Chapter 5

Eruptive and Intrusive Activity, 1967–1975

In the period after 1967–68, more frequent changes in the chemistry of magma entering the system are manifested in the history of the long east-rift eruption at Mauna Ulu. Magma supply continues to increase during and beyond the end of the Mauna Ulu eruption, leading to a large intrusion in the southwest part of Kīlauea, which destabilized the south flank and is interpreted as a proximate cause of the 1975 M7.2 south flank earthquake.

Mauna Ulu lava shield built on Kilauea's east rift zone during the 1969–1974 eruption. USGS photo by J.D. Griggs, June 14, 1989.

The period beginning with the long 1967–68 eruption in Halemaʻumaʻu and ending with the *M*7.2 south flank earthquake in 1975 is an important chapter in HVO's history. Expansion of the seismic network was largely completed, and expansion of ground-deformation networks was accelerating. Improvements in monitoring ground deformation had begun in the 1960's with the nailing of setups and turning points on level lines and the acquisition of electronic distance measuring (edm) instrumentation. Later in the period a "dry" tilt network replaced the water-tube tilt network. In late 1966 a continuously recording Ideal-Arrowsmith (IA) tiltmeter was installed in Uwēkahuna Vault. Although it measured only the east-west component of tilt, it allowed continuous strip-chart recording and precise identification of the onset of summit deflation, filling the same role that the Press-Ewing seismometer installation had filled during the early 1960s.

Along with improved instrumentation and methods came increased challenges to the HVO staff as eruption frequency underwent a dramatic increase. In the years between the two summit eruptions in 1961 and 1967, there were a total of six rift eruptions, although 2 of the 6 years saw no eruptive activity. By contrast, following the summit eruption ending in July 1968, there were four rift eruptions in less than 1 year. The last of these produced the small Mauna Ulu shield that continued in semicontinuous eruption for a total of almost 5 years. As a result, incoming staff members no longer had the luxury of focusing their interpretations on the first eruption observed during their stay, but now had to consider multiple periods of activity.

Kīlauea eruptions, intrusions, and large earthquakes beginning with the 1967–68 Halemaʻumaʻu eruption up to the occurrence of the *M*7.2 south flank earthquake in 1975 are summarized in tables 5.1, 5.3–5.7. The eruptions from 1967 through 1975 are covered in seven papers (Duffield and others, 1982; Jackson and others, 1975; Kinoshita and others, 1969; Lockwood and others, 1999; Swanson and others, 1976b, 1979; Tilling and others, 1987). Additional interpretation of events in this period is covered in two summary papers (Klein and others, 1987; Wright and Klein, 2008). Seismic analysis for the entire period is included in the Klein reference, and figures from that paper are cross-referenced in tables 5.1 and 5.3 to 5.7. In the tables and figures we adopt the definitions of eruption and intrusion given in chapter 1 of this paper, modified from terminology used previously to define intrusions (Wright and Klein, 2008, table 2).

The Mauna Ulu eruption in 1969 is of particular interest for two reasons. First, it is the centerpiece of an epoch of much greater seismic activity than in any previous period in Kīlauea's post-1952 history and takes place within a period of accelerating magma supply that we consider an important factor in the triggering of the 1975 earthquake. Second, it is Kīlauea's first (and failed) 20th century attempt at continuous east-rift eruption, an attempt that finally succeeded with the east-rift eruption that began in 1983 and continues at this writing (2014). The Mauna Ulu eruption has been described in two papers (Swanson and others, 1979; Tilling and others, 1987) and is the primary focus of another paper (Wright and Klein, 2008). In the following we summarize the sequence of activity and amplify and add to the conclusions of the latter paper.

Mauna Ulu Prelude: 1 January 1967–1 April 1969

A long summit eruption in Halemaʻumaʻu occurred from November 1967 to July 1968 (Kinoshita and others, 1969) and was followed by three small east-rift eruptions in 1968 and 1969 (Jackson and others, 1975; Swanson and others, 1976b). Leveling surveys conducted around Kīlauea's summit in the period preceding the summit eruption showed that the center of inflation migrated around Halemaʻumaʻu from northeast to southeast to southwest (chap. 4, fig. 4.2; Fiske and Kinoshita, 1969, figure 5). Parts of this cycle of inflation centers can be identified in the buildup to other eruptions, both before and after 1967–68[20].

The immediate onset for the November 1967 summit eruption was three *M*2.7–2.8 earthquakes shallower than 2 km beneath Kīlauea's summit (fig. 5.1, lower panel). Other activity that might be considered as precursory were magma-supply earthquakes of *M*4+ at 20–35-km depth on 31 December 1966 and 1 July 1967, followed by a *M*4.1 magma-supply earthquake at 10–20-km depth on 8 September 1967—though many such earthquakes occur routinely and not immediately preceding an eruption. Slight increases in the rate of inflation followed each of these earthquakes. The beginning of eruption on 5 November 1967 was marked by a sharp deflation of about 13 μr and, after recovery to a value near the preeruption level, deflation resumed at a lower rate. The initial deflation ended with the occurrence of a swarm of south flank earthquakes on 5–10 January 1968 identified as a multiple suspected deep intrusion labeled SDI 1, SDI 2, and SDI 3 in figure 5.2. All three source areas are seen in subsequent suspected deep intrusions, the most common locus being SDI 2. The end of eruption in Halemaʻumaʻu in July 1968 was preceded by a sharp inflation 5–6 weeks before and by gradually

[20] With reference to chapter 4, figure 4.2, tilt migration for three eruptions out of many can serve as examples: October 1963—south of center 2 to north of center 1 over 2 days; February 1969—south of center 2 to center 1 over 2 days; December 1974—the full cycle from north (center 2) through south (center 3) to west (center 5) over 4 days.

Table 5.1. Kīlauea eruptions, intrusions, and earthquakes, pre-Mauna Ulu (see figs. 5.1, E3).

[In rows with multiple entries text applies down to the next entry; dates in m/d/yyyy format; do = ditto (same as above); data for eruptions and traditional intrusions are emphasized by grey shading]

Time and Date		Region[1]	Event Type[2]	No.[3]	Tilt[4]		Lag[5]	Comment	Figures[6]	References[7]
Start	End				Mag	Az				
02:32 11/05/1967	19:00 7/31/1968	kcal-hm	E		19.3	166.6	no data	Net tilt during eruption	E4	1, 2, 3
06:30 11/5/1967	08:30 11/6/1967				13.4	125		Tilt 11/5-6—initial deflation		
21:44 1/05/1968	20:54 1/08/1968	sf2mer	SDI[8]	29					**5.2**	
06:30 1/07/1968	10:29 1/10/1968	sf3kuer	SDI	49				Slight inflation following SDI		
06:30 1/07/1968	21:50 1/07/1968		EQS	16				Broken earthquakes , of 15 events 1/05/, 02:58–06:11	**5.2**	
15:46 1/07/1968	01:57 1/08/1968		EQS	11						
19:01 1/08/1968	10:29 1/10/1968		EQS	26				5 additional events 1/08, 06:59–11:47		
03:20 8/22/1968	09:39 8/22/1968	koae	EQS	11				Exceptionally few eq in all reions		
03:50 8/22/1968	11:29 8/22/1968	ei3uer		5	56.7	114		No swarm	*43.28*	
06:00 8/22/1968	10:00 8/26/1968	UERZ/koae	E/I				no data	Hiiaka Crater and east; Tilt 8/21–25	E5; *43.28*	4, 8
10:37 10/07/1968	23:27 10/09/1968	sf3kuer	EQS	36				South flank-ant/acc[9]	*43.29*	
10:42 10/07/1968	20:43 10/09/1968	ei2mer	EQS	145						
11:11 10/07/1968	12:04 10/08/1968	sf2mer	EQS	29				South flank acc/resp[9]		
12:32 10/07/1968	00:28 10/08/1968	ms1	EQS	41						
14:35 10/07/1968	04:00 10/12/1968	MERZ	E/I		60.2	116	no data	Nāpau Crater and east; Tilt 10/7–9	**5.3**	4
00:00 10/21/1968	17:00 10/22/1968	MERZ	E				no data	Renewed eruption		
16:33 12/16/1968		sf3kuer	EQ		flat tilt			*M*4.2 with 2 possible foreshocks and >26 aftershocks	E6	
16:25 2/09/1969		sf2mer	EQ					*M*4.3 with 3 possible foreshocks and >30 aftershocks		12
09:56 2/21/1969	14:59 2/22/1969	ms1	EQS	20					*43.31*	
05:23 2/22/1969	09:46 2/22/1969	sf2mer	EQS	17				South flank anticipation/ accompaniment		
06:23 2/22/1969	14:54 2/22/1969	sf3kuer	EQS	6				do		
07:15 2/22/1969	09:29 2/22/1969	ei2mer	EQS	6						
09:50 2/22/1969	03:00 2/28/1969	UERZ	E/I		48.7	124.2	+1h 50m	Aloi Crater and east; tilt 2/21–28	E7	5
12:16 2/22/1969	14:54 2/22/1969	ei3uer	I	5						
02:21 3/21/1969	05:55 3/21/1969	sf3kuer	EQS	15				South flank anticipation/ accompaniment	*43.32*	
02:34 3/21/1969	03:26 3/21/1969	ei3uer	I[10]	11	3.0	101.3	+0h 21m	Tilt 3/20-22	E8	
02:42 3/21/1969	06:04 3/21/1969	sf2mer	EQS	5				South flank-accompaniment/ response		

[1] Earthquake classification abbreviations are given according to the classification in appendix A, table A3, and locations of regions are shown in appendix A, figure A4. Eruption locations are designated in bold type as follows: KC, Kīlauea Caldera; LERZ, lower east rift zone; MERZ, middle east rift zone; UERZ, upper east rift zone; SWR, outhwest rift zone.

[2] E, Eruption; intrusion ("traditional" I; "inflationary" II; "suspected deep intrusion" SDI-see chapter 1; earthquake, EQ; earthquake swarms EQS).

[3] Minimum number of events defining a swarm: 20 for south flank; 10 for all other regions.

[4] Magnitude in microradians and azimuth of daily tilt measurements from the water-tube tiltmeter in Uwēkahuna Vault.

[5] Lag times separating the onset of the earliest earthquake swarm (excluding south flank) for a given event and the beginning of deflation or inflation measured by the continuously recording Ideal-Arrowsmith tiltmeter in Uwēkahuna Vault. (+) tilt leads, (-) tilt lags.

[6] Text figures **bold text**; appendix figures plain text; 43.xx = figures in Klein and others, 1987.

[7] References coded as follows: 1. Fiske and Kinoshita, 1969, 2. Kinoshita and others, 1969, 3. Wright and Klein, 2008, 4. Jackson and others, 1975, 5. Swanson and others, 1976b, 6. Swanson and others, 1979,, 7. Duffield and others, 1974, 8. Klein and others, 1987, 9. Tilling and others, 1987, 10. Nielsen and others, 1977, 11. Lockwood and others, 1999, 12. Klein and others, 2006. Note: This is a master list for all tables in chapter 5. Only some references will be cited in this table.

[8] Suspected deep intrusions are defined by south flank earthquake swarms (10 eq/day minimum) with little rift seismicity or tilt change.

[9] Abbreviations as follows relative to time of intrusion or eruption: ant, anticipation (before); acc, accompaniment (during); resp, response (after).

[10] Traditional intrusions unaccompanied by eruption are defined by at least 5 rift events per day.

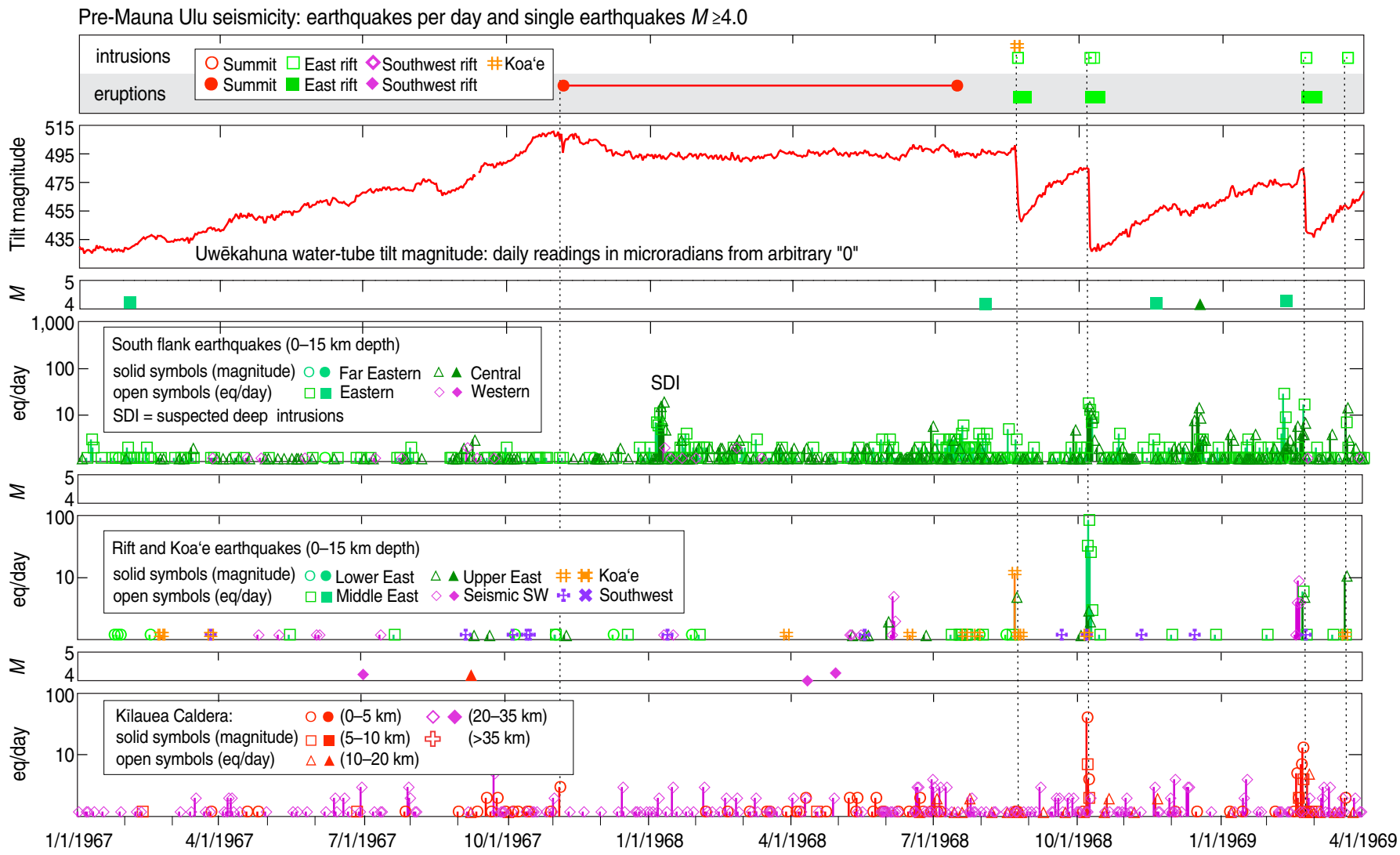

Figure 5.1. Graphs showing Kīlauea activity, 1 January 1967–1 April 1969 (pre-Mauna Ulu): Halema'uma'u eruption (5 November 1967–13 July 1968) and the three east rift eruptions that precede the Mauna Ulu eruption that began on 24 May 1969. Top panel: Times of eruption and traditional intrusion. Second panel from top: Uwēkahuna tilt magnitude related to times of eruption and intrusion emphasized by vertical dotted lines. Tilt magnitudes are given in microradians. Bottom six panels: Seismicity is plotted, from bottom to top, for the magma supply path, rift zones and Koa'e, and south flank. Earthquakes per day (eq/day) and magnitudes (M) greater than or equal to 4.0 are given for each region. Dates on figure in m/d/yyyy format.

increasing seismicity beneath Kīlauea's south flank and the deep magma-supply path (fig. 5.1).

The net volume of summit inflation preceding the 1967–68 eruption can be compared with the volume erupted and with the volume of magma transfer to the rift zone as noneruptive deflations (table 5.2). The preeruption volume of summit inflation estimated from applying a Mogi model to the Fiske-Kinoshita leveling data is ~0.056 km^3, compared with a nearly identical volume of 0.055 km^3 calculated from the daily Uwēkahuna tilt by methods given in appendix A. This represents the volume of magma supplied to the summit reservoir before eruption began. The erupted volume, taken from Kinoshita and others (1969, table 2) after correction for 20 percent vesicles, is 0.078 km^3. Episodes of significant deflation occurring during the 1965–67 cycle, beginning with the deflation associated with the December 1965 eruption/intrusion, represent additional magma transferred to the east rift zone. The initial rapid rate of filling and initial deflation during the 1967 eruption are attributed to lowered pressure on the magmatic system produced by the shift from a capped and throttled magma supply to an open eruption at the surface. We attribute the net deflation during the eruption to additional magma transfer to the rift zone

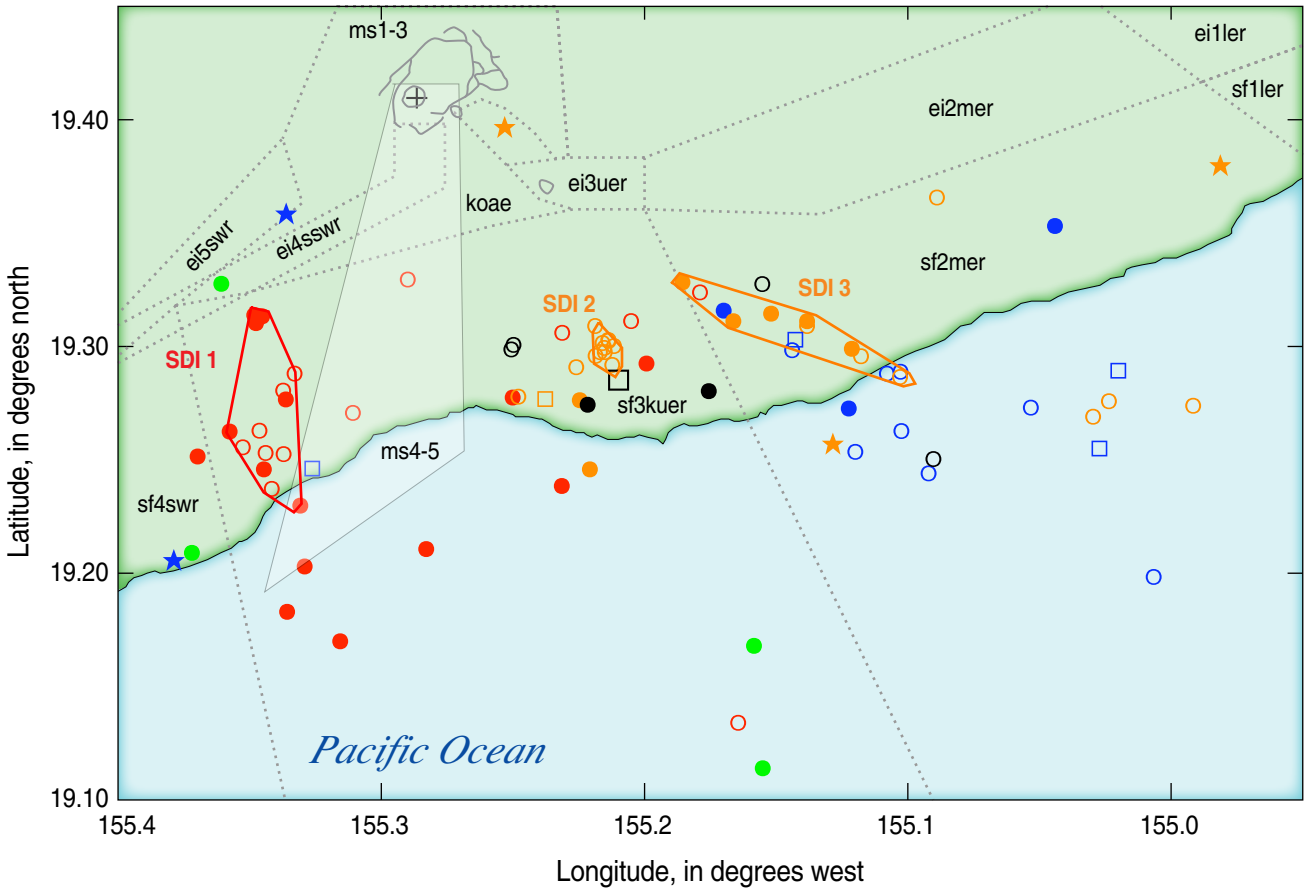

Figure 5.2. Map showing Kīlauea activity, 5–10 January 1968. Earthquake locations are shown for a subset of events covering a period within the 1967–68 Halema'uma'u eruption dominated by suspected deep intrusions. Suspected deep intrusions are distinguished by small swarms of south flank earthquakes oriented at a high angle to the rift zone, in contrast to the south flank response to traditional and inflationary intrusions, in which earthquakes are distributed nearly parallel to the rift zones. Three locations are outlined and labeled SDI 1, SDI 2, and SDI 3. South flank earthquake swarms at these locations appear throughout Kīlauea's history, with earthquakes near SDI 2 being the most common. Dates on figure in m/d/yyyy format.

Table 5.2. Tilt and volume changes associated with 1967–1968 eruption.

Cycle	Event	Date		Δ Time Years	Tilt		Tilt Vol (km^3)[2]	Eruption Volume (km^3)[3]	Magma supply rate msr (km^3/yr)[4]	Comment
		Start	End		Mag[1]	Az				
Preeruption	Net	12/23/1965	11/5/1967	1.8672	123.0	328	0.0555			Total inflation
	Deflation	12/23/1965	12/29/1965		47.4	99	0.0213			Magma transfer to rift zone
	Deflation	10/1/1966	10/7/1966		9.8	140	0.0044			Magma transfer to rift zone
	Deflation	8/9/1967	8/18/1967		8.4	121	0.0038			Magma transfer to rift zone
	Sum				188.6		0.0850		0.0455	Preeruption magma supply rate
	Eruption									
Eruption		11/5/1967	7/15/1968	0.6927				0.0748	0.1083	Filling rate
Syneruption		11/5/1967	7/15/1968					0.0315		Volume added at preeruption msr
								-0.0464		Added volume minus erupted volume
	Deflation	11/5/1967	7/14/1968		4.09	166.57	0.0089			Syneruption deflation
								0.0375		Reservoir gain during eruption
				0.6927				0.1123	0.1208	Syneruption magma supply rate

[1]Tilt magnitude in microradians.

[2]Tilt volume in cubic kilometers = Uwēkahuna tilt magnitude × 0.00045 (see text for explanation).

[3]Equivalent magma volume obtained by multiplying published lava volumes by 0.8 to account for 20 percent vesicles.

[4]Minimum magma supply rate (msr) calculated as described in text.

(table 5.2). The filling rate of 0.109 km^3/yr during the eruption is much greater than the preeruption magma supply rate of 0.046 km^3/yr, and the magma supply rate during the eruption is even higher (0.121 km^3/yr) when the additional transfer of magma to the east rift zone is counted (table 5.2; see also Dvorak and Dzurisin, 1993, discussion on p. 22,263 and following).

The differences in calculated magma supply rate before and after November 1967 may be reflected in the seismicity. The overall rate of deep magma-supply seismicity increased before the eruption from 45 events during all of 1966 to 66 events in the first 10 months of 1967, and it continued to increase to 91 events during the 8-month 1967–68 eruption. South flank seismicity, even excluding south flank events associated with the suspected deep intrusion of January 1968, also increased dramatically during the eruption, 264 events compared to 98 events in the preceding 8-month period. The increase in number of events during this period is much greater than would be expected from improved recording techniques within an expanding seismic network, though the installation of the Develocorder at HVO in March 1967 coincident with the seismicity increase means the numbers quoted above should not be interpreted absolutely.

The 1968–69 eruptions show patterns of seismicity similar to those related to rift eruptions between 1961 and 1965. Ground deformation surveys show that each of these rift eruptions was accompanied by shallow rift intrusion (Jackson and others, 1975, figures 13 and 32; Swanson and others, 1976b, figure 20). The August 1968 eruption was accompanied by intrusion into the Koa‘e Fault Zone (table 5.1). The overall rift seismicity is anomalously low near the eruption site, considering that the east rift segment beneath the eruption site had had no documented intrusions after 1952. We attribute the lack of seismicity to addition of magma to an existing, still molten, dike, or more likely to significant dilation of the rift during the earlier suspected deep intrusion of January 1968 (Wright and Klein, 2008, p. 105). The October 1968 eruption shows a typical pattern of shallow intrusion with strong south flank response (fig. 5.3). A rapid summit inflation occurred just before the February 1969 eruption. The February 1969 eruption/intrusion was accompanied by reduced rift and flank seismicity compared to the October 1968 eruption/intrusion. Another small intrusion occurred on 21 March 1969.

Mauna Ulu Eruption, 1969–1974: Observations

We divide the Mauna Ulu eruption into six parts as follows:

IA: 1 April 1969–31 December 1969 (table 5.3; fig. 5.4). This section discusses the immediate precursors to the beginning of the Mauna Ulu eruption on 24 May 1969 and the 12 episodes of high fountaining ending on 31 December 1969

IB: 1 January 1970–15 June 1971 (table 5.4; fig. 5.5). A period of sustained eruption at two interconnected vents. The primary vent built the Mauna Ulu shield, and a second active vent was beneath the former location of ʻAlae Crater.

Pause: 16 June 1971–3 February 1972 (table 5.5; fig. 5.7). A period of eruption elsewhere on the volcano coincident with temporary cessation of eruption from Mauna Ulu.

II: 4 February 1972–15 June 1974 (table 5.6; fig. 5.9). This period is further divided by the occurrence of a distant earthquake, the *M*6.6 Honumu earthquake off the east coast of Mauna Kea. The period before the earthquake (IIA) was a quiet period of continuous eruption at Mauna Ulu. Following the earthquake (IIB), the eruption was marked by many more intrusions and two eruptions elsewhere on the east rift zone, during which the Mauna Ulu activity temporarily ceased.

Post: 16 June 1974–29 November 1975 (table 5.7; fig. 5.11). This period marks the end of the Mauna Ulu eruption and ends with the *M*7.2 south flank earthquake on 29 November 1975.

Period IA: 24 May 1969–1 January 1970

The month before the Mauna Ulu eruption was marked by heightened seismicity that began at the

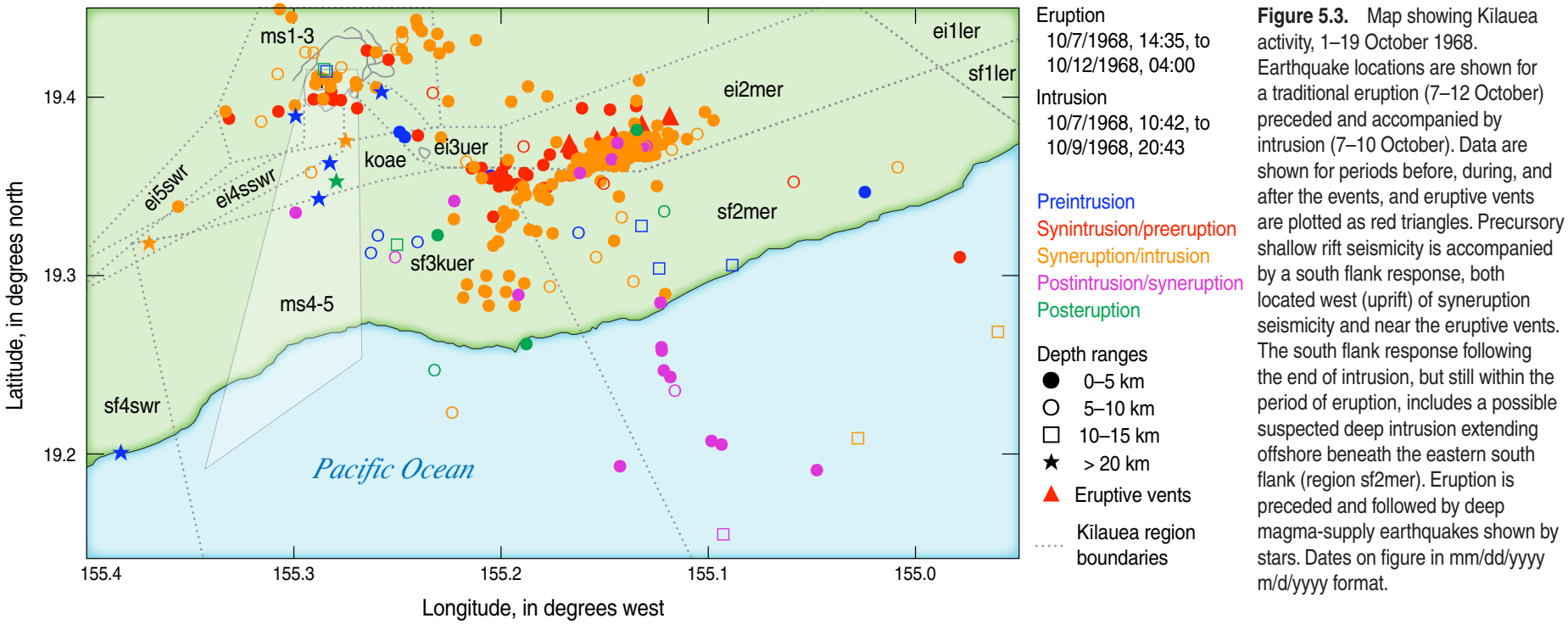

Figure 5.3. Map showing Kīlauea activity, 1–19 October 1968. Earthquake locations are shown for a traditional eruption (7–12 October) preceded and accompanied by intrusion (7–10 October). Data are shown for periods before, during, and after the events, and eruptive vents are plotted as red triangles. Precursory shallow rift seismicity is accompanied by a south flank response, both located west (uprift) of syneruption seismicity and near the eruptive vents. The south flank response following the end of intrusion, but still within the period of eruption, includes a possible suspected deep intrusion extending offshore beneath the eastern south flank (region sf2mer). Eruption is preceded and followed by deep magma-supply earthquakes shown by stars. Dates on figure in mm/dd/yyyy m/d/yyyy format.

end of April and culminated with the beginning of the eruption on 24 May 1969. Intrusions beneath Kīlauea's summit occurred on 30 April and in early May. On 21 May intense seismicity beneath Kīlauea's south flank began 3 days before eruption at the surface on 24 May.

Mauna Ulu IA was marked by 12 different high-fountaining episodes over 8 months. All fountaining episodes were accompanied by small summit deflations and, with the exception of episodes 1, 2, 9, and 12, these eruptive episodes were not accompanied by shallow seismic activity beneath Kīlauea's summit or the rift zone adjacent to the eruption site (fig. 5.4). Two periods of intense south flank earthquake swarms (suspected deep intrusions) occurred during this period. Seismicity marking the suspected deep intrusion of 3–9 June occurred beneath the area of figure 5.2 designated as SDI 3. The swarm of 29 September–4 October occurred beneath SDI 1, and the swarm of 4–16 October occurred beneath both sites. The last high-fountaining episode was preceded by both enhanced south flank seismicity characteristic of a suspected deep intrusion and also by an intrusion into the northernmost seismic southwest and east rift zones that anticipated the more intense inflationary intrusions of Mauna Ulu IB (see below).

Period IB: 1 January 1970–14 June 1971

A high level of seismicity continued following the end of episodic high fountaining during period IA. Although lava was continuously visible in Mauna Ulu and at the nearby former location of ʻAlae Crater, and overflows fed lava flows that traveled downslope from both locations, there were also several intrusive episodes throughout this period. A possible pair of suspected deep intrusions on 8–14 January was followed by a summit intrusion on 22 January. The first of many inflationary intrusions took place during 4–9 February (fig. 5.6), during which time earthquakes clearly migrated downrift (Klein and others, 1987, figure 43.40). Similar intrusions occurred later in February and in March and April.

A large intrusion beneath Kīlauea's summit, the upper east rift zone, and adjacent Koaʻe Fault Zone occurred from 15 to 18 May 1970, with a strong south flank response before, during, and after the intrusion (table 5.4; fig. 5.5). According to Swanson and others (1979, p. 39), this event marked the reopening of the connection between the summit and the east rift zone. Deep seismic activity occurred before the intrusion southwest of Kīlauea's summit and after the intrusion in the mantle beneath the eastern south flank[21].

A large inflationary intrusion occurred between 25 December 1970 and 5 January 1971, with activity concentrated beneath the two main segments of the southwest rift zone. South flank activity, however, was located beneath the central and eastern south flank, focused on the middle segment (SDI 2) associated with the suspected deep intrusions. The end of continuous eruptive activity at Mauna Ulu is arbitrarily placed at 15 June 1971, coincident with the last overflow, although lava remained visible deep in Mauna Ulu Crater until October 1971 (Swanson and others, 1979). As in Mauna Ulu IA, the end of period IB is marked by heightened seismicity, including swarms of deep magma-supply earthquakes between 29 April and 9 May (fig. 5.5). Uwēkahuna tilt shows net inflation up to the end of November 1970, then deflation to February 1971, and renewed inflation up to the end of period IB in June 1971 (fig. 5.5).

[21] Deep earthquakes beneath the eastern south flank, and several kilometers east of the magma supply path previously outlined (Wright and Klein, 2006) are considered to be stress release in the mantle associated with flexure of the Pacific Plate.

Mauna Ulu Pause: 15 June 1971–4 February 1972

During the Mauna Ulu pause two eruptions occurred at and near Kīlauea's summit in August and September 1971 (Duffield and others, 1982), accompanied by strong tilt changes and heightened seismic activity across all sectors of the volcano (table 5.5; fig. 5.7). A noteworthy suspected deep intrusion occurred on 4–5 July beneath area SDI 2 (fig. 5.8). Inflationary intrusions continued—three in July 1971, one preceding the eruption of 14 August, and three preceding the eruption of 24 September. Inflation of more than 100 μrad associated with the September eruption (table 5.5) brought the Uwēkahuna tilt site to its highest level of inflation since 1956. The 24 September tilt azimuth was consistent with intrusion beneath the uppermost seismic southwest rift zone. The earthquake sequence within the south flank resembles the pattern seen during suspected deep intrusions beneath area SDI 2.

Seismic activity beneath Kīlauea's southwest south flank increased relative to preceding periods and a small suspected deep intrusion in November was followed by a major suspected deep intrusion beneath the central and western south flank at the end of December 1971, unaccompanied by eruption or deflationary tilt (fig. 5.7). This event was accompanied by minor activity on the upper section of the east rift zone, the middle section of the seismic southwest rift zone, and an additional concentration of south flank earthquakes south of the uppermost east rift zone located similarly and slightly to the east of the earthquakes associated with the suspected deep intrusion of June 1969.

Return of activity to Mauna Ulu on 4 February 1972 was heralded by a series of east rift inflationary

Table 5.3. Kīlauea eruptions, intrusions, and earthquakes, Mauna Ulu period IA (see figures 5.4, E9).
[In rows with multiple entries text applies down to the next entry; dates in m/d/yyyy format; do, ditto (same as above); data for eruptions and traditional intrusions are emphasized by grey shading]

Time and Date		Region[1]	Event Type[2]	No.[3]	Tilt[4]		Lag[5]	Comment[6]	Fig.[7]	Ref.[8]
Start	End				Mag	Az				
12:35 4/30/1969	13:41 4/30/1969	sf2mer	II	11	5.8	325		South flank anticipation	E10	
18:56 4/30/1969	22:07 4/30/1969	ms1	I	11			+45h 4m	Tilt 4/29-5/4; I–A: inflation 4/29-5/2		
09:16 5/4/1969	00:34 5/6/1969	ms1	II	22	4.4	130	deflation	Tilt 5/4-9; I–A: 5/7-9; 5/4-6/1969	E11	
22:18 5/5/1969	23:57 5/5/1969	ms2	II	10						
15:33 5/9/1969		sf2mer	EQ					*M*4.3; productive aftershock sequence		12
08:40 5/21/1969	12:20 5/22/1969	sf3kuer	EQS	14				South flank anticipation	*43.33*	8
17:32 5/21/1969	03:49 5/22/1969	ms1	I	8	5.3	311		Tilt: 5/19-22; earthquakes move south 5/21-22	E12	
19:03 5/21/1969	02:37 5/22/1969	ei3uer	I?	3						
04:31 5/22/1969	23:19 5/22/1969	ms2	I?	5						
05:22 5/22/1969	23:36 5/22/1969	ei4sswr	I?	9			-16h 38m			
07:31 5/21/1969	00:24 5/25/1969	sf2mer	EQS	119				South flank anticipation		
14:25 5/23/1969	19:21 5/24/1969	sf3kuer	EQS	52				do		
03:42 5/24/1969	12:36 5/24/1969	ei3uer	I	9			-2h 18m	Precursory intrusion		
04:16 5/24/1969	23:29 5/24/1969	koae	EQS	5				No swarm	*43.34*	8
04:45 5/24/1969	15:00 5/25/1969	MERZ	E/I		26.0	110		Episode 1; Tilt 5/22-27	E13	6
07:35 5/25/1969	06:00 5/26/1969	sf2mer	EQS EQS	9				South flank accompaniment/response		
20:38 5/25/1969	05:20 5/26/1969	sf3kuer		5				South flank response		
14:27 5/26/1969	19:47 5/26/1969	sf3kuer	EQS	5				South flank anticipation; also 5/25-26 (8)		
16:40 5/26/1969	17:22 5/26/1969	ei3uer	EQS	9				Precursory seismicity		
19:00 5/27/1969	09:00 5/29/1969	MERZ	E/I		6.6	114	+0h 40m	Episode 2; Tilt 5/28-30	E13	6
10:28 6/3/1969	12:09 6/9/1969	sf3kuer	SDI	130					E14	
15:47 6/3/1969	10:48 6/4/1969	sf2mer	SDI	7						
13:30 6/12/1969	11:00 6/13/1969	MERZ	E		15.2	112	-0h 30m	Episode 3; tilt 6/11-13; no rift earthquakes		6
21:45 6/25/1969	07:00 6/26/1969	MERZ	E		20.0	115	-2h 15m	Episode 4; tilt 7/25-26; no rift earthquakes		6

Table 5.3. Kīlauea eruptions, intrusions, and earthquakes, Mauna Ulu period IA (see figures 5.4, E9).—Continued

[In rows with multiple entries text applies down to the next entry; dates in m/d/yyyy format; do, ditto (same as above); data for eruptions and traditional intrusions are emphasized by grey shading]

Time and Date		Region[1]	Event Type[2]	No.[3]	Tilt[4]		Lag[5]	Comment[6]	Fig.[7]	Ref.[8]
Start	End				Mag	Az				
22:31 7/2/1969	09:07 7/4/1969	sf3kuer	EQS	26				South flank anticipation	E15	
06:20 7/3/1969	13:01 7/3/1969	sf2mer	EQS	8				South flank anticipation/accompaniment		
06:36 7/3/1969	22:15 7/3/1969	ei3uer	I	60	2.7	162	inflation	Tilt 7/2-4; I–A tilt 6/26 -7/6; no deformation indicates redistribution of intruded magma	E15; *43.35*	8
06:59 7/3/1969	18:04 7/3/11969	koae	I	43						
10:39 7/3/1969	13:41 7/3/1969	ei2mer	I	5						
03:15 7/15/1969	05:56 7/15/1969	sf3kuer	EQS	3				South flank anticipation		
03:45 7/15/1969	12:20 7/15/1969	MERZ	E		13.0	111	+1h 45m	Episode 5; tilt 7/14-15; no rift earthquakes	**5.4**	6
16:30 7/15/1969	09:48 7/16/1969	sf3kuer	EQS	7				South flank response		
17:15 8/3/1969	00:10 8/4/1969	MERZ	E		12.4	108	-2h 45m	Episode 6; Tilt 8/2-4; few rift earthquakes	E16	6
21:00 8/5/1969	05:45 8/6/1969	MERZ	E		12.7	120	-1h 0m	Episode 7; Tilt 8/5-6; few rift earthquakes	E16	6
00:15 8/22/1969	04:40 8/22/1969	MERZ	E		10.7	109	+0h 15m	Episode 8; Tilt 8/21-23; no rift earthquakes		6
19:30 9/06/1969	4:30 9/07/1969	MERZ	E		30.0	114.4	+0h 30m	Episode 9: Tilt 9/6–7; no rift eqrthquakes		6
23:51 9/29/1969	18:37 10/4/1969	sf3kuer	SDI	61			inflation	Intrusion from 5-10 km deep source	E17	
10:26 10/7/1969	12:52 10/9/1969	sf3kuer	SDI	154			inflation	South flank anticipation	*43.36*	8
15:41 10/9/1969	09:03 10/10/1969	sf2mer	EQS	8				South flank anticipation; SDI continuation?		
18:55 10/9/1969	12:44 10/11/1969	sf3kuer	EQS	34				South flank anticipation/accompaniment		
09:00 10/10/1969	11:00 10/13/1969	MERZ	E		11.1	121	+7h 0m	Episode 10; Tilt 10/8-13; no rift earthquake		6
12:55 10/14/1969	16:57 10/14/1969	sf2mer	EQS	8				South flank response		
15:41 10/14/1969	19:57 10/14/1969	sf3kuer	EQS	5				do		
15:30 10/19/1969	00:24 10/20/1969	sf3kuer	EQS	7				South flank anticipation		
01:00 10/20/1969	08:20 10/20/1969	MERZ	E		21.5	108.0	+1h 0m	Episode 11; tilt 10/19-20; no rift earthquake		6

Table 5.3. Kīlauea eruptions, intrusions, and earthquakes, Mauna Ulu period IA (see figures 5.4, E9).—Continued

[In rows with multiple entries text applies down to the next entry; dates in m/d/yyyy format; do, ditto (same as above); data for eruptions and traditional intrusions are emphasized by grey shading]

Time and Date		Region[1]	Event Type[2]	No.[3]	Tilt[4]		Lag[5]	Comment[6]	Fig.[7]	Ref.[8]
Start	End				Mag	Az				
10:22 11/3/1969	11:22 11/3/1969	sf2mer	EQS	3				South flank anticipation	E18; *43.37*	8
11:11 11/3/1969	11:44 11/3/1969	ei3uer	I	16	5.8	117	+3h 11m	Tilt 11/1-4		
11:14 11/3/1969	13:13 11/3/1969	ei2mer		4				No swarm		
11:26 11/3/1969	12:54 11/3/1969	sf3kuer	EQS	4				South flank response		
01:58 12/11/1969	13:28 12/12/1969	ei4sswr	II	14	1.7	121	-32h	Tilt 12/12-13	E19	
01:04 12/23/1969	11:51 12/23/1969	ei4sswr	II	15	7.9	303	inflation	Tilt 12/20-27; I–A tilt 12/18-12/23	E20; *43.38*	8
12:05 12/26/1969	00:03 12/29/1969	ei4sswr	II	11				Broken swarm		
16:59 12/27/1969	08:21 12/29/1969	sf3kuer	SDI	41				South flank accompaniment as SDI	E21	
05:00 12/30/1969	08:25 12/30/1969	MERZ	E		4.7	113		Episode 12a; Tilt 12/30-31; no rift eq		6
10:00 12/30/1969	18:30 12/30/1969	MERZ	E					Episode 12b; I–A: deflation		6
10:41 12/30/1969	04:05 12/31/1969	sf3kuer	EQS	8[9]				South flank accompaniment/response		

[1]Earthquake classification abbreviations are given according to the classification in appendix table A3, and locations are shown on appendix figure A4. Eruption locations are designated in bold type as follows: KC, Kīlauea Caldera; LERZ, lower east rift zone; MERZ, middle east rift zone; UERZ, upper east rift zone; SWR, southwest rift zone.

[2] **E**, Eruption; intrusion ("traditional" **I;** "inflationary" II**;** "suspected deep" SDI (see Wright and Klein, 2008, table 2); south flank earthquake swarm EQS.

[3]Minimum number of events defining a swarm: 20 for south flank; 10 for all other regions.

[4]Magnitude in microradians and azimuth of daily tilt measurements from the water-tube tiltmeter in Uwēkahuna Vault.

[5]Lag times separating the onset of the earliest earthquake swarm (excluding south flank) for a given event and the beginning of deflation or inflation measured by the continuously recording Ideal-Arrowsmith tiltmeter in Uwēkahuna Vault. (+) tilt leads, (-) tilt lags.

[6]Abbreviations as follows: ftn, fountaining; eq, earthquake; eqs, earthquake swarm; fs, foreshock; as, aftershock; ms, mainshock; sf, south flank; inf, inflation; def, deflation; ant, anticipation (preceding event); acc, accompaniment (during event); resp, response (following event); I–A, Ideal-Arrowsmith continuously recording tiltmeter in Uwēkahuna Vault.

[7]Text figures **bold text**; appendix figures plain text; 43.xx = figures in Klein and others, 1987.

[8]References coded as follows: 1. Fiske and Kinoshita, 1969, 2. Kinoshita and others, 1969, 3. Wright and Klein, 2008, 4. Jackson and others, 1975, 5. Swanson and others, 1976b, 6. Swanson and others, 1979, 7. Duffield and others, 1974, 8. Klein and others, 1987, 9. Tilling and others, 1987, 10. Nielsen and others, 1977, 11. Lockwood and others, 1999; 12. Klein and others, 2006. Note: This is a master list for all tables in chapter 5. Only some references will be cited in this table.

[9]Productive aftershock sequences defined in reference (12) above.

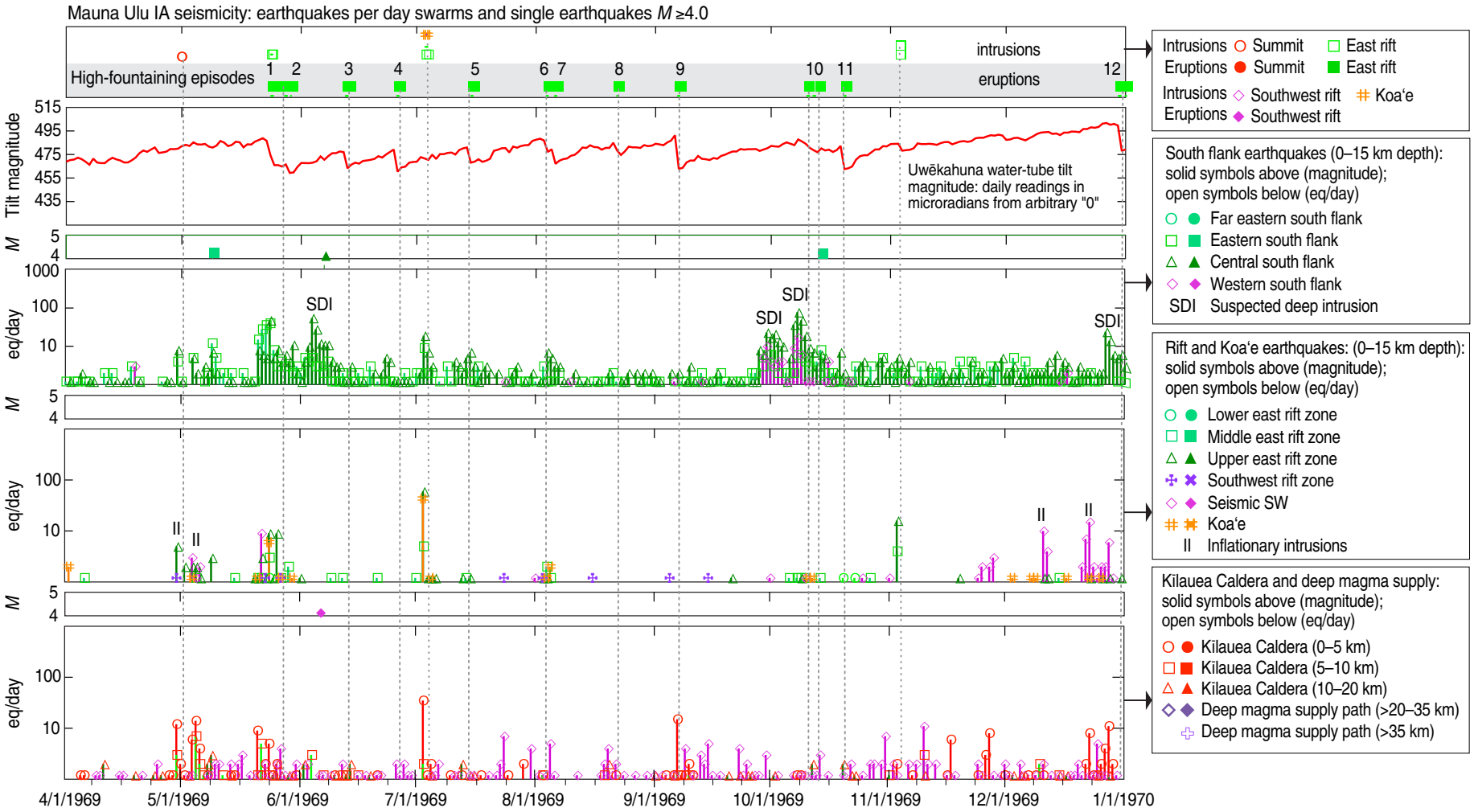

Figure 5.4. Graphs showing Kīlauea activity, 1 April 1969–1 January 1970 (Mauna Ulu period IA): Seismicity precursory to the beginning of the Mauna Ulu eruption on 24 May 1969, continuing through the end of episodic high fountaining on 31 December 1969. High-fountaining episodes 1–12 are labeled on the top panel. Dates on figure in m/d/yyyy format. See also caption for figure 5.1.

Table 5.4. Kīlauea eruptions, intrusions, and earthquakes, Mauna Ulu IB (see figures 5.5, E22).
[In rows with multiple entries text applies down to the next entry; dates in m/d/yyyy format; do = ditto (same as above); data for eruptions and traditional intrusions are emphasized by grey shading]

Time and Date		Region[1]	Event Type[2]	No.[3]	Tilt[4]		Lag[5]	Comment[6]	Fig.[7]	Ref.[8]
Start	End				Mag	Az				
17:38 1/8/1970	05:32 1/15/1970	sf3kuer	SDI	40				Broken earthquake swarm; continuation of 12/1969 SDI	E23	
00:29 1/22/1970	03:41 1/22/1970	ms1	I	61	7.0	308		Tilt 1/17-24; I–A tilt 1/18 1/23	**5.6**; E24**;** *43.39*	8
00:29 2/4/1970	14:57 2/8/1970	ei4sswr	II	30	3.9	306		Tilt 2/4-9; broken earthquake swarm; paired rift intrusion	E25	
16:02 2/8/1970	03:04 2/9/1970	ei3uer	II	8			-52h 34m	I–A tilt 1/30-2/8 inflation; paired rift intrusion		
01:26 2/9/1970	01:55 2/11/1970	ei4swr	II	18	3.7	113		Tilt 2/9-11	*43.40*	8
09:12 2/9/1970	05:14 2/11/1970	ei3uer	II	20				Broken earthquake swarm	do	
15:45 3/17/1970	05:20 3/23/1970	ei4sswr	II	64				Tilt 3/19-22; broken earthquake swarm	E26; *43.41*	3, 8
22:38 3/20/1970	20:24 3/22/1970	ei3uer	II	13	7.3	296		Broken earthquake swarm; I–A tilt 3/9 -3/26: inflation		
21:29 4/4/1970	18:50 4/8/1970	ei4sswr	II	100	6.4	291		Tilt 4/2-8; I–A tilt 4/2 -4/10	E27; *43.42*	
02:21 4/7/1970	18:45 4/8/1970	ei3uer	I	44	10.0	102	-42h 00m	Tilt 4/8-10	E27	7, 8
02:53 5/15/1970	08:10 5/15/1970	sf2mer	EQS	10				South flank anticipation/accompaniment	E28	
03:38 5/15/1970	01:33 5/16/1970	sf3kuer	EQS	34				South flank accompaniment		
11:04 5/15/1970		sf3kuer	EQ					*M*3.8 with aftershocks embedded in earthquake swarm		
04:34 5/15/1970	05:59 5/16/1970	ms1	EQS	44						8
04:40 5/15/1970	13:25 5/18/1970	ei3uer	I	256	9.1	125	-0h 47m	Tilt 5/14-16; I–A tilt: inflation and deflation from 5/15 8:00-5/15 22:00; downrift/uprift migration	*43.43*	
04:43 5/15/1970	02:09 5/16/1970	koae	I	9						
04:48 5/15/1970	06:36 5/15/1970	ei2mer	I	6				Continuing south flank response		
06:08 5/19/1970	17:52 5/19/1970	sf2mer	SDI?	5				Broken earthquake swarm		
10:50 5/19/1970	10:56 5/21/1970	sf3kuer	SDI?	23				Heightened background seismicity		
11:05 7/15/1970	02:02 7/16/1970	sf2mer	EQS	10					E29	
01:27 9/21/1970		sf3kuer	EQ					*M*4.46; as pattern resembles SDI	E30	
13:30 10/26/1970	14:57 10/27/1970	ms1	I	19	5.1	297		Tilt 10/22-26; I–A tilt 10/22-10/27	E31	

Table 5.4. Kīlauea eruptions, intrusions, and earthquakes, Mauna Ulu IB (see figures 5.5, E22).—Continued
[In rows with multiple entries text applies down to the next entry; dates in m/d/yyyy format; do, ditto (same as above); data for eruptions and traditional intrusions are emphasized by grey shading]

Time and Date		Region[1]	Event Type[2]	No.[3]	Tilt[4]		Lag[5]	Comment[6]	Fig.[7]	Ref.[8]
Start	End				Mag	Az				
10:55 12/12/1970	13:19 12/14/1970	ms1	II	37	4.6	288		Tilt 12/10-13; I–A tilt 12/11-12/14		
21:19 12/12/1970	05:26 12/14/1970	er3	II	8				Broken earthquake swarm		8
23:03 12/12/1970	11:26 12/13/1970	sf3kuer	SDI?	6				SDI triggered by preceding II?	E32; *43.44*	8
16:0612/22/1970	08:23 12/23/1970	ms1	II	22	flat tilt			IA tilt 12/20 -12/31: inflation	E33*A*; *43.45*	
00:35 12/25/1970	21:33 12/26/1970	ms1	II	24	do			Summit/seismic southwest rift intrusion	E33*B*	
08:18 12/28/1970	06:57 12/29/1970	ei4sswr	II	22	do			do	E33*C*	
15:20 12/29/1970	01:55 1/01/1971	do	II	22	do			do	E33*D*	
21:06 1/03/1971	11:45 1/05/1971	do	II	24	do			do	E33*E*	
00:29 4/25/1971	04:59 4/27/1971	koae3	EQS	6				No swarm		
08:03 4/25/1971	00:55 4/30/1971	ms3	EQS	10				Scattered; includes *M*4.5 24 km 4/25/71	E34	
20:09 4/25/1971	04:40 4/26/1971	ms4/5	EQS	14					E35; *43.48*	8
17:06 4/26/1971	05:42 4/27/1971	ms2	EQS	5	5.0	121		Tilt 4/25-28; IA tilt flat ± 1μrad	E36; *43.49*	8
08:52 6/1/1971	11:40 6/2/1971	ms1	EQS	16				9 additional events to 06:39 6/1/71		
08:01 6/8/1971	14:54 6/10/1971	ms1	II	36				IA tilt 6/2 13:0-6/10 20:30: inflation		
07:01 6/11/1971	08:02 6/14/1971	ei4sswr	II	177				IA tilt 6/10 20:30-6/16 06:00: deflation		

[1]Earthquake classification abbreviations are given according to the classification in appendix A, table A3, and locations of regions are shown in appendix A, figure A4.

[2]E, Eruption; intrusion ("traditional" I; "inflationary" II; "suspected deep" SDI [see Wright and Klein, 2008, table 2]); south flank earthquake swarm EQS.

[3]Minimum number of events defining a swarm: 20 for south flank; 10 for all other regions.

[4]Magnitude in microradians and azimuth of daily tilt measurements from the water-tube tiltmeter in Uwēkahuna Vault.

[5]Lag times separating the onset of the earliest earthquake swarm (excluding south flank) for a given event and the beginning of deflation or inflation measured by the continuously recording Ideal-Arrowsmith tiltmeter in Uwēkahuna Vault. (+) tilt leads, (-) tilt lags.

[6]"I–A" in comment column refers to readings from the Ideal-Arrowsmith tiltmeter in Uwēkahuna Vault.

[7]Text figures **bold text**; appendix figures plain text; 43.xx = figures in Klein and others, 1987.

[8]References coded as follows: 1. Fiske and Kinoshita, 1969, 2. Kinoshita and others, 1969, 3. Wright and Klein, 2008, 4. Jackson and others, 1975, 5. Swanson and others, 1976b, 6. Swanson and others, 1979, 7. Duffield and others, 1974, 8. Klein and others, 1987, 9. Tilling and others, 1987, 10. Nielsen and others, 1977, 11. Lockwood and others, 1999; 12. Klein and others, 2006. Note: This is a master list for all tables in chapter 5. Only some references will be cited in this table.

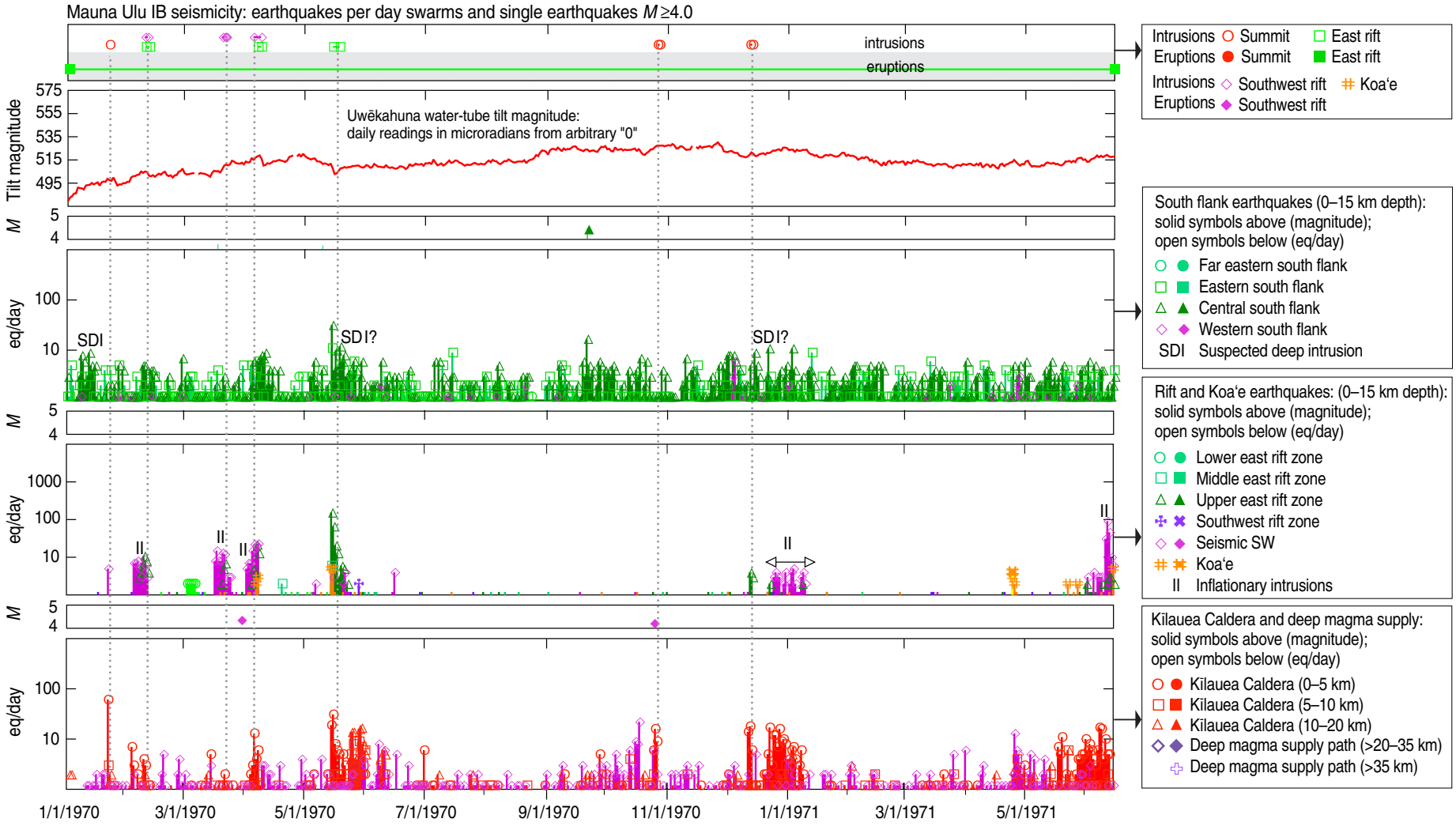

Figure 5.5. Graphs showing Kīlauea activity, 1 January 1970–15 June 1971 (Mauna Ulu eruption stage IB): Earthquake swarms and summit tilt plotted against times of eruption and intrusion. Dates on figure in m/d/yyyy format. See also caption for figure 5.1.

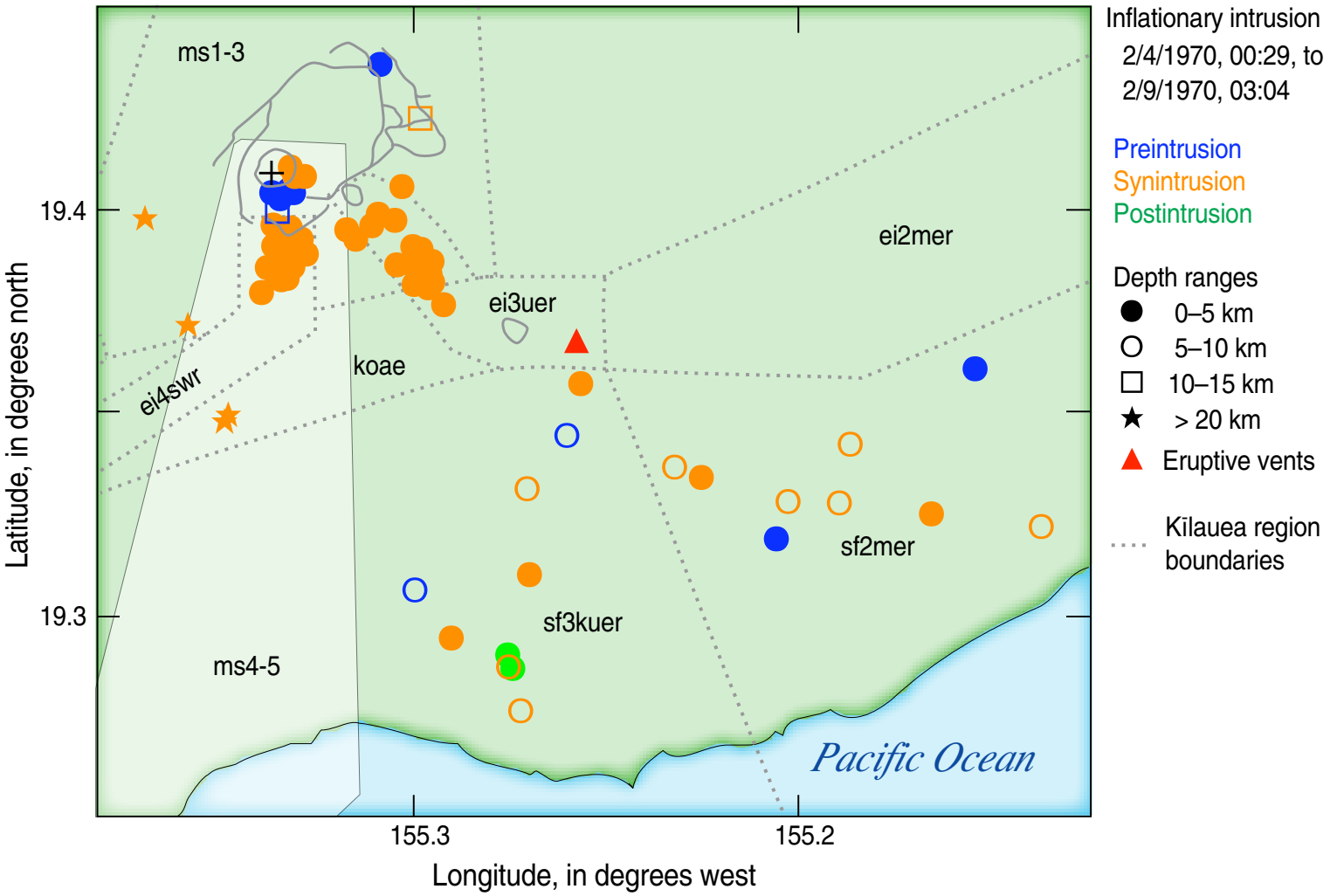

Figure 5.6. Map showing Kīlauea activity, 2–9 February 1970. Locations of earthquakes associated with a paired inflationary intrusion (4–9 February), with activity on the uppermost parts of the east rift zone (ei3uer) and seismic southwest rift zone (ei4sswr). Data are shown for periods before (blue), during (orange), and after (green) the event, and the Mauna Ulu vent is plotted as a red triangle. A small inflationary tilt vector of 3.9 microradians (table 5.3) and the shallow earthquake locations suggest that a small summit intrusion accompanied the inflationary intrusion. Dates on figure in m/d/yyyy format.

intrusions beneath the upper east rift zone and a south flank response that included continuation of the December 1971 sequence on the southwest side. The last of these on 26–28 January, one week before eruption resumed, was beneath the east rift uprift of the Mauna Ulu vent.

Mauna Ulu Period IIA: 4 February 1972–26 April 1973

Continuous eruption was renewed at Mauna Ulu on approximately 4 February 1972 (table 5.6) and continued until the summer of 1974 (Tilling and others, 1987). The immediate precursors included steady seismicity beneath both rift zones and a swarm of deep magma-supply earthquakes that occurred less than a day before eruption resumed (fig. 5.9). The two periods of continuous eruption are divided at the time of a deep *M*6.6 earthquake beneath the offshore east flank of Mauna Kea (table 5.6; fig. 5.9). That distant earthquake caused damage at Kīlauea's summit, and the character of the eruption changed significantly following the earthquake, as documented by Tilling and others (1987, p. 419–421).

The period from February 1972 to 26 April 1973 was the most stable period of the eruption. Summit tilt showed very slight deflation, and shallow seismicity beneath the summit and rift zones was low (fig. 5.9). Long-period (l-p) earthquakes were first catalogued by HVO seismic analysts in May 1972. Subsequently, l-p earthquakes become an important part of Kīlauea's seismic record. Magma-supply activity below 10-km depth and south flank seismicity remained elevated. An intrusion on 18 March 1972 was associated with the opening of a new fissure on the southwest flank of Mauna Ulu (Tilling and others, 1987, p. 413).

Mauna Ulu Period IIB: 26 April 1973–15 June 1974

The Mauna Kea (Honomū) earthquake of 26 April 1973 at 10:26 a.m. was followed immediately by an abrupt inflation of nearly 25 μrad measured at Uwēkahuna and, 7 hours later, by a small flurry of deep (20–35 km) magma-supply earthquakes that overlapped with increased seismicity beneath Kīlauea's east rift zone (table 5.6; fig. 5.9). The Uwēkahuna vector indicates possible inflation of the uppermost east rift zone, consistent with the increased seismicity.

On 5 May 5 1973 the first of two eruptions occurred in Pauahi Crater, coincident with the temporary cessation of activity at Mauna Ulu (fig. 5.10). Following this eruption earthquakes extended into the Koa'e Fault Zone. South flank seismicity preceded this sequence, but was apparently diminished[22] during the eruption and the Koa'e intrusion. Mauna Ulu returned to active eruption on 8 May (table 5.6). Two intrusions followed. The first, on 8–10 June 1973, mimicked the rift/Koa'e seismicity associated with the May eruption/intrusion. The second, on 25 July, occurred downrift from Mauna Ulu, with all seismicity displaced to the east.

A second Pauahi eruption occurred on 10 November 1973, and this eruption continued at a low level through 9 December 1973. Mauna Ulu was quiet during this interval but returned to activity on 10 December. During the November Pauahi eruption, south flank seismic activity occurred widely distributed in time along a broad east-west swath and also within the SDI 2 region, suggesting that a suspected deep intrusion may have occurred during the continuing low-level activity at Pauahi. Another suspected deep intrusion occurred in January 1974. From late January to late March 1974 several low fountaining episodes occurred at Mauna Ulu (Tilling and others, 1987, table 16.3, p. 437–439), associated with a few microradians of summit deflation. During this time intrusions alternated with times of greater surface activity at Mauna Ulu.

The end of Mauna Ulu stage II was presaged by heightened seismic activity in several sectors of the volcano within a few months of the final decline of the Mauna Ulu lava lake. A summit intrusion occurred on 22 May 1974, followed on 24–30 May by increased seismicity beneath both rift zones and a suspected deep intrusion beneath site SDI 1 (fig. 5.9). Using seismicity as our basis, we have placed the end of the Mauna Ulu eruption on 15 June, after the last overflow on 2 June, but before lava disappeared from the Mauna Ulu vent on 22 July (Tilling and others, 1987, p. 442).

Post-Mauna Ulu to 1975 Earthquake: 18 June 1974–28 November 1975

The aftermath of the Mauna Ulu eruption (table 5.7; fig. 5.11) was remarkably similar to the period following the end of the Mauna Ulu stage I in the summer of 1971. Two summit eruptions occurred in July (fig. 5.12) and September, the vents extending toward the east and southwest rift zones, respectively (Lockwood and others, 1999). There were almost no located earthquakes during the two eruptions, possibly because of the high level of tremor. A series of inflationary intrusions beneath both the upper east rift zone and seismic southwest rift zone occurred between 6 October and 20 December 1974.

A third but much larger eruption/intrusion on a long segment of the seismic southwest rift zone occurred on 31 December 1974 (figs. 5.13–5.16). The eruption was preceded by a deep magma-supply swarm on 24 December, followed by an upper east rift inflationary

[22] It is possible that south flank activity near the rift was masked by the intense rift earthquake swarm.

Table 5.5. Kīlauea eruptions, intrusions, and earthquakes, Mauna Ulu pause (see figures 5.7, E37).

[In rows with multiple entries text applies down to the next entry; dates in m/d/yyyy format; do, ditto (same as above); data for eruptions and traditional intrusions are emphasized by grey shading]

Time and Date		Region[1]	Event Type[2]	No.[3]	Tilt[4]		Lag[5]	Comment[6]	Fig.[7]	Ref.[8]
Start	End				Mag	Az				
00:17 7/4/1971	23:45 7/5/1971	sf3kuer	SDI	25				Embedded *M*3.5 mainshock at 11:07 7/5	**5.8**	
02:10 7/12/1971	19:59 7/14/1971	ei4sswr	II	42	3.5	294		Tilt 7/12-16; broken swarm	E38	
09:33 7/18//1971	12:46 7/19/1971	ei4sswr	II	18	flat				E39; *43.50*	8
19:25 7/21/1971	14:37 7/24/1971	ei3uer	II	45	2.2	310		Tilt 7/21-25; broken swarm	E40	
18:32 7/27/1971	01:53 7/30/1971	ei3uer	II	35	6.1	295		Tilt 7/26-28; I–A: 4 µrad inflation 7/27-29	E41	
17:55 7/28/1971	06:06 7/30/1971	ms1	II	25						
22:11 7/28/1971	21:41 7/30/1971	ei4sswr	II	34				South flank response		
04:59 8/1/1971	23:37 8/1/1971	sf3kuer	EQS							
23:20 8/5/1971	15:36 8/6/1971	ei3uer	I	10	3.8	309		Tilt 8/5-8	E42	
01:04 8/8/1971	08:418/14/1971	ei4sswr	II	197				Broken swarm	E43; *43.51*	8
01:29 8/9/1971	10:00 8/13/1971	ms1	II	163	13.5	340		Tilt 8/9-13	do	
13:04 8/10/1971	08:52 8/14/1971	ei3uer	II	115					do	
21:41 8/10/1971	09:28 8/12/1971	ms2	EQS	28				8 additional events to 11:41 8/13	do	
20:51 8/13/1971	08:55 8/14/1971	ms1	EQS	29					do	
08:55 8/14/1971	19:00 8/14/1971	KC	E		14.3	118	+0h 55m	Kīlauea Caldera; tilt: 8/13-15	E44	7
15:36 8/15/1971		ms4.5	EQ					*M*4.9 mainshock with 11 aftershocks		
22:18 8/15/1971		sf3kuer	EQ					*M*4.1 mainshock with 13 aftershocks	*43.52*	8, 12
20:08 8/27/1971	00:06 8/29/1971	ms2	EQS	14	flat			Upward movement of new magma following deep magma supply	E45	
22:59 8/27/1971	05:55 8/28/1971	ms3	EQS	8				earthquakes on 8/15		
19:23 8/28/1971	23:14 8/29/1971	ms1	II	10						
15:29 9/6/1971	17:42 9/8/1971	ei4sswr	II	25	4.0	339		Tilt 9/5-8	E46	
19:37 9/8/1971	06:21 9/9/1971	ei3uer	II	19					*43.53*	8
22:10 9/12/1971	02:41 9/14/1971	ei4sswr	II	16	8.3	314		Tilt 9/12-15	E47	
14:29 9/17/1971	03:28 9/19/1971	ei3uer	II	20	10.1	301		Tilt 9/15-24	E48*A-E*	
21:16 9/17/1971	06:27 9/18/1971	ms1	II	12				I–A: abrupt inflation offset	*43.54*	8
17:53 9/18/1971	07:30 9/19/1971	ei4sswr	II	36						
20:18 9/19/1971	10:01 9/21/1971	ei4sswr	II	24						
04:12 9/22/1971	06:01 9/22/1971	ms4/5	EQS	11				Deep magma supply anticipation	E48*F*	
13:16 9/23/1971	15:00 9/24/1971	ei3uer	I	15				Preeruption	E49*A*	
15:27 9/24/1971	02:27 9/26/1971	ei4sswr	I	21				Pre, during, and posteruption		
16:56 9/24/1971	07:40 9/25/1971	ms1	I	64				do	E49*B*	
19:20 9/24/1971	20:00 9/24/1971	KC/SWR	E		101.1	354	+1h 20m	Kīlauea Caldera/SW rift zone; tilt: 9/24-25; I–A 8/24: 20 µrad inflation	*43.54*	7, 8
23:53 9/24/1971	02:41 10/1/1971	sf3kuer	EQS	75				South flank response; includes *M*4.2 with aftershocks to 21:28 9/30/1971	E49*C*; *43.55*	
14:02 9/27/1971	17:46 9/30/1971	sf4swr	EQS	41						

Table 5.5. Kīlauea eruptions, intrusions, and earthquakes, Mauna Ulu pause (see figures 5.7, E37).—Continued

[In rows with multiple entries text applies down to the next entry; dates in m/d/yyyy format; do, ditto (same as above); data for eruptions and traditional intrusions are emphasized by grey shading]

Time and Date		Region[1]	Event Type[2]	No.[3]	Tilt[4]		Lag[5]	Comment[6]	Fig.[7]	Ref.[8]
Start	End				Mag	Az				
19:20 10/8/1971	17:48 10/09/1971	sf3kuer	EQS	10	10.6	296		Tilt 10/6-14; I–A 10/7-13: inflation	E50	
08:14 11/14/1971	04:55 11/15/1971	sf2mer	EQS	11	9.2	331.8		Tilt 11/11–17	E51	
19:33 11/15/1971	17:27 11/17/1971	sf3kuer	SDI	60						
02:15 12/9/1971		sf2mer	EQ					*M*4.3 with aftershocks		12
20:49 12/12/1971	08:40 12/13/1971	ei3uer	II	10	3.7	321		Tilt 12/10-13	E52	
09:05 12/22/1971	06:38 12/28/1971	sf3kuer	SDI	349				South flank anticipation	E53 *A-E*	
18:36 12/22/1971	14:45 12/23/1971	sf2mer	SDI	14	4.3	321		tilt: 12/23-26		
07:08 12/24/1971	23:04 12/24/1971	ei3uer	II	12						
12:54 12/24/1971	20:14 12/29/1971	sf4swr	SDI	325				South flank accompaniment/response	*43.56*	8
14:37 12/28/1971	08:08 12/29/1971	sf3kuer	SDI	46				Continued south flank response; I–A 12/27-29 3 μrad deflation		
19:52 12/31/1971	07:00 1/4/1972	sf2mer		10				No swarm	E54	
20:31 12/31/1971	02:18 1/4/1972	sf3kuer	SDI?	20				Broken swarm	do	
14:01 12/31/1971	23:40 1/3/1972	sf4swr	do	9				No swarm	do	
Precursors: return to eruption at Mauna Ulu										
15:32 1/9/1972	09:56 1/10/1972	ms1	II	10	4.6	299		Tilt 1/7-9		
21:27 1/10/1972	08:07 1/12/1972	ei3uer	II	14	2.1	124		Tilt 1/9-10; broken swarm	E55	
02:56 1/16/1972	03:01 1/17/1972	sf3.4	SDI	5, 3				Broken swarm; related to preceding and succeeding inflationary intrusions		
03:12 1/19/1972	13:13 1/19/1972	sf3	SDI	6				Related to succeeding inflationary intrusion		
19:06 1/19/1972	00:54 1/20/1972	ei3uer	II	16	flat			I–A 1/17-21 2.5 μrad inflation	E56*A*; *43.57*	8
10:42 1/20/1972	07:07 1/22/1972	ei3uer	II	71						
11:46 1/23/1972	02:13 1/24/1972	ms1	EQS	8						
22:30 1/23/1972	09:22 1/24/1972	ms4/5	EQS	8				Deep magma supply event		
15:52 1/26/1972	11:01 1/28/1972	ei3uer	II	91	2.2	293		Tilt 1/24-28	E56*B; 43.57*	8

[1]Earthquake classification abbreviations are given according to the classification in appendix A, table A3, and locations of regions are shown in appendix A, figure A4. Eruption locations are designated in bold type as follows: KC, Kīlauea Caldera; LERZ, lower east rift zone; MERZ, middle east rift zone; UERZ, upper east rift zone; SWR, southwest rift zone.

[2]E, Eruption; intrusion ("traditional" I; "inflationary" II; "suspected deep intrusion" SDI [see Wright and Klein, 2008, table 2]); earthquake, EQ; earthquake swarm, EQS.

[3]Minimum number of events defining a swarm: 20 for south flank; 10 for all other regions.

[4]Magnitude in microradians and azimuth of daily tilt measurements from the water-tube tiltmeter in Uwēkahuna Vault.

[5]Lag times separating the onset of the earliest earthquake swarm (excluding south flank) for a given event and the beginning of deflation or inflation measured by the continuously recording Ideal-Arrowsmith tiltmeter in Uwēkahuna Vault. (+) tilt leads, (-) tilt lags.

[6]Abbreviations as follows: I–A, Ideal-Arrowsmith continuously recording tiltmeter in Uwēkahuna Vault.

[7]Text figures **bold text**; appendix figures plain text; 43.xx = figures in Klein and others, 1987.

[8]References coded as follows: 1. Fiske and Kinoshita, 1969, 2. Kinoshita and others, 1969, 3. Wright and Klein, 2008, 4. Jackson and others, 1975, 5. Swanson and others, 1976b, 6. Swanson and others, 1979, 7. Duffield and others, 1974, 8. Klein and others, 1987, 9. Tilling and others, 1987, 10. Nielsen and others, 1977, 11. Lockwood and others, 1999; 12. Klein and others, 2006.

Table 5.6. Kīlauea eruptions, intrusions, and earthquakes, Mauna Ulu II (see figure 5.9).
[In rows with multiple entries text applies down to the next entry; dates in m/d/yyyy format; do, ditto (same as above); data for eruptions and traditional intrusions are emphasized by grey shading]

Time and Date		Region[1]	Event Type[2]	No.[3]	Tilt[4]		Lag[5]	Comment[6]	Fig.[7]	Ref.[8]
Start	End				Mag	Az				
03:48 2/4/1972	16:14 2/4/1972	ms4/5	EQS	9	7.1	313		Deep magma supply anticipation; Tilt 1/29–2/5	E58; *43.58*	8, 9
16:28 2/4/1972	4/26/1973	MERZ	E					Mauna Ulu IIA		
2/26/1972	3/3/1972				9.6	104		Continuous deflation		
18:44 3/18/1972	20:07 3/18/1972	ei3uer	I	9	13.8	106	+0h 44m	Tilt: 3/18–22; I–A, 3/18–23 11 µrad deflation	E59	
09:52 5/1/1972	09:31 5/2/1972	sf3kuer	SDI	15					E60	
01:32 9/5/1972		sf3kuer	EQ					*M*5.2 mainshock with 24 aftershocks		
04:36 3/7/1973	02:09 3/8/1973	sf3kuer	SDI	9					E61	
00:01 4/15/1973		sf2mer	EQ					*M*4.46. aftershock pattern mimics SDI	E62	
10:26 4/26/1973			EQ		23.3	305		Mauna Kea *M*6.6 35 km; Tilt 4/26; I–A 17 µrad inflation; triggered Kīlauea earthquakes and changed eruption	**5.9**	3, 9, 10
4/26/1973	6/18/1974	MERZ	E					Mauna Ulu IIB		8, 9
07:14 5/5/1973	09:48 5/5/1973	sf3kuer	EQS	7				South flank anticipation/accompaniment		
07:20 5/5/1973	21:16 5/5/1973	ms1	EQS	15						
07:24 5/5/1973	15:46 5/5/1973	koae	I	75				Koa‘e/upper east rift intrusion; Tilt 5/4-9		
10:11 5/5/1973	07:31 5/6/1973	UERZ	I	164	26.0	108	+0h 24m	do	**5.10**; *43.59*	8, 9
10:25 5/5/1973	12:00 5/5/1973		E					Pauahi-Hiiaka[9]; eruption at Mauna Ulu resumed on 5/8		
04:43 6/4/1973	06:44 6/6/1973	ei3uer	II	11				Additional earthquakes on 6/1 (6) and 6/6 (4)		
23:57 6/8/1973	00:25 6/10/1973	ei3uer	I	82	7.1	102	-0h 3m	Tilt 6/8-9	E63	
01:10 6/9/1973	12:38 6/9/1973	koae	I	31					*43.60*	8, 9
02:26 7/25/1973	23:44 7/25/1973	ei2mer	I	7	2.5	111		Tilt: 7/24-26	E64*F*	
02:25 8/3/1973	18:37 8/3/1973	sf3kuer	SDI	11						
17:22 11/10/1973	08:08 11/11/1973	ei3uer	I	41				Tilt 11/10-13	E65	
21:47 11/10/1973	12:00 12/9/1973	UERZ	E		26.9	109	-0h 38m	Pauahi-Hiiaka[9]; eruption at Mauna Ulu resumed on 12/10	*43.61*	8, 9
08:04 12/25/1973	06:00 12/26/1973	sf3kuer	SDI	13					E66	
06:04 1/12/1974		sf2mer	EQ					*M*4.7 with aftershocks		12
17:49 2/23/1974	07:00 3/4/1974	ei3uer	II	14	5.9	313		Tilt 2/28-3/2; no earthquake swarm	E67	

Table 5.6. Kīlauea eruptions, intrusions, and earthquakes, Mauna Ulu II (see figures 5.9, E57).—Continued
[In rows with multiple entries text applies down to the next entry; dates in m/d/yyyy format; do, ditto (same as above); data for eruptions and traditional intrusions are emphasized by grey shading]

Time and Date		Region[1]	Event Type[2]	No.[3]	Tilt[4]		Lag[5]	Comment[6]	Fig.[7]	Ref.[8]
Start	End				Mag	Az				
00:46 3/11/1974	12:59 3/17/1974	ei3uer	II	28	flat			Broken eqs; I-A: 14:00 3/17 5.5 µrad deflation	E68	
23:23 3/23/1974	03:44 3/24/1974	sf3kue	EQS	7				South flank anticipation	*43.62*	8
03:13 3/24/1974	05:28 3/24/1974	ei3uer	I	11	5.4	106	+1h 13m	Tilt 3/24–24; IA; def from 3/23	E69	
12:51 3/24/1974	23:08 3/27/1974	sf3kuer	EQS	38				Broken eqs south flank response		
05:15 3/26/1974	12:42 3/26/1974	ms4/5	EQS	9				Deep magma supply		
10:03 5/12/1974	05:50 5/22/1974	ei3uer	II					No eq; I–A: inflation	E70*A*	
02:12 5/21/1974	10:45 5/23/1974	sf3kuer	SDI	51				South flank anticipation		
03:09 5/22/1974	11:37 5/22/1974	ms1	I	9	12.5	310		Tilt 5/21-22; I–A: <1 µrad inflation		
5/22/1974	5/23/1974				2.8	129		Tilt 5/22-23; deflation follows inflation	E70*B*	
17:49 5/24/1974	14:07 5/25/1974	sf3kuer	SDI	16				South flank response		
21:37 5/25/74	12:44 5/30/1974	ms3		9				Broken earthquake swarm	E70*C*	
04:24 5/28/1974	03:06 5/30/1974	ei3uer	II	13				Broken earthquake swarm		
6/18/1974		MERZ						End of Mauna Ulu eruption[10]		9

[1]Earthquake classification abbreviations are given according to the classification in appendix A, table A3, and locations of regions are shown in appendix A, figure A4. Eruption locations are designated in bold type as follows: KC, Kīlauea Caldera; LERZ, lower east rift zone; MERZ, middle east rift zone; UERZ, upper east rift zone; SWR, southwest rift zone.

[2]E, Eruption; intrusion ("traditional" I; "inflationary" II; "Suspected deep intrusions" SDI); EQ, earthquake; EQS, earthquake swarm.

[3]Minimum number of events defining a swarm: 20 for south flank; 10 for all other regions.

[4]Magnitude in microradians and azimuth of daily tilt measurements from the water-tube tiltmeter in Uwēkahuna Vault.

[5]Lag times separating the onset of the earliest earthquake swarm (excluding south flank) for a given event and the beginning of deflation or inflation measured by the continuously recording Ideal-Arrowsmith tiltmeter in Uwēkahuna Vault. (+) tilt leads, (-) tilt lags.

[6]Abbreviations as follows: I–A, Ideal-Arrowsmith continuously recording tiltmeter in Uwēkahuna Vault.

[7]Text figures **bold text**; appendix figures plain text; 43.xx = figures in Klein and others, 1987.

[8]References coded as follows: 1. Fiske and Kinoshita, 1969, 2. Kinoshita and others, 1969, 3. Wright and Klein, 2008, 4. Jackson and others, 1975, 5. Swanson and others, 1976b, 6. Swanson and others, 1979, 7. Duffield and others, 1974, 8. Klein and others, 1987, 9. Tilling and others, 1987, 10. Nielsen and others, 1977, 11. Lockwood and others, 1999; 12. Klein and others, 2006. Note: This is a master list for all tables in chapter 5. Only some references will be cited in this table.

[9]Mauna Ulu pauses during each eruption at Pauahi, 5/6- 5/8/1973; 11/9–12/12/1973.

[10]Ending time arbitrary, based on seismicity. Lava visible in Mauna Ulu to 7/22/1974.

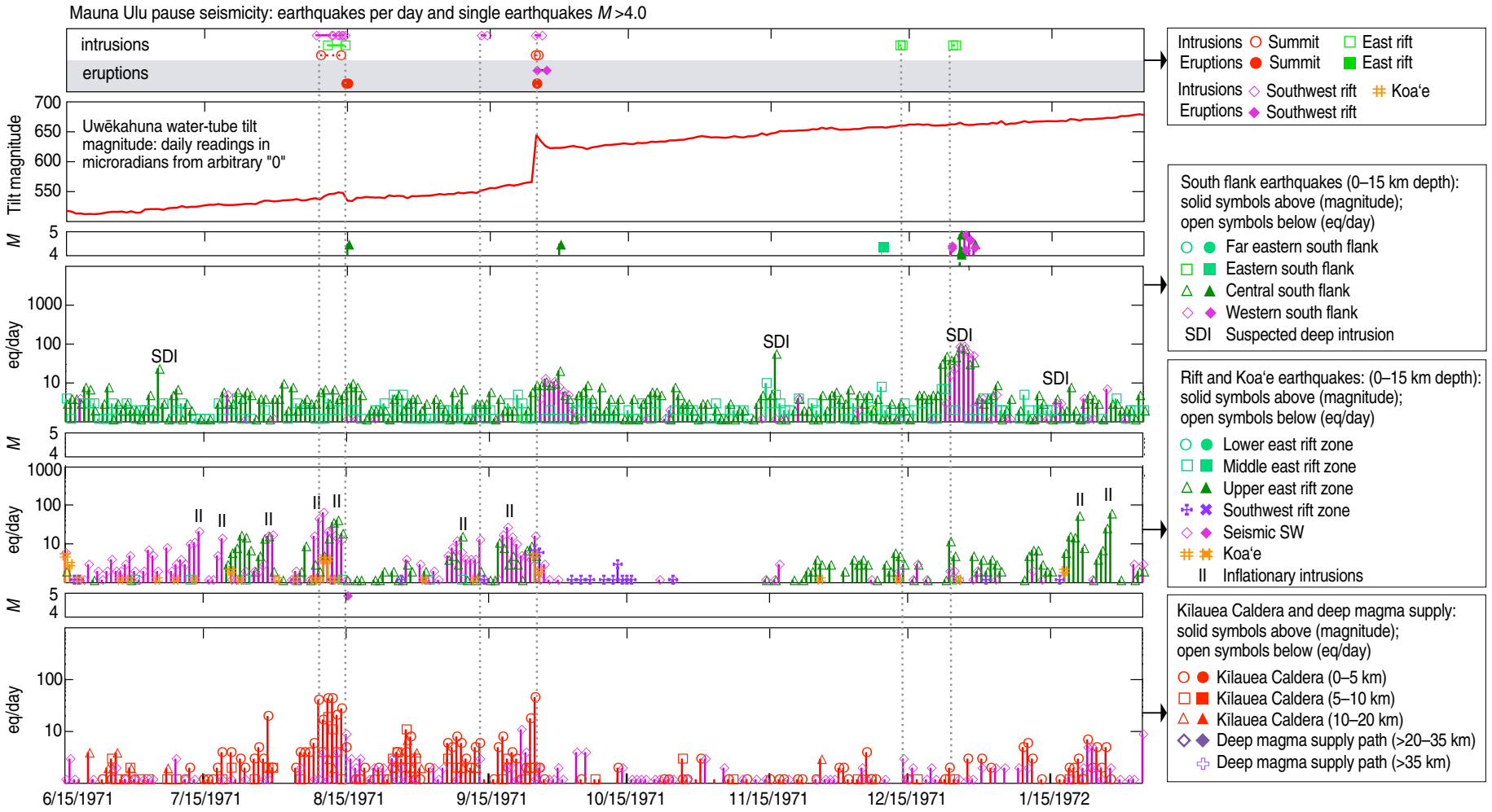

Figure 5.7. Graphs showing Kīlauea activity, 16 June 1971–4 February 1972 (Mauna Ulu pause): Earthquake swarms and summit tilt plotted against times of eruption and intrusion. Dates on figure in m/d/yyyy format. See also caption for figure 5.1.

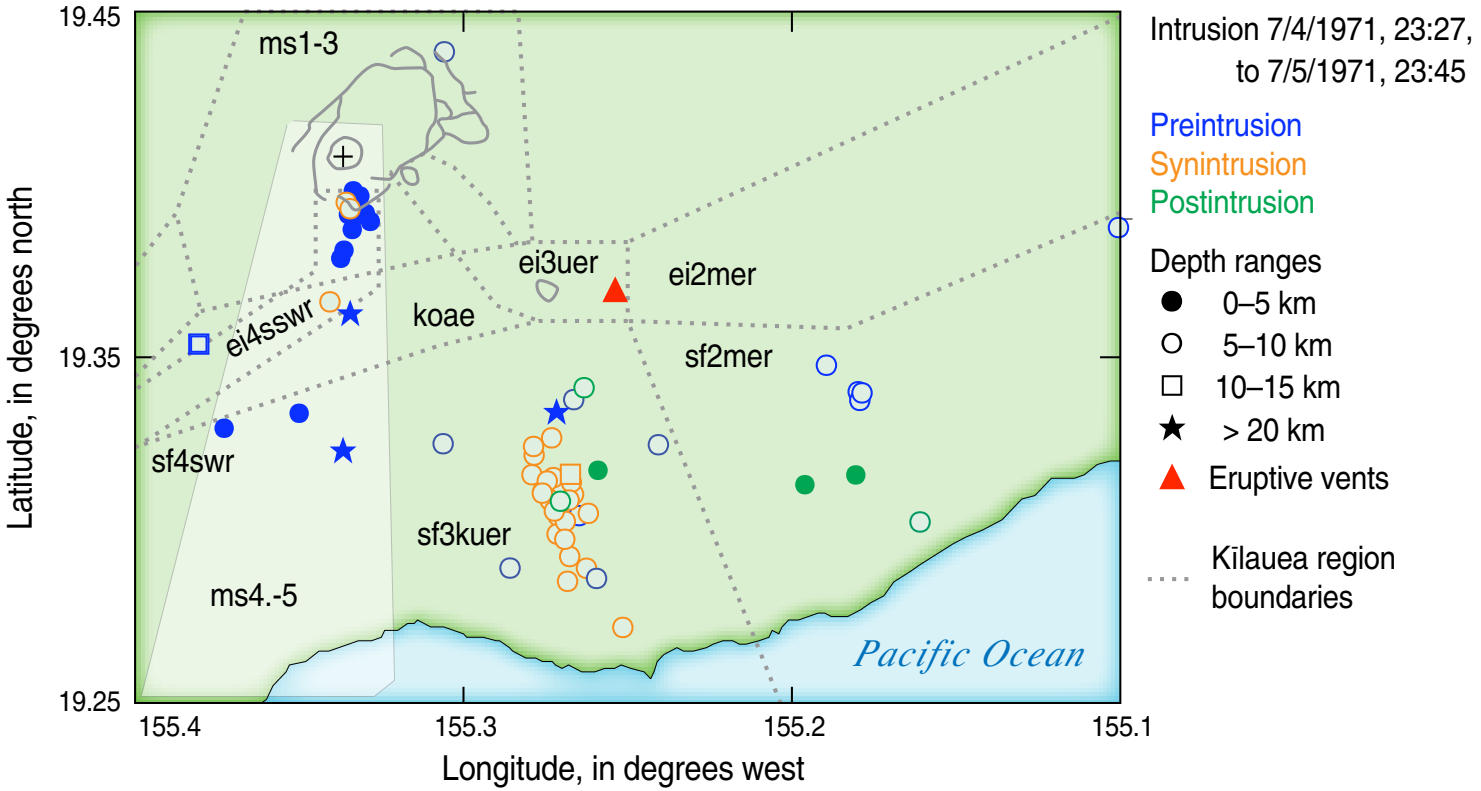

Figure 5.8. Map showing Kīlauea activity, 2–6 July 1971: Location of earthquakes associated with a suspected deep intrusion (4–5 July) at site SDI 2 (see fig. 5.2). Data are shown for periods before, during, and after the intrusion. The Mauna Ulu vent is plotted as a triangle. Dates on figure in m/d/yyyy format.

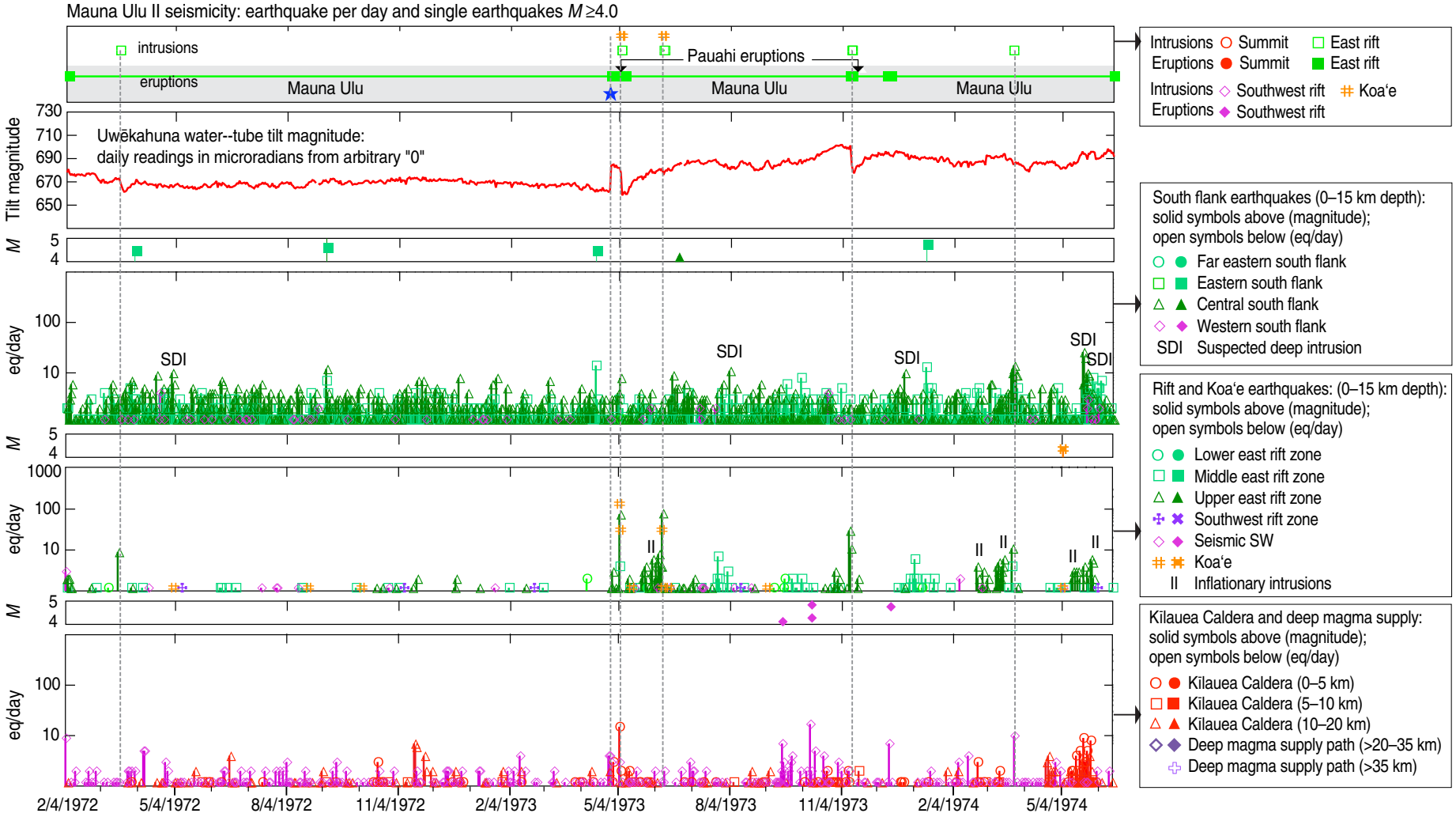

Figure 5.9. Graphs showing Kīlauea activity, 4 February 1972–14 June 1974 (Mauna Ulu stage II): Earthquake swarms and summit tilt plotted against times of eruption and intrusion. Dates on figure in m/d/yyyy format. See also caption for figure 5.1. The star (★) marks the *M*6.6 Honomū earthquake beneath Mauna Kea.

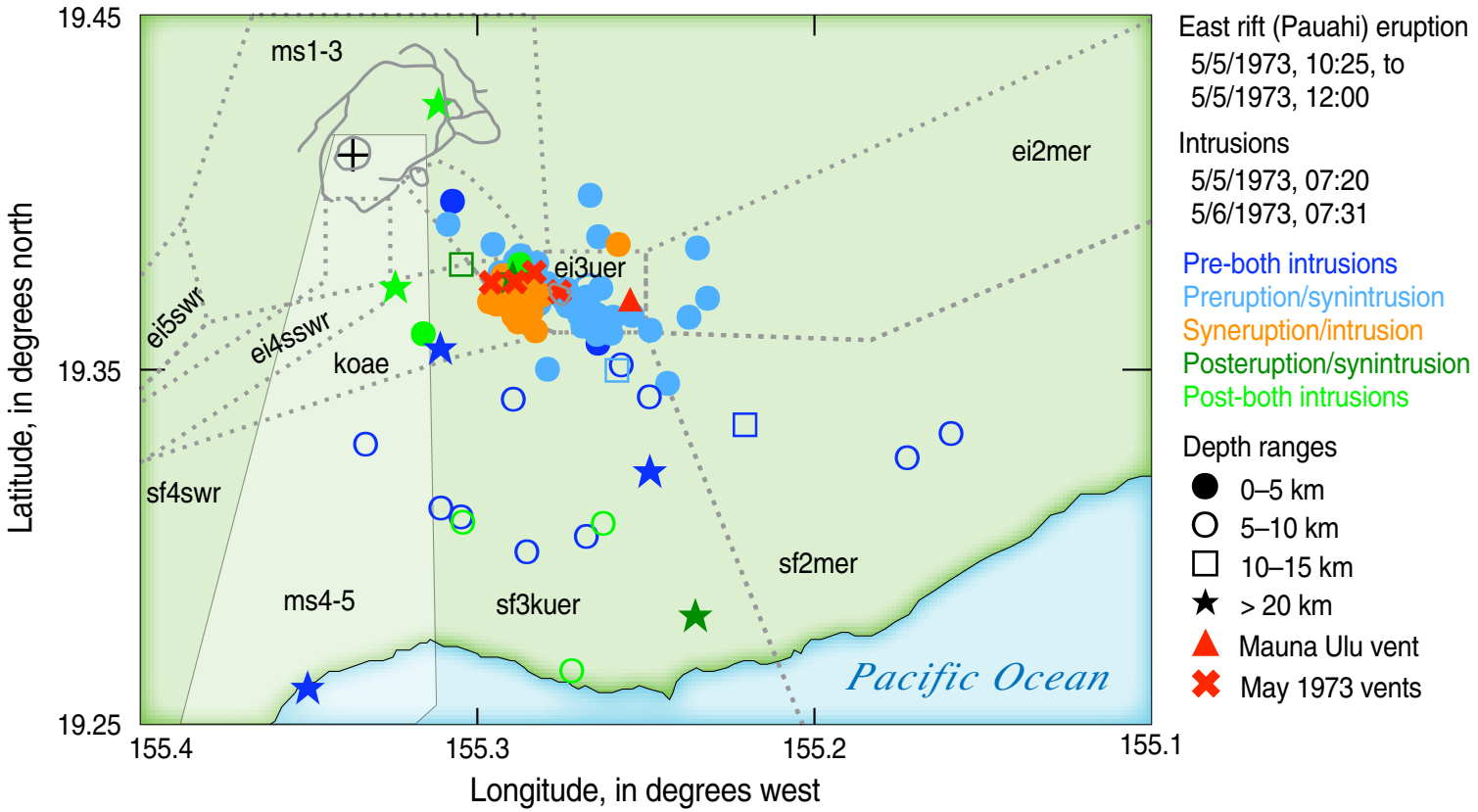

Figure 5.10. Map of Kīlauea activity, 2–9 May 1973: Location of earthquakes associated with the east rift eruption in and near Pauahi Crater (5 May) accompanied and followed by intrusion (5–6 May) extending into the Koa'e Fault Zone, and preceded by enhanced south flank seismicity. Shown are deep earthquakes triggered by the Honomū earthquake and additional deep earthquakes within the period of eruption/intrusion. Data are shown for periods before, during, and after the events, and the Mauna Ulu vent is plotted as a red triangle. Dates on figure in m/d/yyyy format.

Table 5.7. Kīlauea eruptions, intrusions, and earthquakes, post-Mauna Ulu to 1975 earthquake (see figure 5.11, E71).
[In rows with multiple entries text applies down to the next entry; dates in m/d/yyyy format; do = ditto (same as above); data for eruptions and traditional intrusions are emphasized by grey shading]

Time and Date		Region[1]	Event Type[2]	No.[3]	Tilt[4]		Lag[5]	Comment[6]	Fig.[7]	Ref.[8]
Start	End				Mag	Az				
6/19/1974	11/29/1975							Post-Mauna Ulu		11
20:50 6/20/1974		sf3kuer	EQ					*M*4.4 ms; 1 aftershock		
22:14 6/21/1974	11:31 6/22/1974	sf3kuer	SDI?	11				Delayed aftershocks for previous event?	E72	
11:06 6/27/1974	16:59 6/27/1974	ms1	I	6	6.3	317		Tilt 6/29-30	E73	
06:21 7/17/1974	16:00 7/17/1974	sf3kuer	EQS	7				South flank anticipation	*43.63*	8
03:02 7/19/1974	7/19/1974 11:32	ei3uer	I	189	15.9	107	+1h 58m	Tilt 7/19-20; I–A: deflation		
04:11 7/19/1974	12:28 7/19/1974	ms1	EQS	7						
12:30 7/19/1974	06:00 7/22/1974	KC	E					Halema‘uma‘u and east caldera	**5.12**	
15:37 7/23/1974	21:16 7/24/1974	ms3	EQS	14				Broken earthquake swarm		
06:02 9/16/1974	19:48 9/17/1974	ei4sswr	I	11				Precursory seismicity	*43.64*	8
01:21 9/19/1974	15:00 9/19/1974	KC/SWR	E/I		28.7	331	-1h 21m	Southwest rift zone; summit intrusion; tilt 9/18-19	E74	
14:09 10/6/1974	04:02 10/9/1974	ei3uer	II	17	7.9	332		Tilt 10/5-11; broken earthquake swarm	E75	
16:41 10/7/1974	17:19 10/8/1974	ms1	II	8				Broken earthquake swarm	*43.65*	8
15:38 10/12/1974	07:50 10/15/1974	ei3uer	II	14				Broken earthquake swarm		
19:05 10/31/1974	11/2/1974 16:20	ei4sswr	II	21	7.7	326		Tilt 10/27-11/7; broken earthquake swarm	E76	
19:37 11/5/974	03:52 11/6/1974	ei3uer	II	8						
15:02 11/21/1974	23:40 11/25/1974	ei4sswr	II	18	15.3	314		No swarm; I-A: flat	E77	
08:08 12/1/1974	12:35 12/5/1974	ei4sswr	II	28				Tilt 11/29-12/5; broken earthquake swarm	E77	
02:04 12/6/1974	12:42 12/9/1974	ei3uer	II	27	flat			Broken earthquake swarm; I–A: inflation	E78	
13:36 12/10/1974	13:49 12/14/1974	ei3uer	II	47				Broken earthquake swarm; I–A: inflation		
21:55 12/17/1974	08:52 12/21/1974	ei3uer	II	23	11.0	311		Tilt 12/15-22; broken earthquake swarm	E79	
23:59 12/18/1974	22:30 12/20/1974	ei4sswr	II	11				Broken earthquake swarm		
20:26 12/25/1974	23:36 12/30/1974	ei3uer	II	81	42.7	107		Tilt 12/30-31; east rift zone anticipation of southwest rift eruption?	**5.13, 5.14**	
21:43 12/27/1974	08:02 1/6/1975	ei4sswr	I	602	86.5	135		Tilt 12/31/1974-1/1/1975	*43.66*	8
14:44 12/29/1974	23:55 12/29/1974	sf3kuer	EQS	12				South flank anticipation	**5.14**	
02:56 12/31/1974	08:50 12/31/1974	SWR	E		33.2	151	-2h 56m	Southwest rift zone; Tilt 1/1-2/19755; east rift earthquakes end	**5.15, 5.16,** *43.67*	
08:17 12/31/1974	19:24 1/7/1975	sf3kuer	EQS	306	9.1	169		South flank response; Tilt 1/3-4/1975; I–A deflation ends 1/3	E80*A–F*	
12:52 12/31/1974	05:01 1/8/1975	sf4swr	EQS	548	7.1	192		do		

Table 5.7. Kīlauea eruptions, intrusions, and earthquakes, post-Mauna Ulu to 1975 earthquake (see figure 5.11, E71).—Continued
[In rows with multiple entries text applies down to the next entry; dates in m/d/yyyy format; do = ditto (same as above); data for eruptions and traditional intrusions are emphasized by grey shading]

Time and Date		Region[1]	Event Type[2]	No.[3]	Tilt[4]		Lag[5]	Comment[6]	Fig.[7]	Ref.[8]
Start	End				Mag	Az				
12/24/1974	2/25/1975	All reg.	I/E/I					Summary plot: eruption/intrusion	**5.16**	
11:11 3/15/1975	08:17 3/16/1975	sf3kuer	EQS	10	Flat			I–A: inflation	E81	
22:54 3/18/1975	09:14 3/20/1975	sf3kuer	do	13	do			Broken earthquake swarm		
21:06 3/20/1975	14:34 3/21/1975	lpms2	do	6	do					
23:42 3/21/1975	23:22 3/22/1975	lpms3	do	11	do					
19:07 3/24/1975	02:50 3/26/1975	sf3kuer	EQS	11	Flat				E82	
02:00 4/2/1975	10:14 4/3/1975	sf3kuer	SDI	11	flat			I–A: inflation	E83	
04:14 4/5/1975	18:34 4/5/1975	sf3kuer	SDI	12					E83	
14:47 4/16/1975	15:01 4/18/1975	sf3kuer	SDI	25	3.1	311		Tilt 4/16-18; I-A: flat tilt	E84	
07:36 8/5/1975	19:22 8/5/1975	sf4swr	SDI	25	flat			I–A: flat tilt	E85	
00:32 10/23/1975	18:42 10/23/1975	sf3kuer	SDI	11	flat			East rift earthquakes (ei3uer) reappear; I-A: flat tilt	E86	
17:04 11/12/1975	03:58 11/14/1975	ei4sswr	II	11	flat			Broken earthquake swarm; I–A: flat tilt	E87	
12:56 11/15/1975		sf3kuer	EQ					*M*4.5 mainshock with aftershocks		12
04:48 11/29/1975		sf2mer	EQ					*M*7.2 south flank earthquake (see Ando, 1979)		9
05:32 11/29/1975	22:00 11/29/1975	KC	E				-2h 0m	Halema‘uma‘u; triggered by earthquake		9
11/27/1975	11/281975				2.7	108		Tilt 11/27-28/1975; clockwise rotation		
11/281975	11/30/1975				36.8	134		Tilt 11/28-30/1975		
11/30/1975	12/10/1975				178.2	154		Tilt 11/30-12/10/1975		
12/10/1975	3/5/1976				39.2	198		Tilt 12/10/1975-3/5/1976		

[1]Earthquake classification abbreviations are given according to the classification in appendix A, table A3, and locations of regions are shown in appendix A, figure A4. Eruption locations are as follows: KC, Kīlauea Caldera; LERZ, lower east rift zone; MERZ, middle east rift zone; UERZ, upper east rift zone; SWR, southwest rift zone.

[2]E, Eruption; intrusion (“traditional” I; “inflationary” II; “suspected deep intrusion” SDI); EQ, earthquake; EQS, earthquake swarm.

[3]Minimum number of events defining a swarm: 20 for south flank; 10 for all other regions.

[4]Magnitude in microradians and azimuth of daily tilt measurements from the water-tube tiltmeter in Uwēkahuna vault.

[5]Lag times separating the onset of the earliest earthquake swarm (excluding south flank) for a given event and the beginning of deflation or inflation measured by the continuously recording Ideal-Arrowsmith tiltmeter in Uwēkahuna vault. (+) tilt leads, (-) tilt lags.

[6]I–A, Ideal-Arrowsmith continuously recording tiltmeter in Uwēkahuna vault.

[7]Text figures **bold text**; appendix figures plain text; 43.xx = figures in Klein and others, 1987.

[8]References coded as follows: (1) (Fiske and Kinoshita, 1969), (2) (Kinoshita and others, 1969), (3) (Wright and Klein, 2008), (4) (Jackson and others, 1975), (5) (Swanson and others, 1976b), (6) (Swanson and others, 1979), (7) (Duffield and others, 1974), (8) (Klein and others, 1987), (9) (Tilling and others, 1987), (10) (Nielsen and others, 1977), (11) (Lockwood and others, 1999); (12) (Klein and others, 2006). Note: This is a master list for all tables in chapter 5. Only some references will be cited in this table.

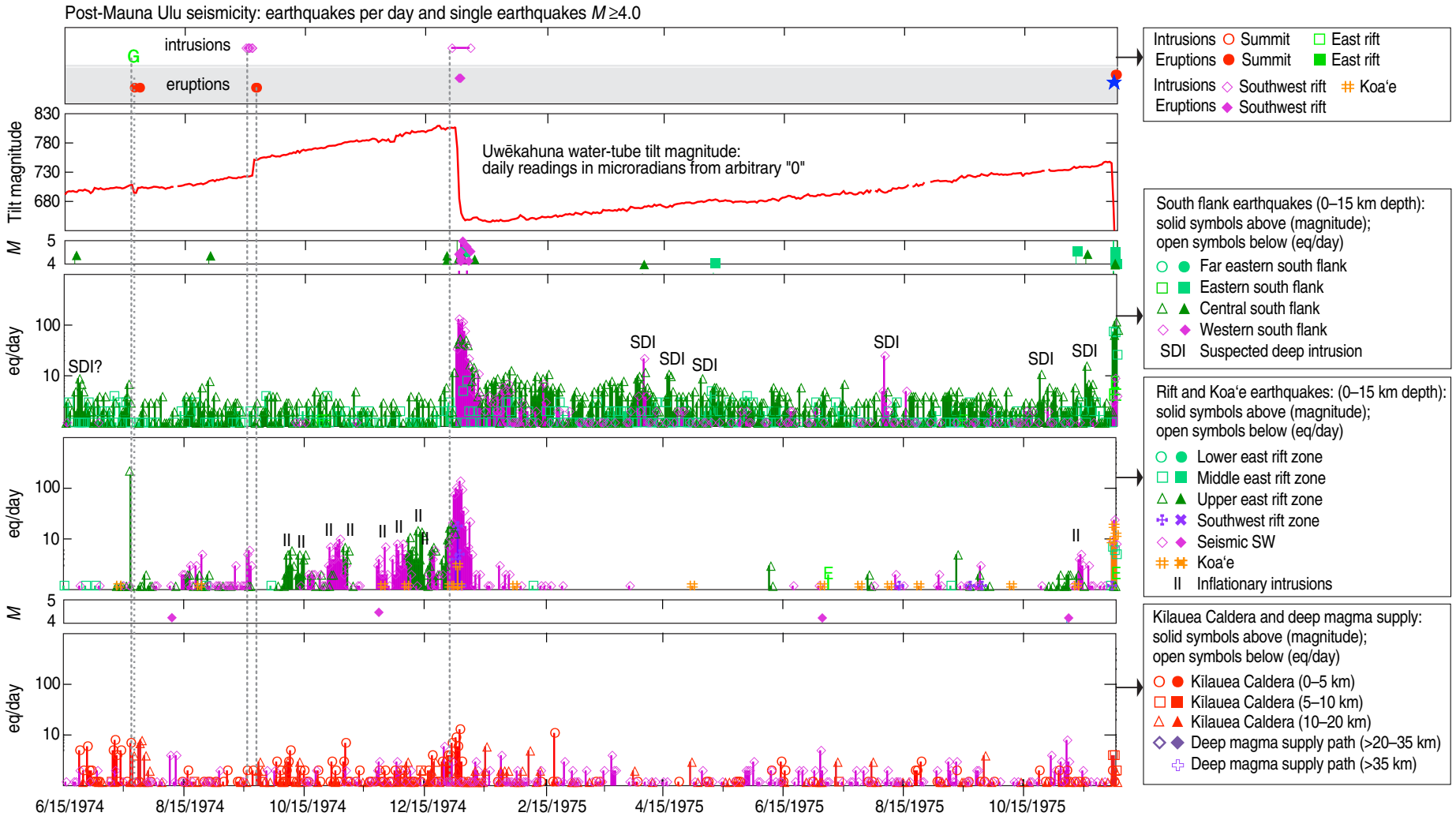

Figure 5.11. Graphs showing Kīlauea activity, 15 June 1974–29 November 1975 (Post Mauna Ulu). The period following the end of the Mauna Ulu eruption ends with the *M*7.2 south flank earthquake of 29 November 1975 (blue star). Earthquake swarms and summit tilt plotted against times of eruption and intrusion. Dates on figure in m/d/yyyy format. See also caption for figure 5.1.

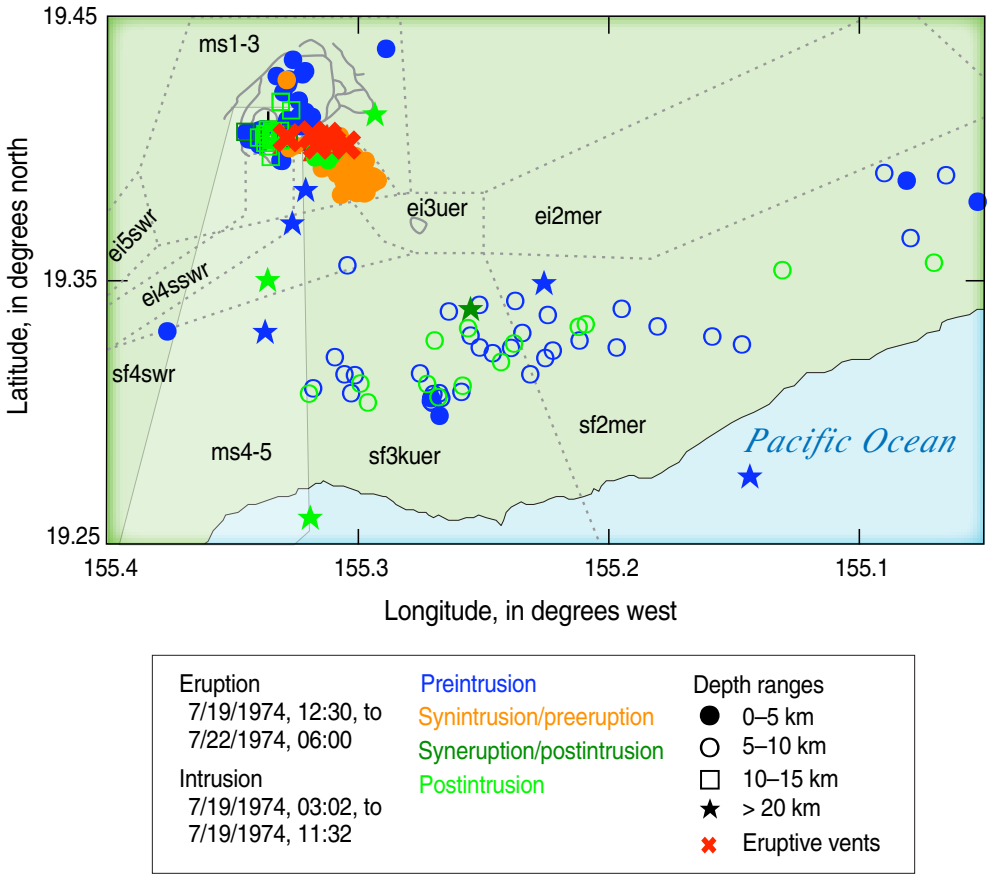

Figure 5.12. Map showing Kīlauea activity, 10–29 July 1974 : Location of earthquakes associated with eruption and intrusion on 19–22 July 1974. Data are shown for periods before, during, and after the event. Continuing intrusion may have been masked by eruption tremor. South flank seismicity precedes and follows eruption/intrusion. Dates on figure in m/d/yyyy format.

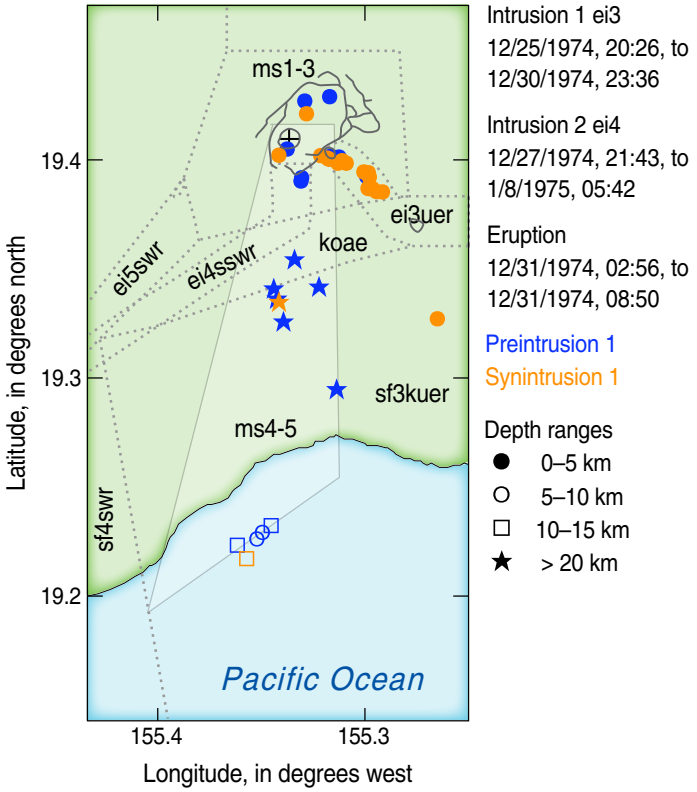

Figure 5.13. Map showing locations of earthquakes precursory to the 31 December 1974 southwest rift zone eruption and intrusion. This map covers the period 24–26 December 1974, during which there was a traditional intrusion beneath the upper east rift zone preceded by deep magma-supply seismicity. See also figures 5.14 and 5.15. Dates on figure in m/d/yyyy format.

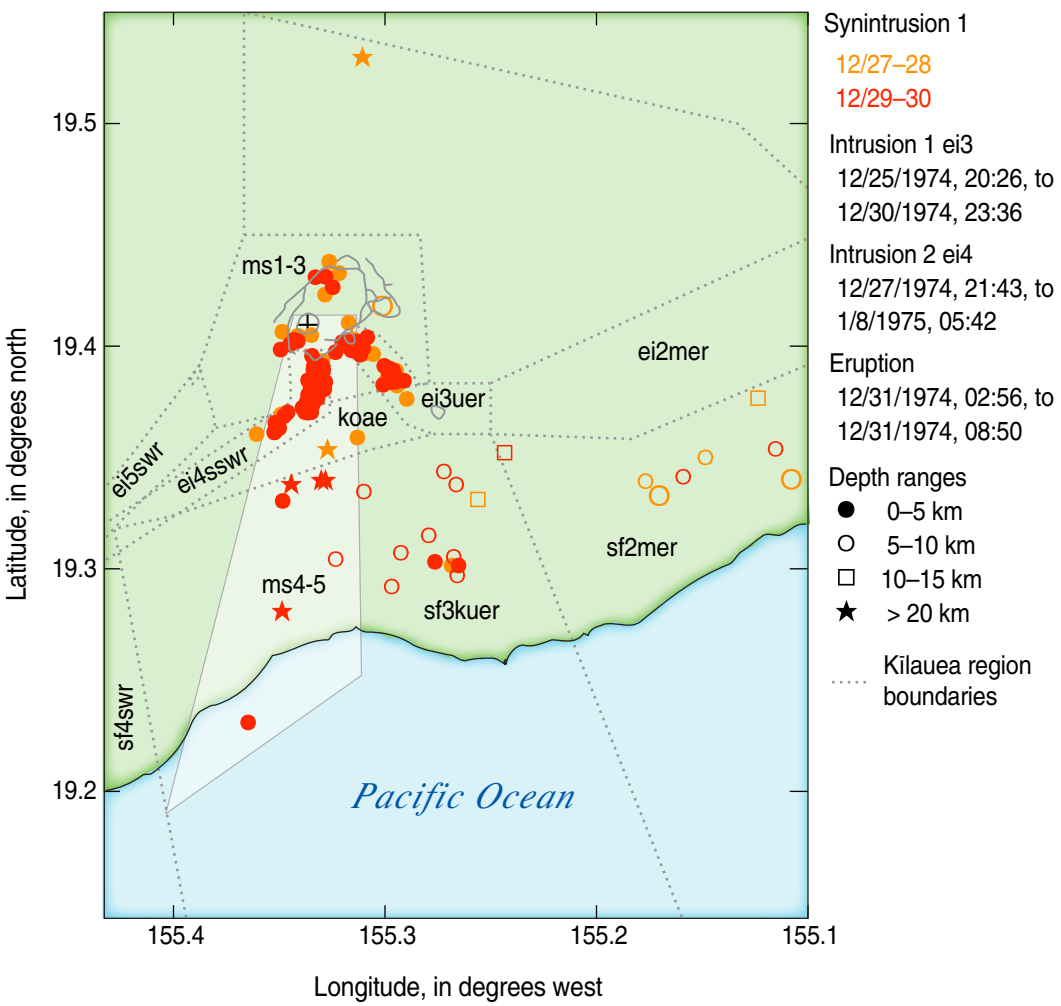

Figure 5.14. Map showing locations of earthquakes precursory to the 31 December 1974 southwest rift zone eruption and intrusion. This map covers the period 27–30 December 1974, during which there was inflationary intrusion beneath the upper part of both rift zones. See also figures 5.13 and 5.15. Dates on figure in m/d/yyyy format.

intrusion on 25 December (fig. 5.13). Inflationary intrusion expanded to the seismic southwest rift on 27–30 December (fig. 5.14). Coincident with and following the short eruption on 31 December seismicity moved down the seismic southwest rift zone and onto the western south flank (fig. 5.15). Intrusion continued for a week following the eruption (fig. 5.16), gradually tapering off during the following 6 weeks. Heightened seismicity beneath the south flank and in the magma-supply regions deeper than 10 km persisted up to the time of the 1975 earthquake.

The vents for the September 1971, September 1974, and December 1974 eruptions were located at increasing distance from the traditional southwest rift zone (1971) southeastward to the trace of the seismic southwest rift zone (December 1974).

Following the end of the large 1974 intrusion into the seismic southwest rift zone, there were several suspected deep intrusions (table 5.7) beneath both sites SDI 1 and SDI 2 in the central south flank. A final *M*4.5 south flank earthquake (table 5.6) beneath the central south flank occurred on 15 November, 2 weeks before the *M*7.2 earthquake beneath the eastern south flank on 29 November 1975.

Interpretations 1967–1975

We interpret this period to have one of steadily increasing magma supply. We also identify cycles in which the eruption efficiency, defined as the ratio of magma erupted to magma intruded, increased with continued use of the plumbing. A full discussion of both of these subjects is deferred to chapter 8.

The events in the period between the 1967–68 summit eruption in Halema‘uma‘u and the 1975 *M*7.2 south flank earthquake are a dramatic illustration of the internal adjustments in the Kīlauea

plumbing needed to accommodate an increasing magma supply from the mantle (Wright and Klein, 2008). The period is also notable for revealing the variety of responses of Kīlauea's south flank to eruptions and the three different types of intrusions. Finally the period offers a clue to precursory signs that could indicate the impending occurrence of a large south flank earthquake.

Response of the Magma Plumbing to Increased Magma Supply

A reliable signal that continuing magma supply is stressing the capacity of the plumbing system is inflation of Kīlauea's summit. The types of accommodation of magma identified during the 1967–75 period are as follows:

1. *Traditional eruption and intrusion within the rift zones.* Magma pressure is relieved by eruption and intrusion, and space for intrusion is created by ongoing dilation of the rift zones during flank spreading and by uplift of the areas adjacent to the intrusion.

2. *Stepwise increase in spreading rate associated with suspected deep intrusions*. In our interpretation, suspected deep intrusions behave in a similar manner to the more recently defined "slow" or "silent" earthquakes, which have measured jumps in seaward spreading of Kīlauea's south flank (see discussion in chapter 8). Unfortunately it was not possible for deformation measurements made during 1967–75 to capture instantaneous movement of Kīlauea's south flank.

3. *Carrying capacity of the magma plumbing.* Repeated use of the magma delivery system leads to increasing eruption efficiency with time (Wright and Klein, 2008, figure 6; discussion in chapter 8).

4. *Change of location.* The east rift zone is the preferred site for eruption and intrusion. When the east rift plumbing is unable to accommodate the magma supply, eruption and intrusion may occur beneath Kīlauea's summit and (or) seismic southwest rift zone. Such shifts occurred during the Mauna Ulu pause in 1971 and following the end of the Mauna Ulu eruption in 1974.

Forecasting the 29 November 1975 *M*7.2 South Flank Earthquake

The earthquake of 29 November 1975 and its accompanying tsunami were widely studied (see, for example, Ando, 1979; Furumoto and Kovach, 1979; Lipman and others, 1985), those studies identifying, for the first time, a deep subhorizontal surface along which the south flank moved seaward. The 1975 earthquake was anticipated within a year of

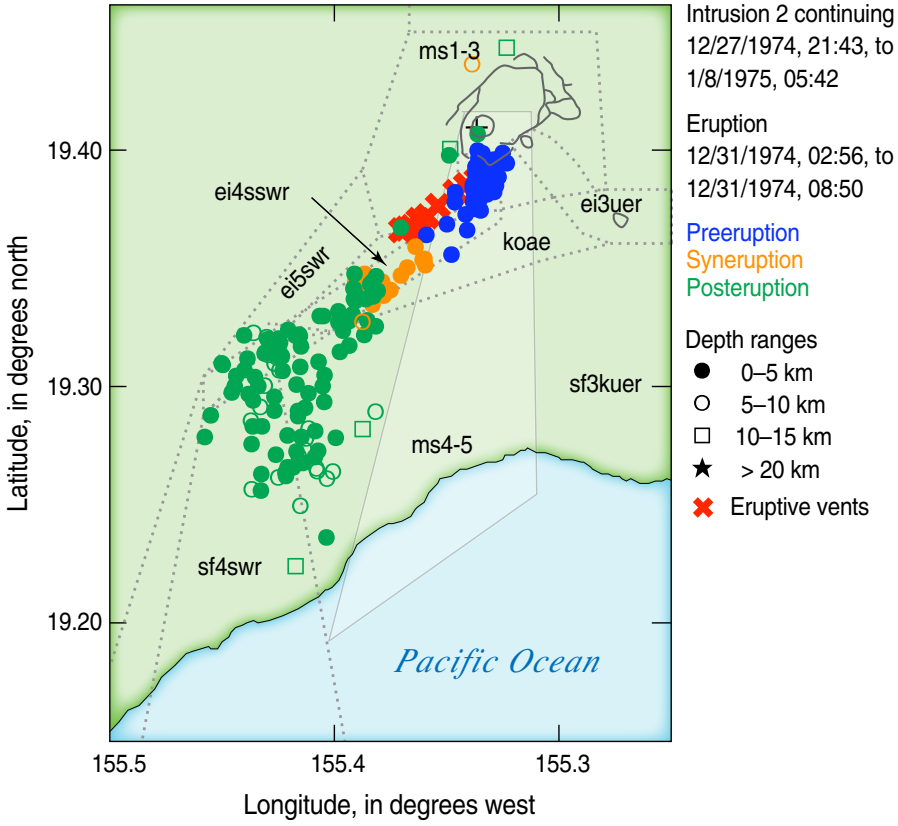

Figure 5.15. Map showing locations of earthquakes precursory to the 31 December 1974 southwest rift zone eruption and intrusion. This map covers the events of 31 December 1974 only, during which time there occurred a southwest rift zone eruption. The eruption is preceded by intrusion beneath the upper seismic southwest rift zone that then migrates downrift during and after the short eruption. A strong western south flank response accompanies the post-eruption intrusion. Note the complete absence of east rift and associated south flank activity. Dates on figure in m/d/yyyy format.

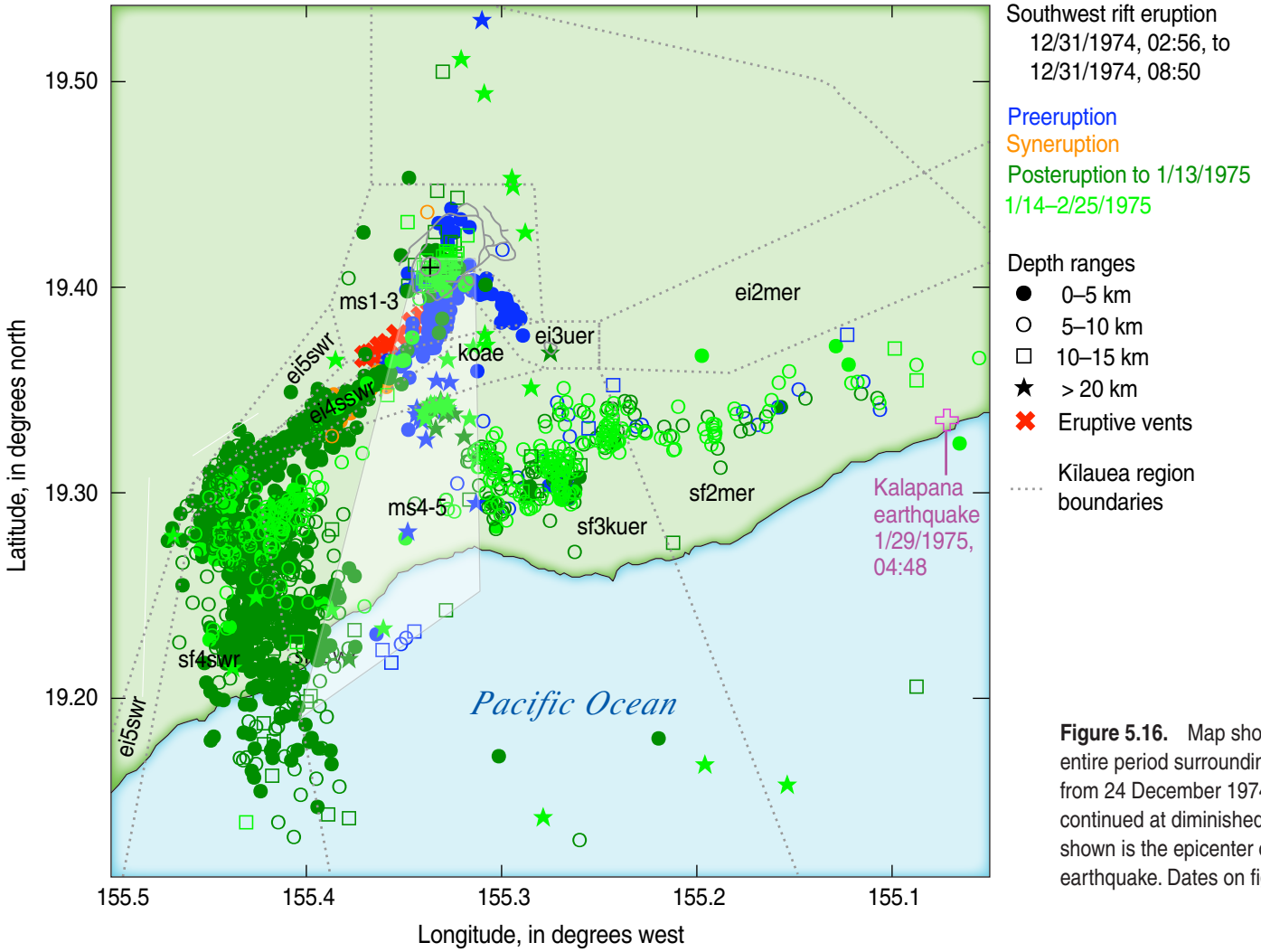

Figure 5.16. Map showing locations of earthquakes for the entire period surrounding the 31 December 1974 eruption. Data from 24 December 1974 through 25 February 1975. Intrusion continued at diminished intensity into mid-February 1975. Also shown is the epicenter of the 29 November 1975 Kalapana earthquake. Dates on figure in m/d/yyyy format.

its occurrence, using the following words (Swanson and others, 1976, p. 35), although the paper was published after the event: " . . . we anticipate a subsidence (strain-release) event of unknown magnitude in the not too far distant future."

A detailed analysis of the earthquake was published in 1981 with the following conclusion (Wyss and others, 1981, abstract): "We conclude that the Kalapana earthquake was preceded by a preparatory process which lasted 3.8 ± 0.3 years and which had dimensions of 45 × 10 km covering approximately the aftershock area."

The period of nearly 4 years mentioned extends from the beginning of stage II of the Mauna Ulu eruption. We conclude that the increase in magma supply, beginning even earlier, stressed the magma plumbing, which in turn stressed the south flank, culminating in the very large intrusion into the western part of Kīlauea's south flank in early 1975. We consider that this was the proximate event that readied the south flank for major failure. Following the intrusion, magma supply continued to increase, Kīlauea's summit was rapidly inflating, and seismicity within the south flank and along the deep magma-supply path remained high right up to the earthquake. A south flank earthquake of this magnitude may be one kind of major adjustment of an edifice within which the plumbing system cannot accommodate by any other means a relentlessly increasing magma supply.

In summary, this period represents the best demonstration of the complexities of magma transport beneath Kīlauea. Incoming magma is always seeking pathways in which its volume can be accommodated over and above space created by inflation of Kīlauea's summit during expansion of the 2–6-km-deep storage reservoir. Extra storage is divided between space found or created near sites of eruption and intrusion and deeper space created by rift dilation during seaward spreading of Kīlauea's south flank. One cannot forecast exactly how and where the accommodation will occur.

The south flank of Kīlauea acts as a useful monitor of the stresses involved in accommodating the pressure of incoming magma (compare Dieterich and others, 2000). Earthquake swarms beneath the south flank are initiated before many eruptions and traditional intrusions, and they continue during and after the volcanic event. Flank patches, including seismic zones nearly normal to the nearest rift zone, are activated during suspected deep intrusions as well as during some traditional intrusions, although most of the south flank seismicity associated with the latter events is distributed parallel to the rift zones.

Supplementary Material

Supplementary material for this chapter appears in appendix E, which is only available in the digital versions of this work—in the DVD that accompanies the printed volume and as a separate file accompanying this volume on the Web at http://pubs.usgs.gov/pp/1806/. Appendix E comprises the following:

Table E1 shows the calculation of magma supply and eruption efficiency during this period.

Figure E1*A,B* presents time series data covering the entire period

Figure E2*A*–*R* presents yearly data from 1967 through 1976 in plots similar to figures 5.1 and E1.

Figures E3–E8 present time series and earthquake locations for events during the pre-Mauna Ulu period listed in table 5.1 and figure 5.1.

Figures E9–E21 present time series and earthquake locations for events during period IA of the Mauna Ulu eruption listed in table 5.3 and figure 5.4.

Figures E22–E36 present time series and earthquake locations for events during period IB of the Mauna Ulu eruption listed in table 5.4 and figure 5.5.

Figures E37–E56 present time series and earthquake locations for events during the Mauna Ulu pause listed in table 5.5 and figure 5.7.

Figures E57–E70 present time series and earthquake locations for events during period II of the Mauna Ulu eruption listed in table 5.6 and figure 5.9.

Figures E71–E87 present time series and earthquake locations for events during the period between the end of Mauna Ulu II and the 1975 earthquake listed in table 5.7 and figure 5.11.

Geodimeter instrument setup. USGS photograph taken on 7 June 1971

Geodimeter mirror setup at Kīlauea. USGS photograph by R.T. Holcomb, 5 December 1972