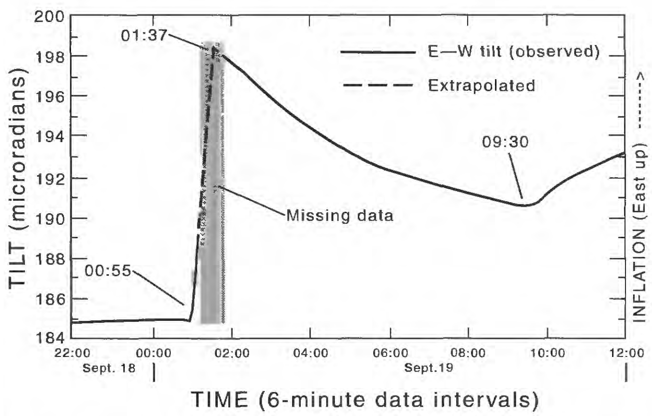

Figure 7.—E-W tilt component from the Ideal-Aerosmith tiltmeter at Uwēkahuna Vault for a 14-hr period preceding, during, and after the September 19 eruption. Based on 6-min reading intervals.

All lava flows during this 3-day eruption were highly fluid and fast flowing, typically less than a meter thick near their source vents. Near eruptive fissures, lava flows appeared to have been gas rich, as indicated by the formation of cavernous "shelly" pāhoehoe (Swanson, 1973), with vesicle and gas-cavity space locally comprising as much as 80 percent of the bulk volume. The flows consisted entirely of pāhoehoe near Keanakāko'i Crater and on the caldera floor, but formed platy pāhoehoe and rubbly 'a'a in the south-trending flow west of Puhimau Crater (fig. 3), where the flow was only 1.5-m thick at its distal end. Lavas from the July 19-22 eruption covered an area of 2.91 km^2, and the estimated total eruptive volume was about 6.5 x 10^6 m^3. These vesicular lavas have an estimated DRE (dense rock equivalent) volume of 4.9 x 10^6 m^3.[1]

The July 1974 lavas are nearly aphanitic tholeiitic basalts with widely scattered minor olivine and/or plagioclase phenocrysts about 1 mm across; representative modal compositions are given in table 2. As later discussed, lavas erupted from the fissures north of Keanakāko'i have chemical compositions quite distinct from those of lavas erupted from fissures south of Keanakāko'i.

SEPTEMBER 19, 1974 ERUPTION

Following the July eruption, leveling and tilt measurements showed a center of tumescence to be migrating westward from the Keanakāko'i area to the area south of Halema'uma'u (figs. 3, 18). Very small, shallow, short-period earthquakes centered south of the caldera near Outlet Vault (fig. 3) also increased, especially after September 16. The news media soon learned of these developments, and HVO spokesmen were being quoted in the press as anticipating an imminent eruption on Kīlauea's SWRZ, largely drawing upon a reasonable comparison with events 3 years earlier, when the August 14, 1971 summit eruption was followed within less than 6 weeks by a summit-SWRZ eruption (Duffield and others, 1982). Thus, by early September 1974, HVO staffers and the public alike were primed for a possible repeat of the 1971 pattern.

There was little warning of the brief eruption soon to occur. In contrast to the July summit eruption, there was much less precursory seismicity (no felt earthquakes) prior to the September eruption. Just after midnight on September 19, however, at 00:44 HST, small instrumentally detected earthquakes (1-3/min) local to the North Pit seismometer (in Kīlauea Caldera) began to occur. At 00:47 these earthquakes increased to 5-10/min and weak tremor began. The Ideal-

Methodologies for determination of areas and volumes:

[1]*Area covered* was determined by digital analysis of mapped flows and is accurate to ± 5 percent.

[2]*Volume erupted* was determined by field estimation of flow thicknesses in each of 26 subareas of known area. Such estimates are inherently imprecise (especially for thicker flows) and are accurate to only perhaps ± 25-30 percent.

Table 2.—Modal compositions (volume percent) of the lavas of the 1974 summit eruptions. [Modal determinations by J.P. Lockwood, John Luczaj, and F.A. Trusdell].

	July 1974		September 1974			December 1974	
	Southern vent	Northern vent	Distal flow	Halema'uma'u		Earliest vent	Distal flow
				Spatter	Pāhoehoe		
Thin section No.	L-92-59A	L-92-60	L-92-61	L-92-65	L-92-66	L-92-63	L-92-64
Total points	3,300	1,500	1,600	2,000	1,500	2,000	2,200
Non-void points used	1,910	1,059	1,039	1,046	1,079	1,309	1,760
Olivine (%)	4	1.4	0.5	1.1	2.2	20.0	8.5
Plagioclase (%)	3.9	0.1	---	0.4	0.4	---	0.1
Clinopyroxene (%)	0.7	0.1	---	0.1	---	---	---
Matrix (%)	91.4	98.4	99.5	98.4	97.4	80.0	91.4
TOTAL (%)	100	100	100	100	100	100	100

Aerosmith continuously recording tiltmeter at Uwēkahuna Vault (fig. 3) also showed an abrupt but slight (0.04 μrad) deflation in E-W tilt at this same time, and at 00:55 a precipitous inflation (west down) began. The tiltmeter recorder went off scale at 01:10, causing the tilt record to be lost for the next 44 min, until the recorder was reset by HVO staff. A reconstruction of the lost record (fig. 7) shows that a little over 13 μrad of inflation occurred at Uwēkahuna (caused by the injection of ascending magma) and that a gradual deflation began about 01:37. Meanwhile, seismic tremor magnitude increased, as did the frequency and magnitude of earthquakes, as the ascending dike neared the surface; tremor alarms sounded at 01:21. At 01:27, glow above Halema'uma'u indicated an eruption was already in progress. By 01:32, tops of lava fountains could be seen above Halema'uma'u's north rim in the northeast corner of the crater. These initial fountains must have been nearly 100 m high. The fountains then rapidly migrated southwestward across Halema'uma'u's floor, and at 01:45 a "curtain of fire" climbed the crater's west wall. A line of fountains about 20 m high migrated across the 0.5 km from the west rim of Halema'uma'u to the west wall of Kīlauea Caldera (fig. 3) within 1 min, where the rapid southwest advance of the fountains came to an abrupt stop. This was a significant deviation from the September 1971 pattern, when eruptive fissures quickly migrated out of the caldera, across the Crater Rim Drive, and far down the SWRZ. The fountains on Halema'uma'u's floor then quickly subsided in height, but lava was still being erupted at an estimated rate of nearly 2 x 10^6 m^3/hr. Fountaining extended across the crater floor in two continuous, N. 60° E fissures about 70 m apart (fig. 3).

By 02:30, lava spreading from the two fissures had covered about three-quarters of Halema'uma'u's floor, and lava falls were cascading into a small central pit crater that had formed near the end of the 1967-68 eruption (Kinoshita and others, 1969). The N. 30° E-trending line of fountains outside Halema'uma'u on the caldera floor produced an active pāhoehoe flow that flowed south and cut the Crater Rim Road at 02:55. By 03:00, Halema'uma'u's floor was completely covered. At 03:05, a flow moving north from the caldera-floor fissures circled back and began cascading into Halema'uma'u. The southern line of fountains on Halema'uma'u's floor began to be drowned by the rising lava lake, and by 04:45 only three small (2- to 5-m-high) fountains remained visible along this fissure, although a linear zone of upwelling indicated that discharge continued along the length of this fissure. The northern row of fountains rapidly diminished in height after 06:00 and at 08:00 began loud degassing. All vigorous fountains on the floor of Halema'uma'u were soon drowned by the rising lake, but broad upwelling dome fountains 15-20 m high were still produced along the linear trends of former fountains. At about this time, the lava lake level began to subside, either through degassing processes or by drainage through unknown openings on the floor of Halema'uma'u. Low fountains nonetheless remained active at a few places along the eruptive fissures until mid-afternoon. Irregular overturning of the lake crust continued until the morning of September 22.

At its highest level, reached at about 09:30, the lake covered the entire floor of Halema'uma'u except for the tops of three high spatter cones formed during the 1967-68 eruption (Kinoshita and others, 1969)[2]. The lake surface lowered rapidly and by 13:00 had dropped about 7 m. During this possible drainback episode, large areas of the lake crust slowly rotated counterclockwise, much as would a large bathtub being drained in the northern hemisphere.

At 09:30, coincident with highest lake level, E-W deflation as recorded by the Uwēkahuna Ideal-Aerosmith tiltmeter "bottomed out" and the Kīlauea summit began to reinflate (fig. 7). The morning's 8-hr deflation did not equal the magnitude of the postmidnight inflation, however, and so the 09:30 reinflation began at a level 5.6 µrad higher than that prevailing before September 19.

The total area covered during this eruption was only 1.06 km^2. Relatively accurate determination of eruptive volumes was possible, since most of the erupted lava was confined to Halema'uma'u. About 11.7 x 10^6 m^3 of lava was erupted initially, all but 0.5 x 10^6 m^3 of which accumulated in Halema'uma'u. Drainback, combined with degassing volume reduction, withdrew about 4.8 x 10^6 m^3 from Halema'uma'u, leaving a prominent lava-subsidence terrace 9 m above the final, solidified lake surface; the estimated average depth of the lake after drainback was about 10 m. The residual volume for the entire eruption was about 6.9 x 10^6 m^3. The extensive convective circulation of lava in Halema'uma'u allowed efficient degassing, resulting in residual dense, sparsely vesicular lava for the bulk of the September lavas. Our estimate of the overall DRE volume of the September lavas is 5.7 x 10^6 m^3.

The September lavas consist of sparsely olivine-phyric fountain-fed pāhoehoe (table 2). In contrast to the lavas of the July summit eruption, the September 19 lavas were relatively uniform in composition (table 2).

A visit to Mauna Ulu on September 23 showed that the crater floor was actively subsiding at that time, as evidenced by loud grinding noises coming from the fume-shrouded crater bottom. Glowing cracks circumferential to the crater rim also indicated ongoing crater collapse, which had apparently accelerated during the September eruption. The crater had enlarged considerably in diameter since the cessation of Mauna Ulu eruptive activity coincident with the July summit eruption.

DECEMBER 31, 1974 ERUPTION

Beginning immediately after the September eruption through December, the summit region of Kīlauea inflated more than 30 µrad, as measured by the E-W component of Uwekāhuna tiltmeters (see fig. 13), attaining the highest inflation state since daily tilt measurements were initiated at Uwēkahuna in 1956. A reoccupation of the summit "Electronic Distance Measurement" (EDM) monitor lines on December 23 showed that the two survey lines across the southwest margin of the caldera continued to show higher rates of extension than the other summit lines, possibly indicating localized inflation not detectable in the Uwēkahuna E-W tilt record.

The December 31 eruption was preceded by a monthlong premonitory increase in summit and upper ERZ seismicity, particularly during the final week of December. On Christmas Day at 07:48, a 32-km deep, magnitude 4.5 summit earthquake was widely felt on Hawai'i. During the following 3 days, more than a hundred aftershocks occurred, one of which at 12:20 on December 25 registered ~M 3.5. Also on Christmas Day, three closely spaced offshore earthquakes occurred south of the Hilina Fault System (fig. 1) at 18:13 (M=4.0), 18:17 (M=3.7), and 18:24 (M=4.5). These were felt by residents of Volcano, parts of Puna, and Hilo. Over the next several days, two shallow summit earthquakes, magnitudes 2.5 and 1.5 respectively, were felt by residents of Volcano and Hawai'i National Park. At 19:24, December 28 a Kīlauea southeast-flank earthquake of magnitude about 3.8 was felt in Puna and Hilo.

On the evening of December 30, shallow summit earthquakes local to the Outlet Vault seismic station, located in the southwestern part of the summit (fig. 3), started to increase in number, with shocks occurring at rates of 2-4 per minute by 22:54. At 23:03, a moderate earthquake (M~2.2) was felt in the Hawai'i National Park housing area (northernmost corner of fig. 2). At 23:58, another south caldera earthquake (M~2.3) was felt, followed by a steady succession of smaller earthquakes, mostly M<1. Shortly after midnight (00:10, December 31), the seismic alarms sounded at HVO residences and the E-W component of the Ideal-Aerosmith tiltmeter (fig. 8) began a precipitous summit deflation (approximately 3 µrad/hr). By 02:05, continuous tremor activity had increased to such an intensity (5 mm peak-to-peak amplitude—fig. 8) that it was detected at the MLO station, located more than 15 km away, on the southeast flank of adjacent Mauna Loa. At the same time, the deflation rate had nearly tripled, increasing to more than 11 µrad/hr (fig. 8). The combination of increasing seismicity, intense tremor, and abrupt deflation signaled an imminent eruption, and all eyes at HVO looked to the southwest, where seismic activity was concentrated.

At 02:56, lava fountains were sighted toward the south-southwest, in the direction of Sand Hill (fig. 2). By 03:10, lava fountains 35-40 m high had formed a 100 m-long, N 80° E.-trending "curtain of fire" approximately 1.5 km south of Sand Hill. The fissure, consisting of several closely spaced en echelon segments (fig. 9), was advancing at both ends, and the line of fountains rapidly extended to a length of about 700 m. Several more widely spaced, left-stepping en echelon fissures, with individual trends of N. 70-85° E., then be-

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[2]These spatter cones, and the central area of the Halema'uma'u crater floor, had subsided 45 m from their 1968 level during the September 1971 eruption (Duffield and others, 1982). Our September triangulation showed that the spatter cones, and presumably the entire crater floor, had subsided an additional 2.5 m between late September 1971 and late September 1974.

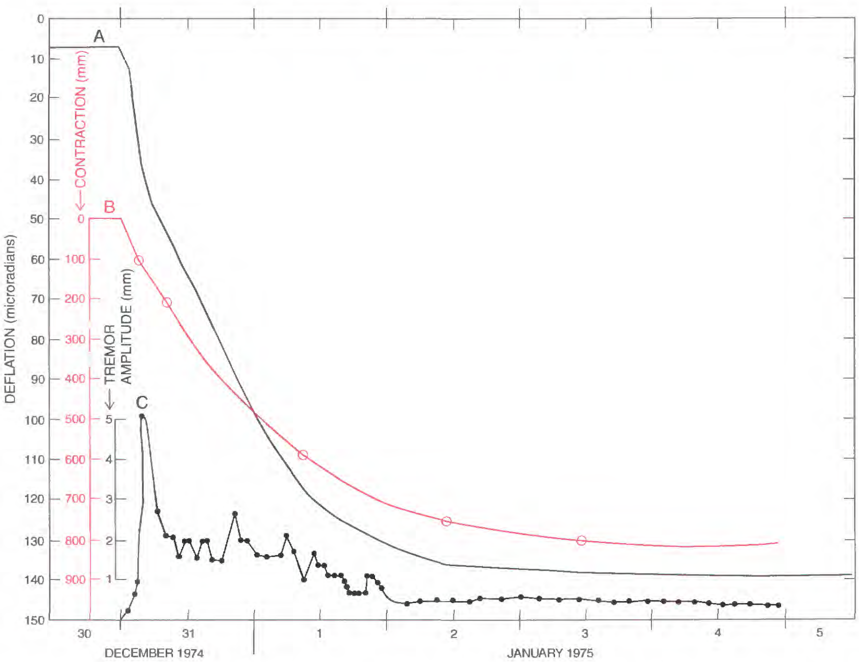

Figure 8.—Deformation and seismicity of the Kīlauea summit area as measured by instruments at Uwēkahuna for the period December 30, 1974 to January 05, 1975. A, E-W tilt component from the Ideal-Aerosmith tiltmeter, based on hourly readings (μrad). B, Contraction of an Electronic Distance Measurement (EDM) line across Kīlauea Caldera, between Uwēkahuna and Ahua geodetic stations (mm). C, Peak-to-peak amplitude of seismic tremor (mm) at UWE seismometer from hourly averages.

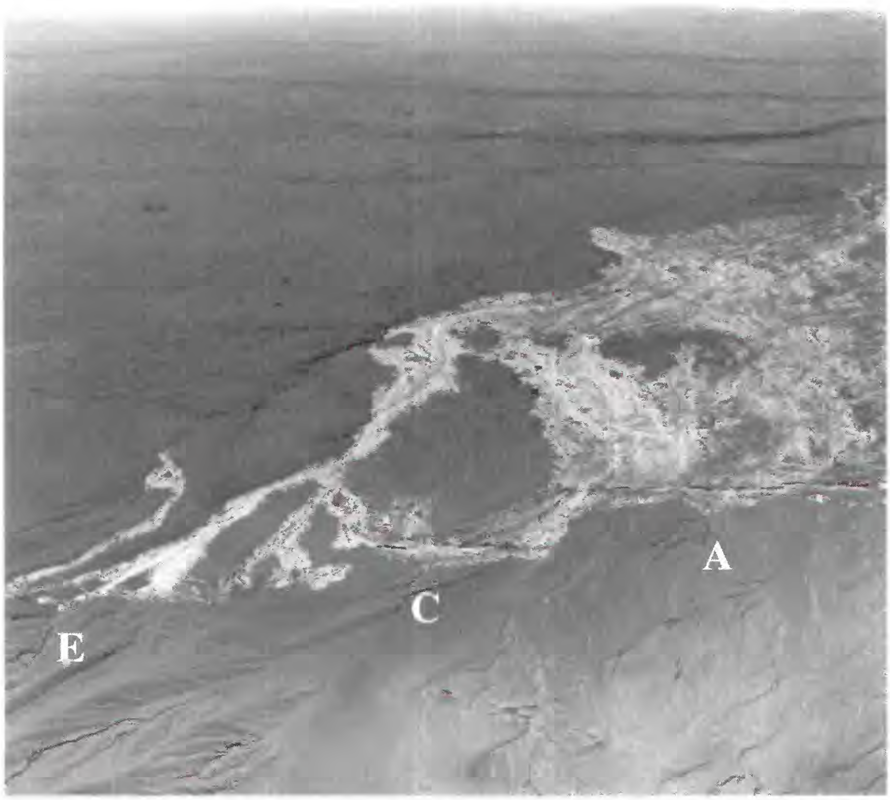

Figure 9.—Aerial view to the southeast of the easternmost, *en echelon* vents and flows of the December 31 eruption. USGS photo by Elliot Endo. A, C, and E mark the vent fissures shown in figure 2.

gan to extend to the east- northeast and to the west-southwest. The approximate chronologic progression of fissure openings is indicated on fig. 2.

The sequence of fissure opening and the appearance of lava were fascinating to observe in the eerie, flickering, predawn red light given off by the dancing lava fountains. As ascending dikes rose close to the surface, a series of new ground cracks would open, typically about 50 m ahead of established fountains, as the entire dike system advanced laterally across the Ka'u Desert, at rates as great as 30 m/min. In the area of opening cracks, numerous small earthquakes caused a near-constant rocking sensation and continuous low-frequency tremor could be felt by on-site observers, usually accompanied by the sharp cracking sounds of breaking rocks. Numerous conspicuous, subparallel cracks formed over elongate areas about 10-m wide, but the cracks from which lava would soon fountain opened wider and were usually marked by small graben structures in the preexisting cover of Keanakākoʻi Ash (Decker and Christiansen, 1984). Such cracks began to fume profusely when they had dilated about 10 cm. Soon the white steam (appearing red in fountain light) would change to pungent, SO_2-rich fume and within two minutes magma could be heard rumbling at depth, as fissures rapidly dilated to 50-80 cm width. Glow then soon could be seen in the cracks, and one quick (but perilous) glance revealed viscous, gas-depleted lava rising rapidly at depths of 5-10 m. Gas bursts would throw clots of spatter out of the crack first, and as magma reached the surface, continuous fountains quickly rose to 10 m and, within a few minutes, would reach 30 m in height. The entire sequence from the initial ground cracking to established lava fountaining took 3-10 min at any one site. Later surveys revealed that minor ground cracking subparallel to the eruptive fissures extended to more than 50 m away from the actual vents (Pollard and others, 1983).

The deflation rate at the summit began to decrease even as the effusion of lava continued unabated. The average deflation rate was 11.4 μrad/hr during the interval 02:00-04:00

Figure 10.—Surface texture of December 31, 1974 pāhoehoe northeast of Pu'u Koa'e. Note the 10-m-diameter "lava coil" in the right middle of the photo. USGS photo by Elliot Endo.

but decreased to 5.2 µrad/hr during the interval 04:00-06:00 (fig. 8). By about 04:40, the eastward migration of the active fissure systems ceased, with the easternmost fissures (segment E, fig. 2) ending within half a kilometer of the September 1971 flow lobe near Outlet Vault (fig. 3). The westward migration of the eruptive fissures was slightly more rapid. By 05:00, fissure vents (segment H, pl. 1) had opened nearly 1 km north of Cone Crater, and a lava flow had cut the Mauna Iki trail and began to cascade into the westernmost pit crater. This area of the southwest rift zone is marked by numerous deep fissures, many of which likely formed in 1868 (Brigham, 1909). Large amounts of lava cascaded into them and into a small pit crater southwest of Cone Crater (fig. 2, 1 mi S. of segment G). The surface lava flows were gas rich and fast flowing, and the pāhoehoe surfaces were constantly breaking apart, reforming, and forming large, thin plates, which formed remarkably large eddies and lava coils (Peck, 1966) where partially congealed, thin lava skins were trapped between plates flowing at different velocities (fig. 10).

At the peak of eruptive activity, fountain heights intermittently reached a maximum of 100 m but generally averaged about 30-40 m. Shortly after 05:00, fountaining waned noticeably and became more gas rich at the east end of the fissure system, but strong activity persisted to the west. Eruptive fissures continued to migrate southwesterly. The westernmost fissure of this eruption (segment I, fig. 2) opened about 06:30 in the area northeast of Pu‘u Koa´e. From that time on, all lava fountains gradually subsided, and by 08:50 all vent activity stopped, although the walls of eruptive fissures still glowed red and a thin fountain-fed ´a‘a flow continued to move toward the Kamakai´a Hills (fig. 2). The gas-charged shelly pāhoehoe of this fast-moving flow converted to ´a‘a within 2 km of eruptive vents, and is a good example of the pāhoehoe to a'a transition (Peterson and Tilling, 1980).

Pollard and others (1983) mapped the December 31 eruptive fissures and associated ground cracks in detail, and readers may refer to their publication for detailed vent geometry, analysis of subsurface dike characteristics, and the detailed distribution of lava flows near the vent areas.

Lava from the eruption covered an area of about 7.25 km^2, the largest area covered southwest of Kīlauea Caldera since the 1919-20 SWRZ eruption centered at Mauna Iki (Macdonald and Abbott, 1970, table 3; Hazlett, 1993). The lava flows were typically less than 1 m in thickness, however, and the total volume of erupted material was estimated to be only about 5.9×10^6 m^3. The lavas were extremely fluid and thin near eruptive vents, and hundreds of small kīpuka of the underlying Keanakāko‘i Ash are exposed within the flows (see Pollard and others, 1983, fig.15) for detailed mapping of these features). The December 31 lavas everywhere consisted of highly vesicular shelly pāhoehoe and low-density fountain-fed ´a‘a, and their estimated DRE volume was only 3.0×10^6 m^3. This estimate should be considered a minimum, however, because some lava flowed into preeruption fissures and cannot be accounted for.

As discussed later, the olivine-phyric lavas erupted during this 6-hr eruption were distinctly more mafic than those of the July and September eruptions, and the lavas were characterized by abundant euhedral olivine phenocrysts (fig. 11). Representative modes of the December 1974 lavas are given in table 2.

TECTONIC SIGNIFICANCE OF THE DECEMBER 31 ERUPTION

The pathways by which magma reaches Kīlauea's surface during the initial eruptive stages are controlled by the orientation of preexisting stress fields in the Kīlauea edifice. In the Kīlauea summit area (above about 1,000 m elevation), most eruptions occur within the boundaries of Kīlauea Caldera, or along either of Kīlauea's two rift zones (fig. 12). The December 31 eruption was not located in either the caldera or the historically active SWRZ, however, but instead belongs to a unique class of eruptions that take place south of the Kīlauea Caldera, in a wedge-shaped area lying between the SWRZ and the Koa´e Fault System (KFS). Individual fissures in this area, including those formed on December 31, trend about N. 75° E. and appear to have been controlled by

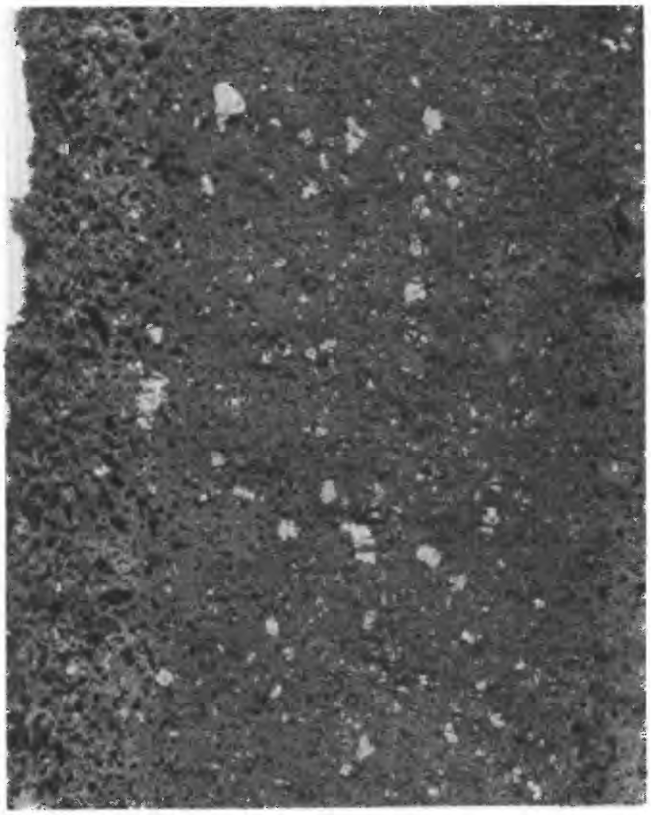

Figure 11.—Selvage on margin of early formed dike on the east end of the December 31, 1974 eruptive vents, showing abundance of euhedral olivine in this early formed lava (mode in table 2, sample L-92-63).

regional stress fields associated with the KFS instead of the stress field governing eruptive pathways of the SWRZ, which typically trend about N. 45° E.. The overall zone of individual en echelon fissures formed on December 31 trends N. 55° E., however, and Pollard and others (1983) speculated that the individual ENE-striking dikes at the surface may merge into a single NE-trending dike at depth, suggesting a complex tectonic regime not strictly part of either the KFS or the SWRZ.

The Koa´e Fault System (Duffield, 1975) is a relatively young feature on Kīlauea and may be generally described as a reflection of the westward extension of stress fields associated with Kīlauea's middle and lower east rift zone. The KFS is a zone of normal faulting and had not been characterized by eruptive activity prior to the 1970's. Magma did, however, migrate westward into the eastern end of the KFS during the small eruption of May 5, 1973, and a small amount of lava reached the surface a kilometer southwest of the Chain of Craters Road (Tilling and others, 1987). Deformation and seismic observation showed clearly that a dike had intruded into the eastern Koa´e at this time and extended west of the surface vents (Koyanagi and others, 1983; Klein and others, 1987). Electrical Self-Potential (SP) measurements by Zablocki (1978) demonstrated the subsurface intrusion of magma extended nearly 3 km into the KFS.

The first recorded injection of magma into the KFS may have taken place 8 years earlier, during and following the eruption of December 1965 (Fiske and Koyanagi, 1968). Sur-

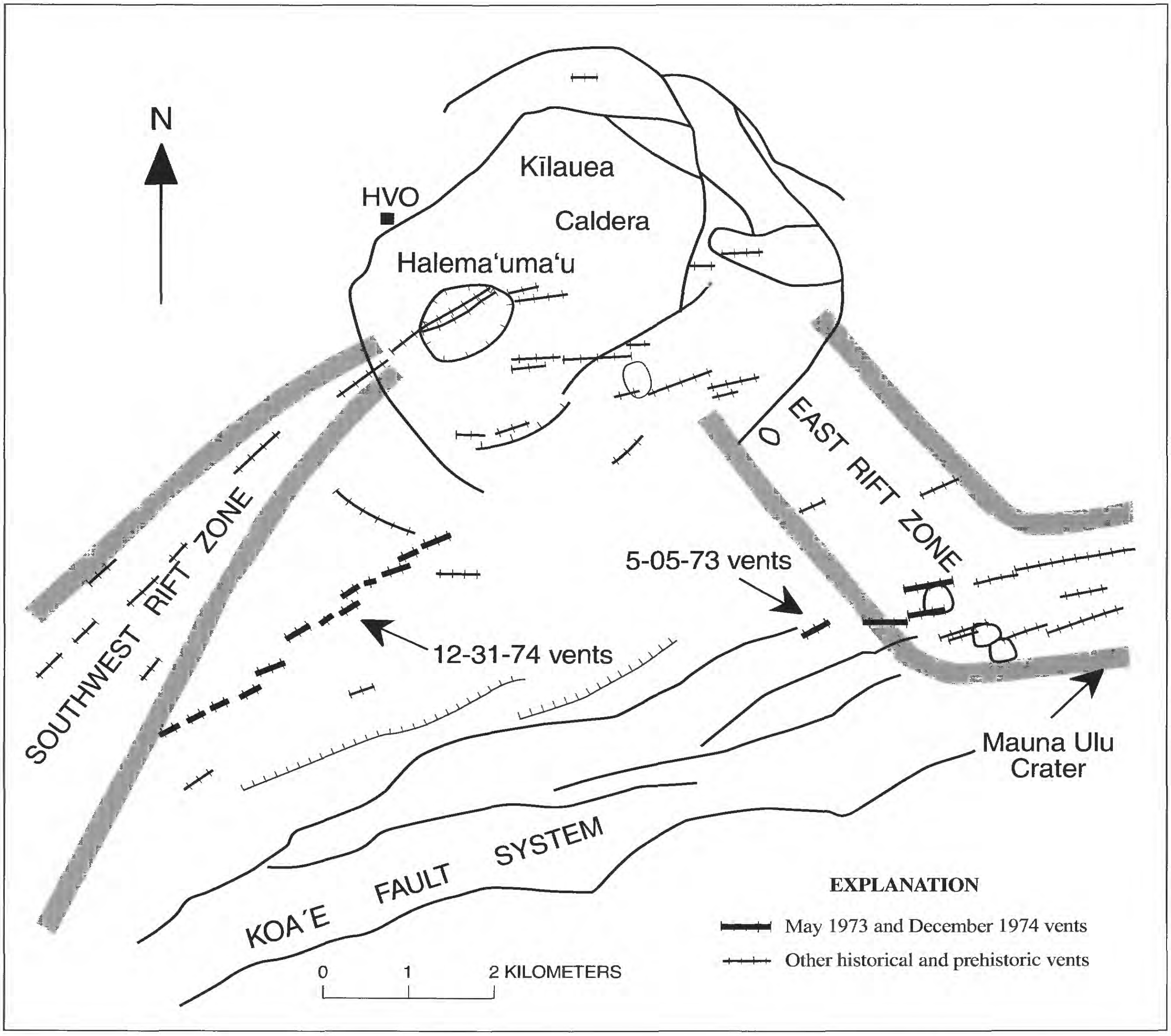

Figure 12.—Location of the May 1973 and December 1974 eruptive vents, showing their relationship to the Koa´e Fault System and to other historical and prehistoric vents in the Kīlauea summit area.

face eruptive vents for this brief eruption were all located within the ERZ, east of the Chain of Craters Road, but major dilation of KFS faults and ground cracking extended about 10 km westward into the KFS (Fiske and Koyanagi, 1968, fig. 1). Although surface eruptive activity ceased by the early morning of Christmas day, volcanic tremor continued for over 36 hours, major fractures continued to dilate, and fresh ground cracks developed. It is probable that magma was injected into the KFS at this time.

The en echelon eruptive vents of December 31, 1974 were individually parallel to, though not located within, the KFS (fig. 12); they represented the largest eruption ever to occur along the KFS trend in this area. Four other small, late prehistoric vents have been mapped with Koa´e orientation near the December 31 vents, but these each had very limited production (Walker, 1969).

The apparent entry of magma into fringes of the KFS is a relatively new development in the evolution of Kīlauea. Is the KFS now likely to become a significant new locus of future Kīlauea eruptive activity, as Kīlauea's south flank continues to be displaced southward (Fiske and Swanson, 1992)? Or, will the pace of extensional dilation in the KFS exceed the supply of magma to this zone, so that most volcanic activity will be intrusive and not extrusive?

JANUARY 1-10, 1975 INTRUSION

As described above, very rapid summit deflation preceded and accompanied the December 31 eruption. However, even after the cessation of visible activity, sharp summit deflation, as measured by the E-W component of the Ideal-Aerosmith tiltmeter, persisted for the next 24 hr at rates between 2 and 3 μrad/hr (fig. 8). Electronic Distance Measurement (EDM) measurements across Kīlauea Caldera were obtained multiple times during following the December 31 eruption. Major contractions of these EDM lines (fig. 8) also showed that deformation of the summit area continued for about 3 days following cessation of eruptive activity. Collectively, the persistence of sharp summit deflation as measured by tilt and EDM surveys after cessation of visible activity, the continuing volcanic tremor through January 2, 1975, the continued intense seismicity downrift of the December 31 vent fissures through early January, and ground cracking in vent as well as nonvent areas (Pollard and others, 1983) strongly suggested substantial posteruption intrusive activity downslope from the area where the KFS meets the SWRZ (fig. 12). This inference is also well substantiated by earthquake distribution (see fig. 23).

An April 1975 level profile across the area of intense January seismicity revealed a 4-km-wide "bulge" of 9 cm height relative to the previous survey in 1921 (unpublished HVO Monthly Report, 8/21/75 - 9/20/75). It is not known when this uplift actually formed, but it is interesting to speculate that it could reflect the injection of magma into this area in January 1975.

GEOPHYSICAL OBSERVATIONS GEODETIC MONITORING

Kīlauea Volcano is well known to deform in a quasi-elastic manner in response to the shifting supply of stored magma within its edifice (Mogi, 1958; Dvorak and others, 1983; Dzurisin and others, 1984). Geodetic measurements by HVO staff document such deformation across Kīlauea's summit area during the last half of 1974 and show that the centers of preeruption magmatic inflations and syneruptive deflations were migrating systematically westward across the volcano during this time.

Continuous measurements of Kīlauea deformation are only possible at specific points on the volcano (measurements of tilt at tiltmeter sites or of strain along local survey lines or across cracks). Regional studies (EDM, GPS, or leveling surveys) are required to understand behavior of larger areas of the volcanic edifice, but such surveys are time consuming and thus infrequent. Because of this, the HVO field surveys were not made at the ideal times immediately before and immediately after eruptive activity, but instead spanned longer periods, which include effects of both preeruptive, syneruptive, and posteruptive deformation (table 3). Continuous or daily tilt measurements at Uwēkahuna can be used to infer the nature of deformation between geodetic surveys.

SUMMIT TILT — THE UWĒKAHUNA RECORD

Beginning in 1956, daily measurements of summit tilt at Kīlauea have been made by means of a short-based water-tube tiltmeter at Uwēkahuna Vault, northwest of Halema'uma'u (fig. 3). These measurements were supplemented by the installation of a continuously recording mercury-capacitance tiltmeter (Ideal-Aerosmith) at the same site in June 1965. The water-tube tiltmeter readings give N-S and E-W tilt components, but the Ideal-Aerosmith tiltmeter record yields only the E-W component. These Uwēkahuna tilt measurements record tilt at only a single point, but nonetheless provide a reliable indicator of the general degree of tumescence of Kīlauea's summit reservoir, as it inflates or deflates in response to influx or withdrawal of magma (Eaton and Murata, 1960).

A plot of summit tilt for the period January 1973 to August 1975 (fig. 13) provides context for the following discussion of the geodetic survey results. The first four months of 1973 show an essentially flat tilt curve with minor oscillations—a pattern characteristic of the quasi-steady-state regime that had prevailed since February 1972. The May-November 1973 period included the two eruptive outbreaks in the Pauahi area in May, each of which produced abrupt summit deflations of ~20 μrad on the E-W component (fig. 13). Despite these two deflation events in 1973, the entire 1972-74 Mauna Ulu eruption resulted in negligible net inflation of Kīlauea's summit (Tilling and others, 1987).

After a small summit deflation associated with the voluminous May-June 1974 eruptive episode at Mauna Ulu (Til-

Table 3.—Geodetic surveys in Kīlauea Volcano summit region before, during, and after the 1974 summit eruptions.

Dates of survey	Type of survey
03-12 to 3-15-74	Summit spirit-level tilt
04-01 to 4-03-74	Summit EDM
04-04 to 4-05-74	Summit leveling
07-19 to 7-22-74	**Keanakāko'i eruption**
07-22 to 7-25-74	Summit EDM
07-22 to 7-26-74	Summit spirit-level tilt
07-31-74	Summit leveling
09-03 to 9-06-74	Summit spirit-level tilt
09-19-74	**Halema'uma'u eruption**
10-01-74	Summit leveling
09-30 to 10-10-74	Summit spirit-level tilt
11-04 to 11-07-74	Summit EDM
12-31-74	**South summit eruption**
01-06 to 01-13-74	Summit spirit-level tilt
01-14 to 01-17-75	Summit EDM
01-23-75	Summit leveling
09-17 to 09-19-75	Summit EDM
09-23 to 10-01-75	Summit spirit-level tilt

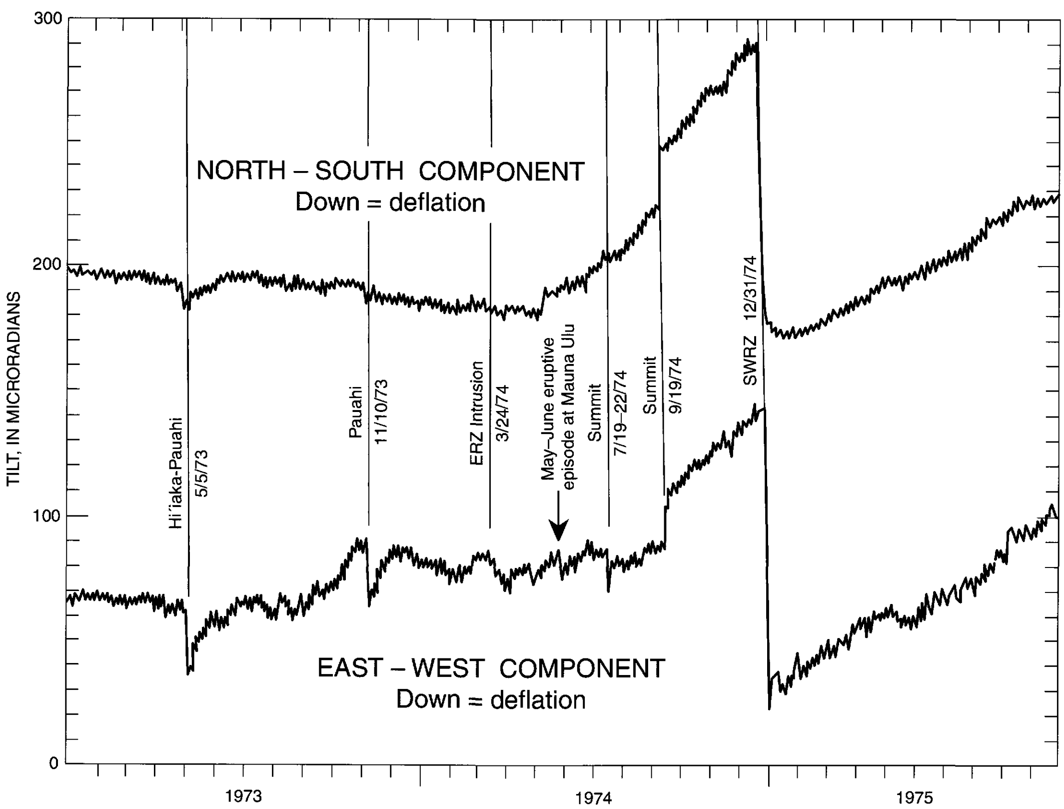

Figure 13.—Plot of E-W and N-S tilt components for the Uwēkahuna water-tube tiltmeter, 1973 to 1975.

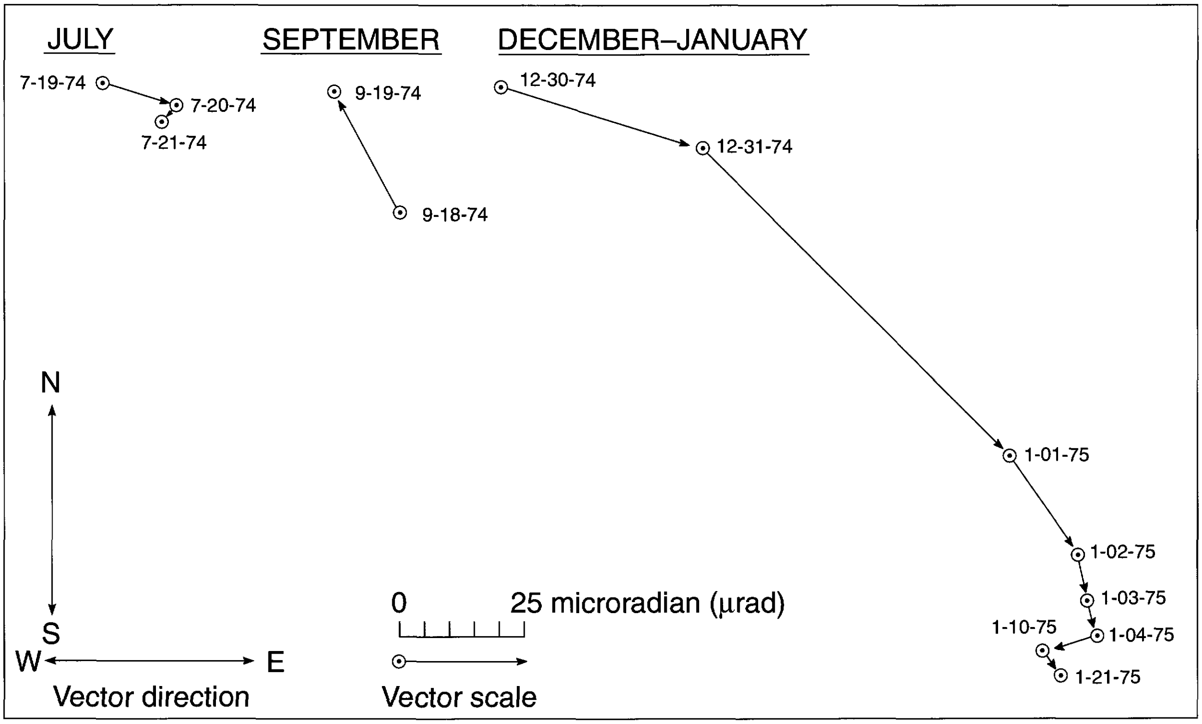

Figure 14.—Cumulative plots of Uwēkahuna water-tube tilt measurements during the July, September, and December 1974 eruptions. The resultant vectors shown are calculated daily readings of E-W and N-S tilt components.

ling and others, 1987), the summit region began to inflate rapidly, at a rate comparable to that for the period of net inflation in the latter half of 1971, which encompassed the summit (August) and SWRZ (September) eruptions. Similarly, net summit inflation during the latter half of 1973 indicated a blocking of the supply conduits to Mauna Ulu (Tilling and others, 1987) and helped set the stage for a return to summit eruptive activity. The July 1974 eruption, which also involved the uppermost ERZ, resulted in an 18-µrad summit deflation (E-W component, fig. 13). On the other hand, the September eruption produced a sharp inflation of ~14 µrad (fig. 7), as is commonly seen for summit eruptions, such as in 1971 (Duffield and others, 1982, fig. 2A). However, neither of the relatively small July or September eruption-related deformation events affected the overall steady summit inflation, that continued until onset of the December eruption. The December eruption was accompanied by a major, precipitous summit deflation (see Figs. 8, 13), which continued at gradually declining rates until the evening of January 5, when the Uwēkahuna tilt finally "bottomed out." This prolonged summit deflation and accompanying seismicity demonstrated that magmatic intrusion into Kīlauea's southwest flank persisted for days after the cessation of the December surface eruption. Summit deflation as measured by the Uwēkahuna short-base water-tube tiltmeter indicated that the E-W tilt bottomed out on January 3, but that the N-S tilt did not bottom out until January 16. Seismic activity was intense in the area southeast of the lower SWRZ for 2 weeks, with dozens of sharp earthquakes felt each day by residents of Pāhala. We have arbitrarily considered the January 1975 intrusion as lasting through about January 10.

The Ideal-Aerosmith E-W tilt data indicate that the summit deflation associated with the December eruption totaled about 132 µrad; however, the short-base water-tube tiltmeter measured somewhat less total deflation between maxima and minima: E-W component, 118 µrad; and N-S component, 117 µrad (fig. 13). This deflation of Kīlauea's summit region is the greatest since that of the September 1961 ERZ eruption, or possibly even since that of the 1959-60 Kīlauea Iki-Kapoho activity in the lowermost, subaerial part of the ERZ[3]. It also should be noted that before the large deflation associated with the December 31 eruption, the inflation state of the volcano attained its highest level since systematic summit tilt measurements began in 1956. Since that time, the Kīlauea summit has been showing overall deflation, and its reservoir is in its least swollen state since 1913 (Tilling and Dvorak, 1993).

The Uwēkahuna water-tube tilt record is conventionally plotted as separate traces of the N-S and E-W tilt compo-

[3]One unexpected secondary effect of this massive deflation was an apparent change in gas emission from the summit area. During the period of summit inflation prior to December, Halema'uma'u was fuming profusely and dense fume obscured all views into the deep crater of Mauna Ulu. Immediately after the December-January deflation, Halema'uma'u stopped all fuming, and the bottom of Mauna Ulu was visible for the first time since July 1974. These changes likely reflect the withdrawal of magma to deeper levels beneath Halema'uma'u and Mauna Ulu.

nents (fig. 13), but a plot of resultant tilt vectors for the three 1974 eruptions is of substantial interest (fig. 14). These plots, based on daily readings at roughly 24-hr intervals, show that the centers of deflation moved southwestward relative to Uwēkahuna during the July and December eruptions, but that a net inflation of the Halemaʻumaʻu area took place during the September eruption and resulted in northwestward tilt at Uwēkahuna. During the course of the July deflation, the deflation center migrated 18° clockwise (as seen from Uwēkahuna), and during the December-January deflation it migrated 30° in the same direction. Tilt vectors from a single point do not, of course, indicate the distance to deformation centers, but if one assumes that the deflation centers are roughly in the Halemaʻumaʻu area (as is indicated by regional spirit-level tilting, EDM, and leveling traverse surveys - - see next section), the shifting deflation vectors measured at Uwēkahuna indicate a westward or southwestward migration of several hundred meters during these deflation events. Another advantage of plotting resultant vectors from the Uwēkahuna water-tube tiltmeter (as in fig. 14) is that the total tilt magnitude can be calculated (about 164 μrad in the case of the December-January deflation).

SUMMIT SPIRIT-LEVEL TILT SURVEYS

Sixteen spirit-level tilt[4] stations around the Kīlauea summit were routinely occupied at the same time as other regional deformation monitoring efforts and provide a general

[4]The term "spirit-level tilting" (Kinoshita and others, 1974) will be used in this paper to describe the common field method of monitoring tilt that is also referred to as "dry-tilt" (Yamashita, 1981) and "single-setup leveling" (SSL—Yamashita, 1992). Yamashita suggests that SSL be the preferred term henceforth, but we prefer to use the original term, "spirit-level tilting," because in Hawaiʻi some stations involve more than one setup.

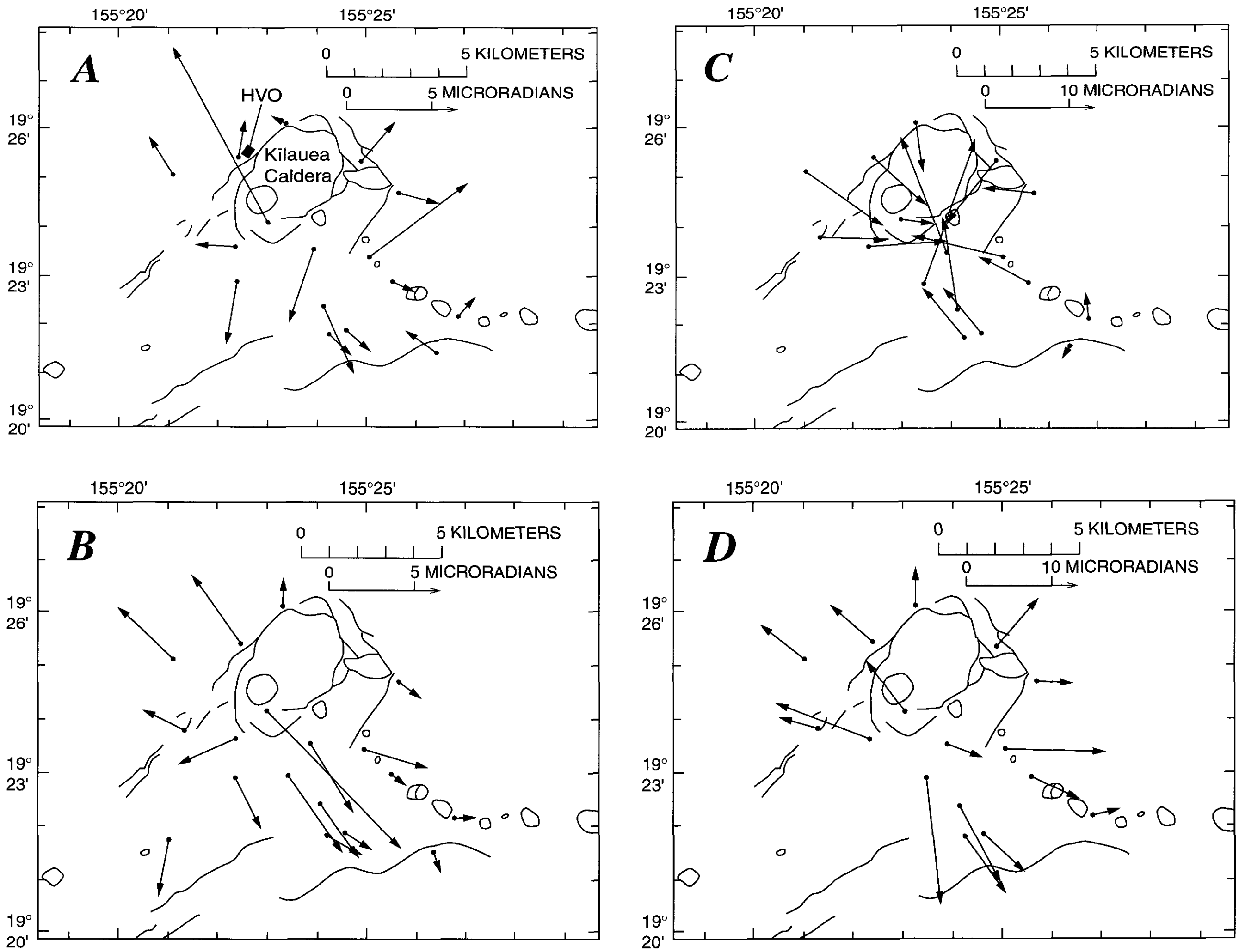

Figure 15.—Spirit-level tilt vectors at Kīlauea summit stations for periods between surveys from March 1974 and October 1975. Survey periods include the earliest and latest readings for each survey interval. ***A***, survey period 3/12/74 to 7/26/74; ***B***, survey period 7/22/74 to 10/10/74; ***C***, survey period 9/30/74 to 1/13/75; ***D***, survey period 1/06/75 to 10/01/75.

understanding of slope changes on the volcanic edifice. Individual calculated tilt vectors can be influenced by local and diurnal perturbations, but when combined with other survey methods (EDM and leveling) are important tools for obtaining a more comprehensive deformation picture for the time periods between surveys.

The Kīlauea spirit-level tilt stations were occupied just after the July eruption (fig. 15*A*), and record the summit inflation that had occurred since April. The apparent center of this inflation was located east of Halema'uma'u, near Keanakāko'i Crater, as is also apparent from concurrent EDM and leveling surveys (see figs. 16*A*, 17). The next survey was made after the September eruption (fig. 15*B*) and shows that the center of inflation after the July eruption had shifted westward, as was also shown by EDM and leveling surveys. The next spirit-level tilt survey, made in January 1975, shows the overwhelming influence of the major deflation which followed the December 31 eruption and points to a deflation center southeast of Halema'uma'u (fig. 15*C*). Another survey late in 1975 (fig. 15*D*) shows that the major reinflation following the December-January deflation was centered in roughly the same area.

HORIZONTAL DISTANCE SURVEYS

EDM surveys just after the July eruption showed that overall inflation in the preceding 3 months was located in the south-central caldera, east of Halema'uma'u (fig. 16*A*). A similar pattern is shown by tilt and leveling surveys (figs. 15, 17). The next EDM survey of the summit area was not made until November, after the September eruption, but at this time the net inflation since July shifted westward, to the Halema'uma'u area (fig. 16*B*). The next regional summit EDM survey, conducted in January 1975 after the December 31 eruption, showed the combined effects of the massive summit deflation, combined with the effects of magmatic injection into the area southwest of Kīlauea Caldera (fig. 16*C*). Repeated EDM measurements during and immediately following the December 31 eruption (fig. 8) showed well the rate of summit contraction. Following the December-Janu-

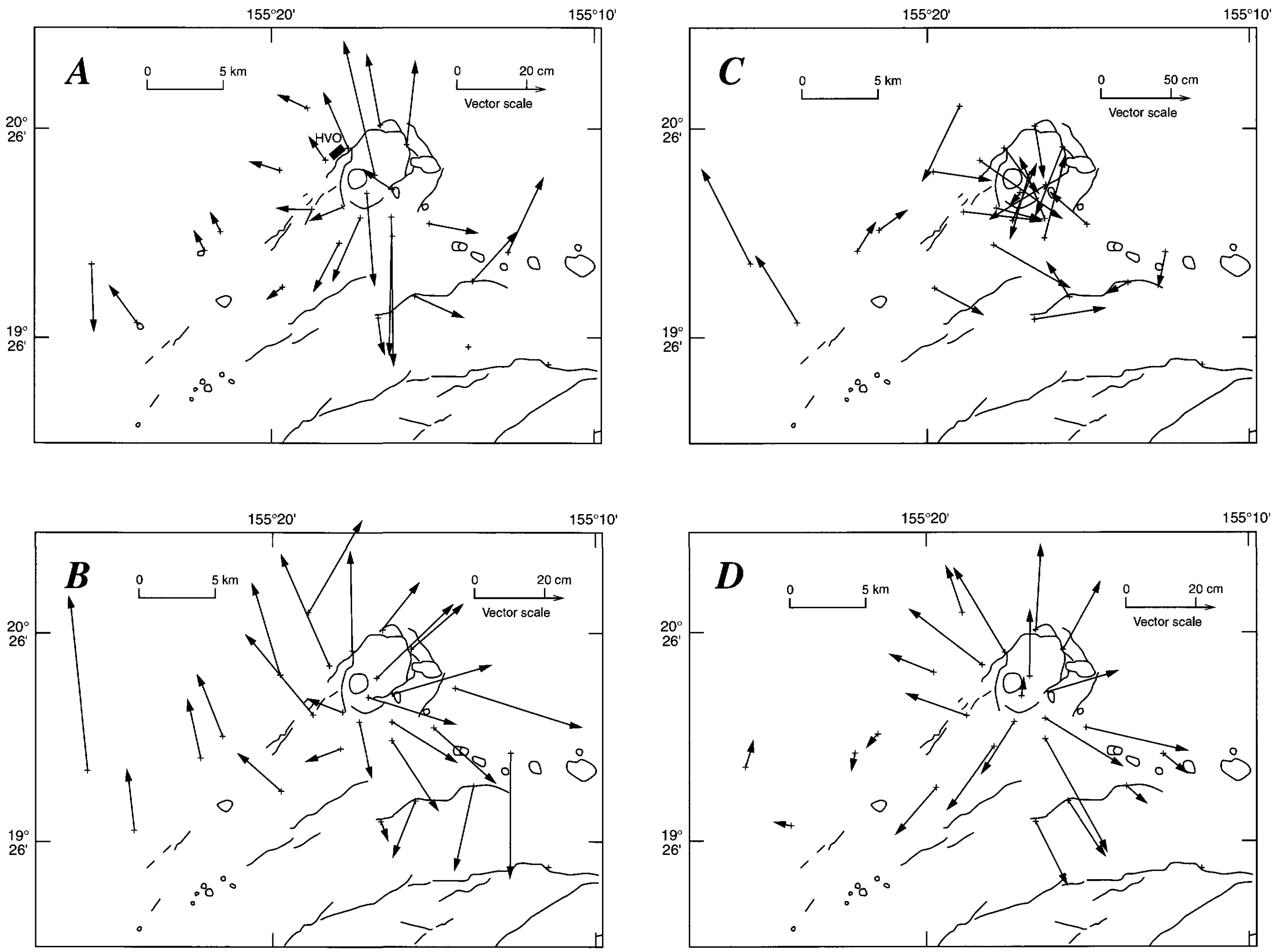

Figure 16.—Calculated best-fit horizontal displacement vectors from EDM surveys conducted across Kīlauea during the period March 1974 to October 1975 (floating horizontal datum). Survey periods include the earliest and latest readings for each survey interval. ***A***, survey period 4/12/74 to 7/25/74; ***B***, survey period 7/22/74 to 11/7/74; ***C***, survey period 11/4/74 to 1/17/75; ***D***, survey period 1/14/75 to 9/19/75.

ary 1975 deflation the summit reservoir inflated for most of 1975 , but the center of inflation was now centered well south of Halemaʻumaʻu (fig. 16*D*).

LEVELING SURVEYS

Leveling precisely documents vertical changes on a volcano's surface and may be used to help constrain volume changes associated with inflation or deflation of the volcano's surface. During the post-1971 period when supply conduits to the active Mauna Ulu eruption were unconstricted, little net deformation occurred at the Kīlauea summit (fig. 17*A*), but as the conduits to Mauna Ulu became blocked in May (Tilling and others, 1987), the summit began to engorge with magma. Leveling of Kīlauea's summit area after the small July and September eruptions documented the overall inflation that had taken place in the months prior to these surveys (figs. 17*B*, 17*C*). Analysis of these data showed that the centers of preeruption inflation had shifted westward by nearly 2 km over the April-October interval (see fig. 18). The survey after the December eruption (fig. 17*D*) reflected a combination of preeruption inflation, syneruptive deflation, and the beginning of posteruption inflation and shows a center of net deflation about 1 km southeast of Halemaʻumaʻu (fig. 18).

All the above geodetic data (tilt, EDM, and leveling) consistently show that geodetically defined centers of surface deformation migrated from east to west across Kīlauea Caldera in 1974, as the supply conduits to the long-active Mauna Ulu vent became constricted and magma began to accumulate within the summit area. The westward migration of the deformation or "pressure" centers indicates that the subsurface magmatic storage reservoirs moved from an initial center near Keanakākoʻi to the Halemaʻumaʻu area and

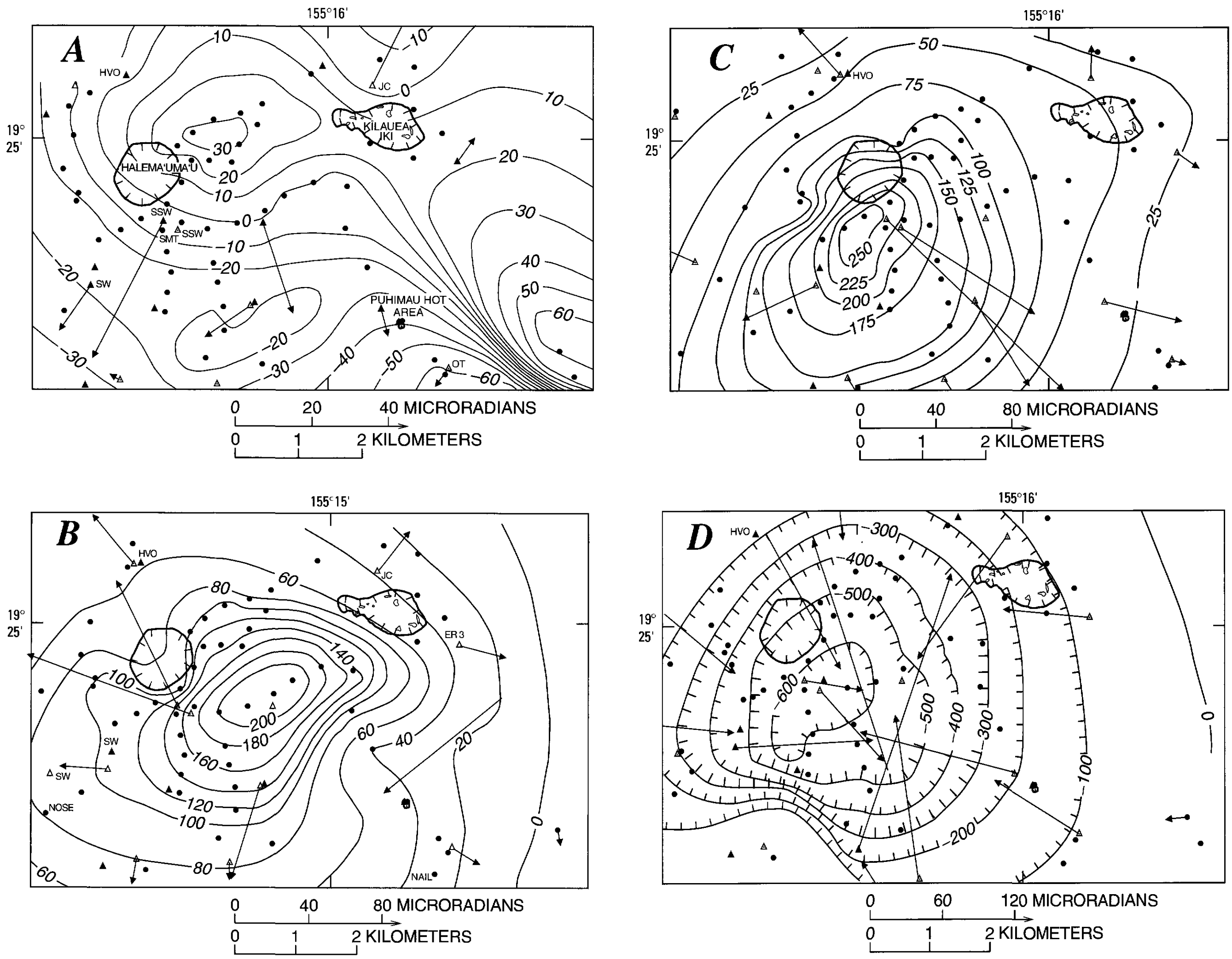

Figure 17.—Leveling data for the Kīlauea summit area for five surveys conducted from November 1973 to January 1975. Contour intervals in millimeters, referenced to a non-stable datum on the southeast slope of Mauna Loa. Survey periods include the earliest and latest readings for each survey interval. ***A***, survey period 11/13/73 to 4/05/74; ***B***, survey period 4/04/74 to 7/31/74; ***C***, survey period 7/26/74 to 10/01/74; ***D***, survey period 9/30/74 to 1/13/75. Tilt vectors (in microradians) shown are determined from available summit spirit-level tilt measurements for approximately the same survey periods.

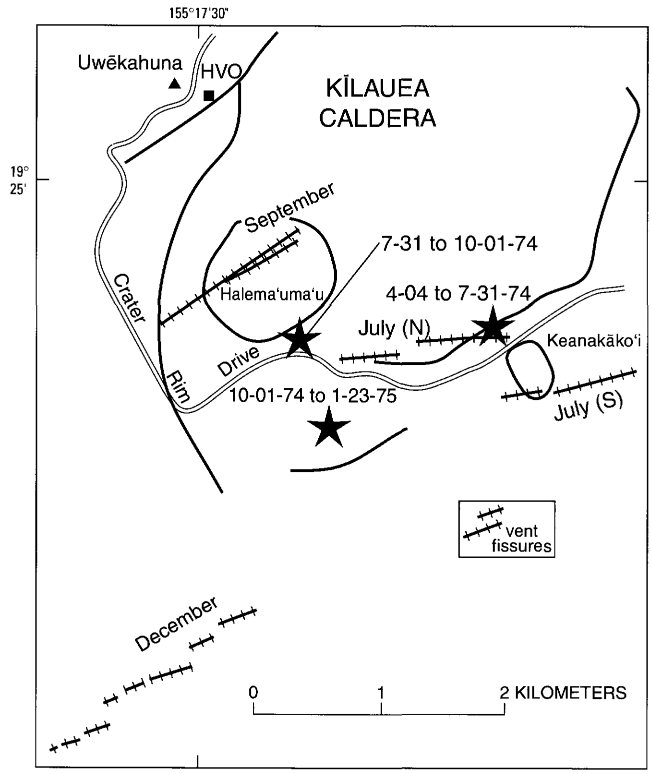

Figure 18.—Inflation centers (stars) for the intervals between leveling surveys on April 4, July 31, and October 1, 1974. Data derived from best-fit point-source solutions for leveling data by J. J. Dvorak (1992, written communication). Lavas erupted from the "northern" vent fissures (N) and the "southern" fissures (S) for the July 19-22, 1974 eruption are chemically distinct (see table 4).

then to an area southeast of Halema'uma'u, possibly outside the bounds of Kīlauea Caldera.

SEISMIC OBSERVATIONS

Seismicity provides critical evidence of magma movement within Kīlauea's shallow magma conduit system and was especially instructive during the last half of 1974, when extensive magma migration occurred beneath the summit area. Volcanic earthquakes during eruptive or intrusive swarms are primarily related to the emplacement of dikes and may thus extend far beyond the eruptive vent area as magma moves elsewhere beneath the surface. The migration of earthquakes with time shows the growth and propagation of new dikes before, during, and after surface eruptive activity.

Seismicity between these intense swarms occurs at much lower rates than during eruptive crises. This interevent seismicity is generally concentrated in Kīlauea's summit region and usually accompanies inflation of the shallow summit magma reservoir. Earthquakes during these times are probably caused by a gradual pressure increase in the magma reservoir(s) and occur either adjacent to magma bodies undergoing expansion, or on nearby fractures gradually stressed by the uplift, extension, and pressure increase in the entire summit region. General seismicity associated with various periods in 1974 are discussed in the following sections; more detailed analyses are given in Klein and others (1987).

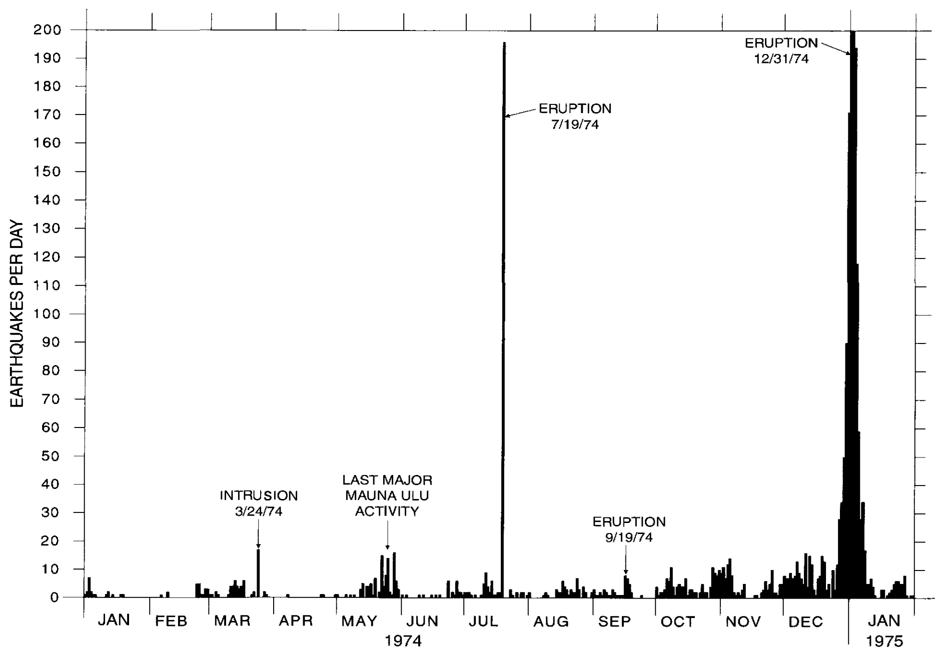

Figure 19.—Daily number of "volcanic" earthquakes (as determined by their locations and depths) timed and located by HVO during 1974 and early 1975. These events are at 0-5 km depth below the surface and under Kīlauea's rift zones or summit caldera. They include swarms accompanying eruptions and intrusions and the more continuous seismicity of the magma system as it inflates between eruptions.

The daily numbers of shallow (0-5 km) volcanic earthquakes that were timed and located in 1974 and early 1975 are plotted in figure 19. These earthquakes mostly occurred beneath Kīlauea's summit region or rift zones and are for the most part related to magmatic rather than tectonic processes. All processed events are included in this plot; the magnitude above which event sampling is complete may vary slightly with time but is generally about M=1.5. Four magmatic events (one minor intrusion and three eruptions) occurred during this period. The level of interevent seismicity increased slightly through 1974, reflecting the gradual inflation of the summit magma reservoir, and culminated with the very large eruption and intrusion at year's end.

After an intrusion near Mauna Ulu on March 24 (Klein and others, 1987), the remainder of March and April was nearly aseismic (fig. 20*A*), but earthquakes resumed in the caldera in May (fig. 20*B*). Periods like May, in which Kīlauea Caldera earthquakes occur in low-intensity swarms lasting a few weeks, are characteristic of times of summit inflation. A similar pattern persisted through June and early July (fig. 20*C*). Earthquakes between March and July also occurred on the uppermost section of the ERZ between Keanakāko'i and Ko'oko'olau, suggesting that the ERZ was participating in the summit inflation and was slowly receiving injections of magma.

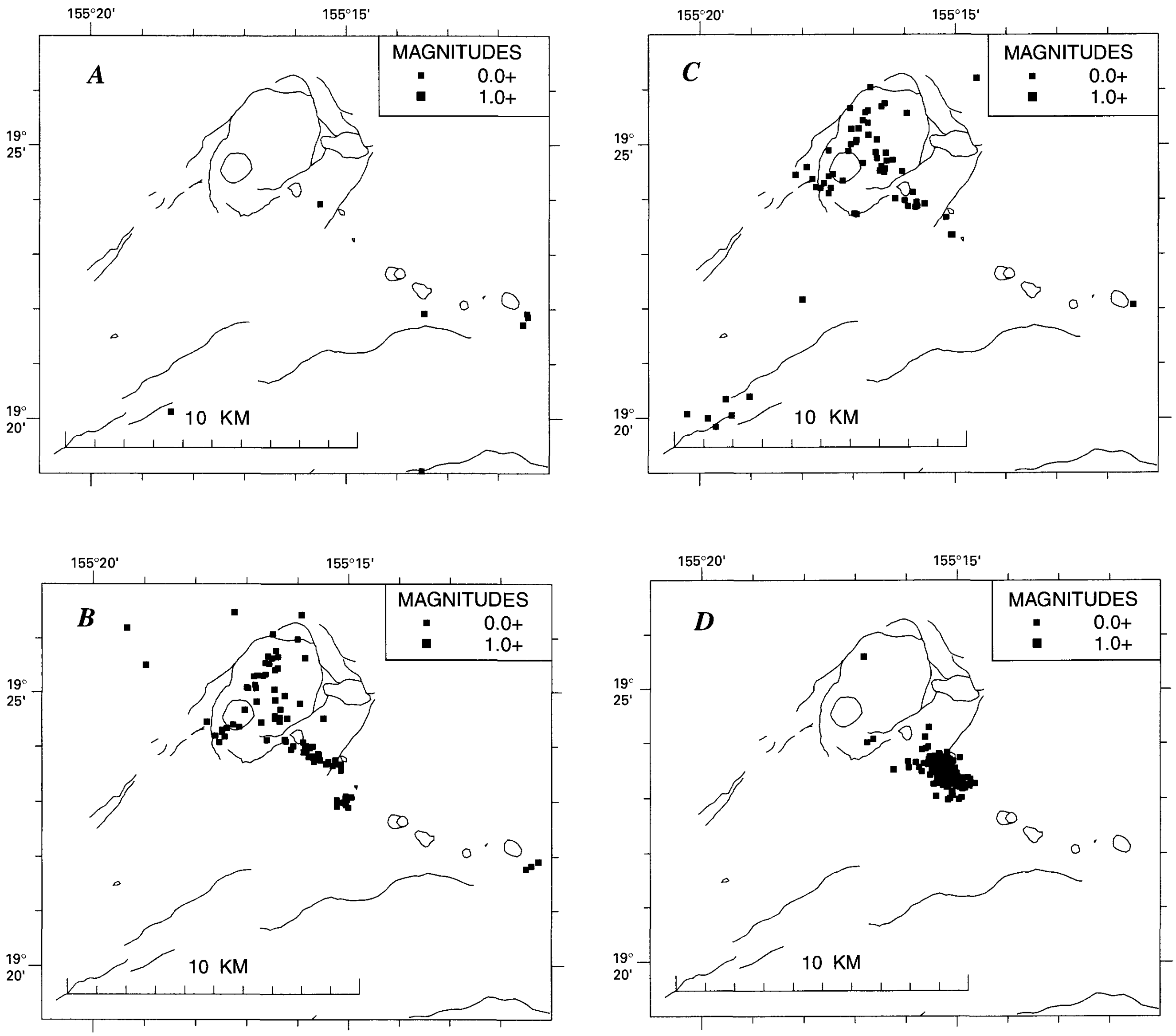

Figure 20.—Earthquakes in the Kīlauea summit region related to and preceding the eruption of July 19, 1974. ***A***, the period 3/25/74 - 4/30/74; ***B***, the period 5/1/74 - 5/31/74; ***C***, the period 6/1/74 - 7/18/74; ***D***, earthquakes during 7/19/74, when the caldera and upper ERZ eruption occurred. Depth, 0-5 km.

ERUPTION OF JULY 19, 1974 AND THE FOLLOWING 2 MONTHS

The earthquake swarm immediately preceding the July eruption was very intense and lasted only 9 hr (fig. 20*D*). The swarm was accompanied by a modest deflation of about 3 μrad, after which tilt nearly leveled off. A larger and more rapid summit deflation occurred at about 10:30, however, when high-amplitude tremor began and the number of earthquakes that could be timed and located sharply diminished. Magma reached the surface about 2 hr later.

The geometry of the seismic zone, presumably reflective of the dike feeding the eruption, is slightly elongate and extends from about 3.5 km depth below Ko´oko´olau to within a kilometer or less of the surface near Puhimau (Klein and others, 1987, fig. 43.63.*C*). The inferred dike thus dips steeply to the southeast, but its geometry cannot be adequately resolved by the distribution of earthquake foci; it is likely a thin blade structure. The locations and depths of earthquakes within about 1 km of the surface are poorly determined. The apparent lack of events in this depth range may result from this poor record or from the fact that the low-rigidity and low-stress surface layer may be too weak to generate earthquakes large enough to be detected.

Earthquakes migrated uprift at an apparent rate of about 160 m/hr (Klein and others, 1987, fig. 43.63*D*), probably along a dipping structure. The fact that the vents were uprift of the swarm location near Keanakāko'i and in the caldera also suggests that uprift migration took place. If the earthquakes propagated up a structure dipping about 60°, the updip migration would be about 300-400 m/hr; this was apparently a forceful intrusion of a dike leading from the East rift conduit

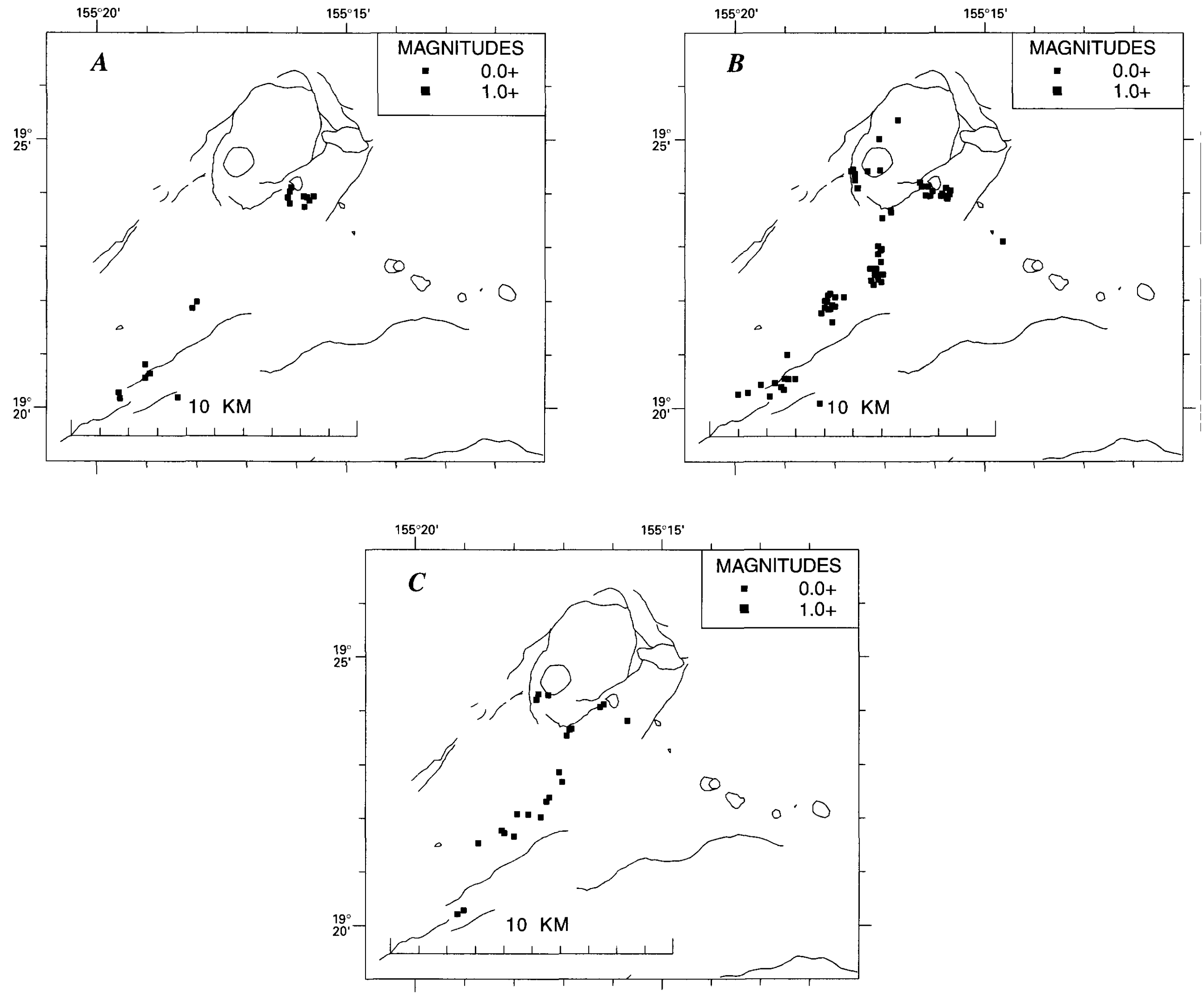

Figure 21.—Earthquakes in the Kīlauea summit region related to and preceding the eruption of September 19, 1974. ***A***, the period 7/20/74 - 8/11/74; ***B***, the period 8/12/74 - 9/15/74; ***C***, during the period 9/16/74 - 9/19/74, which immediately preceded the caldera eruption of 9/19/74. Depth, 0-5 km.

below Ko'oko'olau up to the surface. The intense seismicity and low tilt rates during this swarm show that new rock was breaking under high magma pressure and relatively low volume flow. When the dike reached the surface, pressure and seismicity decreased, and volume flow, tremor, and tilt rate increased.

The earthquakes following the July eruption (fig. 21*A*) were located away from the deeper parts of newly emplaced dike and shifted to the southeast caldera and western part of the KFS fault system. This change in pattern presaged a shift of magmatic activity through the caldera and to the southwest.

THE ERUPTION OF SEPTEMBER 19, 1974

The September caldera eruption was seismically unlike the others during the year and did not generate an intense earthquake swarm. It was instead preceded by 3 days of slightly elevated seismicity south of the caldera along the west end of the KFS (fig. 21*B*). This seismicity may outline a magma conduit or family of dikes that extended south from Kīlauea Caldera, then turned SW between the SWRZ and the western KFS. Low-intensity swarms in the summit region lasting several days are typical of intereruption periods when the volcano is inflating (Klein and others, 1987), and the activity of

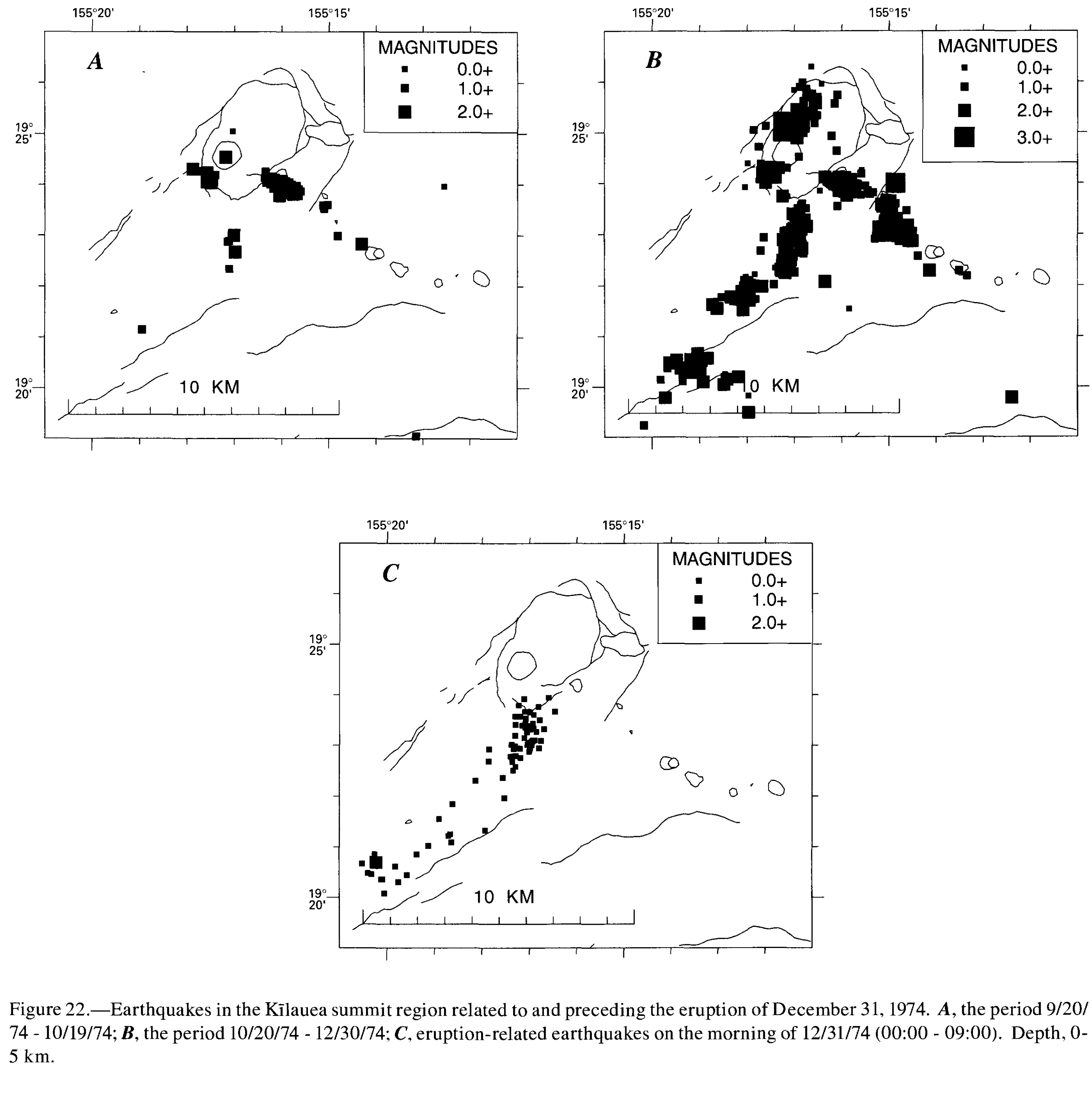

Figure 22.—Earthquakes in the Kīlauea summit region related to and preceding the eruption of December 31, 1974. *A*, the period 9/20/74 - 10/19/74; ***B***, the period 10/20/74 - 12/30/74; ***C***, eruption-related earthquakes on the morning of 12/31/74 (00:00 - 09:00). Depth, 0-5 km.

September 16-19 (fig. 21C) is not distinguishable from background seismicity during the preceding 2 months, except for the activity south-southwest of the caldera. The preeruption earthquakes may have accompanied a relatively passive, low-volume intrusion into the western KFS. Although the swarm was a weak one, it suggests southwestward earthquake migration (Klein and others, 1987, fig. 43.64.*D*). When the brief September 19 eruption began, earthquakes abruptly ceased. This could be expected if magma pressure had induced the earthquakes, but had suddenly dropped when magma flow was redirected to an active vent.

The month following the eruption saw most seismicity confined to the south caldera (fig. 22*A*). Beginning in late October seismicity again moved into the western KFS (fig. 22*B*), suggesting that an intrusion into this area took place, similar to the one prior to the September eruption. Seismicity in the north caldera and the highest Uwēkahuna tilt values recorded since 1956 (see section "Geodetic Monitoring") also indicated that Kīlauea was highly inflated with magma, in preparation for another eruption.

ERUPTION OF DECEMBER 31, 1974

Summit seismicity southwest and southeast of the caldera intensified during the week prior to the December 31 eruption, as it had done before the September eruption. Beginning on December 24, this heightened activity apparently migrated very slowly into both the upper ERZ and western KFS at roughly a kilometer per day (Klein and others, 1987, fig. 43.66). This apparent slow leaking of magma was another symptom of excessive supply in the summit reservoir.

Seismic patterns divide the eruption of December 31 into two different phases: an intense but short swarm just south of the caldera (related to the eruption-feeding dike), and a subsequent, more energetic, 2-week-long seismic crisis related to a massive deflation of Kīlauea's summit and an intrusion that propagated as far as 18 km to the southwest.

The small cluster of earthquakes about 3 km south of Halema'uma'u lies directly below and slightly east of the eruptive vents (fig. 22*C*). Earthquakes began in the middle of this zone around 16:00 on the December 30 and were about 2.5 km deep. The seismic zone slowly grew in size until 00:00-01:00 on the December 31 when it was about 2 km in diameter and reached maximum intensity. The events then ranged between 1 and 4 km depth. Earthquakes migrated upward at about 5 km/hr during the most intense period, but the dike grew aseismically upward at about 300 m/hr during the last 3 hr of its journey to the surface (Klein and others, 1987, fig. 43.67). Earthquakes then diminished and tremor intensity increased (fig. 7, 19) prior to lava breakout shortly before 03:00. This

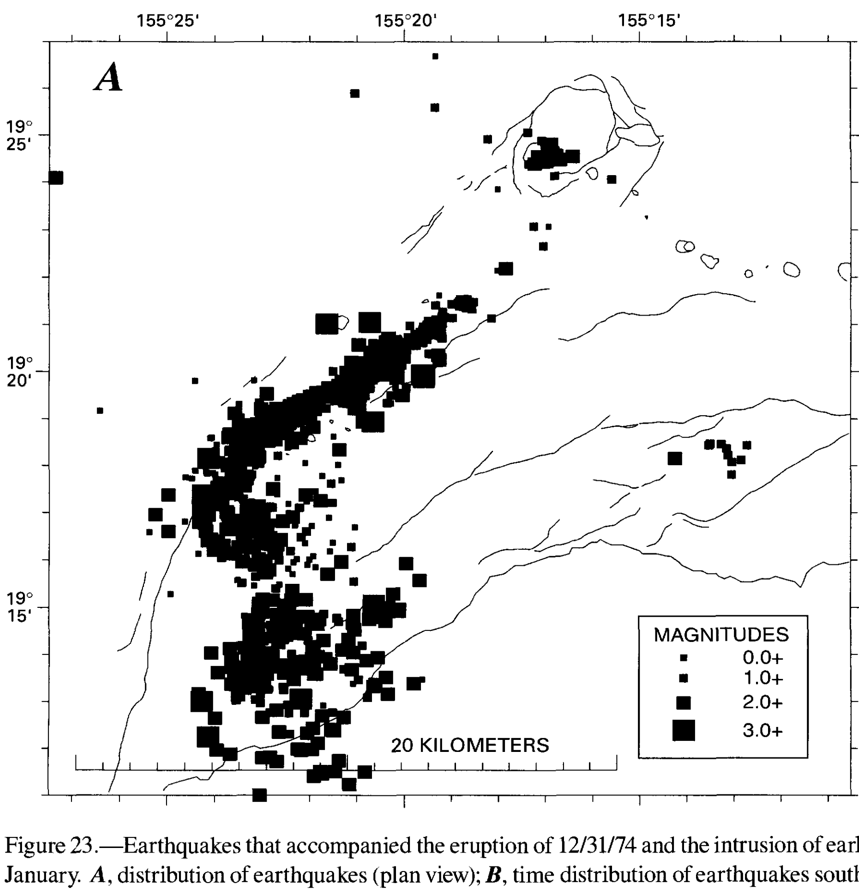

Figure 23.—Earthquakes that accompanied the eruption of 12/31/74 and the intrusion of early January. *A*, distribution of earthquakes (plan view); ***B***, time distribution of earthquakes southwest of the summit and south of the SWRZ, 12/30/74 to 1/7/75.

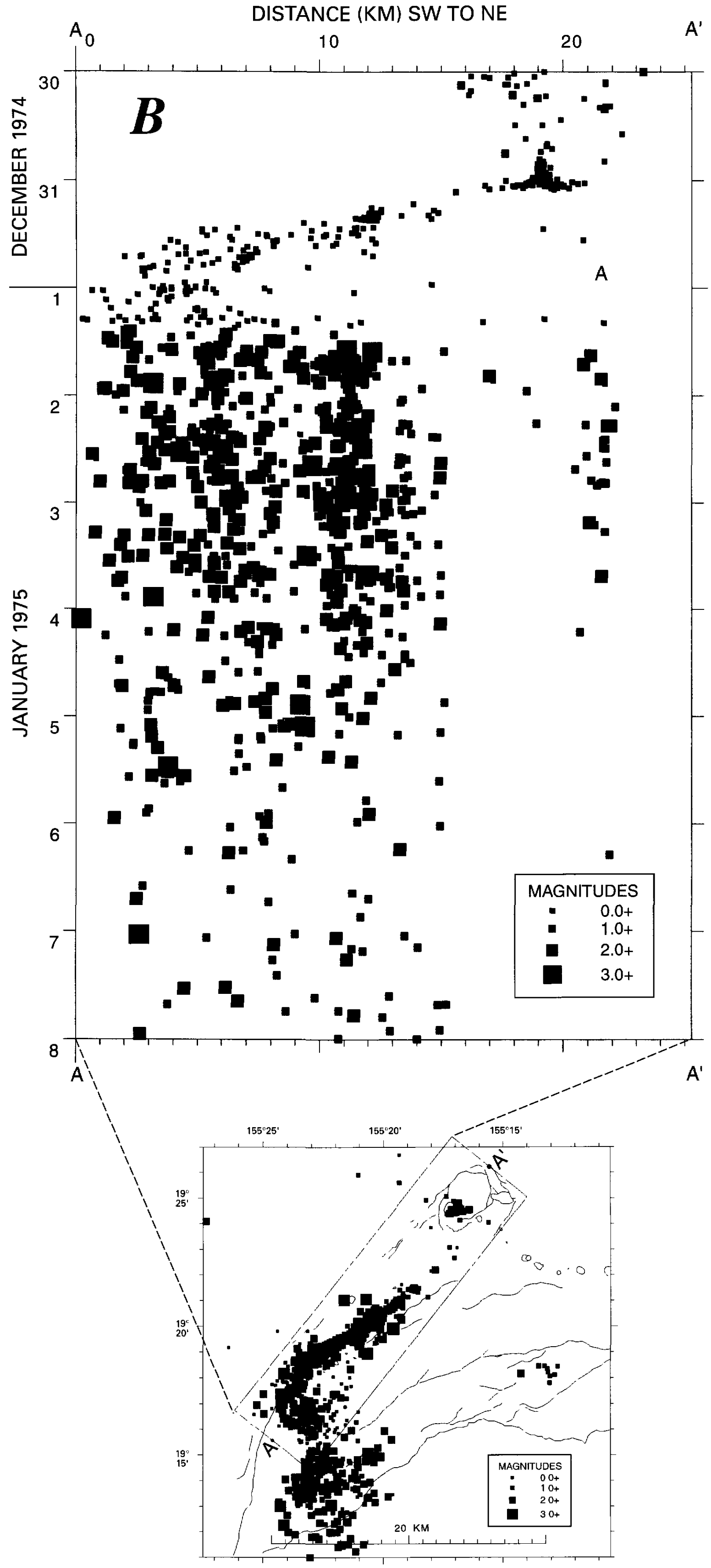

Figure 23.—Continued.

intense swarm accompanied the lateral and vertical growth of the dike that fed the eruption, similar to the July eruption.

About the time this first swarm reached maximum intensity, additional earthquakes began migrating to the southwest. Earthquakes not only occurred parallel to and southeast of the primary SWRZ surface cracks and fissures, but also in a cluster that extends 12 km south into Kīlauea's south flank from the SWRZ to the coast (fig. 23*A*). The seismically active dike initially propagated southwestward at about 1.3 km/hr for about 14 km, then slowed to half that speed as it extended an additional 4 km (fig. 23*B*). The locus of seismicity then migrated southward at the west end of the Hilina Fault System. Earthquakes in this area ranged in depth from 0 to 9 km. They appear typical of tectonic earthquakes in Kīlauea's mobile south flank. These flank earthquakes are likely triggered by compressional stresses from newly emplaced dikes upslope and are analogous to flank earthquakes of the ERZ.

GEOELECTRICAL SURVEYS

Geoelectrical studies during the early 1970s delineated the distribution of numerous subsurface thermal anomalies

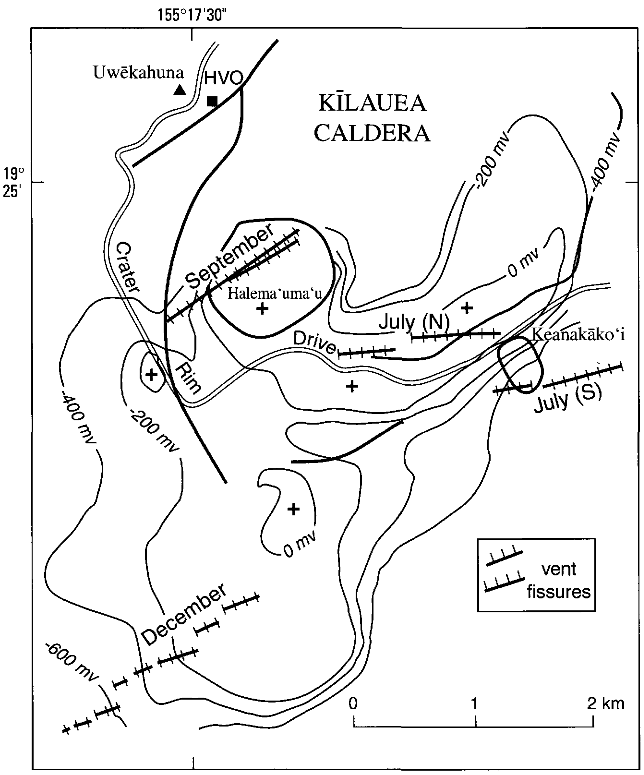

Figure 24.—Distribution of electrical self-potential fields in the area of the southern Kīlauea Caldera and to the south, as measured in July and August 1972. S-P values measured as potential between electrodes spaced 100 m apart, and contoured as millivolts/100m (from C. Zablocki, 1972, unpublished HVO monthly report, 9/21/72 to 10/20/72).

in the summit area of Kīlauea (Zablocki, 1976, 1978). An electrical self-potential (SP) survey in the summer of 1972 revealed a positive SP anomaly along the southern margin of the caldera (an area of frequent historical eruptive activity) that also extended more than 2 km to the south, outside the eruptively active caldera, but above a zone of shallow (<5 km depth) earthquakes. Zablocki (1978) suggested that this SP anomaly represented a previously unrecognized active part of the Kīlauea summit magma reservoir.

The eruption of December 31, 1974 was anomalous, as it occurred in an area where no eruption had ever taken place in historical times (Peterson, 1967). The eruptive fissures opened directly over the earlier recognized SP high south and southwest of the Kīlauea Caldera (fig. 24) and migrated southwestward into the SWRZ. Earlier 1974 summit eruptions had also occurred in areas of positive SP anomalies (fig. 24), although the geochemically anomalous "southern" vents of the July eruption are located south of the caldera SP anomaly.

Zablocki conducted extensive geoelectrical surveys across the December fissures, using both SP and very low-frequency (VLF) induction techniques. His studies showed that several surface segments of the en-echelon eruptive system were accompanied by SP anomalies on their uprift, or eastward, extensions (never to the west). This suggested that the subsurface dikes feeding the surface vents plunged down to the east, toward the inferred extension of Kilauea's magma reservoir system. Further support for this eastward plunge of feeding dikes is provided by an abrupt increase in bicarbonate content of water in a research drill hole located 1 km northeast of the easternmost vents (Tilling and Jones, 1996). This change, apparently coincident with the December 31 eruption, was interpreted by Tilling and Jones to reflect a pulselike influx of CO_2 associated with magma migrating at depth beneath the drill site. The SP and VLF data also indicated that the dikes were near-vertical or dipped steeply to the north, observations supported by later modeling of detailed deformation measurements (Pollard and others, 1983).

GEOCHEMISTRY AND PETROLOGY

In the following discussion, a working knowledge of magma-transfer processes at Kīlauea will be useful, in particular the dynamics between the summit magma reservoir and intrusive/eruptive activity in the summit area or the rift zones. For a general summary of "how Kīlauea works," the interested reader is referred to the classic work of Eaton and Murata (1960) and to review papers by Decker (1987) and Tilling and Dvorak (1993).

Major-element chemical analyses were obtained for 34 samples of lava erupted during the three summit eruptions of 1974 (tables 4-6); 27 of these were collected during or shortly after the eruptions and analyzed in the late 1970s, and 7 were collected and analyzed in 1992 to round out the sample suites. In terms of gross averages (that is, not MgO-adjusted for olivine-control variations), the compositions of the July and

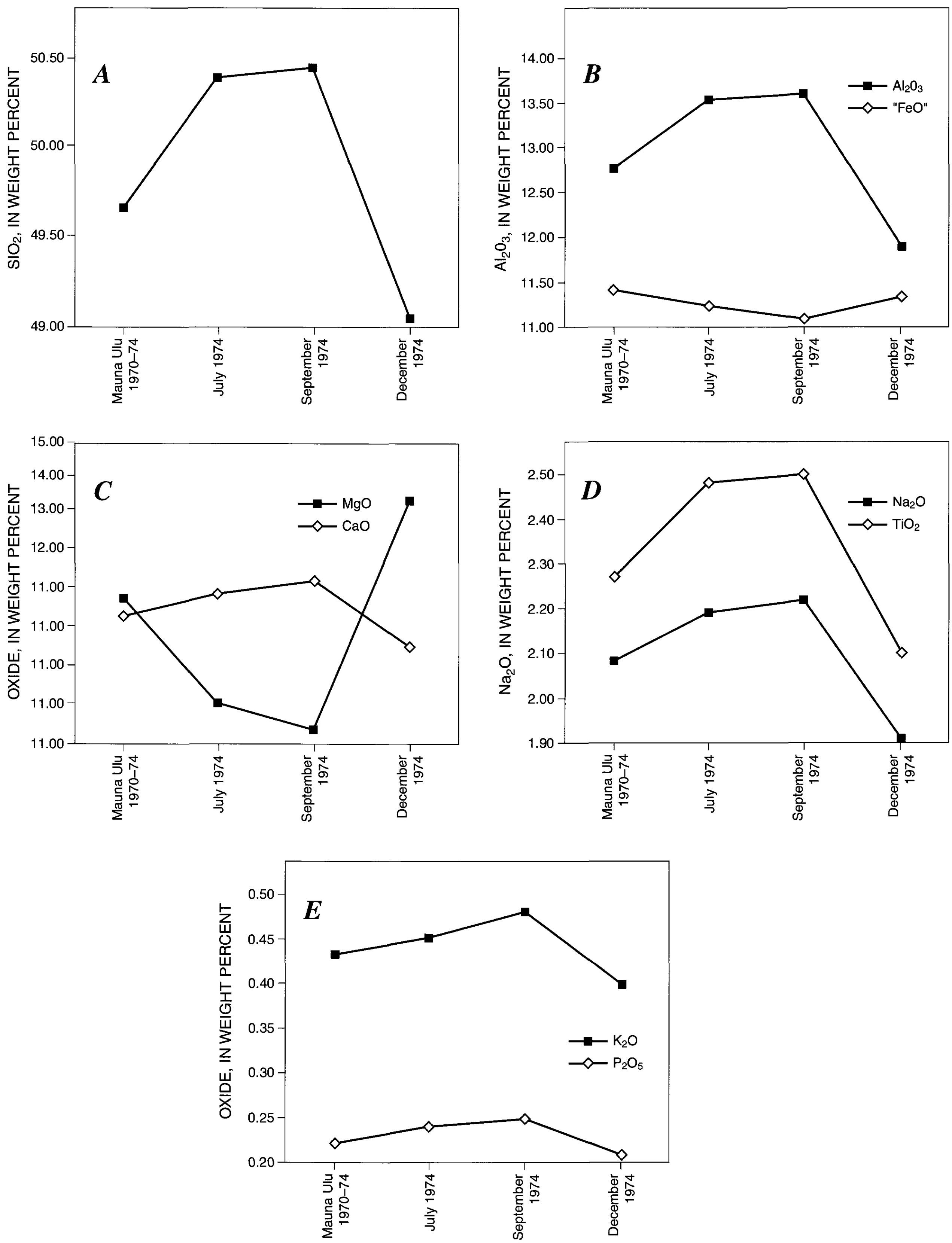

Figure 25.—Average abundance of major oxides for lava erupted at Mauna Ulu (see fig. 1) during the period 1970-1974 and in the July, September, and December 1974 eruptions (fig. 2). ***A***, SiO_2; ***B***, Al_2O_3 and "FeO" (total Fe expressed as FeO); ***C***, MgO and CaO; ***D***, Na_2O and TiO_2; ***E***, K_2O and P_2O_5. In these plots, the compositional distinction between the lavas erupted from the "northern" and "southern" vent fissures of the July 1974 eruption (see text) is not considered.

Table 4.—Chemical analyses of lavas erupted in July 1974, grouped according to vent location (see fig. 18 and text). [Values given in weight percent; LOI = loss on ignition].

	"Northern" vents (*N*)						"Southern" vents (*S*)						
Analysis No.	1	2	3	4	5	"Northern" average	6	7	8	9	10	11	"Southern" average
SiO_2	49.99	49.99	49.74	50.57	50.2	50.1	50.76	50.77	50.76	50.77	50.88	50.5	50.7
Al_2O_3	12.92	12.92	12.68	13.57	13.2	13.1	13.99	13.96	14.00	13.87	14.25	13.8	14.0
Fe_2O_3	0.95	1.02	0.93	1.35	–	1.06	1.26	2.08	1.29	1.24	1.45	–	1.46
FeO	10.43	10.40	10.46	9.91	–	10.30	10.17	9.47	10.12	10.12	9.92	–	9.96
Fe_{Total} (as FeO)					12.5							12.6	
MgO	10.16	10.16	10.96	7.66	7.97	9.38	6.94	6.89	7.12	7.23	6.74	6.91	6.97
CaO	10.46	10.57	10.23	11.15	11.0	10.67	10.97	10.97	11.00	11.08	10.95	10.9	11.0
Na_2O	2.02	2.02	2.01	2.24	2.13	2.08	2.29	2.28	2.27	2.27	2.29	2.25	2.28
K_2O	0.42	0.43	0.39	0.46	0.48	0.44	0.47	0.48	0.45	0.43	0.49	0.49	0.47
TiO_2	2.27	2.20	2.21	2.56	2.48	2.34	2.61	2.60	2.54	2.54	2.67	2.55	2.58
P_2O_5	0.23	0.24	0.21	0.25	0.27	0.24	0.25	0.24	0.24	0.24	0.25	0.27	0.25
MnO	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
CO_2	0.01	0.01	0.01	0.01	–	0.01	0.01	0.01	< 0.01	< 0.01	0.00	–	< 0.01
Cl	0.01	0.01	0.01	0.01	–	0.01	0.01	0.01	0.01	< 0.01	0.01	–	0.01
F	0.03	0.03	0.03	0.04	–	0.03	0.04	0.04	0.04	0.04	0.04	–	0.04
LOI	0.04	0.00	0.06	0.04	< 0.01	0.03	0.02	0.04	0.02	< 0.01	0.00	< 0.01	0.02
Total	100.11	100.19	100.10	99.99	100.40	100.15	99.96	100.01	100.03	100.00	100.11	100.44	100.09

Sample data for the chemical analyses given in **Table 4**

Analysis No.	Field No.	Analysis type	Analyst(s)	Date and approximate time sample erupted		Sample collector
1	KIL-774-1	Wet	E. Engleman	7-19-74	13:30	R. I. Tilling
2	KIL-774-2	Wet	E. Engleman	7-19-74	14:45	R. I. Tilling
3	KIL-774-3	Wet	E. Engleman	7-20-74	00:06	R. I. Tilling
4	KIL-774-6A	Rapid rock	E. Brandt, E. Engleman	7-20-74	12:30	R. I. Tilling
5	L-92-60	XRF	David Siems	7-20-74	—	J. P. Lockwood
6	KIL-1274-9	Rapid rock	E. Brandt, E. Engleman	7-19-74	14:00	J. P. Lockwood
7	KIL-275-13	Rapid rock	E. Brandt, E. Engleman	7-19-74	15:00	R. I. Tilling
8	KIL-275-10	Rapid rock	E. Brandt, E. Engleman	7-19-74	16:00	R. I. Tilling
9	KIL-275-11	Rapid rock	E. Brandt, E. Engleman	7-19-74	17:00	R. I. Tilling
10	KIL-774-4	Wet	E. Engleman	7-19-74	20:00	R. I. Tilling
11	L-92-59A	XRF	David Siems	7-19-74	—	J. P. Lockwood

September lavas are fairly similar and slightly less mafic than the mean composition for lavas for the 1969-74 Mauna Ulu eruptions (fig. 25A). In contrast, the December 1974 lavas are more mafic than any produced during the July and September eruptions, as well as during the Mauna Ulu eruptions (fig. 25*A*). These December lavas (table 6; Fig. 25*C*) are the most magnesian historical summit lavas since those produced in the 1959 Kīlauea Iki eruption (Murata and Richter, 1966; Wright, 1973) or the August 1968 Hi'iaka upper ERZ eruption (Jackson and others, 1975; Wright and others, 1975). Moreover, the December 1974 lavas are also more magnesian than the prehistoric Kīlauea summit lavas exposed in the caldera walls (Casadevall and Dzurisin, 1987).

Figure 26 shows the compositions of the July, September, and December 1974 lavas plotted on the MgO-variation diagram commonly used for Hawaiian lavas, with the three Kīlauea olivine-control lines of Wright (1971) also shown for reference. While some of the chemical variations obviously imply effects of olivine control, the lack of coherent linear variation against MgO also requires the involvement of other petrologic processes (for example, fractionation or mixing of magma batches). In particular, some plagioclase-bearing lavas of the July eruption (tables 2, 4) are differentiated or "hybrid" with values of MgO < 7.00 weight percent, an observation noted previously by Wright and Tilling (1980). Such an occurrence apparently marks a first for historical Kīlauea summit lavas.

Whereas the lavas of the September and December eruptions define relatively homogeneous compositional groups, the lavas of the July eruption do not. While the average composition of the July lavas, taken as a single group, is quite similar to the average composition of the September lavas (fig. 25), the July lavas actually exhibit a bimodal composition reflected in their vent locations (table 4). Lavas erupted from fissures south of Keanakāko'i Crater (figs. 2, 3) (hereafter referred to as the "southern" fissures) are distinctly more silicic and less magnesian than lavas erupted from fissures north of Keanakāko'i Crater (hereafter called the "northern" fissures). The lavas from the "southern" fissures are distinctly more differentiated in composition (table 4, fig. 26) and contain megascopically conspicuous plagioclase — a rarity at Kīlauea's summit. Significantly, the compositional trends of lavas from the "southern" and "northern" fissures, as determined by their estimated time of eruption, define two curves that appear to converge toward a single, uniform composition as the eruption progressed, presumably reflecting greater efficiency of magma mixing as the stored magma was flushed out (fig. 27).

Wright and Tilling (1980) considered the differentiated July 1974 lavas to be the evolved "daughters" of magma residing in the Kīlauea shallow storage system since 1972, or possibly since mid-1970. Their calculations further suggested that the eruptive products of September and December resulted from mixing of various combinations of several olivine-con-

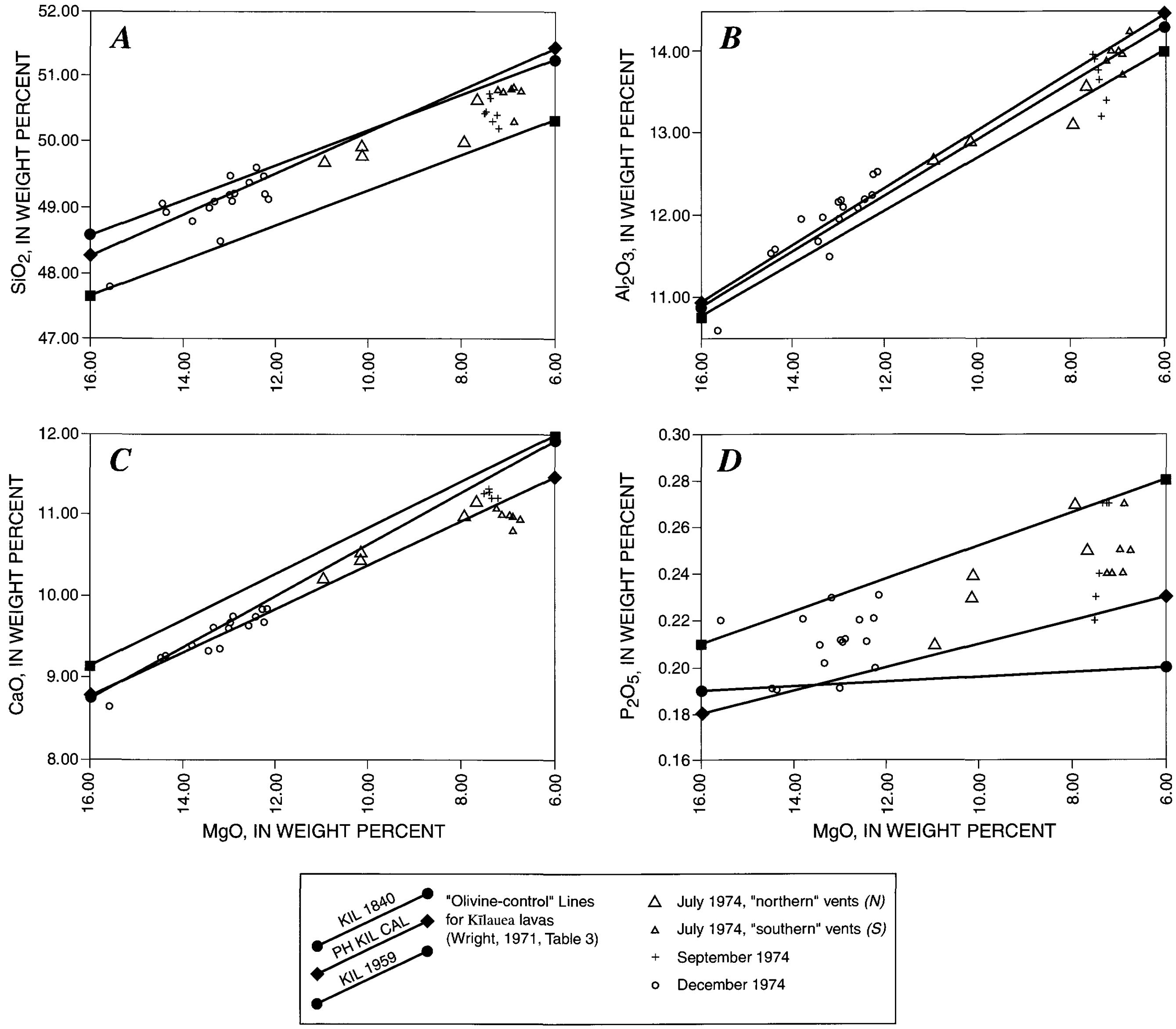

Figure 26.—MgO-variation diagrams for July, September, and December 1974 lavas, compared with "olivine-control" lines (KIL 1840, PH KIL CAL, and KIL 1959) for Kīlauea lavas (see Wright, 1971, Table 3). ***A***, SiO_2; ***B***, Al_2O_3; ***C***, CaO; ***D***, P_2O_5; ***E***, K_2O; ***F***, Na_2O (because of near identity to the other "olivine-control" lines plotted, the line for PH KIL CAL is not shown); ***G***, "FeO" (total Fe expressed as FeO); ***H***, TiO_2.

trolled and chemically distinct variants (magmatic "batches") presumably tapped by Mauna Ulu since 1972 and the July 1974 differentiated lava (Wright and Tilling, 1980, table 3).

The MgO-rich lavas erupted in December 1974 were considered by Wright and Tilling (1980) to be representative of a hypothetical magma batch (their chemical variant No. 10) that was inferred to have been first supplied to, and later mixed with, other variants in the Mauna Ulu system as early as January 1973. This hypothetical, unadulterated variant was considered by Wright and Tilling (1980) to never have reached the surface, however, until the December 1974 eruption, and then at a point on the southwestern flank of the volcano far from Mauna Ulu (fg. 1). Perhaps the hypothethized chemical variant No. 10 in Mauna Ulu lavas needs to be reexamined.

Some of the July 1974 lavas (for example, analyses 7, 9, and 10, table 4) cannot be linked by olivine-control alone, and likely were stored in the Kīlauea summit area for several years before eruption. It seems reasonable that the differentiated 1974 summit lavas were pushed to the surface by upward transport of a new batch of more mafic magma from depth that mixed with stored magma to modulate the hybrid compositions of most lavas erupted in July and September.

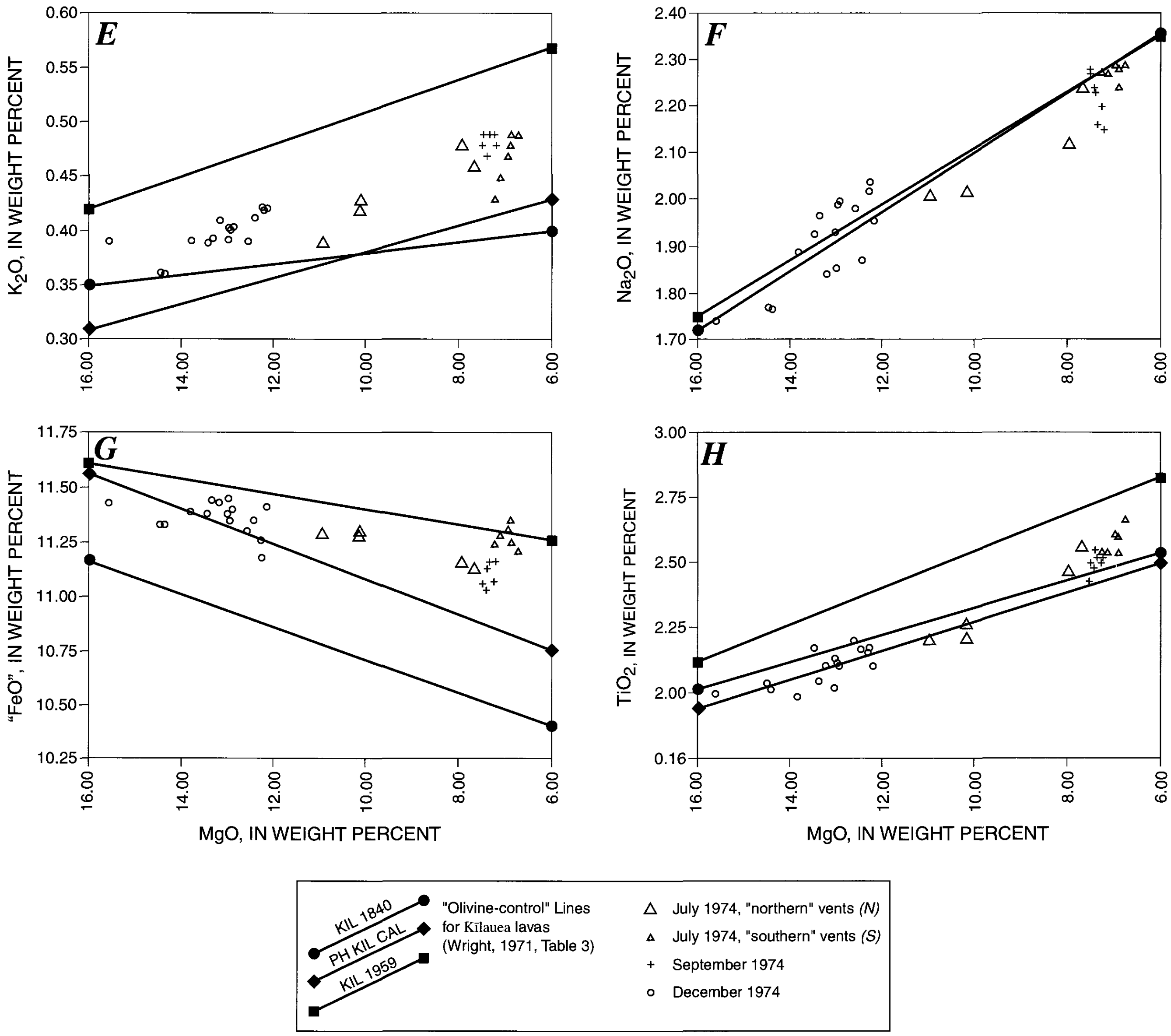

Figure 26.—Continued.

Table 5.—Chemical analyses of lavas erupted in September 1974. [Values given in weight percent; LOI = loss on ignition].

Analysis No.	1	2	3	4	5	6	7	Average
SiO_2	50.50	50.41	50.71	50.60	49.9	50.5	50.5	50.4
Al_2O_3	13.94	13.95	13.77	13.64	13.3	13.4	13.3	13.6
Fe_2O_3	1.64	1.66	1.34	1.56	--	--	--	1.55
FeO	9.59	9.57	9.82	9.72				9.68
Fe_{Total} (as FeO)					12.3	12.3	12.4	
MgO	7.49	7.51	7.41	7.38	7.16	7.27	7.37	7.37
CaO	11.26	11.26	11.32	11.27	11.1	11.1	11.2	11.2
Na_2O	2.27	2.28	2.24	2.23	2.14	2.20	2.17	2.22
K_2O	0.49	0.48	0.47	0.47	0.48	0.49	0.49	0.48
TiO_2	2.50	2.43	2.48	2.55	2.51	2.51	2.53	2.50
P_2O_5	0.23	0.22	0.24	0.24	0.27	0.27	0.27	0.25
MnO	0.16	0.17	0.17	0.17	0.17	0.17	0.17	0.17
CO_2	0.03	0.02	0.01	0.01	--	--	--	0.02
Cl	0.013	0.010	0.011	0.01	--	--	--	0.01
F	0.037	0.033	0.035	0.04	--	--	--	0.04
LOI	0.10	0.13	0.11	0.04	0.10	0.01	0.01	0.07
Total	100.25	100.13	100.14	99.93	99.43	100.22	100.41	100.07

Sample data for the chemical analyses given in **Table 5**

Analysis No.	Field No.	Analysis type	Analyst(s)	Date and approximate time sample erupted		Sample collector
1	KIL-375-14A	Wet	H. Kirschenbaum	9-19-74	04:00	R. I. Tilling
2	KIL-375-14B	Wet	H. Kirschenbaum	9-19-74	04:00	R. I. Tilling
3	KIL-375-15	Wet	H. Kirschenbaum	9-19-74	05:00	R. I. Tilling
4	KIL-375-8	Rapid rock	E. Brandt, E. Engleman	9-19-74	07:30	R. I. Tilling
5	L-92-61	XRF	David Siems	9-19-74	--	J. P. Lockwood
6	L-92-65	XRF	David Siems	9-19-74	--	J. P. Lockwood
7	L-92-66	XRF	David Siems	9-19-74	--	J. P. Lockwood

The first of this postulated new magma batch, as represented by MgO-rich samples such as SWR-375-14 and SWR-1274-6 (analyses 2 and 14, table 6), did not appear at the surface until December 31. Petrologic mixing calculations are pending to test and refine the earlier preliminary model of Wright and Tilling (1980).

CONCLUSIONS AND SPECULATIONS

Sustained lava lake activity was common at Kīlauea's summit before 1924, but there has never been a year like 1974 in historical time, when three discrete eruptions occurred in the summit area. These three eruptions were each distinct events, each taking place from new vents in separate areas, and the lavas of each had different chemical signatures.

Despite their distinct individual characteristics, each of these eruptive episodes was related to underlying, common magmatic processes that affected the entire Kīlauea summit area in the latter half of 1974. Deformation of the Kīlauea edifice and the distribution and character of volcanic earthquakes show that the magma storage areas migrated westward beneath the summit region in 1974: from the upper ERZ, to the area between the uppermost east rift zone and Halemaumau (July), to Halema'uma'u and the west (September), then into an area between the western KFS and the upper SWRZ (December), with subsequent intrusion into an area south and southeast of the SWRZ (early January).

The geochemistry of these summit-erupted lavas shifted from compositions typical of mixed magmas, including "old" slightly differentiated tholeiite basalts (July) to fairly primitive "new" olivine-rich tholeiites (December). We propose that these geochemical changes reflect the injection of a new, primitive magma batch into the shallow storage reservoir beneath Kīlauea's summit in mid-1974. This new magma forced differentiated, stored magma to the surface (July) and gradually mixed with stored magma to form the eruptive products of September and December. Only in December did relatively uncontaminated samples of this new magma reach the surface.

In a general way, the summit eruptions of 1974 repeated much of the script for 1971 Kīlauea eruptive activity. In mid-June 1971, the magma supply to Mauna Ulu was partially blocked (Swanson and others, 1979) and magma accumu-

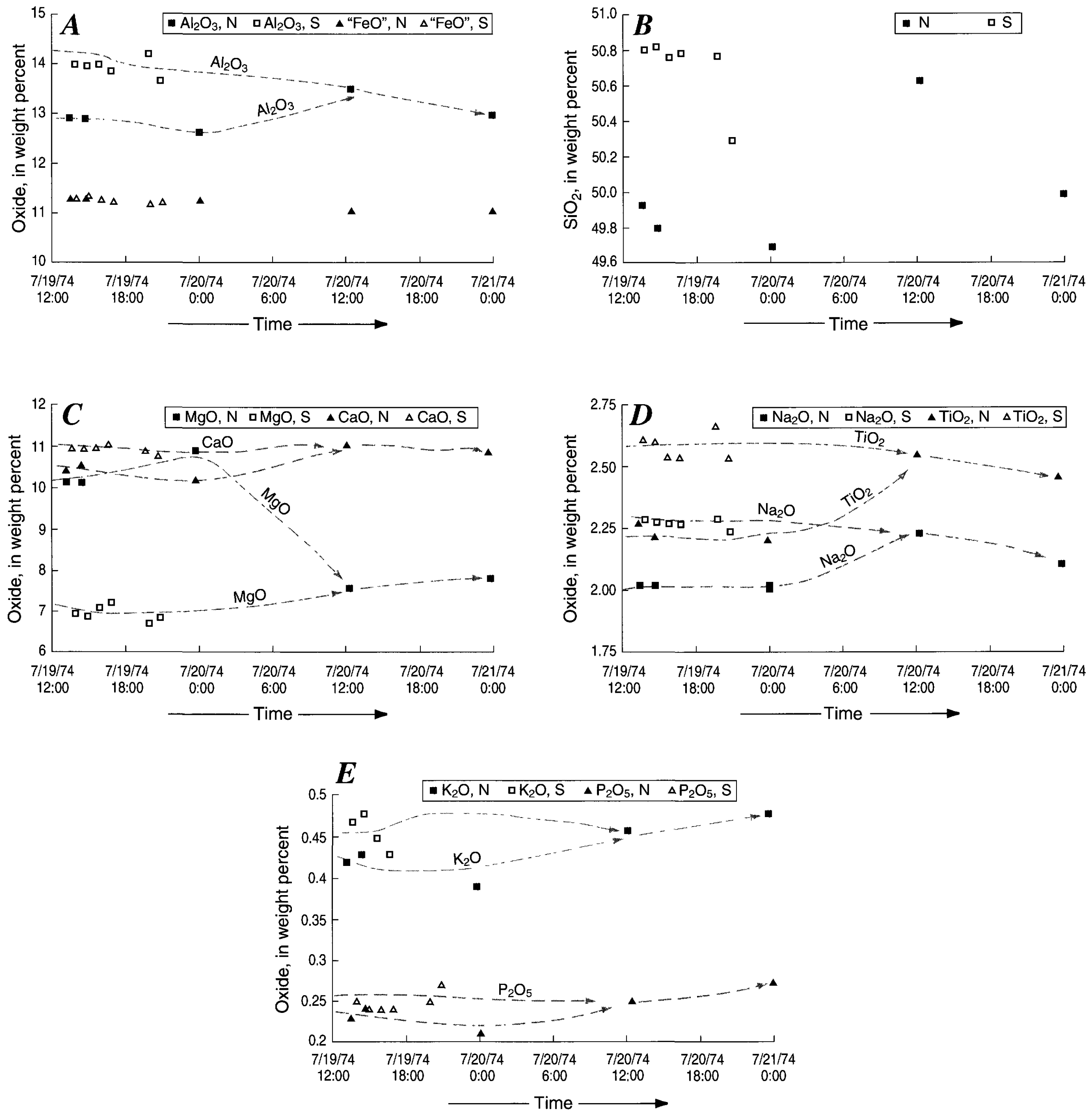

Figure 27.—Variation with time in abundances of major oxides for lavas collected during the July 19-22, 1974 eruption, showing the initially contrasting compositions of lavas erupted from the "northern" vents (**N**, solid symbols) and "southern" vents (**S**, open symbols). Dashed arrows show the compositions of the northern-vents lavas approaching those of the southern-vents lavas as the eruption progressed (see text). ***A***, Al_2O_3 and "FeO" (total Fe expressed as FeO); ***B***, SiO_2; ***C***, MgO and CaO; ***D***, TiO_2 and Na_2O; ***E***, K_2O and P_2O_5.

Table 6.—Chemical analyses of lavas erupted in December 1974. [Values given in weight percent; LOI = loss on ignition].

Analysis No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Average
SiO_2	49.09	48.82	49.24	48.87	49.14	48.69	48.79	49.34	49.32	48.91	49.00	48.60	49.27	48.83	48.1	48.8	48.9
Al_2O_3	11.71	11.56	12.50	12.12	11.88	11.87	11.99	12.13	12.07	12.09	12.48	11.90	12.19	11.49	10.7	11.6	11.9
Fe_2O_3	1.15	0.97	1.15	1.09	1.13	2.42	2.63	1.06	0.86	2.84	1.90	2.30	1.48	0.64	–	–	1.54
FeO	10.35	10.44	10.15	10.34	10.37	9.20	8.96	10.36	10.52	8.78	9.68	9.28	9.90	10.72	–	–	9.93
Fe_{Total} (as FeO)															12.8	12.8	
MgO	13.48	14.35	12.26	12.90	12.91	13.24	12.80	12.37	12.57	12.94	12.14	13.76	12.23	14.40	15.7	13.3	13.2
CaO	9.35	9.24	9.69	9.63	9.62	9.54	9.66	9.70	9.63	9.56	9.82	9.36	9.80	9.20	8.69	9.43	9.50
Na_2O	1.93	1.76	2.04	1.98	1.84	1.95	1.98	1.86	1.98	1.92	1.95	1.88	2.01	1.76	1.75	1.85	1.90
K_2O	0.39	0.36	0.42	0.40	0.40	0.39	0.40	0.41	0.39	0.39	0.42	0.39	0.42	0.36	0.39	0.41	0.40
TiO_2	2.18	2.01	2.18	2.11	2.12	2.03	2.09	2.16	2.20	2.01	2.10	1.98	2.15	2.03	2.01	2.12	2.09
P_2O_5	0.21	0.19	0.20	0.21	0.21	0.20	0.21	0.21	0.22	0.19	0.23	0.22	0.22	0.19	0.22	0.23	0.21
MnO	0.17	0.17	0.17	0.17	0.17	0.16	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
CO_2	0.01	0.01	0.02	0.02	< 0.01	0.03	0.03	0.01	< 0.01	0.01	0.02	0.02	0.02	0.01	–	–	0.02
Cl	0.01	0.01	0.009	0.010	0.01	0.009	0.011	0.01	0.01	0.11	0.011	0.010	0.010	0.01	–	–	0.02
F	0.03	0.03	0.028	0.028	0.03	0.026	0.025	0.04	0.03	0.27	0.027	0.026	0.028	0.03	–	–	0.05
LOI	0.03	0.02	0.11	0.10	0.04	0.10	0.11	0.02	0.01	0.13	0.13	0.13	0.14	0.02	0.01	0.01	0.07
Total	100.09	99.94	100.17	99.98	99.87	99.85	99.86	99.85	99.98	100.32	100.08	100.03	100.04	99.86	100.54	100.72	100.08

Sample data for the chemical analyses given in **Table 6**. [* Poorly constrained eruption times]

Analysis No.	Field No.	Analysis type	Analyst(s)	Date and approximate time*sample erupted		Sample collector	Eruptive vent or flow
1	SWR-1274-1	Rapid rock	E. Brandt, E. Engleman	12-31-74	03:30	J. P. Lockwood	"A"
2	SWR-375-14	Wet	H. Kirschenbaum	12-31-74	04:00	J. P. Lockwood	"A"
3	SWR-375-13	Wet	H. Kirschenbaum	12-31-74	04:30	J. P. Lockwood	"E"
4	SWR-1274-2	Wet	H. Kirschenbaum	12-31-74	04:40	J. P. Lockwood	"A"
5	SWR-1274-3	Rapid rock	E. Brandt, E. Engleman	12-31-74	05:00*	D. W. Peterson	"B"
6	SWR-175-12	Wet	H. Kirschenbaum	12-31-74	06:00*	R. T. Holcomb	"D"
7	SWR-175-11	Wet	H. Kirschenbaum	12-31-74	06:40	R. T. Holcomb	Flow
8	SWR-1274-5	Rapid rock	E. Brandt, E. Engleman	12-31-74	06:40	J. P. Lockwood	"I"
9	SWR-375-18	Rapid rocks	E. Brandt, E. Engleman	12-31-74	06:30*	J. P. Lockwood	"J"
10	SWR-175-10	Wet	H. Kirschenbaum	12-31-74	07:00*	R. T. Holcomb	Flow
11	SWR-175-9	Wet	H. Kirschenbaum	12-31-74	07:00*	R. T. Holcomb	Flow
12	SWR-175-8	Wet	H. Kirschenbaum	12-31-74	07:30*	R. T. Holcomb	Flow
13	SWR-175-7	Wet	H. Kirschenbaum	12-31-74	08:00*	R. T. Holcomb	Flow
14	SWR-1274-6	Rapid rock	E. Brandt, E. Engleman	12-31-74	08:50	J. P. Lockwood	Flow
15	L-92-63	XRF	David Siems	12-31-74	–	J. P. Lockwood	Flow
16	L-92-64	XRF	David Siems	12-31-74	–	J. P. Lockwood	Flow

lated in Kīlauea's summit area, which began to inflate rapidly. Two small summit eruptions occurred, the first on August 14, in the same area as the "northern" vents of the July 1974 eruption (fig. 3). The August 1971 eruption was accompanied by a small deflation, followed immediately by inflation south of Halema'uma'u, as was the case in 1974. The second 1971 summit eruption began on September 24 on the west rim of Halema'uma'u, was preceded by a very sharp summit inflation, and was accompanied by a small deflation (Duffield and others, 1982), as was the September 1974 eruption. Here the parallels between 1971 and 1974 begin to diverge, however. Following the September 1971 eruptive breakout at Halema'uma'u, vents opened down the SWRZ, reaching nearly 12 km southwest of Kīlauea Caldera (Dvorak, 1990). In September 1974 however, eruptive fissures which initially migrated to the southwest stopped at the caldera rim and never extended to the southwest.

What blocked the migration of eruptive vents into the SWRZ in 1974? A possible answer to this question may lie to the northwest of Kīlauea, within the edifice of her giant neighbor volcano, Mauna Loa. Deformation measurements on Mauna Loa, initiated in 1965, had shown no changes through 1973, but in August 1974, at the time of an annual survey, EDM survey lines across Moku'āweoweo indicated significant extensions since the previous summer (Lockwood and others, 1976). This, as well as the sharp increase in seismic activity beneath the summit area that had begun in April 1974 (Koyanagi and others, 1975) indicated that Mauna Loa had begun to inflate, as a prelude to subsequent eruptions in 1975 and 1984 (Lockwood and others, 1987). Later monitoring, referenced to stable points on Mauna Kea and Hualālai, showed that the horizontal dilations measured across Moku'āweoweo were not symmetrically distributed about the summit inflation center, but were instead accommodated by southeastward translation of Mauna Loa's southeast flank. We suggest that this southeast-directed inflationary pressure against neighboring Kīlauea effectively "closed" Kīlauea's SWRZ in 1974 and thus blocked magma from migrating down this rift zone as it had done in 1971. Although the M=5.5 Ka'ōiki earthquake of November 30, 1974 and subsequent aftershock activity on Mauna Loa's southeast flank may have relieved some of Mauna Loa's influence on Kīlauea, inflation continued, leading to the Mauna Loa eruption of July 5, 1975 (Lockwood and others, 1987).

Duffield and others (1982) suggested that the 1971 migration of lava into the SWRZ took place because Mauna Loa was not inflated at the time and wrote (p. 303) that "Eruption along the southwest rift zone could be inhibited by an increase in compressive stress across the zone when a magma reservoir in neighboring Mauna Loa is inflated, effectively squeezing the rift zone closed." Their hypothesis is compatible with the events of September 19, 1974, when a westward-advancing eruptive fissure abruptly stopped at the caldera's rim. It seems reasonable to speculate that Kīlauea's SWRZ eruptions are unlikely to occur during times of Mauna Loa inflation.

The influence of Mauna Loa may also explain basic differences between the SWRZ and ERZ. Duffield and others (1982) have described several differences between the two rift zones, including the much higher frequency of eruptions on the ERZ. This disparity is likely caused by the fact that the north side of the ERZ is relatively immobile, and so any seaward movement of the south flank results in reduced compressive stress and an enhanced environment for magmatic intrusion and storage within the ERZ. The northwest side of the SWRZ is not stable, however. Inflation of the Mauna Loa edifice results in southeastward movement of the SWRZ's northwest flank, thereby increasing compressive stresses across the rift and restricting the environment for magma transport and eruption.

Did the December injection of magma between the SWRZ and the KFS and the subsequent earthquake swarm south of the lower SWRZ, coupled with the succession of earlier ERZ and 1974 summit intrusion/eruption events serve to "unlock" Kīlauea's south flank and facilitate the November 29 M=7.2 Kalapana earthquake? Or, were all these preceding events only symptoms of larger dynamic forces that enabled both the magmatic and tectonic events of the 1970's?

Equally intriguing is the changing role of the Koa'e Fault System in the evolution of Kīlauea Volcano. The KFS is a zone of normal faults and has never before been considered a locus of volcanic activity. The eruptions of May 24, 1969, May 5, 1973, and December 31, 1974, however, as well as the possible intrusion of December 25-27, 1965, all occurred within or near the margins of the KFS. As also suggested by Fiske and Swanson (1992), is it possible that in the future the Koa'e will become a major site for the injection and possible storage of magma, perhaps replacing the summit caldera as the "heart" of Kīlauea?

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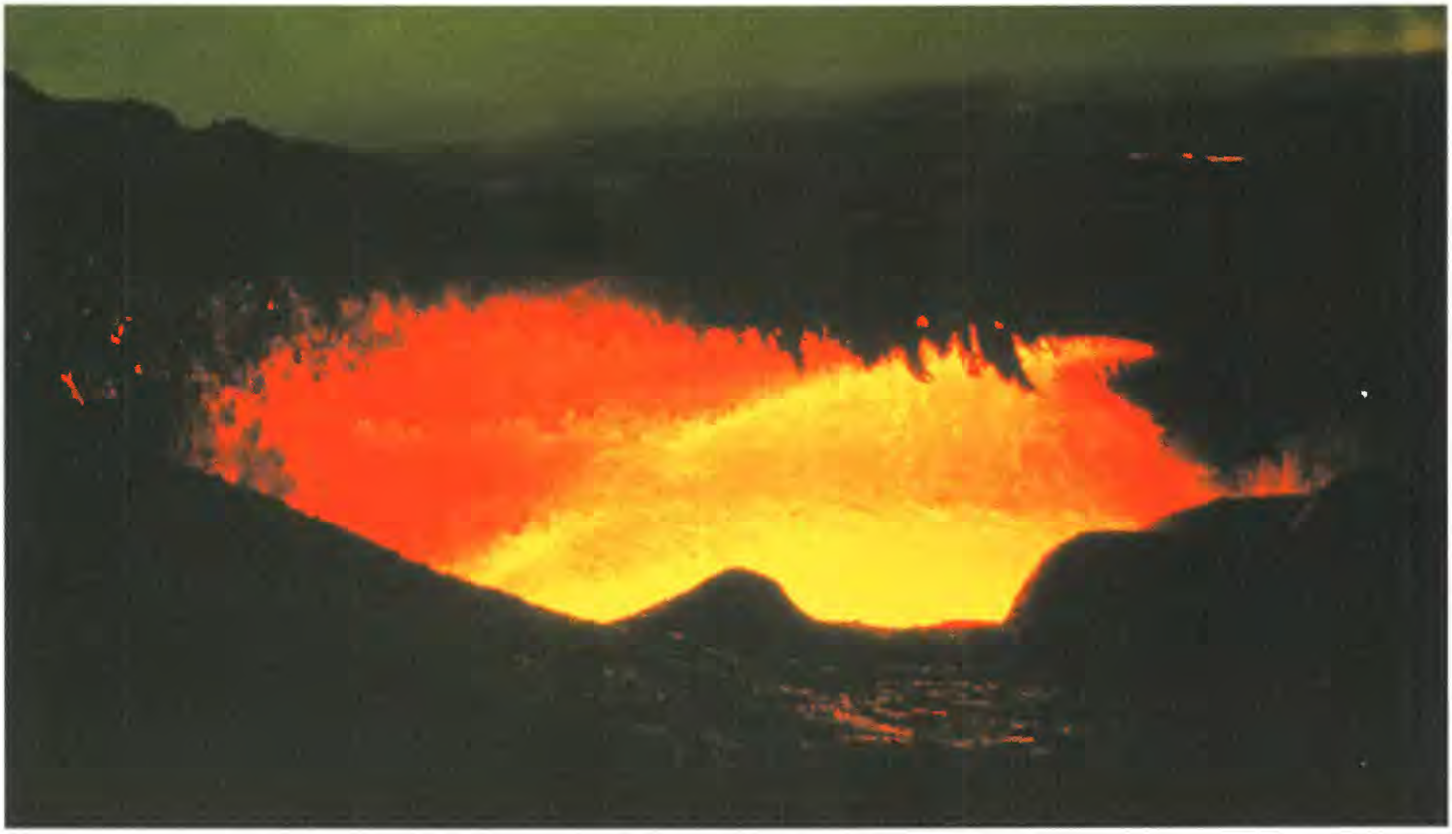
View of pāhoehoe lava flow across the Crater Rim Drive south of Halema'uma'u Crater on the morning of September 20, 1974. This is the same section of road covered by the September 1971 lava flow. If a drill core were obtained from the center of this flow it would reveal the following stratigraphy (top to bottom): 1974 lava flow / asphalt layer / 1971 lava flow / asphalt layer / 1921 lava flow / pre-1921 lava flows. USGS photo by John P. Lockwood.



View into a partially roofed-over eruptive vent taken at dawn on December 31, 1974. Eruptive activity has nearly ceased, but lava flows continue to move downslope in the background. Hot gases continue to be emitted, melting the vent walls and ceiling and forming delicate "lava stalactite" structures. USGS photo by Donald W. Peterson.