The First Two Decades of the Puʻu ʻŌʻō-Kūpaianaha Eruption: Chronology and Selected Bibliography

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Abstract

The Puʻu ʻŌʻō-Kūpaianaha eruption on the east rift zone of Kīlauea Volcano, Island of Hawaiʻi, began on January 3, 1983. The early years of the eruption are vividly remembered for lava fountains as high as 470 m that erupted episodically from the Puʻu ʻŌʻō vent. For the last 16 year, however, the activity has been dominated by near-continuous effusion, low eruption rates, and emplacement of tube-fed pāhoehoe flows. The change in eruptive style began when the activity shifted to the Kūpaianaha vent in mid-1986, and has continued since the eruption returned to flank vents on Puʻu ʻŌʻō in 1992. To date, the total volume of lava erupted, 2.1 km^3, accounts for about half the volume erupted by Kīlauea in the past 160 years. This chapter includes a selected bibliography winnowed from the more than 1,000 reports and abstracts published about this eruption.

Introduction

The Puʻu ʻŌʻō-Kūpaianaha eruption of Kīlauea Volcano, Island of Hawaiʻi (fig. 1), ranks as the most voluminous outpouring of lava on the volcano's east rift zone in the past 6 centuries. By the beginning of 2002, more than 2 km^3 of lava had been erupted, covering an area of 105 km^2 on the volcano's south flank and adding 210 ha of new land to the island.

Since the eruption began, lava flows have repeatedly invaded communities on Kīlauea's south coast, destroying 186 houses and a visitor center in Hawaiʻi Volcanoes National Park (fig. 1*A*). The composite flow field spans 14.5 km at the coastline, forming a lava plain 10 to 35 m thick.

The eruption has progressed through three main epochs: 3½ years of episodic fountaining, mainly from the Puʻu ʻŌʻō central vent, producing a cinder-and-spatter cone and ʻaʻā flows; 5½ years of continuous effusion from the Kūpaianaha vent, creating a lava shield and tube-fed pāhoehoe flows; and more than 11 years (as of January 2003) of nearly continuous effusion from flank vents on Puʻu ʻŌʻō, again creating a lava shield and tube-fed pāhoehoe flows.

This chapter provides a brief overview of the Puʻu ʻŌʻō-Kūpaianaha eruption, followed by general observations on eruptive phenomena that have spanned most of the eruption, with emphasis on topics not covered elsewhere in this volume. The final section of this chapter is a selected bibliography culled from the more than 1,000 publications pertaining directly to the eruption.

Eruption Chronology

Setting the Stage

Before the Puʻu ʻŌʻō-Kūpaianaha eruption, Kīlauea's longest rift zone eruption in the past 2 centuries was at Mauna Ulu (fig. 1*A*), which erupted on the upper east rift zone in 1969–74 (Swanson and others, 1979; Tilling and others, 1987). The site of the current eruption, on the middle east rift zone, was host to several eruptions from 1963 to 1969, all of them short-lived. After the M7.2 earthquake in 1975 on Kīlauea's south flank, magmatic activity in the middle east rift zone was dominated by intrusions. A total of 10 intrusions and a single brief eruption occurred in this section of the rift zone between 1977 and 1980 (Dzurisin and others, 1984; Klein and others, 1987). Leveling and geoelectric measurements in 1979–80 identified an intrusive body within 100 m of the eventual site of Puʻu ʻŌʻō (Jackson, 1988). Three intrusions into the upper east rift zone from September through December 1982 (Jackson, 1988; Koyanagi and others, 1988; Okamura and others, 1988) may have primed the magmatic system for the January 1983 intrusion.

January 1983–April 1983 (Episodes 1–3): Fissures Erupt and Puʻu Halulu Forms

The eruption began on January 3, 1983, after a 24-hour-long seismic swarm propagated down Kīlauea's east rift zone at the leading edge of a basaltic dike. The initial outbreak was from a fissure in Nāpau Crater, within Hawaiʻi Volcanoes National Park (fig. 1*A*). Over the next 4 days, fissures extended nearly 8 km northeastward along a remote section of the east rift zone (Wolfe and others, 1988).

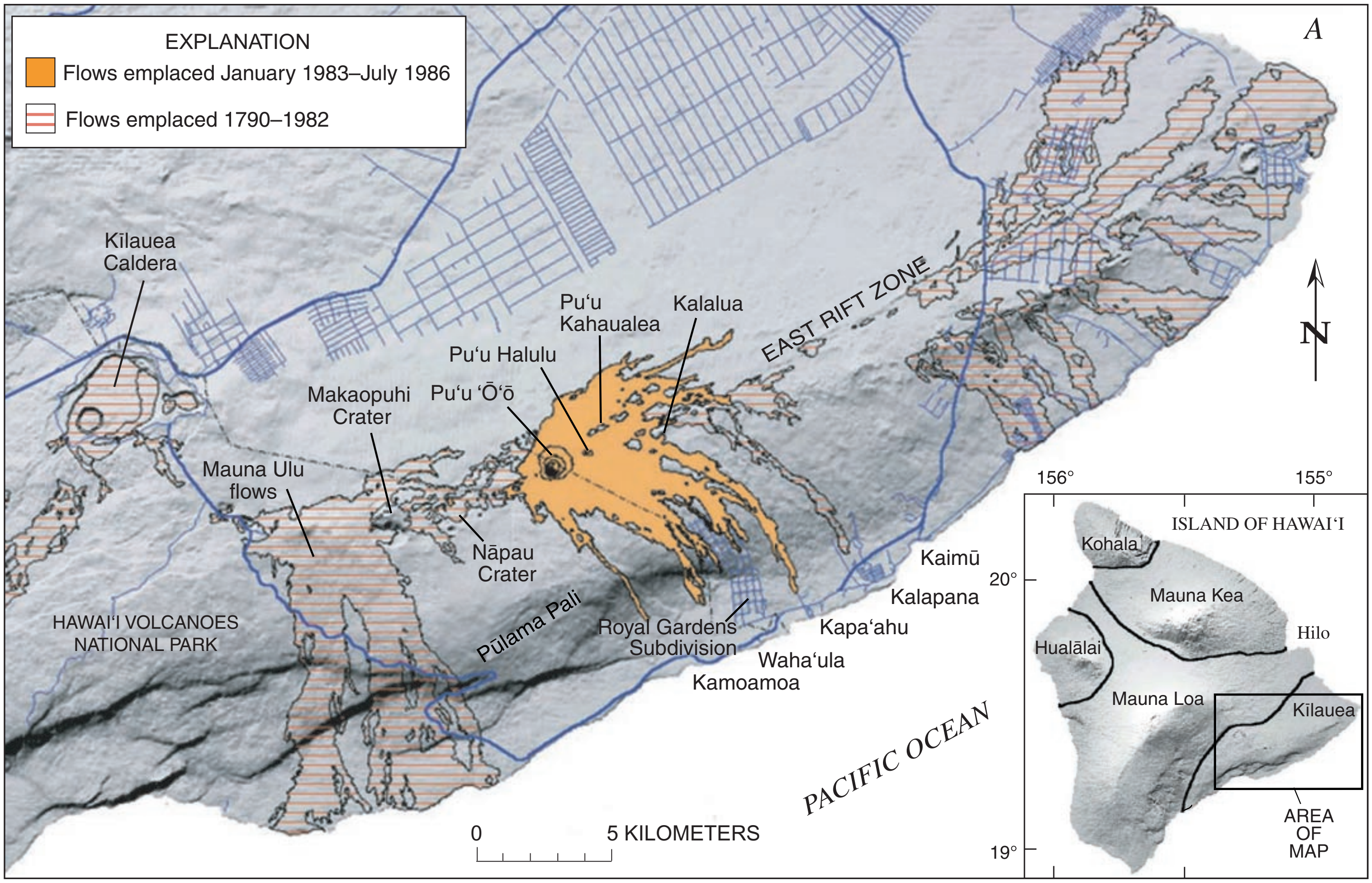


Figure 1. Summit and east rift zone of Kīlauea Volcano, Island of Hawai‘i, showing development of Pu‘u ‘Ō‘ō-Kūpaianaha flow field. *A*, Flows emplaced during 2 centuries before 1983 and flows erupted from January 3, 1983, through July 18, 1986. *B* (facing page), Flows emplaced as of February 1, 1997. *C*, Flows emplaced as of March 2002. Composite flow field has covered much of the same ground many times. In particular, episode 55 flows have buried most of episodes 50–53 flow field and parts of episodes 1–48 flow fields.

Effusion then became localized along a 1-km-long segment of the fissure system south of Pu‘u Kahauale‘a. This segment included the “1123 vent,” later renamed Pu‘u Halulu, which was the main locus of eruptive activity during episodes 2 and 3 (table 1). Fountains from Pu‘u Halulu built a small (60 m high) cinder-and-spatter cone, the only substantial vent structure formed during this eruption, aside from Pu‘u ‘Ō‘ō and Kūpaianaha. The vent later named “Pu‘u ‘Ō‘ō” first erupted during episode 2.

June 1983–June 1986 (Episodes 4–47): Episodic High Fountaining at Pu‘u ‘Ō‘ō

Pu‘u ‘Ō‘ō made its solo debut in June 1983 (episode 4) and was the primary vent for the next 3 years. The eruption assumed an increasingly regular schedule, with brief (mostly less than 24 hour long) episodes, separated by repose periods averaging 24 days in length. These eruptive episodes were characterized by high effusion rates and spectacular lava fountains that reached a height of 470 m (fig. 2). Effusion rates (averaged over the length of an episode) increased through episode 39, reaching a maximum of 1.4x10^6 m^3/h (George Ulrich, unpub. data, 1986). Fountain heights gradually increased through episode 23 and were at a maximum during episodes 24 through 30 (table 1). Fallout from the fountains built a cinder-and-spatter cone 255 m high and 1.4 km in diameter at its base.

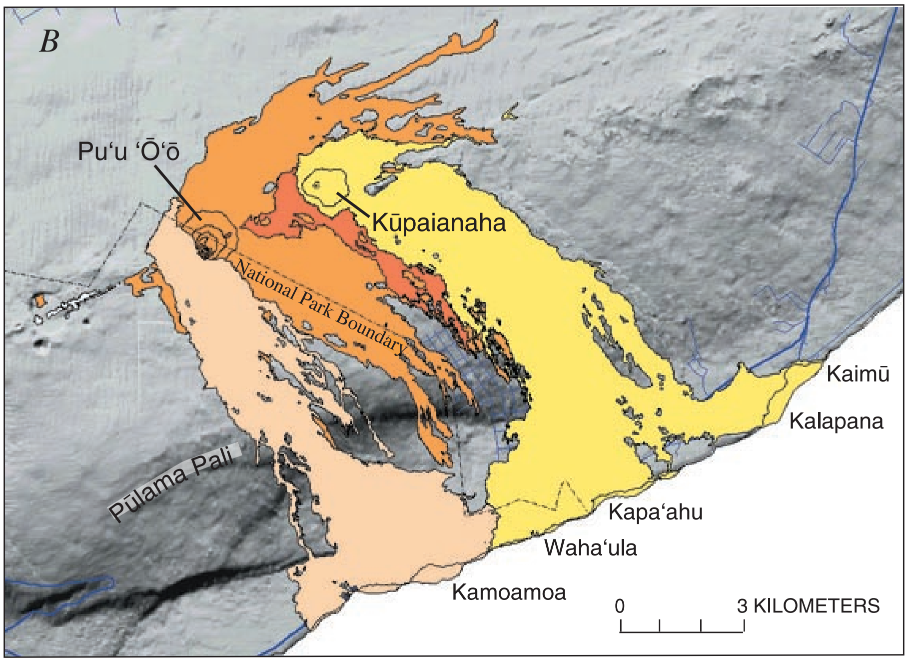
Tiltmeters recorded cycles of gradual inflation of Kīlauea’s summit between eruptive episodes and rapid deflation, averaging 13 µrad, during fountaining episodes. The deflation was accompanied by high-amplitude tremor both at the summit and on the east rift zone. As the summit reinflated during repose periods, the rift zone was slowly repressurized, causing extension and uplift across the rift zone near the vent (Hoffmann and others, 1990). During the same interval, the magma column gradually rose within the Pu‘u ‘Ō‘ō conduit, becoming visible within days to weeks after an eruptive episode.

The style of the eruption at Pu‘u ‘Ō‘ō progressively changed through its first year from low fountains and pāhoehoe rivers to high fountains and ‘a‘ā fans. Episodes 4 through 19

(June 1983–May 1984) were characterized by channeled pāhoehoe flows that spilled from a lava pond at the base of the fountains (Wolfe and others, 1988). These fluid rivers carried most of the lava away from the cone before making the transition to ‘a‘ā 1 to 2 km from the vent.

Beginning in episode 20 (June 1984), fountain-fed ‘a‘ā flows became the norm, mainly because of a substantial increase in fountain heights. During the early Pu‘u ‘Ō‘ō episodes, fountain heights rarely exceeded 250 m, but during episodes 20 through 39, fountains consistently reached heights greater than 300 m and, during about half of these episodes, greater than 400 m. Flows were fed directly by fallback from the fountains, resulting in lava with a higher viscosity and yield strength, owing to the loss of heat and volatile components (Sparks and Pinkerton, 1978). When sustained fountain heights decreased during episodes 42 through 47 in 1986, channeled pāhoehoe flows were observed once again.

From January 1983 through mid-1986, lava flows covered an area of 42 km^2 (for detailed maps, see Wolfe and others, 1988; Heliker and others, 2001). Flows soon threatened the sparsely populated Royal Gardens subdivision, located on a steep slope 6 km from the vent (fig. 1*A*). ‘A‘ā flows reached the subdivision in as little as 13 hours during several eruptive episodes and destroyed 16 houses in 1983 and 1984 (Wolfe and others, 1988).



Episode	Area originally covered by lava (km^2)	Area exposed in January 2002 (km^2)
1–48b	42.0	17.7
48	41.0	34.7
49	3.9	3.9
50	1.0	0.2
51–52	12.3	0.8
53	19.4	10.7
54	0.2	0 .2
55	37.0	37.0
Total	----------------	105.2

EXPLANATION

February 1997–March 2002
Episode 55: Pu‘u ‘Ō‘ō flank vents, mainly tube-fed pāhoehoe

January 1997
Episode 54: fissure vents, pāhoehoe

February 1992–January 1997
Episodes 50–53: Pu‘u ‘Ō‘ō flank vents, mainly tube-fed pāhoehoe

November 1991
Episode 49: fissure vents, pāhoehoe

July 1986–February 1992
Episode 48: Kūpaianaha vent, mainly tube-fed pāhoehoe

January 1983–July 1986
Episodes 1–48b: Mainly Pu‘u ‘Ō‘ō central vent, mainly ‘a‘ā

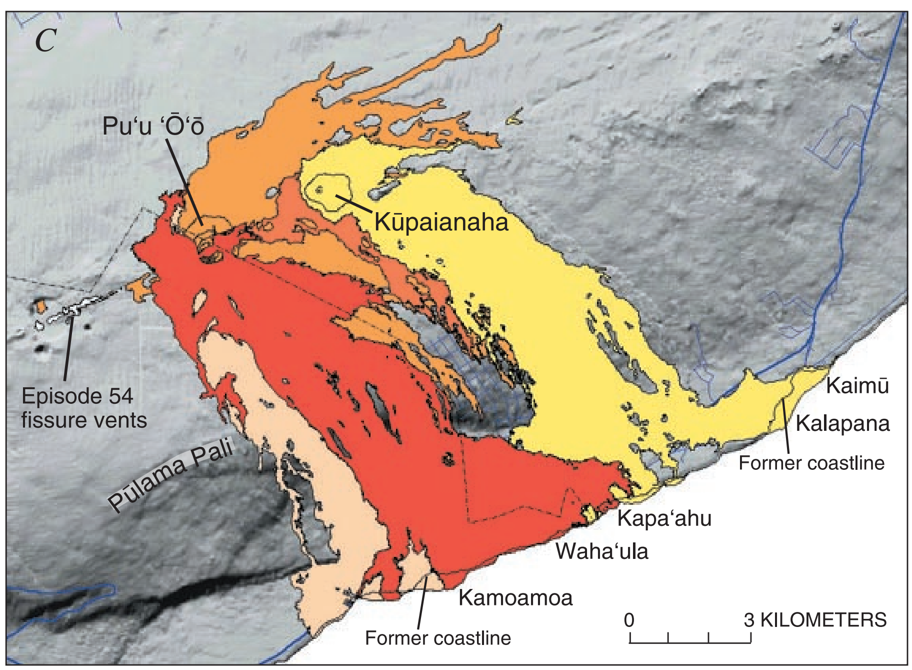


Table 1. Eruption statistics, 1983–2001.

[Raw lava volumes for episodes 1 through 40 were determined from flow areas and measured flow thicknesses. Lack of aerial photographs and accurate flow areas forced us to estimate lava volumes for episodes 41 through 47 from amount of deflation recorded by Uwēkahuna tiltmeter at Kilauea's summit. During the first few months of episode 48, volumes were determined from area and estimated thickness of flows. Once tube-fed lava flows began entering the ocean, we had no accurate way of estimating volumes except to note constant rate of deflation recorded by Uwēkahuna tiltmeter. Beginning in 1988, volumes were estimated from geoelectrical measurements of lava flux, using very low frequency (VLF) profiles over lava tube (see Kauahikaua and others, 1996; Sutton and others, this volume). DRE, dense-rock equivalent (3 g/cm^3). Maximum fountain heights for episodes 2 through 47 were measured either directly by theodolite or indirectly from digitized time-lapse movie-camera film. Data for episodes 1 through 20 from Wolfe and others, 1988; for episodes 21 through 47 from George Ulrich unpub. data, 1986.]

Episode	Episode start		Episode end		Repose period before episode (days)	Episode length (days)	Area covered by lava (km^2)	Raw volume (10^6 m^3)	DRE volume (10^6 m^3)	Maximum fountain height (m)
	Date	Time (H.s.t.)	Date	Time (H.s.t.)						
1	01/03/83	0031	01/23/83	0000	0.0	4.1	4.8	14	9.8	--
2	02/25/83	0900	03/04/83	1451	33.0	7.3	2.7	14	9.8	117
3	03/28/83	0100	04/09/83	0257	23.5	12.1	7.9	38	26.6	278
4	06/13/83	1025	06/17/83	1413	65.3	4.2	2.2	11	7.7	57
5	06/29/83	1251	07/03/83	0715	11.9	3.8	3.4	13	9.1	61
6	07/22/83	1530	07/25/83	1630	19.3	3.0	2.0	9	6.3	129
7	08/15/83	0741	08/17/83	1600	20.6	2.3	3.7	14	9.8	86
8	09/06/83	0511	09/07/83	0526	19.5	1.0	2.0	8	5.6	160
9	09/15/83	1541	09/17/83	1920	8.4	2.2	2.1	8	5.6	200
10	10/05/83	0106	10/07/83	1650	17.2	2.7	2.7	14	9.8	237
11	11/05/83	2350	11/07/83	1845	29.3	1.8	4.3	12	8.4	58
12	11/30/83	0447	12/01/83	1545	22.4	1.5	3.0	8	5.6	65
13	01/20/84	1724	01/22/84	1123	50.1	1.8	2.6	10	7.0	116
14	01/30/84	1745	01/31/84	1318	8.3	.8	2.1	6	4.2	195
15	02/14/84	1940	02/15/84	1501	14.3	.8	2.2	8	5.6	350
16	03/03/84	1450	03/04/84	2231	17.0	1.3	3.2	12	8.4	389
17	03/30/84	0448	03/31/84	0324	25.3	1.0	3.0	10	7.0	177
18	04/18/84	1800	04/21/84	0533	18.6	2.5	6.6	24	16.8	217
19	05/16/84	0500	05/18/84	0050	25.0	1.8	1.4	2	1.4	128
20	06/07/84	2104	06/08/84	0625	20.8	.4	1.6	4	2.8	331
21	06/30/84	1028	06/30/84	1827	22.2	.3	1.9	5.7	4.0	318
22	07/08/84	1930	07/09/84	1017	8.0	.6	2.7	7.7	5.4	--
23	07/28/84	1200	07/29/84	0540	19.1	.8	3.3	9.5	6.7	322
24	08/19/84	2152	08/20/84	1725	21.7	.8	3.7	11.6	8.1	407
25	09/19/84	1604	09/20/84	0532	29.9	.6	3.3	11.1	7.8	467
26	11/02/84	1140	11/02/84	1636	43.3	.2	1.6	6.6	4.6	394
27	11/20/84	0005	11/20/84	1006	17.3	.4	2.3	8.4	5.9	--
28	12/03/84	1905	12/04/84	0941	13.4	.6	3.6	12.4	8.7	421

Table 1. Continued.

Episode	Episode start		Episode end		Repose period before episode (days)	Episode length (days)	Area covered by lava (km²)	Raw volume (10^6 m^3	DRE volume (10^6 m^3)	Maximum fountain height (m)
	Date	Time (H.s.t)	Date	Time (H.s.t)						
29	01/03/85	1315	01/04/85	0504	29.1	.7	3.8	13 .0	9.1	464
30	02/04/85	0546	02/05/85	0246	31.0	.9	4.1	14.1	9.9	445
31	03/13/85	0600	03/14/85	0455	36.1	1.0	4.8	19.4	13.6	309
32	04/21/85	1516	04/22/85	0906	38.4	.8	4.8	16.3	11.4	391
33	06/12/85	2306	06/13/85	0453	51.6	.3	2.2	7.9	5.5	--
34	07/06/85	1903	07/07/85	0850	23.6	.6	2.3	10.6	7.4	410
35	07/26/85	0252	07/26/85	0952	18.8	.3	2.9	12	8.4	--
35a fissure	07/27/85	0414	08/12/85	0430	0.7	16.0	0.8	4.5	3.2	8
36	09/02/85	1400	09/02/85	2335	21.1	.4	2.7	11.5	8.1	441
37	09/24/85	1808	09/25/85	0619	21.8	.5	4.4	14.7	10.3	352
38	10/21/85	0300	10/21/85	1124	25.9	.4	3.9	14.8	10.4	--
39	11/13/85	1534	11/14/85	0124	23.2	.4	4.2	13.7	9.6	436
40	01/01/86	1309	01/02/86	0238	48.5	.6	4.0	11.6	8.1	264
41	01/27/86	2035	01/28/86	0757	25.8	.5	5.0	13.7	9.6	--
42	02/22/86	1515	02/23/86	0420	25.3	.5	3.5	12.1	8.5	--
43	03/22/86	0450	03/22/86	1556	27.1	.5	4.8	10.3	7.2	269
44	04/13/86	2054	04/14/86	0756	22.2	.5	5.2	11.5	8.1	308
45	05/07/86	2241	05/08/86	1106	23.6	.5	5.5	9.4	6.6	257
46	06/02/86	0229	06/02/86	1320	24.6	.5	4.6	9.8	6.9	223
47	06/26/86	0419	06/26/86	1635	23.6	.5	3.8	8.8	6.2	224
48a-b fissure	07/18/86	1205	07/19/86	0930	21.8	.9	4.5	7.2	5.0	30
Subtotal -							42	*559*	*391*	--
48	07/20/86	0830	02/07/92	--	1.0	2, 028.0	41	--	500	5
49	11/08/91	0445	11/26/91	--	0	17.8	3.9	--	11	3
50	02/17/92	~1930	03/03/92	0130	10.0	14.3	1	--	4.5	<4
51	03/07/92	1245	09/27/92	~0600	4.5	197.7	--	--	--	10
52	10/03/92	~0330	02/20/93	1450	5.9	140.5	--	--	--	8
51-52	--	--	--	--	--	--	*12.3*	--	*78*	--
53	02/20/93	1450	01/29/97	1852	0	1,439.2	19.4	--	535	15
54	01/30/97	0240	01/31/97	0033	.3	.9	.2	--	.3	30
55	02/24/97	0700	ongoing	--	24.3	ongoing	37	--	667	15
Grand total -									*2,190*	--

Eruptions from fissures or discrete vents on or near the base of the Pu‘u ‘Ō‘ō cone accompanied nine of episodes 4 through 47. Most of these vents opened just before, or concurrently with, the start of high fountaining from the main Pu‘u ‘Ō‘ō vent, and most died within a few hours once fountaining relieved some of the pressure on the magmatic system. Episode 35 was a conspicuous exception: a fissure on the uprift flank of the cone erupted early in the episode, propagated 2.5 km uprift after the high fountaining ended, and then erupted for the next 16 days.

July 1986–February 1992: Continuous Effusion from Kūpaianaha

On July 18, 1986, the conduit beneath Pu‘u ‘Ō‘ō ruptured, and lava was erupted through new fissures at the base of the cone. Fissures A and B of episode 48 were active for only 22 hours, but fissure C, which opened 3 km downrift of Pu‘u ‘Ō‘ō on July 20, evolved into a single vent, later named “Kūpaianaha” (fig. 1*B*). This event marked the end of the beginning of 5½ years of nearly continuous, quiet effusion (the main phase of episode 48). A tadpole-shaped lava pond, 140 by 300 m in diameter, formed over the new vent, and its frequent overflows built a broad, low shield 1 km in diameter and about 56 m high (fig. 3).

After weeks of continuous eruption, the main channel leaving the pond gradually evolved into a lava tube as crust at the sides of the channel extended across the lava stream, forming a roof. By the end of 1986, this tube became a persistent outlet to the pond; thereafter, the pond rarely overflowed, and shield growth declined.

A broad field of tube-fed pāhoehoe spread slowly toward the coast, 12 km to the southeast, taking 3 months to cover the same distance that ‘a‘ā flows from Pu‘u ‘Ō‘ō traveled in less than a day. Inflated pāhoehoe sheet flows dominated the composite flow field on the low-angle slope near the coast (Hon and others, 1994; Kauahikaua and others, 1998 and this volume). Over the next 5 years, the Kūpaianaha flow field covered an area of 41 km^2 (fig. 1*B*).

Late in November 1986, flows reached the ocean for the first time during this eruption, cutting a swath through the community of Kapa‘ahu (fig. 1*B*) and closing the coastal highway. A few weeks later, the lava took a more easterly course and overran 14 homes on the northwest edge of Kalapana in a single day. This flow abruptly stagnated when the tube became blocked near Kūpaianaha.

From mid-1987 through 1989, most of the lava that erupted from Kūpaianaha flowed through lava tubes to the

Figure 2. Spectacular lava fountain, 450 m high, erupts from the Pu‘u ‘Ō‘ō vent during eruptive episode 25. View southwestward from Pu‘u Halulu; photograph taken September 19, 1984.

Figure 3. Overflows from Kūpaianaha lava pond quickly built a lava shield. View southwestward; photograph taken November 24, 1986.

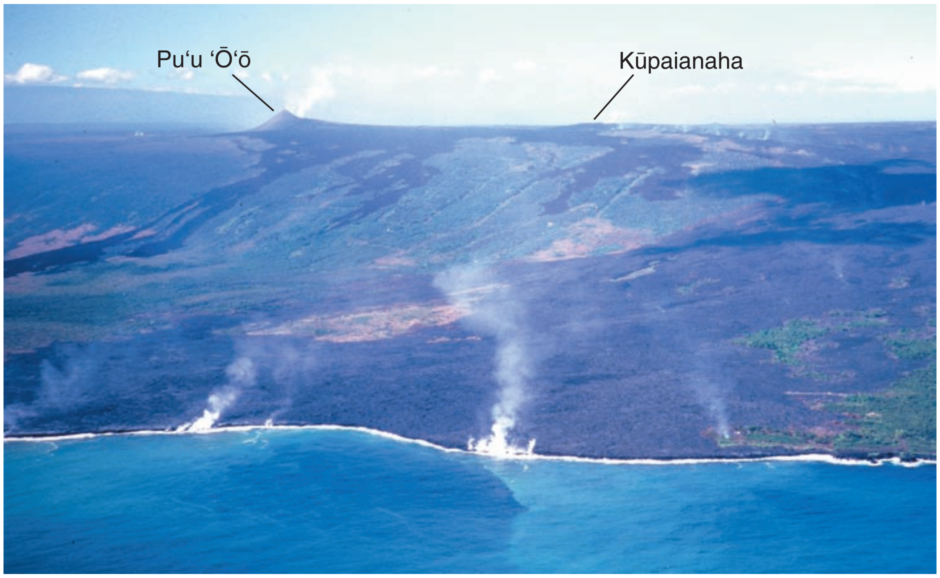


Figure 4. Steam plumes mark sites where lava flows from Kūpaianaha enter ocean on Kīlauea's south coast. Line of fume to right of Kūpaianaha reveals trace of tube feeding lava to coast. Streets of Royal Gardens subdivision, which lie on steep slope below vents, are partly covered by ‘a‘ā flows from Pu‘u ‘Ō‘ō. Photograph taken December 28, 1987.

sea, a distance of 12 km (fig. 4). The long-lived lava-tube system extending from the vent to the ocean began to break down in spring 1989, and lava flows encroached on new territory, overrunning the Waha‘ula Visitor Center in Hawai‘i Volcanoes National Park.

In March 1990, the eruption entered its most destructive period to date when the flows turned toward Kalapana, a village on the flat coastal plain 12 km southeast of Kūpaianaha (fig. 1*B*). Over the next several months, a succession of pāhoehoe sheet flows inundated the community (Mattox and others, 1993; Heliker and Decker, in press). Lava reached the sea at Kaimū and filled the shallow bay, extending the shoreline 300 m seaward. In May 1990, a Federal Disaster Declaration was issued for Kalapana and all other areas previously affected by the eruption.

In late 1990, a new tube diverted lava away from Kalapana and back into the national park, where flows once again entered the ocean. During Kūpaianaha's tenure, from 1986 to 1992, lava entered the ocean approximately 68 percent of the time (fig. 5), creating about 130 ha of new land.

Although Pu‘u ‘Ō‘ō did not produce any lava flows during the 5½ years that Kūpaianaha erupted, Pu‘u ‘Ō‘ō remained actively linked to the conduit that fed magma from Kīlauea's summit to Kūpaianaha. Beginning in June 1987, repeated collapses over the Pu‘u ‘Ō‘ō vent formed a crater approximately 300 m in diameter. A lava pond began to appear intermittently at the bottom of the crater in 1987; by mid-1990, the pond was present most of the time.

Except for a week-long pause in the eruption in 1988 (table 2), lava effusion from Kūpaianaha was continuous

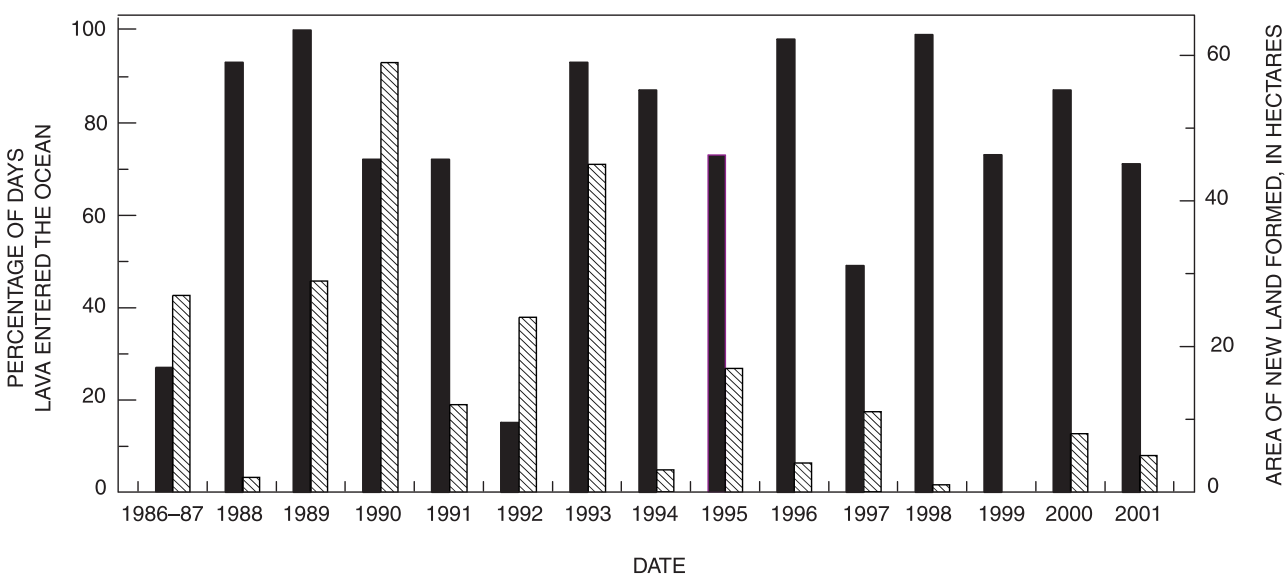


Figure 5. Percentage of days per year when lava entered ocean (black bars) since flows from Kūpaianaha first reached coast in November 1986, and area of new land created (shaded bars). Greatest area of new land formed during 1990 and 1993, when flows filled two largest embayments on coastline, at Kaimū and Kamoamoa, respectively.

Table 2. Eruptive pauses, intrusions, surges, and large earthquakes, 1983–2001.

[Start and end times for episodes in italics. Tilt plots for the 1990 pauses were reexamined, and start and stop times for pauses were picked in a manner consistent with current practice: in general, pause starts at bottom of brief interval of steep deflation at summit and ends at top of intervening summit inflation. Last three pauses originally reported for 1990 (Heliker and Wright, 1991; Mattox and others, 1993) were omitted, because, although instrumental signature resembled those of earlier pauses, we had insufficient evidence that eruption actually stopped. Start and stop times for intrusions and magmatic surges are based solely on beginning and end of period of elevated seismicity at summit. Seismicity tends to tail off gradually, and so end time is much more uncertain than start time. Deformation and eruptive changes associated with these events continue much longer than seismicity. All earthquakes of M>5.5 since 1983 are listed, along with two smaller earthquakes near vent that may have affected eruptive activity.]

Event start		Event end		Pause length	Comments
Date	Time (H.s.t.)	Date	Time (H.s.t.)	(days)	
09/09/83	0630	--	--	--	M=5.7 earthquake, Kīlauea's south flank, 6 km SSE. of Nāpau Crater.
11/16/83	0613	--	--	--	M=6.7 earthquake, Ka‘ōiki, 19 km west of Kīlauea's summit.
04/24/88	a.m.	05/01/88	a.m.	7.00	Pause 48.0.
06/25/89	1727				M=6.2 earthquake, Kalapana, 1.5 km WNW. of Hākuma Point.
02/06/90	0800	02/09/90	1330	3.23	Pause 48.1.
03/19/90	0400	03/21/90	1600	2.50	Pause 48.2.
04/04/90	0200	04/06/90	1700	2.63	Pause 48.3.
05/06/90	0000	05/09/90	1000	3.42	Pause 48.4.
05/28/90	1500	05/30/90	1400	1.96	Pause 48.5.
06/17/90	0400	06/19/90	2200	2.75	Pause 48.6.
07/31/90	0400	08/02/90	0000	1.83	Pause 48.7.
08/09/90	1200	08/11/90	0000	1.50	Pause 48.8.
08/13/90	2200	08/14/90	2200	1.00	Pause 48.9.
12/04/90	1628	12/04/90	~1900	--	Intrusion—upper east rift zone. Brief (<24 h) surge in Pu‘u ‘Ō‘ō.
03/26/91	0532	03/26/91	~0830	--	Intrusion—upper east rift zone. No change in effusion rate at Kūpaianaha, but see below.
03/26/91	0700	--	---	--	Explosion in Pu‘u ‘Ō‘ō's crater, possibly triggered by rockfall into crusted pond.
08/21/91	1100	08/21/91	~1300	--	Intrusion (?)—summit, SE. of Kīlauea caldera. No deformation data.
11/08/91	*0445*	*11/26/91*	---	--	*Episode 49—fissure eruption lasts 18 days.*
02/07/92	--	--	---	--	*Kūpaianaha vent shuts down—end of episode 48.*
02/07/92	--	*02/17/92*	*~1930*	*10.00*	*Eruption hiatus.*
02/17/92	*~1930*	--	---	--	*New fissure erupts—episode 50 begins.*
03/03/92	0045	03/03/92	~0930	--	Intrusion—upper east rift zone. Triggered eruption pause.
03/03/92	0130	03/07/92	1245	4.47	Pause 50.1.
03/07/92	*1245*	---	---	--	*Episode 50 fissure extends—episode 51 begins.*
03/07/92	2100	03/07/92	2400	.13	Pause 51.2.
03/12/92	1519	03/14/92	1130	1.84	Pause 51.3.
03/15/92	1800	03/17/92	0600	1.50	Pause 51.4.
03/18/92	0300	03/18/92	0600	.13	Pause 51.5.
03/26/92	1400	03/29/92	0930	2.81	Pause 51.6.
03/31/92	0000	03/31/92	1230	.52	Pause 51.7.
04/19/92	2000	04/23/92	1100	3.63	Pause 51.8.
04/28/92	1130	05/04/92	0539	5.76	Pause 51.9.
05/22/92	1400	05/27/92	0320	4.56	Pause 51.10.
05/28/92	2020	06/02/92	~0530	4.38	Pause 51.11.
06/05/92	~1700	06/06/92	0400	.46	Pause 51.12.
06/07/92	~0630	06/10/92	1325	3.29	Pause 51.13.
06/16/92	~0500	06/20/92	2314	4.76	Pause 51.14.
07/22/92	p.m	07/27/92	1030	~4.5	Pause 51.15.
08/11/92	~2000	08/15/92	~1300	3.70	Pause 51.16.
08/29/92	~0800	09/02/92	1400	4.25	Pause 51.17.
09/09/92	0900	09/12/92	1700	3.33	Pause 51.18.

Table 2. Continued.

Event start		Event end		Pause length (days)	Comments
Date	Time (H.s.t.)	Date	Time (H.s.t.)		
09/27/92	~0600	10/03/92	~0330	5.90	Pause 51.19.
10/02/92	1951	--	--	--	M=4.2 earthquake, Kīlauea's south flank, 4 km SSE. of Pu‘u ‘Ō‘ō; tremor at Pu‘u ‘Ō‘ō increased.
10/03/92	*~0330*	--	--	--	*New fissure erupts—episode 52 begins.*
09/27/92	*1530*	--	--	--	*Episode 51 vent restarts.*
10/16/92	*p.m.*	--	--	--	*Last observed activity at 52 vent.*
01/03/93	1600	01/04/93	1528	.98	Pause 52.20.
02/07/93	2325	02/08/93 --	~0400 --	--	Intrusion—upper east rift zone. Triggered eruption pause; Pu‘u ‘Ō‘ō's crater floor collapsed <24 h later.
02/08/93	0400	02/16/93	1200	8.33	Pause 52.21.
02/20/93	*1450*	--	--	--	*New vent erupts—episode 53 begins.*
06/08/93	0257	--	--	--	M=4.8 earthquake, Kīlauea's south flank, 8 km WSW. of Nāpau Crater. May have triggered drop in Pu‘u ‘Ō‘ō's pond level.
03/02/94	2230	03/03/94	0600	.31	Pause 53.1.
03/12/94	1330	03/14/94	1400	2.02	Pause 53.2.
04/14/94	1600	04/16/94	0400	1.50	Pause 53.3.
10/05/94	0130	10/07/94	1100	2.40	Pause 53.4.
10/24/94	2100	10/26/94	1200	1.63	Pause 53.5.
11/29/94	1500	12/01/94	0900	1.75	Pause 53.6.
03/16/95	1000	03/17/95	0400	.75	Pause 53.7.
04/11/95	0000	04/11/95	2000	.83	Pause 53.8.
08/22/95	2000	08/25/95	0800	2.50	Pause 53.9.
11/10/95	1500	11/11/95	1800	1.13	Pause 53.10.
12/14/95	1500	12/16/95	2400	2.38	Pause 53.11.
02/01/96	0809	02/01/96	~1210	--	Magmatic event—Kīlauea's summit. Surge in effusion rate.
02/01/96	1130	02/02/96	p.m.	--	Surge in effusion rate—tailed off gradually.
02/04/96	2000	02/14/96	0000	9.17	Pause 53.12.
03/24/96	1036	03/24/96	1151	--	Magmatic event—Kīlauea's summit. Small surge in effusion rate.
05/29/96	2000	06/04/96	1030	5.60	Pause 53.13.
08/21/96	0800	08/22/96	0800	1.00	Pause 53.14.
11/18/96	0900	11/19/96	0900	1.00	Pause 53.15.
01/29/97	1841	01/30/97	0240	--	Intrusion—Nāpau Crater.
--	1930	--	--	--	Onset of summit deflation; probable end of episode 53.
--	~2100	--	--	--	Probable time of collapse of Pu‘u ‘Ō‘ō's crater floor and west wall of cone.
01/30/97	*0240*	*01/31/97*	*0033*	*24.20*	*Episode 54—fissure eruption lasts 22 h.*
01/31/97	*0033*	*02/24/97*	*~0700*	--	*Eruption hiatus.*
02/24/97	*~0700*	--	---	--	*Lava returns to Pu‘u ‘Ō‘ō's crater—start of episode 55.*
05/03/97	0000	05/03/97	0530	.23	Pause 55.1.
05/10/97	0700	05/10/97	1230	.23	Pause 55.2.
05/11/97	2000	05/12/97	0600	.42	Pause 55.3.
05/12/97	2139	05/13/97	0030	.13	Pause 55.4.
05/14/97	0200	05/14/97	0700	.21	Pause 55.5.
05/23/97	0630	05/23/97	2134	.63	Pause 55.6.
05/27/97	0430	05/27/97	0654	.10	Pause 55.7.
06/06/97	2330	06/07/97	1005	.44	Pause 55.8.
06/16/97	1600	06/16/97	2027	.19	Pause 55.9.
06/17/97	1010	06/18/97	~0530	0.81	Pause 55.10.

Table 2. Continued.

Event start		Event end		Pause length (days)	Comments
Date	Time (H.s.t.)	Date	Time (H.s.t.)		
01/14/98	1815	01/15/98	0600		Magmatic event—Kīlauea's summit. Surge in effusion rate. Triggered pause.
01/15/98	1030	01/16/98	1100	1.02	Pause 55.11.
01/26/98	1130	01/27/98	0600	0.77	Pause 55.12.
02/21/98	0000	02/21/98	2400	1.00	Pause 55.13.
03/02/98	0400	03/02/98	1600	0.50	Pause 55.14.
03/09/98	1400	03/10/98	0800	0.75	Pause 55.15.
04/04/98	0400	04/05/98	0041	0.85	Pause 55.16.
05/19/98	0350	05/20/98	2230	1.77	Pause 55.17.
06/19/98	~1400	06/20/98	~0100	0.46	Pause 55.18.
07/16/98	2100	07/19/98	0200	2.21	Pause 55.19.
08/12/98	~1500	08/14/98	~0930	1.75	Pause 55.20.
11/07/98	~0600	11/08/98	~1000	1.17	Pause 55.21.
02/06/99	0400–0800	02/07/99	~0300	.90	Pause 55.22.
04/16/99	1456	--	--	--	M=5.6 earthquake, 6 km NNW. of Pahala.
05/04/99	~1300	05/05/99	~2200	1.38	Pause 55.23.
06/14/99	0010	06/17/99	2300	3.96	Pause 55.24.
08/21/99	~2000	08/22/99	~2000	1.00	Pause 55.25.
09/12/99	0131	09/12/99	~0600	--	Intrusion—upper east rift zone. Triggered pause. Pu‘u ‘Ō‘ō crater floor partially collapsed; new collapse pit formed in west gap.
09/12/99	0131	09/23/99	1100	11.40	Pause 55.26.
10/03/99	~2200	10/05/99	0900	1.46	Pause 55.27.
11/07/99	1400	11/08/99	1015	.85	Pause 55.28.
11/11/99	~1530	11/14/99	1030	2.79	Pause 55.29.
02/23/00	1342	02/23/00	~1600	--	Intrusion—upper east rift zone. Effusion may have slowed or paused briefly (<7 h).
08/23/00	~2300	08/26/00	~1900	2.83	Pause 55.30.
09/24/00	1300	09/25/00	2200	--	Magmatic event—Kīlauea's summit (Dog Day Surge). Surge in effusion rate for ~8 h.
09/25/00	0005	--	--	--	First breakouts on upper flow field.
12/15/00	1715	12/17/00	~0200	1.40	Pause 55.31.
05/20/01	1630	05/21/01	0200	--	Magmatic event—Kīlauea's summit. Surge—two periods of increased effusion rate.
05/20/01	1918	05/21/01	~0400	--	First surge in effusion rate.
05/23/01	~0800	05/23/01	~1800	--	Second surge in effusion rate, associated with summit deflation.

until 1990. From February through August 1990, nine pauses, lasting from less than 1 to 3 days, interrupted the steady effusion of lava.

The 1990 pauses accelerated the demise of the Kūpaianaha lava pond, which had been gradually diminishing in size since late 1987. During the first pause, the pond drained to a depth of 35 to 40 m. When the eruption resumed, the pond partly refilled, but a broad, inner ledge reduced its diameter to 50 m. After subsequent pauses, the shrinking pond was active for a few days when the eruption restarted, and then crusted over. Shortly after the sixth pause in June 1990, the lava pond crusted over for good.

The lava output from Kūpaianaha began to decrease in mid-1990 and steadily declined through 1991 (Kauahikaua and others, 1996). This change also was probably triggered by the frequent pauses, which induced cooling and constriction in the conduit between Puʻu ʻŌʻō and Kūpaianaha (Mangan and others, 1995; Kauahikaua and others, 1996). Concurrently, the level and activity of the Puʻu ʻŌʻō lava pond rose.

In response to pressurization of the magmatic system uprift of Kūpaianaha, fissures opened on the northeast flank of Puʻu ʻŌʻō in November 1991 and quickly propagated 2 km downrift to the base of the Kūpaianaha shield. The downrift end of the fissure system erupted for 3 weeks (episode 49), creating a channeled flow that extended 6.5 km along the western margin of the Kūpaianaha flow field (Mangan and others, 1995). Kūpaianaha continued to erupt during this event, but its output waned. By February 7, 1992, the Kūpaianaha vent was dead.

1992–96: The Return to Puʻu ʻŌʻō

Ten days after Kūpaianaha died, the eruption returned to Puʻu ʻŌʻō. Lava erupted in low fountains along a radial fissure on the west flank of the massive cone (episode 50). New flank vents opened nearby in March 1992 (episode 51), October 1992 (episode 52), and February 1993 (episode 53; Heliker and others, 1998a, b). As at Kūpaianaha, the style of the eruption was nearly continuous, quiet effusion. Flows from the flank vents quickly built a lava shield that banked up against the south and west slopes of Puʻu ʻŌʻō. Spatter cones formed over the initial fissure vents (fig. 6), and during the first 4 months of episode 51, a tube from one of these cones fed a perched lava pond.

By July 1992, new lava tubes formed that bypassed the perched pond. Within a few months, the active vents were completely crusted over, feeding directly into tubes. Tube-fed pāhoehoe flows gradually advanced toward the coastal plain. In November 1992, flows crossed Chain of Craters Road in Hawaiʻi Volcanoes National Park and entered the ocean at Kamoamoa, an archeological site and campground 11 km from the vents (figs. 1*B*, 7). From the end of 1992 through January 1997, tubes fed lava to the ocean almost continuously, forming approximately 93 ha of new land. Surface breakouts from the lava-tube system broadened the new flow field, which was mostly contained within the national park.

During the first year of flank-vent activity at Puʻu ʻŌʻō, the eruption was erratic, with frequent pauses, multiple vents, and two intrusions on the upper east rift zone (table 2; fig. 8). Once episode 53 began in late February 1993 (fig. 9), no more pauses occurred for a year. Pauses resumed in March 1994, with a series of 15 pauses that continued through November 1996.

By 1993, the shield produced by the flank vents was pockmarked with collapse pits, which formed as lava tubes eroded vertically as much as 29 m through the thick deposits of tephra on the downwind side of the Puʻu ʻŌʻō cone (Heliker and others, 1998b). The level of the magma column in the vents feeding the tubes dropped in tandem with the downcutting tubes. As the magma column in the vents dropped, so did the level of the pond in the Puʻu ʻŌʻō crater (fig. 10), demonstrating the hydraulic connection between the flank vents and the crater's pond. The downcutting tubes and the drop in elevation of the magma column beneath the flank vents opened voids that undermined the west side of the Puʻu ʻŌʻō cone.

In addition to the collapse pits on the shield, pits formed on the side of the Puʻu ʻŌʻō cone upslope of the flank vents. The largest of these features, known as the "Great Pit," had engulfed most of the west flank by the end of 1996 (see Heliker and others, this volume).

Figure 6. The cone of Puʻu ʻŌʻō. Spatter cones on skyline to left mark site of episode 51 vents. Lines across lower part of cone are foot trails. View northward; photograph taken December 15, 1992.

Figure 7. Lava flow beginning to fill bay at Kamoamoa on November 12, 1992. Narrow flow has not yet covered picnic ground visible on near side of flow. Dark flows in distance are from Kūpaianaha.

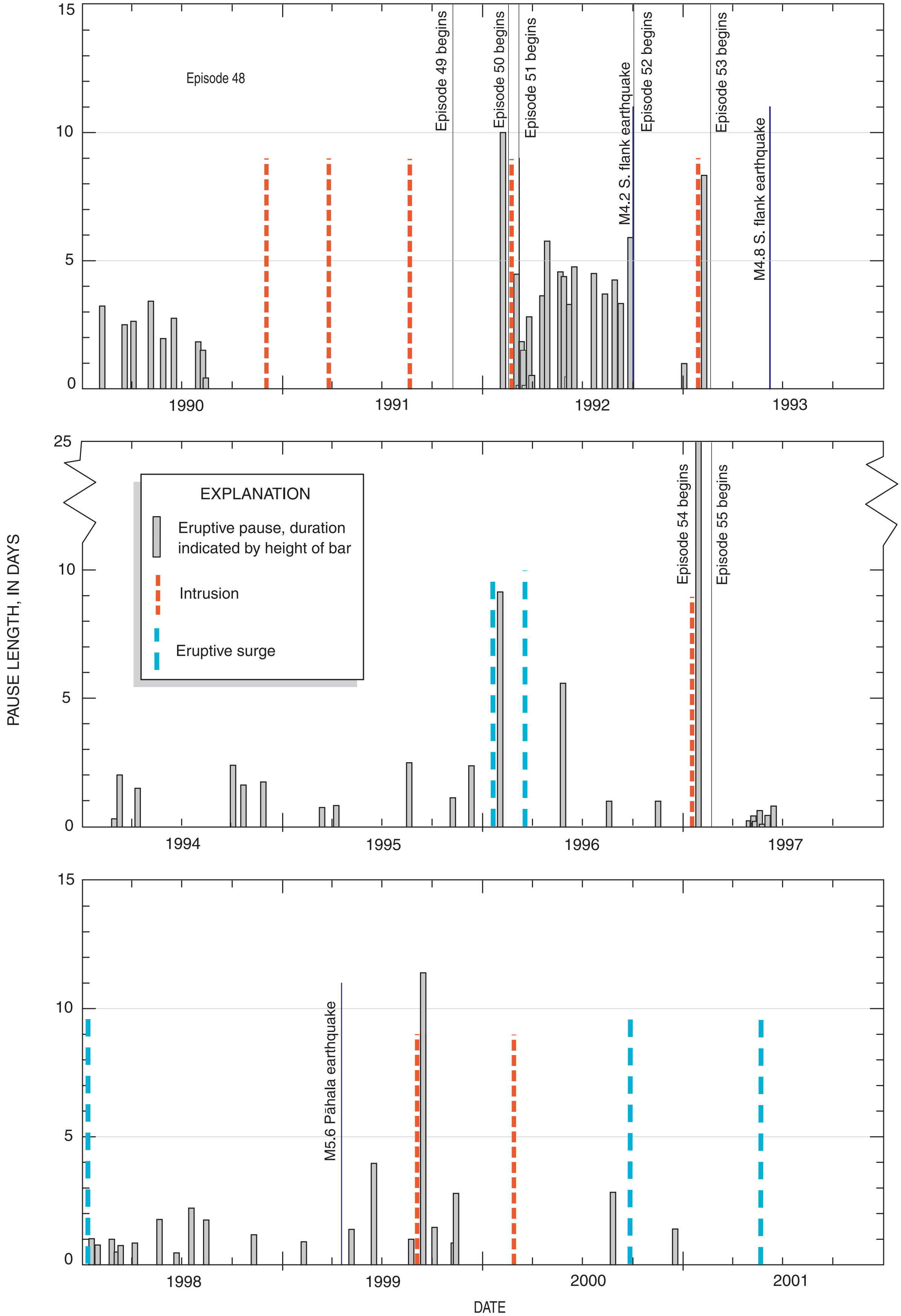


Figure 8. Timeline showing pauses, intrusions, and eruptive surges during Pu‘u ‘Ō‘ō-Kūpaianaha eruption, from 1990 through 2001.

January 1997: Cone Collapse and Fissure Eruption

On the night of January 29, 1997, the conduit leading from the summit reservoir to Puʻu ʻŌʻō was depressurized as magma was diverted to an intrusion uprift of Puʻu ʻŌʻō (Owen and others, 2000; Thornber, 2001; Thornber and others, in press). In rapid sequence, the Puʻu ʻŌʻō conduit drained, the crater floor dropped about 150 m, and the west flank of the cone collapsed, producing a plume of red rock dust that blanketed an area of more than 4 km^2. When the dust settled, Puʻu ʻŌʻō had a nearly vertical walled crater 210 m deep, and the Great Pit had been replaced by a 115-m-wide gap in the west flank of the cone. The height of the cone was reduced by 34 m.

A few hours later, fissures began to erupt in, and downrift of, Nāpau Crater, 4 km uprift of Puʻu ʻŌʻō (figs. 1*C*, 11). The fissure eruption (episode 54) lasted less than a day and was notable for producing lava with the first major differences in whole-rock chemistry in the eruption since 1985—a result of the dike incorporating older magma stored within the rift zone (Thornber, 2001; Thornber and others, in press). Episode 54 was also the first fissure eruption to occur since continuous Global Positioning System (GPS) monitoring of the east rift zone began, resulting in a detailed geodetic record of dike emplacement (Owen and others, 2000; Segall and others, 2001).

Figure 9. Episode 53 vent on southwest flank of the Puʻu ʻŌʻō cone. Photograph taken February 21, 1993, 1 day after vent began erupting.

February 1997 to Present: Eruption of Puʻu ʻŌʻō Flank Vents Resumes

Episode 54 was followed by the longest eruptive hiatus in more than 10 years. Twenty-four days passed before episode 55 began on February 24, 1997, when lava rose through the rubble on the floor of the crater to form a new pond. Lava first erupted outside the crater on March 28, after the pond had risen to within 50 m of the crater rim. Over the next 3 months, several new vents opened on the west and southwest flanks of the cone (see Heliker and others, this volume). As during episodes 50 through 53, the new flank vents initially formed spatter cones (fig. 12) and fed short surface flows onto the shield. Within weeks, however, each vent crusted over and fed lava directly into tubes rather than to surface flows. Before all the vents sealed over, the episodes 50–55 shield grew rapidly. By the end of 1997, the shield was about 80 m high and 0.8 by 1.8 km wide.

In April 1997, the active lava pond in the Puʻu ʻŌʻō crater was replaced by a single vent on the west side of the crater. Flows from this vent intermittently ponded at the crater's east end. In June 1997, the lava rose until it overtopped the gap in the west wall of Puʻu ʻŌʻō formed by the January 1997 collapse. Lava spilled from the crater for the first time in 11 years (fig. 13). Subsequent crater overflows in 1997 also overtopped the east crater rim and extended as far as 1.5 km downrift. The spillovers were brief events, ending when the lava pond

Figure 10. Throughout early 1990s, lava pond in the Puʻu ʻŌʻō crater was typically circular and occupied east end of the crater. Depth to crater floor is 37 m, and pond is about 80 m in diameter. Photograph by M.T. Mangan, taken from north rim of crater on April 16, 1992.

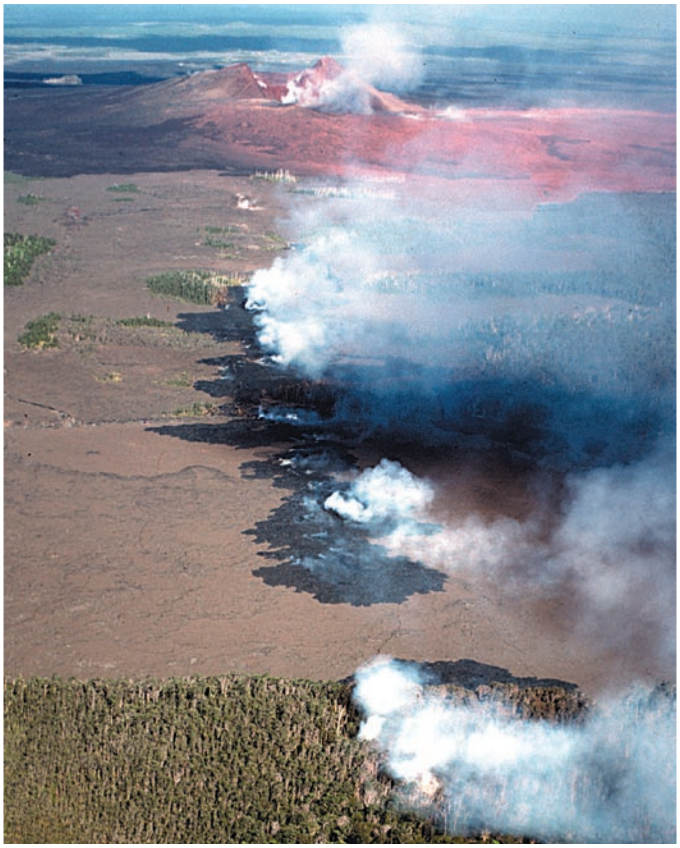


Figure 11. Fuming fissures and fresh black pāhoehoe mark episode 54 fissures, which stopped erupting a few hours before photograph was taken on January 31, 1997. Puʻu ʻŌʻō, in background, is tinted red from rock dust deposited during collapse of crater floor and west side of cone.

drained through conduits in the crater floor. Crater overflows continued intermittently through January 1998 and plated the west gap and east flank of the cone with fresh pahoehoe.

From February 1998 through 2001, eruptive activity within the crater dropped to its lowest level since early 1990, relieved only by a 2-month interval of spattering and extrusion of small flows after a pause in September 1999. In early 2002, crater activity again became conspicuous, with multiple vents contributing lava flows that resurfaced the crater floor and raised its level to within 10 m of the east rim (fig. 14).

Tube-fed flows from the episode 55 flank vents reached the ocean in July 1997 near the east boundary of Hawaiʻi Volcanoes National Park. Episode 55 flows have subsequently buried much of the episodes 50–53 flow field (fig. 1*C*). In early 2000, flows crossed the east boundary of the park and encroached on private property. During the next 2 years, lava overran five abandoned houses in Royal Gardens subdivision, bringing the total number of structures destroyed by this eruption to 189 by the end of May 2002.

Flank-vent activity continued to undermine the Puʻu ʻŌʻō cone during episode 55. In December 1997, a new collapse pit, Puka Nui, formed on the southwest flank of the cone. During the next year, Puka Nui expanded rapidly by coalescing with pits on the adjacent shield. Several spatter cones formed within Puka Nui in September–October 1999 and again in April–May 2002; lava flows floored the shield part of the pit on both occasions. By mid-2002, Puka Nui was 180 by 200 m in diameter, and headward erosion of the upper edge of the pit had carved a notch in the rim of the cone.

A total of 31 pauses had interrupted episode 55 as of May 2002 (fig. 8), two-thirds of which occurred during the first 2 years of the episode. The latest pause was in December 2000.

Long-Term Observations

Effusion and Magma-Supply Rates

The estimated long-term effusion rate averaged over the first 19 years of the Puʻu ʻŌʻō-Kūpaianaha eruption is about 0.12 km^3/yr (dense-rock equivalent; using methods given in table 1. Sutton and others (this volume) average VLF-and SO_2-emission-derived efusion rates to obtain 0.13 km^3/yr.) Tiltmeters at Kīlauea's summit have recorded long-term deflation during the eruption (see Cervelli and Miklius, this volume), indicating that nearly all the magma entering the shallow summit reservoir passes through it to the eruption site. According to several workers who have used geodetic data to model long-term deformation of Kīlauea's south flank, however, the effusion rate does not approximate the full magma-supply rate (Delaney and others, 1993; Owen and others, 1995; Cayol and others, 2000). Their models invoke an extensional source within the deep rift zone that requires diversion of a significant proportion of the magma supply to fill the space opened by this source. Depending on the details of the source geometry, this component of the magma supply rate has been variously estimated at 0.025 km^3/yr (Delaney and others, 1993) and 0.06 km^3/yr (Owen and others, 1995). Added to the effusion rate, these estimates give a magma-supply rate of 0.15 to 0.18 km^3/yr over the course of this eruption.

Alternative models (both old and new) for south-flank deformation do not include a deep rift-zone source (for

Figure 12. Episode 55 flank vent, viewed from the west slope of Puʻu ʻŌʻō. Lava from spatter cone is feeding lava pond to left. Photograph taken April 24, 1997.

example, Douglas and Cervelli, 2002). If these models are correct, then the effusion rate during sustained eruptions does approximate the magma-supply rate, as proposed by Swanson (1972) and Dvorak and Dzurisin (1993). The current effusion rate of about 0.12 km^3/yr is essentially the same as their estimated average magma-supply rates of 0.11 and 0.09 km^3/yr, respectively.

Our estimate of the total volume of lava erupted in 1983–2001 omits the 7 intrusions in the upper east rift zone and 1 intrusion in the middle east rift zone that have occurred since late 1990 (table 2; fig. 15). The volumes of the upper-east-rift-zone intrusions were small: for example, the volume of the September 1999 intrusion was approximately $3.3x10^6$ m^3 (Cervelli and others, 2002), or about a 1-week magma supply to the eruption. The middle-east-rift-zone intrusion of January 1997, which preceded the episode 54 fissure eruption, was much larger, with a modeled volume of $23x10^6$ m^3 (Owen and others, 2000). (The January 1997 event is considered an intrusion because the volume of lava erupted—about $0.3x10^6$ m^3—was small relative to the volume of magma intruded.) On the basis of these figures, the total volume of all eight intrusions would not significantly increase the estimated magma-supply rate.

By updating estimates of the total volume of lava erupted by Kīlauea since 1840 (Dvorak and Dzurisin, 1993), we calculate that about half this total volume is from the Puʻu ʻŌʻō-Kūpaianaha eruption. The ongoing eruption has produced nearly twice the volume erupted during Kīlauea's sustained summit activity from 1840 to 1932.

Volcanic Air Pollution

Once the eruption shifted to Kūpaianaha in mid-1986, the continuous emission of SO_2 from the vent resulted in persistent volcanic smog, called vog, downwind of Kīlauea. SO_2 in the eruption plume reacts with O_2, dust particles, and atmospheric moisture to form H_2SO_4 droplets and solid sulfate particles that result in vog and acid rain (Sutton and others, 1997). The west side of the island, 125 km from the eruption site, is most persistently impacted, because prevailing trade winds cause the vog to accumulate along the Kona coast. The health effects of vog on island residents are still under study, but vog is known to aggravate preexisting respiratory problems.

Another persistent and conspicuous type of gas release during this eruption is created where tube-fed lava enters the ocean. The resulting large steam plume contains a mixture of HCl, concentrated seawater, and particulates created when seawater boils and vaporizes (Gerlach and others, 1989; Sutton and others, 1997). The acidity of this plume decreases rapidly with distance from its source and so is a much more localized hazard than vog.

The Slow Process of Building New Land

Since November 1986, lava flows have entered the ocean more than 70 percent of the time (fig. 5), by far the longest such interval in Hawaiʻi in the past 500 years. The longest lived ocean entry was active for 15½ months (May 1988–Aug. 1989); 30 others lasted longer than 2 months (see Kauahikaua and others, this volume).

New land formed as lava deltas build seaward over steep, prograding submarine slopes of hyaloclastite debris and pillow lava (Kelly and others, 1989; Hon and others, 1993; Kauahikaua and others, this volume). These slopes are inherently unstable and prone to slumping, which removes support for the active, leading edge of the lava delta, or "bench." The catastrophic collapse of a bench can submerge several hectares

Figure 13. Lava from crater of Puʻu ʻŌʻō flows through west gap in cone. View eastward; photograph by J.P. Kauahikaua, taken October 20, 1997.

Figure 14. Crater of Puʻu ʻŌʻō. Fume rises from several vents on crater floor, which is covered with pāhoehoe erupted in 2002. View westward; photograph taken April 11, 2002.

of land in a matter of minutes or hours. Large collapses commonly precipitate violent littoral explosions when the severed lava tubes are exposed to the surf (Mattox and Mangan, 1997). Not all bench collapses are dramatic, however; small, piecemeal collapse has been the dominant process at many benches.

More than 210 ha of new land has been created during this eruption—a net value that does not include new land claimed by calving of active benches or by wave erosion of inactive ones. Owing to these processes, in some years a net decrease was noted in the total area of new land, even though flows entered the ocean the entire year. Both the steep offshore slope and the exposure of the coastline to storm surf have contributed to the slow rate at which new land has formed.

The continuous interaction of lava and seawater at the ocean entry points created black sand that was entrained in the southwest-bound longshore current. Kīlauea's wave-battered coastline has few places sheltered enough to capture and retain sand, and so most of the black sand beaches that formed during this eruption were small and ephemeral. The largest beach (approximately 400 m long by 40 m wide) began to form at Kamoamoa (fig. 1*B*) in January 1988. For the next 2 years, it was fed by ocean entries 2 to 4 km to the northeast. This beach subsequently was buried by lava flows from Pu‘u ‘Ō‘ō flank vents in November 1992 (fig. 7).

Eruptive Pauses, Intrusions, and Surges

When the eruption paused for a week in 1988, the event seemed completely anomalous, occurring midway through 42 months of continuous effusion from Kūpaianaha. In 1990, however, the first of 4 series of pauses began (fig. 8). From February through August 1990, 9 pauses, each lasting approximately 1–3½ days, punctuated the steady effusion of lava. The Kūpaianaha pauses were preceded by sharp, but small, deflation of the summit reservoir and increasing summit tremor (Okubo and others, 1990). After each pause began, the summit inflated rapidly, summit tremor decreased, and microearthquakes beneath the summit increased. The supply from the summit probably resumed at the peak of inflation. The eruption started 4 to 8 hours later.

The 1990 pauses ended in mid-August, and no more pauses occurred as the output of lava from Kūpaianaha declined over the next 17½ months. During this interval, however, three magmatic intrusions took place in the upper east rift zone, followed by a fourth shortly after Kūpaianaha stopped erupting and all activity returned to Pu‘u ‘Ō‘ō (Okubo and others, 1991). These were the first intrusions anywhere on the volcano since the eruption began in 1983.

Since the era of Pu‘u ‘Ō‘ō flank-vent eruptions began, long intervals of frequent pauses have been the norm. During episodes 50 through 52 (Feb. 1992–Feb.1993), 21 pauses occurred, lasting a total of 65 days. About 50 percent of these pauses were immediately preceded by slight summit deflation, but many comparable intervals of deflation were not followed by pauses (see discussion in Heliker and others, 1998b). The most consistent change at the summit was inflation during most pauses. The episodes 50–52 pauses occurred at irregular intervals, separated by periods as short as 8 hours or as long as 90 days, and each pause lasted an average of 3 days.

The last pause in this series was triggered by the fifth upper-east-rift-zone intrusion in February 1993 (Heliker and others, 1998b). Episode 53 began shortly thereafter, and throughout the next year no pauses occurred. In March 1994,

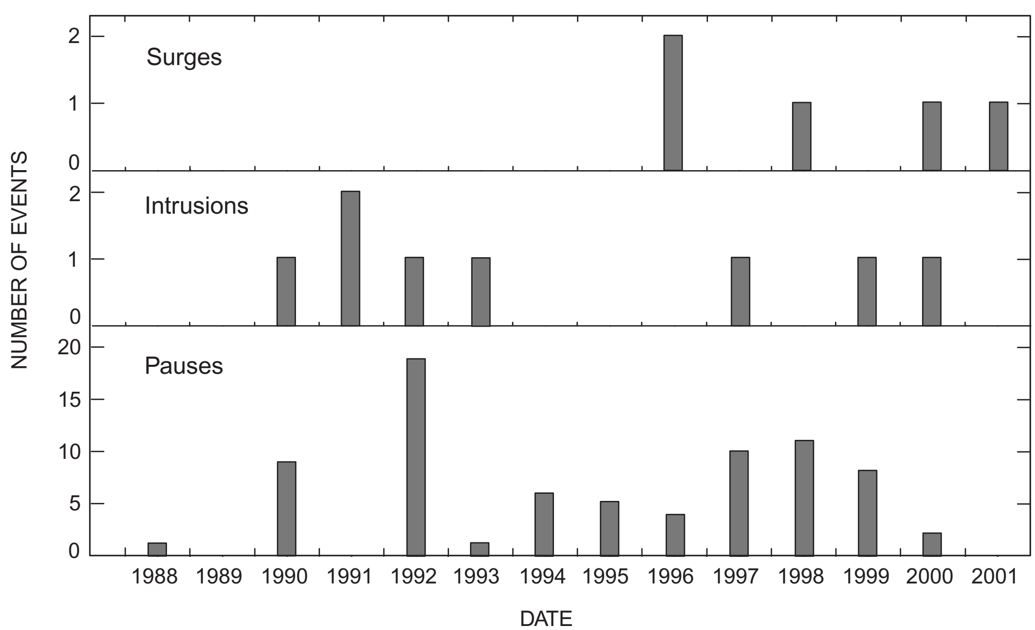


Figure 15. Frequency of eruptive pauses, intrusions, and eruptive surges during Pu‘u ‘Ō‘ō-Kūpaianaha eruption, from 1988 through 2001.

a new series of pauses began (Thornber and others, 1995), with 15 pauses occurring over the next 2¾ years of episode 53. Overall, these pauses had an instrumental signature similar to those during the previous series. The episode 53 pauses, however, were briefer, on average, and less frequent (figs. 8, 15).

The eruption was especially erratic after the long hiatus that followed the cone collapse in early 1997 (see Heliker and others, this volume). The first 2 years of episode 55 were marked by 21 pauses; another 10 pauses punctuated the eruption in 1999–2000. No pauses occurred from January 2001 through 2002.

During the first half-year of episode 55, the tremor amplitude recorded at the closest seismic station (sta. STC, 2.1 km WSE of the Puʻu ʻŌʻō crater), fell to background levels during each pause. This decrease in tremor contrasted markedly with many of the episode 53 pauses, which were accompanied by little detectable change in the station STC tremor. As episode 55 progressed, however, defining a "typical" pause became increasingly difficult. Most episode 55 pauses occurred without any increase in summit tremor; many had no seismic signature either at the summit or on the rift. Yet the last pause in 2000 was preceded by 41 hours of high tremor at the summit that dropped off a few hours after the pause began.

The criteria for picking the start and stop times of pauses have evolved over time. Through episode 53, we generally picked the start of the pause by visual evidence of flagging activity at a vent. This evidence was difficult to obtain when vents had crusted over and flows were encased in lava tubes all the way to the ocean. Our first indication of a pause commonly came only when the steam plume at the ocean entry point died, sometimes more than a day after the eruption stopped. With the advent of a much more sensitive tiltmeter, installed at Kīlauea's summit during episode 55, the summit tilt signal became the most consistent indicator of the beginning of a pause. Many pauses were preceded by a brief interval of steep deflation at the summit. This interval seemed to mark the point at which the magma supply to the eruption site was interrupted; most pauses ended after an interval of summit inflation.

The precursory tilt changes at the summit indicate that most eruptive pauses were initiated by a shutoff of magma supply from the summit. The episodes 50–55 pauses varied widely in their instrumental signature, however, and some were probably triggered locally by transient blockages in the connections between the main Puʻu ʻŌʻō conduit and the flank vents. A new generation of borehole tiltmeters, extending from the summit down the east rift zone to the Puʻu ʻŌʻō cone, may yield the answers to the origin of the pauses once the next series begins.

Two more upper-east-rift-zone intrusions occurred in episode 55: the first in September 1999 (Cervelli and others, 2002), and the second in February 2000. During the past 5½ years, we have also witnessed a different type of magmatic event that begins at the summit and results in a substantial surge in effusion rate at the eruption site. The first of these "surge" events occurred on February 1, 1996 (Lisowski and others, 1996; Okubo and others, 1996; Thornber and others, 1996), and four others occurred before the end of 2001 (table 2; figs. 8, 15). The surges varied in duration, amplitude, and instrumental signature but generally were characterized by increasing seismicity and rapid inflation at the summit, followed by rapid summit deflation and a surge in effusion rate at the eruption site (for a discussion of four of these events, see Cervelli and Miklius, this volume).

The surge in effusion rate caused by these events is striking. Long-dormant vents in the crater become active, and flows break out of the tube on the upper flow field, where breakouts are uncommon. These breakouts generally originate from preexisting skylights in the lava tube, and low fountains are typical at the breakout points during the first few hours of a surge, when effusion rates may be 10 times higher than normal.

The Show Goes On

The chronology of the first 2 decades of the Puʻu ʻŌʻō-Kūpaianaha eruption lacks a final chapter. Our ability to predict the onset of a Kīlauea eruption far exceeds our ability to predict its end. In the early years of this eruption, we speculated that a large earthquake might disrupt the rift-zone plumbing and bring the activity to a close. Although the eruption has not yet been tested by an M≥7 earthquake, the activity has proven remarkably impervious to lesser tectonic and magmatic events.

In its first decade, the eruption weathered the M6.6 Kaʻōiki earthquake of 1983 and the M6.1 Kalapana earthquake of 1989. In March–April 1984, Mauna Loa erupted for 3 weeks, while at Puʻu ʻŌʻō, episode 17 occurred on schedule, and the two volcanoes erupted simultaneously (Wolfe and others, 1988). In 1997, Puʻu ʻŌʻō revived after substantial edifice collapse and a prolonged hiatus in activity. Thus far, the Puʻu ʻŌʻō-Kūpaianaha eruption has withstood all of these events and shows no sign of faltering; the eruption continues unabated.

Selected Bibliography for the Puʻu ʻŌʻō-Kūpaianaha Eruption

Our initial search of the Hawaiʻi Bibliographic Database (Wright and Takahashi, 1998) yielded more than 1,000 references pertaining to the eruption published between 1983 and early 2002. We first culled the list for all references in the geosciences. Additional selection criteria included (1) abstracts containing material not published elsewhere; (2) the most recent, inclusive publication by the same author(s) on an identical topic; (3) articles published in journals with widespread distribution, favored over publications with limited distribution; (4) M.S. and Ph.D. theses not published elsewhere that contained a unique dataset; and (5) USGS Open-File Reports with unique datasets not published in mainstream publications.

Including every report written about every aspect of this eruption is impossible. Readers interested in a complete listing for a particular topic should consult the Hawai‘i Bibliographic Database. Updated instructions on how to access this remarkable research tool are posted on the Hawaiian Volcano Observatory Web site, at URL http://wwwhvo.wr.usgs.gov/products/database.html. To find every reference about this eruption, we recommend searching for the keyword “kl.erz.1983” and for any of the following words within the abstract or title: Kīlauea *and* East Rift, Pu‘u ‘Ō‘ō, and Kūpaianaha.

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References Cited

Cayol, Valérie, Dieterich, J.H., Okamura, A.T., and Miklius, Asta, 2000, High magma storage rates before the 1983 eruption of Kilauea, Hawaii: Science, v. 288, no. 5475, p. 2343–2346.

Cervelli, P.F., Segall, Paul, Amelung, Falk, Garbeil, Harold, Meertens, C.M., Owen, S.E., Miklius, Asta, and Lisowski, Michael, 2002, The 12 September 1999 Upper East Rift Zone dike intrusion at Kilauea Volcano, Hawaii: Journal of Geophysical Research, v. 107, no. B7, p. ECV 3–1 – ECV 3–13.

Delaney, P.T., Miklius, Asta, Árnadóttir, Thóra, Okamura, A.T., and Sako, M.K., 1993, Motion of Kilauea Volcano during sustained eruption from the Puu Oo and Kupaianaha vents, 1983–1991: Journal of Geophysical Research, v. 98, no. B10, p. 17801–17820.

Douglas, Anne, and Cervelli, Paul, 2002, Continuous GPS monitoring of deformation at Kilauea Volcano during the latter half of the Pu‘u ‘O‘o eruption [abs.]: Eos (American Geophysical Union Transactions), v. 83, no. 47, supp., p. F1440.

Dvorak, J.J., and Dzurisin, Daniel, 1993, Variations in magma supply rate at Kilauea Volcano, Hawaii: Journal of Geophysical Research, v. 98, no. B12, p. 22255–22268.

Dzurisin, Daniel, Koyanagi, R.Y., and English, T.T., 1984, Magma supply and storage at Kilauea Volcano, Hawaii, 1956–1983: Journal of Volcanology and Geothermal Research, v. 21, no. 3–4, p. 177–206.

Gerlach, T.M., Krumhansl, J.L., Fournier, R.O., and Kjargaard, J.I., 1989, Acid rain from the heating and evaporation of seawater by molten lava; a new volcanic hazard [abs.]: Eos (American Geophysical Union Transactions), v. 70, no. 43, supp., p. 1421.

Heliker, C.C., and Decker, R.W., in press, The Hawai‘i Island eruptions of Kīlauea, 1983 to 2001, and Mauna Loa, 1984; living with lava, *in* Guffanti, M.C., Miller, C.D., and Ewert, J.W., eds., Responding to volcanic eruptions and unrest—1980–2000; two decades of scientific experience in applied volcanology: U.S. Geological Survey Circular 1250.

Heliker, C.C., Mangan, M.T., Mattox, T.N., and Kauahikaua, J.P., 1998a, The Pu‘u ‘Ō‘ō-Kūpaianaha eruption of Kīlauea, November 1991–February 1994; field data and flow maps: U.S. Geological Survey Open-File Report 98–103, 10 p., 2 sheets, scale 1:50,000.

Heliker, C.C., Mangan, M.T., Mattox, T.N., Kauahikaua, J.P., and Helz, R.T., 1998b, The character of long-term eruptions; inferences from episodes 50–53 of the Pu‘u ‘Ō‘ō-Kūpaianaha eruption of Kīlauea Volcano: Bulletin of Volcanology, v. 59, no. 6, p. 381–393.

Heliker, C.C., Ulrich, G.E., Margriter, S.C., and Hoffmann, J.P., 2001, Maps showing the development of the Pu‘u ‘Ō‘ō-Kūpaianaha flow field, June 1984–February 1987, Kīlauea Volcano, Hawaii: U.S. Geological Survey Miscellaneous Investigations Series Map I–2685, 4 sheets, scale 1:50,000.

Heliker, C.C., and Wright, T.L., 1991, The Pu‘u ‘O‘o-Kupaianaha eruption of Kilauea: Eos (American Geophysical Union Transactions), v. 72, p. 521, 526, 530.

Hoffmann, J.P., Ulrich, G.E., and Garcia, M.O., 1990, Horizontal ground deformation patterns and magma storage during the Puu Oo eruption of Kilauea volcano, Hawaii; episodes 22–42: Bulletin of Volcanology, v. 52, no. 6, p. 522–531.

Hon, K.A., Kauahikaua, J.P., Denlinger, R.P., and Mackay, Kevin, 1994, Emplacement and inflation of pahoehoe sheet flows; observations and measurements of active lava flows on Kilauea Volcano, Hawaii: Geological Society of America Bulletin, v. 106, no. 3, p. 351–370.

Hon, K.A., Mattox, T.N., Kauahikaua, J.P., and Kjargaard, J.I., 1993, The construction of pahoehoe lava deltas on Kilauea volcano, Hawaii [abs.]: Eos (American Geophysical Union Transactions), v. 74, no. 43, supp., p. 616.

Jackson, D.B., 1988, Geoelectric observations (including the September 1982 summit eruption), chap. 8 *of* Wolfe, E.W., ed., The Puu Oo eruption of Kilauea Volcano, Hawaii; episodes 1 through 20, January 3, 1983, through June 8, 1984: U.S. Geological Survey Professional Paper 1463, p. 237–251.

Kauahikaua, J.P., Cashman, K.V., Mattox, T.N., Heliker, C.C., Hon, K.A., Mangan, M.T., and Thornber, C.R., 1998, Observations on basaltic lava streams in tubes from Kilauea Volcano, island of Hawai‘i: Journal of Geophysical Research, v. 103, no. B11, p. 27303–27323.

Kauahikaua, J.P., Mangan, M.T., Heliker, C.C., and Mattox, T.N., 1996, A quantitative look at the demise of a basaltic vent; the death of Kupaianaha, Kilauea Volcano, Hawai‘i: Bulletin of Volcanology, v. 57, no. 8, p. 641–648.

Kelly, K.M., Hon, K.A., and Tribble, G.W., 1989, Bathymetric and submarine studies of an active lava delta near Kupapau Point, Kilauea volcano, Hawaii [abs.]: Eos (American Geophysical Union Transactions), v. 70, no. 43, p. 1202.

Klein, F.W., Koyanagi, R.Y., Nakata, J.S., and Tanigawa, W.R., 1987, The seismicity of Kilauea's magma system, chap. 43 *of* Decker, R.W., Wright, T.L., and Stauffer, P.H., eds., Volcanism in Hawaii: U.S. Geological Survey Professional Paper 1350, v. 2, p. 1019–1185.

Koyanagi, R.Y., Tanigawa, W.R., and Nakata, J.S., 1988, Seismicity associated with the eruption, chap. 7 *of* Wolfe, E.W., ed., The Puu Oo eruption of Kilauea Volcano, Hawaii; episodes 1 through 20, January 3, 1983, through June 8, 1984: U.S. Geological Survey Professional Paper 1463, p. 183–235.

Lisowski, Michael, Owen, S.E., and Segall, Paul, 1996, The Kilauea Volcano, Hawaii, continuous GPS network; recent results [abs.]: Eos (American Geophysical Union Transactions), v. 77, no. 46, supp., p. F808.

Mangan, M.T., Heliker, C.C., Mattox, T.N., Kauahikaua, J.P., and Helz, R.T., 1995, Episode 49 of the Puʻu ʻOʻo-Kupaianaha eruption of Kilauea volcano—breakdown of a steady-state eruptive era: Bulletin of Volcanology, v. 57, no. 2, p. 127–135.

Mattox, T.N., Heliker, C.C., Kauahikaua, J.P., and Hon, K.A., 1993, Development of the 1990 Kalapana flow field, Kilauea Volcano, Hawaii: Bulletin of Volcanology, v. 55, no. 6, p. 407–413.

Mattox, T.N., and Mangan, M.T., 1997, Littoral hydrovolcanic explosions; a case study of lava-seawater interaction at Kilauea Volcano: Journal of Volcanology and Geothermal Research, v. 75, no. 1–2, p. 1–17.

Okamura, A.T., Dvorak, J.J., Koyanagi, R.Y., and Tanigawa, W.R., 1988, Surface deformation during dike propagation, chap. 6 *of* Wolfe, E.W., ed., The Puu Oo eruption of Kilauea Volcano, Hawaii; episodes 1 through 20, January 3, 1983, through June 8, 1984: U.S. Geological Survey Professional Paper 1463, p. 165–182.

Okubo, P.G., Nakata, J.S., Chouet, B.A., and Dawson, P.B., 1996, The February 1, 1996, Kilauea summit earthquake swarm [abs.]: Eos (American Geophysical Union Transactions), v. 77, no. 46, supp., p. F798.

Okubo, P.G., Okamura, A.T., and Miklius, Asta, 1991, Intrusive earthquake swarms and the continuing Kilauea eruption [abs.]: Eos (American Geophysical Union Transactions), v. 72, no. 44, supp., p. 566.

Okubo, P.G., Tomori, A.H., Nakata, J.S., Largo, A.J., and Fukunaga, P.N., 1990, Spatial and temporal patterns of seismicity related to the on-going eruption of Kilauea Volcano, Hawaii [abs.]: Eos (American Geophysical Union Transactions), v. 71, no. 43, p. 1711.

Owen, S.E., Segall, Paul, Freymueller, J.T., Miklius, Asta, Denlinger, R.P., Árnadóttir, Thóra, Sako, M.K., and Bürgmann, R.B., 1995, Rapid deformation of the south flank of Kilauea volcano, Hawaii: Science, v. 267, no. 5202, p. 1328–1332.

Owen, S.E., Segall, Paul, Lisowski, Michael, Miklius, Asta, Murray, Michael, Bevis, M.G., and Foster, James, 2000, January 30, 1997 eruptive event on Kilauea Volcano, Hawaii, as monitored by continuous GPS: Geophysical Research Letters, v. 27, no. 17, p. 2757–2760.

Segall, Paul, Cervelli, P.F., Owen, S.E., Lisowski, Michael, and Miklius, Asta, 2001, Constraints on dike propagation from continuous GPS measurements: Journal of Geophysical Research, v. 106, no. B9, p. 19301–19317.

Sparks, R.S.J., and Pinkerton, Harry, 1978, Effect of degassing on rheology of basaltic lava: Nature, v. 276, no. 5686, p. 385–386.

Sutton, A.J., Elias, Tamar, Hendley, J.W., II, and Stauffer, P.H., 1997, Volcanic air pollution—a hazard in Hawaii: U.S. Geological Survey Fact Sheet 169–97, 2 p.

Swanson, D.A., 1972, Magma supply rate at Kilauea Volcano, 1952–1971: Science, v. 175, no. 4018, p. 169–170.

Swanson, D.A., Duffield, W.A., Jackson, D.B., Peterson, D.W., 1979, Chronological narrative of the 1969–71 Mauna Ulu eruption of Kilauea Volcano, Hawaii: U.S. Geological Survey Professional Paper 1056, 55 p.

Thornber, C.R., 2001, Olivine-liquid relations of lava erupted by Kīlauea Volcano from 1994 to 1998; implications for shallow magmatic processes associated with the ongoing east-rift-zone eruption: Canadian Mineralogist, v. 39, no. 2, p. 239–266.

Thornber, C.R., Heliker, C.C., Reynolds, J.R., Kauahikaua, J.P., Okubo, P.G., Lisowski, Michael, Sutton, A.J., and Clague, D.A., 1996, The eruptive surge of February 1, 1996; a highlight of Kilauea's ongoing east rift zone eruption [abs.]: Eos (American Geophysical Union Transactions), v. 77, no. 46, supp., p. F798.

Thornber, C.R., Heliker, C.C., Sherrod, D.R., Kauahikaua, J.P., Miklius, Asta, Okubo, P.G., Trusdell, F.A., Budahn, J.R., Ridley, W.I., and Meeker, G.P., in press, Kilauea east rift zone magmatism: an episode 54 perspective: Journal of Petrology.

Thornber, C.R., Mattox, T.N., Sutton, A.J., Elias, Tamar, Okubo, P.G., Tomori, A.H., and Denlinger, R.P., 1995, The eruptive pulse of Kilauea Volcano as revealed by continuous temperature monitoring of an active lava tube [abs.]: (American Geophysical Union Transactions), v. 76, no. 46, supp., p. F681.

Tilling, R.I., Christiansen, R.L., Duffield, W.A., Endo, E.T., Holcomb, R.T., Koyanagi, R.Y., Peterson, D.W., and Unger, J.D., 1987, The 1972–1974 Mauna Ulu eruption, Kilauea Volcano; an example of quasi-steady-state magma transfer, chap. 16 *of* Decker, R.W., Wright, T.L., and Stauffer, P.H., eds., Volcanism in Hawaii: U.S. Geological Survey Professional Paper 1350, v. 1, p. 405–469.

Wolfe, E.W., Neal, C.A., Banks, N.G., and Duggan, T.J., 1988, Geologic observations and chronology of eruptive events, chap. 1 *of* Wolfe, E.W., ed., The Puu Oo eruption of Kilauea Volcano, Hawaii; episodes 1 through 20, January 3, 1983, through June 8, 1984: U.S. Geological Survey Professional Paper 1463, p. 1–97.

Wright, T.L. and Takahashi, T.J., 1998, Hawaii bibliographic database: Bulletin of Volcanology, v. 59, no. 4, p. 276–280.

Selected Bibliography

LETTER CODES FOR KEY WORDS

D Deformation	**Gp** Geophysics	**M** Maps	**S** Seismology
E Eruption chronology	**H** Hazards	**P** Petrology/mineralogy	**V** Physical volcanology
G Gas and water geochemistry	**I** Instrumentation	**R** Remote sensing	

V Anderson, S.W., Stofan, E.R., Smrekar, S.E., Guest, J.E., and Wood, B.J, 1999, Pulsed inflation of pahoehoe lava flows; implications for flood basalt emplacement: Earth and Planetary Science Letters, v. 168, no. 1–2, p. 7–18.

V Anderson, S.W., Stofan, E.R., Smrekar, S.E., Guest, J.E., and Wood, B.J, 2000, Reply to Self et al discussion of “Pulsed inflation of pahoehoe lava flows; implications for flood basalt emplacement”: Earth and Planetary Science Letters, v. 179, no. 2, p. 425–428.

G Andres, R.J., Kyle, P.R., Stokes, J.B., and Rose, W.I., 1989, SO_2 from episode 48A eruption, Hawaii; sulfur dioxide emissions from the episode 48A east rift zone eruption of Kilauea volcano, Hawaii: Bulletin of Volcanology, v. 52, no. 2, p. 113–117.

V, R Baloga, S.M., Glaze, L.S., Crisp, J.A., and Stockman, S.A., 1998, New statistics for estimating the bulk rheology of active lava flows; Puu Oo examples: Journal of Geophysical Research, v. 103, no. B3, p. 5133–5142.

Gp Bartel, L.C., Hardee, H.C., and Jacobson, R.D., 1983, An electrical resistivity measurement in molten basalt during the 1983 Kilauea eruption: Bulletin Volcanologique, v. 46, no. 3, p. 271–276.

P Burkhard, D.J.M, 1997, Redox state and crystallizations of recent basalt lava from the East Rift, Kilauea, Hawaii [abs.]: Eos (American Geophysical Union Transactions), v. 78, no. 46, supp., p. F648.

P Burkhard, D.J.M., 2000, Kinetics of crystallization; example of micro-crystallization in basalt lava [abs.]: Eos (American Geophysical Union Transactions), v. 81, no. 46, p. F1291.

S Caplan-Auerbach, Jacqueline, and Duennebier, F.K., 2001, Seismic and acoustic signals detected at Lo‘ihi Seamount by the Hawai‘i Undersea Geo-Observatory: G^3 (Geochemistry, Geophysics, Geosystems), v. 2, paper 2000GC000113.

S Caplan-Auerbach, Jacqueline, Fox, C.G., and Duennebier, F.K., 2001, Hydroacoustic detection of submarine landslides on Kilauea volcano: Geophysical Research Letters, v. 28, no. 9, p. 1811–1813.

P, V Cashman, K.V., and Kauahikaua, J.P., 1997, Reevaluation of vesicle distributions in basaltic lava flows: Geology, v. 25, no. 5, p. 419–422.

P, V Cashman, K.V., and Mangan, M.T., 1994, Physical aspects of magmatic degassing, II. Constraints on vesiculation processes from textural studies of eruptive products, chap. 11b *of* Carroll, M.R., and Holloway, J.R., eds., Volatiles in magmas: Reviews in Mineralogy, v. 30, p. 447–478.

P, V Cashman, K.V., Mangan, M.T., and Newman, Sally, 1994, Surface degassing and modifications to vesicle size distributions in active basalt flows: Journal of Volcanology and Geothermal Research, v. 61, no. 1–4, p. 45–68.

P, V Cashman, K.V., Thornber, C.R., and Kauahikaua, J.P., 1999, Cooling and crystallization of lava in open channels, and the transition of pāhoehoe lava to ‘a‘ā: Bulletin of Volcanology, v. 61, no. 5, p. 306–323.

D, S Cayol, Valérie, Dieterich, J.H., Okamura, A.T., and Miklius, Asta, 2000, High magma storage rates before the 1983 eruption of Kilauea, Hawaii: Science, v. 288, no. 5475, p. 2343–2346.

D Cervelli, P.F., Segall, Paul, Amelung, Falk, Garbeil, Harold, Meertens, C.M., Owen, S.E., Miklius, Asta, and Lisowski, Michael, 2002, The 12 September 1999 Upper East Rift Zone dike intrusion at Kilauea Volcano, Hawaii: Journal of Geophysical Research, v. 107, no. B7, p. ECV 3–1 – ECV 3–13.

G Chartier, T.A., Rose, W.I., and Stokes, J.B., 1988, Detailed record of SO_2 emissions from Pu‘u ‘O‘o between episodes 33 and 34 of the 1983–86 ERZ eruption, Kilauea, Hawaii: Bulletin of Volcanology, v. 50, no. 4, p. 215–228.

S, D Chouet, B.A., and Dawson, P.B., 1997, Observations of very-long-period impulsive signals accompanying summit inflation at Kilauea Volcano, Hawaii, in February 1997 [abs.]: Eos (American Geophysical Union Transactions), v. 78, no. 46, supp., F429–430.

S, D Chouet, B.A., Dawson, P.B., Ohminato, Takao, and Okubo, P.G., 1997, Broadband measurements of magmatic injection beneath Kilauea Volcano, Hawaii [abs.]: Seismological Research Letters, v. 68, no. 2, p. 317.

S, G Chouet, B.A., and Shaw, H.R., 1991, Fractal properties of tremor and gas piston events observed at Kilauea Volcano, Hawaii: Journal of Geophysical Research, v. 96, no. B6, p. 10177–10189.

V Coltelli, Mauro, Heliker, C.C., Okamura, A.T., and Ulrich, G.E., 1991, Lava lakes in the effusive phase of Kilauea’s current eruption [abs.]: Eos (American Geophysical Union Transactions), v. 72, no. 44, supp., p. 565.

R, V Crisp, J.A., and Baloga, S.M., 1991, Thermal processes in lava flows: Lunar and Planetary Science Conference Abstracts of Papers, v. 22, p. 257–258.

V Crisp, J.A., Sakimoto, S.E.H., and Baloga, S.M., 1995, Lava tube pressure & gravity driving forces; constraints on tube lengths, flow rates & surface breakout locations [abs.]: Eos (American Geophysical Union Transactions), v. 76, no. 46, supp., p. F667.

G Crowe, B.M., Finnegan, D.L., Zoller, W.H., and Boynton, W.V., 1987, Trace element geochemistry of volcanic gases and particles from 1983–1984 eruptive episodes of

Kilauea volcano: Journal of Geophysical Research, v. 92, no. B13, p. 13708–13714.

D Delaney, P.T., and Denlinger, R.P., 1999, Stabilization of volcanic flanks by dike intrusion; an example from Kilauea: Bulletin of Volcanology, v. 61, no. 6, p. 356–362.

D Delaney, P.T., Miklius, Asta, Árnadóttir, Thóra, Okamura, A.T., and Sako, M.K., 1993, Motion of Kilauea Volcano during sustained eruption from the Puu Oo and Kupaianaha vents, 1983–1991: Journal of Geophysical Research, v. 98, no. B10, p. 17801–17820.

D Denlinger, R.P., 1997, A dynamical balance between magma supply and eruption rate at Kilauea volcano, Hawaii: Journal of Geophysical Research, v. 102, no. B8, p. 18091–18100.

S Dietel, C.M., Chouet, B.A., Aki, Keiiti, Ferrazzini, Valérie, Roberts, P.M., and Koyanagi, R.Y., 1989, Data summary for dense GEOS array observations of seismic activity associated with magma transport at Kilauea Volcano, Hawaii: U.S. Geological Survey Open–File Report 89–113, 171 p.

D, S Dieterich, J.H., Cayol, Valérie, and Okubo, P.G., 2000, The use of earthquake rate changes as a stress meter at Kilauea volcano: Nature, v. 408, no. 6811, p. 457–460.

D, S Dvorak, J.J., 1994, An earthquake cycle along the south flank of Kilauea Volcano, Hawaii: Journal of Geophysical Research, v. 99, no. B5, p. 9533–9541.

V, D Dvorak, J.J., and Dzurisin, Daniel, 1993, Variations in magma supply rate at Kilauea Volcano, Hawaii: Journal of Geophysical Research, v. 98, no. B12, p. 22255–22268.

D, S Dvorak, J.J., and Okamura, A.T., 1985, Variations in tilt rate and harmonic tremor amplitude during the January–August 1983 east rift eruptions of Kilauea Volcano, Hawaii: Journal of Volcanology and Geothermal Research, v. 25, no. 3–4, p. 249–258.

D, S Dvorak, J.J., Okamura, A.T., English, T.T., Koyanagi, R.Y., Nakata, J.S., Sako, M.K., Tanigawa, W.R., and Yamashita, K.M., 1986, Mechanical response of the south flank of Kilauea volcano, Hawaii, to intrusive events along the rift systems: Tectonophysics, v. 124, no. 3–4, p. 193–209.

G Elias, Tamar, and Sutton, A.J., 2002, Volcanic air pollution in our backyard; gas advisory system helps alert people of Hawai‘i [abs.]: Geological Society of America Abstracts with Programs, v. 34, no. 5, p. A–11.

G Elias, Tamar, and Sutton, A.J., 2002, Sulfur dioxide emission rates from Kilauea Volcano, Hawaii, an update; 1998–2001: U.S. Geological Survey Open-File Report 02–460, 10 p., figs. 23 p.

G Elias, Tamar, Sutton, A.J., Stokes, J.B., and Casadevall, T.J., 1998, Sulfur dioxide emission rates of Kilauea Volcano, Hawaii, 1979–1997: U.S. Geological Survey Open-File Report 98–462, 40 p.

S, G Ferrazzini, Valérie, Aki, Keiiti, and Chouet, B.A., 1991, Characteristics of seismic waves composing Hawaiian volcanic tremor and gas-piston events observed by a near-source array: Journal of Geophysical Research, v. 96, no. B4, p. 6199–6209.

V Fink, J.H., and Zimbelman, J.R., 1986, Rheology of the 1983 Royal Gardens basalt flows, Kilauea Volcano, Hawaii: Bulletin of Volcanology, v. 48, no. 2–3, p. 87–96.

G Finnegan, D.L., Miller, T.L., and Zoller, W.H., 1990, Iridium and other trace-metal enrichments from Hawaiian volcanoes, *in* Sharpton, V.L., and Ward, P.D., eds., Global catastrophes in Earth history: Geological Society of America Special Paper 247, p. 111–116.

R Flynn, L.P., and Mouginis-Mark, P.J., 1992, Cooling rate of an active Hawaiian lava flow from nighttime spectroradiometer measurements: Geophysical Research Letters, v. 19, no. 17, p. 1783–1786.

R Flynn, L.P., and Mouginis-Mark, P.J., 1994, Temperature of an active lava channel from spectral measurements, Kilauea Volcano, Hawaii: Bulletin of Volcanology, v. 56, no. 4, p. 297–301.

R Flynn, L.P., Mouginis-Mark, P.J., Gradie, J.C., and Lucey, P.G., 1993, Radiative temperature measurements at Kupaianaha lava lake, Kilauea Volcano, Hawaii: Journal of Geophysical Research, v. 98, no. B4, p. 6461–6476.

R Flynn, L.P., Mouginis-Mark, P.J., and Horton, K.A., 1994, Distribution of thermal areas on an active lava flow field; Landsat observations of Kilauea, Hawaii, July 1991: Bulletin of Volcanology, v. 56, no. 4, p. 284–296.

P, V Folley, M.J., 1999, Crystallinity, rheology, and surface morphology of basaltic lavas, Kilauea Volcano, Hawaiʻi: Eugene, University of Oregon, M.S. thesis, 205 p.

P, V Friedman, R.C., Taylor, G.J., Keszthelyi, L.P., and Thornber, C.R., 1996, Petrographic textures as indicators of Kilauea lava flow emplacement history [abs.]: Eos (American Geophysical Union Transactions), v. 77, no. 46, supp., p. F807.

V Gaonac’h, Helene, Lovejoy, Shaun, and Stix, John, 1992, Scale invariance of basaltic lava flows and their fractal dimensions: Geophysical Research Letters, v. 19, no. 8, p. 785–788.

P Garcia, M.O., Ho, R.A., Rhodes, J.M., and Wolfe, E.W., 1989, Petrologic constraints on rift-zone processes: Bulletin of Volcanology, v. 52, no. 2, p. 81–96.

P Garcia, M.O., Ito, Emi, Eiler, J.M., and Pietruszka, A.J., 1998, Crustal contamination of Kilauea Volcano magmas revealed by oxygen isotope analyses of glass and olivine from Puu Oo eruption lavas: Journal of Petrology, v. 39, no. 5, p. 803–817.

P Garcia, M.O., Pietruszka, A.J., Rhodes, J.M., and Swanson, K.A., 2000, Magmatic processes during the prolonged Puʻu ʻOʻo eruption of Kilauea Volcano, Hawaii: Journal of Petrology, v. 41, no. 7, p. 967–990.

P Garcia, M.O., Rhodes, J.M., Trusdell, F.A., and Pietruszka, A.J., 1996, Petrology of lavas from the Puu Oo eruption of Kilauea Volcano; III. The Kupaianaha episode (1986–1992): Bulletin of Volcanology, v. 58, no. 5, p. 359–379.

P Garcia, M.O., and Wolfe, E.W., 1988, Petrology of the erupted lava, chap. 3 *of* Wolfe, E.W., ed., The Puu Oo eruption of Kilauea Volcano, Hawaii; episodes 1 through 20, January 3, 1983, through June 8, 1984: U.S. Geological Survey Professional Paper 1463, p. 127–143.

P Garcia, M.O., Wolfe, E.W., Ulrich, G.E., and Ho, R.A., 1992, Petrology of lavas from episodes 2–47 of the Puu Oo eruption of Kilauea Volcano, Hawaii; evaluation of magmatic processes: Bulletin of Volcanology, v. 55, no. 1, p. 1–16.

G Gerlach, T.M., 1986, Exsolution of H_2O, CO_2, and S during eruptive episodes at Kilauea volcano, Hawaii: Journal of Geophysical Research, v. 91, no. B12, p. 12177–12185.

G Gerlach, T.M., 1993, Oxygen buffering of Kilauea volcanic gases and the oxygen fugacity of Kilauea basalt: Geochimica et Cosmochimica Acta, v. 57, no. 4, p. 795–814.

G Gerlach, T.M., 1993, Thermodynamic evaluation and restoration of volcanic gas analyses; an example based on modern collection and analytical methods: Geochemical Journal, v. 27, no. 4–5, p. 305–322.

G Gerlach, T.M., and Graeber, E.J., 1985, Volatile budget of Kilauea volcano: Nature, v. 313, no. 6000, p. 273–277.

G, H Gerlach, T.M., Krumhansl, J.L., Fournier, R.O., and Kjargaard, J.I., 1989, Acid rain from the heating and evaporation of seawater by molten lava; a new volcanic hazard [abs.]: Eos (American Geophysical Union Transactions), v. 70, no. 43, supp., p. 1421.

G Gerlach, T.M., McGee, K.A., Sutton, A.J., and Elias, Tamar, 1998, Rates of volcanic CO_2 degassing from airborne determinations of SO_2 emission rates and plume CO_2/SO_2; test study at Puʻu ʻOʻo cone, Kilauea volcano, Hawaii: Geophysical Research Letters, v. 25, no. 14, p. 2675–2678.

G Gerlach, T.M., and Taylor, B.E., 1990, Carbon isotope constraints on degassing of carbon dioxide from Kilauea Volcano: Geochimica et Cosmochimica Acta, v. 54, no. 7, p. 2051–2058.

G Gill, J.B., Williams, R.W., and Bruland, K.W., 1985, Eruption of basalt and andesite lava degasses $^{(222)}$Rn and $^{(210)}$Po: Geophysical Research Letters, v. 12, no. 1, p. 17–20.

S Gillard, Dominique, Rubin, A.M., and Okubo, P.G., 1996, Highly concentrated seismicity caused by deformation of Kilauea's deep magma system: Nature, v. 384, no. 6607, p. 343–346.

S Gillard, Dominique, Wyss, Max, and Okubo, P.G., 1996, Type of faulting and orientation of stress and strain as a function of space and time in Kilauea's south flank, Hawaii: Journal of Geophysical Research, v. 101, no. B7, p. 16025–16042.

S Goldstein, Peter, and Chouet, B.A., 1994, Array measurements and modeling of sources of shallow volcanic tremor at Kilauea Volcano, Hawaii: Journal of Geophysical Research, v. 99, no. B2, p. 2637–2652.

R Gradie, J.C., Mouginis-Mark, P.J., Hayashi, J.N., and Flynn, L.P., 1988, Surface temperature and variability of an active lava lake; lessons to be applied to Io [abs.]: Lunar and Planetary Science Conference Abstracts of Papers, v. 19, no. 1, p. 407–408.

G Greenland, L.P., 1984, Gas composition of the January 1983 eruption of Kilauea Volcano, Hawaii: Geochimica et Cosmochimica Acta, v. 48, no. 1, p. 193–195.

G Greenland, L.P., 1986, Gas analyses from the Puʻu Oʻo eruption in 1985, Kilauea volcano, Hawaii: Bulletin of Volcanology, v. 48, no. 6, p. 341–348.

G Greenland, L.P., 1988, Gases from the 1983–84 east-rift eruption, chap. 4 *of* Wolfe, E.W., ed., The Puu Oo eruption of Kilauea Volcano, Hawaii; episodes 1 through 20, January 3, 1983, through June 8, 1984: U.S. Geological Survey Professional Paper 1463, p. 145–153.

G Greenland, L.P., and Aruscavage, P.J., 1986, Volcanic emission of Se, Te, and As from Kilauea volcano, Hawaii: Journal of Volcanology and Geothermal Research, v. 27, no. 1–2, p. 195–201.

G, D Greenland, L.P., Okamura, A.T., and Stokes, J.B., 1988, Constraints on the mechanics of the eruption, chap. 5 *of* Wolfe, E.W., ed., The Puu Oo eruption of Kilauea Volcano, Hawaii; episodes 1 through 20, January 3, 1983, through June 8, 1984: U.S. Geological Survey Professional Paper 1463, p. 155–164.

D Hall Wallace, M.K., and Delaney, P.T., 1995, Deformation of Kilauea volcano during 1982 and 1983; a transition period: Journal of Geophysical Research, v. 100, no. B5, p. 8201–8219.

P Halleran, A.D., and Russell, J.K., 1990, Trace elements formulated as Pearce element ratios II; recognition of open system behaviour, chap. 12 *of* Russell, J.K., and Stanley, C.R., eds., Theory and application of Pearce element ratios to geochemical data analysis: Geological Association of Canada Short Course Notes, v. 8, p. 243–269.

R, V Hanley, D.J., and Zimbelman, J.R., 1998, Topographic control of lava flow morphology; putting a number to it [abs.]: Lunar and Planetary Science Conference Abstracts of Papers, v. 29, abstract 1749, n.p.

V Hardee, H.C., 1983, Heat transfer measurements in the 1983 Kilauea lava flow: Science, v. 222, no. 4619, p. 47–48.

R Harris, A.J.L., Flynn, L.P., Keszthelyi, L.P., Mouginis-Mark, P.J., Rowland, S.K., and Resing, J.A., 1998, Calculation of lava effusion rates from Landsat TM data: Bulletin of Volcanology, v. 60, no. 1, p. 52–71.

R Harris, A.J.L., Flynn, L.P., Rothery, D.A., Oppenheimer, Clive, and Sherman, S.B., 1999, Mass flux measurements at active lava lakes; implications for magma recycling: Journal of Geophysical Research, v. 104, no. B4, p. 7117–7136.

R, E Harris, A.J.L., Keszthelyi, L.P., Flynn, L.P., Mouginis-Mark, P.J., Thornber, C.R., Kauahikaua, J.P., Sherrod, D.R., and Trusdell, F.A., 1997, Chronology of the episode 54 eruption at Kilauea Volcano, Hawaii, from GOES-9 satellite data: Geophysical Research Letters, v. 24, no. 24, p. 3281–3284.

V Harris, A.J.L., and Rowland, S.K., 2001, FLOWGO; a kinematic thermo-rheological model for lava flowing in a channel: Bulletin of Volcanology, v. 63, no. 1, p. 20–44.

R Harris, A.J.L., and Thornber, C.R., 1999, Complex effusive events at Kīlauea as documented by the GOES satellite and remote video cameras: Bulletin of Volcanology, v. 61, no. 6, p. 382–395.

V Head, J.W., III, and Wilson, Lionel, 1987, Lava fountain heights at Puʻu ʻOʻo, Kilauea, Hawaii; indicators of amount and variations of exsolved magma volatiles: Journal of Geophysical Research, v. 92, no. B13, p. 13715–13719.

V Head, J.W., III, and Wilson, Lionel, 1987, Magma migration and Hawaiian-style eruptions in shield volcano rift zones;

the Puʻu ʻOʻo eruptive episodes, Kilauea East Rift, Hawaii [abs.]: Lunar and Planetary Science Conference Abstracts of Papers, v. 18, no. 2, p. 411–412.

V Head, J.W., III, and Wilson, Lionel, 1988, Lateral migration and eruption of magma in volcanic edifice rift zones; the Puʻu ʻOʻo eruptions of the east rift zone of Kilauea Volcano, Hawaii [abs.]: Lunar and Planetary Science Conference Abstracts of Papers, v. 19, no. 2, p. 471–472.

H Heliker, C.C., and Decker, R.W., in press, The Hawaiʻi Island eruptions of Kīlauea, 1983 to 2001, and Mauna Loa, 1984; living with lava, *in* Guffanti, M.C., Miller, C.D., and Ewert, J.W., eds., Responding to volcanic eruptions and unrest—1980–2000; two decades of scientific experience in applied volcanology: U.S. Geological Survey Circular 1250.

E, V Heliker, C.C., Hoffmann, J.P., Rowland, S.K., Greenland, L.P., Reason, M.D., and Wright, T.L., 1985, Fissure activity near Puʻu Oʻo, Kilauea Volcano, HI [abs.]: Eos (American Geophysical Union Transactions), v. 66, no. 46, p. 851.

M Heliker, C.C., Mangan, M.T., Mattox, T.N., and Kauahikaua, J.P., 1998, The Puʻu ʻŌʻō-Kūpaianaha eruption of Kīlauea, November 1991–February 1994; field data and flow maps: U.S. Geological Survey Open-File Report 98–103, 10 p., 2 sheets, scale 1:50,000.

V, E Heliker, C.C., Mangan, M.T., Mattox, T.N., Kauahikaua, J.P., and Helz, R.T., 1998, The character of long-term eruptions; inferences from episodes 50–53 of the Puʻu ʻŌʻō-Kūpaianaha eruption of Kīlauea Volcano: Bulletin of Volcanology, v. 59, no. 6, p. 381–393.

M Heliker, C.C., Ulrich, G.E., Margriter, S.C., and Hoffmann, J.P., 2001, Maps showing the development of the Puʻu ʻŌʻō-Kūpaianaha flow field, June 1984–February 1987, Kīlauea Volcano, Hawaii: U.S. Geological Survey Miscellaneous Investigations Series Map I–2685, 4 sheets, scale 1:50,000.

E Heliker, C.C., and Wright, T.L., 1991, The Puʻu ʻOʻo-Kupaianaha eruption of Kilauea: Eos (American Geophysical Union Transactions), v. 72, no. 47, p. 521, 526, 530.

P Helz, R.T., Banks, N.G., Heliker, C.C., Neal, C.A., and Wolfe, E.W., 1995, Comparative geothermometry of recent Hawaiian eruptions: Journal of Geophysical Research, v. 100, no. B9, p. 17637–17657.

P Helz, R.T., and Hearn, B.C., Jr., 1998, Compositions of glasses from the Puʻu Oʻo-Kupaianaha eruption of Kilauea Volcano, Hawaii, January 1983 through December 1994: U.S. Geological Survey Open-File Report 98–511, 75 p.

G Hildebrand, A.R., Boynton, W.V., and Zoller, W.H., 1984, Rhenium enriched Kilauea volcano aerosols; evidence for a volcanogenic component in the K/T boundary clay layer [abs.]: Bulletin of the American Astronomical Society, v. 16, no. 3 (pt. 1), p. 679.

G Hilton, D.R., McMurtry, G.M., and Kreulen, Rob, 1996, Helium-carbon relations of Kilauea volcano, Hawaii (USA); implications for magmatic degassing processes and the nature of the Hawaiian hotspot [abs.]: Eos (American Geophysical Union Transactions), v. 77, no. 46, supp., p. F807.

G Hinkley, T.K., 1991, Distribution of metals between particulate and gaseous forms in a volcanic plume: Bulletin of Volcanology, v. 53, no. 5, p. 395–400.

G Hinkley, T.K., Le Cloarec, M.-F., and Lambert, Gerard, 1994, Fractionation of families of major, minor, and trace metals across the melt-vapor interface in volcanic exhalations: Geochimica et Cosmochimica Acta, v. 58, no. 15, p. 3255–3263.

G Hinkley, T.K, Wilson, S.A., Lamothe, P.J., Landis, G.P., Finnegan, D.L., Gerlach, T.M., and Thornber, C.R., 1997, Metal emissions from Kilauea—proportions, source strength, and contribution to current estimates of volcanic injection to the atmosphere [abs.]: Eos (American Geophysical Union Transactions), v. 78, no. 46, supp., p. F803.

D Hoffmann, J.P., Ulrich, G.E., and Garcia, M.O., 1990, Horizontal ground deformation patterns and magma storage during the Puu Oo eruption of Kilauea volcano, Hawaii; episodes 22–42: Bulletin of Volcanology, v. 52, no. 6, p. 522–531.

S Ho-Liu, Phyllis, Johnson, C.E., Mantagner, J.-P., Kanamori, Hiroo, and Clayton, R.W., 1988, Three-dimensional attenuation structure of Kilauea east rift zone, Hawaii [abs.]: Seismological Research Letters, v. 59, no. 1, p. 30.

V Hon, K.A., Heliker, C.C., and Kjargaard, J.I., 1988, Limu o Pele; a new kind of hydroclastic tephra from Kilauea Volcano, Hawaii [abs.]: Geological Society of America Abstracts with Programs, v. 20, no. 7, p. A112–A113.

V Hon, K.A., Kauahikaua, J.P., Denlinger, R.P., and Mackay, Kevin, 1994, Emplacement and inflation of pahoehoe sheet flows; observations and measurements of active lava flows on Kilauea Volcano, Hawaii: Geological Society of America Bulletin, v. 106, no. 3, p. 351–370.

V Hon, K.A., Kauahikaua, J.P., and Mackay, Kevin, 1993, Inflation and cooling data from pahoehoe sheet flows on Kilauea volcano: U.S. Geological Survey Open-File Report 93–342–A, 27 p.

V Hon, K.A., Mattox, T.N., Kauahikaua, J.P., and Kjargaard, J.I., 1993, The construction of pahoehoe lava deltas on Kilauea volcano, Hawaii [abs.]: Eos (American Geophysical Union Transactions), v. 74, no. 43, supp., p. 616.

R Horton, K.A., 1995, Airborne and satellite infrared imaging spectroscopy of active volcanism at Kilauea volcano, Hawaii: Honolulu, University of Hawaii, Ph.D. dissertation, 343 p.

S, V Ida, Yoshiaki, 1996, Cyclic fluid effusion accompanied by pressure change; implication for volcanic eruptions and tremor: Geophysical Research Letters, v. 23, no. 12, p. 1457–1460.

Gp Jackson, D.B., 1988, Geoelectric observations (including the September 1982 summit eruption), chap. 8 *of* Wolfe, E.W., ed., The Puu Oo eruption of Kilauea Volcano, Hawaii; episodes 1 through 20, January 3, 1983, through June 8, 1984: U.S. Geological Survey Professional Paper 1463, p. 237–251.

D Johnson, D.J., 1992, Dynamics of magma storage in the summit reservoir of Kilauea Volcano, Hawaii: Journal of Geophysical Research, v. 97, no. B2, p. 1807–1820.

V Jones, A.C., 1993, The cooling rates of pahoehoe flows; the importance of lava porosity [abs.]: Lunar and Planetary Science Conference Abstracts of Papers, v. 24, p. 731–732.

R, V Jones, A.C., 1994, Remote sensing and thermal modelling of active lava flows, Kilauea Volcano, Hawai'i: Lancaster, U.K., Lancaster University, Ph.D. dissertation, 288 p.

V, Gp Kauahikaua, J.P., Cashman, K.V., Mattox, T.N., Heliker, C.C., Hon, K.A., Mangan, M.T., and Thornber, C.R., 1998, Observations on basaltic lava streams in tubes from Kilauea Volcano, island of Hawai‘i: Journal of Geophysical Research, v. 103, no. B11, p. 27303–27323.

V, Gp Kauahikaua, J.P., Mangan, M.T., Heliker, C.C., and Mattox, T.N., 1996, A quantitative look at the demise of a basaltic vent; the death of Kupaianaha, Kilauea Volcano, Hawai‘i: Bulletin of Volcanology, v. 57, no. 8, p. 641–648.

D, S Kedar, Sharon, Chouet, B.A., and Dawson, P.B., 1997, Broadband analysis of the February 1996 inflation episode of Kilauea caldera, Hawaii [abs.]: Eos (American Geophysical Union Transactions), v. 78, no. 46, p. F442.

V Kelly, K.M., Hon, K.A., and Tribble, G.W., 1989, Bathymetric and submarine studies of an active lava delta near Kupapau Point, Kilauea volcano, Hawaii [abs.]: Eos (American Geophysical Union Transactions), v. 70, no. 43, p. 1202.

V Kent, R.M., and Pinkerton, Harry, 1994, Modelling the flow and heat transfer of magma in dikes using computational fluid dynamics [abs.]: Lunar and Planetary Science Conference Abstracts of Papers, v. 25, no. 2, p. 693–694.

V Kerr, R.C., 2001, Thermal erosion by laminar lava flows: Journal of Geophysical Research, v. 106, no. B11, p. 26453–26465.

V Keszthelyi, L.P., 1994, Calculated effect of vesicles on the thermal properties of cooling basaltic lava flows: Journal of Volcanology and Geothermal Research, v. 63, no. 3–4, p. 257–266.

V Keszthelyi, L.P., 1995, A preliminary thermal budget for lava tubes on the Earth and planets: Journal of Geophysical Research, v. 100, no. B10, p. 20411–20420.

V Keszthelyi, L.P., 1995, Measurements of the cooling at the base of pahoehoe flows: Geophysical Research Letters, v. 22, no. 16, p. 2195–2198.

V Keszthelyi, L.P., and Denlinger, R.P., 1996, The initial cooling of pahoehoe flow lobes: Bulletin of Volcanology, v. 58, no. 1, p. 5–18.

P Kilinc, A.I., and Lammert, Penny, 1992, Oxidation state of the episode 5 basalt flow, Kilauea, HI [abs.]: Geological Society of America Abstracts with Programs, v. 24, no. 7, p. 262.

S Koyanagi, R.Y., and Nakata, J.S., 1990, Seismicity related to eruption at Kilauea Volcano, Hawaii, 1983–1989 [abs.]: Eos (American Geophysical Union Transactions), v. 71, no. 28, p. 955.

S Koyanagi, R.Y., Tanigawa, W.R., and Nakata, J.S., 1988, Seismicity associated with the eruption, chap. 7 *of* Wolfe, E.W., ed., The Puu Oo eruption of Kilauea Volcano, Hawaii; episodes 1 through 20, January 3, 1983, through June 8, 1984: U.S. Geological Survey Professional Paper 1463, p. 183–235.

D Lisowski, Michael, Miklius, Asta, Sako, M.K., Owen, S.E., and Cervelli, P.F., 1999, Temporal changes in deformation of Kilauea Volcano, Hawaii [abs.]: Eos (American Geophysical Union Transactions), v. 80, no. 46, supp., p. F958.

D Lisowski, Michael, Owen, S.E., and Segall, Paul, 1996, The Kilauea Volcano, Hawaii, continuous GPS network; recent results [abs.]: Eos (American Geophysical Union Transactions), v. 77, no. 46, supp., p. F808.

P Lowther, J.S., and Brunstad, K.A., 1998, Microtextures and microanalysis of olivine in the 1992 Kalapana, Hawaii, lava flow [abs.]: Geological Society of America Abstracts with Programs, v. 30, no. 7, p. 376.

P, V Mangan, M.T., and Cashman, K.V., 1996, The structure of basaltic scoria and reticulite and inferences for vesiculation, foam formation, and fragmentation in lava fountains: Journal of Volcanology and Geothermal Research, v. 73, no. 1, p. 1–18.

P, V Mangan, M.T., Cashman, K.V., and Newman, Sally, 1993, Vesiculation of basaltic magma during eruption: Geology, v. 21, no. 2, p. 157–160.

E, V Mangan, M.T., Heliker, C.C., Mattox, T.N., Kauahikaua, J.P., and Helz, R.T., 1995, Episode 49 of the Pu‘u ‘O‘o-Kupaianaha eruption of Kilauea volcano—breakdown of a steady-state eruptive era: Bulletin of Volcanology, v. 57, no. 2, p. 127–135.

P Mangan, M.T., Heliker, C.C., Mattox, T.N., Kauahikaua, J.P., Helz, R.T., and Hearn, B.C., Jr., 1995, The Pu‘u ‘O‘o-Kupaianaha eruption of Kilauea Volcano; June 1990 through August 1994 lava sample archive: U.S. Geological Survey Open-File Report 95–496, n.p.

E Mattox, T.N., Heliker, C.C., Hoffmann, J.P., Hon, K.A., Mangan, M.T., Neal, C.A., Ulrich, G.E., and Wolfe, E.W., 1994, Timelapse film logs from the Pu‘u ‘O‘o-Kupaianaha eruption of Kilauea Volcano; January 1983 through September 1994: U.S. Geological Survey Open-File Report 94–713, 237 p.

V Mattox, T.N., Heliker, C.C., Kauahikaua, J.P., and Hon, K.A., 1993, Development of the 1990 Kalapana flow field, Kilauea Volcano, Hawaii: Bulletin of Volcanology, v. 55, no. 6, p. 407–413.

V Mattox, T.N., and Mangan, M.T., 1997, Littoral hydrovolcanic explosions; a case study of lava-seawater interaction at Kilauea Volcano: Journal of Volcanology and Geothermal Research, v. 75, no. 1–2, p. 1–17.

R McGee, K.A., and Gerlach, T.M., 1998, Airborne volcanic plume measurements using a FTIR spectrometer, Kilauea volcano, Hawaii: Geophysical Research Letters, v. 25, no. 5, p. 615–618.

G McMurtry, G.M., and Goff, Fraser, 1992, Anomalous deuterium and tritium in magmatic water from Kilauea and Mount St. Helens; implications for deep Earth processes [abs.]: Eos (American Geophysical Union Transactions), v. 73, no. 14, p. 348.

P Meeker, G.P., and Hinkley, T.K., 1993, The structure and composition of microspheres from the Kilauea volcano, Hawaii: American Mineralogist, v. 78, no. 7–8, p. 873–876.

P Meeker, G.P., and Thornber, C.R., 2000, A three dimensional view of basalt crystallization in “lava straws” from Kilauea [abs.], *in* Williams, D.B., and Shimizu, Ryuichi, eds., Microbeam analysis 2000; International Union of Microbeam Analysis Societies Conference, 2d, Proceedings: London, Institute of Physics Publishing, Symposium 9, ser. no. 165, p. 297–298.

P Meeker, G.P., Thornber, C.R., and Hinkley, T.K., 2000, Natural “fly ash” from Kilauea volcano, Hawaii [abs.], *in* Williams, D.B., and Shimizu, Ryuichi, eds., Microbeam analysis 2000; International Union of Microbeam Analysis Societies Conference, 2d, Proceedings: London, Institute of Physics Publishing, Symposium 9, ser. no. 165, p. 309–310.

G Miller, T.L., Zoller, W.H., Crowe, B.M., and Finnegan, D.L., 1990, Variations in trace metal and halogen ratios in magmatic gases through an eruptive cycle of the Puʻu Oʻo vent, Kilauea, Hawaii; July–August 1985: Journal of Geophysical Research, v. 95, no. B8, p. 12607–12615.

R Mouginis-Mark, P.J., Rowland, S.K., Garbeil, Harold, and Flament, Pierre, 1991, AVHRR observations of the Kupaianaha eruption, Hawaii [abs.]: Eos (American Geophysical Union Transactions), v. 72, no. 44, supp., p. 562.

S, E Nakata, J.S., and others, 1986–2001, Hawaiian Volcano Observatory summaries, part I, seismic data (annually), 1986–2001: U.S. Geological Survey Open-File Reports 92–301, 92–333, 94–169, 91–564, 91–578, 94–432, 98–147, 99–415, 00–326, 00–353, 00–354, 00–408, 00–406, 00–433, 01–332, 02–157.

P Neal, C.A., Duggan, T.J., Wolfe, E.W., and Brandt, E.L., 1988, Lava samples, temperatures, and compositions, chap. 2 *of* Wolfe, E.W., ed., The Puu Oo eruption of Kilauea Volcano, Hawaii; episodes 1 through 20, January 3, 1983, through June 8, 1984: U.S. Geological Survey Professional Paper 1463, p. 99–126.

S Ohminato, Takao, Chouet, B.A., Dawson, P.B., and Kedar, Sharon, 1998, Waveform inversion of very long period impulsive signals associated with magmatic injection beneath Kilauea Volcano, Hawaii: Journal of Geophysical Research, v. 103, no. B10, p. 23839–23862.

D Okamura, A.T., Dvorak, J.J., Koyanagi, R.Y., and Tanigawa, W.R., 1988, Surface deformation during dike propagation, chap. 6 *of* Wolfe, E.W., ed., The Puu Oo eruption of Kilauea Volcano, Hawaii; episodes 1 through 20, January 3, 1983, through June 8, 1984: U.S. Geological Survey Professional Paper 1463, p. 165–182.

D Okamura, A.T., Miklius, Asta, and Sako, M.K., 1991, Relation between the Kilauea east-rift-zone eruption and surface deformation of the summit and southwest rift zone, island of Hawaii [abs.]: Eos (American Geophysical Union Transactions), v. 72, no. 44, supp., p. 566–557.

S Okubo, P.G., 1994, Seismicity associated with the continuing eruption at Kilauea Volcano, Hawaii [abs.]: Seismological Research Letters, v. 65, no. 1, p. 55.

S Okubo, P.G., 1997, An evolving seismological view of Kilauea’s east rift zone [abs.]: Eos (American Geophysical Union Transactions), v. 78, no. 46, supp., p. F634.

S Okubo, P.G., Nakata, J.S., Chouet, B.A., and Dawson, P.B., 1996, The February 1, 1996, Kilauea summit earthquake swarm [abs.]: Eos (American Geophysical Union Transactions), v. 77, no. 46, supp., p. F798.

S Okubo, P.G., Okamura, A.T., and Miklius, Asta, 1991, Intrusive earthquake swarms and the continuing Kilauea eruption [abs.]: Eos (American Geophysical Union Transactions), v. 72, no. 44, supp., p. 566.

S Okubo, P.G., Seidl, Dieter, and Hellweg, Margaret, 1994, The broadband wavefield at the Puu Oo vent of Kilauea Volcano, Hawaii [abs.]: Eos (American Geophysical Union Transactions), v. 75, no. 44, supp., p. 714.

S Okubo, P.G., Tomori, A.H., Nakata, J.S., Largo, A.J., and Fukunaga, P.N., 1990, Spatial and temporal patterns of seismicity related to the on-going eruption of Kilauea Volcano, Hawaii [abs.]: Eos (American Geophysical Union Transactions), v. 71, no. 43, p. 1711.

G Olmez, Ilhan, Finnegan, D.L., and Zoller, W.H., 1986, Iridium emissions from Kilauea volcano: Journal of Geophysical Research, v. 91, no. B1, p. 653–663.

D Owen, S.E., Segall, Paul, Lisowski, Michael, Miklius, Asta, Denlinger, R.P., and Sako, M.K., 2000, Rapid deformation of Kilauea Volcano; global positioning system measurements between 1990 and 1996: Journal of Geophysical Research, v. 105, no. B8, p. 18983–18998.

D Owen, S.E., Segall, Paul, Lisowski, Michael, Miklius, Asta, Murray, Michael, Bevis, M.G., and Foster, James, 2000, January 30, 1997 eruptive event on Kilauea Volcano, Hawaii, as monitored by continuous GPS: Geophysical Research Letters, v. 27, no. 17, p. 2757–2760.

P Oze, C.J.-P., and Winter, J.D., 1997, A petrographical study of blue glassy pahoehoe from Kilauea Volcano, Hawaiʻi [abs.]: Geological Society of America Abstracts with Programs, v. 29, no. 6, p. A–137.

G, P Paces, J.B., and Rose, W.I., 1984, Hourly volatile and chemical evolution during phase 16 of the 1983–84 Kilauea east rift zone eruption [abs.]: Eos (American Geophysical Union Transactions), v. 65, no. 45, p. 1130–1131.

V Parfitt, E.A., and Wilson, Lionel, 1994, The 1983–86 Puʻu ʻOʻo eruption of Kilauea volcano, Hawaii; a study of dike geometry and eruption mechanisms for a long-lived eruption: Journal of Volcanology and Geothermal Research, v. 59, no. 3, p. 179–205.

V Parfitt, E.A., and Wilson, Lionel, 1995, Explosive volcanic eruptions; IX. The transition between Hawaiian-style lava fountaining and Strombolian explosive activity: Geophysical Journal International, v. 121, no. 1, p. 226–232.

V, G Parfitt, E.A., Wilson, Lionel, and Neal, C.A., 1995, Factors influencing the height of Hawaiian lava fountains; implications for the use of fountain height as an indicator of magma gas content: Bulletin of Volcanology, v. 57, no. 6, p. 440–450.

R Peitersen, M.N., and Crown, D.A., 1999, Downflow width behavior of Martian and terrestrial lava flows: Journal of Geophysical Research, v. 104, no. E4, p. 8473–8488.

R Peitersen, M.N., and Crown, D.A., 2000, Correlations between topography and intraflow width behavior in Martian and terrestrial lava flows: Journal of Geophysical Research, v. 105, no. E2, p. 4123–4134.

R Perry, D.L., Gunderson, K.W., Herd, D.G., Kauahikaua, J.P., Lange, J.J., McCord, T.B., and Ross, J.P., Jr., 1995, Predicted and measured thermal infrared signatures of Kilauea lava tubes [abs.]: Eos (American Geophysical Union Transactions), v. 76, no. 17, p. S300.

V Pinkerton, Harry, and Herd, R.A., 1996, Field measurements of the rheological properties of basaltic lavas on Kilauea, Hawaii [abs.], *in* Whitehead, P.W., ed., Long lava flows: Chapman Conference on Long Lava Flows, Townsville, Australia, 1996, Abstracts, p. 52–53.

V Pinkerton, Harry, James, Mike, and Jones, Alun, 2002, Surface temperature measurements of active lava flows on Kilauea volcano, Hawaiʻi: Journal of Volcanology and Geothermal Research, v. 113, no. 1–2, p. 159–176.

V Pinkerton, Harry, and Wilson, Lionel, 1994, Factors controlling the lengths of channel-fed lava flows: Bulletin of Volcanology, v. 56, no. 2, p. 108–120.

P, V Polacci, Margherita, Cashman, K.V., and Kauahikaua, J.P., 1999, Textural characterization of the pāhoehoe-ʻaʻā transition in Hawaiian basalt: Bulletin of Volcanology, v. 60, no. 8, p. 595–609.

P Putirka, K.D., 1997, Magma transport at Hawaii; inferences based on igneous thermobarometry: Geology, v. 25, no. 1, p. 69–72.

G Quick, J.E., Hinkley, T.K., Reimer, G.M., and Hedge, C.E., 1991, Tritium concentrations in the active Puʻu Oʻo Crater, Kilauea volcano, Hawaii; implications for cold fusion in the Earth's interior: Physics of the Earth and Planetary Interiors, v. 69, no. 1–2, p. 132–137.

R Realmuto, V.J., Hon, K.A., Kahle, A.B., Abbott, E.A., and Pieri, D.C., 1992, Multispectral thermal infrared mapping of the 1 October 1988 Kupaianaha flow field, Kilauea volcano, Hawaii: Bulletin of Volcanology, v. 55, no. 1, p. 33–44.

R, G Realmuto, V.J., Sutton, A.J., and Elias, Tamar, 1997, Multispectral thermal infrared mapping of sulfur dioxide plumes; a case study from the East Rift Zone of Kilauea Volcano, Hawaii: Journal of Geophysical Research, v. 102, no. B7, p. 15057–15072.

R, G Realmuto, V.J., and Worden, H.M., 2000, Impact of atmospheric water vapor on the thermal infrared remote sensing of volcanic sulfur dioxide emissions; a case study from the Puʻu ʻOʻo vent of Kilauea Volcano, Hawaii: Journal of Geophysical Research, v. 105, no. B9, p. 21497–21508.

P Reinitz, I.M., and Turekian, K.K., 1991, The behavior of the uranium decay chain nuclides and thorium during the flank eruptions of Kilauea (Hawaii) between 1983 and 1985: Geochimica et Cosmochimica Acta, v. 55, no. 12, p. 3735–3740.

G Resing, J.A., and Sansone, F.J., 1999, The chemistry of lava-seawater interactions; the generation of acidity: Geochimica et Cosmochimica Acta, v. 63, no. 15, p. 2183–2198.

G Resing, J.A., and Sansone, F.J., 2002, The chemistry of lava-seawater interactions II; the elemental signature: Geochimica et Cosmochimica Acta, v. 66, no. 11, p. 1925–1941.

P Roeder, P.L., Thornber, C.R., Poustovetov, A.A., and Grant, A.C., in press, Morphology and composition of spinel Puʻu ʻOʻo lava (1996–1998), Kilauea volcano, Hawaiʻi: Journal of Volcanology and Geothermal Research.

R, Gp Roggenthen, W.M., 1994, A ground-penetrating radar survey of the active Kamoamoa delta, Kilauea Volcano, Hawaii [abs.]: Geological Society of America Abstracts with Programs, v. 26, no. 7, p. A–118.

P, G Rose, W.I., Paces, J.B., and Chartier, T.A., 1985, Complex magma mixing and degassing patterns revealed by tephra sampling during Kilauea east rift zone eruptions, 1984–85 [abs.]: Eos (American Geophysical Union Transactions), v. 66, no. 46, p. 1133.

R Rosen, P.A., Hensley, Scott, Zebker, H.A., Webb, F.H., and Fielding, E.J., 1996, Surface deformation and coherence measurements of Kilauea Volcano, Hawaii, from SIR-C radar interferometry: Journal of Geophysical Research, v. 101, no. E10, p. 23109–23125.

R Rowland, S.K., MacKay, M.E., and Garbeil, Harold, 1999, Topographic analyses of Kīlauea Volcano, Hawaiʻi, from interferometric airborne radar: Bulletin of Volcanology, v. 61, no. 1, p. 1–14.

S Rubin, A.M., Gillard, Dominique, and Got, J.-L., 1998, A reinterpretation of seismicity associated with the January 1983 dike intrusion at Kilauea Volcano, Hawaii: Journal of Geophysical Reseach, v. 103, no. B5, p. 10003–10015.

S Saccorotti, Gilberto, Chouet, B.A., and Dawson, P.B., 2001, Wavefield properties of a shallow long-period event and tremor at Kilauea Volcano, Hawaii: Journal of Volcanology and Geothermal Research, v. 109, no. 1–3, p. 163–189.

V Sakimoto, S.E.H., and Zuber, M.T., 1998, Flow and convective cooling in lava tubes, *in* Cashman, K.V., Pinkerton, Harry, and Stephenson, Jon, eds., Long lava flows: Journal of Geophysical Research, v. 103, no. B11, p. 27465–27487.

G Sansone, F.J., Benitez-Nelson, C.R., DeCarlo, E.H., Liangzhong, Zhuang, Heath, J.A., and Huebert, B.J., 2000, Chemical composition of the steam plume resulting from the ocean lava entry at Kilauea Volcano, Hawaii [abs.]: Eos (American Geophysical Union Transactions), v. 81, no. 46, supp., p. F1275.

G, V Sansone, F.J., and Resing, J.A., 1995, Hydrography and geochemistry of sea surface hydrothermal plumes resulting from Hawaiian coastal volcanism: Journal of Geophysical Research, v. 100, no. C7, p. 13555–13569.

G, V Sansone, F.J., Resing, J.A., Tribble, G.W., Sedwick, P.N., Kelly, K.M., and Hon, K.A., 1991, Lava-seawater interactions at shallow-water submarine lava flows: Geophysical Research Letters, v. 18, no. 9, p. 1731–1734.

G, V Sedwick, P.N., McMurtry, G.M., and Tribble, G.W., 1991, Chemical alteration of seawater by lava from Kilauea Volcano, Hawaii: Marine Geology, v. 96, no. 1–2, p. 151–158.

D Segall, Paul, Cervelli, P.F., Owen, S.E., Lisowski, Michael, and Miklius, Asta, 2001, Constraints on dike propagation from continuous GPS measurements: Journal of Geophysical Research, v. 106, no. B9, p. 19301–19317.

S Seidl, Dieter, Hellweg, Margaret, Okubo, P.G., Rademacher, Horst, and Gresta, Stefano, 1996, A preliminary survey of the broadband seismic wavefield at Puu Oo, the active vent of Kilauea Volcano, Hawaii: Annali di Geofisica, v. 39, no. 2, p. 283–297.

V Self, Stephen, Keszthelyi, L.P., and Thordarson, Thorvaldur, 2000, Discussion of "Pulsed inflation of pahoehoe lava flows; implications for flood basalt emplacement", by S.W. Anderson, E.R. Stofan, E.R. Smrekar, J.E. Guest and B. Wood [Earth Planet. Sci. Lett. 168 (1999) 7–18]: Earth and Planetary Science Letters, v. 179, no. 2, p. 421–423.

P, V Sharma, Kirti, Self, Stephen, Thornber, C.R., and Keszthelyi, L.P., 1999, Textural variations through inflated pahoehoe flow lobes from Kilauea, Hawaii [abs.]: Eos (American Geophysical Union Transactions), v. 80, no. 46, supp., p. F1090.

R, V Smith, J.R., 1993, Extent and depositional processes of hyaloclastite and lava delta debris offshore Kilauea Volcano, Hawaii [abs.]: Eos (American Geophysical Union Transactions), v. 74, no. 43, supp., p. 617.

G Sutton, A.J., and Elias, Tamar, 1993, Annotated bibliography; volcanic gas emissions and their effect on ambient air character: U.S. Geological Survey Open-File Report 93–551–E, 26 p.

G Sutton, A.J., Elias, Tamar, Gerlach, T.M., and Stokes, J.B., 2001, Implications for eruptive processes as indicated by sulfur dioxide emissions from Kīlauea Volcano, Hawai‘i, 1979–1997: Journal of Volcanology and Geothermal Research, v. 108, no. 1–4, p. 283–302.

G, H Sutton, A.J., Elias, Tamar, Hendley, J.W., II, and Stauffer, P.H., 1997, Volcanic air pollution—a hazard in Hawaii: U.S. Geological Survey Fact Sheet 169–97, 2 p.

G, H Sutton, A.J., Elias, Tamar, and Navarrete, R.M., 1994, Volcanic gas emissions and their impact on ambient air character at Kilauea Volcano, Hawaii: U.S. Geological Survey Open-File Report 94–569, 34 p.

G, S Thomas, D.M., and Koyanagi, R.Y., 1986, The association between ground gas radon concentrations and seismic and volcanic activity at Kilauea volcano [abs.]: Eos (American Geophysical Union Transactions), v. 67, no. 44, p. 905.

I Thornber, C.R., 1997, HVO/RVTS–1; a prototype remote video telemetry system for monitoring the Kilauea east rift zone eruption, 1997: U.S. Geological Survey Open-File Report 97–537, 19 p.

P Thornber, C.R., 2001, Olivine-liquid relations of lava erupted by Kīlauea Volcano from 1994 to 1998; implications for shallow magmatic processes associated with the ongoing east-rift-zone eruption: Canadian Mineralogist, v. 39, no. 2, p. 239–266.

E Thornber, C.R., Heliker, C.C., Reynolds, J.R., Kauahikaua, J.P., Okubo, P.G., Lisowski, Michael, Sutton, A.J., and Clague, D.A., 1996, The eruptive surge of February 1, 1996; a highlight of Kilauea's ongoing east rift zone eruption [abs.]: Eos (American Geophysical Union Transactions), v. 77, no. 46, supp., p. F798.

P Thornber, C.R., Sherrod, D.R., Siems, D.F., Heliker, C.C., Meeker, G.P., Oscarson, R.L., and Kauahikaua, J.P., 2002, Whole-rock and glass major-element geochemistry of Kilauea Volcano, Hawaii, near-vent eruptive products; September 1994 through September 2001: U.S. Geological Survey Open-File Report 02–17, 41 p.

P Thornber, C.R., Heliker, C.C., Sherrod, D.R., Kauahikaua, J.P., Miklius, Asta, Okubo, P.G., Trusdell, F.A., Budahn, J.R., Ridley, W.I., and Meeker, G.P., in press, Kilauea east rift zone magmatism: an episode 54 perspective: Journal of Petrology.

V Tribble, G.W., 1991, Underwater observations of active lava flows from Kilauea volcano, Hawaii: Geology, v. 19, no. 6, p. 633–636.

D Troise, Claudia, de Natale, Giuseppe, Pingue, Folco, and Dvorak, J.J., 1999, Variable opening of dike-fed eruptive fissures determined from geodetic data; the 1971 and 1983 rift-zone eruptions of Kilauea Volcano, Hawaii: Journal of Geodynamics, v. 27, no. 1, p. 75–88.

E Ulrich, G.E., Wolfe, E.W., Heliker, C.C., and Neal, C.A., 1987, Pu‘u ‘O‘o IV; evolution of a plumbing system [abs.], *in* Decker, R.W., Halbig, J.B., Hazlett, R.W., Okamura, R.T., and Wright, T.L., eds., Hawaii Symposium on How Volcanoes Work, Hilo, Hawaii, 1987, Abstract volume: Honolulu, University of Hawaii, Hawaii Institute of Geophysics, p. 259.

G Vergniolle, Sylvie, and Jaupart, Claude, 1990, Dynamics of degassing at Kilauea volcano, Hawaii: Journal of Geophysical Research, v. 95, no. B3, p. 2793–2809.

V, G Wallace, P.J., and Anderson, A.T., Jr., 1998, Effects of eruption and lava drainback on the H_2O contents of basaltic magmas at Kilauea Volcano: Bulletin of Volcanology, v. 59, no. 5, p. 327–344.

P White, A.F., and Hochella, M.F., 1992, Surface chemistry associated with the cooling and subaerial weathering of recent basalt flows: Geochimica et Cosmochimica Acta, v. 56, no. 10, p. 3711–3721.

V Wilson, Lionel, and Head, J.W., III, 1988, Nature of local magma storage zones and geometry of conduit systems below basaltic eruption sites; Pu‘u ‘O‘o, Kilauea east rift, Hawaii, example: Journal of Geophysical Research, v. 93, no. B12, p. 14785–14792.

V Wilson, Lionel, Parfitt, E.A., and Head, J.W., III, 1995, Explosive volcanic eruptions—VIII. The role of magma recycling in controlling the behavior of Hawaiian-style lava fountains: Geophysical Journal International, v. 121, no. 1, p. 215–225.

E Wolfe, E.W., Garcia, M.O., Jackson, D.B., Koyanagi, R.Y., Neal, C.A., and Okamura, A.T., 1987, The Puu Oo eruption of Kilauea Volcano, episodes 1–20, January 3, 1983, to June 8, 1984, chap. 17 *of* Decker, R.W., Wright, T.L., and Stauffer, P.H., eds., Volcanism in Hawaii: U.S. Geological Survey Professional Paper 1350, v. 1, p. 471–508.

E, M Wolfe, E.W., Neal, C.A., Banks, N.G., and Duggan, T.J., 1988, Geologic observations and chronology of eruptive events, chap. 1 *of* Wolfe, E.W., ed., The Puu Oo eruption of Kilauea Volcano, Hawaii; episodes 1 through 20, January 3, 1983 through June 8, 1984:U.S.Geological Survey Professional Paper 1463, p. 1-97.