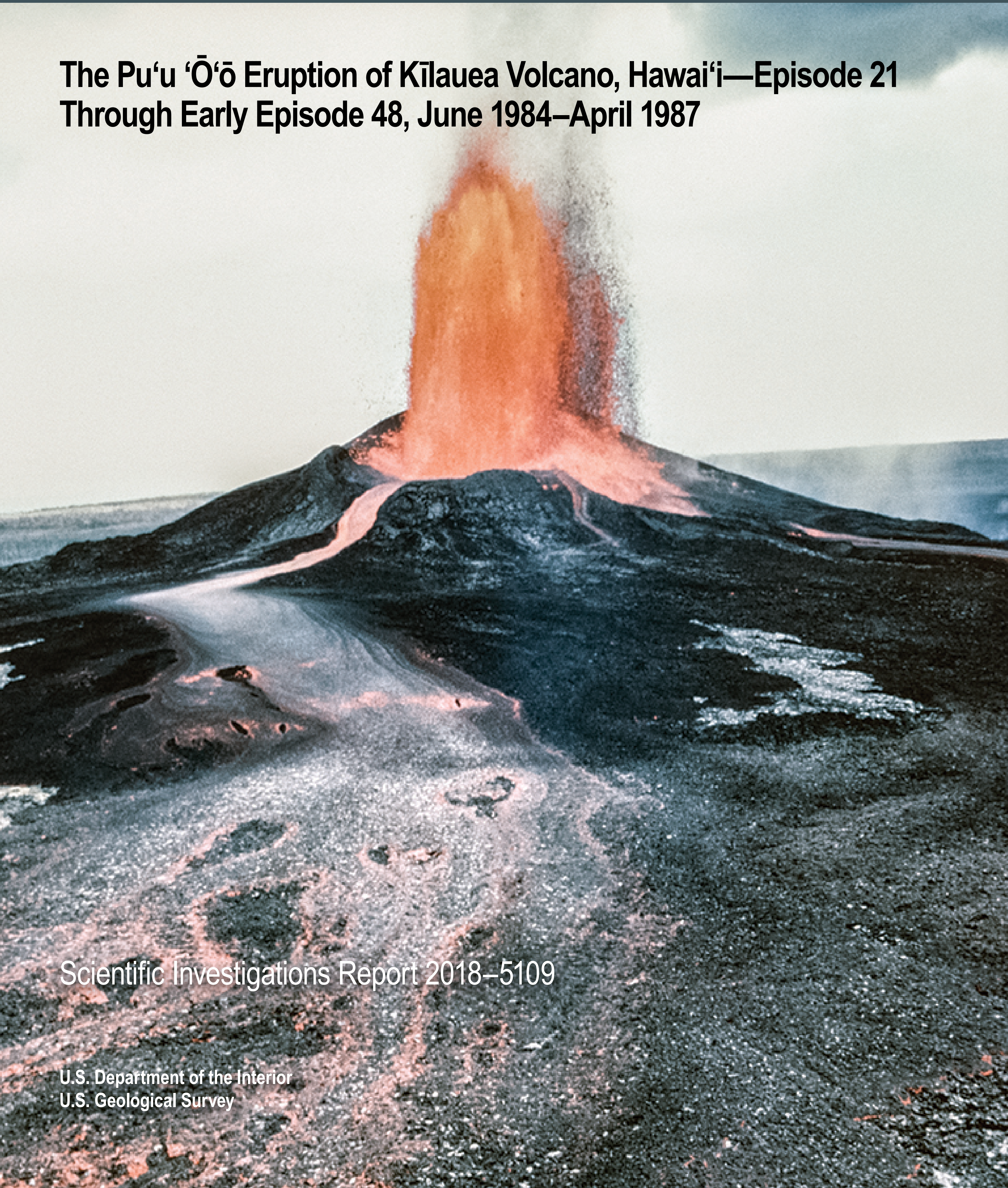

The Puʻu ʻŌʻō Eruption of Kīlauea Volcano, Hawaiʻi—Episode 21 Through Early Episode 48, June 1984–April 1987

Scientific Investigations Report 2018–5109

U.S. Department of the Interior
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Cover. Oblique aerial photograph, looking southwest, showing the episode 21 lava fountain feeding an ʻaʻā flow advancing northeast from Puʻu ʻŌʻō. A spatter-fed ʻaʻā flow on the north (right) flank of the cone feeds a stubby flow. The fountain height is ~180 meters. Photograph by J.D. Griggs, U.S. Geological Survey, 1343 HST, June 30, 1984.

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Contents

Figures

Tables

The Puʻu ʻŌʻō Eruption of Kīlauea Volcano, Hawaiʻi—Episode 21 Through Early Episode 48, June 1984–April 1987

By Tim R. Orr,[1] George E. Ulrich,[1] Christina Heliker,[1] Liliana G. DeSmither,[2] and John P. Hoffmann[1]

Abstract

The Puʻu ʻŌʻō eruption from the middle East Rift Zone of Kīlauea Volcano began in January 1983 with intermittent activity along several fissures. By June 1983, the eruption had localized at the Puʻu ʻŌʻō vent and the activity settled into an increasingly regular pattern of brief eruptive episodes characterized by high lava fountains. The first 18 months of the eruption (episodes 1–20) are chronicled in previous publications.

In the two years following episode 20, Puʻu ʻŌʻō produced another 27 high-fountaining episodes. Episodes 21–47 lasted an average of 12.9 hours and were separated by inter-episode periods averaging 26.5 days. The lava fountains, which reached as high as 510 meters (m), fed lava flows (mostly channelized ʻaʻā) that brought the total area covered by the eruption to 40 square kilometers (km^2) by the end of episode 47. Flow thickness measurements obtained for episodes 21–40 averaged 3.4 m; lava volumes for episodes 21–47 averaged 8.0×10^6 m^3 per episode (including the 16-day fissure outbreak of episode 35).

The Puʻu ʻŌʻō cone—a composite of pyroclastic material and lava flows—reached its maximum height of 255 m above the pre-eruption surface during episode 43 and maintained that height through episode 47. Short-lived eruptive fissures and vents at or near the base of the Puʻu ʻŌʻō cone accompanied episodes 21, 25, 29, 35, 39, and 44. Episode 35 was unusual in that a fissure on the uprift flank of the cone erupted early in the episode, and then reactivated and extended 2.5 km uprift after the high fountaining was over and erupted for the next 16 days.

The volcano was primed for the 48th episode of high fountaining on July 18, 1986, when the conduit beneath Puʻu ʻŌʻō ruptured again and magma erupted through new fissures at the base of the cone on both its uprift and downrift sides. These fissures were active for only 21 hours, but a third fissure, which opened 3 km downrift from Puʻu ʻŌʻō on July 20, persisted and evolved into a single vent, later named Kupaianaha. Kupaianaha erupted almost continuously for the next 5.5 years (the main part of episode 48). The onset of episode 48 marked the end of episodic high fountaining and the transition to nearly continuous effusion. A lava lake developed over the Kupaianaha vent, and overflows from the lake built a broad, low shield that reached a relatively stable height of 45 m by November 1986.

After weeks of continuous eruption, the main lava channel leading from the lake gradually roofed over, forming a lava tube. By November 1986, the tube had extended from the lake to the ocean, 12 km southeast, closing the coastal highway. Tube-fed flows overran 28 houses in the coastal communities of Kapaʻahu and Kalapana over the next month.

Introduction

Kīlauea's longest-lasting flank eruption in the volcano's relatively short recorded history (~200 years) began in the middle part of the East Rift Zone on January 3, 1983. The first eruptive episode was heralded by a seismic swarm that accompanied the emplacement of a dike along the rift zone axis. The dike subsequently fed intermittent fissure outbreaks that propagated downrift from Nāpau Crater for nearly 8 kilometers (km) (Koyanagi and others, 1988; Okamura and others, 1988; Wolfe and others, 1988).

The next two episodes (episodes 2 and 3) saw renewed fissure outbreaks along the trace of the dike, and the development of localized vents from which high lava fountains issued, constructing spatter cones at several locations. The first significant cone, later named Puʻu Halulu, reached a height of 60 meters (m) and served as a prominent observation point (figs. 1 and 2) for the majority of episodes after episode 17.

The embryonic Puʻu ʻŌʻō vent structure was also active during episodes 2 and 3 at its location 1,500 m uprift (southwest) of Puʻu Halulu. Subsequent episodes (episodes 4–47) were characterized by high fountains exclusively from the Puʻu ʻŌʻō vent, with occasional fissure outbreaks around the Puʻu ʻŌʻō cone, as also described by Wolfe and others (1988).

Altogether, nearly 0.4 km^3 of basalt was erupted over the course of these 47 episodes (through mid-1986), covering 40 km^2 with new lava flows (fig. 1). Most of this lava was discharged through the Puʻu ʻŌʻō vent. The Puʻu ʻŌʻō cone, with a final height of 255 m, became the most prominent topographic feature along the East Rift Zone.

A fundamental change occurred at Puʻu ʻŌʻō in July 1986, when the conduit beneath Puʻu ʻŌʻō ruptured before the expected

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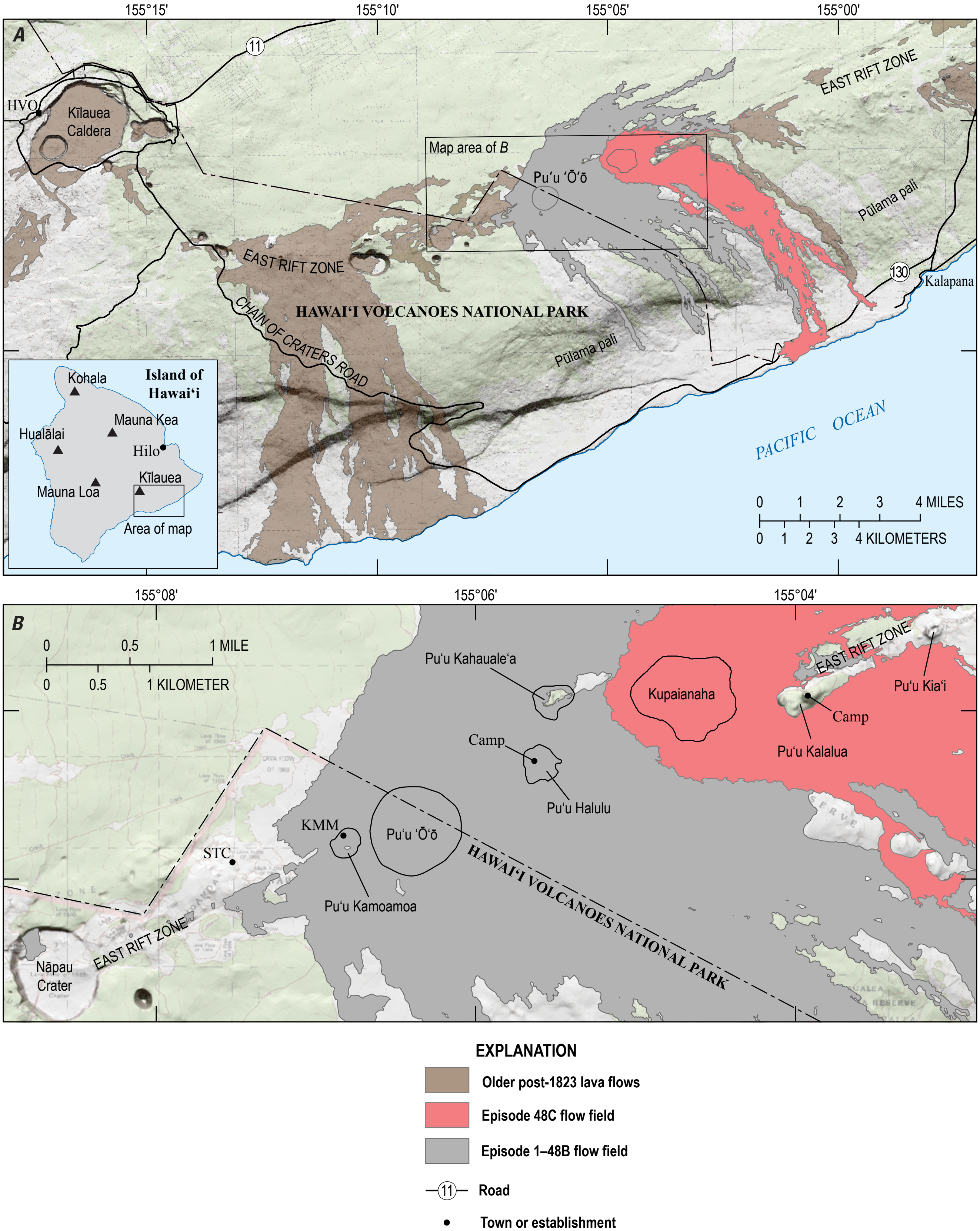


Figure 1. *A*, Map showing the distribution of the episodes 1–48B lava flow field (gray), the episode 48C flow field (red), and older post-1823 lava flows (brown) on Kīlauea's East Rift Zone and southeast flank. The dash-dot line is the boundary of Hawaiʻi Volcanoes National Park; the boundary southeast of Puʻu ʻŌʻō is frequently referred to in this report. Inset: Island of Hawaiʻi and its five volcanoes. *B*, Map showing Puʻu ʻŌʻō and other nearby topographic features, seismic stations, and observation camps. HVO, Hawaiian Volcano Observatory; STC and KMM, seismometer locations.

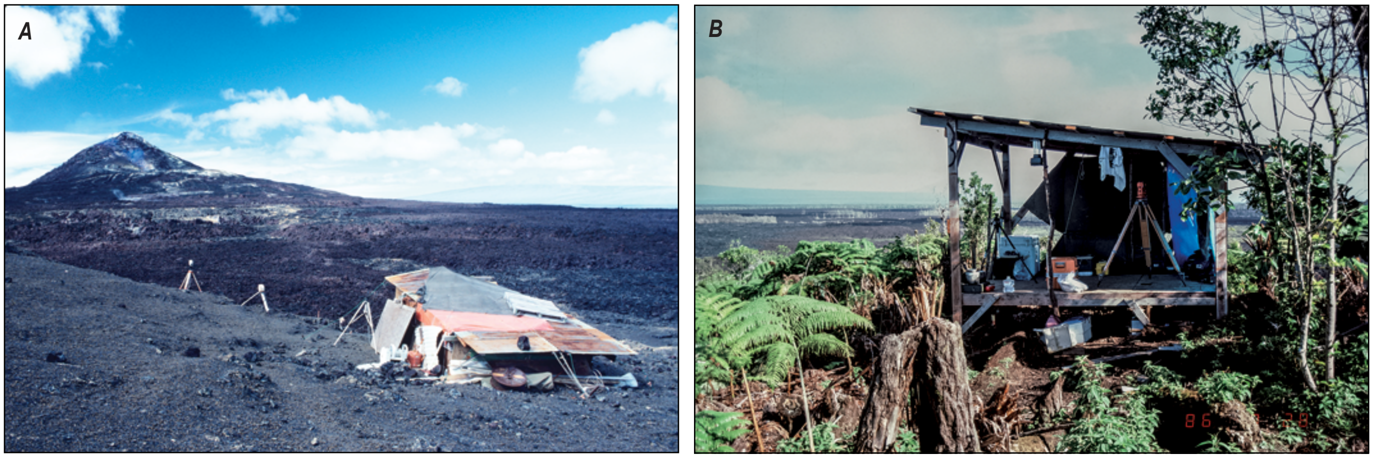


Figure 2. Oblique aerial photographs of *A*, the observation camp and time-lapse cameras at Pu‘u Halulu, looking west, with Pu‘u ‘Ō‘ō in the background, and *B*, the observation camp on the summit of Pu‘u Kalalua, looking northwest. Photographs by J.D. Griggs, U.S. Geological Survey, November 12, 1985, and G. Ulrich, U.S. Geological Survey, July 28, 1986.

onset of lava fountaining, and lava erupted instead through new fissures at the base of the cone. Two days later, another fissure opened 3 km downrift to form Kupaianaha (fig. 1), a volcanic shield that erupted effusively until early 1992, sending flows into the ocean and adjacent communities along Kīlauea’s southeastern coast. No high lava fountain as characterized during the first 47 episodes of the eruption occurred during the Pu‘u ‘Ō‘ō eruption thereafter.

This paper provides an on-the-ground chronology of the period from June 1984 through April 1987, which included eruptive episodes 21 through 47 and the beginning of episode 48. Many publications have covered various aspects of this period (see Heliker and Mattox [2003] for a selected bibliography). The papers cited within this text have specific contributions regarding the geologic observations chronicled in this report. All times are reported in Hawai‘i Standard Time (HST).

Previous Work

A summary report of the first 20 episodes of the Pu‘u ‘Ō‘ō eruption by Wolfe and others (1987) gave the first overview of the geologic, geodetic, petrologic, and seismic observations of those events. Wolfe and others (1988) give a far more detailed chronological narrative of those episodes and recount the development of central vent structures from the early fissure outbreaks to the establishment of Pu‘u ‘Ō‘ō as the main vent for the East Rift Zone magma system. The correspondence of chemical variation in the lavas with increasing temperatures was documented by Neal and others (1988) and Thornber (2003). Neal and others (1988) also describe field methods for sample collection and thermocouple measurements.

Heliker and Wright (1991) give a summary of the eruptive activity at Pu‘u ‘Ō‘ō and Kupaianaha from 1983 through late 1991. Heliker and Mattox (2003) provide a chronology and bibliography covering the first 20 years of the eruption, and the maps for this period were published by Heliker and others (2001). Orr and others (2015) extend this chronology through 2013. The growth of the Pu‘u ‘Ō‘ō cone (much of which occurred during episodes 21–47), the nature of its connection with Kupaianaha, and the cone’s subsequent collapse are the subject of a paper by Heliker and others (2003). Timelapse-film logs of the eruption from January 1983 through September 1994 are available in Mattox and others (1994). Horizontal ground deformation data obtained near Pu‘u ‘Ō‘ō from episodes 22 through 42 were modeled by Hoffmann and others (1990).

Compositional variations in the first 20 episodes are interpreted by Garcia and Wolfe (1988) and Garcia and others (1989) to reflect crystal fractionation of older magma stored in the East Rift Zone, the introduction of more mafic summit magma with time, and short-term fractionation between some episodes in a local magma reservoir beneath Pu‘u ‘Ō‘ō. Whole-rock and glass major-element geochemistry and eruption temperatures for samples collected from January 1983 through September 2001 are compiled in Thornber and others (2003a) and interpreted by Thornber (2003). Thornber and others (2003b) compiled and Thornber (2003) interpreted trace element and neodymium, strontium, and lead isotope geochemistry for samples from the same interval. The petrology of Pu‘u ‘Ō‘ō lava erupted from episodes 2–47 was discussed in Garcia and others (1992), and the petrology during early episode 48 in Mangan and others (1995). An overview of the eruption petrology from 1983–2013 is covered in Thornber and others (2015). Helz and others (1995) discussed geothermometry techniques, and the results obtained from those techniques, during the period of this report.

The compositions of eruptive gases in the Pu‘u ‘Ō‘ō area during the first 16 episodes (Greenland, 1988), combined with Kīlauea summit inflation/deflation data (Greenland and others, 1988), were used to define the dynamics of fountain behavior and to place constraints on the diameter of the conduit and rate of rise of magma at the Pu‘u ‘Ō‘ō vent.

Methods

During the period covered by this report (June 1984–April 1987), the only telemetered data came from a single seismometer located first at Puʻu Kamoamoa (designated KMM; fig. 1*B*), and later, when that site was overrun, at a 1968 spatter rampart 1.2 km uprift (Steam Cracks, designated STC; fig. 1*B*). The remote location of the eruptive vents required helicopter access to effectively monitor the eruption and map the lava flows. We relied on locally (and sporadically) available fixed-wing aircraft for aerial photography between episodes. Time-lapse 8-millimeter (mm) movie cameras were our main source of information during inter-episode periods, at times when helicopter budgets were lean, and when the weather was so bad that the eruption site could not be reached.

Lava flow contacts were typically mapped on aerial photographs taken between eruptive episodes and were then transferred to a 1:24,000 topographic base. For more details on the method and accuracy of the mapping, see Heliker and others (2001, sheet 1). Bad weather or lack of an airplane prevented us from obtaining aerial photographs following episodes 26, 27, and 42–47. Following these episodes, contacts were drawn onto older aerial photos during helicopter overflights; consequently, the contacts for these episodes are less detailed.

Flow thicknesses for episodes 21–47 were measured by hand level along the margins of the cooled flows, picking places where the thickness seemed representative of that section of flow. Flow thicknesses and areas were used to calculate the bulk flow volumes, which were then converted to dense-rock equivalent (DRE) volumes (fig. 3; table 1) using a pore space correction of 30 percent. This is based on an average bulk density of 2.1 grams per cubic centimeter (g/cm^3), as determined by D.J. Johnson (Wolfe and others, 1987), and a DRE density of 3.0 g/cm^3. The DRE volumes were then divided by episode duration to give the time-averaged discharge rate (in cubic meters per second [m^3/s]) for each episode (fig. 4). Only DRE volumes and mean DRE output rates are reported in table 1 and in the text. Wolfe and others (1988) report bulk volumes. Volumes for episodes 42–48B were estimated as a function of the amount of summit deflation, which had shown a good correlation with the well-determined volumes of episodes 4–40.

Lava temperatures were measured by thermocouple using the technique summarized by Helz and others (1995). In addition, the eruption temperature for some lava samples (fig. 5; Thornber and others, 2003a) was calculated using the MgO glass geothermometer of Helz and Thornber (1987). Where appropriate, the geothermometry temperatures were corrected for flow travel distance.

Fountain heights were measured to the highest visible incandescent material and determined primarily from time-lapse film that was calibrated by way of sporadic theodolite measurements (Wolfe and others, 1988). In some instances, fountain heights were estimated visually. The time-lapse cameras and theodolite measurements were made from the observation camp on Puʻu Halulu (fig. 2). Forced by the gradual inundation of Puʻu Halulu by lava flows, a new camp was established on Puʻu Kalalua between episodes 46 and 47 (fig. 2), but most observations during episode 47 were still made from the Puʻu Halulu camp.

Approximate tephra volumes for some episodes were calculated by contouring deposit thickness based on accumulation of tephra in metal coffee cans placed on the downwind side (during typical trade wind conditions) of Puʻu ʻŌʻō. A density of 0.32 g/cm^3 for the unconsolidated tephra was used when calculating bulk volume (Heliker and others, 2003). Bulk tephra volumes were converted to DRE volumes assuming a lava density of 3.0 g/cm^3, which corresponds to a pore-space correction of 89 percent.

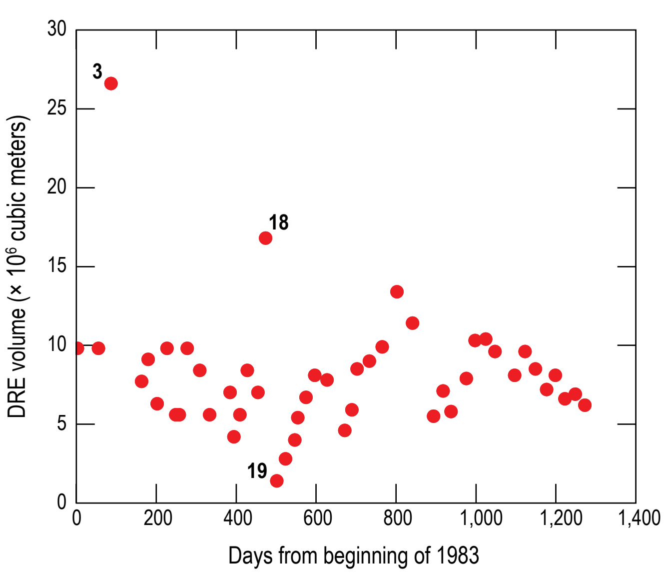


Figure 3. Graph showing dense-rock equivalent (DRE) lava flow volume for episodes 1 through 47. Some outliers are labeled with the episode number.

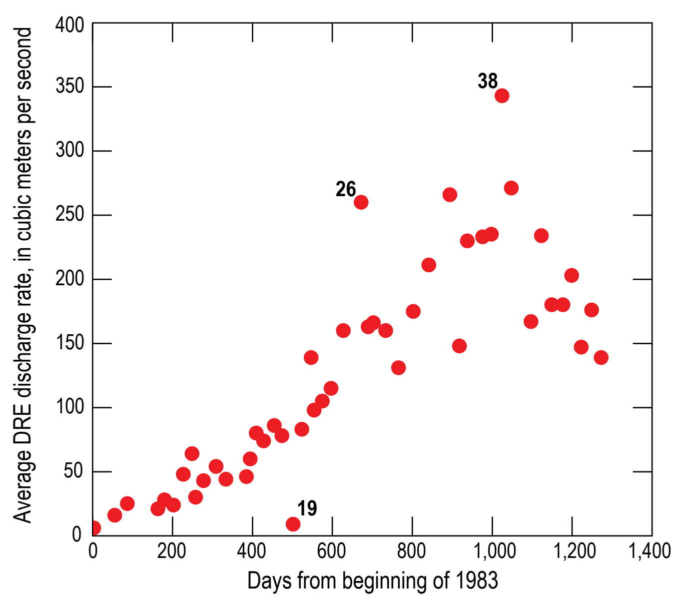


Figure 4. Graph showing time-averaged dense-rock equivalent (DRE) discharge rate for episodes 1 through 47. Some outliers are labeled with the episode number.

Table 1. Eruption statistics for episodes 21–48C.

[HST, Hawaii Standard Time; hr, hours; °C, degrees Celsius; km², square kilometers; DRE, dense-rock equivalent; m, meter; s, second; –, no data; >, greater than]

Episode	Inter-episode duration (days)	Episode start date/time (HST)	Episode end date/time (HST)	Episode duration (hr)	Maximum temperature (°C)[b]	Area covered by lava (km^2)[c]	DRE lava volume ($\times 10^6$ m^3)	DRE tephra volume ($\times 10^6$ m^3)	Mean DRE output rate (m^3/s)	Maximum fountain height (m)	Median fountain height (m)	Cone height (m)
21	22.2	06/30/84 1028	06/30/84 1827	8.0	1,164	2.1	4.0	–	139	390[a]	161	142
22	8.0	07/08/84 1859[a]	07/09/84 1017	15.3	1,164	2.8	5.4	–	98	–	–	145
23	19.1	07/28/84 1200	07/29/84 0540	17.7	1,165	3.4	6.7	–	105	322	158	–
24	21.7	08/19/84 2152	08/20/84 1725	19.6	1,165	3.7	8.1	–	115	407	275	150
25	29.9	09/19/84 1604	09/20/84 0532	13.5	1,166	3.2	7.8	0.1	160	467	216	157
26	43.3	11/02/84 1140	11/02/84 1636	4.9	–	1.6	4.6	0.1	260	394	283	164
27	17.3	11/20/84 0005	11/20/84 1006	10.0	–	2.3	5.9	–	163	–	–	167
28	13.4	12/03/84 1905	12/04/84 0941	14.6	–	3.7	8.7	0.2	162	421	270	174
29	29.1	01/03/85 1315	01/04/85 0504	15.8	1,165	3.8	9.0[a]	0.2	158	510[a]	288	193
30	31.0	02/04/85 0546	02/05/85 0246	21.0	1,173	4.1	9.9	–	131	445	254	194
31	36.1	03/13/85 0720[a]	03/14/85 0455	21.6	–	4.9	13.4[a]	0.2	172	340[a]	194	206
32	38.4	04/21/85 1804[a]	04/22/85 0906	15.0	1,171	4.9	11.3[a]	0.2	209	391	273	209
33	51.6	06/12/85 2306	06/13/85 0453	5.8	–	2.4	5.5	–	266	>268[a]	–	212
34	23.6	07/06/85 1903	07/07/85 0850	13.8	–	2.3	7.1[a]	0.3	143	410	263	228
35[d]	18.8	07/26/85 0252	07/26/85 0952	7.0	1,165	3.4	5.8[a]	–	230	–	–	232
35A	0.7	07/27/85 0414	08/12/85 0430	384.3	–	0.6	3.2	–	2	8	–	–
36	21.1	09/02/85 1400	09/02/85 2335	9.6	1,169	2.7	7.9[a]	0.2	229	441	303	242
37	21.8	09/24/85 1808	09/25/85 0620[a]	12.2	–	4.4	10.3	–	235	352	247	243
38	25.9	10/21/85 0301[a]	10/21/85 1124	8.4	1,164	3.9	10.4	–	343	295[a]	–	251
39	23.2	11/13/85 1534	11/14/85 0124	9.8	1,165	4.2	9.6	–	271	435[a]	230	250
40	48.5	01/01/86 1309	01/02/86 0238	13.5	1,164	3.9	8.1	–	167	264	70	250
41	25.8	01/27/86 2035	01/28/86 0757	11.4	1,164	5.1	9.6	–	234	~250[a]	–	250
42	25.3	02/22/86 1515	02/23/86 0420	13.1	1,164	3.7	8.5	–	180	308[a]	110	250
43	27.1	03/22/86 0450	03/22/86 1556	11.1	–	4.8	7.2	–	180	308[a]	190	255
44	22.2	04/13/86 2054	04/14/86 0756	11.0	–	5.2	8.1	–	203	308	220	255
45	23.6	05/07/86 2241	05/08/86 1106	12.4	1,163	5.2	6.6	–	147	257	146	255
46	24.6	06/02/86 0229	06/02/86 1320	10.9	1,165	6.1	6.9	–	176	223	150	255
47	23.6	06/26/86 0419	06/26/86 1635	12.3	1,162	3.2	6.2	–	139	224	153	255
48A	21.8	07/18/86 1205	07/19/86 0335	15.5	1,154	3.1	3.5	–	63	30	–	–
48B	–	07/18/86 1309	07/19/86 0930	20.4	–	1.4	1.5	–	21	30	–	–
48C	1.0	07/20/86 0800[a]	–	–	–	18.5[e]	–	–	–	–	–	–

[a]Revised from Heliker and Mattox (2003); excludes jetting events.

[b]From Thornber and others, 2003a.

[c]Updated where appropriate using revised mapping.

[d]Excludes preceding fissure outbreak and episode 35A.

[e]As of April 24, 1987.

General Observations

Systematic measurements (particularly for episodes 21–40 and 47–48) of lava flows, the Pu‘u ‘Ō‘ō cone, fountain height patterns, and ground deformation, combined with the continuously recorded seismic data, provided useful information about the evolving East Rift Zone magma plumbing system. The most important of these well-documented characteristics are described below. Eruptive episodes are defined as the period of continuous lava production, usually characterized by fountaining from the main Pu‘u ‘Ō‘ō vent. The intervals between eruptive episodes are called inter-episode periods, and these were characterized by low-level eruptive activity, particularly as the next episode neared.

Lava Fountains

From June 1983 to June 1986, Pu‘u ‘Ō‘ō produced 44 high-fountaining episodes (episodes 4–47). High-fountaining episodes 4–20, as well as episodes 1–3, are described in Wolfe and others (1988). This report extends the work of Wolfe and others (1988) and details high-fountaining episodes 21–47 (July 1985–June 1986; table 1), which lasted an average of 12.9 hours and were separated by inter-episode periods that averaged 26.5 days (table 2). All the high fountains issued from the same conduit, which varied little in appearance over the two-year period. The visible portion of the conduit, which generally extended to a depth estimated at about 50 m, was a near-vertical pipe 20–25 m in diameter. It was roughly cylindrical in cross section, although its rim sometimes had a slight flare. After each eruptive episode, the magma usually fell beyond view and so was deeper than about 50 m below the vent rim.

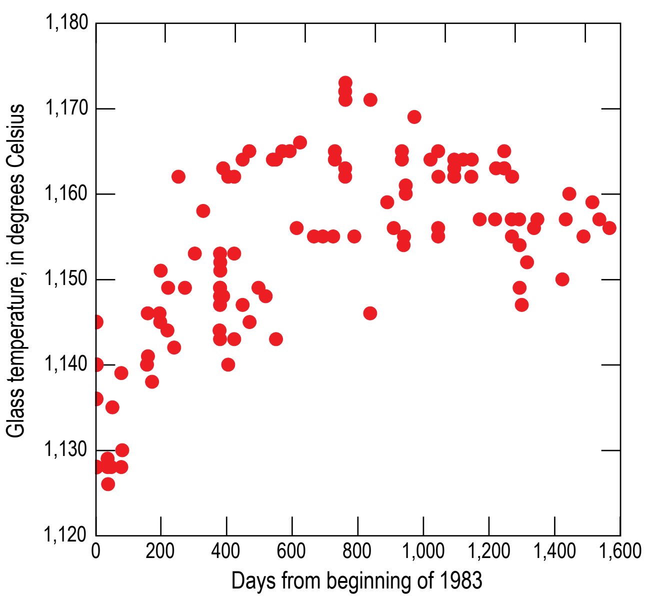


Figure 5. Graph showing glass temperatures determined for episodes 1 through 48.

The typical Pu‘u ‘Ō‘ō fountain was a vertical pillar that ranged from tens to hundreds of meters in height (fig. 6). A less-common variation was a fountain that leaned as much as 15 degrees toward the north or northeast (fig. 7). This generally happened only during the first few hours of an episode (for example, episodes 25 and 26). During the early stages of episodes 29 and 31, the fountain split into two leaning jets, which sprayed lava to both the north and east. Within minutes, though, these consolidated into a single fountain. During episodes 29 and 31, as well as episode 36, which also initially produced a leaning fountain, the base of the fountain was conspicuously narrower than usual for part of the episode, resulting in a fan-shape fountain (fig. 8). None of these variations from a broad-based vertical fountain persisted for an entire episode, and all were probably the result of a temporary

Figure 6. Oblique aerial photograph of Pu‘u ‘Ō‘ō, during episode 26, showing a typical broad-based fountain. Tephra accumulation was mostly southeast of the vent, because of the prevailing wind direction, making that the highest part of the cone and giving it a pronounced asymmetry. Photograph by C. Heliker, U.S. Geological Survey, 1626 HST, November 2, 1984.

Figure 7. Photograph showing a north-leaning fountain at Pu‘u ‘Ō‘ō on January 3, 1985, during episode 29. Fountains angled north or northeast occurred occasionally at Pu‘u ‘Ō‘ō. Photograph by C. Heliker, U.S. Geological Survey.

Table 2. Average inter-episode durations, average duration of continuous fountaining, average and total lava flow coverage area, average dense-rock equivalent (DRE) volume, and average and total DRE discharge rate for high-fountaining episodes at Puʻu ʻŌʻō.

[km², square kilometers; m³, cubic meters; s, second]

Eruption parameter	Value
Average inter-episode duration (episodes 4–20)	23.1 days
Average inter-episode duration (episodes 21–48)	26.5 days
Average inter-episode duration (episodes 4–48)	25.1 days
Average duration of continuous fountaining (episodes 4–20)	46.2 hours
Average duration of continuous fountaining (episodes 21–47)	12.9 hours
Average duration of continuous fountaining (episodes 4–47)	25.5 hours
Average area covered by lava flows (episodes 4–20)	2.8 km^2
Average area covered by lava flows (episodes 21–47)	3.7 km^2
Average area covered by lava flows (episodes 4–47)	3.4 km^2
Total area covered by lava flows (episodes 1–48B)	40 km^2
Average DRE volume of lava erupted (episodes 4–20)	7.1×10^6 m^3
Average DRE volume of lava erupted (episodes 21–47)	8.0×10^6 m^3
Average DRE volume of lava erupted (episodes 4–47)	7.7×10^6 m^3
Total volume of lava erupted (episodes 4–20)	121×10^6 m^3
Total volume of lava erupted (episodes 21–47)	216×10^6 m^3
Total volume of lava erupted (episodes 4–47)	337×10^6 m^3
Total volume of lava erupted (episodes 1–47)	383×10^6 m^3
Average DRE discharge rate (episodes 4–20)	51 m^3/s
Average DRE discharge rate (episodes 21–47)	186 m^3/s
Average DRE discharge rate (episodes 4–47)	134 m^3/s

blockage or constriction in the conduit that was reamed out after several minutes to hours of high fountaining.

The initial fountaining during an episode was through an opening in the crusted cap over the conduit. This crust was excavated during fountaining, and the width of the fountain at its base presumable grew commensurately, presumably filling the conduit. The width of the ascending fountain could not, however, be determined, because it was generally obscured by incandescent fallout. This fall-back material, still molten, then coalesced to feed the flows that emanated from the cone (Heliker and others, 2003).

Less dense tephra was mostly carried downwind, and, because of the prevailing northeasterly trade winds, it accumulated predominantly southwest of the vent, giving the cone a pronounced asymmetry (for example, fig. 6; Heliker and others, 2003). Billowing clouds of gray and brown dust were often seen rising from where fresh tephra impacted the flank of the cone, pulverizing itself and the hot tephra already on the ground (fig. 9). The production of this secondary ash cloud was confined mostly to the flanks of the cone, where tephra fall-back was heaviest. Breaking of clasts was also a common process

Figure 8. Photograph showing a fan-shaped fountain with a narrow base during episode 29 at Puʻu ʻŌʻō. Photograph by C. Heliker, U.S. Geological Survey, January 3, 1985.

Figure 9. Photograph from the Puʻu Halulu camp, looking southwest, showing the episode 25 fountain and the fissure vents near the base of Puʻu ʻŌʻō. The fountain is angled north ~15°; typical northeast trade winds carry the tephra and fume south-southwest, away from the camera. Tephra falling out of the plume is impacting the cone behind the fountain, forming the dust cloud visible behind the fountain to the right. Photograph by C. Heliker, U.S. Geological Survey, 1630 HST, September 19, 1984.

farther afield. Large lapilli and bombs are not common in the tephra deposit downwind of Pu‘u ‘Ō‘ō because most clasts of those sizes were observed to break on impact with the ground. Most of the larger clasts that did survive impact were very low-density reticulite bombs as much as 30 cm across (fig. 10).

Overall, fountain heights increased from episode 4 through 29, although there was a fair amount of variability (fig. 11). During episodes 24–25, 28–30, 34, 36 and 39, maximum fountain heights exceeded 400 m (fig. 11). The maximum fountain height recorded for each episode was frequently short-lived, often being a pulse that appears as a single spike on the graph of fountain heights for that episode (fig. 12) and which may not have been consistent with the fountaining occurring before and after. Following episode 39 in November 1985, fountain heights declined, and the maximum heights varied from 223 m to 308 m thereafter, although episodes 42 through 47 had unusual late jet-like fountains that also approached or exceeded 400 m (see section on Jetting Events).

Wolfe and others (1988) concluded that the heights of Pu‘u ‘Ō‘ō fountains in episodes 4–20 were controlled by a complex interaction of several factors, including eruption rate, conduit geometry, and gas content of the magma. They noted that the rate of lava discharge increased through episode 20 (fig. 4), and they attributed the increase in fountain vigor, at least in part, to increasing discharge rate. Changes in conduit geometry were impossible to evaluate, except to note that the visible portion of the conduit was essentially unchanged after episode 14 (Wolfe and others, 1988). Wolfe and others (1988), based on the work of Greenland and others (1988), discounted variation in overall gas content of the magma, except within individual episodes. Thus, the highest fountains, which occurred in the early hours of most episodes, were the result of slightly more gas-rich magma, presumably because gas collected in the upper part of the magma column during inter-episode periods.

Greenland and others (1988) concluded that the variation in fountain heights was a function of magma-rise rate and the damping effects of lake drainage. From episode 4 through 18, a bowl-shaped crater surrounded the conduit, and the fountain erupted through a lake of lava. No significant crater remained after episode 19, thus reducing the influence of lava ponding over the vent during subsequent fountaining episodes. Maximum fountain heights increased thereafter, consistent with their hypothesis.

Discharge rates, averaged over the length of the episode, do not show a strong correlation with maximum fountain heights during episodes 21–47 (fig. 13). As Wolfe and others (1988) point out, the time-averaged discharge rate for the duration of the fountain, which is all that we are able to calculate, may not apply to that interval of the episode that produced the highest fountain. Time-averaged discharge rates continued to increase irregularly through episodes 38 (fig. 4), whereas fountain heights were consistently higher during episodes 25–30 (figs. 11 and 12). Eruption temperature also peaked around episode 30 (fig. 5; Thornber, 2003). When fountain heights declined, beginning with episode 40, eruption rates also declined somewhat but were still generally higher than those that produced the highest fountains in the series.

Other eruption parameters besides fountain height suggest that the magma transport system between Kīlauea’s summit reservoir and Pu‘u ‘Ō‘ō was becoming increasingly streamlined through episode 39. For instance, episodes became more regularly spaced following episode 34; in other

Figure 10. Photograph of a reticulite bomb ~30 centimeters across, from an undetermined Pu‘u ‘Ō‘ō high fountain. The bomb is one of many that are present on the tephra-covered floor of Nāpau Crater, about 4 kilometers southwest of Pu‘u ‘Ō‘ō. At least some of the smaller fragments visible in the photograph broke from the larger bomb, probably during impact. Photograph by C. Parcheta, U.S. Geological Survey, January 9, 2014.

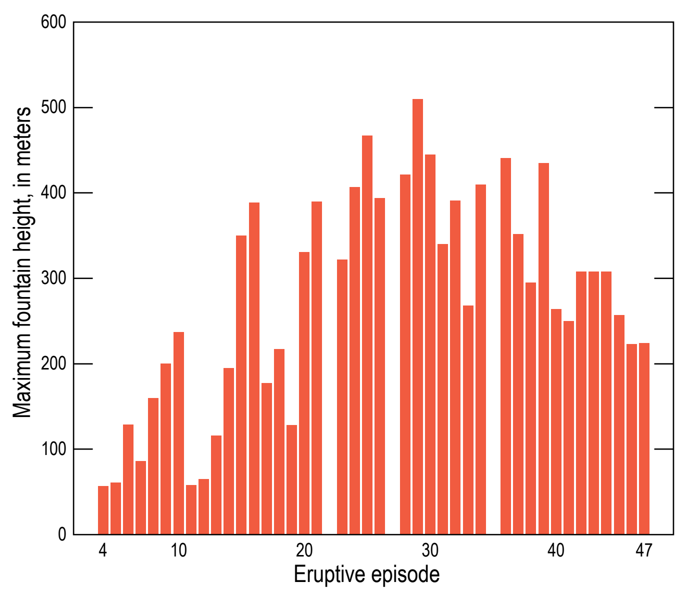


Figure 11. Bar graph showing the maximum fountain height measured during each high-fountaining episode, excluding the jetting events near the end of some episodes.

words, the durations of the inter-episode periods became more consistent (with the exception of the interval between episodes 39 and 40; fig. 14). Episode lengths also approached a fairly uniform value in episodes 36 through 47 (fig. 15).

A major change in fountain style occurred following episode 39, and subsequent episodes (40–47) displayed: (1) maximum fountain heights that were uniformly lower than in episodes 21–30 (fig. 11), and (2) episodes that began much more gradually, with a slower buildup period of intermittent spillovers and low fountains. Since other eruptive-cycle parameters, including inter-episode duration (fig. 14), episode duration (fig. 15), and overall pattern of deflation (fig. 16) showed little change during this interval, we surmise that the abrupt change in the character of the fountains was not the result of decreased efficiency in magma transport between the summit and East Rift Zone. A review of seismic data raises the possibility that these changes may have been associated with increased earthquake activity near Puʻu ʻŌʻō. Four earthquakes greater than *M*3 occurred on Kīlauea's south flank near the middle East Rift Zone between episodes 39 and 40, producing a large step in seismic moment (fig. 16). An anomalously long inter-episode and tilt-recovery period followed episode 39 (figs. 14 and 16).

Deformation data suggest that this long recovery could have been the result of extension within the rift zone associated with the earthquakes. Following the earthquakes, leveling along a line that crossed the East Rift Zone just uprift of Puʻu ʻŌʻō revealed subsidence (fig. 17) that can be interpreted as graben formation owing to extension and collapse over the presumed trace of the

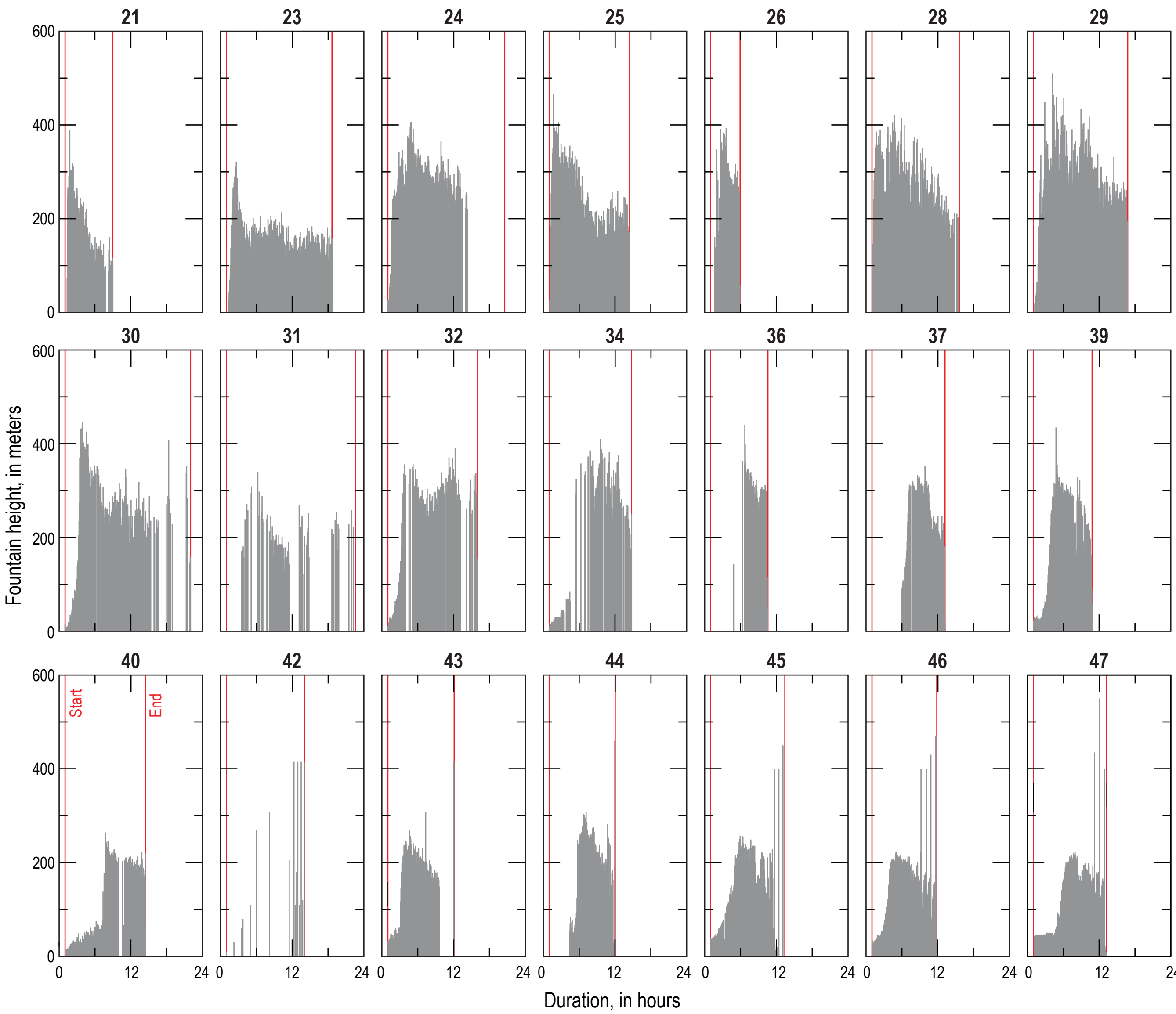


Figure 12. Graphs showing fountain heights for episodes 21–47. Missing episodes (22, 27, 33, 35, 38, and 41) are those when visibility was too poor to make observations. The red lines represent the beginning and ending of each episode. Fountain heights were determined primarily by digitizing film from 8-millimeter time-lapse movie cameras deployed on Puʻu Halulu. Theodolite measurements were also made from Puʻu Halulu when viewers were present; these provided an instantaneous record of fountain heights and a calibration point for the movie film. Gaps in the data for individual episodes are periods when visibility was too poor to make observations.

Figure 13. Graph comparing time-averaged discharge rate to fountain height for high-fountaining episodes 21 through 47. DRE, dense-rock equivalent.

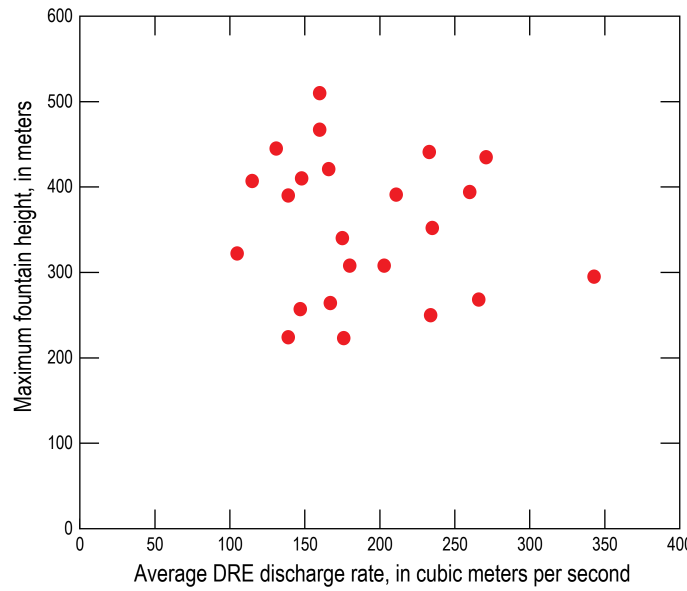
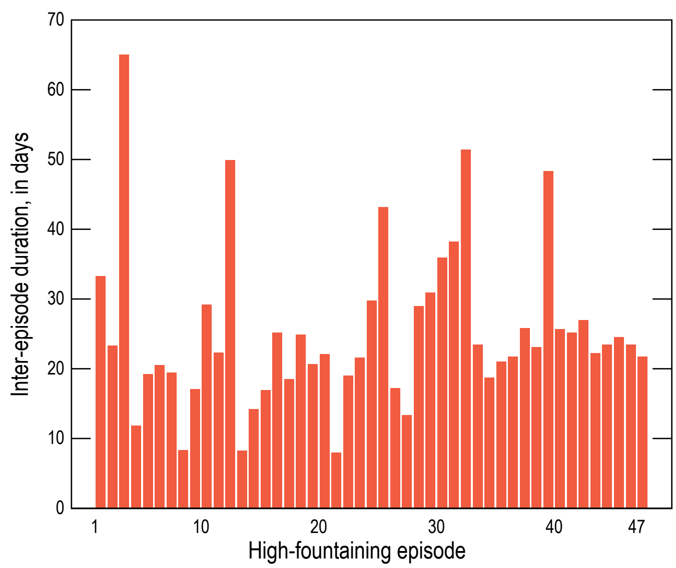


Figure 14. Bar graph showing the time span between high-fountaining episodes.



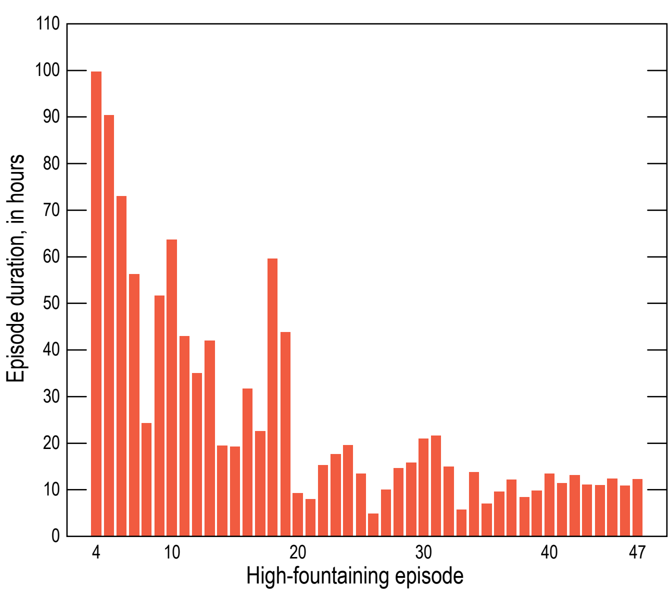


Figure 15. Bar graph showing episode duration for high-fountaining episodes 4 through 47.

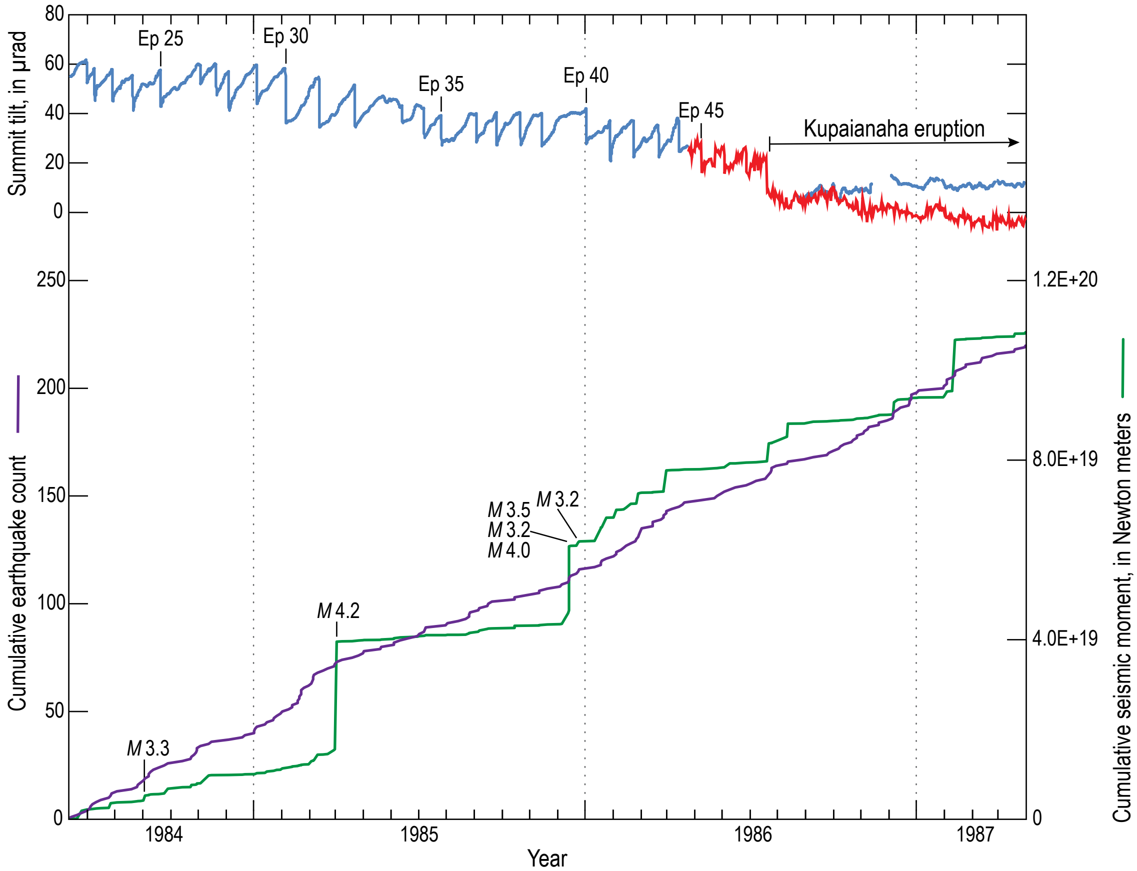


Figure 16. Graph showing summit tilt (Ideal Aerosmith tilt instrument in blue; Applied Geomechanics tilt instrument in red) compared to the cumulative number of earthquakes (purple) and the seismic moment (green) for Kīlauea's upper and middle East Rift Zone region for the period from June 1984 through April 1987. Episode number shown on tilt plot; earthquake magnitudes shown on seismic moment plot.

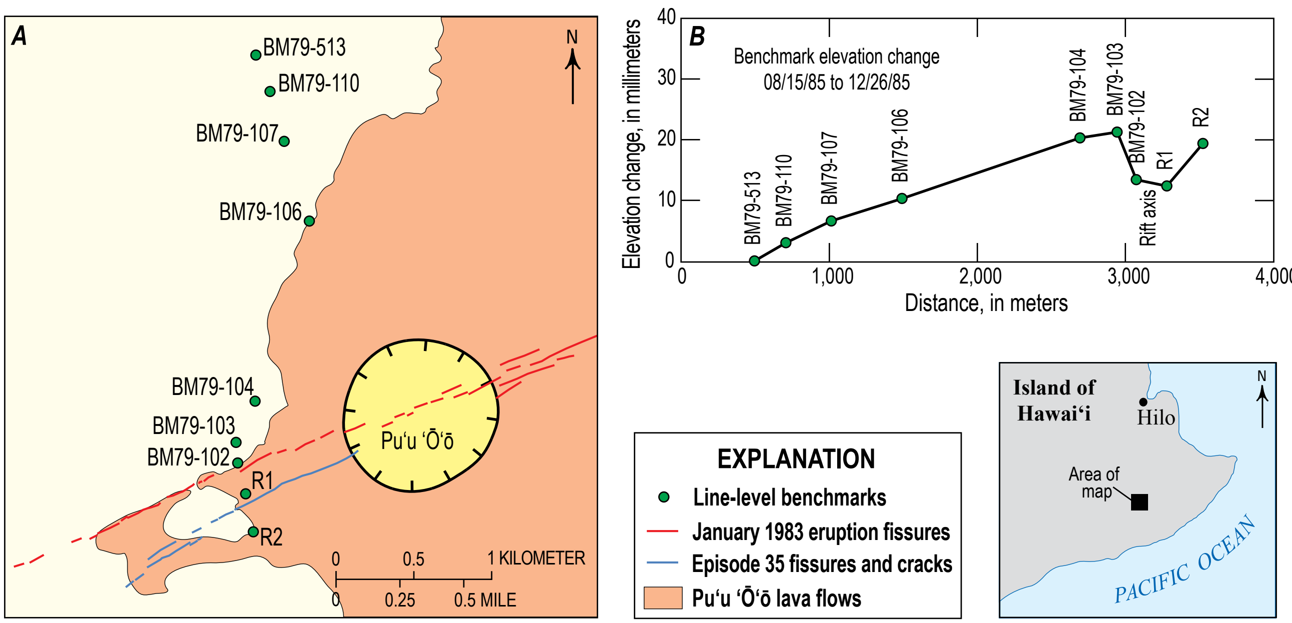


Figure 17. *A*, Map showing the location of level-line benchmarks (BM) crossing the East Rift Zone (ERZ) west of Pu'u 'Ō'ō. *B*, Graph showing elevation changes for the period from August 15, 1985, to December 26, 1985 (post-episode 35A to pre-episode 40), indicating ERZ graben formation, possibly associated with earthquake activity between episodes 39 and 40 (fig. 16). Leveling datum is BM79-513.

East Rift Zone dike. Seaward movement of Kīlauea's south flank could have enlarged the effective size of the local reservoir beneath Puʻu ʻŌʻō, prolonging the inter-episode period because additional filling was necessary to build pressure for the next episode. Likewise, extension in the East Rift Zone could have increased the cross-sectional area of the dike, reducing the overall pressure of the system, and resulting in lower fountain heights.

Jetting Events

During the final hours of episodes 42–47, we witnessed a new type of fountaining behavior, in which 1–4 brief jetting events occurred within the last 2 hours of the episode. A similar event near the end of episode 38 was recorded only by time-lapse film. Each event lasted 1–2 minutes and consisted of several pulses of magma-poor, gas-rich fountains that reached heights as great as 550 m (table 3) and created enormous, black tephra columns (fig. 18). Jetting fountains were accompanied by a loud hissing noise and followed by a brief period when the gas-and-tephra plume was so dense that it obscured the incandescent part of the fountain. After each event, the fountain died for a few minutes and then slowly recovered to its former (pre-jetting) height as a broad, smooth-looking fountain (fig. 19). The dome-shaped tops of these fountains had a roiling appearance that was unique to these events. The jetting pulses were separated by 31–53 minutes. Seismic tremor amplitudes dropped following each jetting event and picked up again before the next (Hawaiian Volcano Observatory, written commun., February 1986).

A similar event was recorded once before at Puʻu ʻŌʻō, during episode 12, when four separate vents within the crater were fountaining. Wolfe and others (1988) reported that 20 hours into the 35-hour-long episode, one vent began to produce a "vigorous jet of gas, possibly steam, with entrained tephra," after previously emitting a vigorous lava fountain. Unlike the jetting events of episode 42–47, the episode 12 jet was only 50 m high, and it persisted throughout the rest of the eruptive episode.

As in episode 12, the jetting events may have been driven by steam, possibly as the result of groundwater in proximity to the conduit. Geoelectrical data suggest that the groundwater table is sufficiently shallow near Puʻu ʻŌʻō that groundwater could have caused the jetting events. Electrical self-potential measurements made near Puʻu Kamoamoa, 0.8 km uprift of the vent, in May 1985 showed that the water table there was about 250 m below the ground surface (J. Kauahikaua, U.S. Geological Survey, written commun., late 1980s or early 1990s; data lost during Hawaiian Volcano Observatory building evacuation, 2018).

If the jetting events were steam-driven, we have no ready explanation for why they did not occur during other episodes. The rainfall pattern in 1986 was not unusual; in fact, there was less rain that winter and spring than in the same seasons in 1985. The jetting events occurred only in the waning stages

Table 3. Jetting events in episodes 42–47.

[–, no data; HST, Hawaiian Standard Time; m, meter; min, minute]

Episode and date	Jet number	Start time (HST)	Jet duration (min)	Height of fountain after jet (m)	Interval between jets (min)	Start of jet relative to episode end (min)	Height of jet (m)	Measurement techniques
38 (10/21/85)	1	1121	<3			3	–	
42 (2/23/86)	1	0233	~2	~180	38	107	370–460	Visual estimate
	2	0311	~2	~110	34		–	
	3	0345	~2	~110	31		–	
	4	0416	–			4	–	
43 (3/22/86)	1	1553	1–2			3	370–460	Visual estimate
44 (4/14/86)	1	0752	–			4	460	Theodolite
45 (5/8/86)	1	0921	1–2	–	45	105	–	
	2	1006	1	–	41		–	
	3	1047	2	–		19	450	Theodolite
46 (6/2/86)	1	1041	1.5	200	53	160	–	
	2	1137	1.5	100	43		–	
	3	1219	1.5	110	49		430	Time-lapse camera
	4	1310	1.5			14	470	Time-lapse camera
47 (6/26/86)	1	1433	–	212	52	123	435	Time-lapse camera
	2	1524	–	188	48		550	Theodolite
	3	1614	–			23	–	

of the eruptive episode, suggesting that somehow water, if the cause, was gaining access to the conduit as magma pressure declined.

On the other hand, a similar ash-laden plume formed during the Mauna Ulu eruption and was thought to be the result of fragmented crust being ejected by a pulsating gas jet during the waning phase of a lava fountain (Swanson and others, 1979). Perhaps waning pressure or a dropping lava level allowed material adhered to the vent walls to peel off and fall into the magma column, triggering vesiculation and providing material readily entrained in the resulting jet. No such material, however, was identified in the field following the jetting events.

Inter-episode Activity

The sequence of events leading to the next eruptive episode was generally predictable, but the timing was variable, and each inter-episode period was unique in detail. Inter-episode periods between episodes 20–48 ranged in length from 8.0 days (pre-episode 21) to 51.6 days (pre-episode 33) (fig. 14; table 1) and averaged 26.5 days (table 2), compared with an average of 23.1 days for episodes 4–20 (table 2; Wolfe and others, 1988). The durations of the inter-episode periods closely approached the average inter-episode period for the last 11 episodes; all but three were within 3 days of the average.

Rising Magma Column

Following each high fountaining episode, the magma column dropped rapidly in the near-vertical conduit. This event was observable only from a helicopter following the final bursts of lava, spatter, and fume that signaled the end of the episode. In a few optimal instances, the top of the outgassing column was afterward observed at a depth of 50 m or more, but in most cases it was too deep to see or obscured by fume.

If weather and fume conditions were favorable, the top of the magma column was visible again within a few days or weeks, rising from below the typical maximum depth of visibility of about 50 m. Though not generally visible when below this depth, we believe that the magma column was still present and that the magmatic system remained open. The column was often covered by a cooled crust, though frequent openings through the crust permitted spatter to be ejected (fig. 20). Visual estimates of depth were calibrated by timing the fall of a dense rock to the top of the column. Though not directly observed, we believe that the cap over the magma column, when present, moved in a piston-like fashion, essentially riding on top of the molten magma column as it rose and fell. As the crusted column neared the surface, spatter reached and coated the vent rim. Occasionally, during gas piston activity or Strombolian activity, the entire crust would be disrupted, and at night the reflected glow from the conduit during these events was sometimes visible for miles.

Figure 18. Photograph showing the final jetting event near the end of episode 44, as seen from Pu‘u Halulu. Photograph by C. Heliker, U.S. Geological Survey, 0753 HST, April 14, 1986.

Figure 19. Photograph showing a smooth-topped fountain following an episode 46 jetting event, as viewed from north of the Pu‘u ‘Ō‘ō cone. Photograph by C. Heliker, U.S. Geological Survey, 1059 HST, June 2, 1986.

Figure 20. Oblique aerial photograph looking at the Pu‘u ‘Ō‘ō vent showing a small spatter cone with an incandescent opening on top of the crusted magma column, during the period between episodes 29 and 30. Photograph by J.D. Griggs, U.S. Geological Survey, January 24, 1985.

Gas-piston Activity

Gas-piston activity—a short-term cycle of magma-column rise, vigorous outgassing, and magma drainage (for example, Swanson and others, 1979; Wolfe and others, 1988; Orr and Rea, 2012)—was a common occurrence during inter-episode periods. Gas-piston activity at Pu‘u ‘Ō‘ō produced a characteristic seismogram pattern, in which short bursts of higher-amplitude tremor developed and decayed in a symmetrical, cigar-shaped pattern, generally less than one minute in length, in alternation with longer periods of low-amplitude tremor (Koyanagi and others, 1988). Gas-piston activity occurred sporadically during inter-episode periods, with no obvious correlation to other processes, and was noted in 17 of the 28 inter-episode periods covered by this report. It occurred for various lengths of time and at various times between episodes, and it seemed to occur randomly for periods ranging from a few hours to a few days, except during the inter-episode period preceding episode 29, when gas-piston activity continued for the entire period of 29 days. When gas-piston activity was observed at the vent, it usually (but not always) coincided with the characteristic seismogram pattern described above.

Low-Level Eruptive Activity

Low-level eruptive activity preceding eruptive episodes 21–23 was minimal, but became more important through the remainder of the high-fountaining episodes. Beginning with the build-up to episode 24, we saw an evolution from weak spattering to intermittent effusion from low fountains that fed one or more short pāhoehoe flows. This sequence of events occurred in the few hours prior to continuous fountaining.

However, not all eruptive activity between episodes followed a pattern of gradual buildup to the main event. Four days prior to episode 25, a spatter cone formed over the crusted magma column, about 10 m below the top of the conduit. On the day before the onset of high fountaining, spatter from the 3-m-high cone fed several small pāhoehoe flows. The vent then remained quiet for 12 hours, at which time it was approached for gas sampling. Lava fountaining suddenly commenced and exceeded 100 m in height within 10 minutes, leading to an exciting scramble down the cone.

The pre-episode 26 activity was likewise unique in that (1) it was preceded by a long inter-episode period of 43 days (fig. 14), (2) magma reached the top of the conduit on day 35, and (3) the conduit overflowed intermittently for 8 days and formed a lava shield 10 m high and 100 m across, accompanied by pronounced gas-piston cycles. The 5-hour-long high-fountaining episode that followed was the shortest for episodes 21–47 (fig. 15).

Subsequent episodes were typically preceded by a rising magma column that was only partly crusted. A spatter cone generally formed on top of the crusted magma column, and, as the column neared the vent rim, more vigorous spatter bursts deposited Pele’s tears and other pyroclasts on the rim, in some cases forming a spatter rampart.

As noted above, the vigor of eruptive activity during the inter-episode periods typically increased from weak spattering, which built a spatter cone, to a low fountain, which produced short pāhoehoe flows that were active for as long as nearly 70 minutes. The entire interval of inter-episode activity during which pāhoehoe flows traveled beyond the vent area ranged from 3 to 18 hours. During the final inter-episode interval prior to episode 48, the column rose and formed a high spatter rampart/cone at the vent, but it collapsed under its own weight when the fissures opened at the base of Pu‘u ‘Ō‘ō, and the magma found an easier route to the surface.

Lava Flows

The early history of the Pu‘u ‘Ō‘ō eruption was characterized mainly by low fountains from the growing composite cone, producing a combination of rootless flows of spatter-fed ‘a‘ā near the cone and channelized pāhoehoe flows that transitioned to ‘a‘ā flows downslope, as described by Wolfe and others (1988). When the Pu‘u ‘Ō‘ō vent was enclosed by crater walls (episodes 4–19), a lava lake constrained the fountains, and overflows through the low points of the walls formed channels, or spillways, down which the lava rivers moved. These episodes tended to produce long, narrow flows—as long as 13 km in episode 18 (see Wolfe and others, 1988, plate 5).

The crater filled during episode 19, and fountains thereafter reached heights of more than 300 m early in most episodes (figs. 11 and 12). The lava flows of these episodes were dominantly spatter-fed and thus tended to be short, stubby ‘a‘ā flows that formed broad fans near Pu‘u ‘Ō‘ō, with a few exceptions. Although the lava leaving the vent appeared to be quite fluid, it seldom formed channels, except locally during the beginning stages of some episodes. The spillway terminology, however, was retained to describe the places around the cone down which lava flows were preferentially fed.

Thin pāhoehoe flows were also produced by the short-lived satellite and fissure vents that preceded and (or) overlapped the beginning of some high-fountaining episodes. Episode 35 was an exception, in that 16 days of continuous pāhoehoe effusion followed 7 hours of high-fountaining and ‘a‘ā flows, themselves preceded by a brief fissure outbreak. A 26-m-high pāhoehoe shield grew near the southeast base of Pu‘u ‘Ō‘ō in this event—a rare event in the eruption until the beginning of Kupaianaha in July 1986. A small pāhoehoe shield also formed over the Pu‘u ‘Ō‘ō conduit during the low-level activity preceding episode 26.

As the eruption continued, new flows were diverted around the higher ground of preceding flows. The patterns of mapped flows provide some insight into the systematic accumulation of basalt along rift zones. Prior to episode 20, lava accumulation was concentrated first along the axis of the rift zone where the early fissure vents produced pāhoehoe lava that filled existing depressions. Continued lava production resulted in flows moving southeast down the steeper slopes of the south flank of Kīlauea (see Wolfe and others, 1988, plate 1). Within eight months (during episode 6), new lava was first diverted northeast around the northern margin of the new lava field (see Wolfe and others, 1988, plate 2), and subsequent episodes continued this trend, controlled partly by the main exit channel through the northeast wall of Pu‘u ‘Ō‘ō. However, following episode 19 and the evolution of Pu‘u ‘Ō‘ō’s summit crater to a more level surface open in all directions except southwest, new lava could move away from the vent over a broad northwest-to-southeast sector and along paths of least resistance over and around the growing lava field. Most new lava produced in episodes 20–47, excepting episode 35, was ‘a‘ā. The distribution of these slow-moving, bulky flows was constrained by the flows of preceding episodes. Flows from episodes 20–26 advanced northeast, episodes 27–29 were diverted more toward the east, and episodes 30–35 even farther clockwise southeast. Episodes 36–41 were emplaced back to the east, in the same general direction as episodes 27–29. Episodes 42–46 traveled mostly east, with smaller branches that went north or south. Episode 47 finished up the sequence with lobes that traveled north, east, and south. Witnessing the construction of the new lava field in this manner makes it clear that, when studying undocumented lava sequences from basaltic volcanoes, one should not expect to find a complete stratigraphic sequence in any one location.

An average of 7.7×10^6 m^3 of lava erupted per episode during high-fountaining episodes 4–47 (table 2). The volume of lava flows for episodes 21–47 is estimated to be 216×10^6 m^3 (table 2), which, when combined with the volume of 121×10^6 m^3 determined for episodes 4–20 (Wolfe and others, 1988), brings the total DRE volume to 337×10^6 m^3 (table 2). This volume divided by the duration of the eruption from episode 4 through episode 47 (1,109 days) corresponds to an average eruption rate of about 3.5 m^3/s—remarkably close to the average eruption rate from the Kupaianaha vent during the first several months of episode 48C (see below). The cumulative volume of each episode from episode 4 through episode 47 is plotted on figure 21. These data are best fit by a line with a slope of 0.290, suggesting an average discharge rate of 3.4 m^3/s.

The total area covered by flows from the beginning of the Pu‘u ‘Ō‘ō eruption through episode 48B was about 40 km^2 (fig. 1; table 2). There are no obvious correlations between the inter-episode period that preceded or followed an episode and the time-averaged discharge rate and volume erupted by the episode (figs. 22–25), nor is there a correlation between discharge rate and erupted volume (fig. 26). There is also no obvious correlation between the duration of an episode and the volume of lava erupted (fig. 27). However, there is a correlation between episode duration

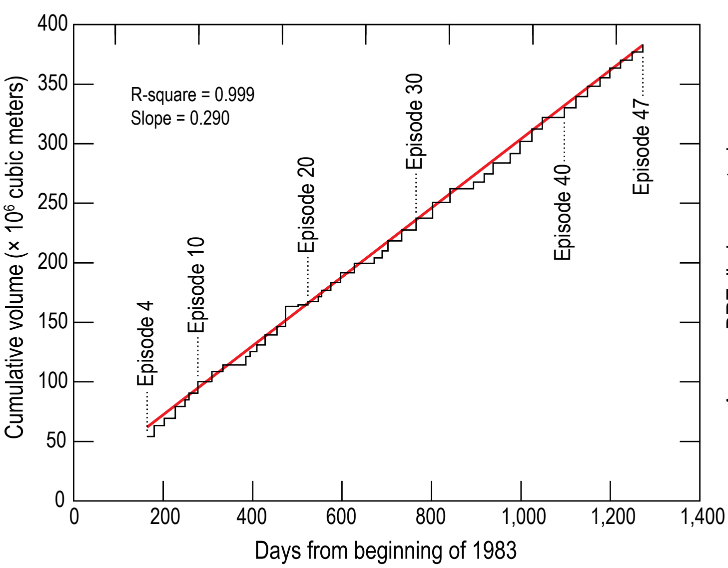


Figure 21. Graph showing cumulative volume of lava flows erupted during high-fountaining episodes 4 through 47. The data are fit well by a line with a slope of 0.290, indicating an average discharge rate of 3.4 cubic meters per second (m^3/s) for that period of the eruption.

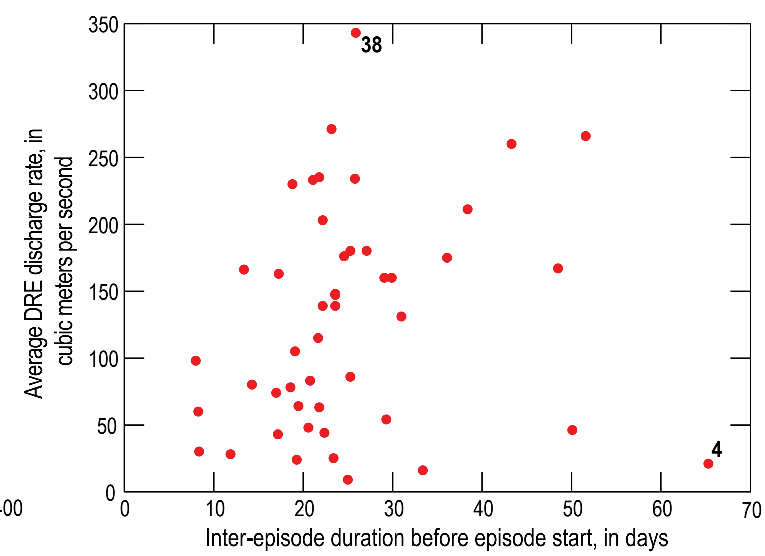


Figure 22. Graph comparing time-averaged discharge rate and the preceding inter-episode duration for episodes 2 through 48. DRE, dense-rock equivalent.

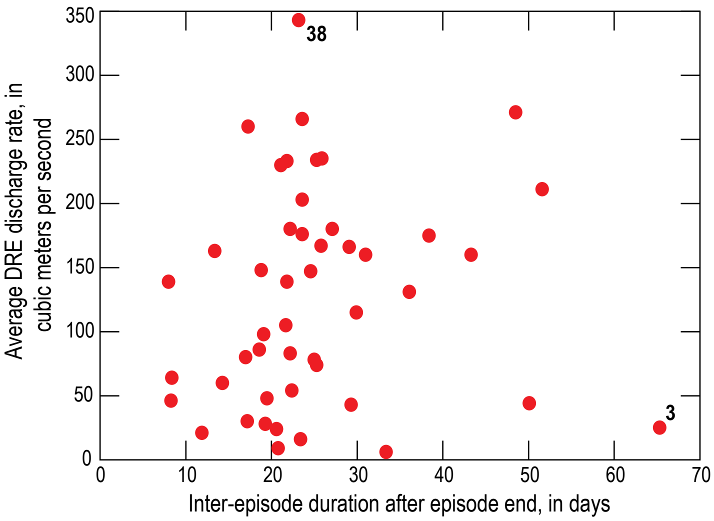


Figure 23. Graph comparing time-averaged discharge rate and the subsequent inter-episode duration for episodes 1 through 47. DRE, dense-rock equivalent.

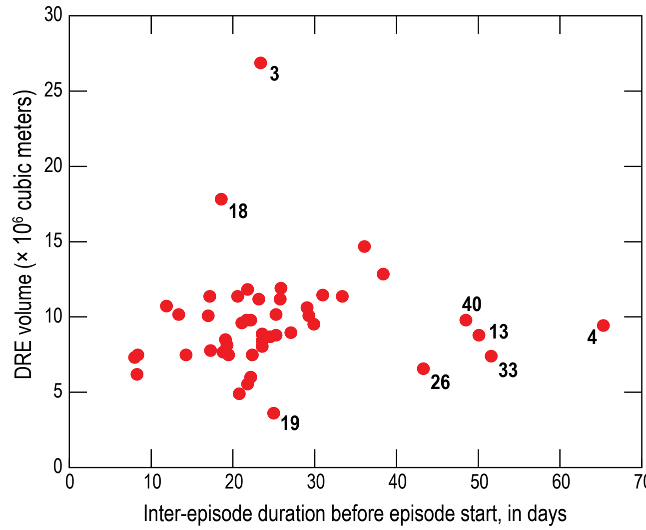


Figure 24. Graph comparing dense-rock equivalent (DRE) lava flow volume and the preceding inter-episode duration for episodes 2 through 48.

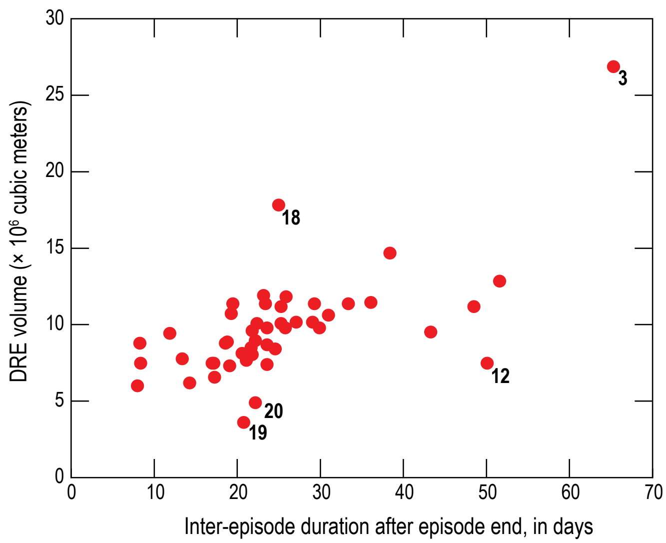


Figure 25. Graph comparing dense-rock equivalent (DRE) lava flow volume and the subsequent inter-episode duration for episodes 1 through 47.

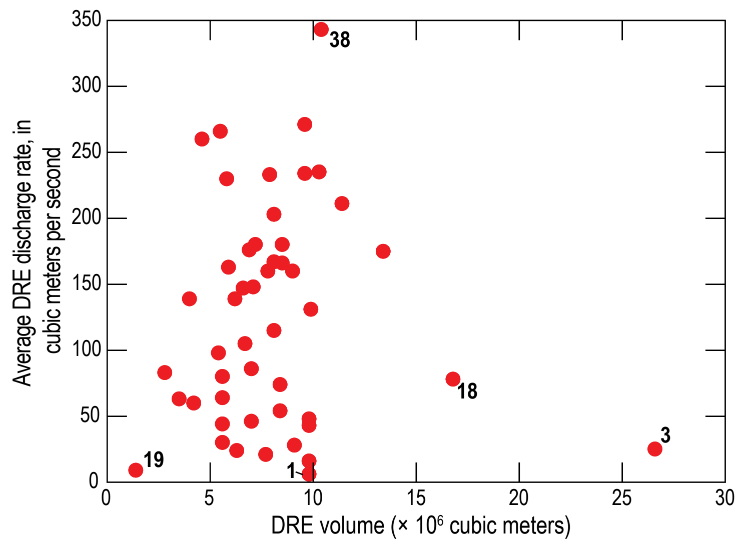


Figure 26. Graph comparing time-averaged discharge rate to the dense-rock equivalent (DRE) volume of lava erupted for high-fountaining episodes 1 through 47.

and the time-averaged discharge rate (fig. 28). This suggests that, for most episodes, roughly the same amount of lava erupted regardless of how quickly it came out.

The Kupaianaha part of the eruption (episode 48C), in July 1986, began less than 24 hours after the episode 48A and 48B fissure outbreaks ended at Pu‘u ‘Ō‘ō. A nearly continuous discharge of pāhoehoe from the episode 48C fissure 3 km downrift from Pu‘u ‘Ō‘ō slowly accumulated to form of a lava shield that reached ~45 m high and 1×1.5 km wide by April 1987 (the end of the period covered by this report). Long-lived overflows from a lava lake atop the shield evolved into a series of lava tubes that carried pāhoehoe lava to the south coast of the island until 1992. Lava breakouts from the tube system produced occasional short-lived lobes of ‘a‘ā and frequent flows of pāhoehoe. The estimated DRE volume produced from the Kupaianaha vent through its first 9.5 months (through April 1987) was about 98×10^6 m^3, which equates to a time-averaged discharge rate of about 4 m^3/s.

Fissure Outbreaks

Brief fissure or satellite-vent outbreaks (fig. 29) occurred in the early stages of 7 of the 27 high-fountaining episodes covered in this report, as detailed below (table 4). In addition, a 17-day-long fissure outbreak (episode 35A) followed the

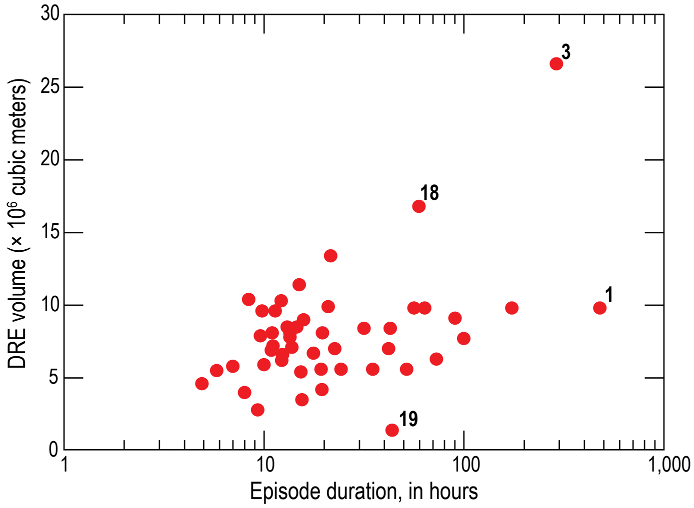


Figure 27. Graph comparing dense-rock equivalent (DRE) lava flow volume and episode duration for episodes 1 through 47.

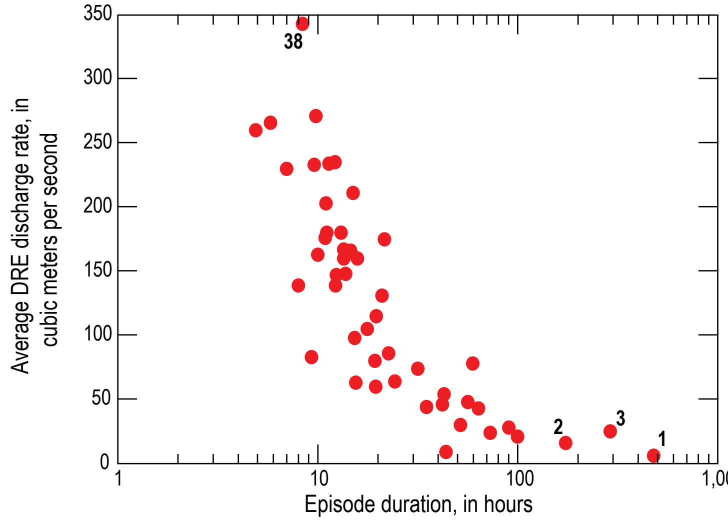


Figure 28. Graph comparing time-averaged dense-rock equivalent (DRE) discharge rate and episode duration for episodes 1 through 47.

high fountaining of episode 35; and, at the beginning of episode 48, fissure outbreaks (episodes 48A and 48B) preempted high fountaining and heralded the shift in vent site to Kupaianaha (episode 48C). Prior to episode 21, fissure outbreaks accompanied Puʻu ʻŌʻō high fountaining only during episodes 4 and 11 (fig. 29; Wolfe and others, 1988).

The first five of the seven early-episode events described here (episodes 21, 25, 28, 29, and 35A) opened along the surface trace of the East Rift Zone dike, either uprift or downrift from the cone, and were active for durations of ~2.5–3.75 hours. The other two early-episode events (episodes 39 and 44) were unique because of their longer durations (9 and 14 hours) and locations off the trace of the East Rift Zone dike.

Lava samples were obtained and analyzed from five of the seven early-episode fissures (episodes 21, 29, 35, 39, and 44). These showed no significant differences in whole-rock chemistry compared to samples from the main Puʻu ʻŌʻō vent during the same episode (Thornber and others, 2003a). Lava volumes produced by early-episode eruptive activity were usually unobtainable because the flows were buried by lava from the subsequent high fountaining, but none, except for episode 48, contributed much to the overall volume erupted during the entire episode.

The fissures and satellite vents of episodes 21–48 are described individually below and summarized in table 4. Refer to Heliker and others (2001) for detailed episode maps and fissure locations.

Episode 21

Spattering from the Puʻu ʻŌʻō conduit commenced at 1028 on June 30, 1984. Minutes later, lava overtopped the vent rim and began to flow down the northeast flank of the cone. At

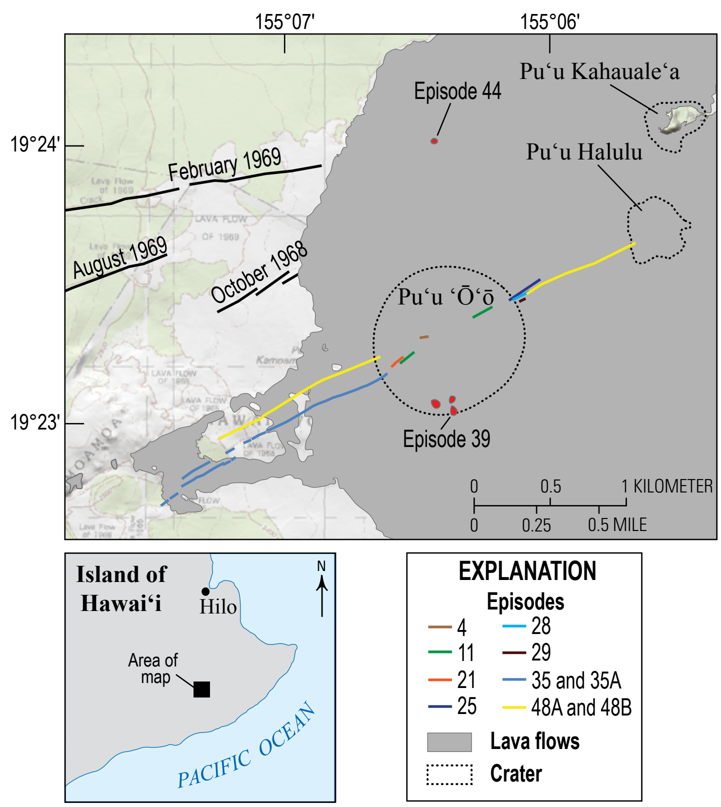


Figure 29. Map showing major topographic features and the locations of fissures and satellite vents associated with high fountaining episodes at Puʻu ʻŌʻō, including those of episodes 4 and 11 from Wolfe and others (1988). Fissures associated with eruptions in 1968 and 1969 that are roughly in line with the episode 44 flank vent are also shown. The episode 1 fissures associated with the start of the eruption are not shown.

Table 4. Summary of fissures and satellitic vents associated with high fountaining episodes at Puʻu ʻŌʻō.

[hr, hours; min, minutes; –, no data; km, kilometers]

Episode	Location	Duration	Start time relative to start of continuous effusion at Puʻu ʻŌʻō
4	Uprift fissure	–	Simultaneous
11	Uprift and downrift fissures	Entire episode	6 min before
21	Uprift fissure	≥3 hr 15 min	Simultaneous
25	Downrift fissure	2 hr 29 min	16 min after
28	Downrift fissure	3 hr 45 min	14 min after
29	Downrift fissure	≥2 hr 37 min	11 min before
35	Uprift fissure	<3 hr	Simultaneous or slightly before
35A	Uprift fissure	17 days	18 hr 20 min after
39	3 vents, south flank Puʻu ʻŌʻō	~12.5 hr	10 hr before
44	1 vent, 1.2 km north of Puʻu ʻŌʻō	9–15 hr	6.75 hr before
48A	Uprift fissure	15 hr 30 min	No effusion from Puʻu ʻŌʻō
48B	Downrift fissure	20 hr 51 min	No effusion from Puʻu ʻŌʻō

about the same time, a ~100-m-long fissure opened on the uprift (southwest) flank of the cone, producing a line of low fountains and a small pāhoehoe flow that ponded on the south side of Puʻu Kamoamoa. Vigorous fountaining of episode 21 from the main conduit started at ~1045; the fissure activity continued until at least 1352.

Episode 25

High fountaining during episode 25 began abruptly at 1604 on September 19, 1984. Sixteen minutes later, low (1–10 m) fountains erupted from a fissure 150 m downrift (northeast) from the Puʻu ʻŌʻō vent. The fissure propagated 400 m northeast rapidly, producing 10–12 discrete fountains. These fed small pāhoehoe flows that were compositionally identical to those from the main vent. The fissure vents died at 1849.

Episode 28

Continuous fountaining at the main vent during episode 28 began at 1905 on December 3, 1984. A fissure roughly 100 m long began fountaining on the downrift flank of the cone 14 minutes later and remained active until 2304. The fissure was in the same area as that of episode 25.

Episode 29

At 1315 on January 3, 1985, a helicopter pilot reported low fountains erupting from a fissure on the downrift flank of the cone, coincident with the onset of continuous lava production from the vent. The first high fountaining at the main Puʻu ʻŌʻō vent during episode 29 was recorded on the time-lapse camera film 11 minutes later. When observers arrived at 1345, low fountains (2–4 m high) from a fissure roughly 50 m long fed a thin pāhoehoe flow advancing southeast. The fissure activity died at 1622. The episode 29 fissure was in approximately the same location as those of episodes 25 and 28.

Episode 35

During episode 35, a fissure opened on the uprift flank of Puʻu ʻŌʻō either shortly before, or simultaneously with, the start of continuous fountaining at the main vent at 0252 on July 26, 1985. One branch of the pāhoehoe flow from the fissure advanced 300 m northwest into the center of the horseshoe-shaped Puʻu Kamoamoa cone, and a second branch advanced 1.7 km southeast. The fissure was inactive and buried beneath 50–100 centimeters (cm) of tephra by 0700. High fountaining at the main vent ended at 0952. Two hours later, a small pad of outgassed pāhoehoe oozed from the early episode fissure. This flow was active for an additional 80 minutes.

The same fissure reactivated at 1540 (but did not erupt) and propagated farther uprift. At 0414 on July 27, the fissure, which by then had extended 2.5 km uprift, began to erupt along the 1-km stretch closest to Puʻu ʻŌʻō (episode 35A). This activity persisted for 16 days.

Episode 39

Episode 39 was preceded by more than 24 hours of inter-episode activity mainly consisting of spattering from the Puʻu ʻŌʻō vent. At 0530 on November 13, 1985, three satellite vents opened on the south flank of the Puʻu ʻŌʻō cone. No fissure was evident. Continuous lava production began from the Puʻu ʻŌʻō vent four minutes later. The most active satellite vent was the farthest east and the lowest on the flank of the cone. When observers arrived at 0830, a 2-m-high fountain from this vent was feeding a flow that eventually covered an area 200 m wide and 600 m long. A smaller vent 150 m west lacked a fountain, but contributed a steady ooze of pāhoehoe to a flow that was 150 m long by the end of the day. The least productive vent was the highest up the flank of the cone, and it was inactive by 0830. From 0900 to 1530, the low fountain at the easternmost vent gradually increased to a height of 6 m. When observers left the south side of the cone at 1600, the activity was undiminished. Activity on this flank of the cone continued for approximately 2 more hours.

Episode 44

Episode 44 was preceded by the opening of a single satellite vent 1.2 km north of the Puʻu ʻŌʻō vent, just beyond the break in slope at the base of the cone. The satellite vent was already erupting when first observed from the air at 1410 on April 13, 1986, nearly 7 hours before sustained fountaining began at Puʻu ʻŌʻō. When observers arrived on the ground at ~1850, a 5–10 m high fountain was feeding a pāhoehoe flow that extended 500 m northeast. The satellite vent was active until sometime between 2300 on April 13 and 0455 on the April 14, and produced a flow about 300 m wide by 1 km long. The composition of the lava was identical to that from the main vent.

Episode 48

Episode 48 differed from preceding episodes by lacking a high fountain and by voluminous outpouring of lava from three fissures. Spattering and short overflows from the Puʻu ʻŌʻō conduit were interrupted by a swarm of microearthquakes beneath the cone on July 18, 1986. A little over an hour after the swarm began, the conduit drained and a fissure opened on the uprift side of the Puʻu ʻŌʻō cone. An hour later, a second fissure opened downrift from the cone. Both fissures eventually grew to over a kilometer in length. The uprift fissure (episode 48A) was active for nearly 16 hours, and the downrift fissure (episode 48B) for just over 20 hours. Together they produced a lava volume of 5.0×10^6 m^3, which is only a little less than each of the previous three high-fountaining episodes. Two days later, a third fissure (episode 48C) opened 3 km downrift from the Puʻu ʻŌʻō vent. This fissure evolved into the Kupaianaha vent, which assumed the leading role in the eruption for the next 5.5 years.

Insights on Episodes 21–48

The early-episode fissure and satellite-vent outbreaks were likely the result of excessive pressurization within the magmatic system beneath Puʻu ʻŌʻō, though why this was the case is not clear. The fissures usually stopped after a few hours of high fountaining, presumably once some of the pressure had been relieved. The satellite vent of episode 44 is puzzling given the structure of the rift zone. The vent was roughly on line with large cracks formed during eruptions in 1968 and 1969 (fig. 29), but there is no evidence that those fractures dipped southward such that they could have tapped the magma body beneath Puʻu ʻŌʻō. It seems unlikely that a new radial fracture could develop from Puʻu ʻŌʻō and cut across the rift zone, though such a scenario cannot be ruled out. Another possibility is that magma squeezed from the pressurized reservoir intersected and then leaked through pre-existing en echelon fractures to find its way to the surface. The episode 39 satellite vents were much closer to the main conduit and could have been shallow offshoots of that conduit. Both the episode 39 and 44 satellite vents were active much longer than the early-episode fissures, perhaps because the same volume was escaping from single vents rather than long fissures, making it easier for the vents to stay open.

The high fountaining during episode 35 produced a low volume of lava compared to all but one of episodes 28–42 (table 1). That may explain why there was sufficient pressure left in the Puʻu ʻŌʻō magmatic system to cause magma to reoccupy the fissure formed early in the episode and to extend it farther uprift. The combined lava volume of episodes 35 and 35A was only slightly less than that of most of episodes 28–42 (table 1).

The fissures at the beginning of episode 48 were apparently the result of a rupture in the Puʻu ʻŌʻō conduit that was large enough to divert all of the magma, rather than only some of it, as happened with the fissures that accompanied earlier episodes. And, unlike before, this diversion was permanent and brought to a close the episodic high fountaining at Puʻu ʻŌʻō.

Chronologic Narrative

Episode 21 (June 30, 1984)

Eruptive episode 21 started 22 days after episode 20. During this inter-episode period, the top of the active magma column, when first observed, was about 30 m below the vent rim (in other words, the rim of the conduit). After the first week, when the column was exposed and gas emissions were low, a crust formed over 50 to 90 percent of the surface. This condition was interrupted by occasional outgassing events and crustal overturn until shortly before the high-fountaining episode commenced on the morning of June 30, 1984.

Early on June 30, harmonic tremor recorded by a seismometer on the north flank of Puʻu Kamoamoa (KMM; figs. 1 and 30), about 600 m from the Puʻu ʻŌʻō vent, indicated that gas-piston activity was occurring. This pattern became erratic several hours prior to the episode, and tremor amplitude increased abruptly at 1028, which is taken to be the start of episode 21. High-amplitude tremor continued until the end of lava production, when it returned to background level, as it did during previous episodes (Koyanagi and others, 1988).

The first evidence of eruptive activity, recorded by a time-lapse camera, was spattering visible above the vent rim starting at 1033 on June 30. By 1037, lava was spilling over the northeast side of the cone. At approximately the same time, a 100-m-long fissure opened on the southwest flank of Puʻu ʻŌʻō, producing a line of low fountains and a small pāhoehoe flow that ponded on the south side of Puʻu Kamoamoa (fig. 30). Observers arrived at the eruption site at ~1045 to witness the beginning of vigorous fountaining. The fissure activity continued until at least 1352.

Fountain-fed flows moved down the north and northeast flanks of the cone (fig. 31). The largest flow traveled northeast over and around either side of a flow emplaced during

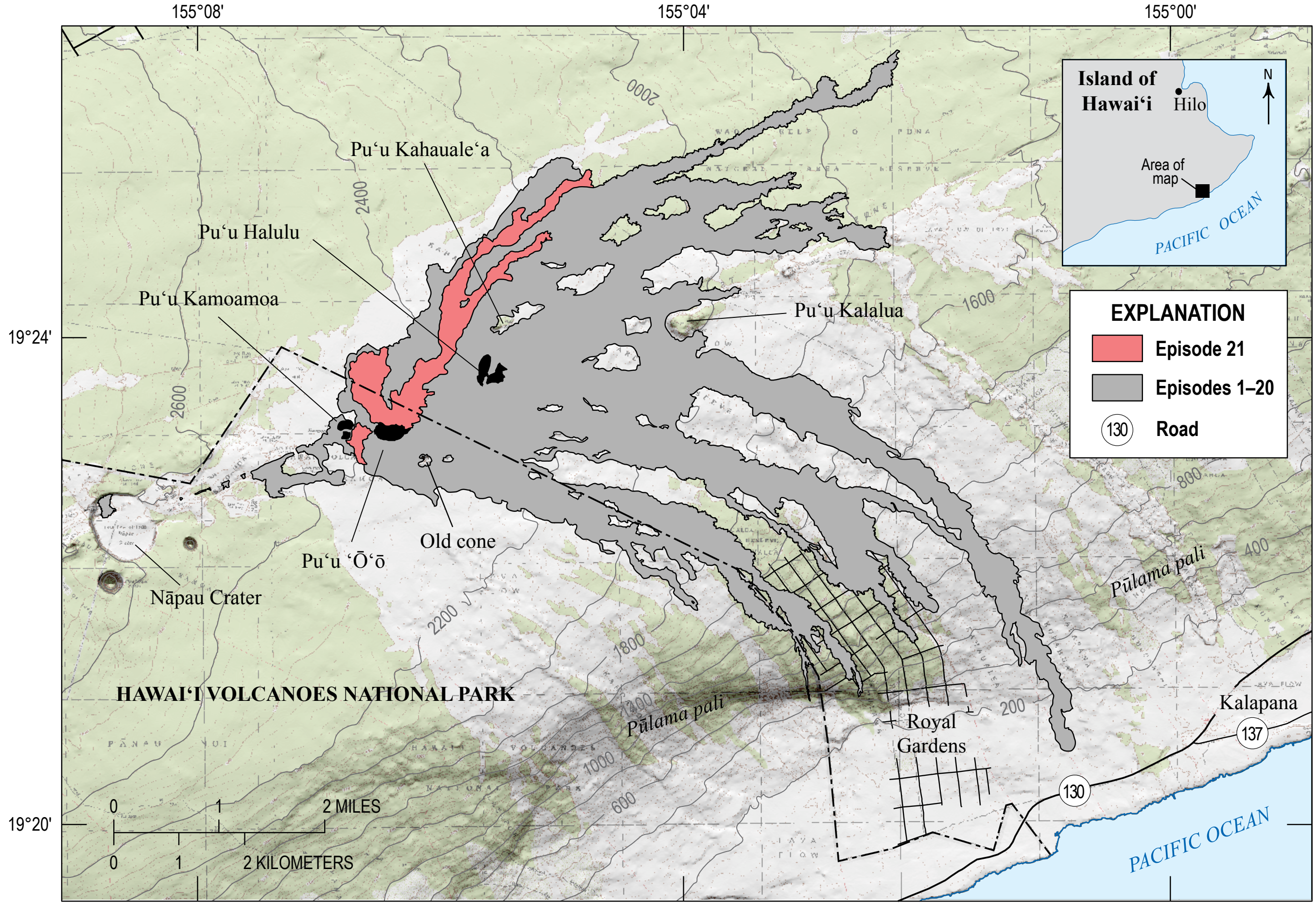


Figure 30. Map showing the distribution of episode 21 lava flows compared to earlier Pu‘u ‘Ō‘ō flows.

episode 20. Its terminus continued advancing after the end of fountaining, traveling several hundred meters into the forest beyond the northern margin of the Pu‘u ‘Ō‘ō flow field and reaching a maximum length of nearly 5 km (fig. 30). Spatter-fed ‘a‘ā from the northwest rim of the cone over-rode a similar episode 20 flow for approximately one kilometer. A thermocouple measurement of the active flow stabilized at 1,140 °C. A blanket of tephra, including reticulite from the highest fountaining, was deposited downwind on the summit and southwest side of the vent.

A maximum fountain height of 390 m (above the vent rim) was recorded 47 minutes after the start of the episode (fig. 32). This high burst was measured by theodolite during continuous sighting of the fountain. Fountain heights of more than 300 m were measured during three previous episodes, beginning with episode 15 in February 1984 (see table 1 in Heliker and Mattox, 2003). After about the first hour, fountain heights decreased gradually for the next 3 hours to less than 150 m, but remained vigorous until 1827, when lava production abruptly ended. Heavy fuming and sporadic orange flames, possibly from combusting hydrogen, continued from the vent for about another hour.

Summary

Episode 21 (table 1, fig. 30) produced an estimated 4.0×10^{6} m^3 of lava over a duration of 8.0 hours and covered an area of 2.1 km^2, corresponding to a time-averaged discharge rate of ~139 m^3/s. This was the highest time-averaged discharge rate measured to date for the Pu‘u ‘Ō‘ō eruption. The previous record-high time-averaged discharge rate was 93 m^3/s, achieved by episode 20 (Wolfe and others, 1988). The eight-hour-long episode was also the shortest to date. The summit of Pu‘u ‘Ō‘ō grew by 12 m, reaching a height of 142 m in its first year of existence as the main eruption center (fig. 33). A glass temperature of 1,164 °C was calculated from tephra collected from the ground after fountaining ended (Thornber and others, 2003a).

Figure 31. Oblique aerial photograph, looking southwest, showing the episode 21 lava fountain feeding an ʻaʻā flow advancing northeast from Puʻu ʻŌʻō. A spatter-fed ʻaʻā flow on the north (right) flank of the cone feeds a stubby flow. The fountain height is ~180 meters. Photograph by J.D. Griggs, U.S. Geological Survey, 1343 HST, June 30, 1984.

Figure 33. Oblique aerial photograph looking south of Puʻu ʻŌʻō after episode 21, when the summit of the cone was 142 m above the pre-eruption ground surface. Photograph by G. Ulrich, U.S. Geological Survey, July 1, 1984.

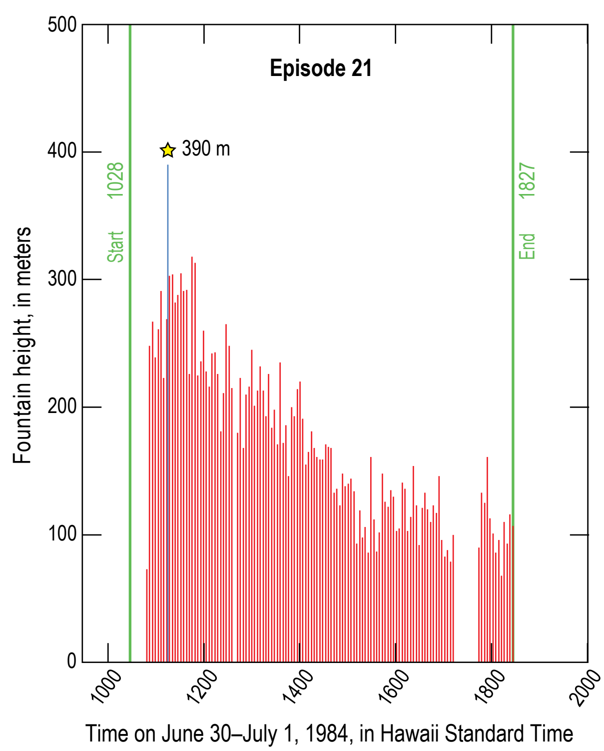


Figure 32. Graph showing episode 21 fountain heights measured from time-lapse film. The blue line and yellow star marks the highest fountain, measured by theodolite. The time interval between measurements is 3.6 minutes; data gaps are the result of poor visibility.

Episode 22 (July 8–9, 1984)

Episode 22 began only 8 days after episode 21. During this time, the top of the conduit remained open, with a diameter of about 20 m. The top of the magma column was partly visible at a depth of about 40 m on three visits.

Foggy weather on the evening of July 8 prevented a clear view of Pu‘u ‘Ō‘ō from the time-lapse cameras. The tremor amplitude increased significantly at 1859, however, and was continuous thereafter, providing our best indication of the episode onset. At 2030, the cameras on Pu‘u Halulu first recorded a faint glow through dense clouds, coincident with the first visual and audio reports received from residents south of Glenwood (13 km NNW of Pu‘u ‘Ō‘ō), indicating that either eruption vigor increased or that the clouds lifted about an hour and a half after the onset. The fountaining was first heard at the Hawaiian Volcano Observatory (HVO), nearly 20 km away, at 2045, and fountaining was occasionally recorded by the time-lapse cameras through the night. Observers did not reach the eruption site until 0815 the following morning, when they estimated fountain heights at 60–90 m above the crater rim.

Lava flows issued from the north and northeast sectors of Pu‘u ‘Ō‘ō, following the channel of episode 21. Flows advanced over three areas (fig. 34): (1) northeast for more than 6 km, partly on top of episode 21 flows and along the forest margin at the northern edge of the Pu‘u ‘Ō‘ō flow field; (2) southeast for approximately 2 km; and (3) east-northeast as a stubby ‘a‘ā fan about 1 km long. Pāhoehoe broke through the margins of the stubby ‘a‘ā flow briefly as its forward motion ceased. A thermocouple reading on active slabby pāhoehoe of the southeast flow gave a temperature of 1,139 °C. The fountaining ended abruptly at 1017 on July 9. The subsequent level of the crater floor was even with both spillways and formed a relatively flat surface surrounding the otherwise unchanged conduit opening.

Summary

Episode 22 (table 1, fig. 34) covered an area of 2.8 km^2 and produced an estimated 5.4×10^6 m^3 of lava over its 15.3-hour duration, with a time-averaged discharge rate of 98 m^3/s. The summit of Pu‘u ‘Ō‘ō grew by 3 m during episode 22, reaching a height of 145 m. A glass temperature of 1,164 °C was calculated from tephra collected from the ground surface after fountaining ended (Thornber and others, 2003a).

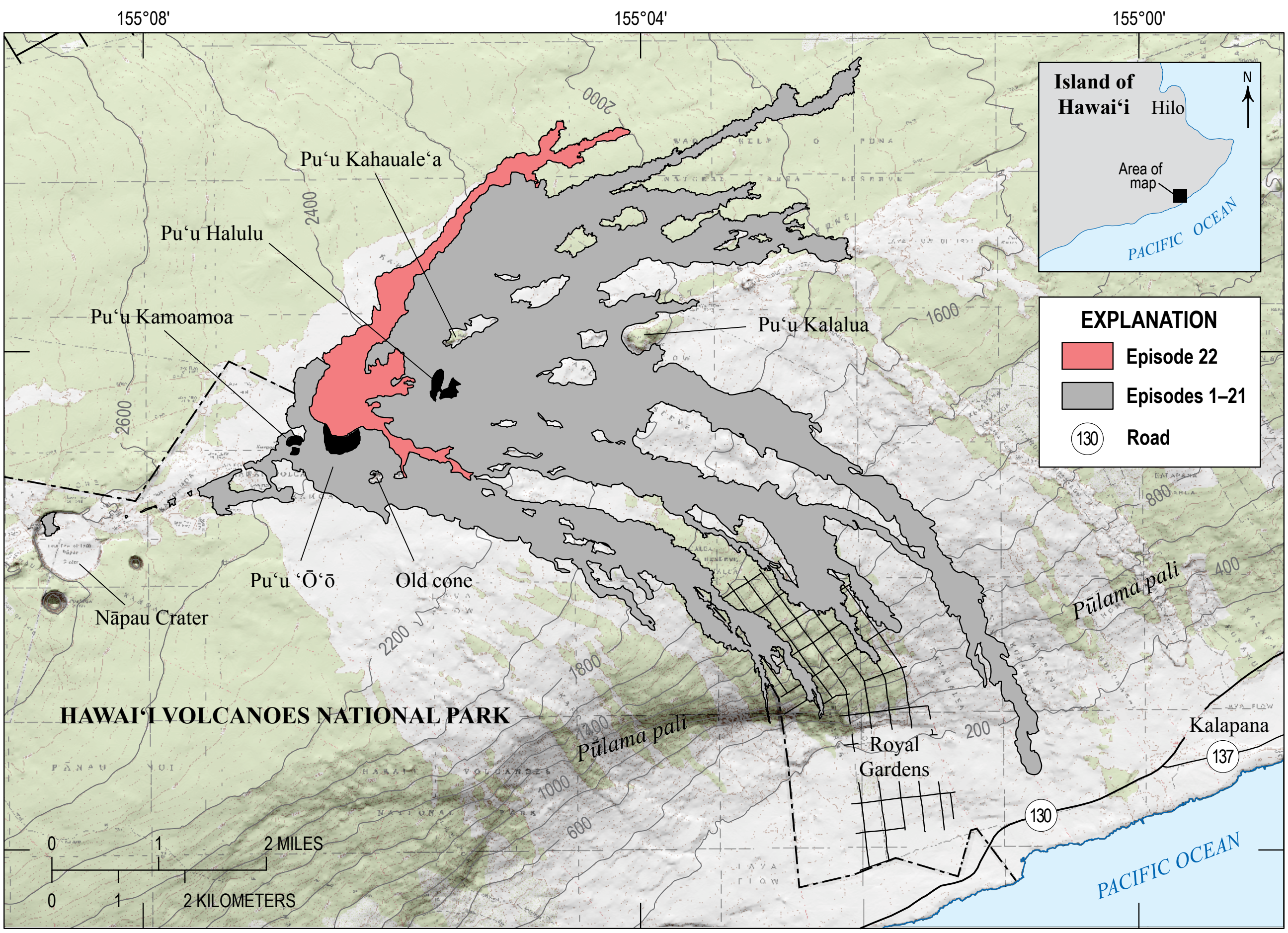


Figure 34. Map showing the distribution of episode 22 lava flows compared to earlier Pu‘u ‘Ō‘ō flows.

Episode 23 (July 28–29, 1984)

Episode 23 started 19 days after episode 22. Ten days prior to the episode, an observer on an overflight reported the magma column visible in the conduit at a depth of about 25 m. Five days later, the conduit was observed to narrow downward to the top of the column approximately 40 m below the surface. As the episode drew nearer, the column rose and fell at varying intervals of several minutes to hours, coincident with seismicity consistent with gas-piston activity. On July 26, the magma rose to within 10 m of the vent rim, and gas-piston cycles occurred at 2- to 3-minute intervals, depositing spatter on the rim during the outgassing phase of the events.

Visiting photographers occupying the Puʻu Halulu camp witnessed the first lava to overflow the northeast spillway at 1200 on July 28, which was marked as the onset of continuous discharge. Twenty minutes later, fountaining was observed from 25 km away on the Mauna Loa Strip Road, west of Kīlauea's summit. HVO observers arrived at the eruption site at 1325 and measured fountain heights of 150–200 m (fig. 35). Spatter-fed lava flows moved rapidly down the cone (fig. 36), following channels formed during episode 22, but the flows' advance rates soon slowed to about 5 meters per hour (m/h) as their ʻaʻā termini cooled and thickened.

The main flow, supplied by way of the north spillway, maintained a nearly constant rate of advance of 250 m/h across a broad front for the entire episode. It overran much of the episode 22 flow and an additional 100–200-m-wide swath of forest north of Puʻu ʻŌʻō (fig. 37). A smaller flow followed the northeast channel and terminated 1.4 km from the cone, flowing mostly over episode 22 flows. The northeast spillway, a major route of former eruptive phases, was subordinate to the north spillway and became inactive before the end of the episode.

In addition, a stubby ʻaʻā flow with a front several meters wide advanced 800 m from the southeast rim, invading for

Figure 36. Oblique aerial photograph of Puʻu ʻŌʻō, looking southwest, showing the episode 23 fountain and spatter-fed flows 5 hours after the start of the episode. The flows originate at the base of the fountain from fallback and move rapidly down channels inherited from the preceding episode. Photograph by J.D. Griggs, U.S. Geological Survey, 1654 HST, July 28, 1984.

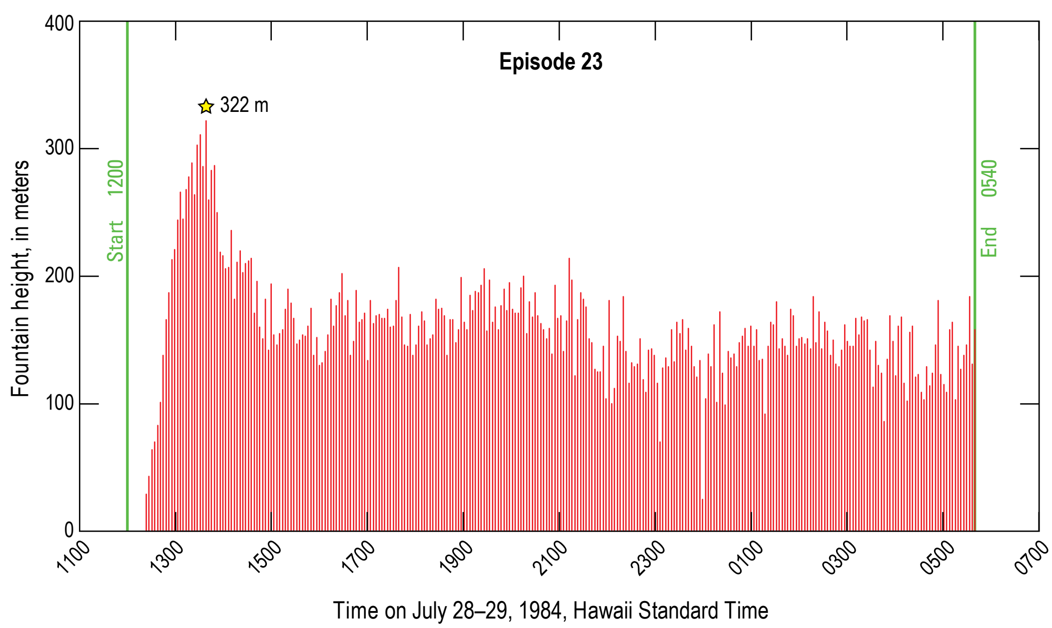


Figure 35. Graph showing episode 23 fountain heights measured from time-lapse film. The yellow star marks the highest fountain. The time interval between measurements is 3.6 minutes.

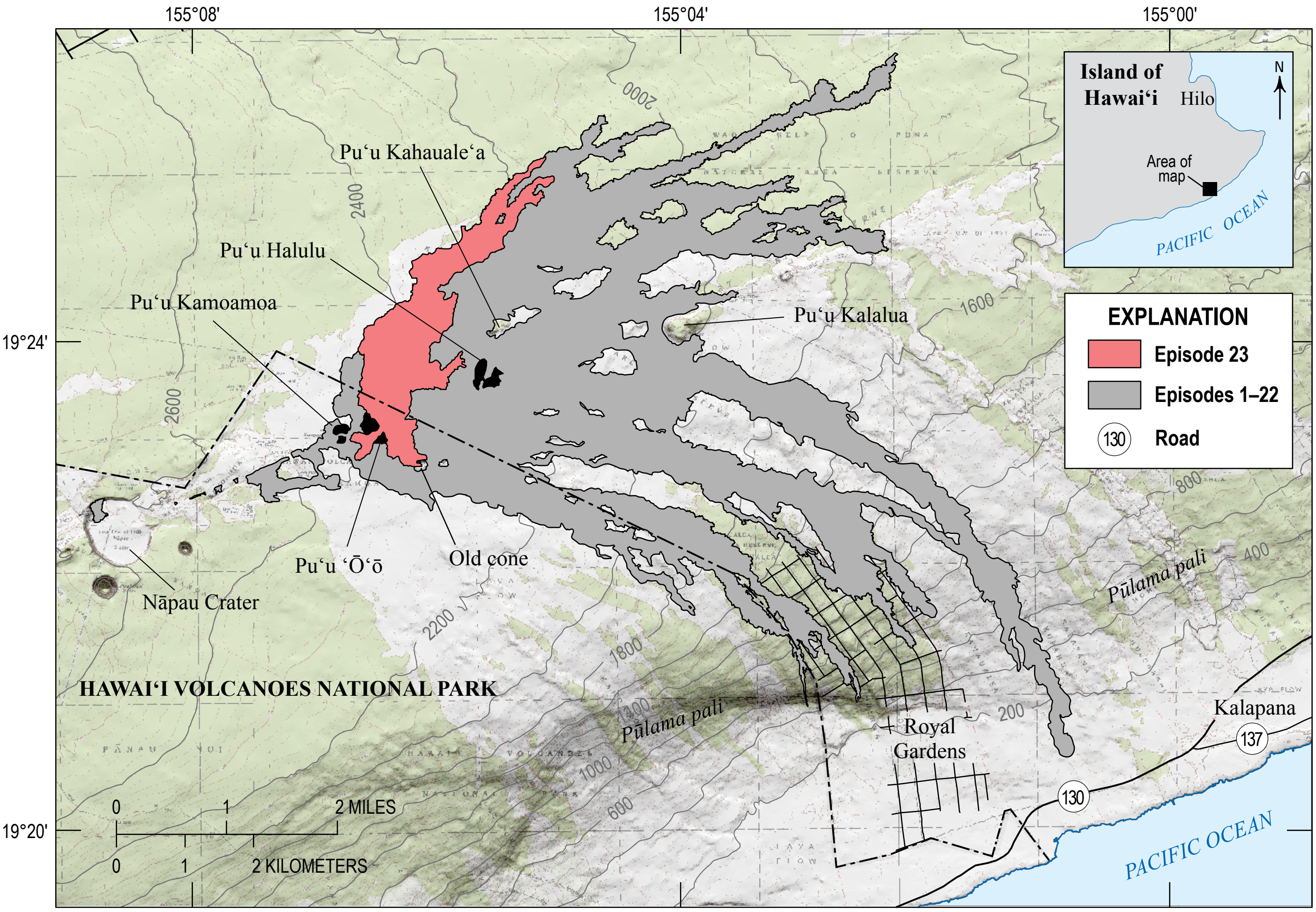


Figure 37. Map showing the distribution of episode 23 lava flows compared to earlier Puʻu ʻŌʻō flows. Flows also invaded the crater of a >1,500-yr-before present vent (see text).

the first time the crater of a cone assigned a >1,500-yr-before present age by Holcomb (1987) (fig. 37).

At 1338, time-lapse film recorded a maximum fountain height of 322 m, in general agreement with the highest theodolite measurement (7 minutes later) of 305 m. Subsequent fountain heights were lower than 300 m, fluctuating generally between 100 and 200 m for the remainder of the episode. The pattern of fountain heights as sampled every 3.6 minutes on film is shown in figure 18. Continuous observation revealed that as the fountaining decreased in height, it broadened at the base and exhibited a pulsating pattern of ~30-second-long pulses (fig. 38*A*) separated by 30-second to 3-minute intervals (fig. 38*B*). The pulses were accompanied by increases in fountain height and sound volume and by surges of lava down the slopes of Puʻu ʻŌʻō.

The episode ended abruptly at 0540 on July 29, after several minutes of sporadic low fountaining. An orange flame, interspersed with moderate-to-heavy fume, flared above the vent for several tens of minutes afterward. The flame was visible from the camp at Puʻu Halulu, about 1.5 km away, suggesting that it reached at least 10–20 m above the vent.

Summary

Episode 23 (table 1, fig. 37) produced an estimated 6.7×10^6 m^3 of lava over 17.7 hours for a time-averaged discharge rate of ~105 m^3/s. Lava flows, which were almost entirely spatter-fed ʻaʻā, were supplied from three spillways (north, northeast, and southeast); the flow from the north spillway overran a new swath of forest. An area of 3.4 km^2 was covered by lava. A glass temperature of 1,165 °C was calculated from tephra erupted about 4.5 hours after the onset of fountaining (Thornber and others, 2003a).

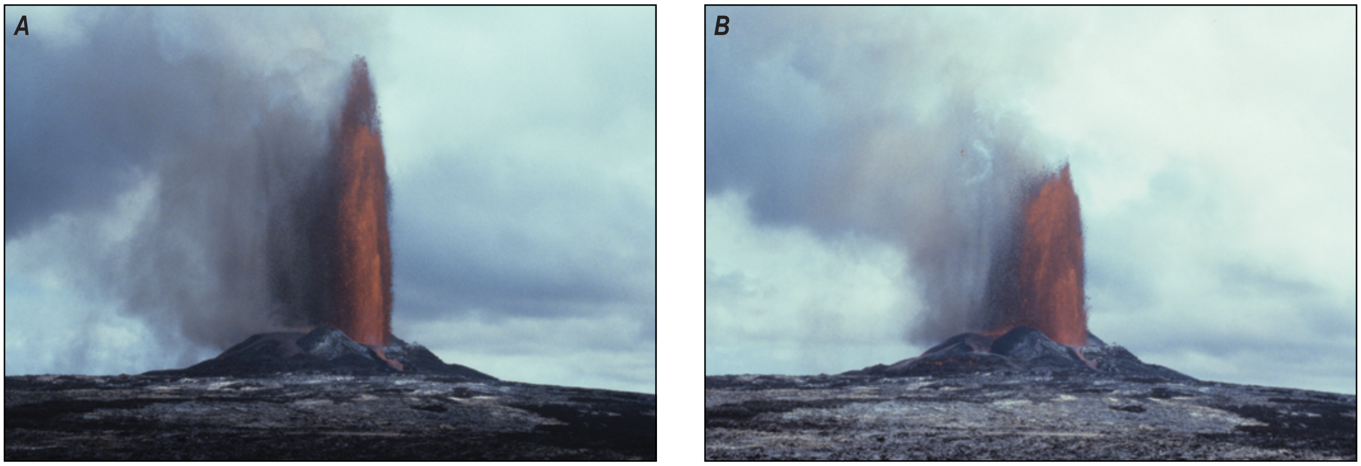


Figure 38. Photographs of Puʻu ʻŌʻō lava fountain during episode 23, looking southwest, showing differences in the height of the pulsating fountain. Photographs by J.D. Griggs, U.S. Geological Survey, July 28, 1984.

Episode 24 (August 19–20, 1984)

The inter-episode period preceding episode 24 lasted 22 days. During this time, the top of the magma column, when observed, was estimated at 30–40 m below the vent rim. The column was partly crusted over, but actively spattering. From August 6 to 13, gas-piston events occurred at intervals of 3–10 minutes.

At 0500 on August 19, summit tremor amplitude increased and summit inflation accelerated. When observers arrived at the rim of Puʻu ʻŌʻō at 1630, the magma column had risen to within 5 m of the crater floor and was producing sporadic spatter bursts. The spattering became more regular by 1815 and evolved to a nearly continuous low fountain over the next few hours. The low fountain intermittently fed a pāhoehoe lava flow down the northeast spillway. The recorded start of episode 24 at 2152 was marked as the time when lava flows began to continuously overtop the north spillway, which was the main pathway for flows in this episode. Within an hour, the northeast spillway was abandoned, and all of the lava was directed down the north spillway, feeding a broad channelized ʻaʻā flow that spread north and northeast. This flow overran the initial pāhoehoe flow and much of the episode-23 flow area and invaded forest along the northern margin of the flow field (fig. 39). The rate of flow advance was approximately 230 m/h throughout the episode. Nearly an hour after midnight, the flow terminus was about 600 m wide and approximately 1 km north of the vent.

Fountain height increased rapidly between 2220 and 2240 to about 250 m above the vent rim (fig. 40). During the next 3 hours, the fountain climbed irregularly to a maximum height of 407 m at ~0143 on August 20. The fountain remained vigorous thereafter but had declined to levels 200–300 m above the conduit by the next morning, although it continued to feed lava over the north spillway (figs. 41 and 42). At 0945 on August 20, the broad ʻaʻā front (about 1.5 km wide) was still advancing northeast.

By late morning (1030) August 20, the weather had deteriorated, and the fountaining was obscured most of the time thereafter by fog and rain. Beginning about 1100, a late-stage channelized pāhoehoe flow, which transitioned to ʻaʻā downstream, overran a large area of the earlier ʻaʻā flow. The fountaining, when briefly visible at 1235, had decreased in height by 10–20 percent. The channelized flow fed a narrow lobe of ʻaʻā that moved eastward from the stagnating ʻaʻā front of earlier in the day, eventually reaching a final straight-line distance of 4 km from the vent by the end of the episode (fig. 39).

Winds were light and variable throughout episode 24. As a result, tephra fallout was widely dispersed and shifted from one sector to another around the cone. Late in the afternoon, large dust devils played above the open channel, lofting 1–2-m-sized plates of glowing crust 10 m or more above the surface of the channel.

The end of the fountaining was detected by sound rather than sight. The steady roar of the fountain began to fluctuate shortly after 1700, producing “chugging” sounds, and by 1725 the vent was silent and the episode was over.

Summary

The total volume of lava erupted in episode 24 (table 1, fig. 39) was about 8.1×10^6 m^3 over 19.6 hours, giving a time-averaged discharge rate of ~115 m^3/s. The flows covered 3.7 km^2. The cone height reached 150 m above the pre-1983 ground surface, increasing 20 m in height since episode 20 on June 8 (fig. 43). A glass temperature of 1,165 °C was calculated from tephra erupted about 10 hours after the start of fountaining (Thornber and others, 2003a).

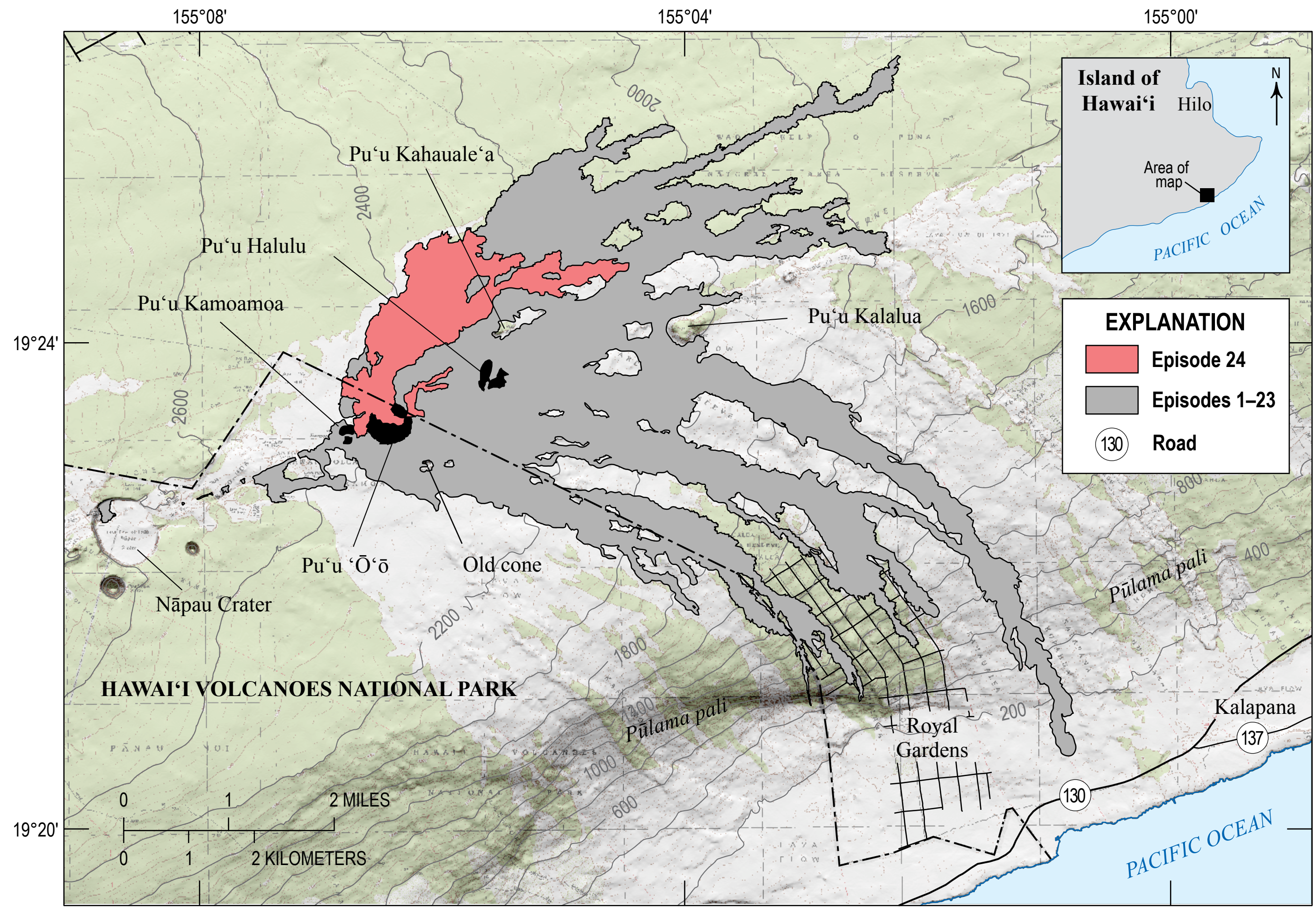


Figure 39. Map showing the distribution of episode 24 lava flows compared to earlier Pu‘u ‘Ō‘ō flows.

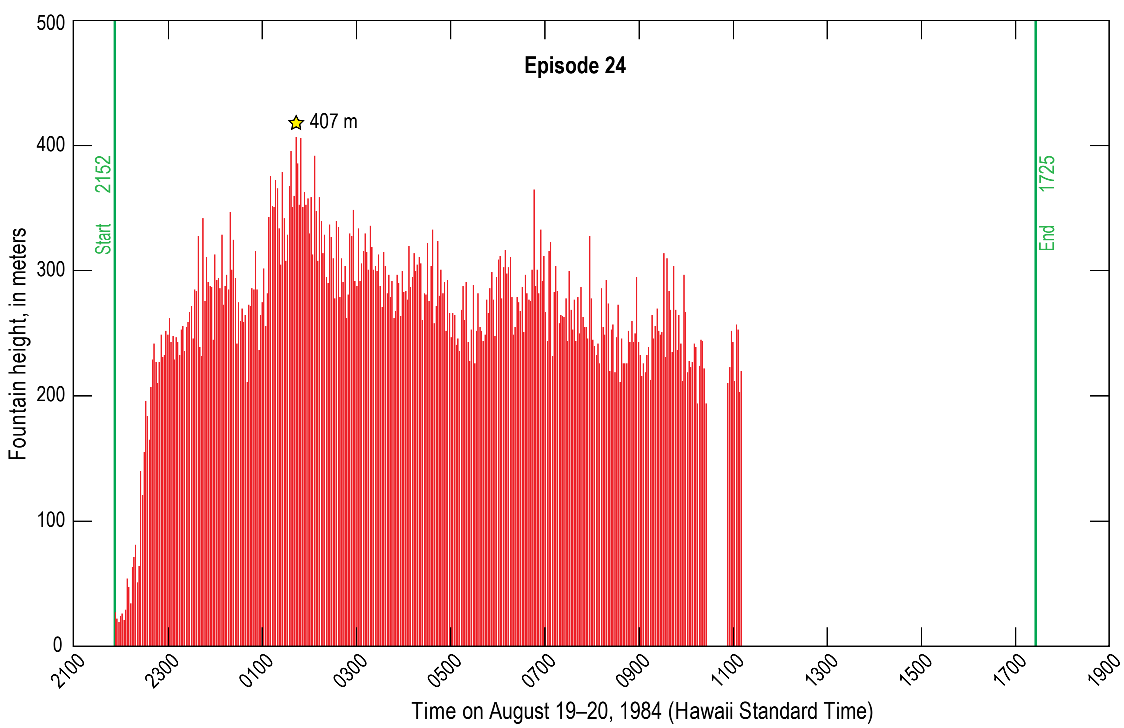


Figure 40. Graph showing episode 24 fountain heights measured from time-lapse film. The yellow star marks the highest fountain. The time interval between measurements is 2.2 minutes; data gaps are the result of poor visibility.

Figure 41. Oblique aerial photograph of the Puʻu ʻŌʻō cone showing the episode 24 fountain feeding a channelized lava flow. Puʻu Kamoamoa is at bottom left. Photograph by J.D. Griggs, U.S. Geological Survey, ~0900 HST, August 20, 1984.

Figure 42. Oblique aerial photograph of the base of episode 24 fountain. The fountain feeds a spatter-fed, channelized ʻaʻā flow down the north spillway of Puʻu ʻŌʻō. Photograph by J.D. Griggs, U.S. Geological Survey, 0920 HST, August 20, 1984.

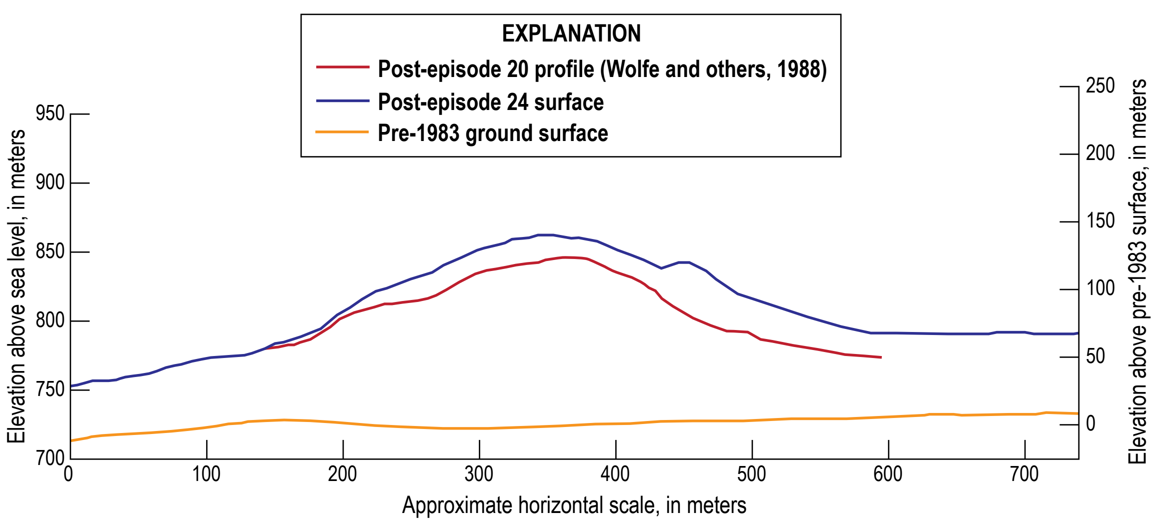


Figure 43. Profiles of Puʻu ʻŌʻō after episodes 20 and 24, illustrating cone growth. Profiles are drawn looking southwest from the perspective of the camera station on Puʻu Halulu. The vertical scale is constrained by theodolite measurements; the horizontal scale is from topographic surveys.

Episode 25 (September 19–20, 1984)

Episode 25 started 30 days after episode 24. During this interval, a 10-m-high north-facing scarp formed on the north edge of the Puʻu ʻŌʻō crater floor. First noted on August 29, it created a pronounced step and lower terrace on the broad spillway (fig. 44). The structure was probably the result of gravitational collapse of the cone's flank, which had accreted new material during previous episodes. Wolfe and others (1988) described similar collapse of crater floor material after episode 6. The event may have triggered short seismic bursts, recorded by the Puʻu Kamoamoa seismometer over a period of days, that resembled rockfall signatures.

The conduit's location and opening remained unchanged after episode 24. Its walls, however, which tapered downward in earlier observations, now appeared to be nearly vertical. During this time, gas-piston activity was recorded on the seismic records and later by observers at the vent. This activity lasted for an hour on September 5, occurred regularly at 3- to 4-minute intervals from late September 9 through September 14, and again briefly at the end of the day on September 17.

Fume from the conduit obscured views of the magma column until September 7, when it was first sighted 30–40 m below the conduit opening. The magma column continued to rise over the following days. On September 10, pilot Bill Lacy successfully maneuvered a stainless-steel triangle, attached to his helicopter by a long cable, into the lava through a hole in the crust at the top of the column. This was a new technique for collecting samples of molten lava, which was otherwise inaccessible. The resulting basalt sample, from about 2 m below the surface, was free of all but the smallest microphenocrysts, and its bulk chemical composition was indistinguishable from that of the lava specimens collected from the preceding and following eruptive episodes.

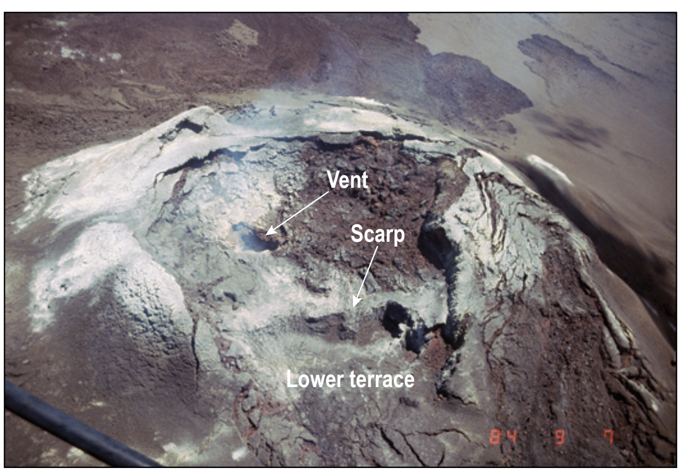


Figure 44. Oblique aerial photograph, looking south, of the Puʻu ʻŌʻō crater, 9 days after episode 24, showing the 10-meter-high scarp and lower terrace that formed on the north side of the crater floor. The light-colored mineral coating, probably gypsum or anhydrite, on the flanks of the cone and on the crater rim is from post-episode fumarolic activity. The view is south. Photograph by G. Ulrich, U.S. Geological Survey, August 29, 1984.

When the crusted column was 8 m below the surface on September 15, a spatter cone formed over a hole in the crust. By the 18th, the magma column had risen to within 2–3 m of the vent rim, and the spatter cone was dome-shaped, 4–5 m across and 3 m high, and was feeding small overflows. Early in the morning of the 19th, about 12 hours prior to continuous discharge, short intervals of spatter and fountaining were visible from the camp at Puʻu Halulu, and a thin pāhoehoe flow nearly 100 m long moved down the north spillway.

At 1604 on September 19, while an HVO geochemist sampled gases from the spatter cone over the conduit, low-level activity suddenly increased, resulting in continuous overflows and vigorous spattering. As the spatter cleared the vent, it formed a fountain that, at 1613, was angled northward 15 degrees from vertical, slopping lava over the rim. A minute later it rose to a height exceeding 100 m above the conduit. This coincided with increased tremor amplitude at the Puʻu Kamoamoa seismometer and a simultaneous broadening of the fountain's base.

At 1620, observers on Puʻu Halulu watched with trepidation as an irregular line of erupting fissures opened near the northeast base of Puʻu ʻŌʻō and propagated rapidly in their direction (fig. 9). The line of fountains stabilized after reaching a length of about 300 m, and 10–12 vents formed an array of 1- to 10-m-high fountains, which were active for 2 hours and 20 minutes, producing a small pāhoehoe flow that extended 900 m southeastward.

The fountain maintained its lean north through the early part of the episode, reaching its maximum height of 467 m about 45 minutes after the start (fig. 45). The angle of the fountain had diminished to 4–6 degrees by 1800, and by 2300 the fountain was nearly vertical. This phenomenon presumably reflected the early southward plunge of the uppermost part of the conduit, and its subsequent modification to a vertical pipe as the episode continued. After reaching its maximum height, the fountain decreased irregularly thereafter until the end of the episode (fig. 45). During the early morning hours on September 20, during this decrease, the fountain sometimes dropped to a height of about 100 m, but returned to a height of 150–200 m until final shutdown occurred at 0532.

The primary lava flow exited the crater by a channel down the north spillway and quickly transformed to ʻaʻā, which fanned out in three lobes north and northeast (fig. 46), covering much of the lava flow of episode 24. The north lobe destroyed a thin strip of forest along the northwestern margin of the flow field. The most easterly and longest lobe traveled into the north edge of Puʻu Kahaualeʻa and terminated only 3 km from the vent. Despite not traveling far, the total area covered by new lava (3.2 km^2) was close to the average value for episodes 4–47 (3.4 km^2; table 2) because of the breadth of the flow.

The high fountaining was accompanied by heavy tephra fallout, which produced a brown dust cloud that billowed out from the base of the fall-back column on the northwest flank of the cone (fig. 9). Fortuitously, we had just installed an array of coffee-can tephra collectors downwind of Puʻu ʻŌʻō, allowing tephra volume estimates to be made. A bulk volume of 1.0×10^6 m^3 was obtained, which is equivalent to a DRE volume of 0.1×10^6 m^3.

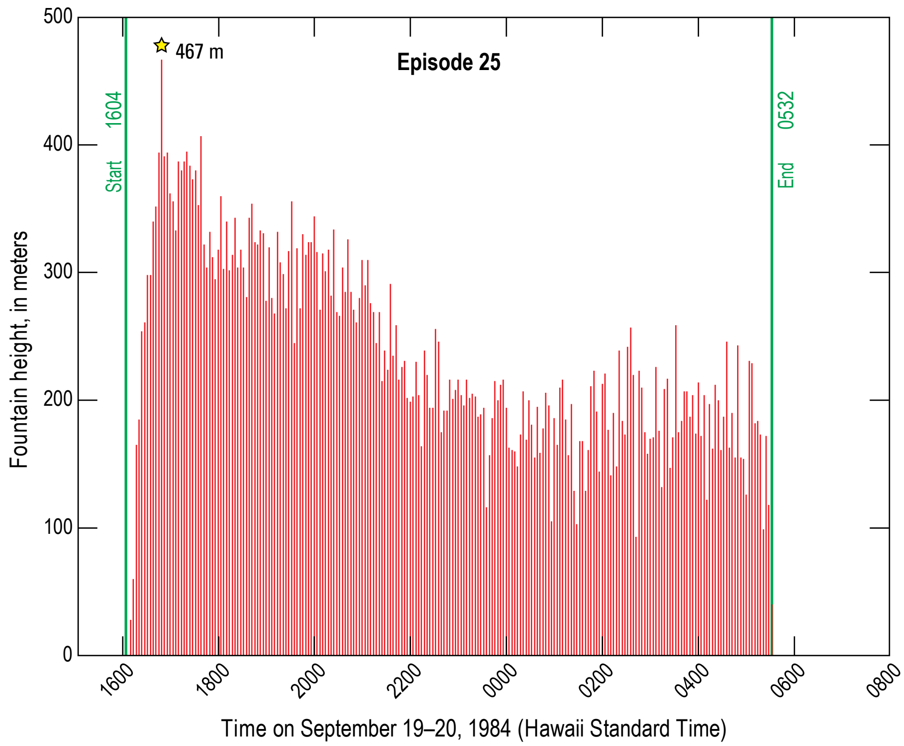


Figure 45. Graph showing episode 25 fountain heights measured from time-lapse film. The yellow star marks the highest fountain. The time interval between measurements is 3.5 minutes.

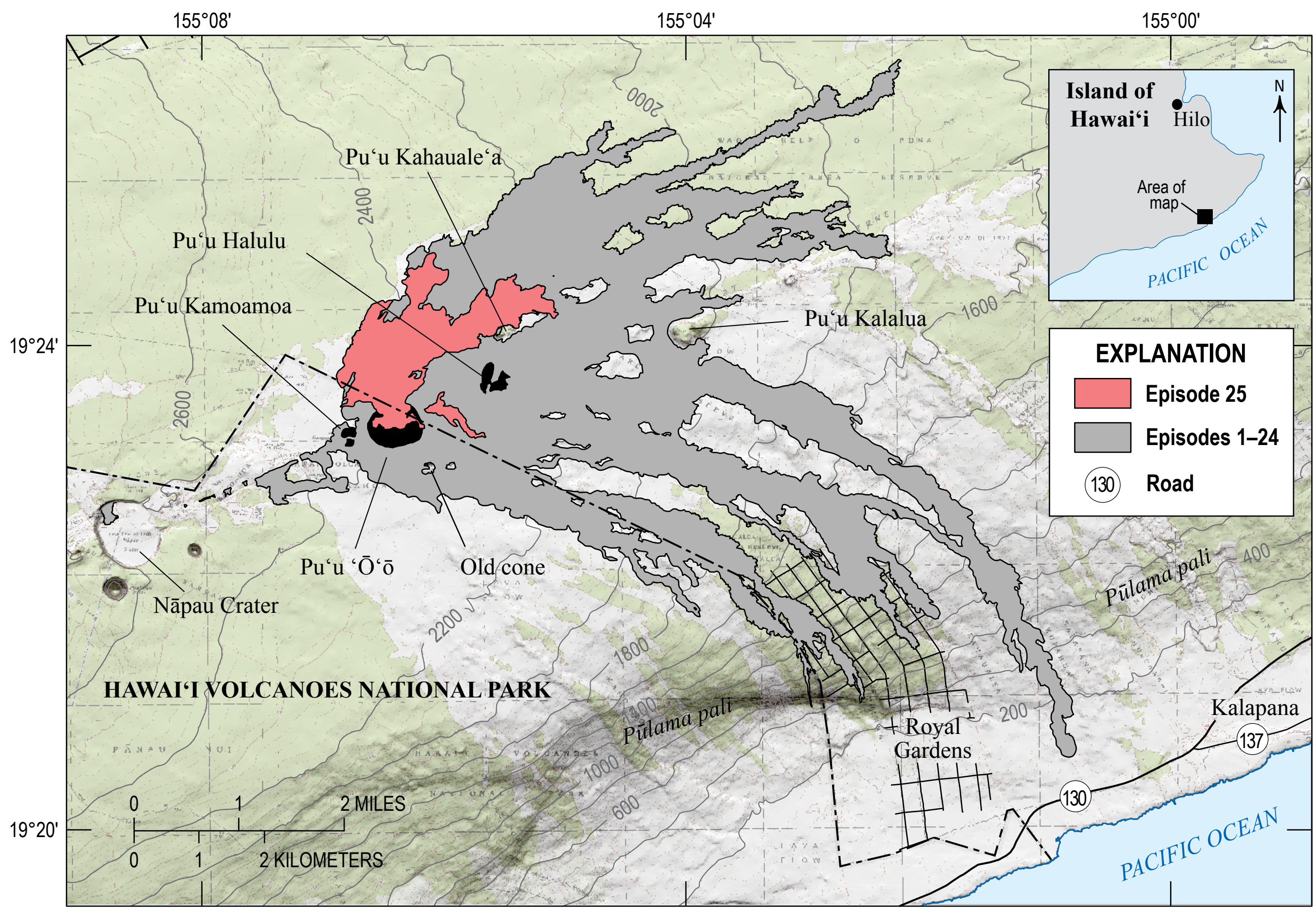


Figure 46. Map showing the distribution of episode 25 lava flows compared to earlier Pu‘u ‘Ō‘ō flows.

Summary

Episode 25 (table 1, fig. 46) produced an estimated 7.8×10^6 m^3 of lava over its duration of 13.5 hours and covered 3.2 km^2. About 0.1×10^6 m^3 of tephra was deposited. The time-averaged discharge rate during the episode, 160 m^3/s, and the height of the fountain, 467 m, were both the highest to that date at Pu‘u ‘Ō‘ō. The accumulation of tephra and spatter added 12 m to the height of Pu‘u ‘Ō‘ō during episode 25, but this was reduced to a net increase of only 7 m owing to collapse and compaction over the following 11 days, for a cone height of 157 m. A glass temperature of 1,166 °C was calculated from tephra collected from the top of the deposit (Thornber and others, 2003a).

Episode 26 (November 2, 1984)

Eruptive episode 26 occurred 43 days after episode 25, 18 days longer than the average for episodes 4–48 (25.3 hours; table 2). The top of the magma column was first observed on October 11, when it was 25–30 m down in the ~20-m-diameter conduit. The column was largely crusted over, emitting spatter through multiple small openings. By October 25, the magma column had risen and lava was ponded at the top of the conduit, intermittently spilling onto the flat crater floor. A more prolonged overflow sent a thin pāhoehoe flow about 300 m down the north spillway of the cone on October 27.

Over the next 5 days, a small pāhoehoe shield, about 100 m in diameter and 10 m high, formed over the conduit in response to gas-piston activity. The gas pistoning was characterized by brief overflows, at intervals of minutes to hours, followed by spatter bursts and roiling lava, which ended with outgassing and drainage (fig. 47). The gas pistoning coincided with cigar-shaped seismic signatures recorded by the Pu‘u Kamoamoa seismometer. Beginning about 1800 on November 1, time-lapse cameras show an average of 3–4 lava overflows per hour from the shield. These coalesced into a broad fan at the northeast base of the cone.

Starting shortly after 0300 on November 2, residents about 12 km northeast of the cone began reporting fountaining at Pu‘u ‘Ō‘ō. The intermittent activity increased slowly until the start of continuous lava extrusion at 1140. Observers, trudging through rain, arrived on site at 1158. A vigorous fountain was continuously erupting, but was visible only to a height equal with the summit of the Pu‘u ‘Ō‘ō cone, above which it was obscured by a dense cloud layer. In contrast to previous episodes, when maximum sustained fountain heights were reached within minutes of the episode start, the episode 26 fountain grew gradually higher over a 2-hour period. Tephra fall was heavy and spatter-fed lava flows cascaded down the north-to-east flanks of the cone. Lava flows, mostly ‘a‘ā, traveled north and east but were diverted away from the forest by the ‘a‘ā flows that had built up during episodes 20–25 (fig. 48).

The fountain top was finally observed at 1245, as the weather improved, and was seen to be tilted several degrees

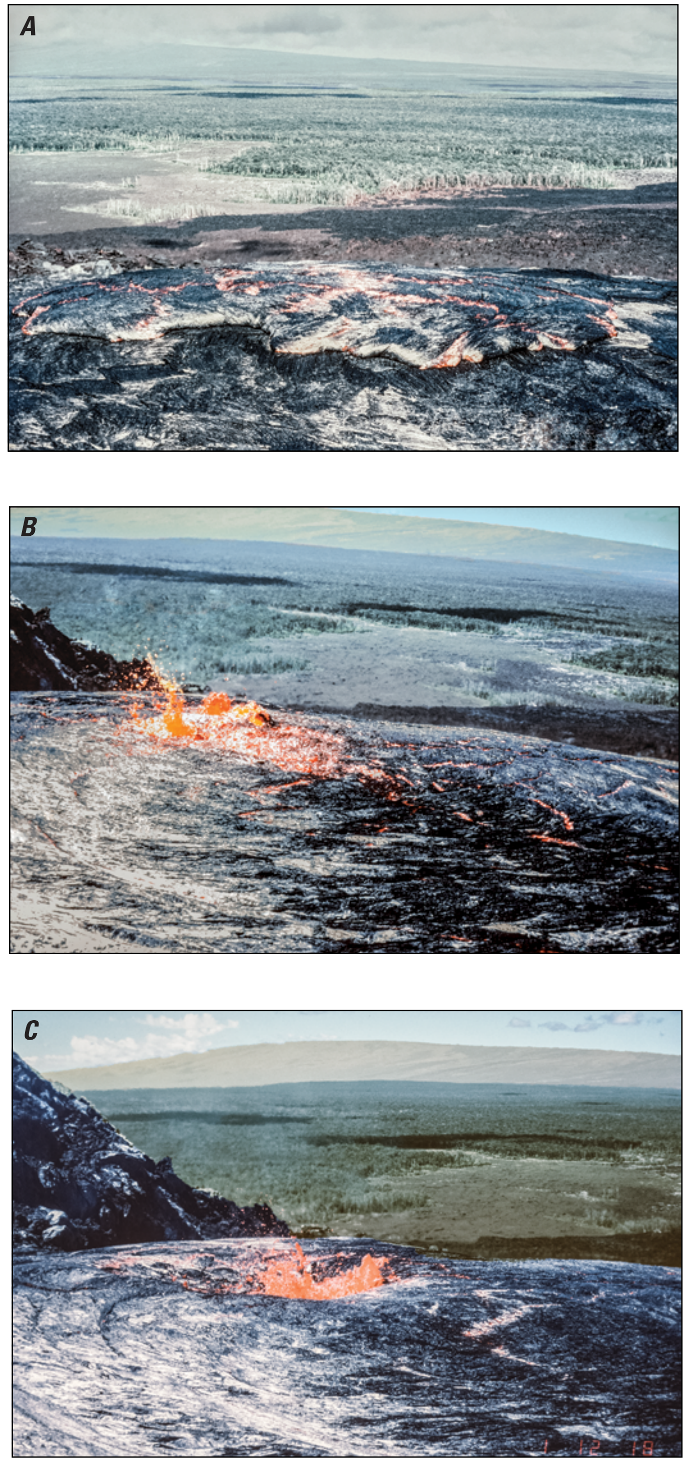


Figure 47. Photographs looking west showing gas-piston activity at the Pu‘u ‘Ō‘ō vent prior to episode 26. Mauna Loa shield volcano forms skyline. *A*, Outflow of pāhoehoe onto the shield surface. *B*, Spatter activity from the conduit as magma column begins to drop. *C*, Drainage of lava coincident with outgassing marking the end of the gas-piston event. Photographs by G. Ulrich, U.S. Geological Survey, 1215–1220 HST, November 1, 1984.

from vertical and shifting back and forth from east to west. The maximum fountain height measured during the subsequent period was 394 m at 1416 (fig. 49). Fountain heights were generally between 200 and 300 m for the remainder of the episode (figs. 6, 49, and 50). ʻAʻā flows encircled all but the northeast side of Puʻu Halulu; the longest flow reached 2.3 km northeast (fig. 48). The episode ended at 1636, after 5 minutes of erratic sputtering followed by continuous emission of fume from the conduit (fig. 51).

To determine if ground deformation could be detected just downrift of Puʻu ʻŌʻō where the fissure had opened at the beginning of episode 25, an array of reflector targets was installed across the fissures following that episode. Horizontal and vertical measurements were made using a theodolite set up at Puʻu Halulu. Frequent readings were taken for a month before episode 26—every 5 days or so for 3 weeks, and every few hours for the week preceding the onset of episode 26. Multiple sets of readings indicated that the precision of the measurements was no better than 5–7 seconds of arc (3–4 cm of movement). The changes between readings were mostly less than the resolution of the instrument, and the targets that survived the episode (4 out of 7) could not be read accurately during that critical time owing to the distorted view through the heated atmosphere. No motions larger than 3–4 cm were detected at the base of Puʻu ʻŌʻō during this interval.

Summary

Episode 26 (table 1, fig. 48) produced an estimated 4.6×10^6 m^3 of lava over a duration of 4.9 hours, covering an area of 1.6 km^2. It was the shortest duration episode to date in the Puʻu ʻŌʻō eruption, but it resulted in a time-averaged discharge rate of 260 m^3/s, which is much higher than the previous maximum established in episode 25. A temperature of 1,145 °C was measured by thermocouple during the pāhoehoe shield stage about a day before the onset of episode 26. In comparison, lava adhered to the thermocouple yielded a glass temperature of 1,155 °C (Thornber and others, 2003a). About 0.1×10^6 m^3 of tephra was deposited, and the summit of Puʻu ʻŌʻō grew by 7 m, reaching a height of 164 m. The change in the profile of Puʻu ʻŌʻō since episode 24 as seen from Puʻu Halulu is shown in figure 52.

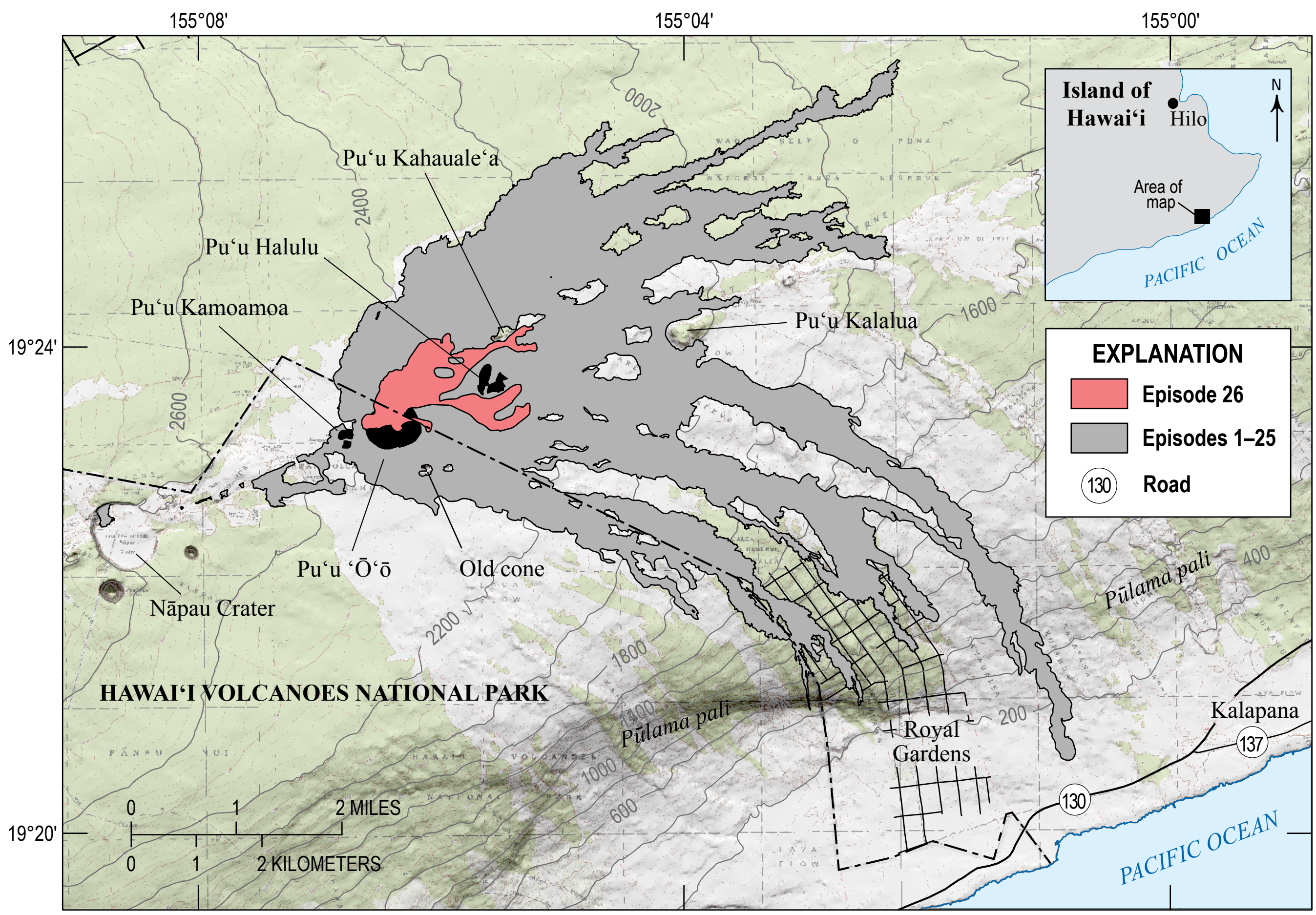


Figure 48. Map showing the distribution of episode 26 lava flows compared to earlier Puʻu ʻŌʻō flows.

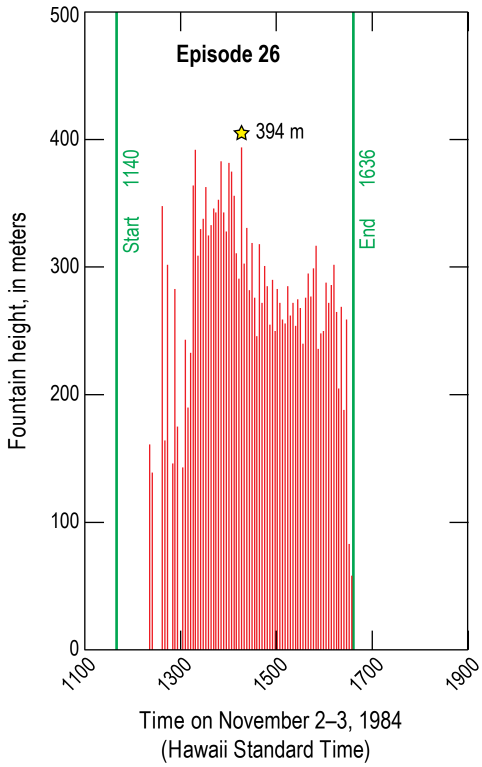


Figure 49. Graph showing episode 26 fountain heights measured from time-lapse film. The yellow star marks the highest fountain. The time interval between measurements is 3.2 minutes; data gaps are the result of poor visibility.

Figure 50. Oblique aerial photograph, looking east, showing Pu‘u ‘Ō‘ō fountaining 6 minutes before the end of episode 26. Heavy tephra fall on the downwind (southwest) side of the vent added 7 meters to the height of the cone during the episode. Photograph by G. Ulrich, U.S. Geological Survey, 1628 HST, November 2, 1984.

Figure 51. Photograph of Pu‘u ‘Ō‘ō, looking southwest from Pu‘u Halulu, 3 minutes prior to end of episode 26. Fuming and the cessation of fountaining signal the end of lava production. The new tephra deposit gives the cone a smooth summit, which then cracked and slumped in the succeeding week. A channelized, slowing ‘a‘ā flow crosses the middle ground from right to left. Photograph by J.D. Griggs, U.S. Geological Survey, 1631 HST, November 2, 1984.

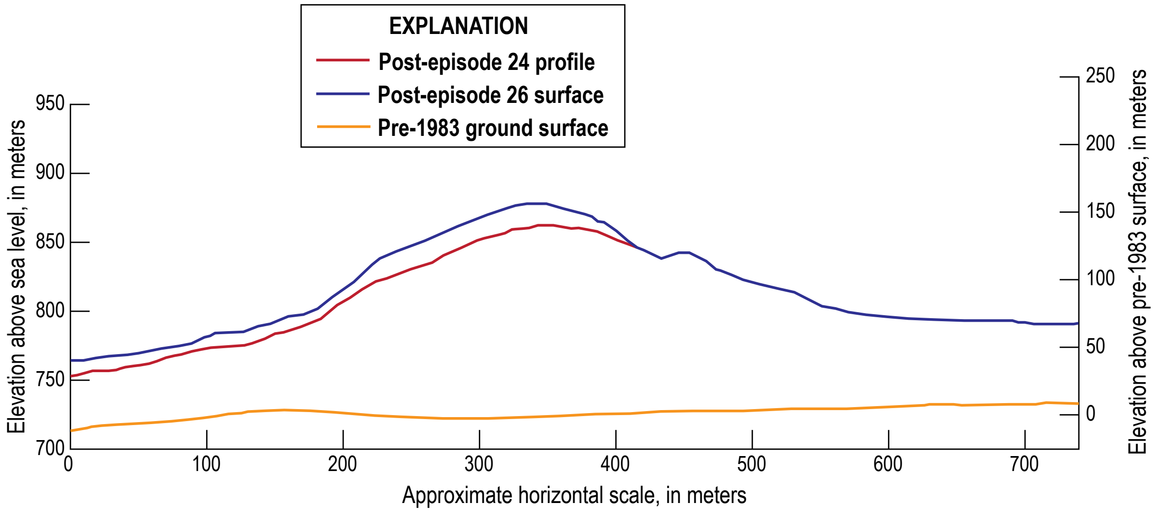


Figure 52. Profiles of Puʻu ʻŌʻō after episodes 24 and 26, illustrating cone growth. Profiles are drawn looking southwest from the perspective of the camera station on Puʻu Halulu. The vertical scale is constrained by theodolite measurements; the horizontal scale is from topographic surveys.

Episode 27 (November 20, 1984)

Episode 27 started 17 days after episode 26—8 days fewer than the average inter-episode duration for episodes 4–48 (table 2). The top of the magma column was visible in the conduit at a depth of about 30 m for most of this time. We saw significant cracking of the cone's upper slopes almost immediately after episode 26, and the Puʻu Kamoamoa seismometer recorded seismicity consistent with rock falls, suggesting that nearly 1,500 small rock falls occurred at the vent on November 2 and 3 alone. On November 12, a 5-inch rainfall event increased the eruption-site tremor to near-saturation levels like those of eruptive activity, but the vent remained quiet. Irregular gas-piston events began on November 13 and became more regular as the start of the episode approached.

On November 16, beginning at 1919, time-lapse cameras recorded low intermittent fountaining for 30 minutes that fed small pāhoehoe flows down the north flank of the cone. This activity resumed at 0200 on November 17 and continued until 0612 on November 18. Roaring sounds from gas-bursts were reported from State Highway 11, 10 km northwest of Puʻu ʻŌʻō, on November 17. Sporadic low fountaining and overflows occurred again from 2042 to 2400 on November 19, just prior to the onset of continuous discharge at 0005 on November 20, which marked the start of episode 27.

Inclement weather prevented all but minimal photographic documentation by the time-lapse cameras, which recorded a large increase in glow at the eruption site at 0005 on November 20. The cloud distribution was such that, over the next hour, reports of red glow in the sky came from the Mauna Kea Hotel and the Waikōloa Golf Club on the northwest side of the island. Occasional high fountaining was recorded on film after 0151. Observers arrived at 0735 and measured fountain height by theodolite; the highest reading was about 305 m at 0834. Heavy tephra fall accompanied the high fountaining, depositing an average of 45 cm on Puʻu Kamoamoa, 600 m west of Puʻu ʻŌʻō. ʻAʻā flows covered much of the episode 26 flow area, encroaching higher on Puʻu Halulu than in previous episodes and traveling eastward about 3.5 km (fig. 53). At 1006, the fountain died away and was replaced by an orange flame interspersed with dense fume.

Summary

Episode 27 (table 1, fig. 53) produced an estimated 5.9×10^6 m^3 of lava in 10.0 hours, covering an area of 2.3 km^2. The time-averaged discharge rate, at 163 m^3/s, was significantly below that of the preceding episode but above the average of 134 m^3/s for episodes 4–47 (table 2). The summit of Puʻu ʻŌʻō grew by 20 m to a height of 184 m, but collapse and compaction reduced this by 17 m (to 167 m) over the next 8 days.

Episode 28 (December 3–4, 1984)

Episode 28 followed a short inter-episode period of 13.4 days. Substantial cracking and numerous rock falls occurred shortly after episode 27, like those after episode 26. Gas-piston activity was first observed on seismographs 4 days into the inter-episode period (November 24) and continued irregularly until the onset of episode 28.

The top of the magma column was 15–20 m below the vent rim 2 hours after episode 27, but dropped to about 50 m later in the inter-episode period. An hour and a half prior to the start of episode 28, the magma column was observed to have

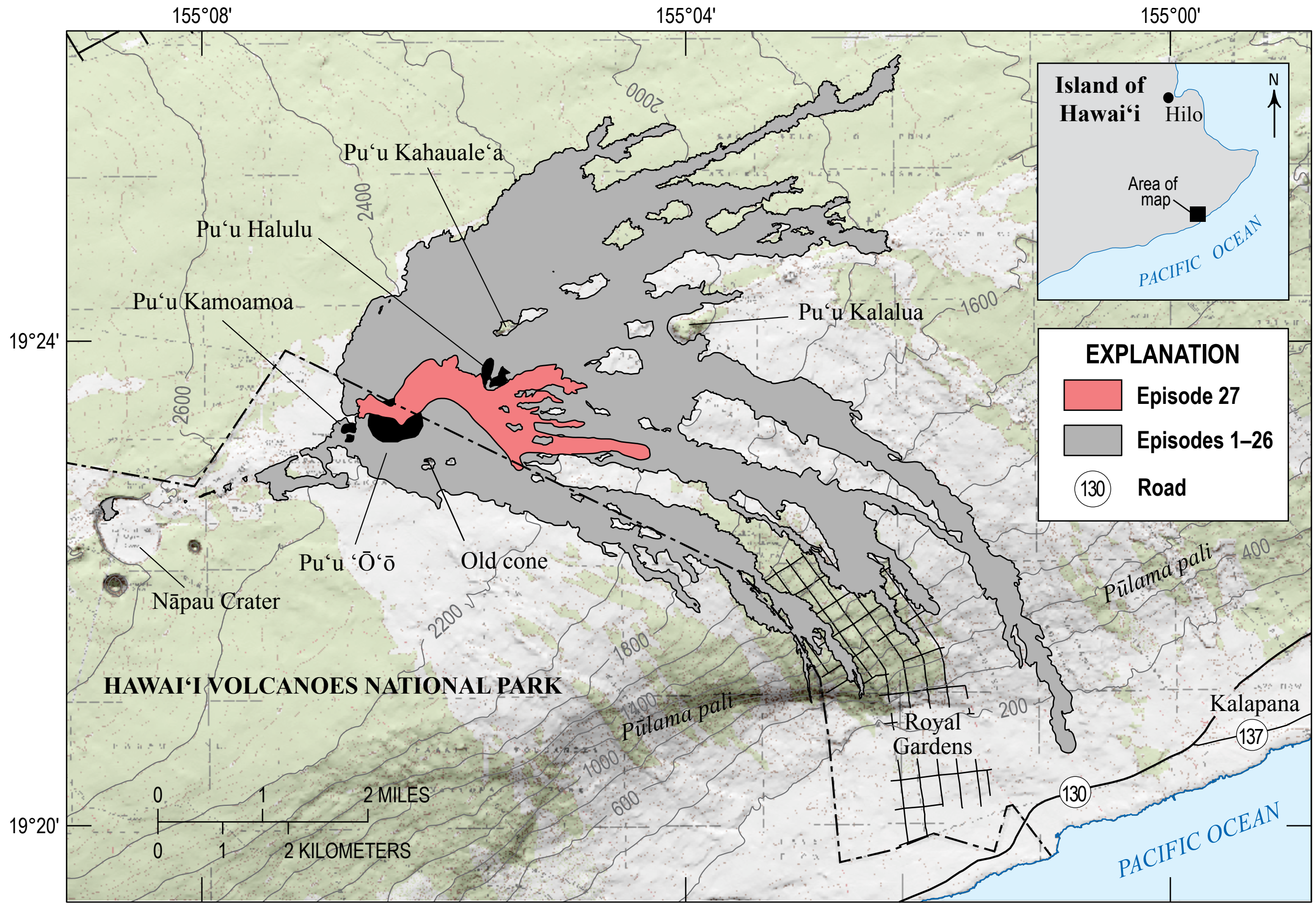


Figure 53. Map showing the distribution of episode 27 lava flows compared to earlier Pu‘u ‘Ō‘ō flows.

climbed back to within 15 m of the top of the conduit, was 75 percent crusted over, and lava was rising and falling beneath the crust, occasionally throwing spatter onto the vent rim.

Episode 28 began at 1905 on December 3 in clear weather. The tremor alarm at the Observatory signaled the start, and the rapidly growing fountain was widely observed and heard across east Hawai‘i. Tephra, including Pele’s hair, was deposited west and southwest of the vent, dusting parts of the summit region of Kīlauea and the Chain of Craters Road. Fourteen minutes after the start of the episode, time-lapse cameras recorded low fountaining from several vents along a fissure that had opened on the northeast flank of the cone, roughly at the site of the episode 25 fissure. These remained active until about 2304, after which they were no longer visible on film. The Pu‘u ‘Ō‘ō fountain was somewhat erratic, climbing and falling several times before reaching its maximum height of 421 m at 2250 (fig. 54). The fountain subsequently diminished over the last 12 hours of the episode in a cyclic pattern of decreases and smaller increases.

The fountain-fed lava flows exited the crater’s flat floor over a wide sector to the northeast. Two arms of a broad ‘a‘ā fan, which was constrained on the north and east by flows of episodes 26 and 27, reached a maximum distance of 2.0 km from the vent (fig. 55). By the following morning, when HVO observers arrived, another broad ‘a‘ā flow had advanced southeast and subsequently split into two lobes, the longest of which traveled 4.7 km, terminating about 1.2 km short of the Royal Gardens subdivision (fig. 55). Shortly before 0800, the fountain began pulsating with an interval of several minutes from 180 to 250 m in height, but poor visibility soon hindered viewing for the remainder of the episode. Fountaining ceased at 0941 and was followed by heavy fuming from the vent for the remainder of the day. The high-amplitude tremor slowly decreased and was replaced by the recurrence of the cigar-shaped seismic signature indicative of gas-piston activity.

The early ‘a‘ā flows that passed north of Pu‘u Halulu were littered with large blocks of reddish oxidized and lava-encrusted agglutinated spatter, as large as 8 m in diameter, that came from the cone and were rafted 1–2 km on the flow (fig. 56). These blocks had probably slumped from the spillway walls not far from the vent.

A thick deposit of new tephra blanketed the southwest side of the Pu‘u ‘Ō‘ō cone. Twenty meters of ejecta were deposited on the summit, whereas earlier flows near the base of the cone, with 5 or more meters of relief, were completely buried by tephra, and a tephra thickness of 0.5 to 1 m was measured as far as 600 m downwind from the base of the cone.

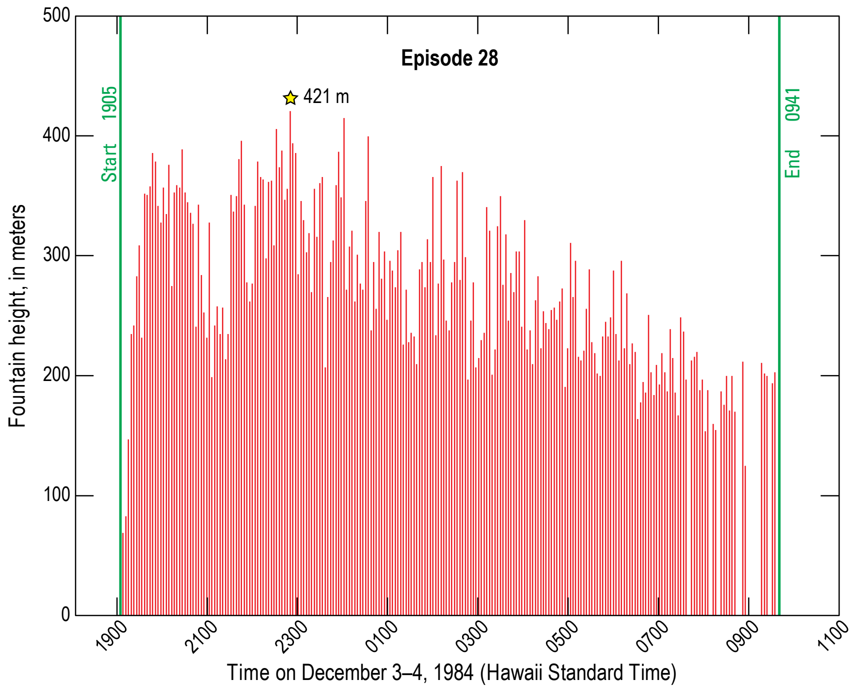


Figure 54. Graph showing episode 28 fountain heights measured from time-lapse film. The yellow star marks the highest fountain. The time interval between measurements is 3.6 minutes; data gaps are the result of poor visibility.

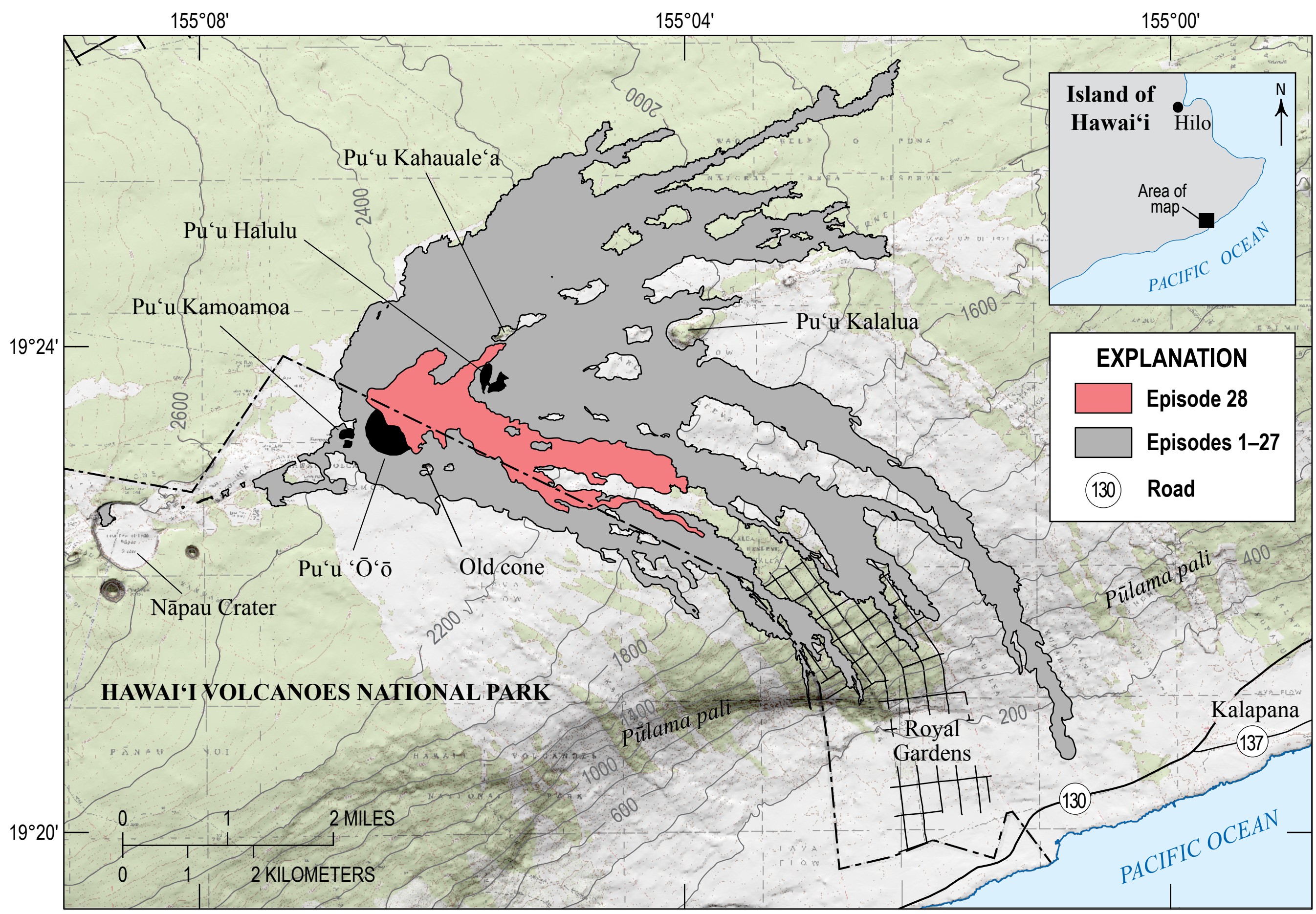


Figure 55. Map showing the distribution of episode 28 lava flows compared to earlier Pu‘u ‘Ō‘ō flows.

Figure 56. Photograph of a large block of rafted cone material near Pu‘u Halulu. Photograph by C. Heliker, U.S. Geological Survey, January 3, 1985.

Summary

Episode 28 (table 1, fig. 55) produced an estimated 8.5×10^6 m^3 of lava in 14.6 hours and covered an area of 3.7 km^2. As during the previous three episodes, the time-averaged discharge rate of 162 m^3/s was above the average for episodes 4–47 (table 2). The summit of Pu‘u ‘Ō‘ō grew by 20 m, but subsequently lost 13 m prior to episode 29 owing to slumping and compaction, for a cone height of 174 m. About 0.2×10^6 m^3 of tephra was deposited. The profile of Pu‘u ‘Ō‘ō, as viewed from Pu‘u Halulu, had become less rounded and more cone-shaped since episode 26 (fig. 57). In the 6 months since episode 20, the summit had grown by a net 44 m (including inter-episode collapse), and the elevation of the vent rim increased by a comparable 45 m.

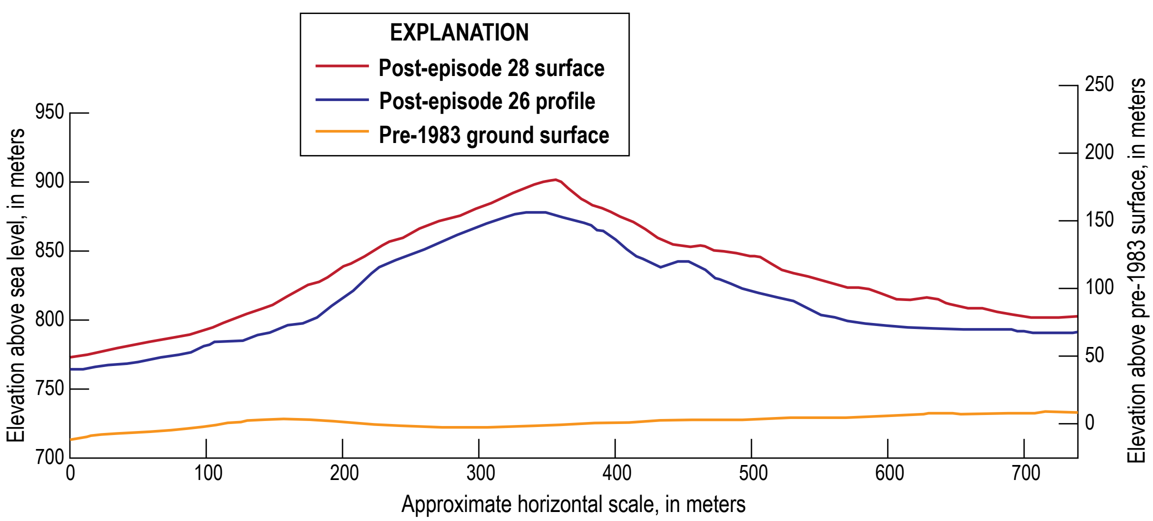


Figure 57. Profiles of Pu‘u ‘Ō‘ō after episodes 26 and 28, illustrating cone growth. Profiles are drawn looking southwest from the perspective of the camera station on Pu‘u Halulu. The vertical scale is constrained by theodolite measurements; the horizontal scale is from topographic surveys.

Episode 29 (January 3–4, 1985)

Episode 29 began 29 days after episode 28, on the second anniversary of the major dike intrusion that initiated the Puʻu ʻŌʻō eruption. Gas-piston activity began almost immediately after episode 28 and continued sporadically until the start of episode 29. Magma was first observed in the conduit on December 20, when the column was 90 percent crusted over and about 50 m below the vent rim. The conduit had widened to a maximum diameter of about 25 m, but the vent retained its position on the cone, 135 m above the original ground surface, which had an elevation of 719 m. By December 28, the magma column had risen to 20–30 m from the top of the conduit, and in the following 5 days, it alternately rose and fell, eventually building a small dome-shaped spatter cone on top of the column.

On December 30, intermittent fountains 3–10 m high were active for about 10 minutes and produced a pāhoehoe spillover that reached the lower northeast flank of the cone. On January 2, a low fountain fed a pāhoehoe spillover again for about 2 hours (1750–1950), ending with a large gas-piston burst and withdrawal of the magma. Early on the morning of January 3, HVO personnel reported dense fume at the conduit, which obscured the position of the magma column. After completing routine tasks at the site, workers returned to the Observatory, presuming that the next fountaining episode was not yet ready to begin.

Observers on an overflight later that day reported the beginning of episode 29 at 1315, about 2.25 hours after the onset of rapid deflation of Kīlauea's summit. Pāhoehoe lava had broken out along a 50-m-long fissure on the northeast side of the cone. The first fountain from the main conduit was recorded by time-lapse cameras at 1326. Within 20 minutes, HVO observers were back on site and witnessed the onset of major fountaining, as well as low fountains (2–4 m high) playing along the northeast-trending fissure, from which a thin pāhoehoe flow was moving southeast.

Fountaining consisted of two lava jets—one vertical and the other tilted toward the north. The jets consolidated within minutes into a single fountain (fig. 58) that climbed unevenly to a maximum height of 510 m at 1629 (fig. 59). The fountain fluctuated thereafter between a wide fan nearly 400 m high (fig. 8) and a narrow column 300–350 m high. About 4 hours after onset, the fountain height began to slowly decrease (fig. 59) and continued to do so until the episode ended at 0504 on January 4. Tephra fall south and southwest was heavy through much of the episode, and at 0100 on January 4, residents of Nāʻālehu, 60 km southwest of the vent, reported Pele's hair falling from the plume.

The fissure vents that began the episode (fig. 58) became inactive at 1622, after producing the only pāhoehoe flow of this episode. The fissure was in approximately the same location as those of episodes 25 and 28. By 1730, the spatter-fed ʻaʻā leaving Puʻu ʻŌʻō over the northeast spillway was forming a broad fan with a glowing front about 10 m high around the base of the cone. A narrow ʻaʻā flow, also spatter-fed, traveled down the southeast flank. From 1945 until after midnight, the main flow advanced at an average rate of 0.4–0.5 km/h. It followed a course that buried much of, and was partly diverted southward by, the episode 28 flow. By 0200, the flow had divided into two lobes, both still moving southeast. These lobes terminated at 4 and 4.4 km from the vent; the longer one stopped 1.7 km short of Royal Gardens (fig. 60).

Figure 58. Photograph looking northwest from Puʻu Halulu showing episode 29 fountain with fissure vents in the foreground. This activity was shortly followed by the maximum fountain height of 510 meters measured during the Puʻu ʻŌʻō eruption (excluding jetting events). Photograph by C. Heliker, U.S. Geological Survey, ~1600 HST, January 3, 1985.

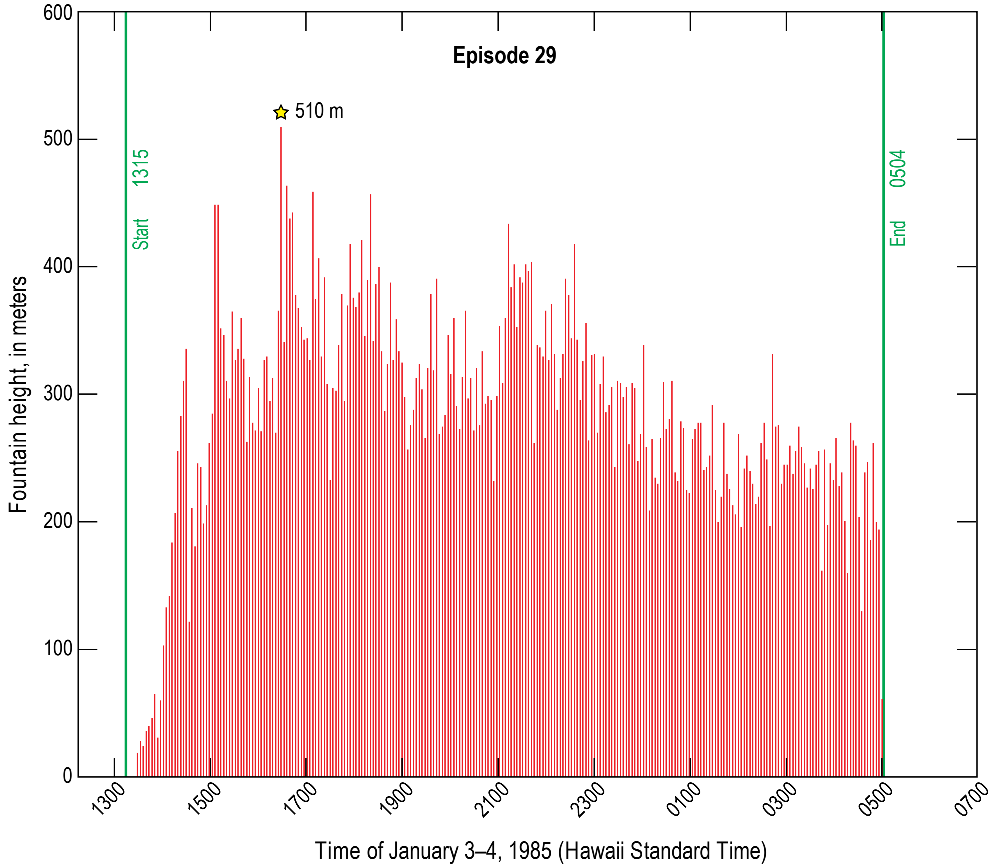


Figure 59. Graph showing episode 29 fountain heights measured from time-lapse film. The yellow star marks the highest fountain, measured by theodolite. The time interval between measurements is 3.6 minutes; data gaps are the result of poor visibility.

The waning fountain dropped rapidly at 0500, and, within 4 minutes (at 0504 on January 4), fountaining and lava production ceased altogether. After about 10 minutes of intermittent sputtering and flaming, the incandescent walls of the cone and conduit were obscured by heavy fume.

Summary

Episode 29 (table 1, fig. 60) produced an estimated 9.0×10^6 m^3 of lava in 15.8 hours, covering an area of 3.8 km^2. The time-averaged discharge rate, 158 m^3/s, was close to that of other recent episodes and about 20 percent higher than the average for episodes 4–47. A glass temperature of 1,165 °C was calculated from tephra collected from the top of the deposit after fountaining ended (Thornber and others, 2003a). The summit of Pu‘u ‘Ō‘ō grew by 27 m, but then lost 8 m owing to collapse over the next 13 days, giving a post-episode cone height of 193 m (fig. 61). About 0.2×10^6 m^3 of tephra was deposited.

Episode 30 (February 4–5, 1985)

The inter-episode preceding episode 30 of the Pu‘u ‘Ō‘ō eruption lasted 31 days, during which the magma column was occasionally visible 30–40 m below the vent rim. The conduit retained its diameter of about 25 m and appeared to taper slightly downward. Gas-piston activity was infrequent prior to episode 30, except during January 21–26, when it occurred regularly at intervals ranging from 3 to 7 minutes to judge from the seismograms.

On the morning of January 31, the magma column was observed to be crusted over at a level 5 m below the vent rim, having risen over the preceding several days, with a spatter chimney 2 m wide and 5 m high on its surface. From 2237 until 2302 that same day, low fountaining fed two pāhoehoe flows over the north and northeast spillways, accompanied by elevated tremor on the Pu‘u Kamoamoa seismometer. On February 1, the magma column reached the top of the conduit, where a spatter cone soon formed (fig. 61). Flows from this spatter cone spilled over the northeast flank of Pu‘u ‘Ō‘ō several times, advancing slightly beyond the flows of the previous night. Just past midnight on February 2, new spatter activity, lasting at least until morning, generated a small pāhoehoe flow. On February 3, from midnight until 0502 and for a half hour before noon, several additional small spillovers occurred. The spatter cone continued to grow through the afternoon and early evening, and at 1929 another small spillover was recorded. Early on the morning of February 4, low-level spatter activity from the conduit was observed, but continuous lava discharge had not yet begun.

At 0546 on February 4, the time lapse film showed a low fountain playing where the spatter cone had been, and continuous lava discharge began, officially starting episode 30. A visual

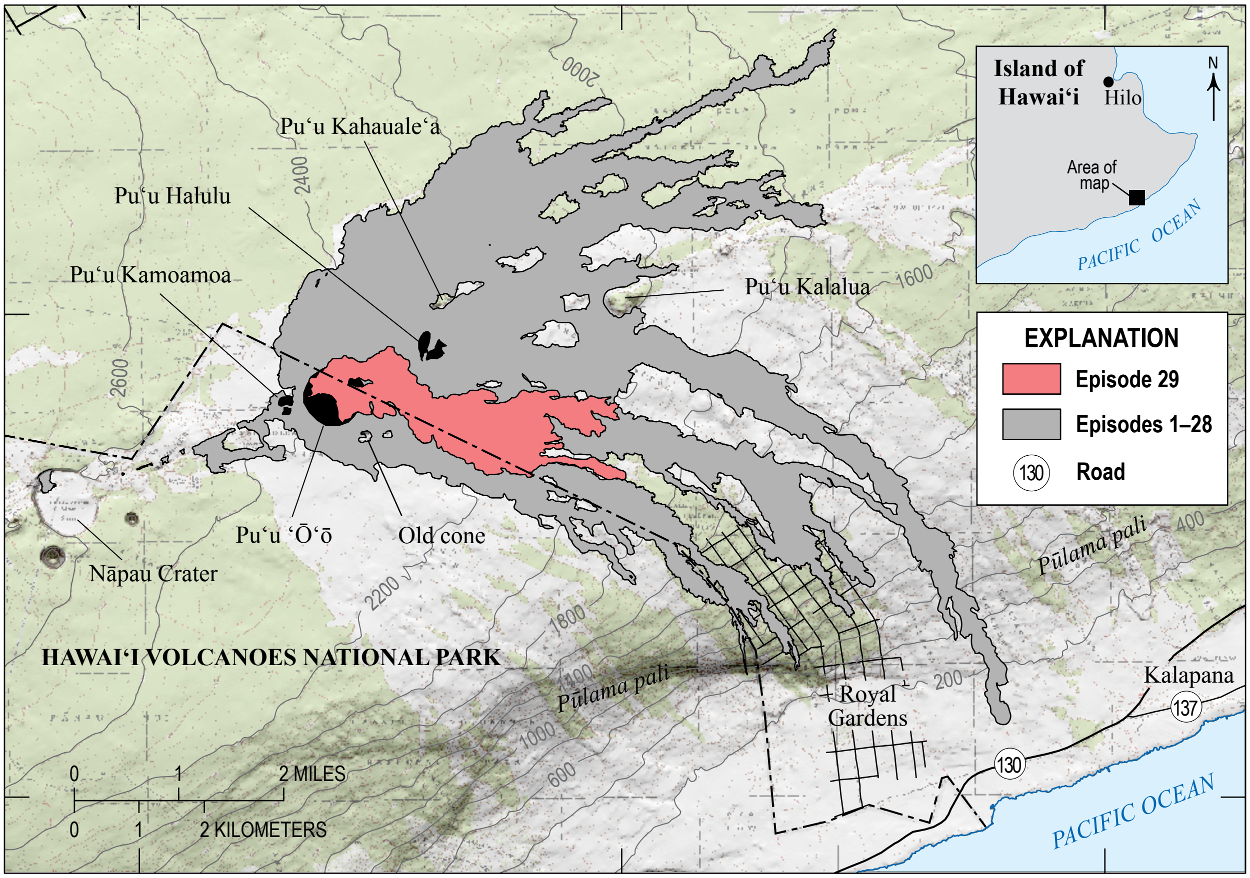


Figure 60. Map showing the distribution of episode 29 lava flows compared to earlier Pu‘u ‘Ō‘ō flows.

Figure 61. Oblique aerial photograph of Pu‘u ‘Ō‘ō looking west, showing disintegration and collapse of the top of the cone from a height of 201 meters to 193 meters during the period between episodes 29 and 30. The magma column is at the top of the conduit, feeding small overflows onto the flank of Pu‘u ‘Ō‘ō. Photograph by G. Ulrich, U.S. Geological Survey, February 1, 1985.

report from Mountain View (18 km north of Puʻu ʻŌʻō) described increasing fountain heights at 0600, and 4 minutes later, a pāhoehoe flow moving northeast from the base of the cone. At 0640, the flow turned eastward while fountain heights climbed to nearly the height of the Puʻu ʻŌʻō cone. The flow advanced to within 100 m of Puʻu Halulu by around 0800, when it changed from pāhoehoe to ʻaʻā in concert with the gradually increasing effusion rate. The change occurred as fountain heights increased from about 80 m above the conduit at 0730 to a maximum height of 445 m at 0839 (fig. 62). Heavy tephra fall accompanied the high fountaining and was directed north by southerly winds estimated at 10–15 knots (fig. 63). For the next 3 hours, the fountain's height declined irregularly (fig. 62), though the ʻaʻā flow continued to advance at an average rate of about 330 m/h. During this interval, the fountain was generally less than 300 m high, and after 2130 it was largely obscured by poor weather. A single spike of about 400 m was recorded at 2306. From about 1600 until 2300, shifting winds rained lapilli and some small bombs on the observation shelter at Puʻu Halulu, but caused no damage.

Observers from HVO arrived at the site at 0850 in rainy weather. The ʻaʻā flow was being fed from coalesced spatter spilling across the northeast flank of Puʻu ʻŌʻō and was overrunning most of the earlier pāhoehoe flow. By 1000, its front was moving southeast over the episode 29 flow and was 0.7 km from the base of the cone. Thereafter, the single lobe of ʻaʻā followed the southwestern margin of the episode 29 flow, staying inside the east boundary of the National Park. The ʻaʻā flow was 400–800 m wide as it began to cut a new path through the forest on the south side of the Puʻu ʻŌʻō flow field (fig. 64). As the flow passed 1,800-ft elevation, the slope steepened, the flow's rate of advance increased, and its width narrowed to 100–300 m.

At 2000, a National Park Service ranger at the Wahaʻula Visitor Center on Kīlauea's southeast coast (fig. 64) reported that the flow was visible at 1,500-ft elevation. At 2030, a lobe farther west also appeared at the crest of the Pūlama pali, a steep escarpment on Kiluaea's south flank.. Observatory staff arrived at Wahaʻula at 2130 to observe and evaluate hazards to the Park and the Royal Gardens subdivision. The western lobe subsequently increased in vigor at the expense of the eastern lobe. The rate of advance from 1800 to 2225 was approximately 850 m/h. The two narrow lobes recombined as a single flow after reaching the base of the pali, and then became sluggish, forming a delta-like fan that moved slowly toward the coast.

From 0140 to 0148, a surge of ʻaʻā at the top of the pali released a large volume of lava down the western lobe, which spread over the ʻaʻā emplaced earlier near the base of the slope. The characteristics of this lava surge were like those described for episodes 2 through 5 by Neal and Decker (1983; see also Wolfe and others, 1988, p. 31–32). As viewed from the coast, the surge began as a dark, rubble-topped plug with a discernible front, moving slowly down the existing channel. It was funneled down the western lobe over the pali, starting fires in the forest on either side. When the front reached the steepest part of the pali, it plunged down the slope, releasing behind it a flood of fluid lava that must have been ponded behind the front for a few hours.

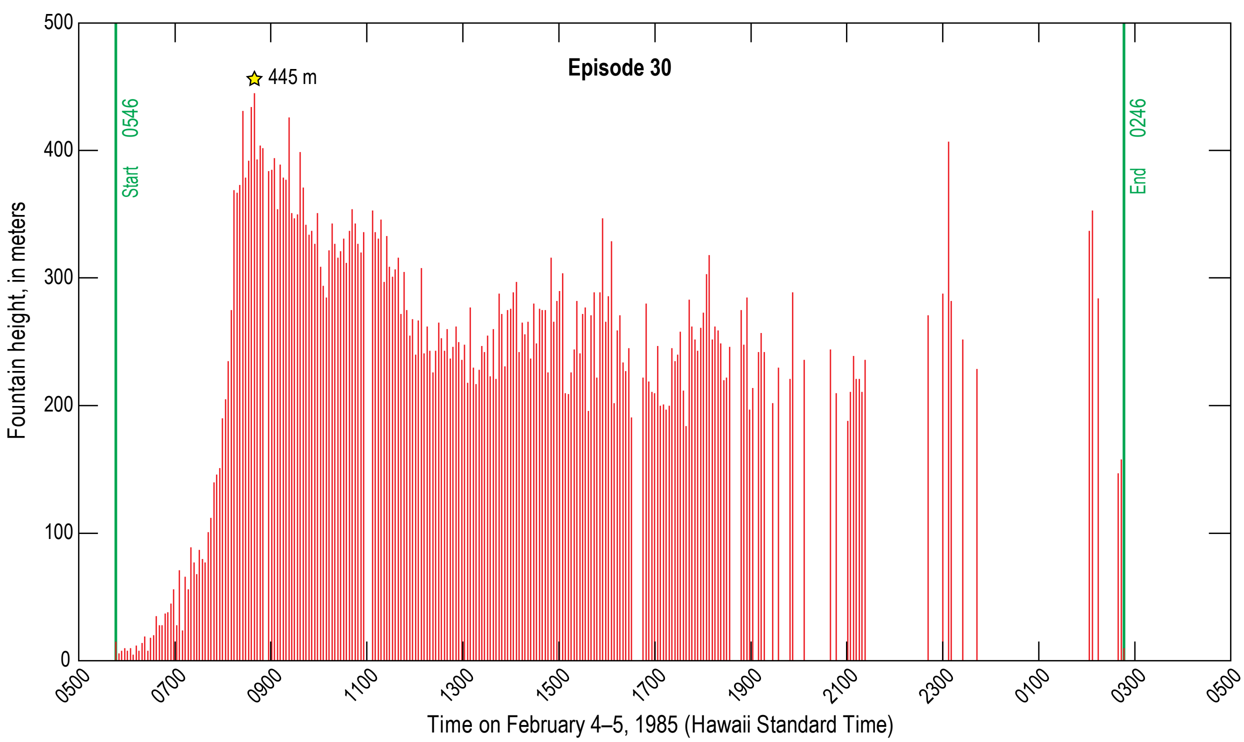


Figure 62. Graph showing episode 30 fountain heights measured from time-lapse film. The yellow star marks the highest fountain. The time interval between measurements is 3.6 minutes; data gaps are the result of poor visibility.

Figure 63. Oblique aerial photograph looking northwest at episode 30 fountain showing the black tephra fall, and the gray dust cloud from fragmenting fall-back material, blown north by southerly winds. The summit of Puʻu ʻŌʻō, just left of the fountain, normally received the bulk of new tephra fall during the usual northeast winds, but in this episode increased by only 1 meter. Photograph by J.D. Griggs, U.S. Geological Survey, ~1015 HST, February 4, 1985.

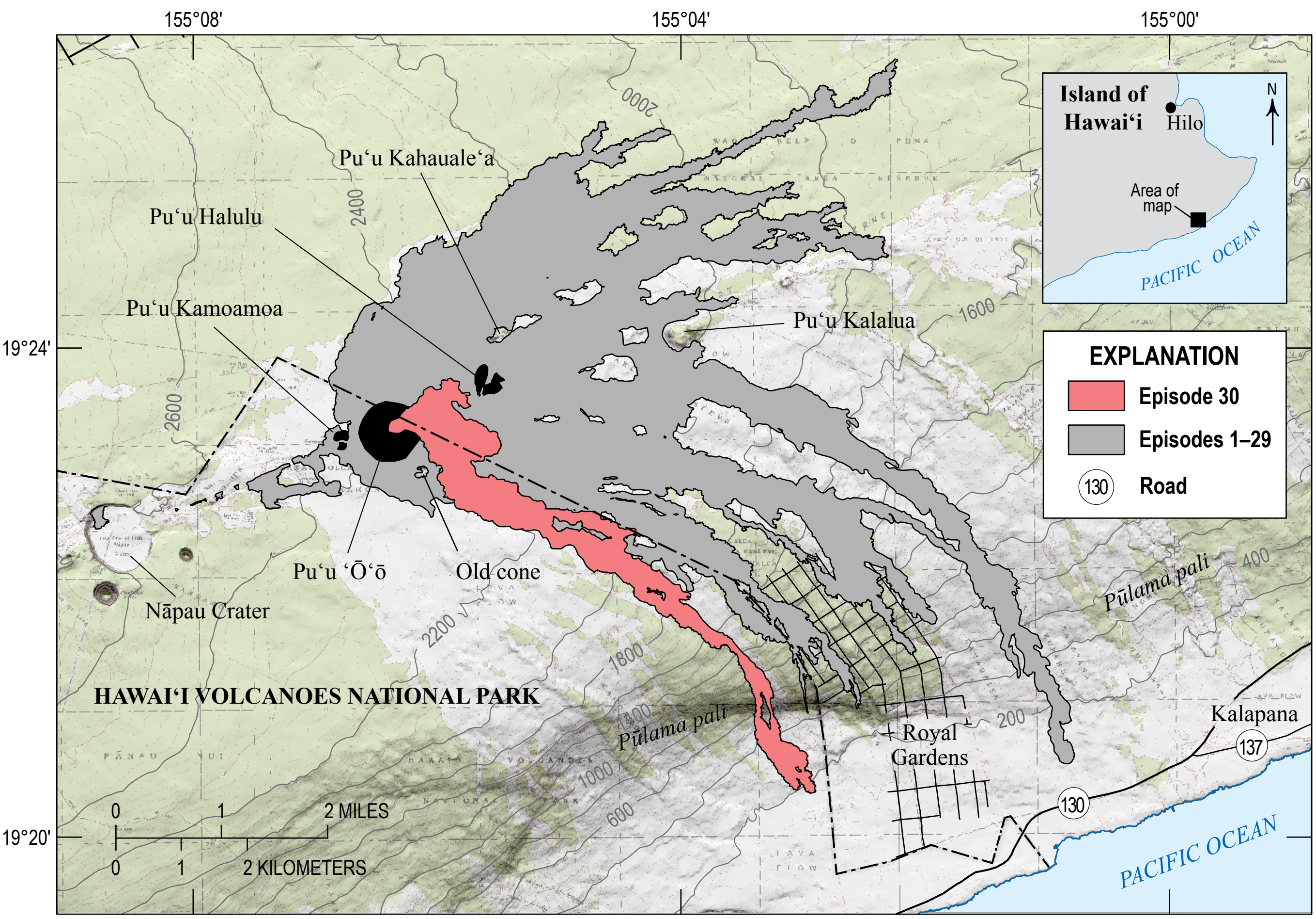


Figure 64. Map showing the distribution of episode 30 lava flows compared to earlier Puʻu ʻŌʻō flows.

As the surge advanced down the pali, it formed a levied ‘a‘ā channel (fig. 65). At 0246, the fountain died and lava production stopped. The terminus of the flow, however, continued to advance through the night as its interior remained fluid. The rate of advance averaged about 20 m/h for 10 hours after the fountaining ended. Perceptible movement then slowed to about 30 cm/h before stopping sometime on February 8. The flow terminus was 11 m thick after it had cooled.

Gusty winds shifting east ignited fires in the dry grass adjacent to the ‘a‘ā flow on the coastal plain. The main fire eventually burned an area 1.5 km long by 200–300 m wide on the west side of the flow terminus. A fire-fighting force of 16 rangers and 2 helicopters, one of which crashed en route, was mobilized to fight the fire, which was extinguished 3 days later.

The dense ‘a‘ā at the flow terminus had abundant olivine microphenocrysts, easily visible in hand specimen, which was a noticeable change from previous episodes. Whole-rock chemical analyses revealed that this lava and the last lava erupted—collected from the conduit area—both contained significantly more MgO (9.0 and 9.7 weight percent, respectively) than the early spatter and flows of episode 31 (7.6 percent) and other eruptive products since episode 20.

Figure 65. Oblique aerial photograph of the empty episode 30 lava channel on the Pūlama pali formed within the February 5, 1985, ‘a‘ā surge. The channel wall on the right is striated parallel to the flow on surfaces of coherent compacted gouge, like that described by Wolfe and others (1988, p. 30–31). Photograph by J.D. Griggs, U.S. Geological Survey, March 11, 1987.

Summary

After 3 days of fits and starts, Pu‘u ‘Ō‘ō erupted for almost 2 days and provided more than the usual excitement as it fed a major fast-moving ‘a‘ā flow that traveled to the base of the Pūlama pali and threatened the Royal Gardens subdivision, burning significant areas of forest and grassland in its path. No structures were damaged, but southerly winds raised the public’s awareness of the event by advecting tephra, including Pele’s hair, northward over the more densely populated Hilo region.

Episode 30 (table 1, fig. 64), which lasted 21 hours, produced an estimated 9.9×10^6 m^3 of lava that covered an area of 4.1 km^2. The time-averaged discharge rate was 131 m^3/s. The 8.3-km-long ‘a‘ā flow was the second longest in the history of Pu‘u ‘Ō‘ō, exceeded in length only by an episode 18 flow that traveled down the east side of the Royal Gardens subdivision in April 1984 (Wolfe and others, 1988). The summit of Pu‘u ‘Ō‘ō grew by only 1 m, to 194 m, owing to the southerly winds, which carried tephra away from the high point. The profile of Pu‘u ‘Ō‘ō after episode 28 and after episode 30 is shown in figure 66 to illustrate the growth of the cone.

The intra-episode change from less mafic to more mafic lava compositions had not occurred since episodes 5 through 10 in 1983 (excluding minor variations in episode 18; see Garcia and others, 1992). Magnesium oxide values for lava erupted during episode 30, however, were a full percent higher than those found in the lava erupted in 1983. A glass temperature of 1,173 °C was calculated from tephra erupted a few hours before fountaining ended (Thornber and others, 2003a).

Episode 31 (March 13–14, 1985)

The inter-episode period of 36 days following episode 30 was 11 days longer than the average for episodes 4–48 (table 2). On February 15, during this period, the seismometer at the base of Pu‘u Kamoamoa cone was moved to the northern ridge crest of that cone, placing it 800 m WSW of the Pu‘u ‘Ō‘ō vent.

The day after episode 30, the magma column was deeper than the visible part (the upper 50 m) of the tapered conduit and could not be seen. The diameter of the vent rim was still about 25 m (fig. 67), and its elevation had not changed significantly since episode 28.

Harmonic tremor near the eruption site maintained a moderate amplitude for 2 days following episode 30. At about 1400 on February 7, an atypical pattern of banded seismicity commenced, in which low-amplitude tremor lasting about 3 hours alternated with moderate tremor lasting about 30 minutes. This cyclic pattern (fig. 68) continued for 4 days before returning to normal background levels for the remaining duration of the inter-episode period. The banded tremor

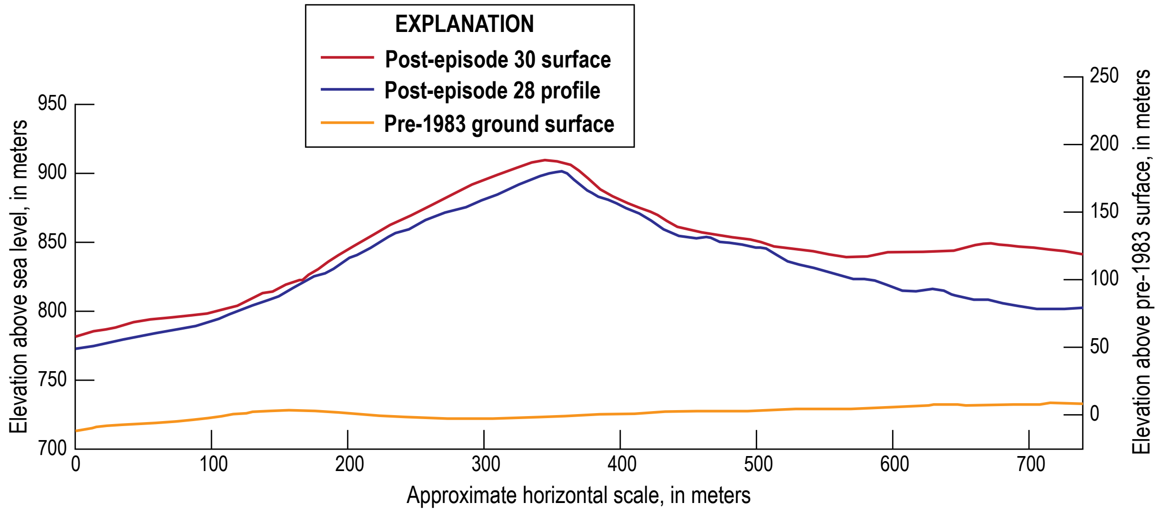


Figure 66. Profiles of Puʻu ʻŌʻō after episodes 28 and 30, illustrating cone growth. Profiles are drawn looking southwest from the perspective of the camera station on Puʻu Halulu. The vertical scale is constrained by theodolite measurements; the horizontal scale is from topographic surveys.

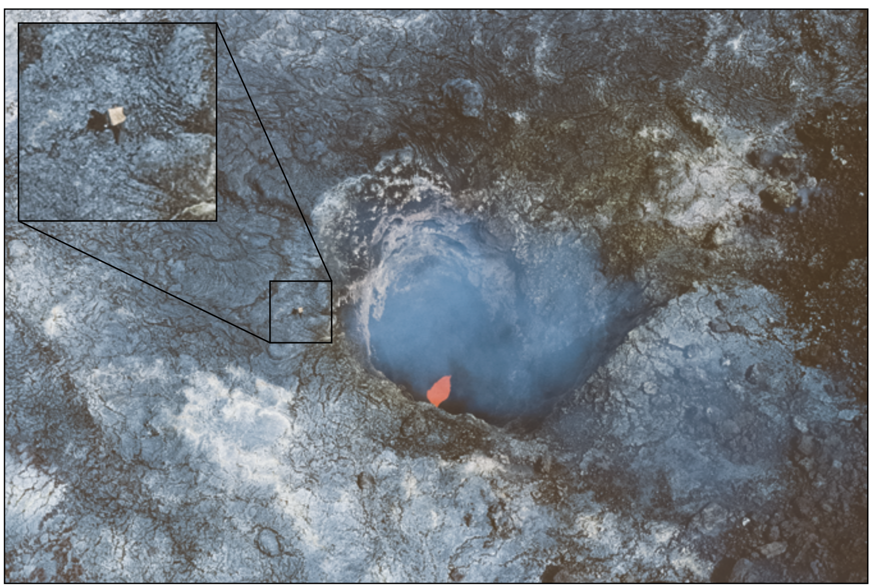


Figure 67. Nearly vertical aerial photograph of the ~25-meter-diameter Puʻu ʻŌʻō conduit on March 4, 1985, prior to episode 31. White fumarolic deposits veneer the month-old episode 30 lava surface. The inset shows a Hawaiian Volcano Observatory scientist walking near the vent. Photograph by J.D. Griggs, U.S. Geological Survey.

appeared to correlate with above-average earthquake counts in the East Rift Zone (100–200/day) but showed no obvious correlation with deformation, vent activity, or rainfall. A similar pattern was described by McKee and others (1981, p. 64–5 and 79–80) on the andesitic Karkar Volcano in Papua New Guinea during the 6 months preceding an explosive eruption in January 1979, as well as during and after the phreatic eruption. The pattern was interpreted as deep hydrothermal geyser-like activity, although no corresponding surface events were observed. The similarity between this seismic pattern at Karkar and some produced by Old Faithful geyser in Yellowstone National Park was described by Kieffer (1984), who proposed acoustic decoupling between the magma and the rock owing to a transformation from undersaturated fluid to a saturated liquid-plus-gas to explain the low tremor phases. Such a mechanism increases the acoustic differences between the media, resulting in a low seismic signal.

On February 21, 16 days into the inter-episode period, the magma column was still not visible owing to heavy fume emission, but the roar from the conduit was typical of the noise produced when magma was only a few tens of meters below the surface. The first view of the magma column came March 4, when it was 60 percent crusted over and about 30 m below the rim (fig. 67). That same day, the rain gauge at Puʻu Halulu

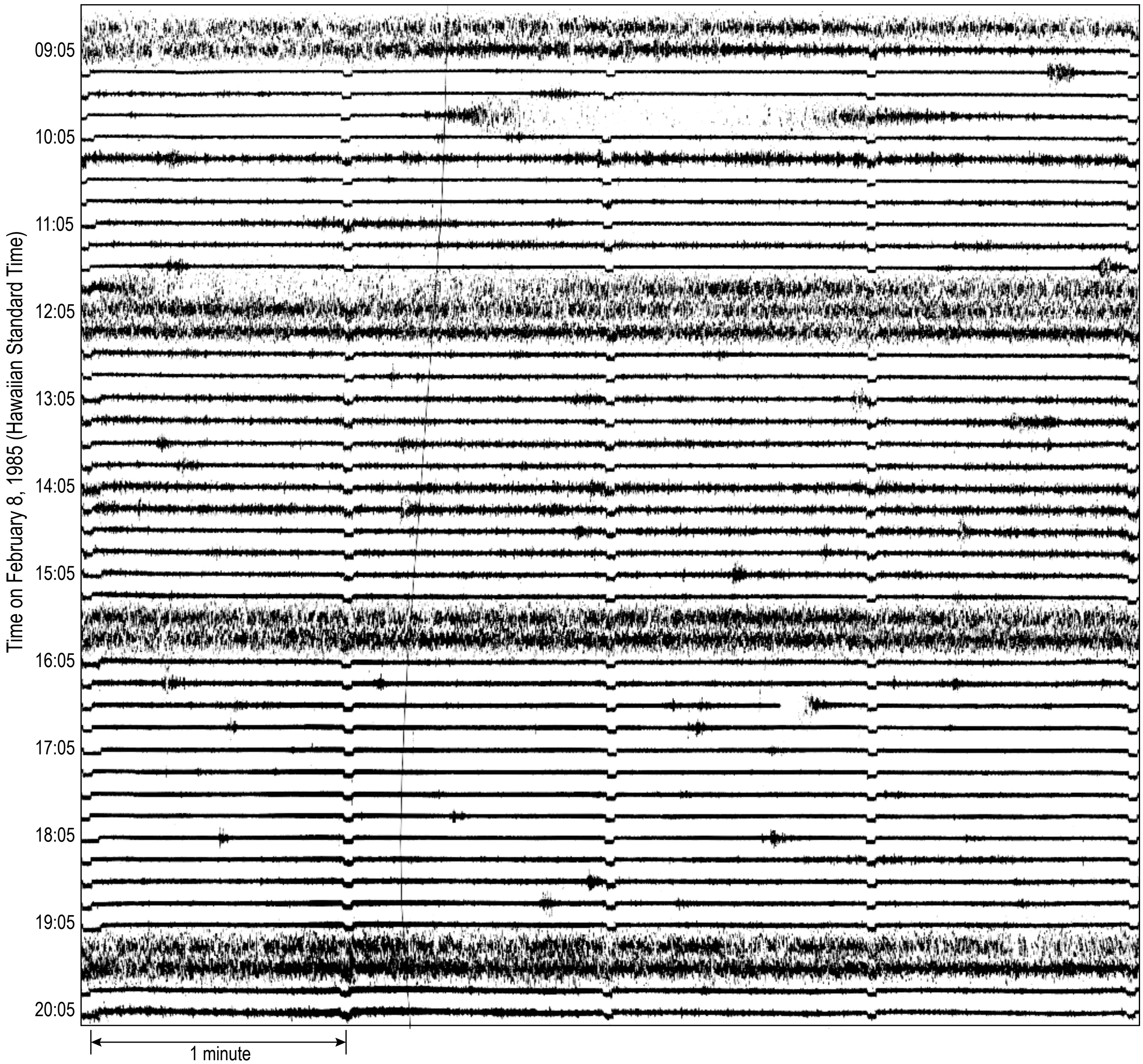


Figure 68. A scanned section of the February 8, 1985, paper helicorder record from the Pu‘u Kamoamoa (KMM) seismic station, 600 meters from Pu‘u ‘Ō‘ō. Each horizontal line represents a duration of 4 minutes, and each line is 15 minutes apart. The helicorder shows a pattern of alternating bands of high and low amplitude harmonic tremor at 3- to 4-hour intervals. The pattern was repeated continuously during the period from February 7 to 11. Frequent microearthquakes were recorded throughout interval, best seen during intervals of low tremor. The isolated cigar-shaped tremor burst at 0946–0948 is consistent with gas-piston activity.

overflowed, indicating more than 56 cm of rain in the preceding 11 days (5.1 cm/d), the highest average daily rainfall rate measured for the period from September 1984 through December 1986. The following 8 days were nearly as wet, restricting monitoring activities considerably. Spattering lava in the crater was observed on the evening of March 11, however, from State Highway 11 about 12 km north of Pu‘u ‘Ō‘ō. By the following day, the magma column was observed almost completely covered with crust, having risen to within 5–8 m below the top of the conduit. A small spatter cone, its top nearly at the level of the vent rim, had formed on top of the crusted column and was emitting spatter sporadically. Lava broke out at the base of the spatter cone occasionally and spread over the surrounding crust.

Increasing tremor beginning at 0600 on March 13 may have signaled the beginning of low-level lava effusion at Pu‘u ‘Ō‘ō; but, lacking on-site observations, the start of episode 31 is placed at 0720 when the tremor alarm at HVO sounded in response to continuous high-amplitude tremor recorded by the Pu‘u Kamoamoa seismometer. At 0800, a resident of Glenwood, 12 km northwest of the vent, reported seeing low-level fountaining roughly even with the high point of Pu‘u ‘Ō‘ō (60 m above the vent rim). At 0930, a flight over the vent reported fountain heights of 30 m higher than the top of the cone (90 m above the vent rim), with heavy tephra fallout southwest. HVO observers finally arrived at the Pu‘u Halulu camp at 0945 in typically unsettled weather. At 1026, the fountain briefly split into two leaning jets that sprayed lava north and the east, and then was followed by a single fountain leaning a few degrees north. Soon the fountain became fan-shaped, narrowing toward its base in Venturi-effect fashion and spraying tephra widely around the cone, particularly over the summit on the downwind side (fig. 69). Accompanying the heavy tephra fall were clouds of gray and brown dust billowing outward from around the base of the fall-back column.

The fountain increased in height until 1235, when it reached a maximum of approximately 340 m, as measured by theodolite (fig. 70). The fountain height decreased thereafter and became obscured at 1800, when the weather closed in completely. From then until the end of the episode, there were only occasional sightings of the fountain. From what was seen, fountain heights were generally erratic and mostly less than 300 m, but somewhat higher than before visibility became sporadic (fig. 70). The fountaining stopped abruptly at 0455 on March 14, followed for several minutes by an orange flame flickering above the vent.

The main lava flow was initially a narrow pāhoehoe river exiting the northeast spillway. By 0950, it was moving southeast over the episode 30 flow and had advanced 1.3 km from the vent. The increasingly vigorous fountaining soon produced mainly ‘a‘ā, which moved more slowly over the same terrain. By 1555, the distal end of the ‘a‘ā flow was only 1 km from the vent but was nearly 1 km wide. The flow had been moving 100–150 m/h until then, but thereafter its rate of advance increased. It largely filled the crater of an old cone 700 m southeast of the Pu‘u ‘Ō‘ō vent (fig. 71; the crater was first invaded by a small lava overflow during episode 23). By 1700, the flow had advanced another 1.5 km at an average rate of more than 1 km/h and was just inside the National Park boundary at about 2,150-ft elevation.

Figure 69. Photograph of the Pu‘u ‘Ō‘ō episode 31 lava fountain from the Pu‘u Halulu camp on March 13, 1985, illustrating the Venturi effect of decreased pressure and increased velocity as magma exits the constricted conduit. The top of the incandescent part of the fountain is ~200 meters above the conduit. Steam rises from the surrounding ‘a‘ā owing to intermittent rain on hot flows. Photograph by J.D. Griggs, U.S. Geological Survey.

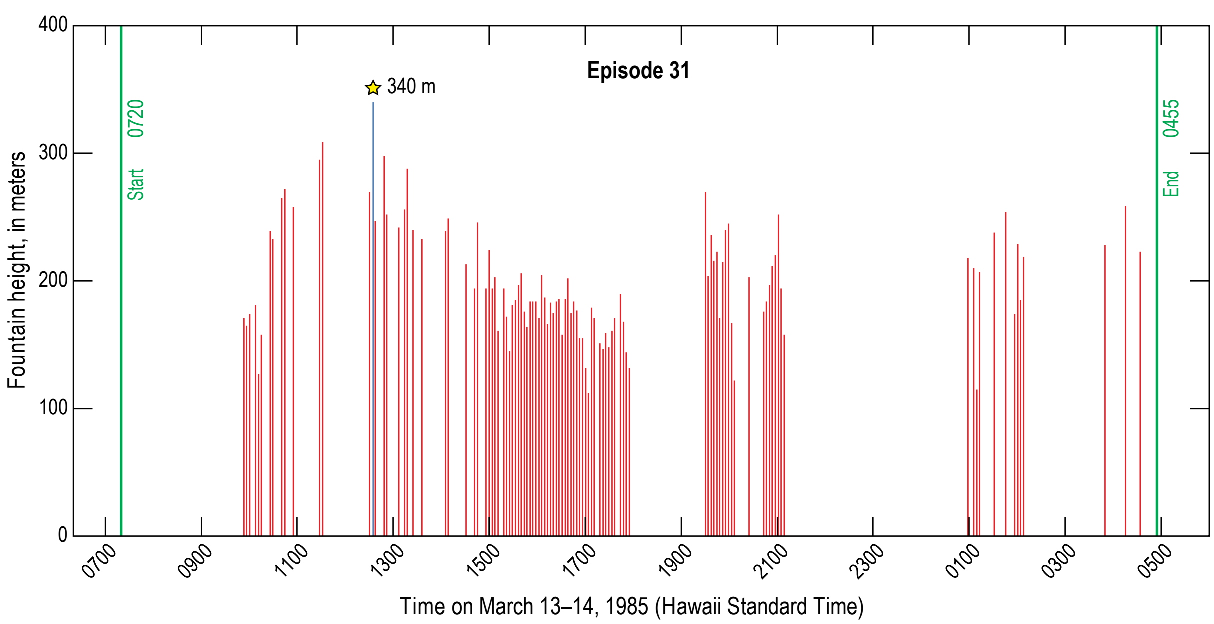


Figure 70. Graph showing episode 31 fountain heights measured from time-lapse film. The yellow star marks the highest fountain, measured by theodolite and shown in blue. The time interval between measurements is 3.7 minutes; data gaps are the result of poor visibility.

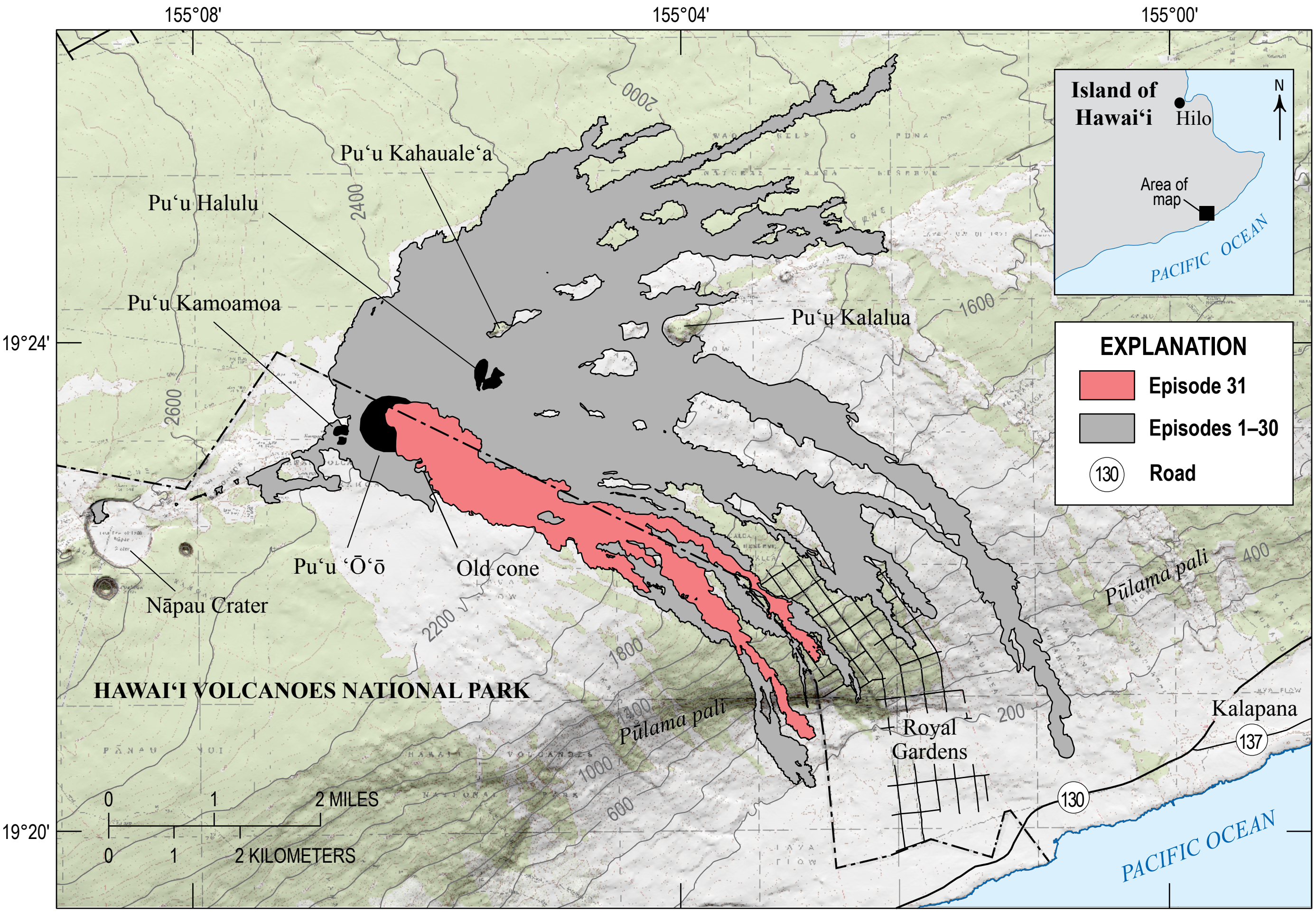


Figure 71. Map showing the distribution of episode 31 lava flows compared to earlier Pu‘u ‘Ō‘ō flows.

By 1800, most of the lava was pouring over the southeast flank of the cone and feeding the broad ‘a‘ā lobe, which was traveling toward the Royal Gardens subdivision. Because of the complete loss of visibility on the East Rift Zone owing to poor weather, the flow could not be monitored until it reached the upper streets of Royal Gardens, where it was sighted just before midnight at approximately 1,700-ft elevation. Later mapping showed that the flow had split into two main lobes and two minor lobes at around 2,200-ft elevation; the two main lobes moved eastward off the path of the episode 30 flow below this point and headed toward Royal Gardens, overriding the main flows of episodes 4 and 5 (fig. 71). By 0100 on March 14, the eastern of these two lobes had passed the west end of ‘Ēkaha Street (fig. 72), following an episode 5 channel, averaging ~800 m/h. By 0214, the east lobe had slowed considerably, but the western of the two lobes was still advancing rapidly through forest along the east edge of the episode 30 flow at 1,100-ft elevation, 6 km from the vent. By 0240, however, the distal ends of both lobes were barely moving, and no residences were in immediate danger.

Meanwhile, fountain-fed lava—occasionally visible through the clouds—continued to stream down the sides of the cone and feed the ‘a‘ā flow above the Pūlama pali. At 0348, observers in Royal Gardens reported increasing glow above the pali, which in 12 minutes materialized as a lava surge moving down the west lobe, picked up speed as it descended the pali. This surge produced a lava channel like that in episode 30 (fig. 65) and advanced the flow front to near its final position, 7.9 km from the vent, just above 300-ft elevation (fig. 71). Later smaller surges moved down the east lobe after the fountain had shut down, bringing that terminus to within 100 m of a house located near the intersection of Hoku Avenue and Plumeria Street (fig. 72).

Summary

Episode 31 (table 1, fig. 71) produced an estimated 13.4×10^6 m^3 of lava over a duration of 21.6 hours. The time-averaged discharge rate was 172 m^3/s, and 4.9 km^2 were covered by lava. About 0.2×10^6 m^3 of tephra was deposited. The summit of Pu‘u ‘Ō‘ō grew by 12 m, to a height of 206 m, and the vent rim decreased in elevation by about 2 m. Compositional variation from early in the episode to the end was reminiscent of episode 30; the MgO content increased from 7.7 weight percent in lava collected at 1040 on March 13 to 9.5 weight percent in the last lava erupted at 0455 on March 14 (Garcia and others, 1992).

A notable milestone was reached in episode 31: the total volume of lava produced to that date exceeded that of the previous largest historical eruption monitored on Kīlauea Volcano—the Mauna Ulu eruption. The several stages of the Mauna Ulu eruption from 1969 through 1974 produced a total volume of 243×10^6 m^3 over a period of 5 years and 59 days (Swanson and others, 1979; Tilling and others, 1987; converted to DRE). The volume of lava in the Puʻu ʻŌʻō eruption as of the end of episode 31 was 251×10^6 m^3 over a period of 2 years and 72 days. The time-averaged discharge rates were 1.5 m^3/s for Mauna Ulu and 3.6 m^3/s to date for Puʻu ʻŌʻō; the East Rift Zone magma system was discharging lava in 1983–85 at more than twice the rate of extrusion for the 1969–74 interval.

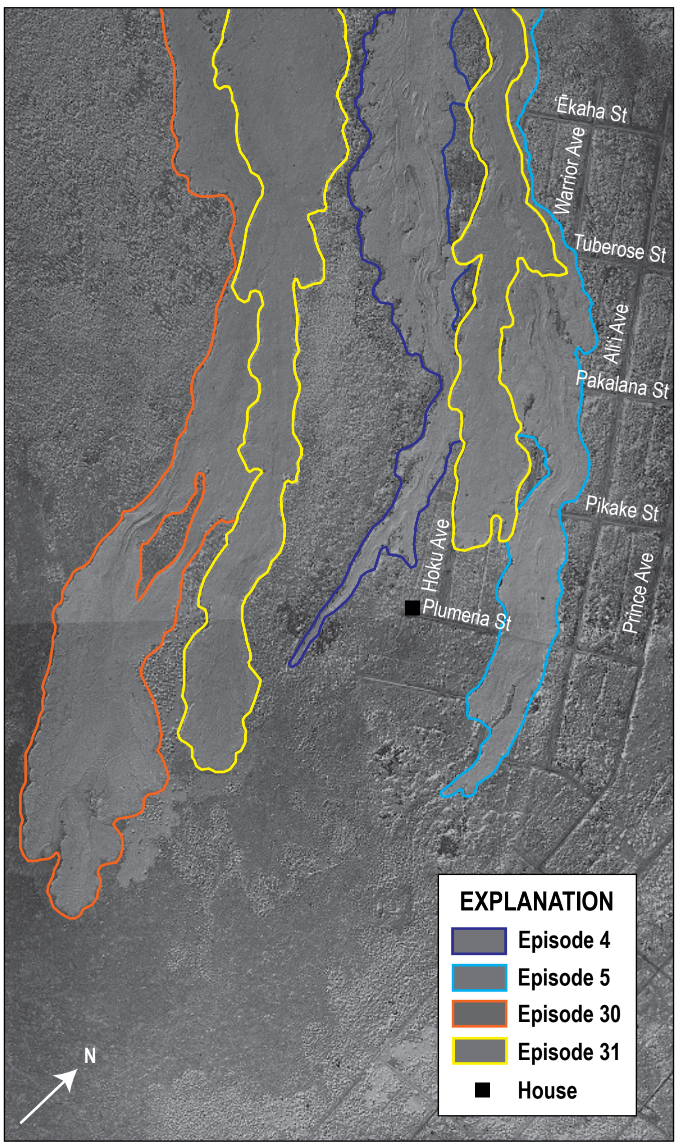


Figure 72. Aerial image of the west side of Royal Gardens showing the ʻaʻā lava flows of episodes 4, 5, 30, and 31. The channels created by lava surges described in the text are visible in the episode 30 flow and left-most (west) episode 31 lobe where they cross the steep face of the Pūlama pali. The black square marks the structure mentioned in the text. The image is a composite of two U.S. Geological Survey photographs taken by J.D. Griggs, April 1, 1985.

Episode 32 (April 21–22, 1985)

The inter-episode period following episode 31 was 38 days—13 days longer than the average for episodes 4–48 (table 2). Gas-piston events were recorded by the Puʻu Kamoamoa seismometer at varying intervals on 12 of the days between the two episodes. A magnitude-4.3 earthquake occurred slightly south of Puʻu ʻŌʻō on April 1 at about 9 km depth; this earthquake had no observed effect on the eruption.

The magma column first reappeared at a depth of 40–50 m below the vent rim on April 3, 20 days after the end of episode 31. By April 10, the column had climbed to 25 m below the rim and was 90 percent crusted over. It may have been higher during preceding days because fresh spatter was present on the vent rim. On April 13, observers on an overflight reported that a spatter cone had formed on the crust of the column 10–12 m below the vent rim. By April 17, the column, still mostly crusted, was between 5 and 10 m below the rim. At 0600 on April 21, a spillover from the conduit was observed from Glenwood. Lava effusion ceased within minutes, however, and episode 32 was still on hold. Observers on a National Park Service overflight at 1250 that same day reported active spattering at the vent, and that the magma column was positioned at the lip of the conduit, but continuous spillover had not begun.

Observers reached the site on foot on April 21 and witnessed the start of a low fountain at 1516. The fountain fed a thin pāhoehoe flow that extended about 400 m down-slope from the vent before stopping at 1547 (fig. 73). A second interval of fountaining, which lasted from 1554 to 1708 and reached heights of 15–25 m, was in progress when a second team of HVO observers arrived. This activity fed a thin pāhoehoe flow that traveled about 1 km southeast from the vent. A stable thermocouple temperature of 1,134 °C was obtained from this pāhoehoe flow on the flank of the cone after the fountaining interval had stopped. In comparison, a distance-corrected glass geothermometry temperature of 1,146 °C was calculated from lava adhered to the thermocouple (Thornber and others, 2003a). The fountaining resumed again at 1718 and ended abruptly at 1756 with a large gas burst, followed by lava draining back into the vent.

Eight minutes later, at 1804, fountain activity resumed, marking the official start of episode 32. Fountaining was continuous for the next 15 hours, ending at 0906 on April 22. The early fountain remained roughly dome-shaped for about an hour as it increased gradually in height (fig. 74). Within 2.5 hours, the fountain's height reached 300 m and took the usual shape of a vertical pulsating fountain. From 2100 to about 2200, clouds obscured the vent, and after 2300, fountain heights decreased through the early hours of April 22. A reversal in this trend occurred at about 0100, when fountain heights began to increase again, reaching a maximum of 391 m at 0520 (fig. 74). The pulsating fountain became irregular in height at 0822, and at 0906 the fountain died, marking the

Figure 73. Photograph showing the first of three low fountains and pāhoehoe spillovers during the pre-episode breakouts of episode 32. The fountain is 15–20 meters (m) high; the summit of Pu‘u ‘Ō‘ō is ~75 m above the base of the fountain. Photograph by S.K. Rowland, U.S. Geological Survey, April 21, 1985.

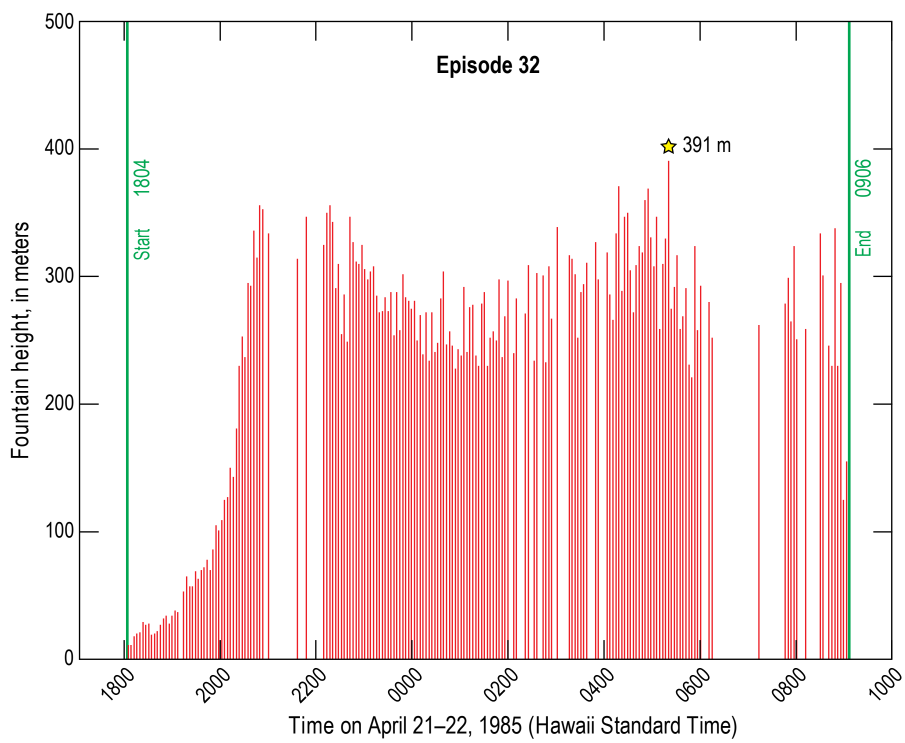


Figure 74. Graph showing episode 32 fountain heights measured from time-lapse film. The yellow star marks the highest fountain. The time interval between measurements is 3.7 minutes; data gaps are a result of poor visibility.

end of episode 32. Six minutes of restarting, sputtering, and outgassing then ensued (fig. 75). At 1030, about 1.5 hours after the episode ended, roiling lava was still visible in the conduit at about 40 m depth, but it soon disappeared.

During the early part of episode 32, three rootless ‘a‘ā flows formed on the south and southwest flanks of Pu‘u ‘Ō‘ō. Tephra from the episode later buried these flows to the base of the cone, so they could not be traced to their sources, but the fact that they were ‘a‘ā instead of pāhoehoe argues for a spatter-fed origin rather than a fissure source on the cone’s flanks.

An hour after the start of continuous fountaining, the main flow was a slow moving pāhoehoe lobe about 200 m wide that extended 1.1 km southeast from the vent. By 1945, the increasing fountain height resulted in an ‘a‘ā flow front whose distal end had broadened to nearly 400 m and was

Figure 75. Oblique aerial photograph of the Pu‘u ‘Ō‘ō vent and cone immediately after the end of episode 32 fountaining. The incandescent conduit wall and the face of the cone shows the drainage of the lava that veneers the surface around the vent. Photograph by J.D. Griggs, U.S. Geological Survey, April 22, 1985.

1.4 km from the vent, advancing at a rate of 400 m/h along the same general route as the flows of episodes 30 and 31. This flow also partly buried the old cone 700 m southeast of Pu‘u ‘Ō‘ō (fig. 76). The flow advanced through the night, overriding the episode 31 flow and staying mostly inside the National Park boundary. A 100–200 m wide swath of forest on the southwestern margin of the flow was burned and overrun (fig. 77).

Early in the morning of April 22, two narrow lobes split off from either side of the larger (600 m wide) main lobe. Advance rates varied from 200–400 m/h, decreasing significantly after 0630. The main lobe advanced an additional 900 m after the fountain died, reaching 1,500-ft elevation, where it came to a stop on April 23, 5.9 km southeast of the vent (fig. 77).

Summary

Episode 32 (table 1, fig. 77) produced an estimated 11.3×10^6 m^3 of lava in 15.0 hours, covering an area of 4.9 km^2. The time-averaged discharge rate was 209 m^3/s. The summit of Pu‘u ‘Ō‘ō grew by 8 m but lost 5 m of that within a week owing to collapse, giving the cone a height of 209 m. The profile of Pu‘u ‘Ō‘ō after episode 30 is compared to episode 32 in figure 78, illustrating the growth of the cone. The tephra blanket was estimated to be about 0.2×10^6 m^3 in volume. Compositions of lava samples collected prior to, during, and at the end of the episode did not show the large intra-episode chemical variation of episodes 30 and 31, although the presence of olivine microphenocrysts continued (Garcia and others, 1992). A glass temperature of 1,171 °C was calculated for spatter deposited as (or shortly after) fountaining ended (Thornber and others, 2003a).

Figure 76. Oblique aerial photograph of an old undated cone ~700 meters (m) southeast of Pu‘u ‘Ō‘ō after episode 32. Infilling of the 37-m-deep crater began in episode 23; the last vestiges of the tree-covered rim were buried in episode 38. Photograph by J.D. Griggs, U.S. Geological Survey, April 22, 1985.

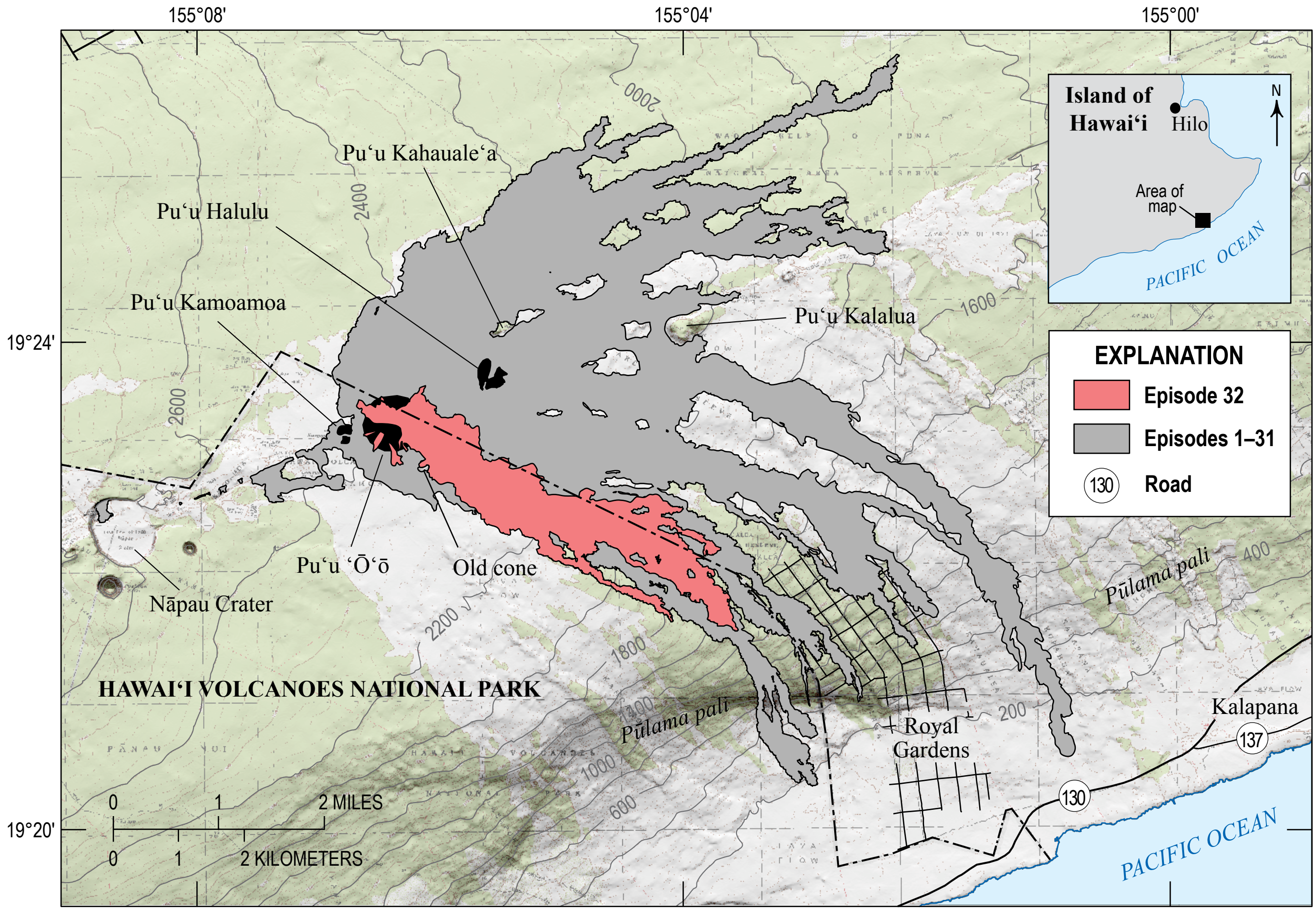


Figure 77. Map showing the distribution of episode 32 lava flows compared to earlier Pu‘u ‘Ō‘ō flows.

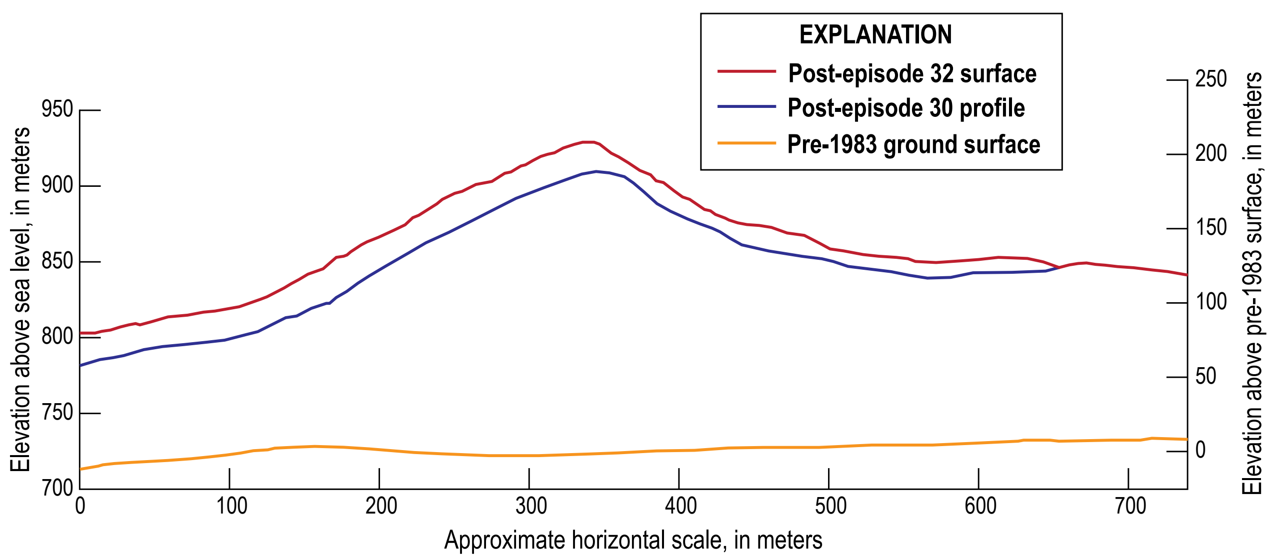


Figure 78. Profiles of Pu‘u ‘Ō‘ō after episodes 30 and 32, illustrating cone growth. Profiles are drawn looking southwest from the perspective of the camera station on Pu‘u Halulu. The vertical scale is constrained by theodolite measurements; the horizontal scale is from topographic surveys.

Episode 33 (June 12–13, 1985)

The duration of the inter-episode period following episode 32, at 52 days (table 1), was more than twice the average for episodes 4–48 (table 2) and was exceeded only by the 65-day inter-episode period following episode 3 (Wolfe and others, 1988). The summit inflated 13.8 microradians (mrad) during the 30 days following episode 32, but, atypically, deflated 5 mrad thereafter (fig. 79), suggesting a loss of magma from the summit reservoir. The destination of the magma remains unknown.

The vent was initially obscured by dense fume following episode 32, but on May 9 the magma column reappeared at a depth of 50 m below the vent rim. The lava surface was observed on May 20 to have fallen to a deeper level in the conduit, which narrowed with depth, but by May 24 it had risen again and was roiling about 30 m below the vent rim. On June 1, the lava was within 10–15 m of the top of the conduit, and fresh spatter was observed on the vent rim. Until June 9, the top of the column remained partly open, and fume alternated with increased spattering, coinciding with seismicity interpreted as representing gas-piston activity. On June 10, a small spatter cone like those of earlier episodes formed on the crusted magma column. Intermittent spatter bursts from the cone reached as high as 40 m above the conduit until 2000. By June 11, the magma column had risen to within 3 m of the vent rim, and the spatter cone had grown to 5 m in height.

On June 12, low fountains and spillovers occurred intermittently from 0430 to 2246 (figs. 80 and 81). The duration of the low fountaining intervals increased during the first 9 hours, decreased during the next few hours, and was erratic thereafter, with mostly short-duration events, before the main episode began at 2306. The early fountaining intervals terminated abruptly, but, as the intermittent activity continued, the later fountains shut down more slowly. In all cases, the fountains were terminated by an explosive gas burst. The combined duration of each fountaining interval and the inter-episode period that followed was variable but decreased generally through the 18.5-hour period. The fountains were roughly dome-shaped and varied in

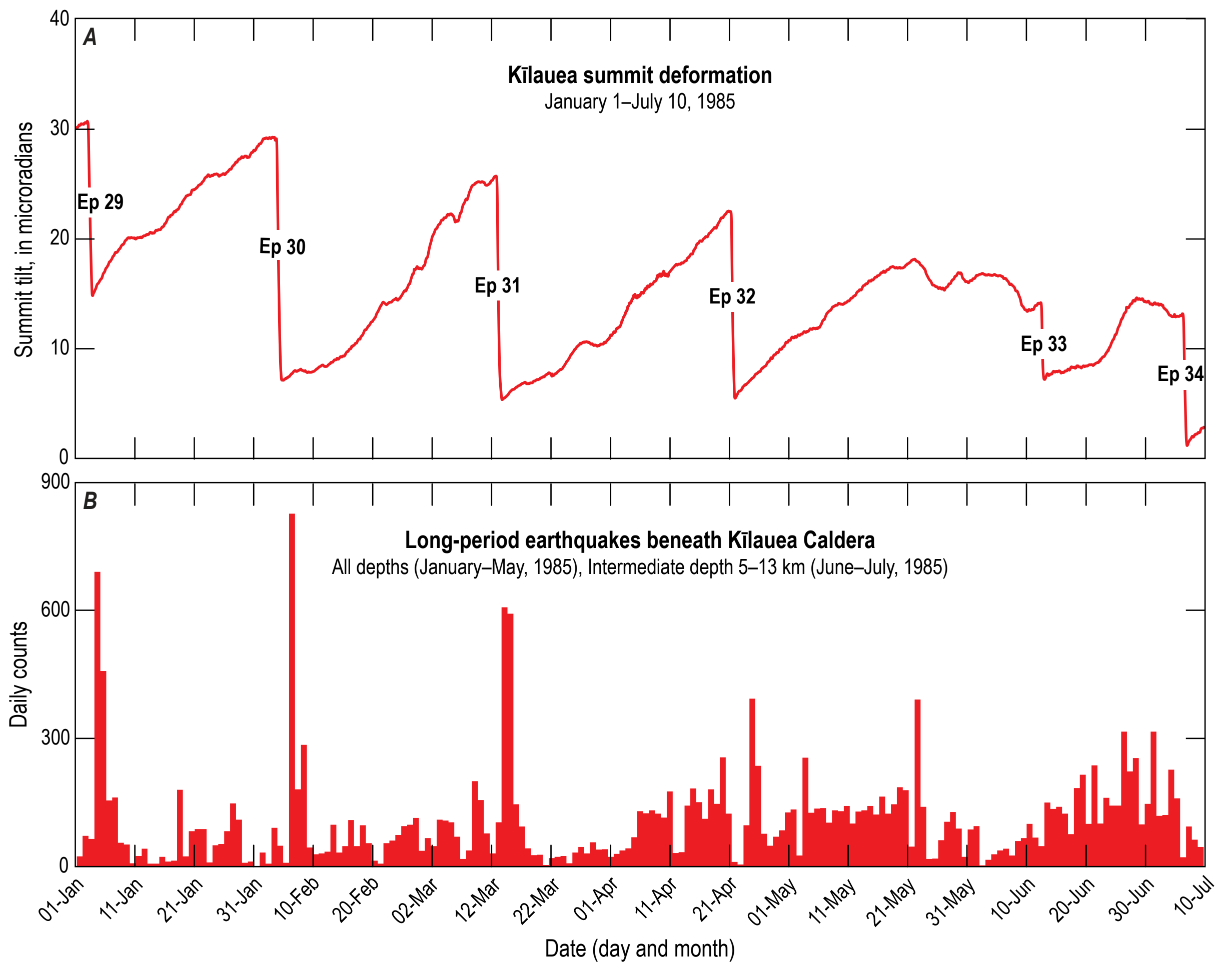


Figure 79. Graph comparing *A*, Kīlauea summit tilt (west-to-east tilt change measured by Ideal Aerosmith tilt instrument) and *B*, long-period earthquakes beneath the caldera from January 1 to July 10, 1985. High fountaining episodes at Puʻu ʻŌʻō are indicated by the numbers at each sharp deflationary interval. Note the change to deflation prior to episodes 33 and 34. Long-period earthquakes at 5–13-kilometer depths were normally sparse except immediately following most episodes.

height from 5 to 46 m, reaching their maximum for each interval at the end of the inter-episode period. A glass temperature of 1,159 °C was calculated from the crust of a pāhoehoe spillover from the vent that ended at 1215 (Thornber and others, 2003a). In comparison, a maximum lava temperature of 1,137 °C was measured by thermocouple on a pāhoehoe flow that was active from 1351 to 1420. The spatter cone above the conduit was eroded away during this period, and the vent area assumed the appearance of a shallow bowl with a low spatter levy around its perimeter (fig. 82).

A serious field accident befell the second author as he attempted to sample a spillover about 150 m downslope of the vent. Misjudging the boundary between older, thicker crust and newly formed crust, Ulrich broke through, receiving second- and third-degree burns from the knees down on both legs and on the mid-thigh of one leg. Dario Tedesco, an Italian

Figure 80. Photograph looking southwest from Pu‘u Halulu of a low fountain and pāhoehoe overflow preceding episode 33. Photograph by C. Heliker, U.S. Geological Survey, June 12, 1985.

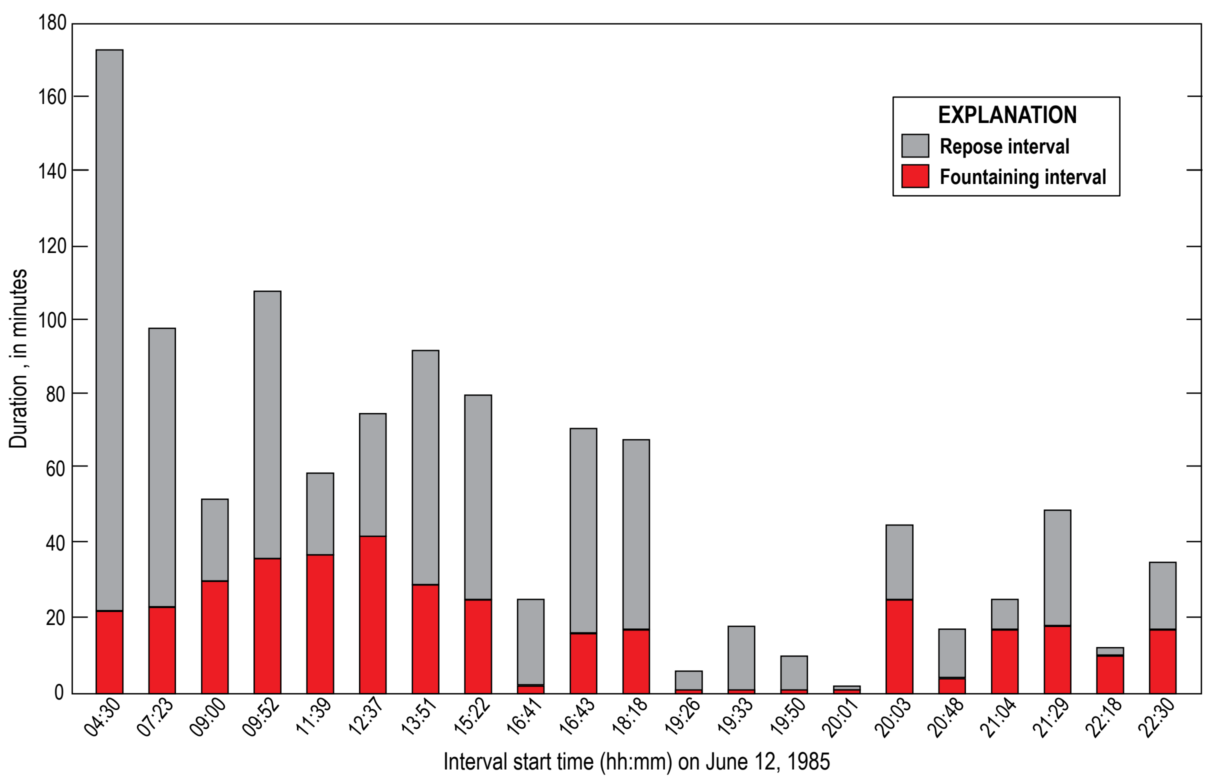


Figure 81. Graph showing the duration of the low fountains (red bars) on June 12, 1985, that occurred during the eruptive activity that preceded the onset of episode 33. The gray bar after each fountaining interval shows the time elapsed before the next fountain started.

Figure 82. Photograph of a spatter cone over the Puʻu ʻŌʻō conduit, looking northeast, ~15 minutes before the sixth low-fountaining interval before the onset of episode 33. The preceding pāhoehoe overflow ponded around the spatter cone and formed the visible low levy before exiting the vent area over the spillway to the left. Photograph by G. Ulrich, U.S. Geological Survey, 1222 HST, June 12, 1985.

geochemist, immediately pulled Ulrich from the lava, thus preventing more serious injury. Ulrich was initially treated in the Hilo hospital, but within a few days was evacuated to the Straub Clinic burn center in Honolulu where he stayed for 2 months. He returned to duty in late August and recovered completely over the next 5 months.

Episode 33 began at 2306 on June 12 and continued for only 5.8 hours. The fountain grew from the onset, reaching 125 m by midnight. A maximum measured height of 268 m occurred at 0053, but clouds obscured the top during intervals of higher fountaining from 0100 to 0230; as a result, the time-lapse film record of the episode was too incomplete to illustrate. As the vigor of the fountain increased, its roaring was heard widely, possibly rebounding from the low cloud layer, and windows rattled in Mountain View, 18 km north. The fountain died at 0453, followed by a few last gasps of spatter for 2 minutes and then an orange flame above the conduit until 0530.

The early pāhoehoe spillovers poured down the northeast flank of the cone and advanced southeast. By 2000, the distal end of the farthest flow was 700 m from the vent and about 150 m wide, overriding the episode 32 flow. By midnight, the pāhoehoe flow was 1.7 km long. The flow had stagnated by 0100 the next day (June 13), however, and was being overrun by ʻaʻā. In addition, rootless ʻaʻā flows were soon spilling down the west and northwest flanks of Puʻu ʻŌʻō, reaching the base of the cone by 0200. One of these flows eventually reached the western margin of the flow field. At 0230 the distal end of the main ʻaʻā flow was 2.5 km southeast of the vent, and by 0400 it had reached 2,100-ft elevation, about 3 km from the vent. It reached a final length of 4.4 km, at about 1,940-ft elevation (fig. 83) and lay almost entirely on top of the episode 32 flow. About 2.5 hours after the end of fountaining, an overflight revealed that the conduit was still completely incandescent, yet so bright that it was impossible to determine if magma was present in the upper tens of meters.

Summary

Episode 33 (table 1, fig. 83) produced an estimated 5.5×10^6 m^3 of lava during its 18.5 hours of intermittent fountaining and 5.8 hours of continuous lava effusion—well below the average of 7.7×10^6 m^3 for high-fountaining episodes 4–47—and covered an area of 2.4 km^2. The average rate of lava discharge was 266 m^3/s for the interval of continuous lava effusion. The summit of Puʻu ʻŌʻō grew by 3 m, for a cone height of 212 m. The composition of early, main phase, and late-stage lava samples showed no significant chemical variation. A glass temperature of 1,159 °C was calculated from a vent overflow about 11 hours before the onset of fountaining (Thornber and others, 2003a).

The anomalous summit tilt pattern of pre-episode deflation, and a corresponding increase in long-period earthquakes beneath the caldera, may have indicated a transfer of magma from the summit reservoir at intermediate depths, and possibly accounted for the relatively low volume of lava erupted.

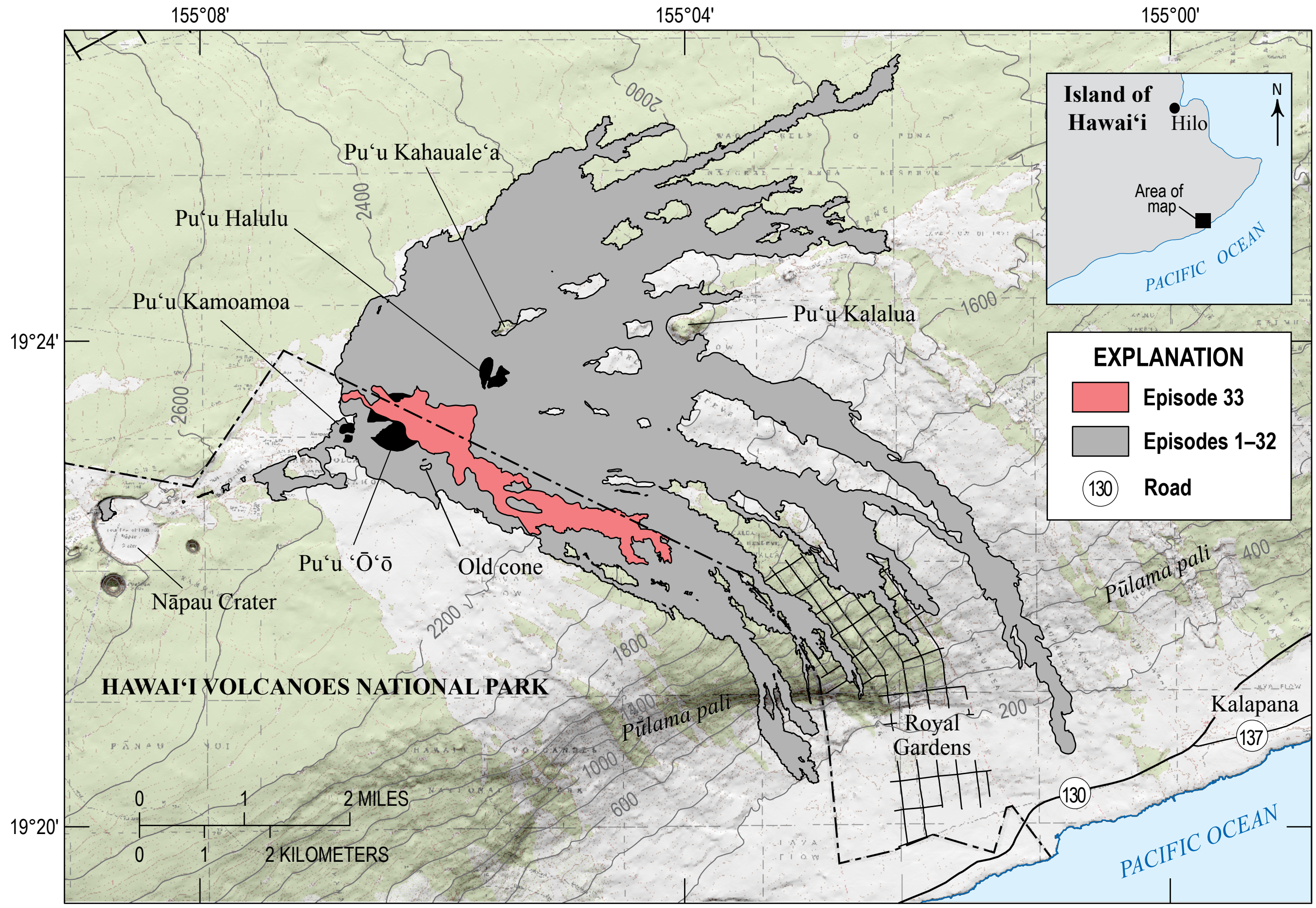


Figure 83. Map showing the distribution of episode 33 lava flows compared to earlier Puʻu ʻŌʻō flows.

Episode 34 (July 6–7, 1985)

The inter-episode period of 24 days following episode 33 was close to the average for episodes 4–47. Summit inflation followed a pattern of normal increase until ~85 percent of the preceding deflation was recovered. As the inflation approached a trendline connecting the peaks of episodes 29 through 33 (fig. 79), inflation ceased and deflation occurred for 6 days until just before the episode. Neither cross-rift deformation nor seismicity in the Puʻu ʻŌʻō area showed behavior indicative of a magma intrusion into the shallow reservoir there.

The magma column was visible in the conduit of Puʻu ʻŌʻō during every visit from the end of episode 33 until the start of episode 34, except when prevented by inclement weather or obscured by heavy fume. It produced a faint glow during the week immediately following episode 33 (as viewed from the Puʻu Kamoamoa side of the cone) that became brighter and pulsed as the free surface rose in the conduit. On June 20, the top of the magma column was 30–40 m below the vent rim and about 75 percent crusted over, though spatter was occasionally thrown onto the vent rim. During the following week the column rose 5–10 m and was 50–75 percent covered with crust. By June 28, spatter was being tossed 10–15 m above the vent rim, and, by July 1, a spatter cone once again had formed on the crust about 5 m below the vent rim. Over the next 4 days, an increase in spattering was observed, interspersed with an orange flame, and the spatter cone grew until it stood 1–2 m above the vent rim.

Inter-episode fountaining from the spatter cone, like that of episodes 29–33, began at 0654 on July 6. A low fountain about 10 m high ensued, feeding fluid flows over the northeast spillway for 15 minutes before stopping. From 1036 to 1230, intermittent spattering and brief intervals (<1 minute) of low fountaining as high as 6 m occurred at the spatter cone, now 2 m high and 6 m across. Fountains a few meters high, lasting about 5 seconds each, occurred at 1112 and 1155, and a low fountain was active from 1230 to 1256, producing more spillovers. This was followed by 6 hours of intermittent spatter, further building the spatter cone.

Episode 34 began at 1903 on July 6 and continued for nearly 14 hours. Initially 10–15 m high, the fountain grew to about 45 m by 2112 and soon surpassed the summit of Puʻu ʻŌʻō, which stood 75 m above the vent rim. A maximum fountain height of 410 m was recorded on film at 0339 on July 7 (fig. 84). Starting around 0730, the fountain fell below 250 m except for brief pulsating jets, described as tall and narrow, that occurred after 0846. The fountain died with a roaring burst of gas at 0850, followed by an orange flame above the vent that lasted for another 10 minutes.

The early pāhoehoe traveled down the northeast spillway and turned southeast, where it was later overrun by ʻaʻā that went 3.0 km (fig. 85), overrunning the upper part of the episode 33 flow as a broad fan about 1 km wide before stopping.

Summary

Episode 34 (table 1, fig. 85) produced an estimated 7.1×10^6 m^3 of lava during 13.8 hours of continuous lava production, covering an area of 2.3 km^2. The time-averaged discharge rate was 143 m^3/s. The summit of Puʻu ʻŌʻō grew by 16 m, to 228 m, and the volume of the tephra blanket deposited downwind was estimated at about 0.3×10^6 m^3. The profile of the cone after episode 32 and after episode 34, illustrating the cumulative growth of the cone, is shown in figure 86. Anomalous behavior of Kīlauea's summit tilt prior to the episode, like that described in episode 33, was repeated. It is not clear whether these events might have been precursors to the upcoming fissure outbreak of episode 35.

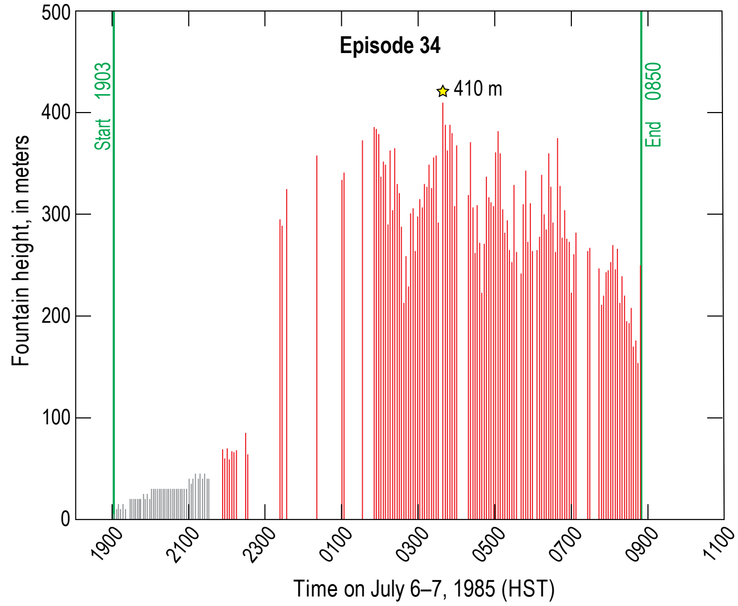


Figure 84. Graph showing episode 34 fountain heights measured from time-lapse film. The yellow star marks the highest fountain. The time interval between measurements is 3.6 minutes. Fountain heights for the period from 1903 until 2132, shown in gray, were estimated generally every 3 to 4 minutes from onsite observations. Data gaps are the result of poor visibility.

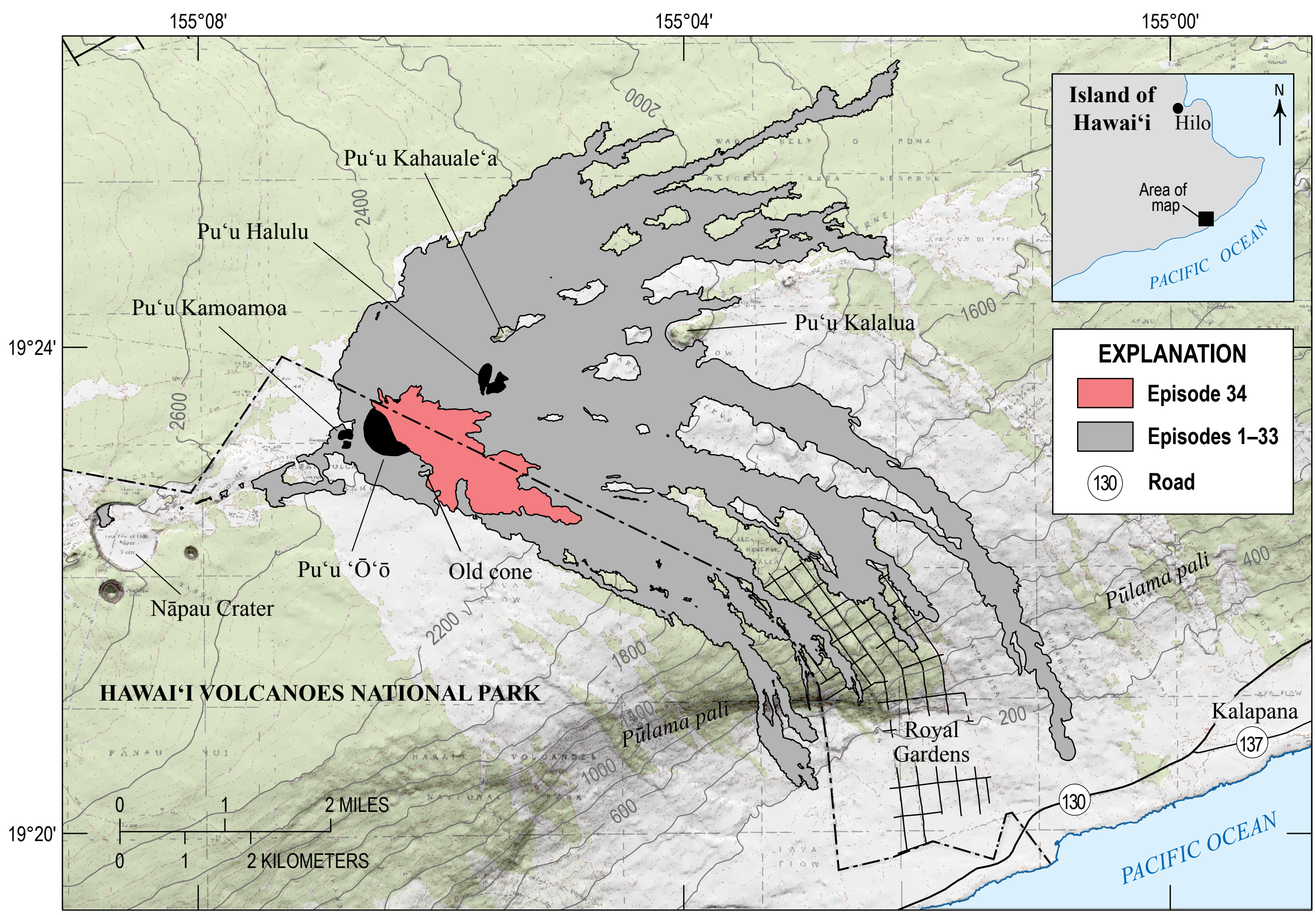


Figure 85. Map showing the distribution of episode 34 lava flows compared to earlier Puʻu ʻŌʻō flows.

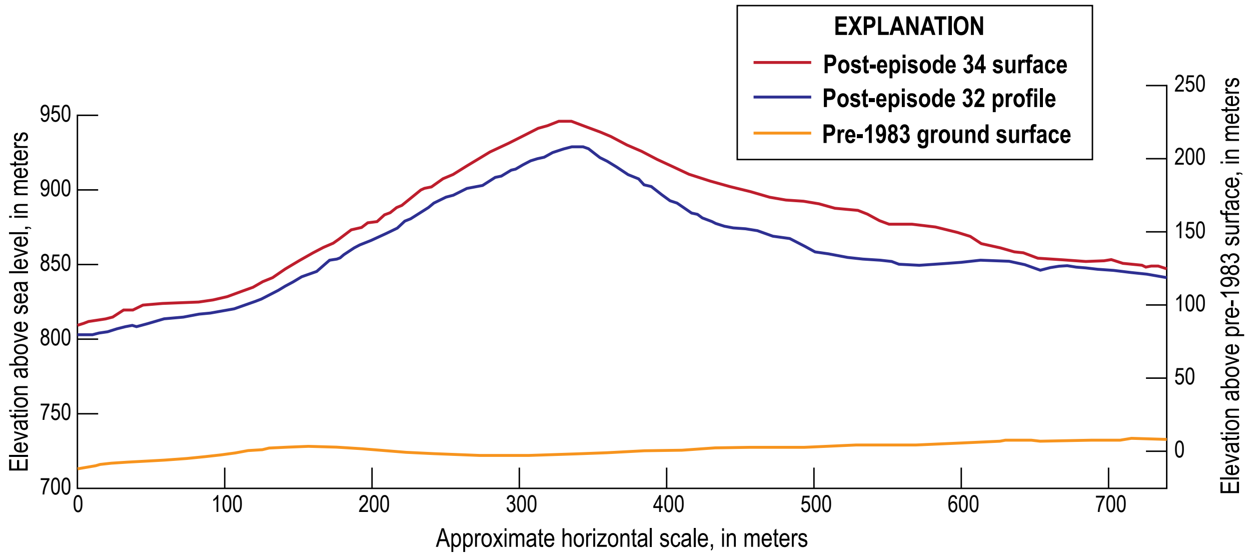


Figure 86. Profiles of Pu‘u ‘Ō‘ō after episodes 32 and 34, illustrating cone growth. Profiles are drawn looking southwest from the perspective of the camera station on Pu‘u Halulu. The vertical scale is constrained by theodolite measurements; the horizontal scale is from topographic surveys.

Episode 35 (July 26, 1985) and Episode 35A (July 27–August 12, 1985)

Episode 35 began as a brief but normal high-fountaining episode with early fissure activity, and it was closely followed by the longest duration fissure outbreak (35A) to occur in the Pu‘u ‘Ō‘ō series prior to episode 48. There were no precursors to this departure from the normal pattern, except, perhaps, for the anomalous summit inflation and long-period earthquakes preceding episodes 33 and 34.

The inter-episode period of 19 days following episode 34 was less than the average of 25 days for episodes 4–48 (table 2). Magma was first observed in the Pu‘u ‘Ō‘ō conduit following episode 34 on July 10, at a depth of approximately 100 m. Over the next 12 days, the magma rose to within 10 m of the vent rim, and once again a spatter cone formed on the crusted column. Frequent spattering continued through July 25, by which date the top of the spatter cone was 1–2 m below the vent rim. The next episode was imminent, but geologists had to abandon the Pu‘u Halulu camp because of Hurricane Ignacio, which was passing south of the island and gracing it with torrential rainfall. Thus, the early hours of episode 35, which began at 0252 on July 26, were observed only by time-lapse camera.

Fissure vents opened on the west flank of Pu‘u ‘Ō‘ō either shortly before, or simultaneously with, the start of fountaining at the Pu‘u ‘Ō‘ō vent. The fissure-fed pāhoehoe flows advanced 300 m northwest into the center of the horseshoe-shaped Pu‘u Kamoamoa cone and 1.5 km southeast to the edge of the forest (figs. 87 and 88). By 0700, the fissure was inactive and buried under 50–100 cm of tephra from the ongoing fountaining, which reached a height of 245 m; only rising fume gave evidence of the fissure's location. Tephra also buried much of the pāhoehoe flow produced by the fissure, preventing the accurate mapping of that part of the flow.

The high fountain from Pu‘u ‘Ō‘ō fed two main ‘a‘ā flows. The larger eventually reached 2.2 km southeast along the course of the episode 34 flow; the smaller stagnated 1.1 km northwest (fig. 88). The volume of episode 35 lava from the main Pu‘u ‘Ō‘ō vent was approximately 5.0×10^6 m^3 of ‘a‘ā, and that from the early fissures on the west flank of Pu‘u ‘Ō‘ō was roughly 0.8×10^6 m^3 of pahoehoe, for a total of 5.8×10^6 m^3.

At 0952, exactly 7 hours after episode 35 began, the fountain died. Two hours later, we noticed tephra bouncing like popcorn over the buried fissures near Pu‘u ‘Ō‘ō. Soon largely outgassed pāhoehoe oozed slowly from the fissure (fig. 89) on the west side of Pu‘u ‘Ō‘ō. This activity continued for about 80 minutes and ceased after producing a pāhoehoe pad 25 m long. Three hours later, at 1540, new ground cracks began to open 400 m west of Pu‘u ‘Ō‘ō, at the west edge of the fissure-fed pāhoehoe produced earlier in the day. The cracks propagated uprift, in line with the eruptive fissures at the base of Pu‘u ‘Ō‘ō that erupted during the early part of episode 35. The measured rate of propagation at 1648 was 0.3 m/min; shortly afterwards, however, the cracking accelerated to a walking pace—approximately 20 m/min—and was accompanied by booming noises. The tephra in this area was about 2 m thick, and the surface expression of the cracking was two parallel lines of holes, approximately 1.5 m apart, that gradually coalesced into continuous cracks with the ground down-dropped between them, forming a small graben. The cracks emitted neither heat nor fumes. The Pu‘u Kamoamoa seismometer recorded many microearthquakes associated with the propagation of the cracks, but the overall level of seismicity associated with the ground cracking was low.

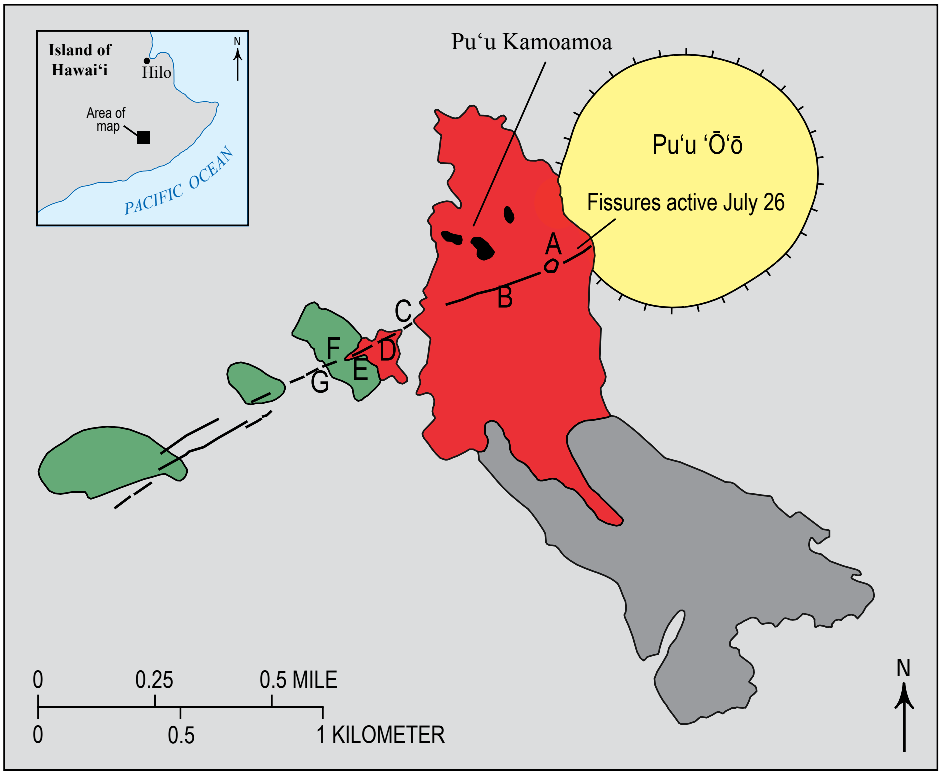


Figure 87. Sketch map showing the episode 35 and episode 35A fissures. The active fissure at the start of episode 35 on July 26 extended from between the A- and B-vents to approximately 75 meters northeast of the A-vent and produced the gray-shaded pāhoehoe flow. The fissure also erupted a small pāhoehoe pad shortly after high fountaining ended. The fissure began to propagate during late afternoon of July 26, and episode 35A eruptive activity started early on July 27 at vents A–G, producing the red-shaded flow. Activity was limited to the A and B vents by July 28.

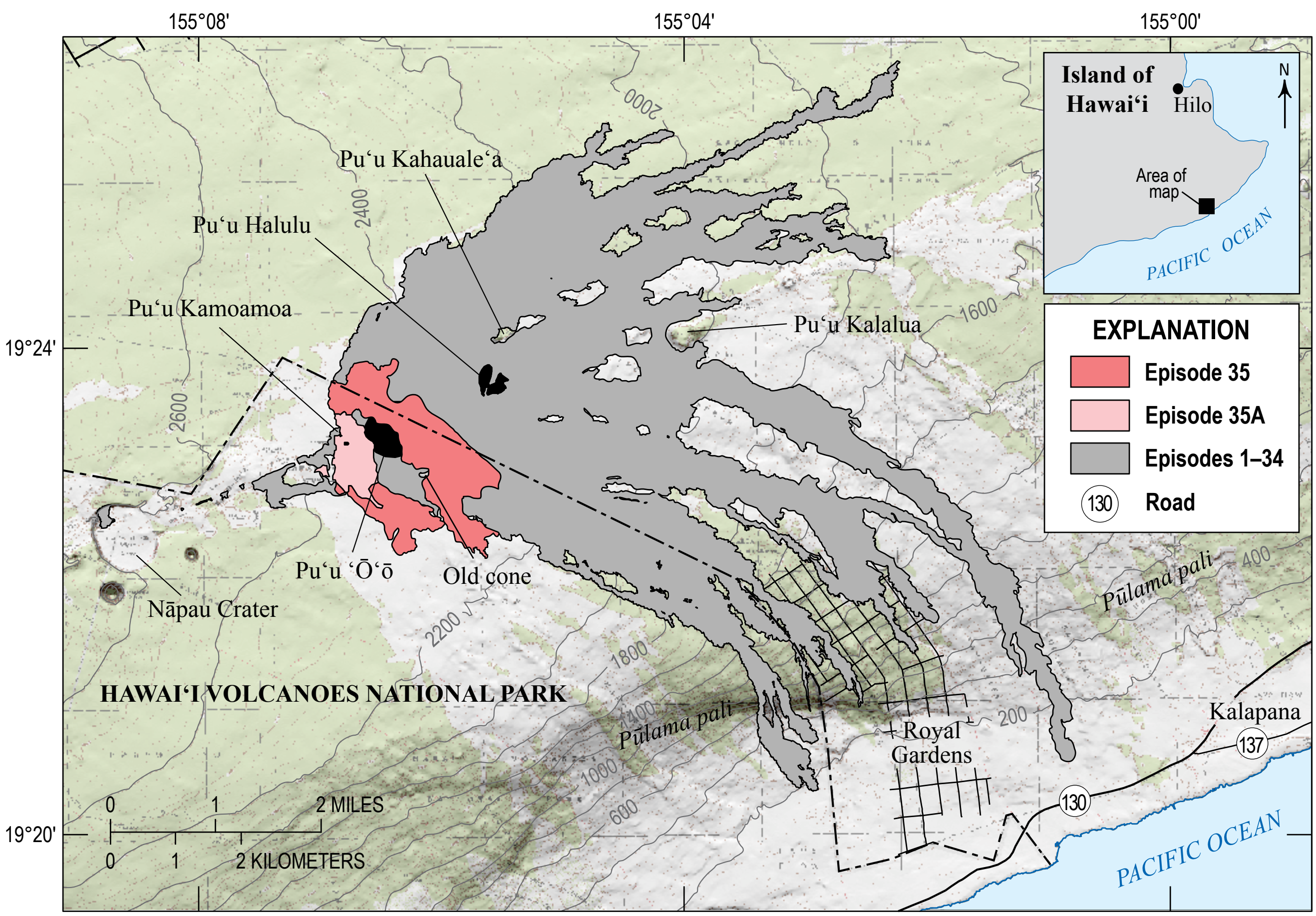


Figure 88. Map showing the distribution of episode 35 lava flows compared to earlier Puʻu ʻŌʻō flows.

Figure 89. Photograph looking uprift along the reactivated episode 35 fissure. Photograph by J. Hoffmann, U.S. Geological Survey, ~1330 HST, July 26, 1985.

By the following morning, the cracks had extended 2 km uprift of Puʻu ʻŌʻō (fig. 87), forming a parallel set along most of their length. The distance between the main cracks was 55 m, 1.5 km uprift of the cone (fig. 90); the separation increased to about 100 m farther uprift. Short, discontinuous cracks formed outside of the main set. We installed several crack stations across the cracks and monitored them over the next week. The uprift end of the cracks showed 6 cm of extension from July 27 to August 5; we measured 12 cm of extension from July 30 to August 5 at the crack station 600 m from Puʻu ʻŌʻō. Most of the extension occurred before July 31; after August 5, the cracks showed no changes. The actual width of the cracks in the lava at the base of the tephra varied from 23 to 56 cm, at the sites where measurements were possible, and showed as much as 9 cm of left lateral offset, suggesting that the opening direction was oblique to the strike of the cracks. The maximum total extension measured across the crack zone was about 115 cm.

Fissure Outbreak—Episode 35A

Episode 35A began at 0414 on July 27, when several vents along the northeastern-most kilometer of the fissure system erupted. The activity shifted back and forth along that section of the fissure system, but in general, the area of highest output was a 300-m-long stretch of the fissure that included several intermittently active vents, designated the B-vents (fig. 87). Fountains were less than 5 m high, and much of the lava welled out of the fissures without fountaining (fig. 91). Many of the initial vents were short-lived (fig. 92). Most of the lava flowed southeast, forming a broad apron of pāhoehoe within 400 m of the fissure (figs. 87 and 88).

Early on the morning of July 28, the vents at the uprift end of the fissure system died, and thereafter the activity was limited to the A-vent and the northeastern-most B-vents. Lava output remained constant through July 29, but the effusion rate decreased substantially on July 30, and only a few brief periods of activity were observed at the B-vents. On July 31, the activity resumed along a 50-m stretch of the fissure that included the A-vent and the northeastern B-vents, producing low spatter and a pāhoehoe flow that curled around the southwest side of Puʻu Kamoamoa.

From August 5 on, the A-vent was the sole source of the effusion, except for one or two small vents a few meters downrift of the A-vent that sputtered intermittently. The vigor of activity at the A-vent increased gradually, and, once it was the only active vent, produced fountains 5–8 m high, in contrast to the 1-m fountains that were active during the first few days of the episode. Activity seemed to wax and wane over periods lasting several hours. Lava volume estimates suggest that there was only a slight, if any, increase in effusion rate from July 30 to August 12.

Lava temperatures ranging from 1,139 to 1,148 °C were measured by thermocouple during the first 5 days of the fissure activity. Glass geothermometry temperatures ranged from 1,154 to 1,161 °C for the period July 31–August 7 (Thornber and others, 2003a).

Throughout the fissure activity, the flows tended to pile up close to the fissures, rather than spreading over new ground. As a result, a small shield formed with its summit between the A-vent and the northeastern B-vents (fig. 93). Theodolite readings showed that the shield grew vertically an average of 1.4 m/day from July 30 to August 12, when episode 35A ended, reaching a final height of 26 m.

The flows eventually extended about 700 m both southeast and north of the fissures and overran most of Puʻu Kamoamoa, which was reduced to three kīpukas barely above the level of the surrounding pāhoehoe (figs. 87 and 93). The growing shield eventually threatened to overrun the Puʻu Kamoamoa seismometer, which, on August 7, was moved to a new spot called Steam Cracks (designated STC), located 2.1 km uprift (west–southwest) of the Puʻu ʻŌʻō conduit (fig. 1).

The benchmark located at Puʻu Kamoamoa was ultimately spared, but its usefulness as an electronic distance measurement

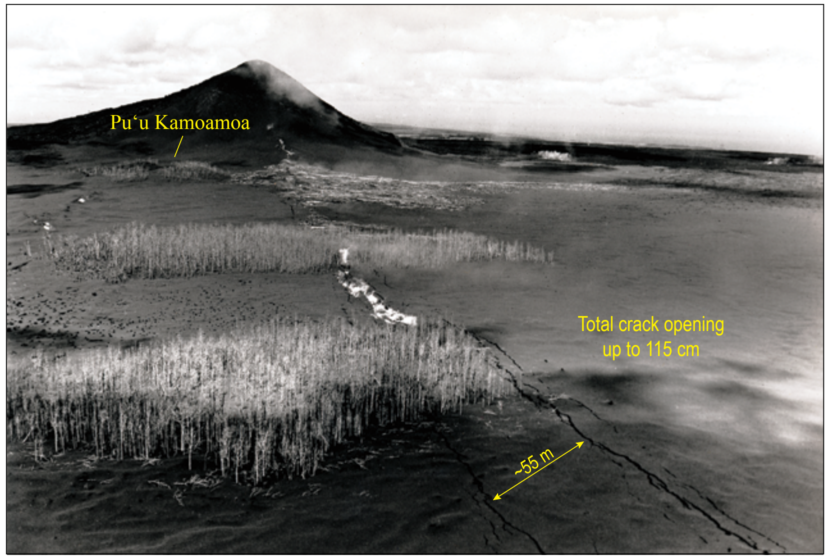


Figure 90. Oblique aerial photograph of the episode 35A fissure system, showing the parallel set of ground cracks that extended for almost the entire length of the 2-kilometer-long crack system. The eruptive portion of the system begins at the base of Pu‘u ‘Ō‘ō and extends through the clump of dead trees at the center of the image. Photograph by J.D. Griggs, U.S. Geological Survey, July 27, 1985. m, meters; cm, centimeters.

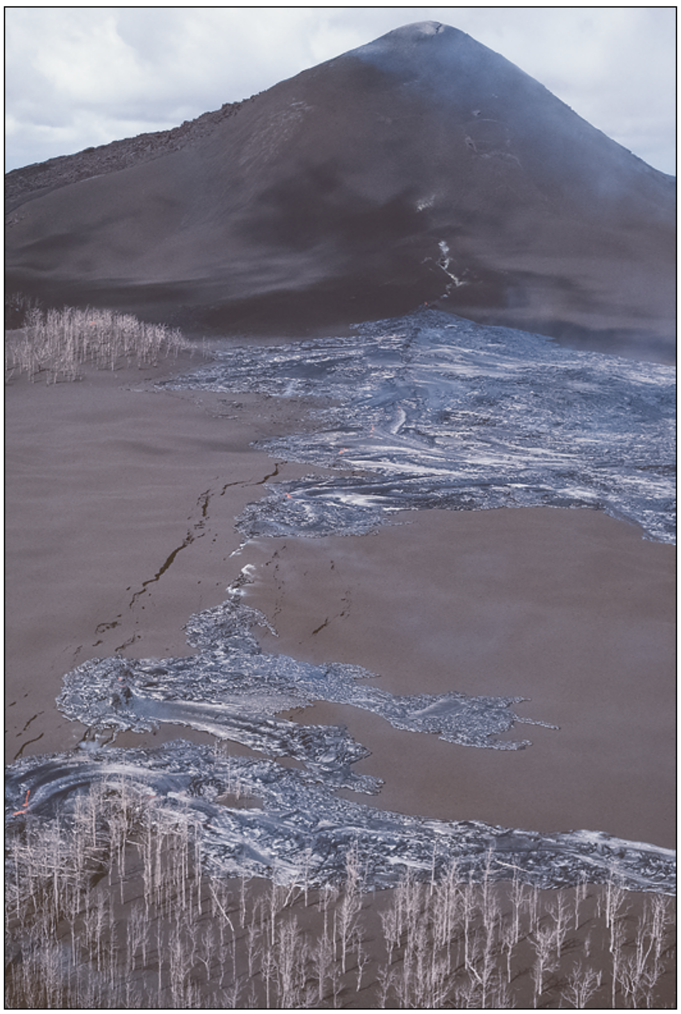


Figure 91. Oblique aerial image of the episode 35A fissure outbreak on July 27. Gentle effusion through new cracks in the tephra, with little or no fountaining, was typical until the activity became localized at the A-vent on August 5. The fissure extends up the lower flank of Pu‘u ‘Ō‘ō. Pu‘u Kamoamoa is the forested mound to the left of the fissure in distance. Photograph by J.D. Griggs, U.S. Geological Survey.

Figure 92. Photograph of the short-lived C-vents of episode 35A, active briefly on July 27, that were exposed as the surrounding tephra slumped into the fissure during the following months. Column of lava is ~1 meter high. Photograph by C. Heliker, U.S. Geological Survey, November 6, 1985.

(EDM) station (fig. 94), important for documenting deformation across the rift zone, was greatly diminished after August 1, because the new shield blocked the view south. Episode 35 showed the normal pattern of line length contraction over the 3-km-long EDM line (Hoffman and others, 1990) during the high fountaining on July 26, which produced flows that overran all of the permanent reflectors on the south side of the rift, except the one farthest from Puʻu Kamoamoa.

The displacement owing to the fissures opening was superimposed upon the normal pattern of line contraction that occurred during a high fountaining episode. Most of this displacement occurred between July 24 and July 27, but minor deformation continued until July 31. The intrusion of the episode 35A dike moved the Puʻu Kamoamoa benchmark 34 cm north, relative to the assumed center of deformation at the fissures (fig. 94). The dashed vector south of the fissure in figure 94 assumes that the deformation was symmetrical across the fissures. The outer targets showed about 1 cm of contraction during this period, indicating that the displacement caused by the intrusion of the dike was taken up near the fissures, evidently by older cracks in the rift zone.

Continued measurement of the northern half of the Puʻu Kamoamoa EDM line showed 2 cm of extension from August 1 to 19, a return to normal inter-episode behavior after Puʻu Kamoamoa was pushed north by the opening fissures in July. On August 28, a new EDM station was established on a spatter cone 300 m uprift of Puʻu Kamoamoa, and a new line of cross-rift targets was installed.

Following the end of the episode 35A fissure outbreak, a leveling crew traversed the shield along a pre-existing level line in order to determine the thickness of the new lava for a volume estimate. The final volume of lava emplaced during episode 35A is estimated to be 3.2×10^6 m^3.

During and immediately after the high fountaining part of episode 35, the summit tilt showed the normal pattern of deflation followed by steep re-inflation (fig. 95). However, shortly after the fissure outbreak began, the tilt flattened, and there was no net inflation for the next week and a half. This suggests that most of the magma entering the summit reservoir during this period was moving directly into the East Rift Zone and feeding the fissure. The summit tilt began to climb continuously again about 4 days before episode 35A ended (fig. 95).

Figure 93. Photograph of the lava shield formed by episode 35A. The depression at the top of the shield was formed by subsidence and (or) drainage of the ponded lava after the episode ended. The dark patches within the flow below and to the left of the shield summit are remnants of Puʻu Kamoamoa. Photograph by J.D. Griggs, U.S. Geological Survey, August 22, 1985.

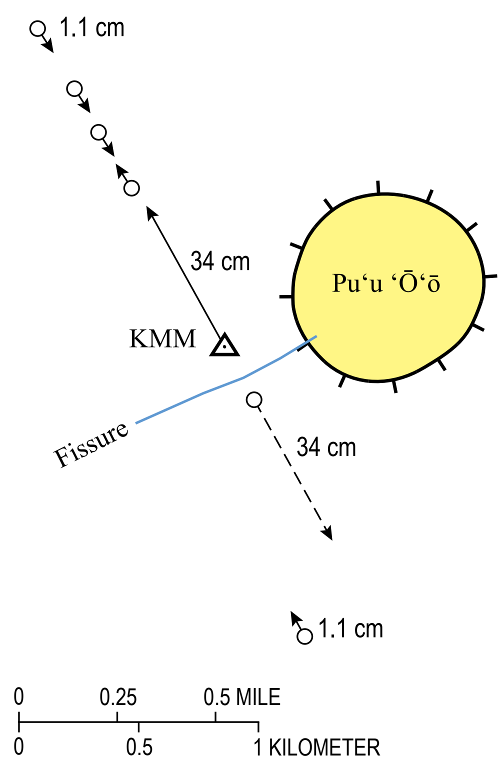


Figure 94. Schematic showing displacements on the Puʻu Kamoamoa electronic distance measurement (EDM) line relative to the assumed center of deformation at the episode 35 fissures, July 24–31, 1985. KMM marks the benchmark and EDM station on Puʻu Kamoamoa. Open circles with arrows show the EDM reflectors and their direction of movement. The dashed vector south of the Puʻu ʻŌʻō assumes symmetrical deformation across the fissure.

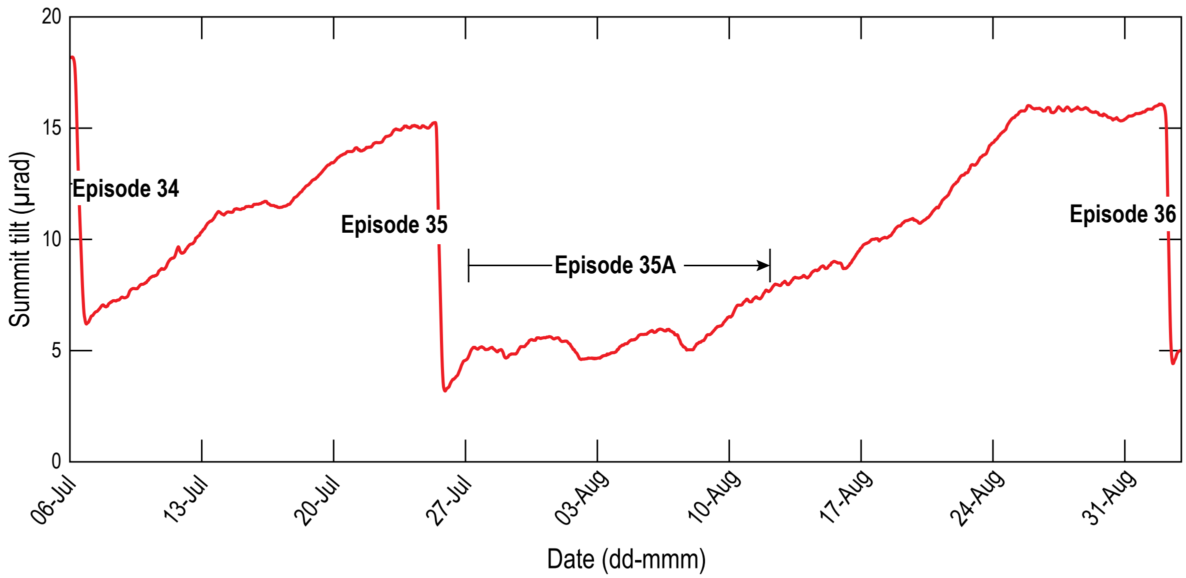


Figure 95. Kīlauea summit tilt for the period July 6–September 3, 1985, spanning episodes 34, 35, 35A, and 36.

The low level of seismicity associated with the emplacement of the episode 35A dike suggests that the magma followed preexisting fractures within the rift zone. Similar, but much briefer, fissure outbreaks occurred uprift and (or) downrift of Puʻu ʻŌʻō in the early stages of episodes 4, 11, 21, 25, 28, and 29, and later during episodes 39, 44, and 48 (fig. 29; table 4). The fissures of episodes 11 and 21 were close to, and on strike with, the downrift end of the episode 35A fissure.

Summary

Episode 35 (table 1, fig. 88), one of the more unusual episodes of the Puʻu ʻŌʻō eruption, displayed brief fissure activity at the start, followed by high fountaining for 7.0 hours, a pause of less than a day, and 16 days of renewed slow effusion of pāhoehoe from the newly formed cracks (episode 35A). The resulting contribution to the Puʻu ʻŌʻō lava field was a total volume of 9.0×10^6 m^3, higher than the average volume for episodes 4–47. Of the total volume produced, ~64 percent (~5.8×10^6 m^3) was composed of ʻaʻā from the Puʻu ʻŌʻō conduit and coeval pāhoehoe flows from fissures on the west flank of the cone, erupted over a duration of 7.0 hours and covering about 3.4 km^2. The remaining 36 percent (~3.2×10^6 m^3) formed a roughly 600-m-wide, 26-m-high pāhoehoe shield and peripheral flows that erupted from the fissures on the west flank of the cone after the roughly 1-day-long pause (episode 35A), covering about 0.6 km^2 (fig. 88). These flows all but buried the prehistoric Puʻu Kamoamoa cone. The average effusion rate for the high-fountaining part of the episode was 230 m^3/s, and that for episode 35A was ~2 m^3/s. A glass temperature of 1,165 °C was calculated from tephra erupted about 5 minutes before fountaining ended, and a glass temperature of 1,161 °C was calculated from a flow from the A-vent on August 7 (Thornber and others, 2003a). The summit of Puʻu ʻŌʻō grew by 4 m, to 232 m.

Episode 36 (September 2, 1985)

After the anomalous activity of episode 35A, Puʻu ʻŌʻō rested for 21 days before starting episode 36 with its conventional high fountain and ʻaʻā flows. Immediately following episode 35A, the magma column in the conduit was visible at an estimated depth of 80 m. On August 19, spattering and gas-piston activity were observed, with the column rising and falling between 25 and 50 m below the vent rim. One pāhoehoe spillover about 100 m long occurred sometime during this period, possibly on August 25 or 26, when the summit tilt reversed its inflationary trend.

By August 28, the column had risen to within 10 m of the vent rim and was crusted over, supporting a 2-m-high spatter cone in similar fashion to what had preceded many earlier episodes. On August 29, spatter activity was visible from Mountain View, 18 km north, but none was recorded on time-lapse film until early on the morning of August 31. From then on, spatter bursts occurred intermittently until continuous discharge started on September 2.

That day, HVO geologists arrived at the vent at 0945 and observed the free surface 5 m below the vent rim, but continuously throwing spatter as much as 20 m above the vent rim. At 1320, just prior to the episode start, a 10-m-high fountain developed that lasted for 20 minutes, feeding a spillover that extended 200–300 m southeast.

Fountaining began at 1400 on September 2, marking the start of episode 36, and continued for 9.6 hours. The fountain grew slowly, taking 3 hours to reach the height of the cone (95 m). During this period, the fountain leaned south (fig. 96), suggesting

Figure 96. Oblique aerial photograph of the ~120-meter-high southward-leaning fountain at Puʻu ʻŌʻō about 4 hours after the start of episode 36, looking southwest. Photograph by S. Rowland, U.S. Geological Survey, 1746 HST, September 2, 1985.

an obstruction near the top of the conduit, and then gradually evolved into a narrow-based fan-shaped fountain (fig. 97). At 1750, shortly after the photograph in figure 96 was taken, the fountain stood 120 m above the conduit, and the pāhoehoe flow it produced had extended 1.7 km southeast from the northeast spillway, overriding the previous episode 35 ʻaʻā flow.

Variable weather through the evening provided intermittent views from the observation camp on Puʻu Halulu, while southerly winds occasionally showered the camp with tephra. By around 1830, the fountain had developed into the more-common broad-based column, and this persisted until the last 10 minutes of the episode. A maximum fountain height of 441 m was recorded at 1943 (fig. 98). A broad ʻaʻā fan was accumulating at the same time at the northeast-to-southeast base of the cone. During the next 1.5 hours, two new ʻaʻā flows broke out of the fan; one moved 1.7 km east of the vent, past the south side of Puʻu Halulu, and the other advanced 1.3 km northeast to the north flank of Puʻu Halulu (fig. 99). Meanwhile, the main flow continued to advance southeastward, transitioning from pāhoehoe to ʻaʻā and reaching 2.1 km from the vent by 2110 (fig. 99). At 2324, the fountain height began to wane, and 10 minutes later it dropped abruptly to zero. Moments later a burst of spatter rose to the height of the cone and was followed by an orange flame above the vent, marking the end of the episode at 2335.

Summary

Episode 36 (table 1, fig. 99) produced an estimated 7.9×10^{6} m^3 of lava during 9.6 hours of continuous lava production that covered an area of 2.7 km^2. ʻAʻā flows reached final lengths of 1.8 km northeast, 1.95 km east, and 2.5 km southeast (fig. 99). The time-averaged discharge rate for the episode was 229 m^3/s, about twice the time-averaged discharge rate of 134 m^3/s for episodes 4–47. The summit of Puʻu ʻŌʻō grew 10 m to a height of 242 m, despite the occasional southerly winds that diverted tephra away from the summit. The volume of the tephra blanket was estimated at about 0.2×10^{6} m^3. A glass temperature of 1,169 °C was calculated from tephra erupted about 5.5 hours after the onset of fountaining (Thornber and others, 2003a).

Figure 97. Photograph showing fan-shaped fountain at Puʻu ʻŌʻō during episode 36. Fountain height is approximately 200 meters (m), increasing soon after to 275 m. Photograph by S. Rowland, U.S. Geological Survey, 1833 HST, September 2, 1985.

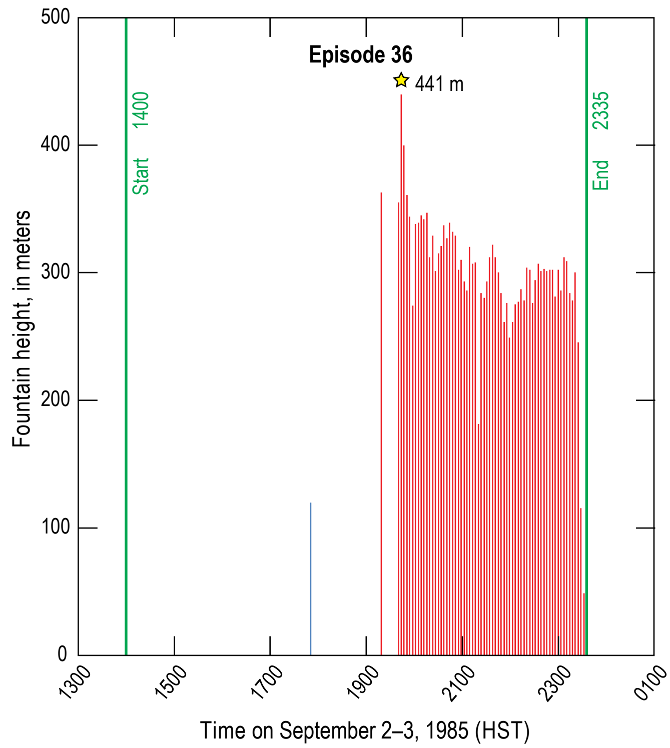


Figure 98. Graph showing episode 36 fountain heights measured from time-lapse film, except for one theodolite measurement, shown in blue. The yellow star marks the highest fountain. The time interval between measurements is 3.6 minutes; data gaps are the result of poor visibility.

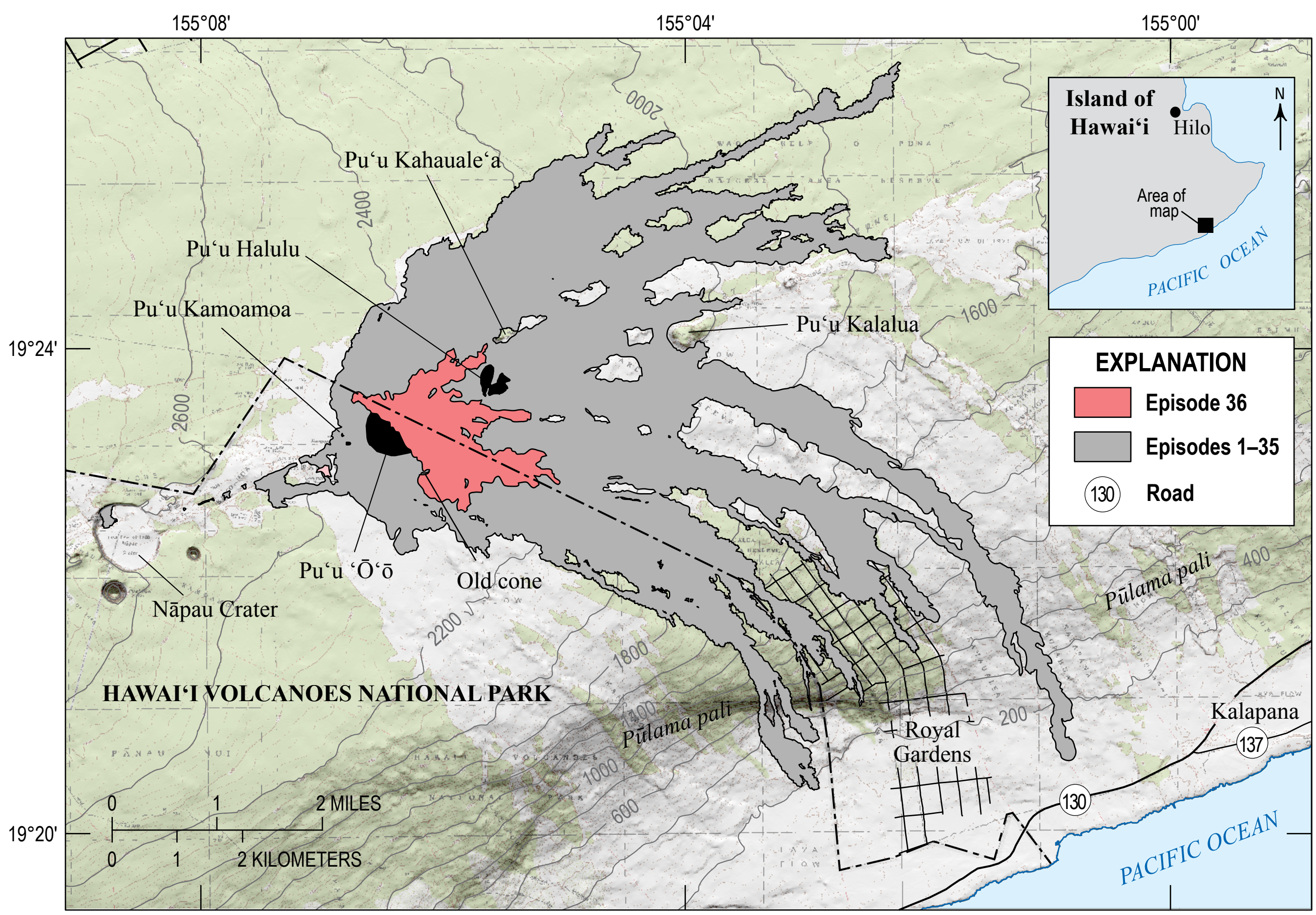


Figure 99. Map showing the distribution of episode 36 lava flows compared to earlier Pu‘u ‘Ō‘ō flows.

Episode 37 (September 24–25, 1985)

The incandescent top of the magma column was an estimated 60–80 m below the vent rim when observed 10 hours after the end of episode 36, but it was obscured by dense fume the following day (September 4). The ensuing inter-episode period lasted 22 days. Magma was next seen on September 13, at about 80 m depth. Occasional gas-piston events occurred during the first 4 days of the inter-episode period and again on September 13–15. By September 17, the crusted magma column had risen to 50–60 m below the vent rim and supported a 2–3-m-high spatter cone, as was typical in inter-episode periods since episode 32. Through the night of September 22–23, the conduit glowed brightly, and by 1030 on September 23, spatter was occasionally being thrown 5–10 m above the vent rim. At 0830 on September 24, the crusted magma column was 5–10 m below the vent rim, but it had been higher at some time over the preceding hours, feeding a pāhoehoe flow about 50 m long. The intermittent activity continued with low fountaining and additional brief spillovers from 1125 to 1140, and again from 1210 to 1223, on September 24.

The start of continuous fountaining and lava effusion occurred during poor visibility at 1808 on September 24. The fountain grew very slowly, rising from about 15 m to the height of the Pu‘u ‘Ō‘ō summit, about 100 m above the vent rim, by 2256. Shortly thereafter, clearing weather allowed systematic recording of fountain heights (fig. 100). At 0010 on September 25, the top of the fountain had reached a height of approximately 270 m and was visible from HVO, 19 km west–northwest. By that time, tephra was falling on the Pu‘u Halulu camp as winds shifted southwest. The fountain had climbed to 300 m by 0020, and it maintained that general level for 3 hours, reaching its peak height of 350 m at 0300 (fig. 100). Fountain height began decreasing at 0330, and the fountain died at 0620, after dwindling rapidly over the preceding few minutes.

The first lava erupted fed a pāhoehoe flow that traveled down the northeast spillway and then turned southeast. In 35 minutes, it had overrun episode 36 ‘a‘ā for a distance of 800 m, and, by 1952, the flow was 1 km southeast of the cone. At 2341, the lava discharge rate increased, forming a broad ‘a‘ā fan around the east-to-southeast base of the cone. By midnight, the high volume of lava had covered a large part of the Pu‘u ‘Ō‘ō flow field south of Pu‘u Halulu and was branching out in three lobes arrayed from east to south (fig. 101). The east lobe reached a total length of 3.7 km. The south lobe buried most of the episode 35 ‘a‘ā flow, encroaching into the forest near its final terminus about 2 km from the vent. The middle lobe, with an average width of about 200 m, traveled 5.2 km southeast and stagnated about 900 m from the Royal Gardens subdivision. A separate ‘a‘ā flow moved 1.1 km northwest on a broad front before it stopped, less than 100 m from the forest (fig. 101).

Summary

Episode 37 (table 1, fig. 101) produced an estimated 10.3×10^6 m^3 of lava during 12.2 hours of continuous lava discharge, covering an area of 4.4 km^2. It produced the first threat to the Royal Gardens subdivision in 5 months; its longest flow stopped 900 m from the north boundary. The time-averaged discharge rate was 235 m^3/s, very close to that of the preceding episode and nearly twice the average for episodes 4–47 (table 2). The summit of Pu‘u ‘Ō‘ō grew by only 1 m, to a height of 243 m, owing to the southerly winds that diverted most tephra away from the cone. The combined growth of episodes 35 through 37 and the cumulative growth of the cone since January 1983 is shown in figure 102.

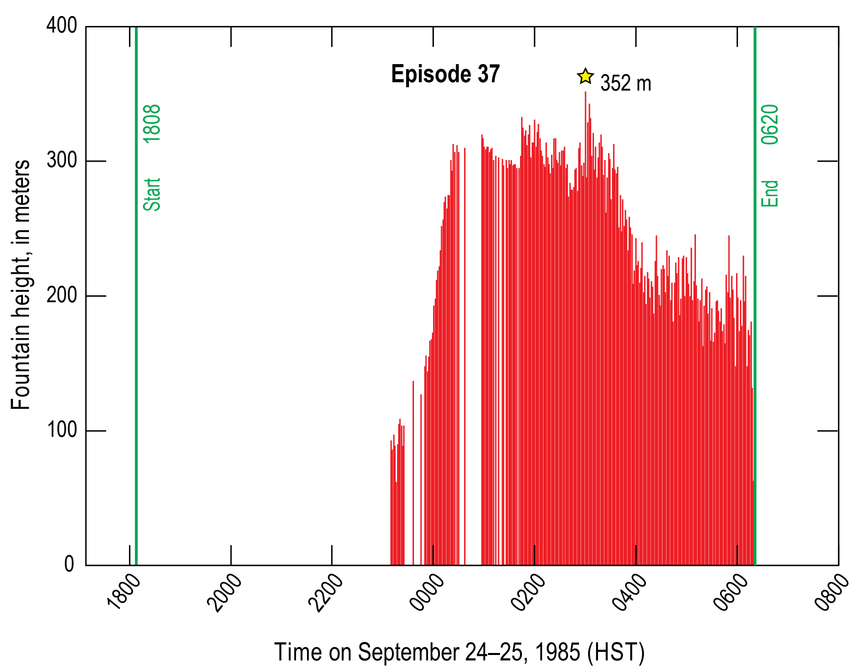


Figure 100. Graph showing episode 37 fountain heights measured from time-lapse film. The yellow star marks the highest fountain. The time interval between measurements is 1.5 minutes; data gaps are the result of poor visibility.

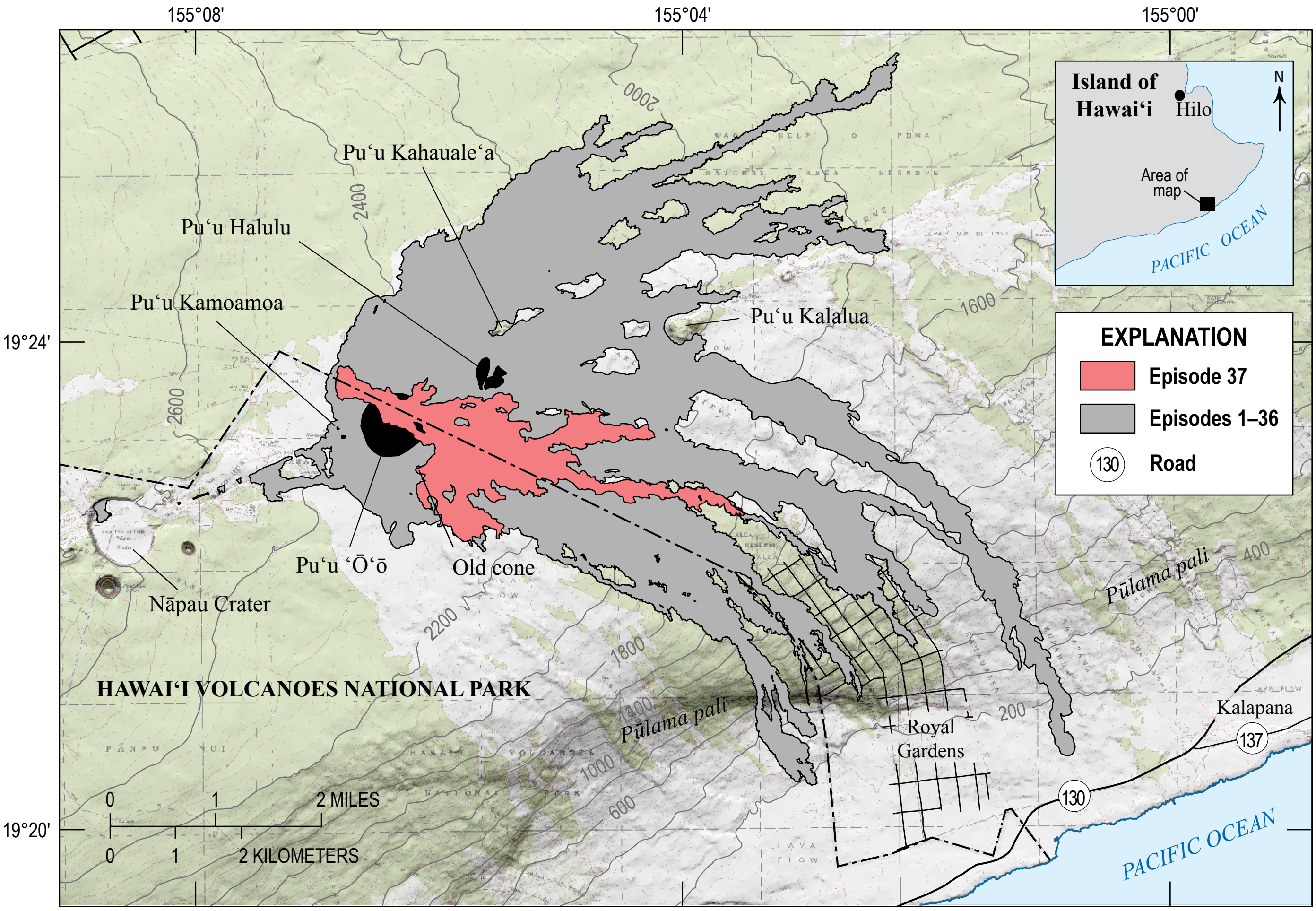


Figure 101. Map showing the distribution of episode 37 lava flows compared to earlier Pu‘u ‘Ō‘ō flows.

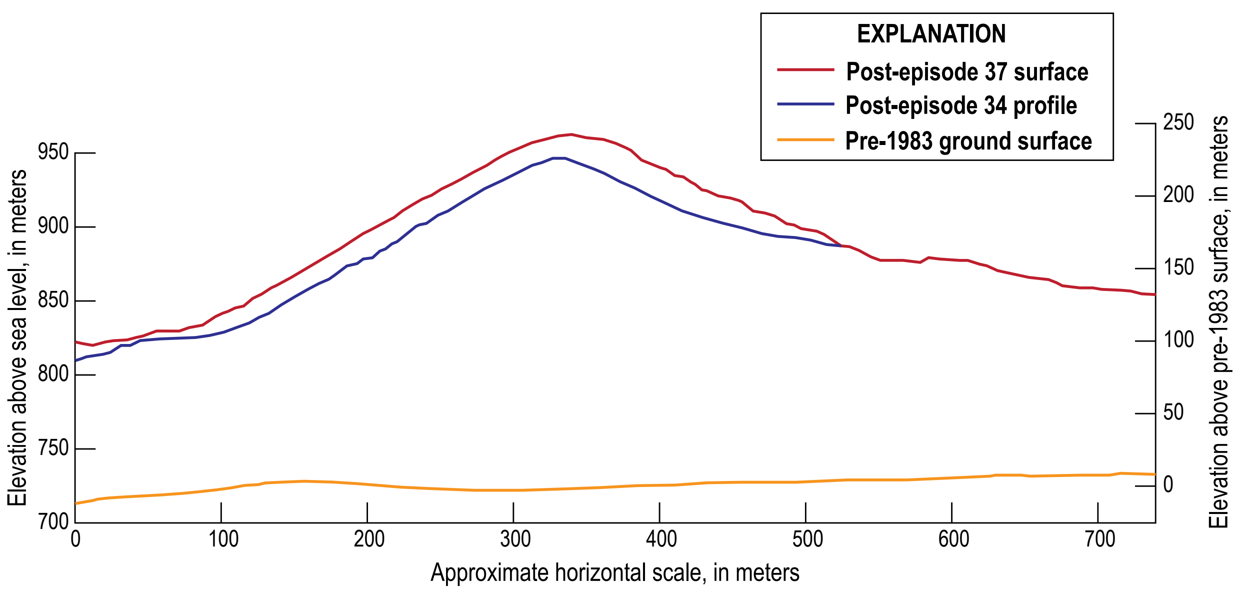


Figure 102. Profiles of Pu‘u ‘Ō‘ō after episodes 34 and 37, illustrating cone growth. Profiles were drawn looking southwest from the perspective of the camera station on Pu‘u Halulu.

Episode 38 (October 21, 1985)

The magma plumbing system evidently became more efficient as the eruption wore on, and the eruption cycle, for the most part, developed an increasingly regular—and forecastable—pattern of behavior. The inter-episode period following episode 37 was 26 days. Gas-piston events recorded by the near-vent seismometer were sparse during this period, occurring only on October 5–6 and October 11. The magma column rose slowly in the conduit and was first observed on October 10 about 50 m below the vent rim. On October 15, the column was at 40 m depth and crusted over except for several holes emitting spatter. By October 18, the column was at 20 m depth and, as before the previous six episodes, supported a small spatter cone on its surface; in less than an hour the magma column rose an additional 10 m. By the morning of October 19, the column had dropped to 20 m below the surface, but it rose back up to 7 m depth by the evening, and spatter was ejected several meters above the vent rim. The first of several low fountains, producing thin pāhoehoe flows, began on October 20 at 1620. The spillovers ranged from 8 to 13 minutes in duration and were separated by intervals of 2 to 90 minutes when lava was confined to the conduit and only minor spattering took place. Pāhoehoe flows fed down the spillway on the southeast quadrant of the terrace around the conduit ranged in length from a few hundred meters to 1.5 km.

For 11 hours on late October 20 and early October 21, about 12 periods of low fountaining and lava spillovers occurred during generally poor weather, forming an intermittent, channelized lava river flowing southeast from the vent. As before episode 33, the less active intervals between the low fountains grew progressively shorter. At 0301 on October 21, the fountain rose to 20–30 m above the small lava lake at the top of the conduit, marking the official start of episode 38, and was continuous for the next 8.4 hours. The fountain grew slowly, both in height and width, and was frequently obscured in fog. At 0410, the fountain was about 60 m high, and 11 minutes later the time lapse film recorded a sudden increase in height and width. Five to eight minutes later another increase occurred. By 0445, the fountain was approximately 100 m and still climbing. The fountain grew by nearly 200 m over the next hour, and from 0600 to 0730 its height fluctuated from 270 to 295 m—the maximum values obtained from the field and roughly coincident with the highest deflation rate measured at Kīlauea's summit.

By 0350, an ‘a‘ā fan was forming around the east base of the cone, feeding east- and southeast-moving flows. Both flows had slowed significantly by 0540, but by then a new lobe of ‘a‘ā was advancing south, following the same path that had been covered in the four preceding episodes. This flow finally buried the last vestiges of the old cone (fig. 76) that had originally been invaded during episode 23, in July 1984. The flow went on to reach the edge of the forest, 2.4 km from the vent, before it stopped (fig. 103). The southeast flow overran the upper part of the episode 37 flow, maintaining a width of about 300 m, and reached a final length of 4.2 km.

After daybreak on October 21, a spectacular gas plume emanated from Pu‘u ‘Ō‘ō and drifted southwest in the trade winds (fig. 104). The plume was clearly visible from HVO above the dense fog bank that engulfed the eruption site. From 0830 to 1100, the fountain height decreased to about 250 m. At 1118 it dropped rapidly, and 3 minutes later a single high, narrow jet of lava was recorded on time-lapse film (table 3). Fountaining ceased at 1124, followed for a few minutes by an orange flame from the vent. Following the end of episode 38, gas-piston activity in the conduit was recorded by the STC seismometer for about 24 hours.

Summary

Episode 38 (table 1, fig. 103) erupted an estimated 10.4×10^6 m^3 of lava during its relatively short 8.4 hours of continuous lava effusion, covering an area of 3.9 km^2. The time-averaged discharge rate was 343 m^3/s—the highest rate of the entire Pu‘u ‘Ō‘ō eruption to date. The composition of basalt changed from the earliest to the latest spatter collected at the conduit, with a 0.40 weight percent increase in MgO. A glass temperature of 1,164 °C was calculated from tephra erupted about 1.5 hours before fountaining ended (Thornber and others, 2003a). The summit of Pu‘u ‘Ō‘ō grew by 8 m, to 251 m above the pre-eruption surface (figs. 105 and 106); the vent rim elevation increased by 1 m.

Episode 39 (November 13–14, 1985)

The inter-episode period following episode 38 was a typical 23 days. The first observations at Pu‘u ‘Ō‘ō were made on November 6, when the magma column had risen to 30 m below the surface. On November 9, the column was at 20 m depth, and spatter was thrown being thrown 5 m above the vent rim. Two days later at 1000, the crusted free surface was 5 to 10 m below the vent rim, with an opening in the crust 1.5×10 m in size. Three hours later, lava was oozing from the hole 4–5 m below the rim. The next day, November 12, after an all-night show of spatter thrown as high as 20 m above the vent rim, the free surface rose to the lip of the conduit, but no spillovers occurred (fig. 107).

Fissure activity, unusual in that it was off the trend of the rift zone, preceded episode 39. At 0530 on November 13, observers at the Pu‘u Halulu camp site saw a glow on the south side of Pu‘u ‘Ō‘ō. Inspection of the area revealed that three small vents had opened through the tephra on the south flank of the cone (fig. 108). The most active vent hosted a 2-m-high fountain and supplied a thin pāhoehoe flow about 200 m wide and 300 m long (fig. 109). A thermocouple temperature of 1,140 °C was obtained from lava extruded from this vent. The next most active vent issued lava at a much lower rate, and the weakest vent was active only briefly, having erupted a few cubic meters of pāhoehoe (fig. 108). The three vents lacked any obvious structural alignment and are

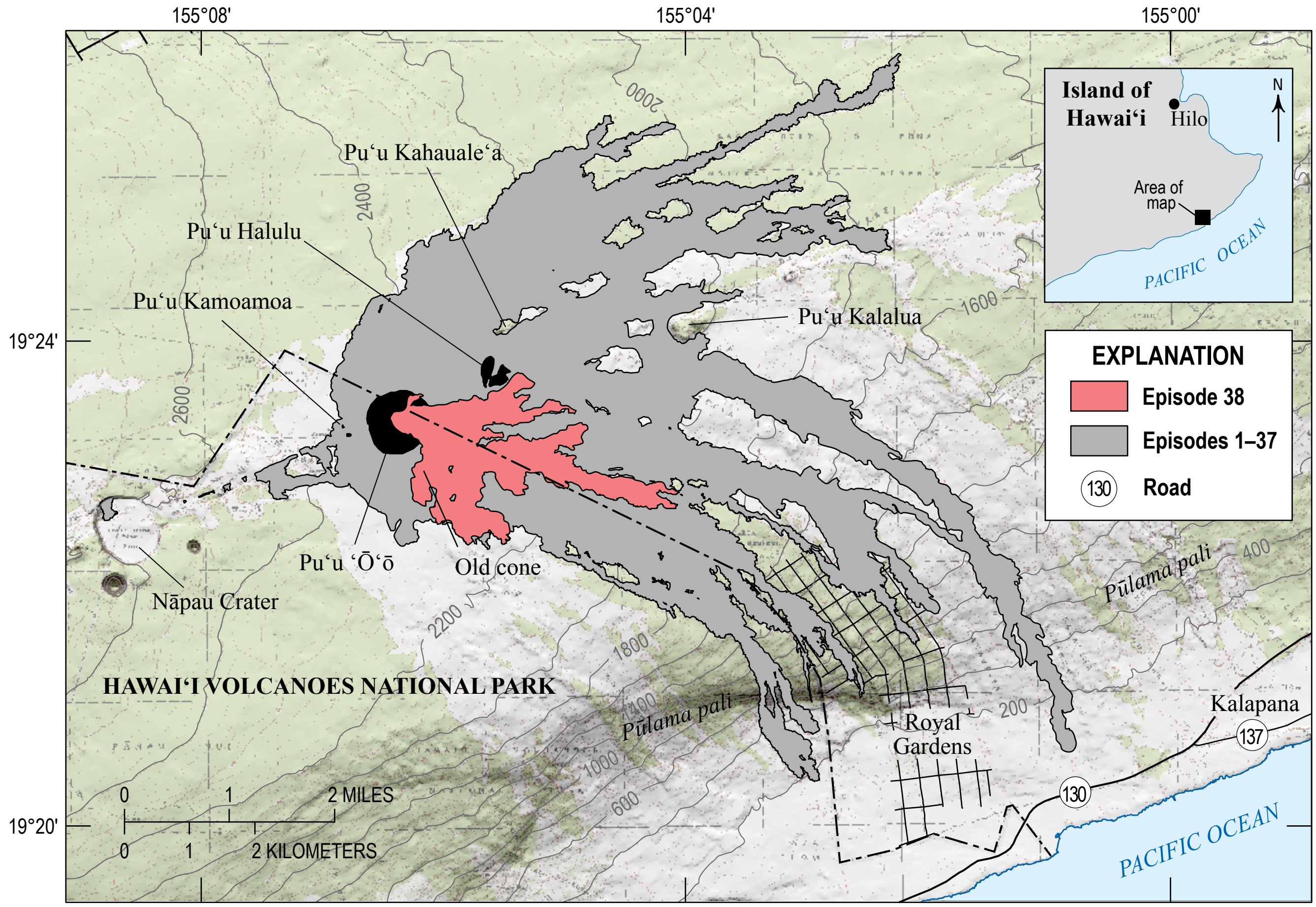
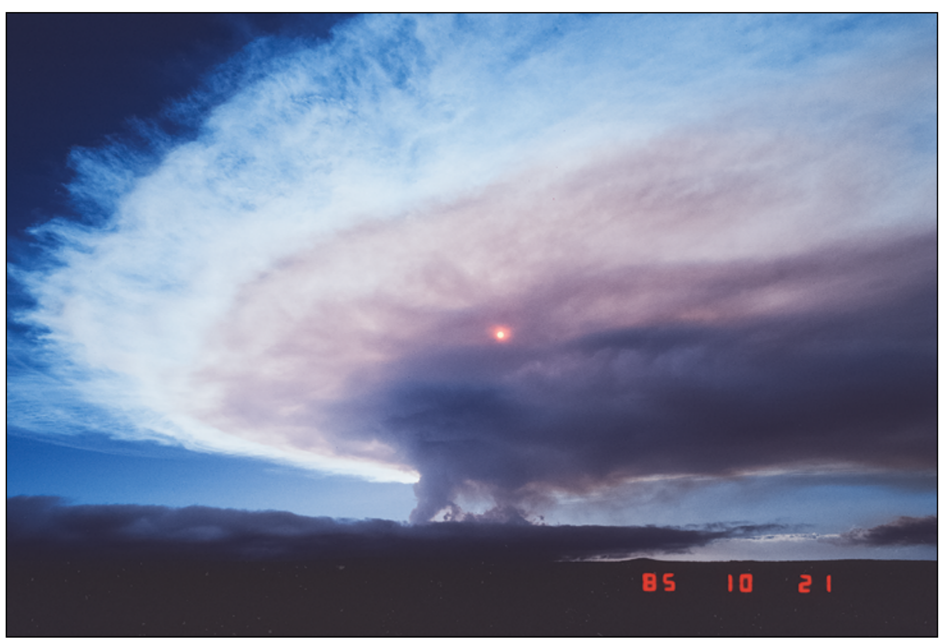


Figure 103. Map showing the distribution of episode 38 lava flows compared to earlier Pu‘u ‘Ō‘ō flows.

Figure 104. Photograph showing the banded gas plume above Pu‘u ‘Ō‘ō during episode 38 being blown southwest by the trade winds, as seen from the Hawaiian Volcano Observatory, 19 kilometers west–northwest of the eruption site. Photograph by J.D. Griggs, U.S. Geological Survey, October 21, 1985.



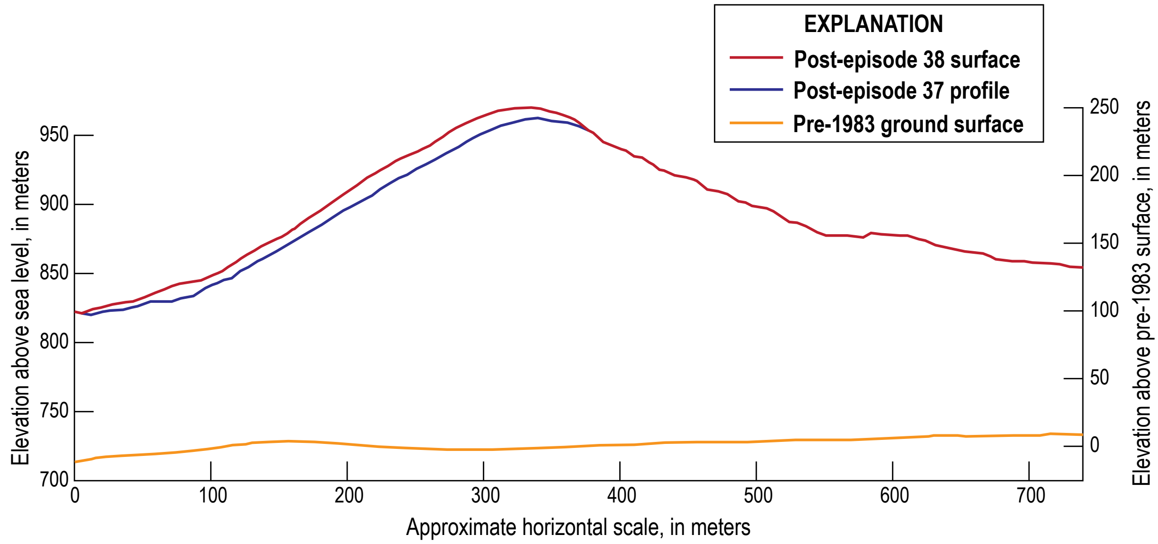


Figure 105. Profiles of Pu‘u ‘Ō‘ō after episodes 37 and 38, illustrating cone growth. Profiles are drawn looking southwest from the perspective of the camera station on Pu‘u Halulu. The vertical scale is constrained by theodolite measurements; the horizontal scale is from topographic surveys.

Figure 106. Oblique aerial photograph looking south toward Pu‘u ‘Ō‘ō after episode 38 showing the 251-meter-high cone. The subdued terraces at center, and in the foreground, are buried flow scarps from episode 28 (December 1984) and earlier. The light-colored material mantling the flows is tephra deposited by southerly winds, mostly during episode 30 (February 1985), but also episode 32 (April 1985). The tephra is overlain on the right (west) by ‘a‘ā flows from episodes 35 and 37 and on the left (east) by ‘a‘ā from episode 36. The thin, light-colored flow on the flank of the cone that leads back toward the fuming vent is pāhoehoe formed early in episode 37. Photograph by J.D. Griggs, U.S. Geological Survey, November 12, 1985.

Figure 107. Oblique aerial photograph of the Puʻu ʻŌʻō conduit one day before episode 39 began. The conduit is mostly crusted over and covered with dark spatter fragments from recent spatter activity, surrounding a hole several meters across which exposes roiling lava below. The spatter rampart on far side of conduit, with the small incandescent opening, is beginning to construct a spatter cone that grew to 7–8 meters height over the next 24 hours. Photograph by J.D. Griggs, U.S. Geological Survey, November 12, 1985.

Figure 108. Oblique aerial view looking east, showing satellite vents erupting on the south flank of Puʻu ʻŌʻō prior to episode 39. The largest vent (1) feeds the broad, thin pāhoehoe flow extending beyond the right side of the image. The smallest vent (3) is just left of the main vent and inactive. The nearest vent (2) is active, but with a slow rate of effusion. People, surveying tripods, and other equipment in the foreground provide scale. Photograph by J.D. Griggs, U.S. Geological Survey, ~0900 HST, November 13, 1985.

Figure 109. Oblique aerial view, looking northwest, showing the satellite vents on the south flank of Puʻu ʻŌʻō. The largest pāhoehoe flow, about 300 meters long at the time this photo was taken, is from the principal vent. The other vents are visible on both sides of main vent. Photograph by J.D. Griggs, U.S. Geological Survey, ~0900 HST, November 13, 1985.

presumed to reflect a transient zone of weakness—or possibly three closely spaced cracks—radial to the conduit.

The main vent of Puʻu ʻŌʻō built a spatter cone 7–8 m high through the day on November 13 and fed four brief spillovers a few tens of meters long. Meanwhile, the low fountain at the largest satellite vent increased gradually until it was about 6 m high at around 1530. Attention was then directed back to the main Puʻu ʻŌʻō vent, which began to host a fifth overflow. The satellite vent shut down at about 1800, with the most prominent result being a pāhoehoe flow that reached a total length of 600 m, much of which was overrun by the later ʻaʻā flow from the main vent (fig. 110).

Puʻu ʻŌʻō's fifth overflow, which started at 1534 on November 13, was the beginning of continuous effusion that gradually evolved into a fountain. The fountain was sluggish until about 1800, when it began to climb more rapidly (fig. 111), reaching a maximum height of 435 m at 1921. Thereafter, the fountain (fig. 112) declined slowly, with some pronounced variability, through the remainder of the episode.

Early pāhoehoe flows traveled south and southeast, extending as far as 2 km by 1745, when the fountain height had reached 70 m, and an ʻaʻā fan began to form at the base of Puʻu ʻŌʻō. At 1820, tephra fallout became heavy on the east side of the cone and at the Puʻu Halulu camp, continuing to the end of the episode. A broad ʻaʻā flow advanced southeast, reaching a length of about 3 km by 1920. In another hour, the southeast ʻaʻā flow had nearly stopped, and most of the lava was advancing east-southeast at a rate of about 400 m/h, having traveled 2 km by that time.

Despite the decrease in fountain height, the narrow east-southeast flow (100–200 m wide) continued to advance, eventually reaching a length of 5.9 km and coming to within 1.1 km of the northeast corner of Royal Gardens at 1,650-ft elevation (fig. 110). The flow advanced 1.9 km in the last 1.25 hours of the episode—a rate of 1.5 km/h. From 0112 to 0124 on November 14, the fountain decreased abruptly in height and was replaced by an orange flame interspersed with spatter bursts reaching as high as 50 m above the conduit. Episode 39 ended at 0124, but intermittent bursts of flaring gas continued from the vent until 0530.

Summary

Unusual low-level activity occurred 10 hours prior to the episode 39, as three small vents opened on the south flank of the

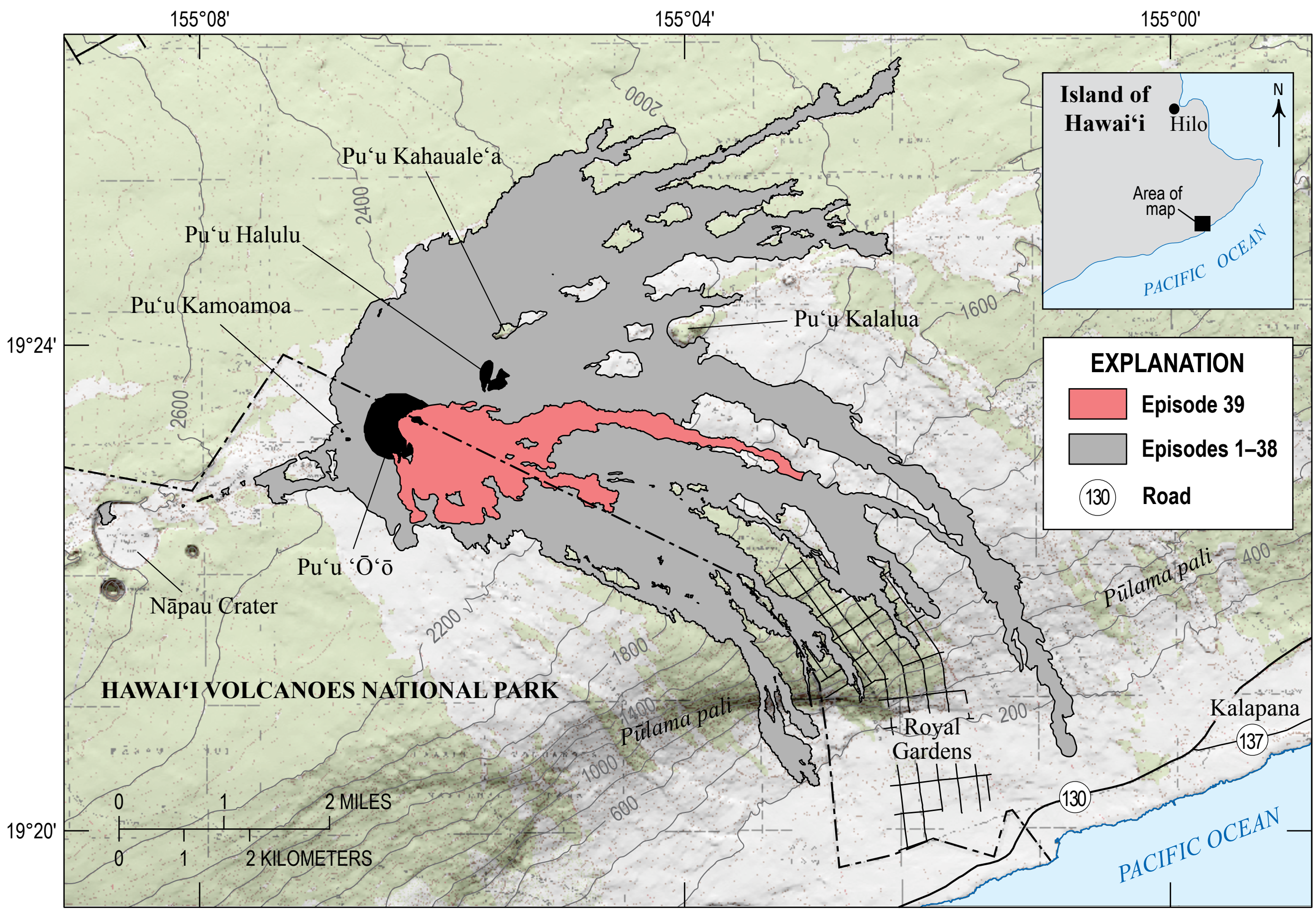


Figure 110. Map showing the distribution of episode 39 lava flows compared to earlier Puʻu ʻŌʻō flows.

Pu‘u ‘Ō‘ō cone. These vents had no apparent relation to fissures in the area, which had controlled other secondary vents in past episodes. Episode 39 (table 1, fig. 110) erupted an estimated 9.6×10^6 m^3 of lava in 9.8 hours, covering an area of 4.2 km^2. The time-averaged discharge rate was 271 m^3/s. The summit of Pu‘u ‘Ō‘ō received no new tephra, owing to southerly winds; its height, in fact, decreased slightly to 250 m and did not increase again until episode 43 in March 1986. The vent rim elevation, however, increased by 3 m.

A glass temperature of 1,165 °C was calculated from tephra erupted about 3 hours after the onset of fountaining (Thornber and others, 2003a). Chemical analyses showed no significant compositional variation between samples collected from the satellite vents and the main vent (Thornber and others, 2003a).

Gas samples from both the main and satellite vents of episode 39 were collected and analyzed for comparison with gases from the episode 35 fissure and earlier episodes of the Pu‘u ‘Ō‘ō series. The results confirmed that volatile compositions from the ongoing eruption had not changed significantly in three years (Greenland, 1986).

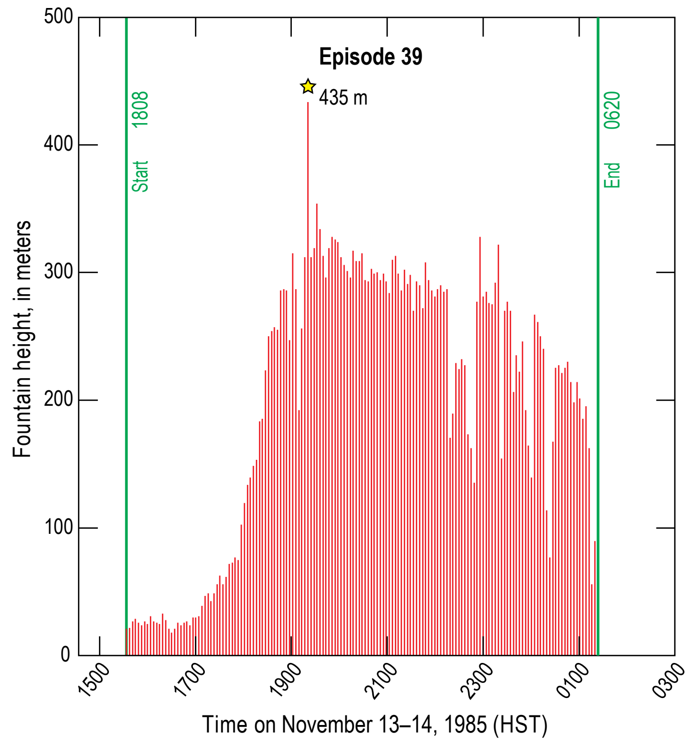


Figure 111. Graph showing episode 39 fountain heights measured from time-lapse film. The yellow star marks the highest fountain. The time interval between measurements was slightly variable, ranging from 3.7 to 3.9 minutes.

Figure 112. Photograph of the Pu‘u ‘Ō‘ō fountain during episode 39, looking southwest from Pu‘u Halulu. Lights left of center are from an airplane. Photograph by C. Park, U.S. Geological Survey, 2336 HST, November 13, 1985.

Episode 40 (January 1–2, 1986)

After one of the longest inter-episode periods (48.5 days) since January 3, 1983, Puʻu ʻŌʻō erupted on New Year's Day 1986, 2 days before the third anniversary of the beginning of the eruption. Our first view of the vent after episode 39 was on November 29, when the magma column was more than 50 m below the vent rim and 90 percent crusted over. By December 6, the crusted column had risen to a depth of 30 m. Except for sporadic spatter activity, indicated at night by fluctuating glow above the conduit, the column remained unchanged until December 15, when the crust began to overturn and spattering became more vigorous, with ejecta reaching the vent rim. On December 16, spatter bursts rose 6–7 m above the vent rim, and a spatter cone was building on the thick crust covering the magma column. The top of the spatter cone was only 5 m below the vent rim, and churning lava was visible within the cone. Spatter activity increased through the following day.

In the final days of 1985, the spatter cone grew to a height of about 7 m, and a moat-like depression formed around its base. Early on January 1, a small overflow from the top of the spatter cone flowed 6–7 m toward the spillway, which contained a channel formed during episode 39. The magma column had risen within the spatter cone to 1 m or so above the top of the conduit. The stage was set for episode 40 to begin.

At about 1015 on January 1, the fog covering the eruption site lifted long enough for an observer at Puʻu Halulu to see a second overflow beginning from the spatter cone. Fifteen minutes later, half of the cone collapsed and a low fountain rose above the partly open conduit nearly to the height of the remnant spatter cone, and continued for 31 minutes. After a brief cessation, low fountains repeated this performance at 1132 for 20 minutes, and again at 1240 for 27 minutes (fig. 113), each sending a pāhoehoe river east of the vent. Between the low-fountaining intervals, sporadic spatter and minor overflows continued. The collapsed spatter cone had the shape of a high-backed throne (fig. 114), reminiscent of the horseshoe-shaped cone at Mauna Ulu described as a pedestal cone by Swanson and others (1979). The Mauna Ulu cone was formed by a combination of repeated immersion by pooled lava and spatter deposition, while the episode 40 cone was built entirely of spatter draped over the remains of the collapsed cone capping Puʻu ʻŌʻō's conduit.

At 1309, low fountaining resumed, this time erupting lava continuously for the next 13.5 hours. When another group of HVO scientists arrived at 1435, in foggy and rainy weather, a 30-m-high fountain was feeding three pāhoehoe flows advancing southeast, with the longest extending 1.6 km. The fountain grew very slowly for 6 hours (fig. 115), becoming more plume-shaped, and then increased abruptly to a maximum height of 264 m at 1957. At that time, a vigorous ʻaʻā flow, 100–200 m wide, followed the newly formed channel east-southeast, and an ʻaʻā fan began to grow at the southeast base of the cone. The main ʻaʻā flow moved steadily toward the northeast corner of Royal Gardens, initially staying mostly on the episode 39 flow, and then following the episode 17 flow of March 1984. The flow passed 500 m northeast of an already buried corner of Royal Gardens and finally stopped 8.0 km from the vent (fig. 116).

After 2000, the fountain height generally hovered around 200 m, except for brief decreases at 2210 and 2250, after which it was generally at or below 200 m (fig. 115). At 0235, the fountain dropped rapidly to intermittent bursts less than 100 m high. Lava discharge ceased 3 minutes later and irregular flaming bursts continued for about a half hour. The episode was followed by gas-piston activity at intervals of 2 to 5 minutes, diminishing over the next several days.

Figure 113. Photograph of the pre-play dome fountain at Puʻu ʻŌʻō, looking east, during the last spillover event before the start of episode 40. The low fountain feeds a pāhoehoe river that flows over the spillway and down the east flank of Puʻu ʻŌʻō. A remnant of the spatter cone over the vent is visible at the right edge of the image (see fig. 114). Photograph by B. Pedit, U.S. Geological Survey, 1249 HST, January 1, 1986.

Figure 114. Photograph showing the remaining part of the collapsed spatter cone built by early episode 40 fountaining at Puʻu ʻŌʻō and enlarged by additional spatter during pre-play eruptive activity. Spattering 4 minutes after the start of the continuous output feeds a rapidly cooling pāhoehoe flow with a discontinuous crust that travels toward the spillway of Puʻu ʻŌʻō. The south wall of Puʻu ʻŌʻō rises in the background. The view is southwest. Photograph by B. Pedit, U.S. Geological Survey, 1313 HST, January 1, 1986.

Summary

A long slow increase in fountain heights, which were generally lower than usual (approximately 200 m) characterized episode 40. The episode (table 1, fig. 116) produced an estimated 8.1×10^6 m^3 of lava during 13.5 hours of continuous lava production, covering an area of 3.9 km^2. The time-averaged discharge rate was 167×10^3 m^3/s, a significant decline compared to the rate of the previous four episodes. A glass temperature of 1,164 °C was calculated from tephra erupted about 5.5 hours after the onset of fountaining, and the composition of the basalt showed no significant change over the course of the episode (Thornber and others, 2003a). The summit of Puʻu ʻŌʻō once again received no new tephra and remained 250 m above the pre-eruption surface; the vent rim elevation increased by 1 m. The conduit had become oval shaped and measured 15×20 m. A well-defined channel, floored with pāhoehoe and with walls as high as 2 m, led southeast from the vent. The channel was 10–15 m wide near the conduit, increasing to 30 m downstream.

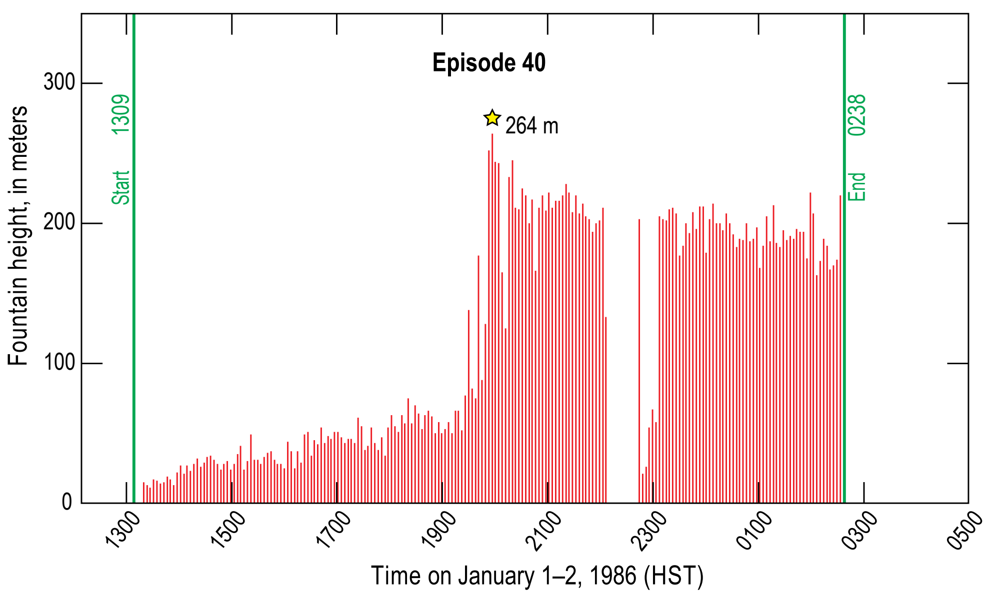


Figure 115. Graph showing episode 40 fountain heights measured from time-lapse film. The yellow star marks the highest fountain. The time interval between measurements is 3.8 minutes; data gaps are the result of poor visibility.

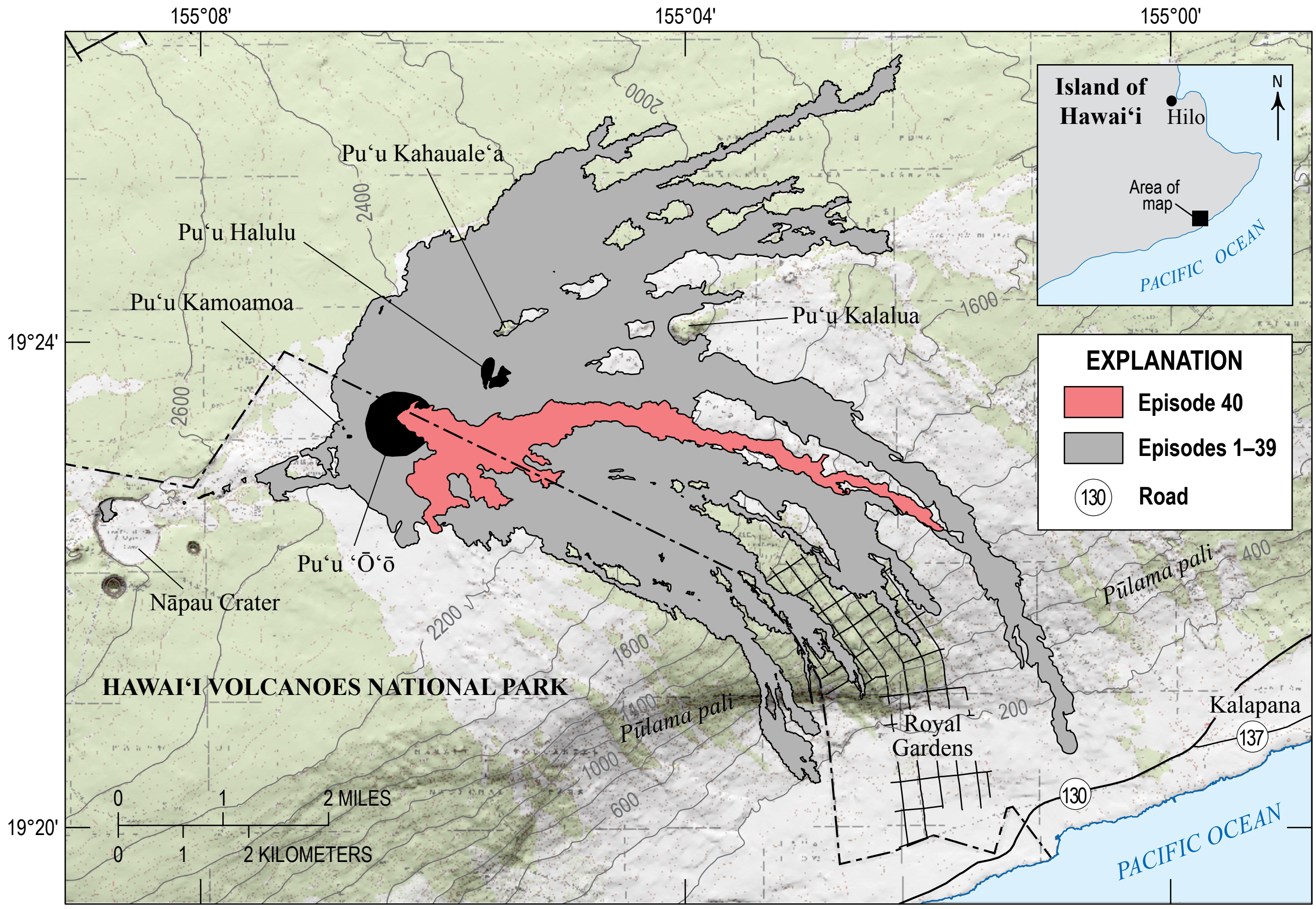


Figure 116. Map showing the distribution of episode 40 lava flows compared to earlier Pu‘u ‘Ō‘ō flows.

Episode 41 (January 27–28, 1986)

After an inter-episode period of 26 days, several hours of low-level, intermittent fountaining and lava spillovers from the conduit preceded the onset of continuous high fountaining of episode 41. Poor weather prevented complete documentation of the episode, but the measurements obtained were typical of Pu‘u ‘Ō‘ō’s recent eruptive episodes.

Gas-piston events returned during the inter-episode period, occurring sporadically during the first 5 days and again on January 11 and January 17–18. For the first time in five episodes, the inflation of Kīlauea’s summit during the inter-episode period failed to regain all deflationary tilt from the previous episode.

A local helicopter pilot first observed the reappearance of the magma column on January 4, 2 days after episode 40, and estimated that the free surface was greater than 50 m below the vent rim. The next observation was on January 22, when the free surface was about 60 m below the rim and mostly crusted. On January 25, the same pilot reported the column was at a depth of 20 m. By 1240 the next day, the column had filled the conduit and was intermittently overflowing, and weak fountain activity was observed from Glenwood, 12 km to the north.

Intermittent low fountaining and attendant lava overflows began around 1030 on January 27. As in most of the recent inter-episode activity, a spatter cone had formed on the crusted magma column. The fountain was often as high as 10–15 m and filled the episode 40 channel with viscous pāhoehoe, which moved toward the southeast to just beyond the base of the cone.

Because the activity was discontinuous, episode 41 did not officially start until 2035, when the tremor amplitude increased and the time-lapse film helped to confirm the beginning of continuous lava discharge. Fountain heights increased to a maximum of approximately 250 m around midnight. Fountain-fed ‘a‘ā flows advanced along a broad front south, and narrower tongues flowed southeast and east. The easternmost flow was the longest, following the path of the episode 40 flow and passing within 400 m of the northeast corner of Royal Gardens. It eventually stalled about 6.7 km southeast of the vent (fig. 117). From 0618 to 0716 on January 28, the fountain became narrower and lower; at 0737 it dropped abruptly to about 60 m, and 20 minutes later, at 0757, it ceased altogether.

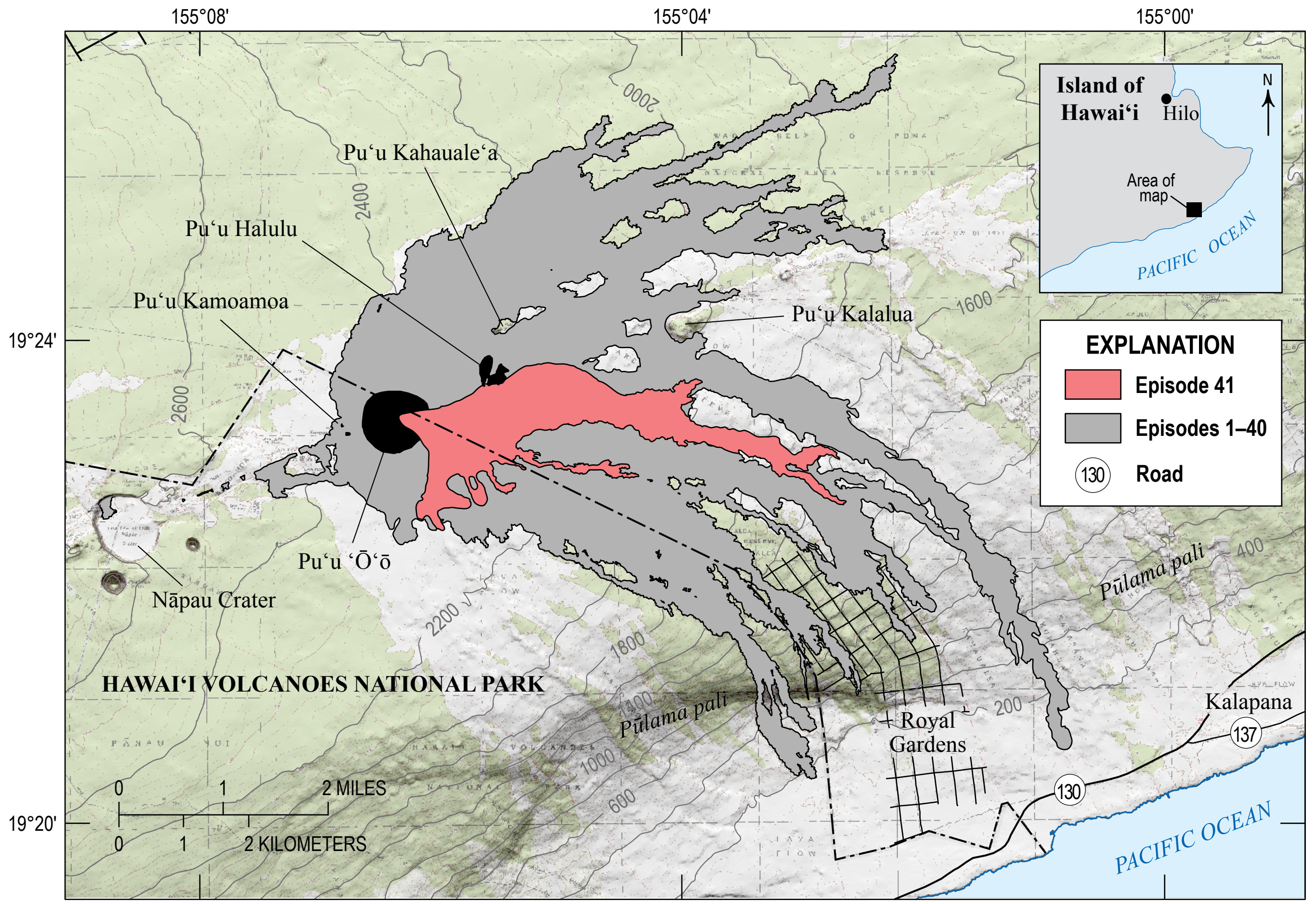


Figure 117. Map showing the distribution of episode 41 lava flows compared to earlier Pu‘u ‘Ō‘ō flows.

Summary

Lower fountain heights than usual (when visible) and a modest increase in the height of the vent rim were the most noteworthy aspects of episode 41. The remaining characteristics that could be measured were typical of the Pu‘u ‘Ō‘ō eruption. The episode (table 1, fig. 117) produced an estimated 9.6×10^{6} m^3 of lava during 11.4 hours of continuous fountaining, including the small volume of pāhoehoe produced during the inter-episode activity. Lava covered 5.1 km^2, and the time-averaged discharge rate was 234 m^3/s. The lava flow volume for episode 41 was estimated as a function of the amount of summit deflation (16.5 mrad), which had shown a good correlation with the well-determined volumes from earlier episodes. The composition of the basalt revealed no significant changes between lava erupted several hours before the onset of fountaining and the last spatter from the Pu‘u ‘Ō‘ō conduit (Thornber and others, 2003a). A glass temperature of 1,164 °C was calculated from vent spatter (Thornber and others, 2003a). The summit of Pu‘u ‘Ō‘ō once again escaped new tephra deposits owing to southerly winds, remaining at 250 m above the pre-eruption surface. The vent rim, on the other hand, increased in elevation by 3 m, as it would in future episodes: this required the top of the magma column to be lifted that much higher before an overflow could occur.

Episode 42 (February 22–23, 1986)

Episode 42 followed a pattern like that set by its predecessors. The 25-day inter-episode period preceding it was exactly average for episodes 4–48. Gas-piston events, with durations of 1–2 minutes, occurred every 2–3 minutes for about 24 hours immediately after episode 41, as recorded by the STC seismometer. A helicopter pilot was the first to spot the top of the magma column in the Pu‘u ‘Ō‘ō conduit on February 4, at an estimated depth of 30–50 m. A week later, it was still 30–40 m below the rim, 80 percent crusted over, and actively spattering. By February 17, the column had risen to 10–15 m below the vent rim and was depositing spatter on the rim.

On February 21, 1 day before episode 42 started, the column had nearly reached the top of the conduit, and new spatter formed a circular rampart around the vent rim. Inside the rampart, several small spatter mounds gave the crusted surface of the magma column a hummocky appearance, and spatter was occasionally thrown from holes through the crust.

Once again, intermittent fountaining resulted in short pāhoehoe overflows that preceded the high fountaining episode. Pre-episode activity began at 1010 on February 22 with a low fountain that lasted 9 minutes and fed a flow about 50 m long. Fountains as high as 10 m produced six more spillovers through early afternoon, the flows extending short distances beyond the base of Puʻu ʻŌʻō. The bulk lava discharge rate was estimated at 17 to 33 m^3/s based on the geometry of the channel and the velocity of the flows. There was no apparent trend in the durations of the 7 pre-episode 42 events (fig. 118), in contrast to the pre-episode 33 events, in which 21 spillover events occurred and the combined fountaining and ensuing inter-episode interval became generally shorter as the onset of continuous fountaining approached (fig. 81).

Using a tripod-mounted optical pyrometer about 50 m from the low fountain, we obtained maximum temperature readings of 1,160 °C. The instrument was calibrated at 1,177 °C by an internal source. The readings were taken about 3 hours prior to continuous fountaining and were hampered somewhat by fume drifting between the pyrometer and the fountain. This compares well with the glass temperature of 1,164 °C that was calculated for tephra erupted about 2 hours before fountaining ended (Thornber and others, 2003a).

Continuous fountaining and lava discharge began at 1515 on February 22, with a 10-m-high fountain. The fountain grew slowly and, owing to poor weather, was not well documented on time-lapse film. A maximum observed height (excluding high lava jets near the end of the episode) of approximately 308 m (fig. 119) was measured by theodolite about 7 hours after the start of the episode (~2230). Winds from the southwest once again deposited tephra on our field camp at Puʻu Halulu.

The main pāhoehoe flow was several hundred meters wide and moved east-northeast as far as the south edge of Puʻu Halulu by 1600. Two hours later, with fountaining still only 80 m high, the flow had reached 3 km from the vent, and a second, narrower east-moving tongue had advanced 2.7 km. As the fountain increased to 110 m high after 1900, a spatter-fed ʻaʻā flow began advancing down the north flank of the cone. By 1918, the east-northeast flow had changed to ʻaʻā and was spreading outward at its distal end and slowing. The east-northeast and east flows had merged by 1940, 3.9 km from the vent, having advanced at about 450 and 750 m/h respectively for the previous 1.5 hours. By 2155, the merged flow had stagnated, but a broad ʻaʻā front continued to build a fan around the southeast base of Puʻu ʻŌʻō. The north ʻaʻā flow was inactive by 2350 after advancing about 1.5 km from the vent (fig. 120).

At about 0013 on February 23, the lava flow at the base of the cone began to break out, sending new ʻaʻā flows advancing rapidly east-northeast (overrunning earlier pāhoehoe) and east-southeast. The ʻaʻā that blanketed the area around the base of the cone visibly deflated as the accumulated lava was channeled into

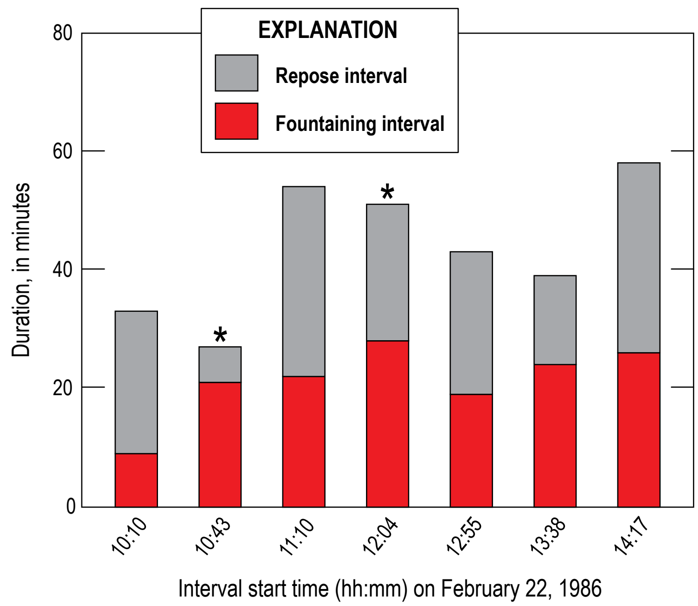


Figure 118. Graph of low fountaining and inter-episode intervals during episode 42 pre-play eruptive activity on February 22, 1986. Asterisks indicate estimated durations.

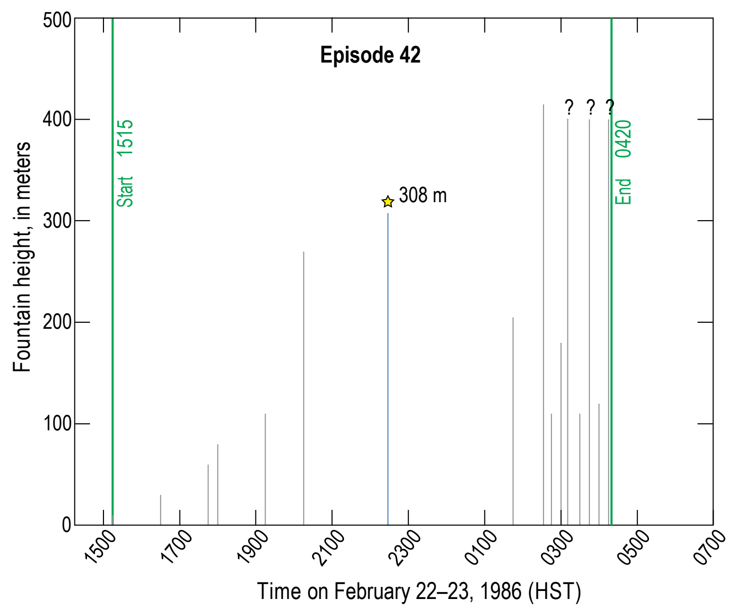


Figure 119. Graph showing episode 42 fountain heights based mostly on visual estimates. The yellow star marks the highest fountain (excluding the late jetting events), measured by theodolite and shown in blue. The heights of the three final jetting events, were not recorded and are shown here with question marks at 400 m for display purposes. Data gaps are the result of poor visibility.

these advancing flows. For example, accretionary lava mounds, apparently formed around irregularities on the previous flow surface, were left standing as high as 2 m above the surface of the flow at the base of the cone. The east-northeast flow advanced about 2.5 km before stagnating at about 0233. The east-southeast flow, on the other hand, slowed and was overtaken by a new ‘a‘ā lobe that subsequently stagnated at about 0245, having traveled about 2.6 km along the same east-southeast course (fig. 120). Subsequent flow advances were sporadic and short-lived because of the shifting locations of the main lava supply.

Between 0233 and the end of the episode at 0420 on February 23, four brief pulses (each about 2 minutes long) of very high, thin, jetting lava fountains, rising an estimated 360 to 460 m above the vent, were followed by abrupt drops in fountain height and slow recoveries to the approximate height of the cone (100 m above the vent) or higher. Each jetting fountain (table 3) was accompanied by a loud hissing noise, which terminated with a vigorous black plume of tephra so dense that it obscured the fountain. After the final jetting fountain died at 0416, the fountain did not recover, and lava production ended a few minutes later at 0420.

Distinctive seismic characteristics were also noted during the last 2 hours of the episode. Following each jetting fountain, the tremor amplitude decreased rapidly and remained at a moderate level for about 20 minutes, before returning gradually to near-normal high amplitude as the fountain height recovered. This pattern repeated itself after each jet until the last, when the tremor dropped completely to a low background level.

Summary

Episode 42 (table 1, fig. 120) erupted an estimated 8.5×10^6 m^3 of lava during its 13.1 hours of continuous fountaining and covered an area of 3.7 km^2. Because of the lack of aerial photographs of this episode, the volume was estimated based on summit deflation (14.8 mrad), which had shown a strong correlation during preceding episodes. The time-averaged discharge rate was 180×10^3 m^3/s. The composition of the basalt stayed approximately constant between early spatter and the last tephra from the Pu‘u ‘Ō‘ō conduit (Thornber and others, 2003a). A glass temperature of 1,164 °C was calculated for tephra erupted about 2 hours before fountaining ended (Thornber and others, 2003a). The summit of Pu‘u ‘Ō‘ō once again escaped new tephra deposits owing to southerly winds, remaining 250 m above the pre-eruption surface.

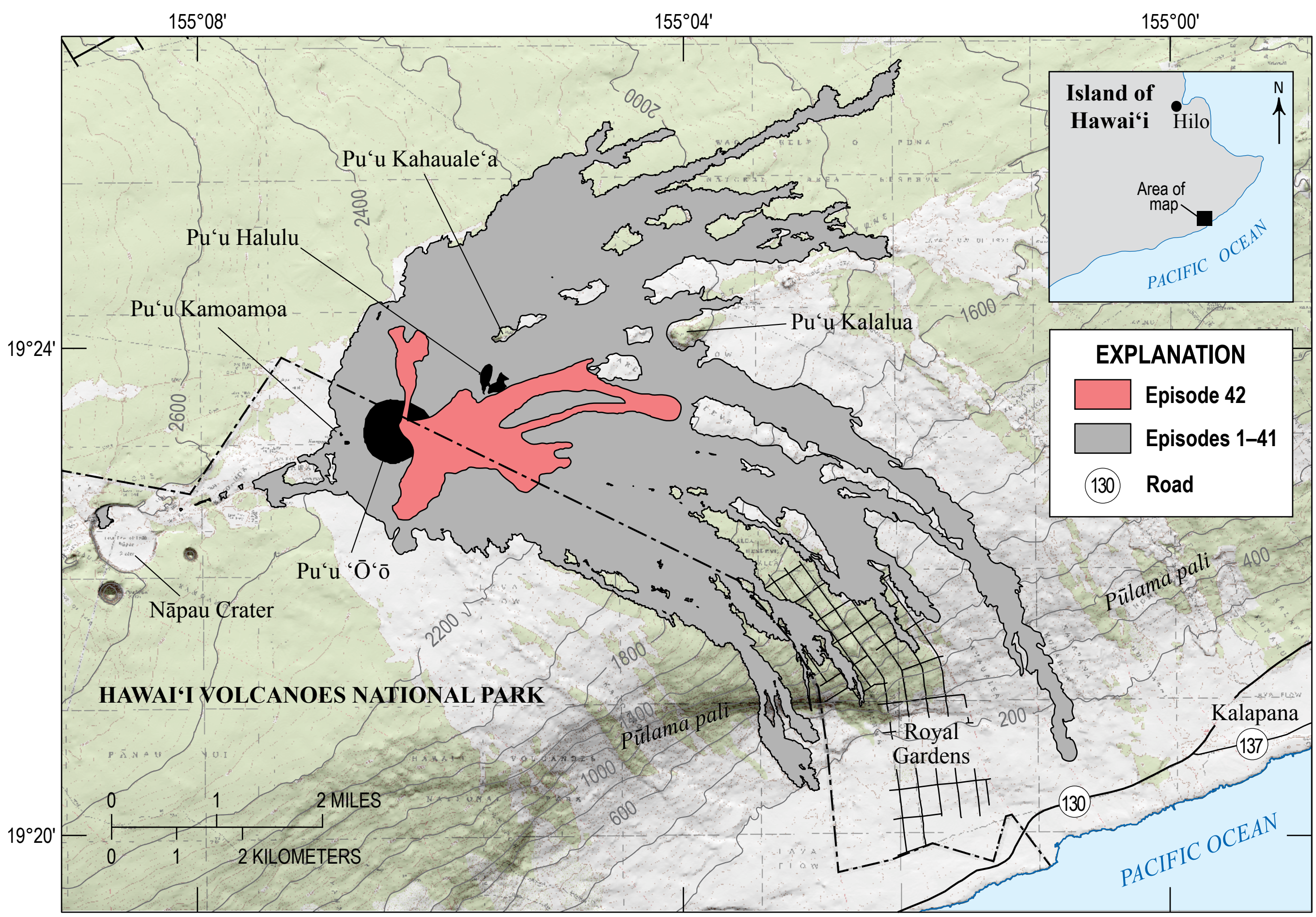


Figure 120. Map showing the distribution of episode 42 lava flows compared to earlier Pu‘u ‘Ō‘ō flows.

Episode 43 (March 22, 1986)

Episode 43 followed a pattern close to that of its predecessors. The inter-episode period preceding it was 27 days. Gas-piston activity started about 17 hours after the end of episode 42 and continued sporadically for about 6 days through the month of February. On the evening of March 10, an observer on State Highway 11, about 12 km northwest of the site, reported seeing glow reflected by clouds above the vent. The top of the magma column was first observed on March 11 by a local pilot, who estimated its depth in the conduit at about 25 m. On March 13, it was reported to be 15 m below the vent rim and 60 percent crusted over, with churning lava visible 6 m below the crust. By March 17, the magma column had risen to 5 m below the vent rim, was 90 percent crusted over, and had formed a 2-m-high spatter cone on top of the crust.

On March 16, an intense electrical storm disabled most of the telemetry at HVO, and remote monitoring of seismicity near the vent was impossible for a week. A team of three volunteer observers walked to the site on March 18 to report events leading up to the episode.

Upon arrival at the vent, the observers reported that the crusted magma column was at the vent rim, supporting a small spatter cone. Frequent spattering during the next 3 days increased the height of the cone by about 2 m per day. A circular spatter rampart surrounding the spatter cone also grew upward 1–2 m per day, forming a moat-like depression. During brief clearing intervals in foggy and rainy weather, observers witnessed the earliest overflow, which was a result of lava splashing over the rampart shortly before 1340 on March 21, producing a 30-m-long pāhoehoe tongue. Two more spillovers occurred within the next 2 hours, and the corresponding flows remained on the terrace surrounding the vent area. Intermittent activity continued into the evening, mostly obscured by dense fog. Frequent low fountains, some as high as 30 m, fed pāhoehoe flows that reached a maximum distance of about 1.5 km southeast of the vent.

The beginning of continuous fountaining was observed from Puʻu Halulu through the fog at 0450 on March 22. At 0530, a pāhoehoe flow was moving southeast along the boundary of the national park at a rate of 570 m/h. At about 0700, the fountain height began to increase rapidly, and the southeast flow front slowed considerably as the lava behind it spread over a large area south of Puʻu Halulu. At 0815 a new channelized flow with slabby pāhoehoe margins reached the south side of Puʻu Halulu (fig. 121). Farther downstream, the earlier southeast flow continued to advance, transitioning to ʻaʻā as it turned northeast.

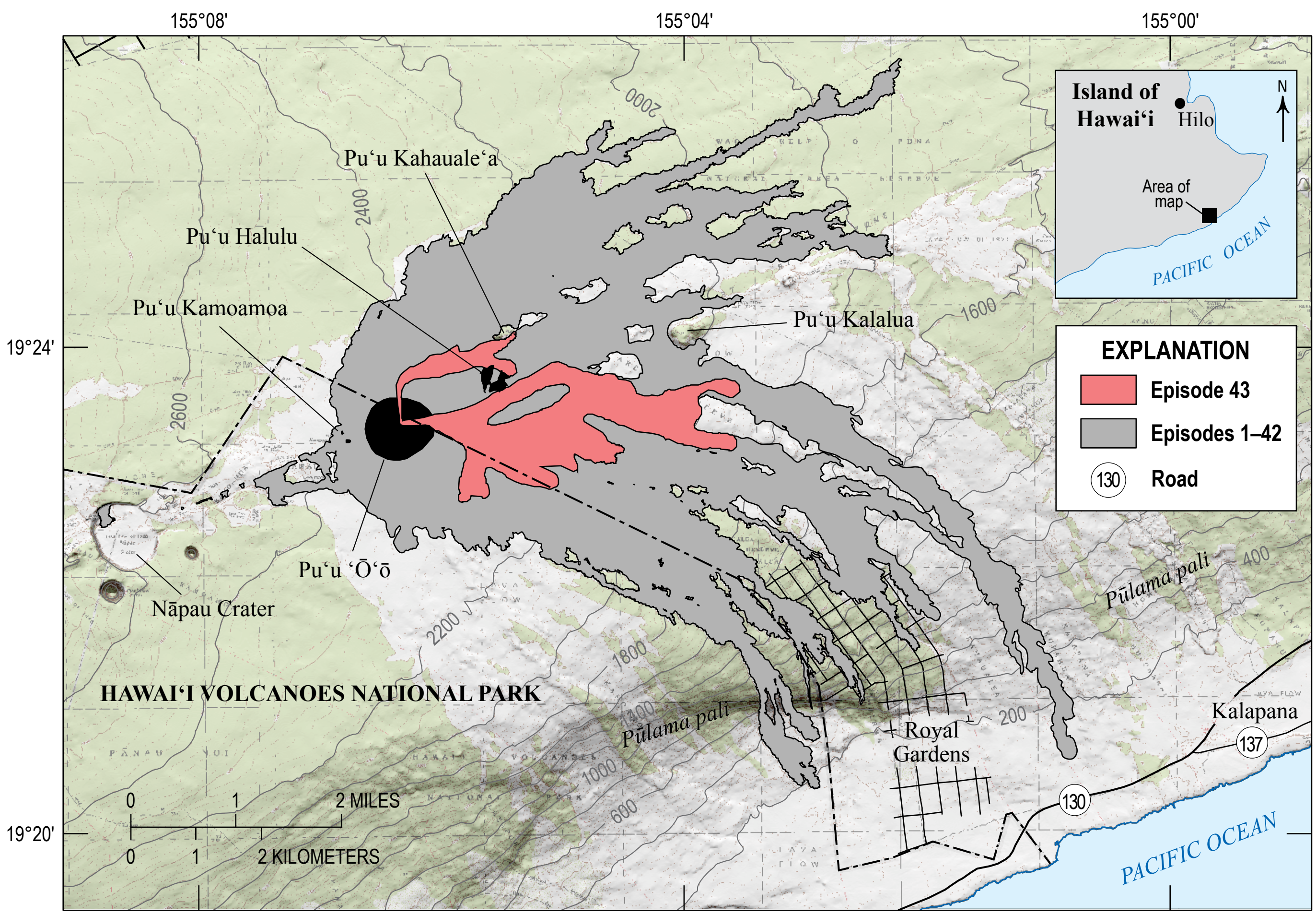


Figure 121. Map showing the distribution of episode 43 lava flows compared to earlier Puʻu ʻŌʻō flows.

When the fog lifted briefly at 0915, the fountain height was measured at 230 m. An additional ‘a‘ā flow was seen traveling down the north spillway of Pu‘u ‘Ō‘ō and advancing eastward toward the north flank of Pu‘u Halulu. The flow on the south side of Pu‘u Halulu, moving at a rate of about 720 m/h, began ponding and thereafter advanced much more slowly. At 1110, the fountain reached a maximum height of 308 m (fig. 122). From 1300 until 1400, the amount of lava passing the south side of Pu‘u Halulu increased from about half of the total discharge to an estimated 70 percent, and the flow velocity increased to approximately 730 m/h. At 1553, the fountain began pulsating and a single jet of lava rose to an estimated height of 350–450 m for 1 or 2 minutes and then died (table 3), like activity during the final stages of episodes 38 and 42. At 1556, only small bursts of spatter and an orange flame remained, marking the end of episode 43. This continued for about 10 minutes.

Because of the lightning damage noted above, the eruption-site seismometer was inoperable until March 22. An alternative seismometer at Pu‘u Kalalua, 4.5 km northeast of the vent, recorded the usual variations in tremor during the episode, which returned to background level at 1554, roughly coincident with the end of fountaining.

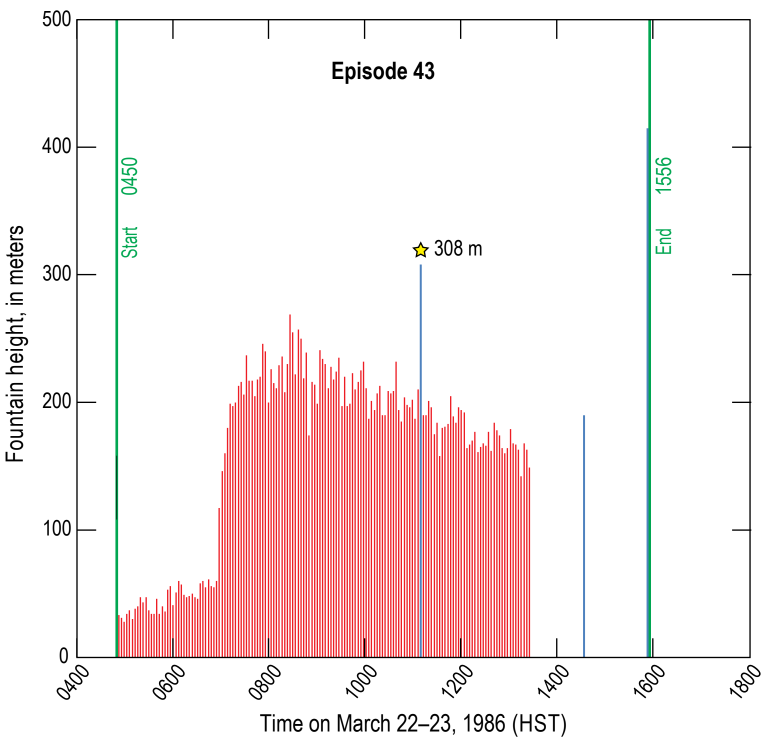


Figure 122. Graph showing episode 43 fountain heights measured from time-lapse film. The yellow star marks the highest fountain, excluding the late jetting event. Theodolite measurements are shown in blue. The time interval between measurements is 3.4 minutes; data gaps are the result of poor visibility.

Summary

Episode 43 (table 1, fig. 121) of Pu‘u ‘Ō‘ō’s high-fountaining activity was characterized by fountaining generally lower than that before episode 40 (fig. 122) and narrow channelized flows that were partly pāhoehoe, although ponding downstream caused the eventual spreading of ‘a‘ā over a broad area east of the vent. Two flow lobes reached approximately 5.0 km from the vent at about 1,900-ft elevation. The estimated volume was 7.2×10^6 m^3 of lava erupted during the 11.1 hours of continuous fountaining, covering 4.8 km^2. The volume was estimated based on summit deflation (12.8 mrad). The time-averaged discharge rate was 180 m^3/s. The summit of Pu‘u ‘Ō‘ō grew by 5 m to 255 m above the pre-eruption surface, the highest elevation that it was to reach during the Pu‘u ‘Ō‘ō eruption. The single high pulsing jet fountain at the end of the episode (table 3) had characteristics like those described for episodes 38 and 42.

Episode 44 (April 13–14, 1986)

Episode 44 began with the surprise opening a satellite vent 1.3 km due north of the Pu‘u ‘Ō‘ō vent (fig. 123). This was like the satellite vents of episode 39 in November 1985, on the south side of Pu‘u ‘Ō‘ō, in that neither involved fissures parallel to the rift zone. In both cases, the satellite vent was at or near the base of the Pu‘u ‘Ō‘ō cone and started erupting before the central vent did. We think that fractures formed radial to the Pu‘u ‘Ō‘ō conduit, probably at a shallow depth, owing to the pressure in the conduit. After high fountaining began, the satellite vents continued to erupt until mid-way through the episode, presumably when pressure was relieved sufficiently to seal the fractures.

The inter-episode period preceding episode 44 lasted 22 days. Sporadic gas-piston activity recorded by the repaired eruption-site seismometer (STC) was noted about 4 hours after the end of episode 43 and again on March 27 and March 30. The top of the magma column was first sighted on April 7 by a helicopter pilot, who estimated its depth in the Pu‘u ‘Ō‘ō conduit at about 10 m. By April 12, it had risen to the vent rim and was supporting several small spatter cones on top of the crust.

On April 13, at 1410, the same pilot reported that a vent had opened on the north side of Pu‘u ‘Ō‘ō. A 3–4-m-high fountain fed a pāhoehoe flow 50–70 m wide that had traveled about 150 m toward the northeast. The vent was still active 4.5 hours later, supplying a 5–10 m high fountain and a 500-m-long flow, and discharge continued at least until 2300, when the activity was last observed. The satellite vent was inactive when next seen at 0455 on April 14. The final area covered by this flow was about 300 m wide by 1 km long.

Upon arrival at the eruption site in foggy weather at 1850 on April 13, HVO observers reported that the north vent was still active, but a clear view of the main Pu‘u ‘Ō‘ō vent was not possible. Fifteen minutes later, glow from spattering at the conduit was visible through the clouds, and at 1922 a lava spillover was seen on the southeast flank of the cone. A 10-m-high fountain was briefly visible a few minutes later.

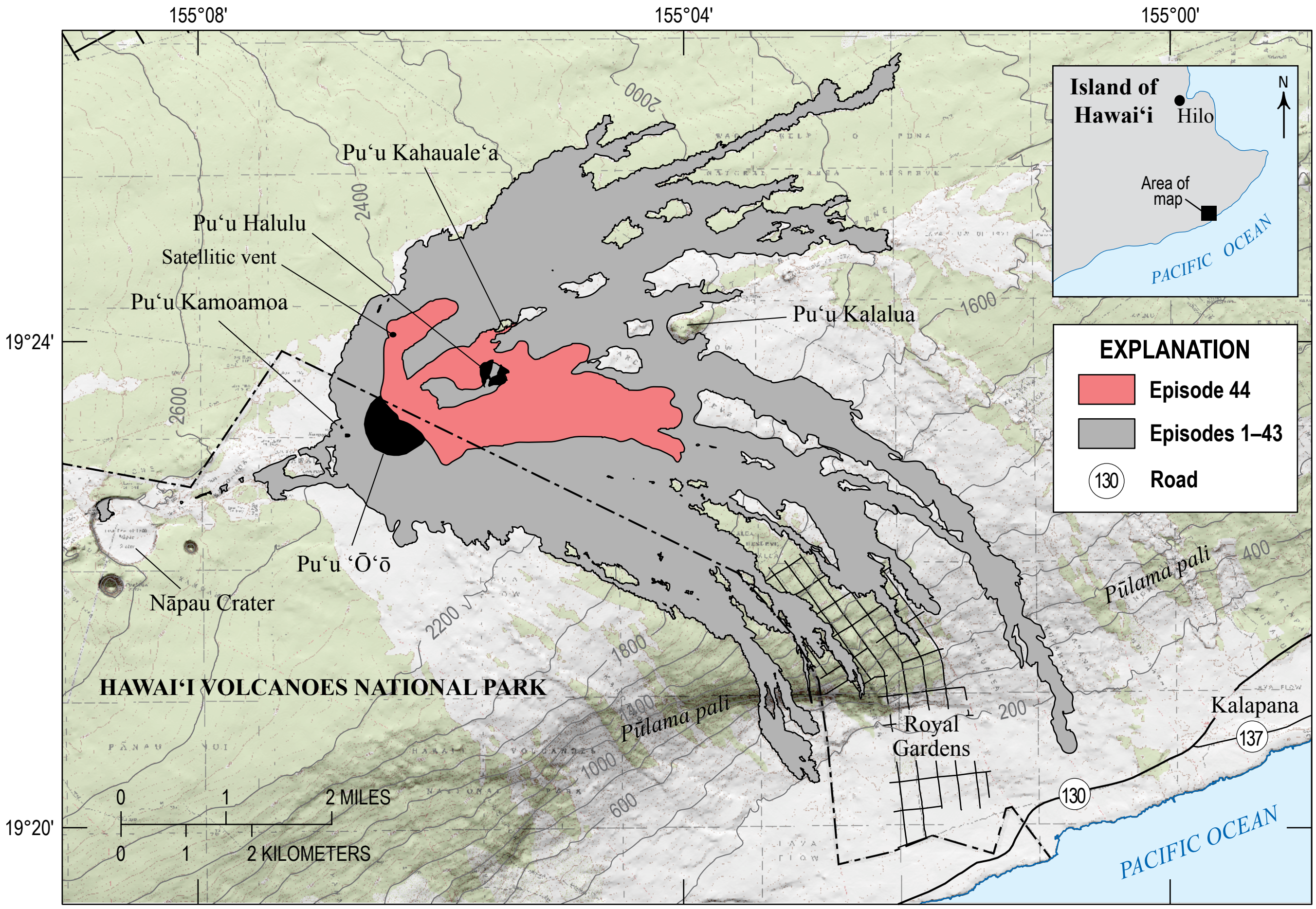


Figure 123. Map showing the distribution of episode 44 lava flows compared to earlier Pu‘u ‘Ō‘ō flows.

The pāhoehoe river that resulted split into two flows that advanced east and south from the base of the cone. At 1954, the largest volume was in the east-moving flow, which formed a broad pāhoehoe front advancing past the south flank of Pu‘u Halulu. The fountain shut off shortly before 2034, and the two flows began to stagnate.

The beginning of continuous fountaining was observed from Pu‘u Halulu through the fog at 2054 with an initial fountain height of 10–15 m. At 2130, the fountain, seen briefly through the rain, was about 20 m high; it had climbed gradually to 25–30 m by 2245, feeding the rejuvenated pāhoehoe flow that was still moving east past the south side of Pu‘u Halulu. At 2315, this flow was ponding behind its front 400 m east of Pu‘u Halulu, having moved about 2 km from the vent. Shortly after midnight, visibility improved and the time-lapse camera recorded continuous fountain activity thereafter until the end of the episode (fig. 124).

At 0100 on April 14, a new flow was sighted on the northeast flank of the cone. The flow advanced rapidly toward Pu‘u Halulu, and by 0230 had filled a low area on the west side of Pu‘u Halulu that had escaped inundation for more than a year. The flow initially advanced in two broad ‘a‘ā fans, which later coalesced to form a channel that carried lava past the north side of Pu‘u Halulu. Overflows from this channel soon threatened the helicopter landing-site on Pu‘u Halulu, forcing pilot Bill Lacy to move his aircraft to safer ground. By 0348, the flow had wrapped around the east side of Pu‘u Halulu and joined the flow from the southeast spillway moving east, completely surrounding the Pu‘u Halulu camp (fig. 123). In addition, a third ‘a‘ā flow advanced from the north flank of the cone to the location of the satellite vent described earlier. As the episode progressed, the northeast spillway visibly eroded, until by 0300 the lava output appeared to be evenly divided between the two spillways (northeast and southeast). The fountain reached its maximum height of 308 m a few minutes later, at 0304 (fig. 124). Shortly afterward, at 0330, observers noticed that a fresh surge of lava, derived from increased output at the vent, was overriding the older, cooler parts of all three flows. The surge passed the south flank of Pu‘u Halulu at 0345, and by 0420 was about 3 km from the vent, having advanced at a rate of about 550 m/h; the fountain at that time was 255 m high.

By 0600, the flow moving past the north side of Pu‘u Halulu had reverted from a broad ‘a‘ā fan to a fast-moving, channelized flow, but the river was short-lived. It overrode the earlier ‘a‘ā, which had wrapped partly around the west end

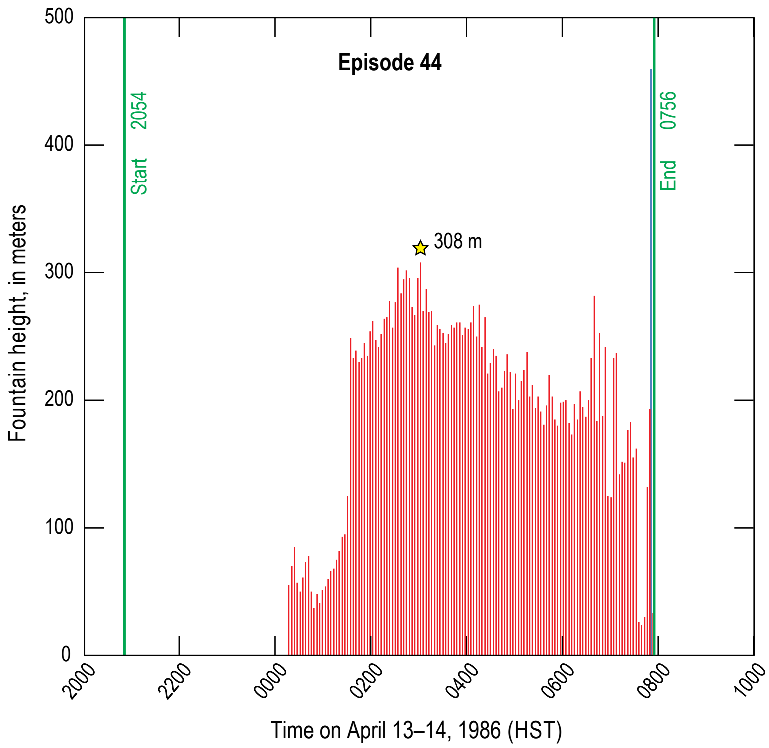


Figure 124. Graph showing episode 44 fountain heights measured from time-lapse film. The yellow star marks the highest fountain, excluding the late jetting event, which was measured by theodolite and is shown in blue. The time interval between measurements is 3.5 minutes; data gaps are the result of poor visibility.

of Puʻu Kahaualeʻa. This late-stage pāhoehoe, not witnessed previously, may have resulted from a sustained lower level of fountaining at 160–200 m height, followed by erratic alternating high and low fountaining during the last hour and a half of the episode. Episode 44 ended at 0756 on April 14, after a high, narrow, jetting fountain that reached to about 460 m (figs. 18 and 124; table 3).

Summary

Episode 44 (table 1, fig. 123) included an unusual satellite-vent outbreak 1.3 km north of the Puʻu ʻŌʻō vent that preceded the main fountaining activity. Unusually sustained low fountaining in the latter part of the episode may explain the transition from ʻaʻā to pāhoehoe lava in the last hours of the episode. One high, jetting lava fountain at the end of the episode was documented. An estimated 8.1×10^6 m^3 of lava (based on a net summit deflation of 13.7 mrad) was produced during the 11.0 hours of continuous fountaining. The time-averaged discharge rate was 203 m^3/s, and flows covered 5.2 km^2. The summit of Puʻu ʻŌʻō remained the same height, 255 m above the pre-eruption surface, because southerly winds blew most of the tephra toward the north. Lava compositions remained unchanged.

Episode 45 (May 7–8, 1986)

Episode 45 competed for attention with a state-wide tsunami warning, beginning just as the tsunami warning was canceled. The inter-episode period preceding episode 45 was 24 days, very close to the average of 25 days for episodes 4–48. Gas-piston activity was first recorded seismically on April 18, 4 days after episode 44, and continued through April 24. The open conduit still measured 20 m across at the top, and the magma column within it was first observed on April 29. The depth to the top of the column at that time was estimated at about 35 m, with a mostly crusted surface containing two holes, each approximately a meter across, emitting small amounts of spatter. On May 5, the column was crusted over at a depth of about 20 m and supported an active spatter chimney on its south side that reached to within 5 m of the vent rim. On May 7 at 1000, a pilot reported that bubbling lava was near the top of the conduit, but no spillover had yet occurred.

That same day, HVO observers in a small plane made observations of Puʻu ʻŌʻō from 1654 until 1836, occasionally flying by while also observing Hilo Bay in anticipation of the arrival of the afore-mentioned tsunami. At 1721, no activity at Puʻu ʻŌʻō was seen, though clouds obscured most of the cone. On another pass by Puʻu ʻŌʻō an hour later, though, the observers saw a 5–15 m high intermittent fountain. Several overflows had fed a small pāhoehoe tongue that advanced east-northeast beyond Puʻu Halulu.

A time-lapse camera at the Puʻu Halulu camp recorded eruptive activity starting at 1731 on May 7. A fountain rose to 15 m above the conduit and erupted intermittently for much of the next 5 hours, until continuous fountaining began at 2241. The fountain increased very slowly, finally surpassing 100 m a little after 0100 on May 8.

HVO observers hiked to the eruption site on the evening of May 7 to rescue a portable seismic instrument on the flank of Puʻu ʻŌʻō before it was overrun. Despite cloudy weather, they could see reflected glow from lava flows much of the way. After arriving at 0035 on May 8, too late to save the instrument, they reported that the broad-based fountain was only half as high as the cone, or roughly 50 m above the conduit. The fountain surpassed the approximate height of the cone at 0235 (~110 m high) and was feeding lava flows down both the northeast and southeast spillways. At the base of Puʻu ʻŌʻō, the northeast flow turned east toward the north flank of Puʻu Halulu. There was a sudden two- to three-fold increase in lava output at 0317, and the breadth of the fountain rapidly increased. The fountain leaned north briefly and showered most of the north flank of Puʻu ʻŌʻō, although the fountain height increased only slightly. During the next 40 minutes, the fountain remained high, reaching a maximum of 257 m at 0337 (fig. 125). At 0448, most of the lava appeared to be flowing northeast. The fountain height dropped about 100 m just after 0600 and continued to fall over the next hour to about 60 m just before 0700. It climbed again to over 200 m just after 0700, and then dropped again at around 0800. The fountain was somewhat erratic for the next hour, fluctuating between 100 and 220 m in height, before dropping rapidly to a height of a few tens of meters just after 0900.

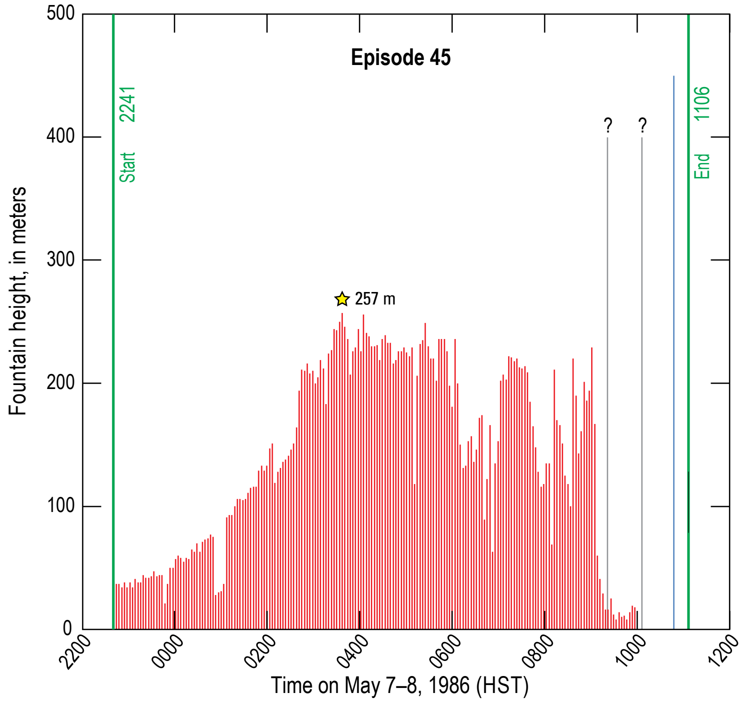


Figure 125. Graph showing episode 45 fountain heights measured from time-lapse film. The yellow star marks the highest fountain, excluding the late jetting events. The first two jetting events, in gray, were not measured and are shown here at 400 m for display purposes. The final jetting event, shown in blue, was measured by theodolite. The time interval between measurements is 3.5 minutes; data gaps are the result of poor visibility.

As was becoming the pattern, three intervals of high jetting fountains occurred during the last few hours of the episode (table 3). The fountain briefly shot upward as a high jetting shaft at 0921, and then was replaced in about 4 minutes by a broad, smooth-looking, roiling fountain that reached the height of the cone (~100 m). At 1006, a second jetting fountain occurred, lasting about a minute, and again was replaced by a roiling fountain, this time not quite as high. A third lava jet occurred at 1047, lasted 2 minutes, and reached an approximate height of 450 m before dying. It was followed by intermittent gas bursts and spatter until 1105, when dense white fume and a dark vortex of fume and dust rose above the conduit to mark the end the episode at 1106.

Summary

Episode 45 (table 1, fig. 126) of the Pu‘u ‘Ō‘ō eruption was characterized by a very gradual increase in fountain height at the beginning, and an erratic ending leading to three sequences of high narrow jets alternating with a low, broad, smooth-topped fountain. These sequences suggest brief states of equilibrium following intense outgassing events. Light winds deposited tephra to the north and northwest, and the summit of Pu‘u ‘Ō‘ō, its height unchanged since episode 43, remained 255 m above the pre-eruption surface. The profile of the Pu‘u ‘Ō‘ō cone after episode 45 compared to that after episode 38, when it was 5 m lower, is shown in figure 127. The main lava flows advanced about 4.5 km east (again encroaching on Pu‘u Halulu). A broad ‘a‘ā fan reached nearly 2 km north, and another lobe reached about 1.5 km south of the vent. An estimated 6.6×10^6 m^3 of lava (based on a net summit deflation of 11.8 mrad) was produced during the 12.4 hours of continuous fountaining, covering 5.2 km^2. The time-averaged discharge rate was 147 m^3/s. A glass temperature of 1,163 °C was calculated from tephra erupted about 3.5 hours before fountaining ended (Thornber and others, 2003a). In comparison, a thermocouple temperature of 1,115 °C was measured at an active ‘a‘ā flow front 1.5 km north of the vent at about the same time. The lava composition was unchanged from the previous several episodes (Thornber and others, 2003a).

Episode 46 (June 2, 1986)

The inter-episode period following episode 45 was 25 days long. Gas-piston activity, recognized seismically, occurred sporadically on 6 different days between May 9 and May 23 at intervals ranging from 1 to 20 minutes in length. The top of the magma column was first observed on May 28, when it was about 20 m below the top of the conduit.

Early in the afternoon of June 1, spatter and intermittent low fountaining at the vent were observed from Mountain View and Hilo, 18 km and 35 km north, respectively. This was the start of about 13 hours of low-level activity at the conduit that heralded episode 46. In contrast to the usual pattern of brief intervals of fountaining and discontinuous spillovers prior to earlier episodes, the interval of pre-play activity before episode 46 included nearly 6 hours of continuous low-level activity. Pāhoehoe flows were fed by low fountains as high as 30 m alternating with slow, passive effusion over the vent rim.

HVO observers arrived at the eruption site at 1805 on June 1 to find a low fountain feeding a spillover traveling southeast. From then until the start of the episode, 8.5 hours later, at 0229 on June 2, 18 periods of low fountaining took place (fig. 128); an estimated 10–12 periods may have occurred during the 5 hours preceding the arrival of observers. The pattern recorded was like that observed before episode 33 (fig. 81), but durations of individual fountaining and inter-episode periods prior to episode 46 were generally shorter. From 2000 on June 1 to 0150 on June 2, lava overflowed the conduit continuously, even though fountaining was intermittent.

The fountain finally became continuous at 0229, marking the start of episode 46, and it gradually increased in height thereafter, reaching a maximum height of 223 m at 0630 (fig. 129). The fountain maintained a nearly constant height until about 0930, after which it began to decrease, fluctuating considerably.

During the last 3 hours of the episode, four intervals of high jetting fountains occurred (table 3). Each lasted about 1.5 minutes, followed by a rapid collapse of the fountain for 1 or 2 minutes and

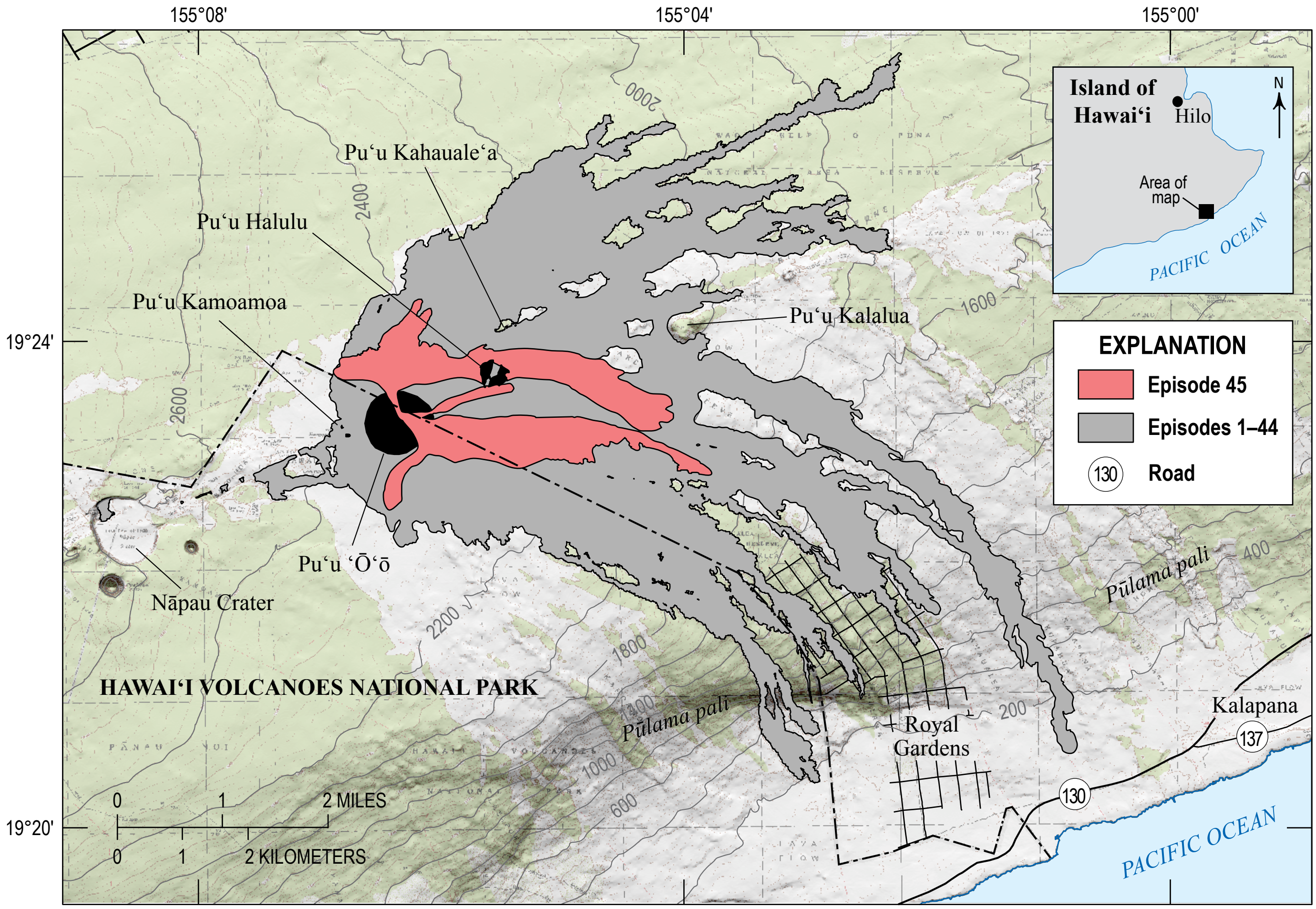


Figure 126. Map showing the distribution of episode 45 lava flows compared to earlier Pu‘u ‘Ō‘ō flows.

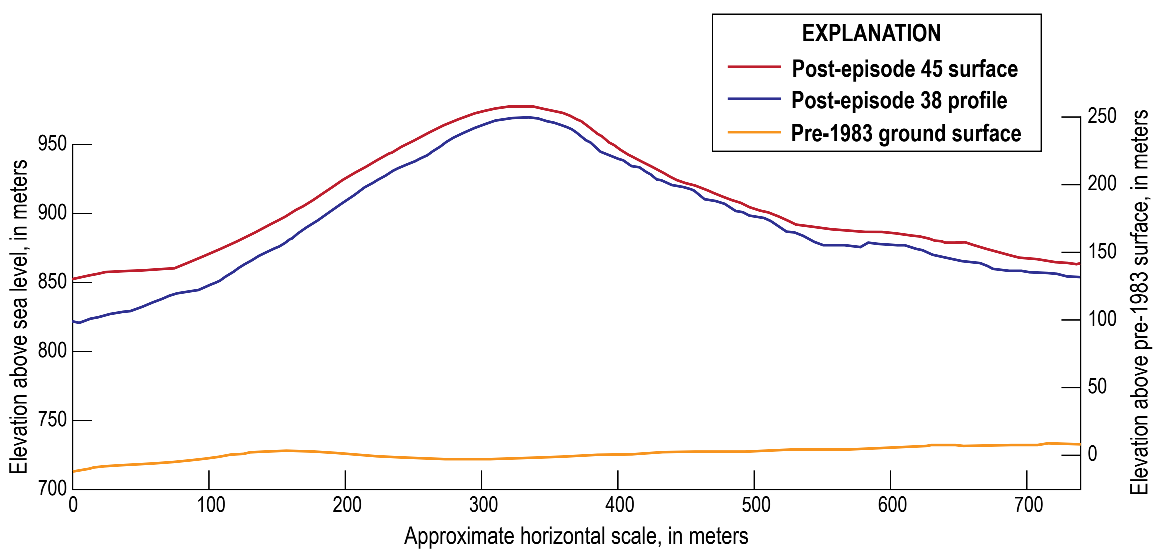


Figure 127. Profiles of Pu‘u ‘Ō‘ō after episodes 38 and 45, illustrating cone growth. Profiles are drawn looking southwest from the perspective of the camera station on Pu‘u Halulu. The vertical scale is constrained by theodolite measurements; the horizontal scale is from topographic surveys.

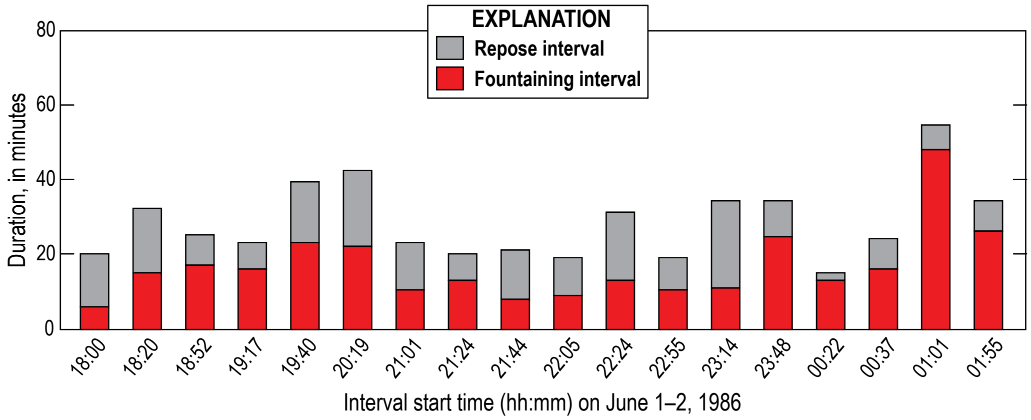


Figure 128. Graph of low fountaining and inter-episode intervals during episode 46 pre-play eruptive activity on June 1–2, 1986. Data shown start about five hours after the first fountain and overflow.

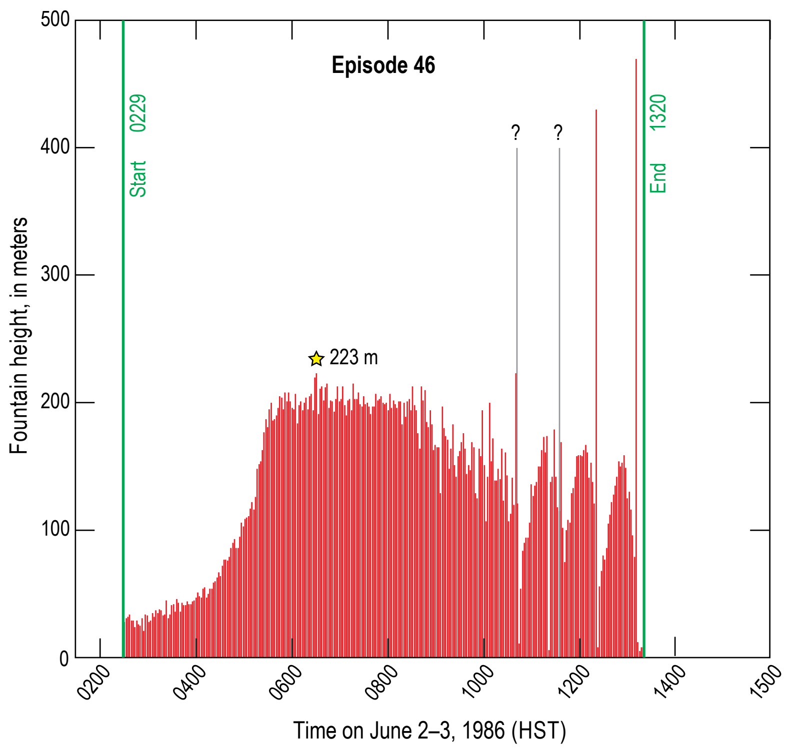


Figure 129. Graph showing episode 46 fountain heights measured from time-lapse film. The yellow star marks the highest fountain, excluding the late jetting events. The heights of the first two jetting events, in gray, were not documented and are shown here at 400 m for display purposes. The time interval between measurements is about 2.2 minutes; the camera acquisition interval varied slightly through the episode.

then a quick recovery of the pulsing column to a height of 150 to 180 m. The top of the recovering fountain stabilized as a broad, smooth, dome-shaped surface (fig. 19) that gradually degenerated again into a pulsing fountain prior to the next jetting event. The time-lapse film documented parts of all four events, but not all their peaks. The last jet of lava reached a height of 470 m and then died completely 40 seconds later. This was followed immediately for 10 minutes by flames above the vent, interspersed with bursts of spatter that reached as high as the top of the cone, before the episode ended at 1320 on June 2.

Lava flows radiated from the broad spillway over the entire east flank of Puʻu ʻŌʻō. The early pāhoehoe flows erupted before the high fountaining stage of the episode covered a wide area extending for 2 km south of the vent. Once again, flows partly inundated Puʻu Halulu, rising gradually toward the observation camp. By the end of the episode, ʻaʻā fans spread approximately 1 km north from the vent, 3 km northeast, and 2 km south (fig. 130), mostly by early morning on June 2. The longest flow was a narrow tongue that advanced 5.2 km southeast late in the episode.

Summary

Episode 46 (table 1, fig. 130) began with a very gradual increase in fountain height and ended with an alternating sequence of high lava jets and a smooth-looking, roiling fountain. Fountain heights during the main part of the episode were consistently near 200 m—about 50 m lower than those of episode 45. The main lava flow advanced about 5.2 km east-southeast of the vent. An estimated 6.9×10^6 m^3 of lava (based on a net summit deflation of 12.2 mrad) was erupted during the 10.9 hours of continuous fountaining, covering 6.1 km^2. The time-averaged discharge rate was 176 m^3/s. The height of Puʻu ʻŌʻō did not increase, remaining 255 m above the pre-eruption surface. A glass temperature of 1,165 °C was calculated from tephra erupted about 4.5 hours before fountaining ended (Thornber and others, 2003a). The major-element compositions of the lava and the tephra were the same and virtually unchanged from those of recent episodes (Thornber and others, 2003a).

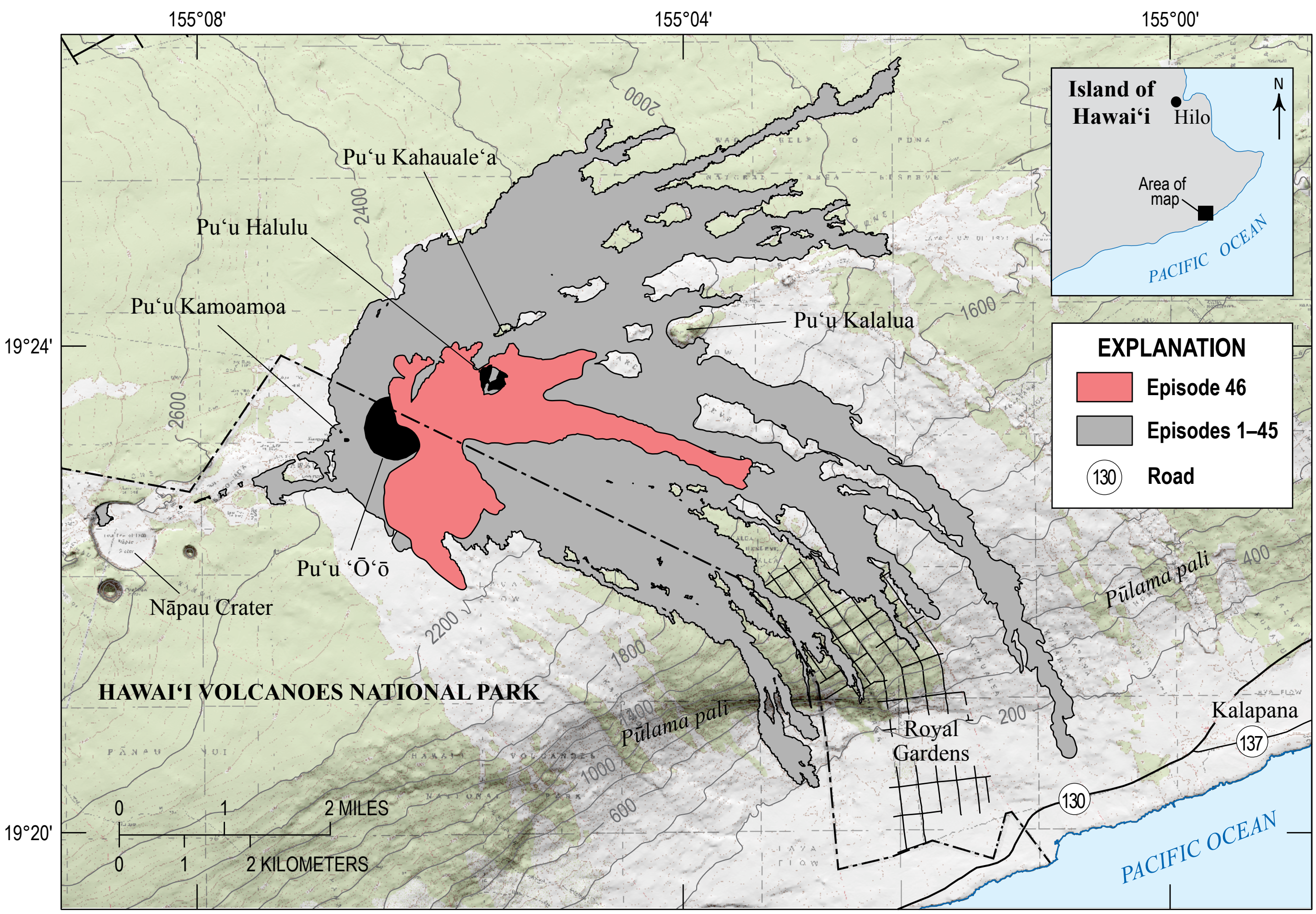


Figure 130. Map showing the distribution of episode 46 lava flows compared to earlier Puʻu ʻŌʻō flows.

Episode 47 (June 26, 1986)

Our observation camp at Pu‘u Halulu (fig. 2*A*), which had provided shelter from rain and tephra through 37 episodes since October 1983 (“camp E” of Wolfe and others, 1988, and later known as Camp 7 until Pu‘u Halulu received its formal name), was nearly encircled by flows in episodes 43–46. The cone became a much warmer place as heat was transferred from the surrounding flows through ground cracks. After episode 44, we could no longer rely on our helicopter pilot being able to take off or land on Pu‘u Halulu once an episode began, because of the tremendous heat radiating from the surrounding flows. For safety, the crew had to be removed whenever the helicopter had to leave. Furthermore, although the top of the cone was in no danger of being buried, the rustic lean-to was in danger of being inundated. So following episode 46, during which temperatures were reaching an uncomfortable level for instruments and observers, a new observation camp (fig. 2*B*) was established on top of Pu‘u Kalalua, an old cone 4.5 km northeast of Pu‘u ‘Ō‘ō. Visibility of the vent from that location was considerably less than that enjoyed at Pu‘u Halulu, but the vantage point was on high ground and turned out to be a fortunate choice for monitoring future activity.

Episode 47 was the last of the 3-year-long series of high-fountaining episodes at Pu‘u ‘Ō‘ō. It was preceded by an inter-episode period of 24 days and followed a pattern close to that of the two previous episodes. Gas-piston activity, seismically detected, occurred regularly every 3 minutes or so during the first 3 days following episode 46. On the fourth day (June 7) gas-piston activity ceased, but then occurred again June 11–13, at irregular to 2-minute intervals. The top of the magma column was first observed on June 23 when it was near the vent rim. It was largely crusted over, but abundant spatter was coming through a 2-m-wide crack, building a 5-m-high spatter cone during the day. A spillover occurred that day between 1100 and 1640, in foggy and rainy weather, producing a viscous pāhoehoe flow about 3 m wide and 20 m long in the southeast channel inherited from episode 46.

Spattering continued sparingly through the night, and by the next morning several more pāhoehoe flows had advanced a few tens of meters down the southeast channel. Observers spent the night at the edge of the lava field north of Pu‘u ‘Ō‘ō and at the new Pu‘u Kalalua field camp. Foggy weather on the morning of the June 24 inhibited viewing from Pu‘u Kalalua, and both groups returned to the Pu‘u Halulu camp. Frequent spattering and spillovers continued through that day, producing additional 10- to 20-m-long pāhoehoe flows. Foggy weather obscured the vent during much of the subsequent night.

The spatter cone over the conduit had grown to a 15-m-high double cone by 0900 the next day (June 25). Both cones emitted spatter from opposing openings, usually independently but sometimes in concert. From beneath the base of the double cone, a very viscous tube-shaped pāhoehoe flow, with a thick crust and incandescent cracks, oozed down the southeast channel at rates of 10 to 15 m/h. A cyclic pattern developed, with intense outgassing and increased spattering alternating with low-level spattering. The more active spatter intervals lasted about 2 minutes and were separated by about 4 minutes of relative quiescence. Several minutes after each high-level event, fresh lava broke out of the distal end of the crusted pāhoehoe and flowed several meters downslope. Conditions were ideal for measuring lava temperatures by thermocouple, and the highest stable temperature obtained was 1,149 °C. Increased spattering and overflows from the top of the cone at 10- to 15-minute intervals started around noon, and lava output from the base of the spatter cone stagnated. At 1300, one half of the double cone had reached a height of 17 m and its vent had closed, while the slightly lower north part was still active. Ten minutes later, an opening broke through the south cone and other openings in both spatter cones increased their incandescence. The cones themselves appeared to be bulging.

At 1400 on June 25, the saddle between the cone doublet opened and lava gushed out, spreading rapidly over the terrace surrounding the Pu‘u ‘Ō‘ō conduit (fig. 131) as six observers scampered for higher ground. The outbreak lasted for 19 minutes and was the first of a series of 15 major overflows during the next 14 hours. During this time, fountain heights ranged between 10 and 40 m above the conduit. Ninety-five percent of the lava traveled down the southeast channel; the remainder flowed over the northeast spillway. The inter-episode activity ended with a 70-minute-long overflow that stopped at 0354 on June 26. By that time, two pāhoehoe lava tongues had moved about 1 km northeast and southeast of the vent, respectively.

The pattern of intermittent fountaining was unlike those of previous observed episodes (for example, figs. 81, 118, and 128). The first nine fountain intervals were nearly equal in duration, about 20 minutes each (fig. 132). Five of the final six intervals showed a progressive increase of from 4 to 70 minutes in duration, suggesting a systematic increase in the volume of magma erupted.

Episode 47 started at 0419 on June 26, when fountain activity became continuous. From 0430 until 0615, the fountain height varied from 30 to 45 m (fig. 133). It rose gradually to 100 m by 0850 and to 200 m by 1005. The maximum height, excluding the high jetting fountaining at the end, was about 224 m at 1117 (fig. 134). Starting at about 1400, the fountain began to pulsate erratically but remained higher than 150 m.

Two hours before the end of the episode, the first of three high jetting fountains occurred, rising about 435 m above the conduit (table 2; fig. 135*A*). The fountain died after about 2 minutes and then slowly built back up to a broad, smooth, roiling fountain (fig. 135*B*). This fountain was constant in height for several minutes before resuming its pulsating form. A similar sequence occurred during two more jetting events at 1524 and 1612. The second of these jets reached 550 m, as measured by theodolite, but the height of the third was not recorded. The intervals between the three jetting events were 53 and 48 minutes respectively. A comparison with episodes 45 and 46 shows that these phenomena have remarkably similar timing: the intervals between jetting events in these three episodes ranged from 41 to 54 minutes, and the jets themselves lasted for 1.5 to 3 minutes. After the third jetting event, intermittent fountaining, with bursts reaching as high as the top of the cone, continued until 1635, when the episode ended.

Figure 131. Photo showing pre-play fountaining from the Puʻu ʻŌʻō conduit during the first of 15 major overflows prior to episode 47. The spatter cone is ~17 meters high; note the tripod in the foreground to the right. Photograph by D. Weisel, U.S. Geological Survey, ~1400 HST, June 25, 1986.

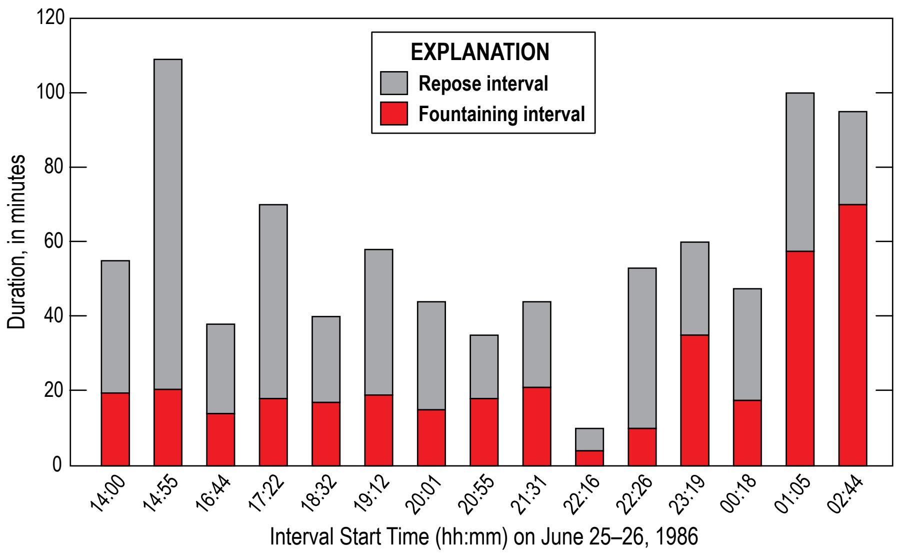


Figure 132. Graph of low fountaining and inter-episode intervals during episode 47 pre-play eruptive activity on June 25–26, 1986. The first fountain and spillover occurred two days before data shown.

Figure 133. Photograph of Puʻu ʻŌʻō, looking southwest from Puʻu Halulu, during episode 47, about 1 hour after the start of continuous fountaining. The ~30-meter-high fountain feeds pāhoehoe flows south (left side of photo), northeast (right side of photo), and out of sight north. Photograph by G. Ulrich, U.S. Geological Survey, ~0521 HST, June 26, 1986.

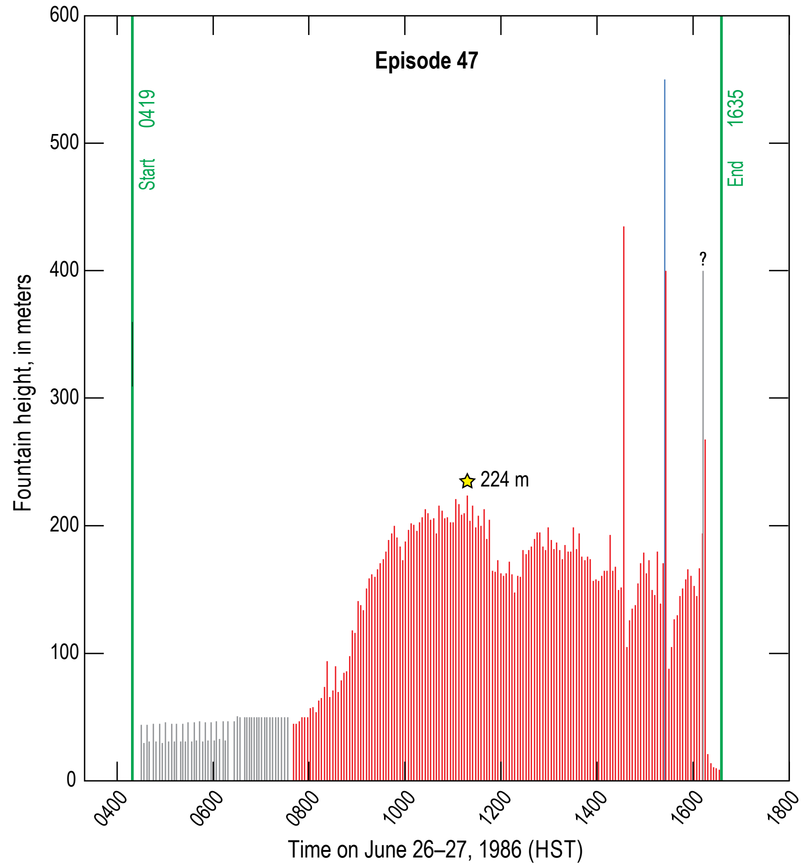


Figure 134. Graph showing episode 47 fountain heights measured from time-lapse film. The yellow star marks the highest fountain, excluding the late jetting events. The height of the tallest jetting event, shown in blue, was measured by theodolite. The height of the final jetting event, in gray, was not documented and is shown here at 400 meters for display purposes. The time interval between measurements is about 3.5 minutes; data before 0740 on June 26, 1986, also shown in gray, is from visual estimates.

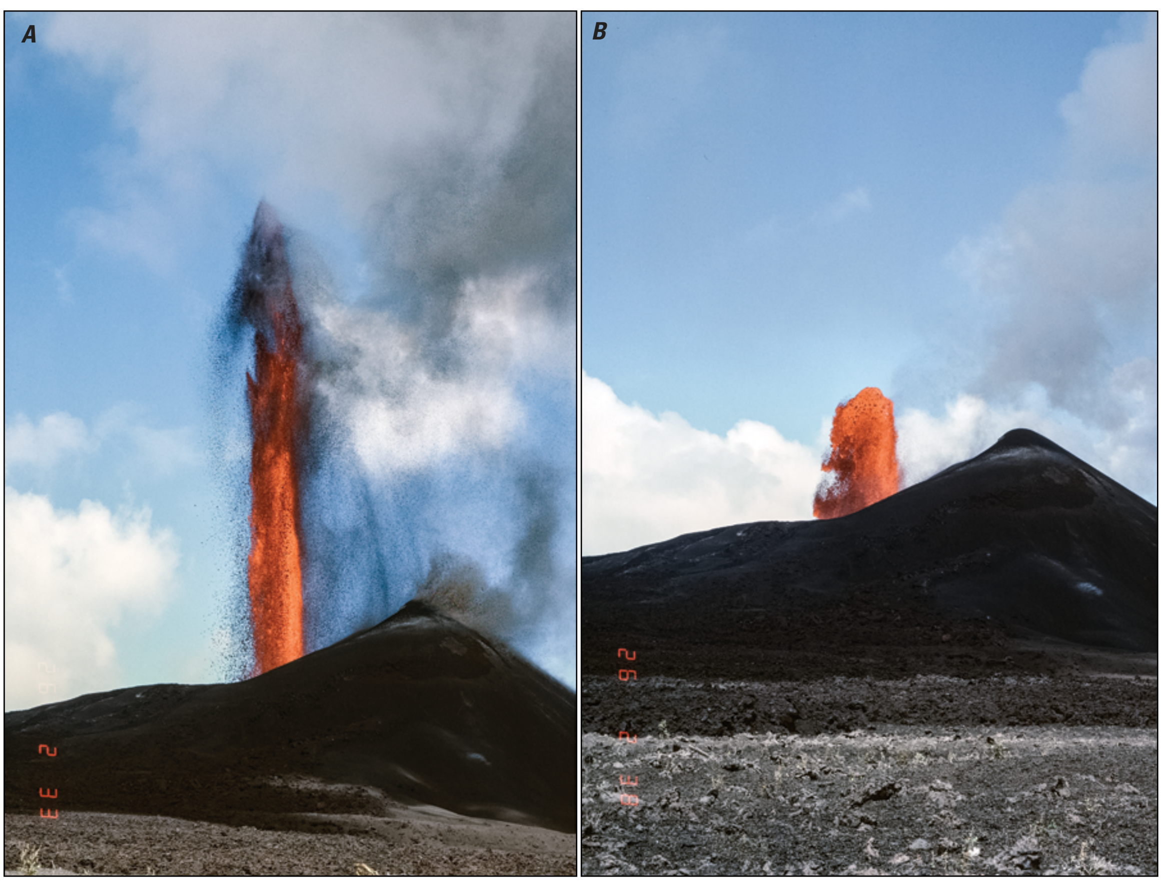


Figure 135. *A*, Photograph showing jetting fountain at 1433 HST, June 26, 1986. The top of the fountain is approximately 490 meters (m) above conduit; the incandescent part is about 410 m high. The view is southeast. Photograph by F.A. Trusdell, U.S. Geological Survey. *B*, Photograph taken 5 minutes after *A*, showing the typical smooth, rolling fountain after a high jetting interval. The fountain is approximately 140 m high. The view is southeast. Photograph by F.A. Trusdell, U.S. Geological Survey, 1438 HST, June 26, 1986.

Early pāhoehoe flows advanced by way of the northeast spillway to the south side of Puʻu Halulu. The southeast spillway fed a flow south for more than 1 km, beyond the visible range of the Puʻu Halulu camp. By 0830 on June 26, three ʻaʻā flows of about equal volume had overrun the pāhoehoe and reached distances of approximately 2.2 km north, 2.1 km east, and 1.9 km south (fig. 136). At 1030, an overflight revealed that the flows north and south were decreasing in velocity while a branching tongue from the east flow was advancing around the north flank of Puʻu Halulu. The observation camp was encircled for the fifth episode in a row. By the end of the episode at 1635, the northern ʻaʻā flow had reached the northwest edge of the lava field, burning a strip of forest about 200 m wide at its terminus about 3.6 km from the vent. The distal end of the eastern flow was about 3.6 km from the vent, and that of the southern flow was 2.4 km, having overrun more forest on the southern margin of the flow field (fig. 136).

Summary

Episode 47 (table 1, fig. 136) closed out the series of high-fountaining episodes at Puʻu ʻŌʻō that began 3.5 years earlier. It was the seventh in a subseries of episodes (episodes 41–47) that were about 12 hours long and separated by inter-episode periods of about 25 days. Episode 47 was much like episodes 45 and 46 in the style of inter-episode activity that preceded it, in its duration, in its fountain heights of 200–250 m, and in its ending sequence of high jetting lava fountains followed by a broad, roiling fountain. The brief duration of the jetting fountains and the intervals between them were almost the same in all three episodes (table 3).

ʻAʻā lava flows again radiated north, east, and south, again encircling Puʻu Halulu, whose circumference was considerably reduced as flows encroached ever closer on the observation camp there. An estimated 6.2×10^6 m^3 of lava (based on net summit deflation of 11.1 mrad) was produced during the 12.3 hours of continuous fountaining, covering an area of 3.2 km^2. The time-averaged discharge rate was 139 m^3/s, and the summit of Puʻu ʻŌʻō remained 255 m above the pre-eruption surface. The elevation of the conduit, last measured after episode 44, had risen 15 m to 169 m above the pre-eruption surface. The major-element compositions of lava were unchanged from recent episodes (Thornber and others, 2003a). A glass temperature of 1,162 °C was calculated for the last spatter erupted as fountaining ended (Thornber and others, 2003a). A thermocouple temperature of 1,149 °C was measured on a pāhoehoe overflow that preceded the onset of continuous fountaining.

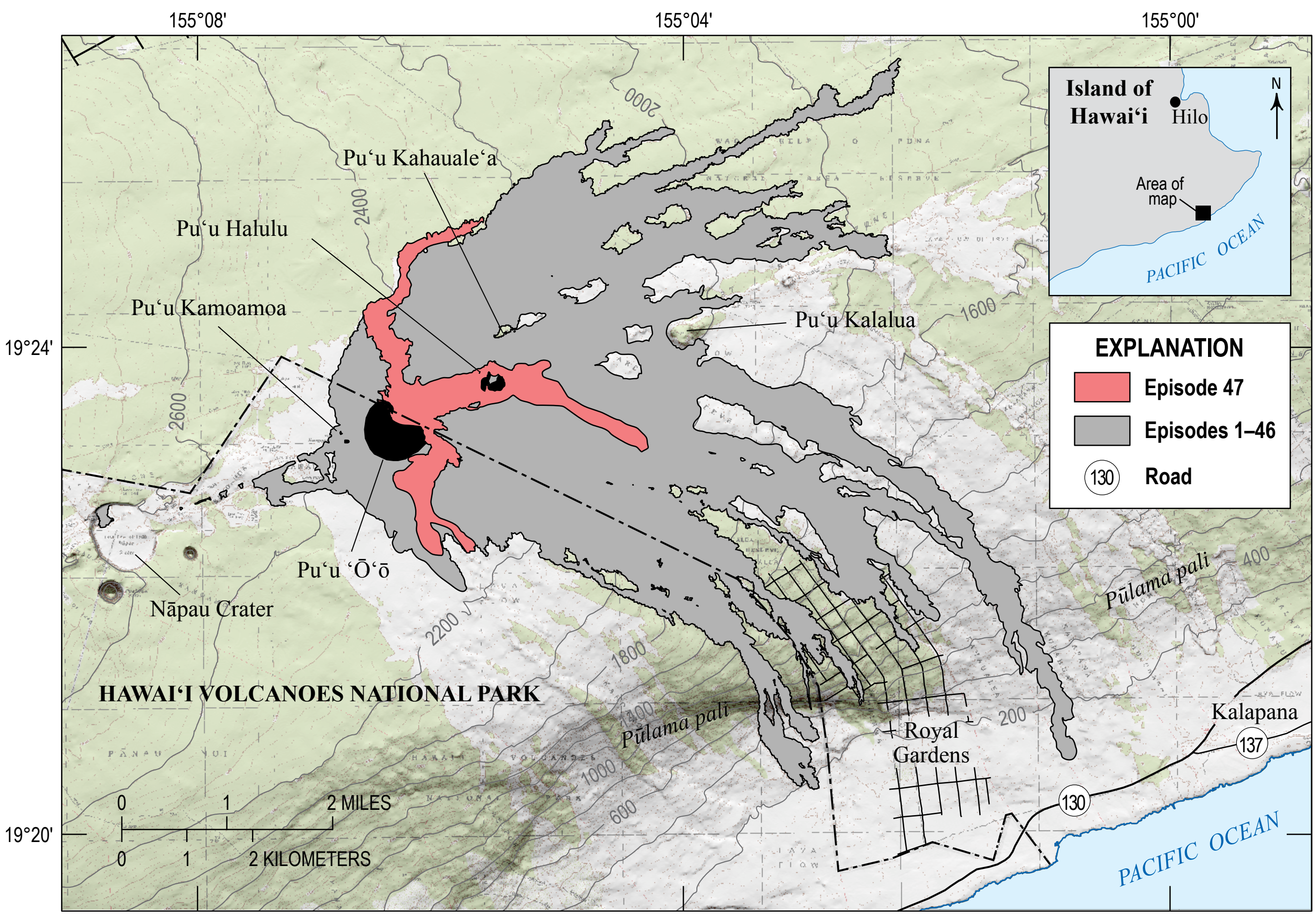


Figure 136. Map showing the distribution of episode 47 lava flows compared to earlier Puʻu ʻŌʻō flows.

Episode 48 (July 18–19, 1986)

The beginning of episode 48 signaled the apparent end of the long series of eruptive episodes at Pu‘u ‘Ō‘ō. The inter-episode activity leading up to episode 48 followed the established pattern, with a 22-day inter-episode period. The magma column gradually rose in the conduit, a spatter cone formed on the crusted surface of the column, and on July 17, spatter-fed spillovers advanced a few tens of meters from the conduit. Just when it appeared that another high fountaining episode was imminent, the magma drained back down the conduit and a series of fissure outbreaks began, first uprift, and then downrift, of Pu‘u ‘Ō‘ō. For the first time since March 1983, Pu‘u ‘Ō‘ō was no longer the primary vent.

Following episode 47, the top of the magma column was first seen on July 14 at a depth of 25–30 m below the top of the conduit, where it was open and spattering. By the next day, the free surface had risen to 3 m below the vent rim, formed a partial crust, and had then withdrawn to 10 m below the surface. On July 16, the crusted magma column rose again and reached the vent rim. At 0320 on the July 17, spattering was recorded on time-lapse film, and, through the day, a spatter rampart ring grew around the conduit to a height of about 10 m. At 2305 on July 17, and intermittently through the early morning of July 18, spatter-fed pāhoehoe flows moved several tens of meters down the east slope of Pu‘u ‘Ō‘ō. By 0700 on July 18, the spatter rampart had grown another 2 m and was becoming more cone-shaped as the opening above the conduit became smaller. At 1040, the cone top was completely crusted over and spattering ceased.

At 1046 on July 18, observers at the conduit felt the first of 17 small earthquakes that occurred over the next few hours. At 1149, a sudden burst of dense gray-brown fume broke through the top of the 12-m-high spatter cone, leaving a hole several meters across, presumably owing to the removal of support as the magma column withdrew. Eleven minutes later, a similar, larger burst occurred and the entire spatter cone collapsed into the conduit. The now-empty upper conduit was incandescent and emitted an orange flame that reached several meters above the vent rim. The conduit had ruptured, and magma intruded laterally along the trend of the rift zone, accompanied by the small felt earthquakes.

Minutes later, at 1205, lava broke the surface at the uprift base of Pu‘u ‘Ō‘ō, marking the opening of the episode 48A fissure (figs. 137*A* and 138). A line of fountains 30 m long and 1–2 m high persisted for 16 minutes. Thirty minutes later, the time-lapse camera on Pu‘u Halulu recorded fume rising along newly opened cracks, designated the 48B fissure, on the downrift side of the cone, between Pu‘u ‘Ō‘ō and Pu‘u Halulu (figs. 137*B* and 138). At 1309, this fissure also began to erupt, feeding low fountains that eventually propagated 800 m northeast. Meanwhile, at 1258,

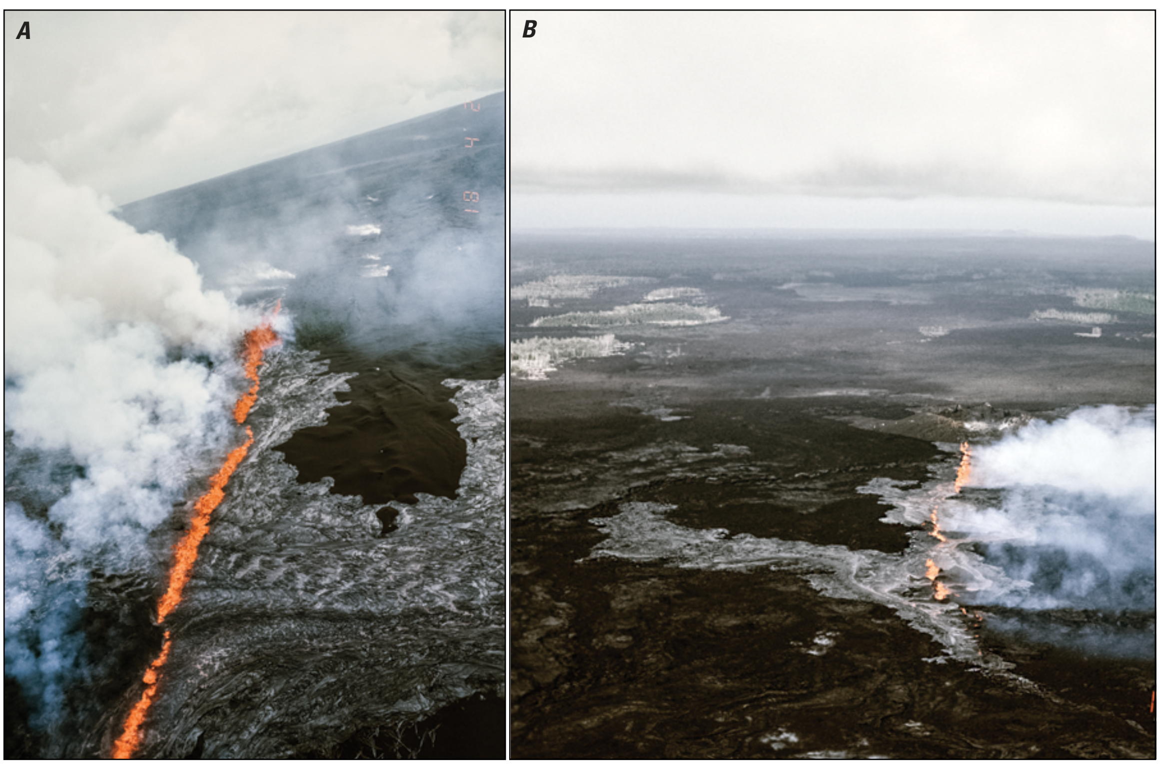


Figure 137. *A*, Oblique aerial photograph showing the episode 48A fissure uprift of Pu‘u ‘Ō‘ō. The main fissure steps *en echelon* to the left, whereas smaller segments, mostly obscured by fume at the far (southwest) end of the fissure, step to the right. The total fissure length was 1.2 kilometers. Photograph by G. Ulrich, U.S. Geological Survey, 1627 HST, July 18, 1986. *B*, Oblique aerial photograph showing the episode 48B fissure downrift (northeast) of Pu‘u ‘Ō‘ō extending 800 meters to Pu‘u Halulu. The pāhoehoe flow on the left (north) is nearly stagnant. The primary flow, obscured by heavy fume, extends to the right from the far end of the fissure. Photograph by G. Ulrich, U.S. Geological Survey, 1630 HST, July 18, 1986.

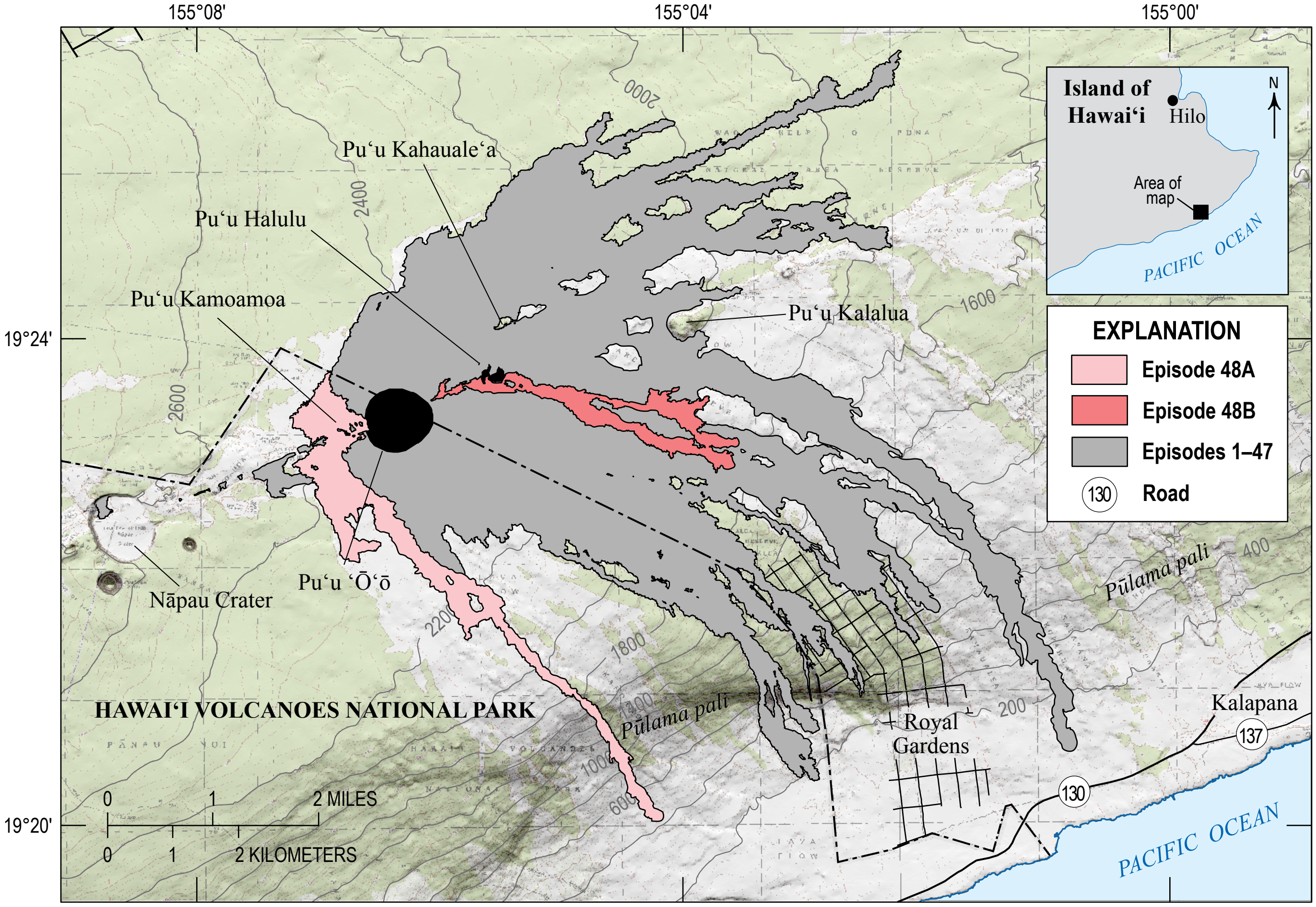


Figure 138. Map showing the distribution of episodes 48A and 48B lava flows compared to earlier Pu‘u ‘Ō‘ō flows.

the 48A fissure reactivated, and a 2–3-m-high curtain of lava propagated 700 m uprift, passing just south of the remnants of Pu‘u Kamoamoa.

Pāhoehoe flows began spreading from the 48A fissure northwest and southeast on either side of the rift zone, and fountain heights increased to 4–6 m. By 1355, the northwest flow was moving into the forest against the west edge of older ‘a‘ā flows from Pu‘u ‘Ō‘ō. Another pāhoehoe flow was moving east-southeast from the 48B fissure past the south edge of Pu‘u Halulu after a short-lived earlier flow had advanced northeast from the fissure's upper vents. At 1530, the 48A fissure opened farther west from its uprift end along ground cracks that were 5–50 cm wide, with vents 1 to 5 m apart, bringing the total length of the fissure to about 1.1 km. Methane explosions and possibly related ground cracking, extending several hundred meters farther west, were observed between 1550 and 1645.

The fountaining along the east end of the episode 48A fissure increased several-fold to 20–30 m high at 1550, but reverted to low, 3–4-m-high fountains 5 minutes later. Shortly thereafter, a high-volume flow was observed moving southeast from the 48A fissure, across a broad 700-m-wide swath. About 1 km from the fissure, it split into two lobes, each 200–300 m wide (fig. 138).

By 1640, the more active eastern lobe was overrunning forest 2.5 km south of the source. In 25 minutes it moved an additional kilometer, averaging an unusually high velocity of about 2.4 km/h. This flow, the longest produced by the 48A fissure, followed the path of a lightly vegetated older flow that originated in the Pu‘u Kamoamoa area. Even though the slope increased as it moved down Kīlauea's south flank, the flow slowed between 1705 and 1930 to an average speed of 1.2 km/h, igniting fires in the forest and grass to the west as it advanced (fig. 139). Because of the high flow velocities and the fire danger, the National Park Service closed the Chain of Craters Road from 2130 until 2340 and set up a fire-fighting camp at the Waha‘ula Visitor Center. By 0630 on July 19, however, forward motion at the distal end had almost ceased. Ultimately the flow reached 420-ft elevation low on the Pūlama pali, 7.5 km from the fissure (fig. 140) and 1.8 km from the Chain of Craters Road, having averaged only 300 m/h during its last 3 hours before stagnating.

By 1800 on July 18, the west end of the 48A fissure had begun to shut down, while 10–20-m-high fountains on its east end continued to feed the long ‘a‘ā flow. At 1920, the gaps between fountains were observed to be widening, and, from 2140 on July 18 until 0145 on July 19, the decreasing activity migrated progressively toward Pu‘u ‘Ō‘ō as the uprift vents died and the

FIgure 139. Photograph of the 7.5-kilometer-long flow from the episode 48A fissure as viewed looking north from the Chain of Craters Road. Grass fires parallel to bottom of picture were ignited by west winds crossing the flow from right to left. The forest burning behind the grass fire to the left was probably ignited by windblown burning debris. Photograph by D. Little, U.S. Geological Survey, sometime after 2200 HST, July 18, 1986.

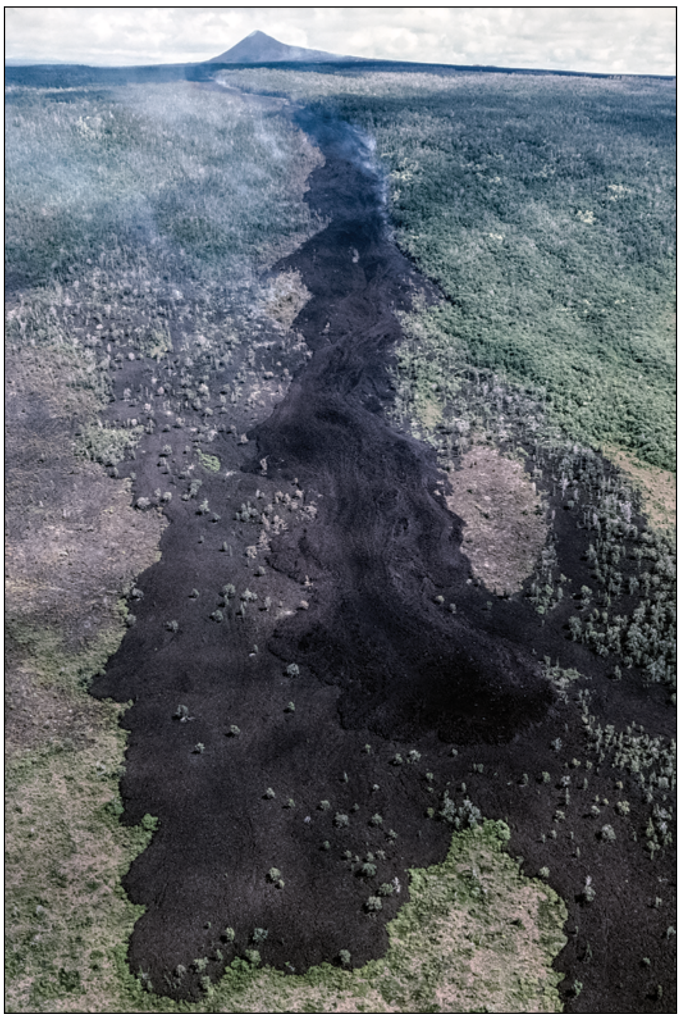


Figure 140. Oblique aerial photograph looking northwest of the 7.5-kilometer-long episode 48A flow on top of a sparsely vegetated older flow; both originated in the Pu‘u Kamoamoa area. The Pu‘u ‘Ō‘ō cone straddles the axis of the most active part of the East Rift Zone. The episodes 48A and 48B fissures extend from the base of Pu‘u ‘Ō‘ō to the left and right, respectively. Photograph by J.D. Griggs, U.S. Geological Survey, July 19, 1986.

downrift fountain heights decreased. Activity ceased on the 48A fissure at 0145, but at 0215, active fountains returned to the east end of the fissure, coincident with an increase in tremor registered by the nearby seismometer. Fountaining on the 48A fissure ended again at 0335, this time permanently.

Meanwhile, the 48B fissure appeared to increase in vigor between 1815 and 2000 as the 48A fissure was slowly shutting down. Because the 48B fissure had extended to the base of Pu‘u Halulu, we elected to move our observation post for the night to the new camp on Pu‘u Kalalua, 3 km downrift. The view of the fissure was not as good, but that of the lava flow it fed was improved (fig. 141). The pāhoehoe flow from the 48B fissure had transitioned to ‘a‘ā downstream and, at 2 km, split into two lobes, which merged again at a distance of 3.2 km. The flow eventually stagnated 4.0 km east-southeast of the fissure (fig. 138). At 2210, gaps were developing between the fountains; 10 minutes later, the 48B fissure fountains began to decrease in height. Fountain heights continued to decrease after midnight and progressively died from the uprift end near Pu‘u ‘Ō‘ō toward the downrift end. By 0500 on July 19, the fissure was weakly active only near Pu‘u Halulu, as lava slowly welled out of several glowing vents. Between 0900 and 1000 lava production ceased, and the end time of 48B fissure activity was marked at 0930.

Summary

The final eruptive event at the long-lived conduit of Pu‘u ‘Ō‘ō produced only spatter around the rim prior to the onset of episode 48. The magma column was barely able to rise to the lip of the conduit, which had grown to 169 m in elevation since its first appearance in March 1983. The rupture of the conduit at the start of the episode caused the column to drain as magma intruded uprift and downrift of Pu‘u ‘Ō‘ō. The removal of support led to the collapse of the spatter cone over the conduit (fig. 142). Fissure vents opened for a combined length of nearly 2 km, preempting the high fountains that had become so typical of the series of episodes. A glass temperature of 1,154 °C was

Figure 141. Photograph of the episode 48B fissure from Pu‘u Kalalua camp, showing two lobes of ‘a‘ā lava moving toward the camera. The conduit of Pu‘u ‘Ō‘ō, incandescent at upper left, is 4.5 kilometers southwest. The north flank of Pu‘u ‘Ō‘ō is partly visible at upper right, and Pu‘u Halulu is silhouetted below the fissure fountains at lower right. Photograph by C. Heliker, U.S. Geological Survey, after 2200 HST, July 18, 1986.

calculated from a flow sample erupted from the episode 48A fissure about 15 minutes after the fissure opened (Thornber and others, 2003a). The highest recorded velocity for an ‘a‘ā flow during the Pu‘u ‘Ō‘ō eruption, 2.4 km/h, was achieved in episode 48A.

The volume of new lava produced during episodes 48A and 48B (table 1, fig. 138), based on the first aerial photographs we obtained since episode 40, was 5.0×10^6 m^3, covering an area of about 4.5 km^2. Considered separately, episode 48A covered 3.1 km^2 over 15.5 hours with a volume of 3.5×10^6 m^3, and episode 48B covered 1.4 km^2 over 20.4 hours with a volume of 1.5×10^6 m^3 (table 1). The average rate of lava discharge was a relatively low 63 m^3/s for episode 48A and 21 m^3/s for episode 48B. The summit of Pu‘u ‘Ō‘ō remained 255 m above the pre-1983 surface, at an elevation of 974 m. The conduit was 169 m above the pre-1983 surface at an elevation of 888 m (86 m below the summit).

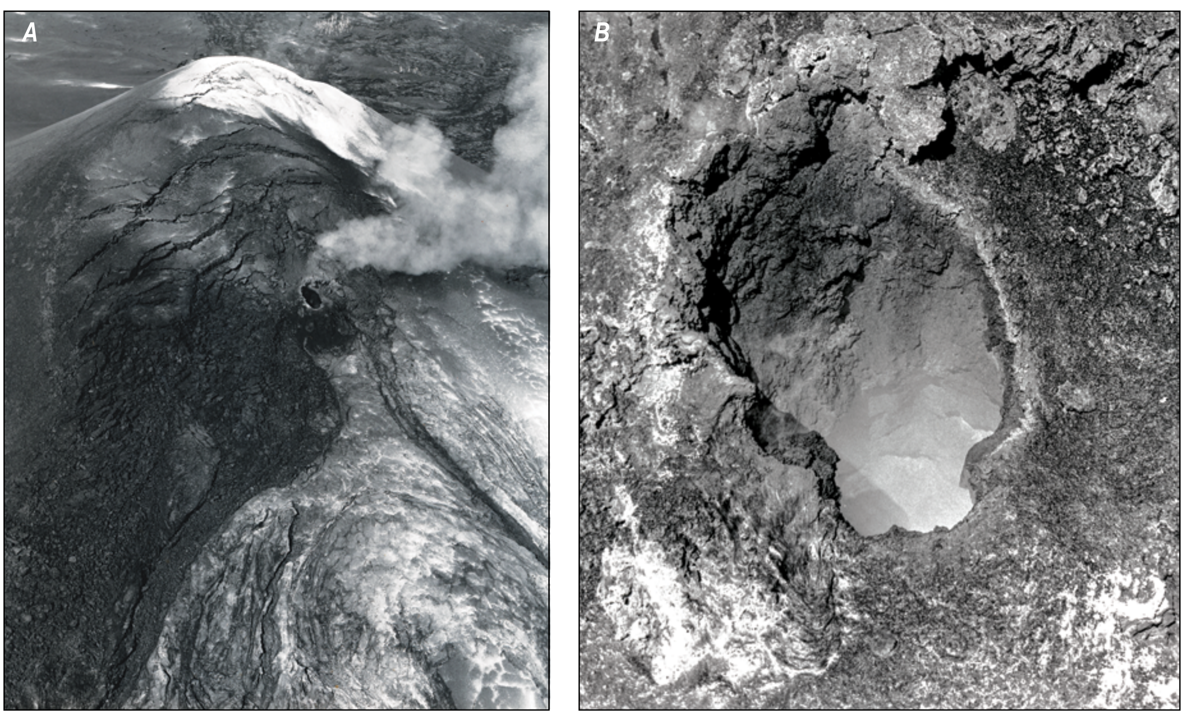


Figure 142. Oblique aerial photographs of Pu‘u ‘Ō‘ō during episode 48C. *A*, View of light-colored fumarolic deposits coating the summit and discoloring fractures in the tephra and in the last pāhoehoe flows around vent. The view is southwest. Photograph by J.D. Griggs, U.S. Geological Survey, September 17, 1986. *B*, View of the conduit opening shortly after withdrawal of the magma column. The long dimension is approximately 15 meters. The base of the former spatter cone, sloping away beneath the spatter-covered surface, forms the rim of the opening. Photograph by J.D. Griggs, July 19, 1986.

Later evaluation of the seismicity (Hawaiian Volcano Observatory, written commun., July 1986) described the early swarm of microseisms as an irregular cluster near, or immediately west of, Puʻu ʻŌʻō. The swarm epicenters do not define a linear trend and thus are not obviously related to the eruptive fissures that opened thereafter. However, most of the earthquakes were too small to be precisely located.

The Kupaianaha Stage of Episode 48, July 20, 1986–April 30, 1987

On the morning of July 20, the day after the episode 48A and 48B fissures shut down, and 3.5 years after the Puʻu ʻŌʻō eruption began, a new fissure opened approximately 3 km downrift from Puʻu ʻŌʻō (fig. 143), on trend with the 48A and 48B fissures. The new 48C fissure evolved into a single vent, later named Kupaianaha. Within a month, a lava shield topped by a lava lake had formed over the fissure. For the next 5.5 years, a succession of lava tubes leading from the lake fed lava southward to the coast. This part of the eruption resulted in the burial of the lower half of the Royal Gardens subdivision, the Wahaʻula Visitor Center in Hawaiʻi Volcanoes National Park, and the residential communities of Kapaʻahu and Kalapana.

From a Fissure to a Shield

Early on the morning of July 20, 1986, a flurry of microearthquakes was recorded by the Puʻu Kalalua seismometer, 4.3 km northeast of Puʻu ʻŌʻō, and at 0713, the tremor amplitude began increasing slowly. Just before 0800, a helicopter pilot reported low fountains (5–7 m high) erupting along a new fissure downrift from the 48B fissure, which had ceased erupting about 22 hours before. We arrived at 0950, to find that the new 48C fissure was located 150 m north of, and parallel to, the fissure of episode 1, which erupted January 7–8, 1983 (see Wolfe and others, 1988, plate 1). The fountains of the 48C fissure system, which was about 1 km long, were only a few meters high through the first day (fig. 144) and were unevenly spread along the fissure. As the fissure opened progressively downrift, the earlier fountains at the uprift end became inactive. Pāhoehoe flows from the active downrift fountains spread laterally across old ʻaʻā flows of episodes 1 and 3, ponding close to the fissure and moving slowly southeast (fig. 143). The Puʻu ʻŌʻō conduit remained incandescent, and the 48A and 48B fissures continued to emit fume.

Through the second day, activity continued without significant change, but by the third day (July 22), the active part of the fissure appeared to be shortening. Meanwhile, a collapse

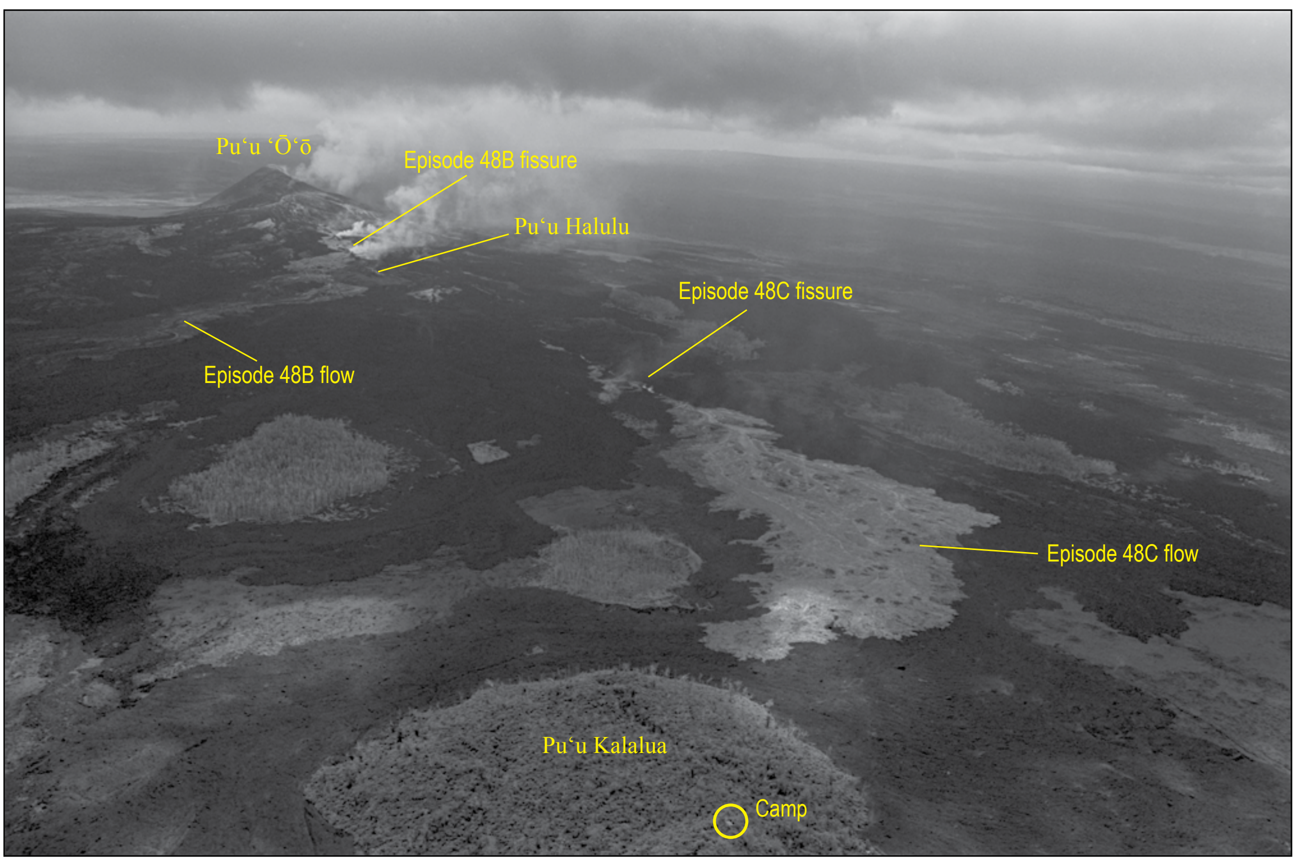


Figure 143. Oblique aerial photograph looking west of the Puʻu ʻŌʻō cone, the heavily fuming episode 48B fissure and flow, and the low fountains of the episode 48C fissure feeding a small pāhoehoe flow overrunning earlier ʻaʻā flows of episodes 1 and 3. Puʻu Kalalua is the forested cone in the foreground. Photograph by J.D. Griggs, U.S. Geological Survey, 1430 HST, July 20, 1986.

structure just uprift of Pu‘u ‘Ō‘ō was first observed. An irregular depression several meters deep, about 20 m wide and 100 m long, extended south from the location of the episode-35 fissure (July–August 1985). The structure formed under the tephra-covered pāhoehoe flows of episode 35 adjacent to the flank of Pu‘u ‘Ō‘ō, perhaps as a result of the withdrawal of magma from beneath the 48A fissure on July 19.

On July 23, the outer rain bands of Hurricane Estelle dropped 11 inches (28 cm) of rain on the eruption site, and no observations were possible. The weather had not improved much on July 24, but brief clearing during an overflight allowed observation of three small fountains on the 48C fissure. Early on the following day, HVO observers counted six fountains barely visible above the surrounding pāhoehoe, which had buried most of the original fissure.

By the evening of July 25, only two fountains, less than 100 m apart, were active, feeding pāhoehoe spillovers across the top of a slowly forming elongate shield, initially referred to as the C-shield. The main flows developed channels, which gradually roofed over progressively downslope to form lava tubes. Hand leveling at that time showed that the shield was approximately 4 m high.

Lava continued to upwell quietly through the end of July, with occasional low spattering from the two vents. Pāhoehoe flows spread out in various directions across the low shield, with the longest traveling 4.5 km southeast before stagnating in early August. By August 3, the shield had grown to a height of nearly 10 m and, though not well defined, was approximately 500 m across.

For the rest of August, lava continued to pond around the larger eastern vent, forming a lava lake 150×200 m across. Pāhoehoe flows were fed by overflows from the lake and by tubes that originated at the lake and extended 100–400 m downslope. The longest flow reached only 1.2 km southeast. At any given time, several small pāhoehoe flows were usually active on different areas of the shield; these flows rarely remained active for more than a few hours. By the end of August, the shield was approximately 1×1.5 km in diameter and stood 34 m above the pre-1983 surface—an average vertical growth rate of a little less than a meter per day.

Many pasty ‘a‘ā flows added to the bulk of the shield during August. Most originated midway down the shield on the east and south quadrants (fig. 145). The largest ‘a‘ā flows were about 100 m across, 3–4 m thick, and 300–500 m long; these flows crept downslope over a period of several days. The ‘a‘ā flows were not tube-fed; rather, they were preceded by fracturing and uplifting of the older, solid pāhoehoe of the shield, forming a scarp, and extruded from the interior of the shield. The uplift on the scarp was as much as 3 m and exposed the dense interior of pāhoehoe flows emplaced in July. Within a day after we first noticed the scarp, pasty ‘a‘ā flows emerged at several points along its face. This cycle of shield uplift, fracturing, and extrusion of pasty flows, and sometimes less-viscous pāhoehoe flows, occurred several times over the next 2 years. It gave clear indication that the shield was growing endogenously through sill-like intrusions, as well as exogenously by lake overflows.

Figure 144. Photograph showing a line of 1- to 2-m-high fountains on the episode 48C fissure as viewed looking northwest across East Rift Zone. Heat waves rise from pāhoehoe lava, which is spreading laterally from fissure. Photograph by J.D. Griggs, U.S. Geological Survey, 1452 HST, July 20, 1986.

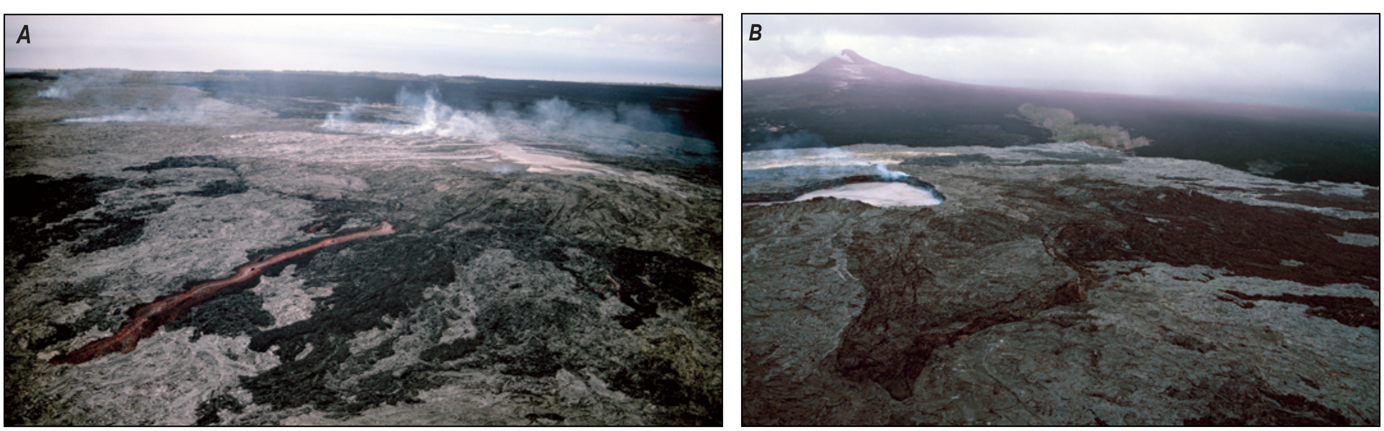


Figure 145. *A*, Oblique aerial photograph looking south showing the extrusion of a pasty lava flow from a scarp on the north flank of Kupaianaha occurring simultaneously with a full and overflowing lava lake. Photograph by C. Heliker, U.S. Geological Survey, April 12, 1987. *B*, Oblique aerial photograph showing the well-developed scarp and uplifted area on the north flank of Kupaianaha. Photograph by D. Weisel, U.S. Geological Survey, May 25, 1987.

The same phenomenon, on a smaller scale, was observed at many places elsewhere on the shield, where small ʻaʻā flows could be traced back to areas of jumbled pāhoehoe blocks that had been fractured and uplifted. Most uplifts occurred normal to the slope of the shield, but in some places the scarps were parallel to the fall line.

The conduit at Puʻu ʻŌʻō was steadily incandescent through the end of 1986, and at night it formed a beacon visible not only from the new field camp on Puʻu Kalalua, but for miles around, inspiring many erroneous reports of fountaining from concerned citizens. The incandescence was a constant feature, providing evidence of the continuing connection between the old and new vents. The Puʻu ʻŌʻō conduit provided a chimney for flaming gases released from magma rising into shallow storage beneath the cone on its way to the episode 48C shield.

Puʻu Kalalua proved an excellent vantage point and was our base for ground access to the growing shield and lava flows. The new camp also provided protection from wind and rain for geodetic measurements and allowed continuous visual and photographic observation of the Kupaianaha shield.

Formation of the Lava Lake

As the shield grew, its summit broadened, and the upwelling lava developed low levees at the perimeters of spreading lava sheets. The levees, a meter or so high at first, began as a wall of folded shelly pāhoehoe left by the advance and retreat of fluid lava. The ponded melt remained fluid, permitting the levees to stabilize into permanent structures, which grew with the increasing height of the lake by being repeatedly mantled by overflows. In mid-August the lake was roughly 100×200 m in size, continuously in motion, and covered by a thin, flexible crust. By early September, the lake was becoming more defined with a discontinuous levee around its margins and well-developed levees constraining its main outlet channel (fig. 146). Flows leading away from the channel quickly roofed over to form a lava tube.

Occasional low fountaining occurred along a line 40–50 m long in the lake, but mostly the lava quietly supplied the lake with little spattering. Small spatter ramparts also formed over the secondary vent west of the growing lake (fig. 146), presumably at one of the two vents active at the end of July. Activity at this vent, which was intermittent, was last observed on September 10; all subsequent lava presumably issued from the submerged east vent.

During its formative days, through September 1986, the lake was mostly full and overflowed its levees frequently, building them and the shield ever higher (fig. 147). Circulation in the lake was evident in the motion and disruptions in the thin crust that covered most of the lake's surface. Occasionally the lake level dropped several meters below the rim, presumably when either the tube(s) drained more efficiently or, more likely, the magma supply to the lake decreased. In the last 10 days of September, waves that formed on the lake surface reached heights of several meters at the southeast end of the channel, accompanied by crustal overturning. The waves apparently occurred because a constriction formed in the tube entrance and disrupted the lava current directed from the main body of the lake down a slight gradient toward the entrance. The splashing from the waves built a spatter pile 4 m high on the edge of the channel by October 1, but it collapsed into the lake shortly afterward when the splashing stopped.

During October, the level of the lava lake began to fluctuate more than in previous weeks—on some days as much as 5–10 m (figs. 148 and 149)—but it never exhibited the large variations of as much as 200 m observed in the Mauna Ulu lava lake (Tilling, 1987). Measurements were made by theodolite, Abney level, and Brunton compass from the northeast rim of the lake across a known 65-m-wide span to calculate the level of the lake in a manner like that described by Tilling (1987). Supplementary estimates were made on overflights by experienced observers and were included in the recorded measurements. In the case of Mauna Ulu, short-term variations of 20 m or less were ascribed to buildup and release of gases during gas-piston activity (Swanson and others, 1979; Tilling and others, 1987; Tilling, 1987). This is likely

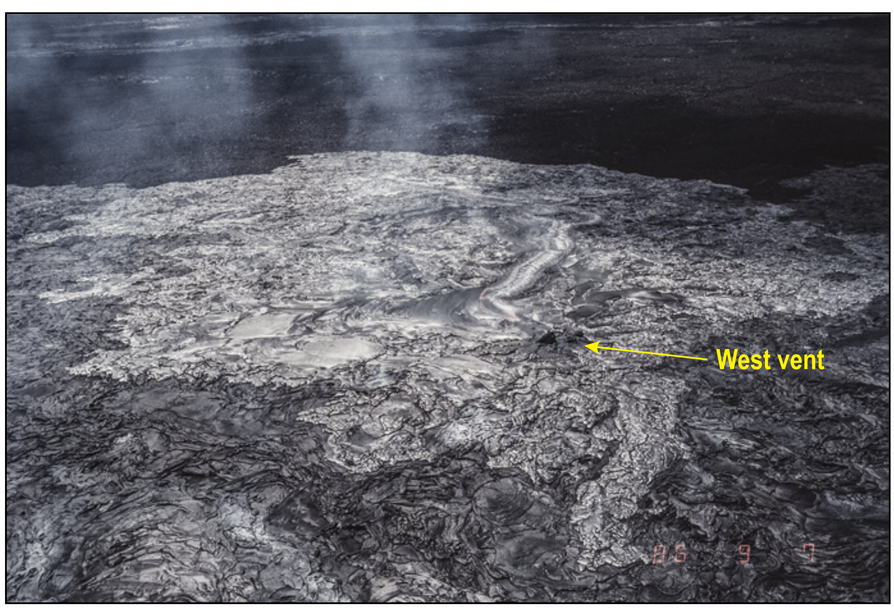


Figure 146. Oblique aerial view of the Kupaianaha shield, 7 weeks after the opening of the episode 48C fissure. The shield summit is 35 meters above the pre-1983 surface. The young lake is beginning to develop its eventual tadpole shape, with its discharge channel forming a southeast tail feeding into the main tube system. The west vent at the lake margin was intermittently active until September 10. The main east vent is hidden beneath the lava crust left of the incandescent stream. The lighter pāhoehoe surface is composed of recent overflows. Photograph by G. Ulrich, U.S. Geological Survey, September 7, 1986.

the case at Kupaianaha as well. Changes of similar amplitude from gas-piston activity have also been documented at a perched lava channel at Puʻu ʻŌʻō in 2007 (Patrick and others, 2011), as well as at a lava lake in Halemaʻumaʻu during Kīlauea's 2008–2018 summit eruption (Patrick and others, 2016). When the Kupaianaha lake changed level, rising or falling as much as 10 m, its change in volume was as much as ~0.125×10^6 m^3.

As the lava tube system leading from Kupaianaha developed progressively down slope, magma appeared to be entering the lake at a constant rate and discharging through the main tube entrance at the southeast end of the lake. The magma supply to the vent beneath the lake was assumed to be constant based on the uniform harmonic tremor recorded by the Puʻu Kalalua seismometer and the relative lack of variation in the west-east tilt record at the summit of Kīlauea.

Variations in lake level may have crudely reflected the efficiency of the tube system. The activity downslope tended to decrease when the lake filled, suggesting a blockage in the intervening tube system. Sometimes the correlation was seemingly obvious, as when both the lake and skylights in the lava tube overflowed simultaneously, leaving the tube dry downstream from the blockage. Sometimes the blockage cleared, and the tube was reoccupied; at other times a new tube formed. Rapid drops in lake level, however, did not consistently precede or accompany increases in outflow downslope. We are unsure how much of the variation is the result of short-term change in the magma supply to the lake, and how much is the result of lava intruding the shield, or perhaps filling old facture systems, such as the buried 1977 fissure, which was a major consumer of lava during episode 1 in January 1983.

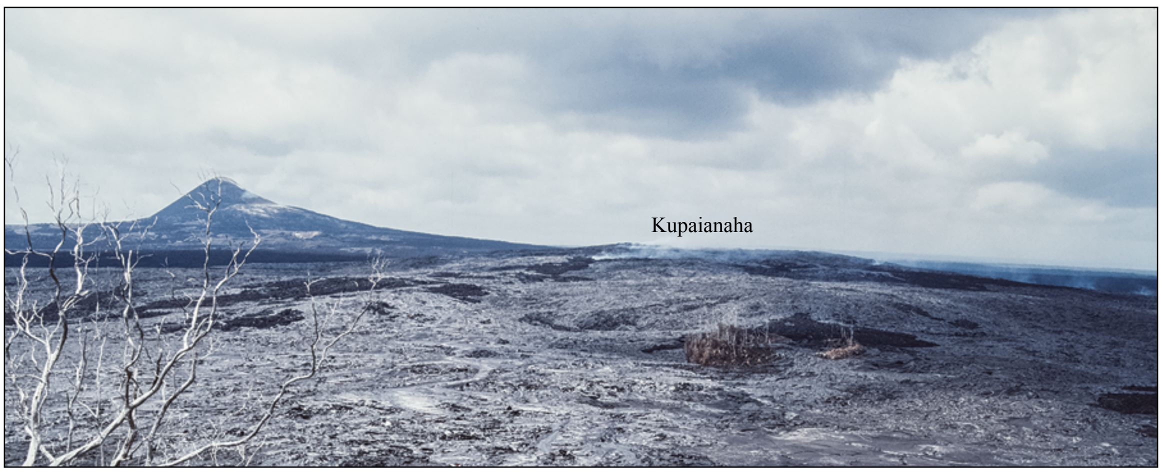


Figure 147. Photograph of the Kupaianaha shield (foreground) and Puʻu ʻŌʻō (left), looking west from Puʻu Kalalua. The top of the shield is approximately 37 meters above the pre-1983 surface. The pāhoehoe flows in the near field are from shield overflows. Photograph by J.D. Griggs, U.S. Geological Survey, September 17, 1986.

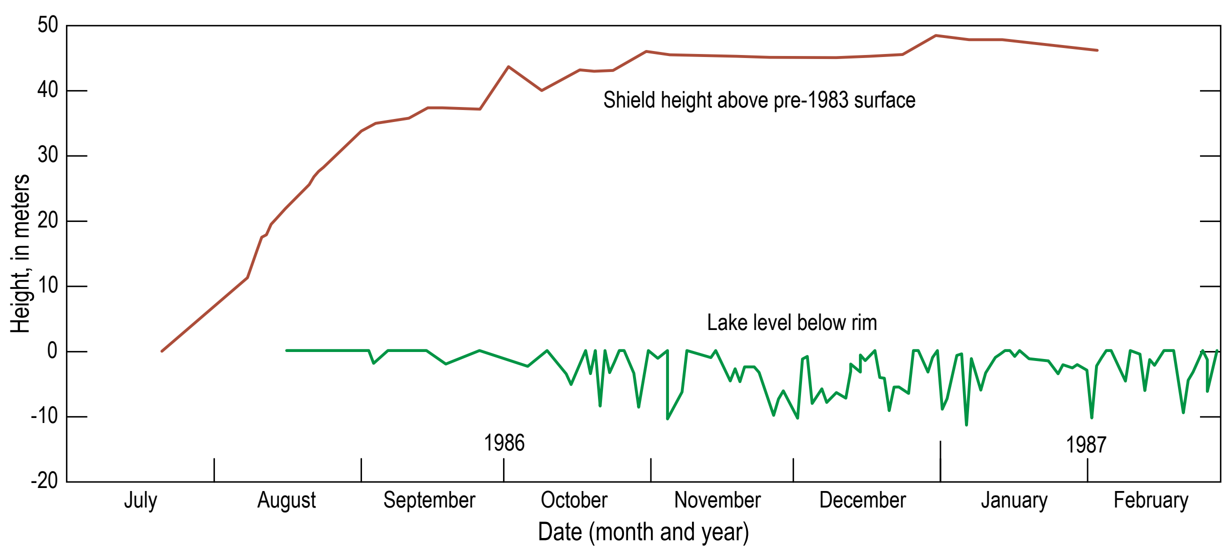


Figure 148. Graph comparing the growth of the Kupaianaha lava shield with fluctuations in the level of lava lake on its summit from July 20, 1986, to March 1, 1987.

During the last week in October, a large tumulus formed over the main lava tube about 150 m downstream from the tube entrance at the southeast end of the lake. The tumulus grew to roughly 75 m in diameter and 10 m in height within a few days, during which the lake was full and overflowing. The tumulus apparently formed in response to a constriction in the main tube and grew through both intrusion and extrusion of lava diverted from the tube in a process probably like that which forms shatter rings (Orr, 2011). Small ‘a‘ā flows intermittently emerged from circumferential fractures that partly encircled the tumulus; within a week the ‘a‘ā outbreaks had obscured the original structure. A line of new skylights led eastward from the tube entrance, indicating growth of a new tube that was bypassing the presumed constriction.

The bottom of the lake was never visible, but its depth was obviously increasing as the shield grew. There was no way to determine if thermal erosion lowered the floor of the lake below the original ground level. Between mid-August and November 1986, the shield grew by 26 m (fig. 148). The level of the lake surface below the rim was, at times, more than 14 m (fig. 149). There was no obvious correlation between lake level and summit tilt, and the lake level sometimes fluctuated widely over periods of minutes to hours, probably because of gas-piston activity. When the lake level dropped, the upper part of the tube entrance was normally visible; it was crudely circular in shape and estimated at ~10 m in diameter (fig. 150).

As the lake deepened, the magma supplied to it was discharged increasingly into the nascent tube system. As the tube system extended downslope, the number of overflows from the lake decreased, and, by November, the rate of shield growth diminished to nearly zero. The lake widened to its eventual size (125×255 m) by collapse of the walls, occurring principally when

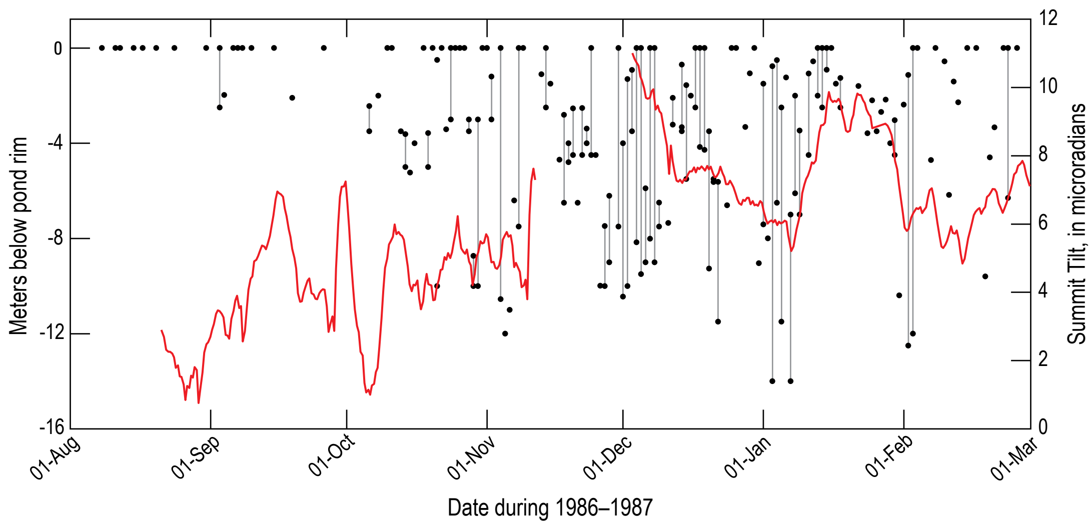


Figure 149. Graph showing summit tilt (red line) and the Kupaianaha lava lake level from the beginning of August 1986 through the end of February 1987. Points mark the level of the lava lake below the crater rim. Lines with points on both ends show lake level variations on individual days.

Figure 150. Oblique aerial photograph showing the lava tube entrance at the southeast end of the Kupaianaha lava lake. Lines of incandescence show the breakup of the lake crust as lava pours into the 10-meter-wide tube opening. The lake surface is approximately 13 meters below the rim. Photograph by G. Ulrich, U.S. Geological Survey, February 2, 1987.

the lake level was lowest or had just dropped quickly from high levels. Obvious care was required when working on the rim of the lake to avoid areas with circumferential cracks and to move away when the lake level dropped quickly.

The frequent collapse of wall material into the lake, and the transitory islands composed of wall blocks that sometimes formed as a result, indicated to us that remelting of older flows did occur. In their observations of the Mauna Ulu lava lake of 1970–71, Swanson and others (1979) described the initial depression as a collapse crater on the summit of Mauna Ulu. The lake that filled this depression evolved by widening and coalescence with a collapse trench into a complex linear depression 530 m long and 145 m deep by October 1971. Subsequently in the 1972–74 eruption of Mauna Ulu, that crater drained to a maximum depth of 200 m within the 90-m-high shield (Tilling, 1987) and thus extended well below the base of the shield. It seems apparent that the collapsed material in Mauna Ulu must have undergone stoping and remelting for it to have been removed from the crater, and Swanson and others (1979) suggest that these processes, in combination with collapse, were the agents of removal. In contrast to Mauna Ulu, the Kupaianaha lake was not originally formed by collapse, but once it was formed, the processes of collapse and thermal erosion that widened and deepened it were like those suggested for Mauna Ulu.

Quasi-steady-state Eruption

The Kupaianaha part of the eruption achieved a more-or-less steady state of activity by the middle of October 1986. Shield growth leveled out at a height of about 45 m (fig. 148) because few overflows occurred once most of the lava was being discharged through the tube system. The lake maintained its tadpole shape with little modification (fig. 151), even though some overflows resulted from collapse of short segments of the lake's rim.

Our best estimates of discharge rate for the shield-building stage of the episode are based on two periods of mapping with aerial photographs and field measurements 15 and 95 days following the onset of continuous activity. The average bulk daily production determined for this period was 0.45–0.50×10^6 m^3 of predominantly pāhoehoe lava, or roughly 5–6 m^3/s. Correcting for 30 percent vesicles and intra-flow voids yields a DRE effusion rate of about 4 m^3/s. Less accurate effusion rate estimates made from observing pāhoehoe rivers in primary tubes through skylights ranged from 5–10 m^3/s. Correcting for 30 percent void space yields a comparable DRE effusion rate range of roughly 4–7 m^3/s.

The tilt record for Kīlauea's summit showed only relatively small variations after the beginning of the Kupaianaha part of the eruption (fig. 149), and, when combined with uniform low-amplitude harmonic tremor from seismometers on the middle East Rift Zone (Nakata and others, 1992a,b), the indications are that the magma transfer system was in an approximate steady-state condition much like that described for the Mauna Ulu eruption by Tilling (1987) and Tilling and others (1987).

The Kapaʻahu Flow (November–December 1986)

For the remainder of 1986, tube-fed pāhoehoe flows and associated breakouts of ʻaʻā advanced relentlessly to the sea from Kupaianaha. Flows traveled sporadically downslope from the shield, constrained in their course between the 1977 ʻaʻā flow on the northeast and the episode 18 (April 1984) ʻaʻā flow from Puʻu

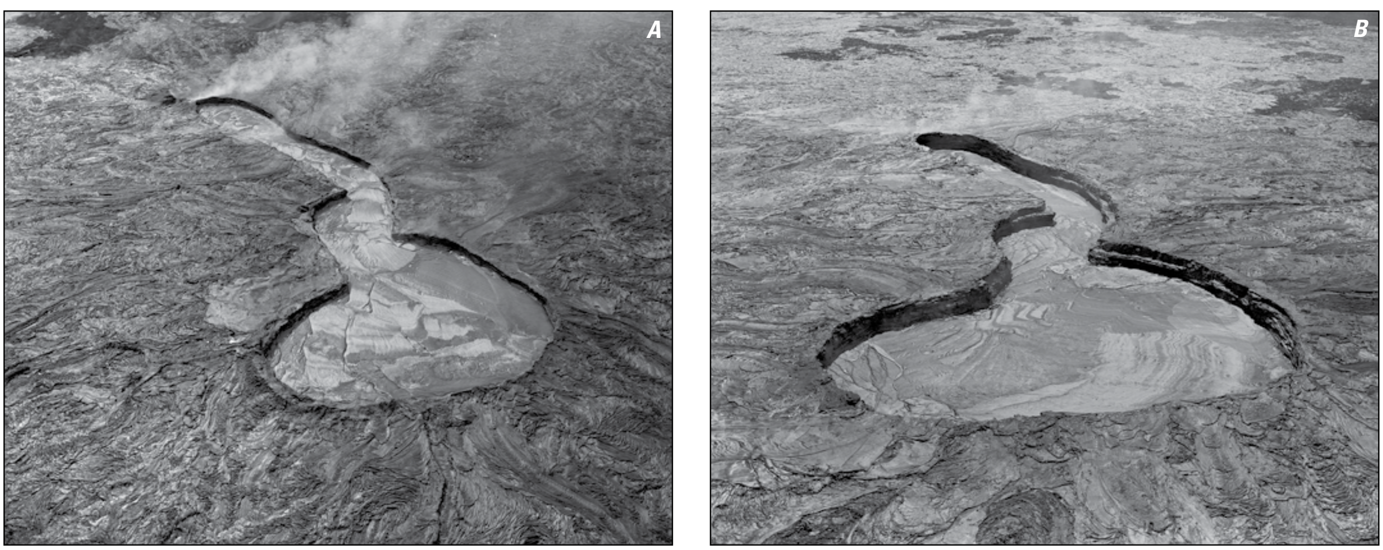


Figure 151. Oblique aerial photographs of the lava lake capping the Kupaianaha shield. *A*, View of the well-established tadpole-shaped lake 3 months after the start of episode 48C. The floating crustal plates reflect light differently as circulation carries lava toward the submerged outlet at the narrow southeast end of the lake. The lake surface is 5 meters (m) below the rim. Photograph by J.D. Griggs, U.S. Geological Survey, October 23, 1986. *B*, View of the lake 8 months after the start of the episode. The sharp cusps apparent in *A* have become slightly rounded, but the general shape and size of the lake remains the same. The lake is 13 m below rim. Dark ʻaʻā flows from Puʻu ʻŌʻō underlie the light gray pāhoehoe flows of Kupaianaha in the distance. Photograph by J.D. Griggs, U.S. Geological Survey, March 11, 1987.

‘Ō‘ō on the southwest. By October 22, flows had spread laterally beyond the margins of the early Kupaianaha flow field but had reached only a few hundred meters beyond the farthest downslope flow terminus of August 3 (fig. 152).

November began with a rapidly moving tube-fed flow that reached the brink of the Pūlama pali at 950-ft elevation (approximately 7 km from the vent). By November 5, however, the flow had stagnated, and the activity reverted to areas upslope. On November 16, another tube-fed flow broke out at 1,350-ft elevation and advanced steadily to 750-ft elevation on November 20. The tubed part of the flow had migrated down to 1,040-ft elevation, from which the flow established a course over the pali. A narrow, swift pāhoehoe river flowed from the tube outlet for about 1 km to 750-ft elevation, then turned to sluggish ‘a‘ā. By November 22, the pāhoehoe channel was partly roofed most of the way down the pali, and its ‘a‘ā terminus extended to below 400-ft elevation, putting it 8.6 km from the vent and 2.1 km from the coastal Highway 130.

Despite the steep terrain, the flow advanced at an average rate of only 600 m/day (25 m/h) and, by November 23, had broadened to a width of 200 m. The highway was closed on November 25, and at 0538 on November 26, the flow reached the highway just east of the small community of Kapa‘ahu, which included the sparsely populated Pacific Paradise Ocean Front Estates subdivision (fig. 153). All coastal access to the National Park and Waha‘ula Visitors Center from the east was now cut off, and the endangered homes were evacuated by the Hawai‘i County Civil Defense authorities.

The stage was set for the nearly inevitable destruction of homes on both sides of the highway on Thanksgiving Day 1986, as the flow (soon named the Kapa‘ahu flow) moved slowly westward. By 1500 on November 26, 450 m of asphalt had been overrun by pāhoehoe, casting a pall of noxious blue smoke as the flow advanced on the first of five houses on the north side of the highway. The buried water main beneath the active flow continued to deliver fresh hot water to the threatened homes for a while longer, but not in sufficient volume for fire hoses to alter the flow’s advance. At 1730, the tube-fed channel feeding this flow became inactive, but the flow continued to creep westward, and by 2000 only the crumpled metal roofs of five homes and several abandoned vehicles immersed in lava remained.

Meanwhile, a second tube outlet, a few hundred meters east of the first, fed a separate channelized flow that crossed the highway and advanced westward on its south side, overrunning the remaining two dwellings in Pacific Paradise Ocean Front Estates late on November 26 and early on November 27 (fig. 153).

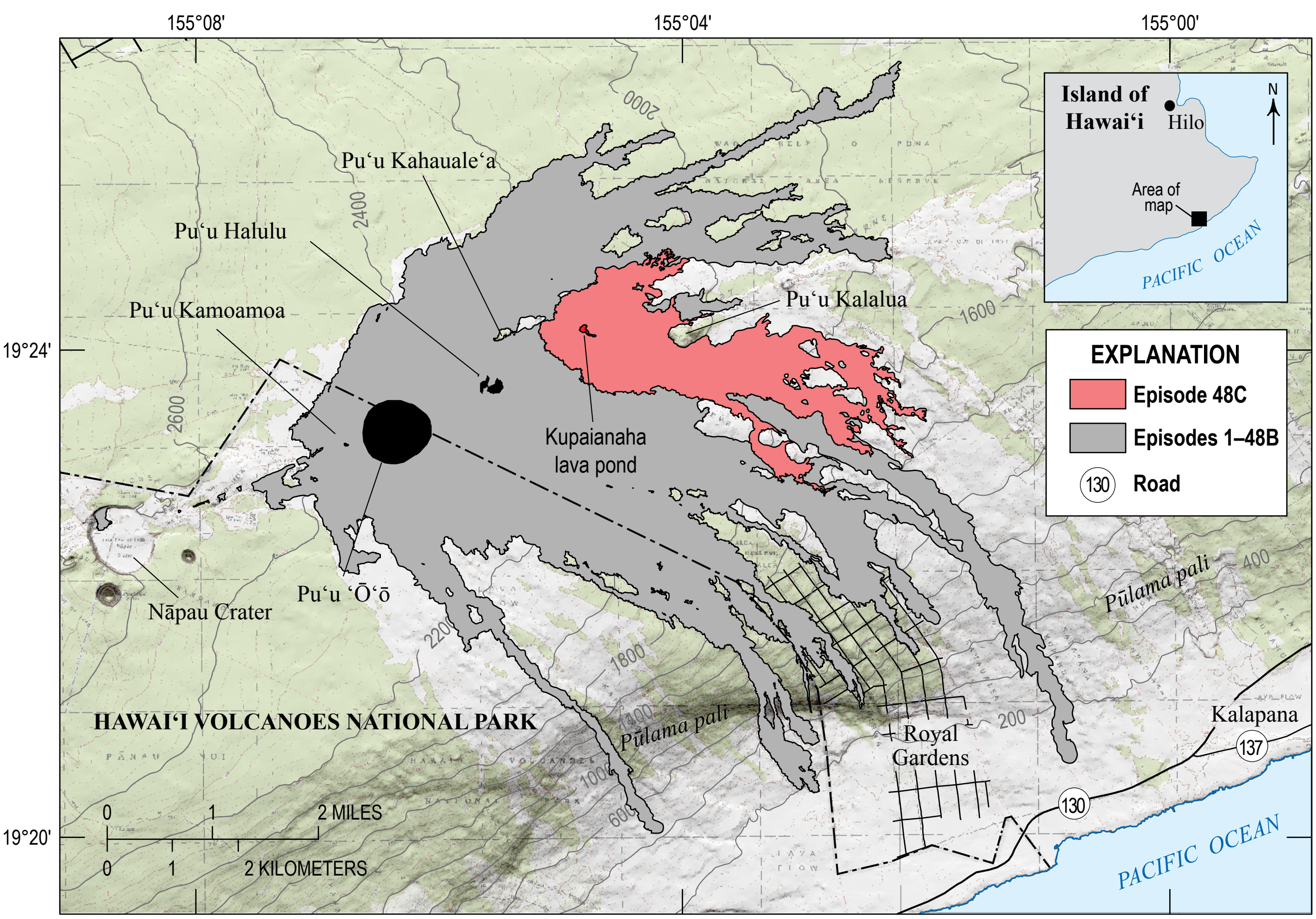


Figure 152. Map showing the distribution of episode 48C lava flows (Kupaianaha flow field) from July 20 to October 22, 1986, compared to earlier Pu‘u ‘Ō‘ō flows. The shield grew rapidly during this period with relatively little lava fed downslope.

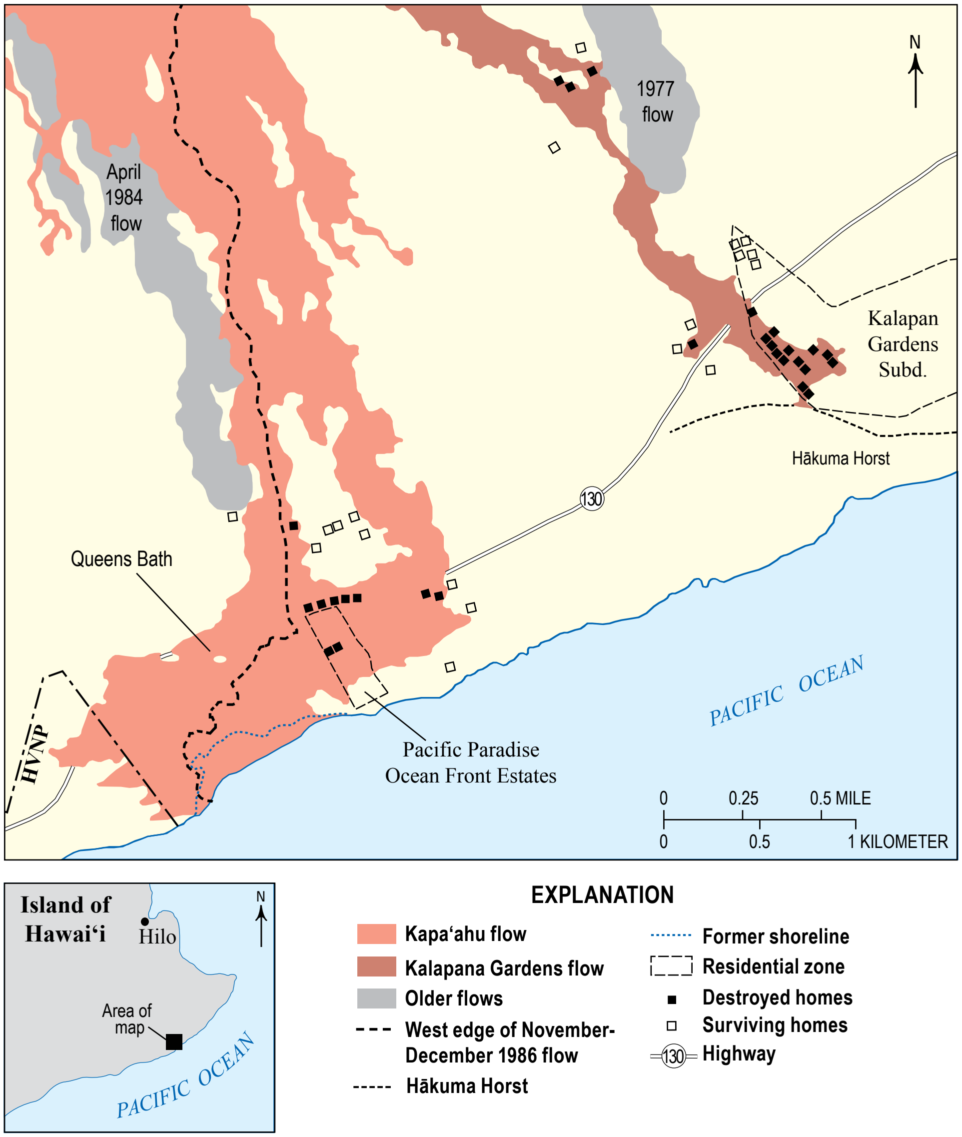


Figure 153. Simplified map showing November–December 1986 Kapa‘ahu flow, the December 1986 Kalapana Gardens flow, and March–April 1987 flows near Kapa‘ahu. Dashed line in Kapa‘ahu flow is the west edge of the November–December 1986 flow buried by the March–April flow. HVNP, Hawai‘i Volcanoes National Park.

The principal remains of the subdivision’s former existence were the upper parts of street signs at the corners of undeveloped lots and an iron gate at the entrance.

As several lava lobes moved southwest from the highway, a new lobe branched off from the main flow upslope at 120-ft elevation and traveled southward along the edge of the April 1984 ‘a‘ā flow, converging with the other flows at the west edge of Kapa’ahu. It destroyed one of a cluster of six houses, leaving the remaining five isolated within a kīpuka completely surrounded by new lava (fig. 153). The merged flows continued their advance along several fronts toward the National Park boundary and the ocean, coming within 70 m of Queens Bath, a historical landmark and popular swimming spot. Early on the morning of November 28, the flow entered a tide pool just south of Queens Bath, and at 0930 a 75–100-m-wide flow was oozing into the sea for the first time since Mauna Ulu flows entered the ocean in April 1973, 13 years earlier (Tilling and others, 1987). For the next 8 days, lava flowed into the sea, spreading laterally along the coast, particularly west, where it extended 600 m, filling tidal lagoons and creating more than 17 acres of new land in an embayment just east of the National Park boundary (fig. 153). Scuba divers took the opportunity to photograph the formation of lava pillows and submarine avalanches. A new black sand beach formed on the west edge of the flow and in embayments along the flow front.

On December 1 and 8, breakouts from the lava tube on the east side of the Kapa‘ahu community burned two more homes belonging to former employees of the National Park Service, despite earlier efforts by the Hilo Fire Department to quench and divert the pāhoehoe flows with water (fig. 154). By December 10, all flows near the coast were inactive.

Figure 154. Photograph showing firefighters attempting to quench and divert an advancing pāhoehoe flow away from the Louis Pau residence in Kapa‘ahu on November 26, 1986. The effort was temporarily successful, but the house was destroyed during activity on December 1. Photograph by J.D. Griggs, U.S. Geological Survey.

During the time of the Kapa‘ahu flow, the lava lake continued to fluctuate between 0 and 12 m below the rim (figs. 148 and 149). The lake overflowed on several occasions while vigorous flow in the tube system was observed through skylights downstream. We infer these instances to be caused by increases in supply to the Kupaianaha vent. A major breakout from a skylight on the east side of the shield on December 8–9 caused a drop in the fluid pressure in the system, allowing the lake level to drop from full to 8–10 m down; tube-fed breakouts between 1,300- and 1,000-ft elevation remained active.

The Kalapana Gardens Flow (December 1986)

On December 12, the main tube system appeared fully active again down to 1,200-ft elevation. From there the lava broke out on the surface and proceeded southeasterly toward the Kalapana Gardens subdivision on the west side of the village of Kalapana (fig. 153). The ‘a‘ā flow advanced at an average rate of 970 m/day from the top of the Pūlama pali (~1,300-ft elevation) to the base (~200-ft elevation) and slowed down only briefly upon reaching nearly level ground at the bottom of the pali. On December 17, the flow banked against the 1977 ‘a‘ā flow to the east, destroying two homes and a religious temple at 220-ft elevation before proceeding toward the highway (fig. 153). On the morning of December 18, the flow surged across 600 m of gently sloping terrain to the highway in only 5 hours. After crossing the highway, the flow front slowed to a creep for the next 12 hours. In the early morning hours of December 19, a new pāhoehoe front advanced over and around the ‘a‘ā flow and across the highway and rapidly decimated the west edge of Kalapana Gardens (figs. 153 and 155), burning nine homes in 4.5 hours. The flow pushed slowly seaward through the subdivision, destroying six more homes by early on December 20. The flow reached the north-facing scarp of the 15-m-high Hākuma horst (fig. 153) and began to spread southeastward toward more heavily populated areas. Fortuitously, the tube ruptured 150 m southwest of Pu‘u Kalalua, and the flow in Kalapana stagnated on the morning of December 21, removing the immediate threat to the remaining residences.

As the Kalapana Gardens flow advanced from the Kupaianaha shield to the coastal plain from December 12 to 19, 1986, the lava lake rose from 9 m below the rim to full and overflowing (fig. 148). This suggests that an increase in magma supply to the vent was responsible. However, in the earlier case of the Kapa‘ahu flow described above, the lake level correlated poorly with the level of activity at the lava front downslope owing to local factors such as gas pistoning of the lava lake.

The behavior the Kapa‘ahu and Kalapana Gardens flow showed striking differences. The Kapa‘ahu flow advanced as a thick, broad tube-fed pāhoehoe front, delivering lava erratically to the coast. In contrast, the Kalapana Gardens flow descended the pali toward the coast more rapidly than did the Kapa’ahu flow. It consisted of channelized ‘a‘ā flows that advanced well ahead of the lava tube. The ‘a‘ā flows then stagnated and were overrun by pāhoehoe breakouts from the tube, which themselves soon turned to ‘a‘ā only to be overrun again by new pāhoehoe.

Mid-December 1986 through April 1987

After December 21, 1986, and through much of January and February 1987, the active lava flows were confined mainly to the area of Kupaianaha, primarily as pāhoehoe breakouts on the east and southeast slopes of the shield. Sluggish flows moved around the north and south flanks of Pu‘u Kalalua. Observations at skylights over the tube system revealed no lava movement at lower elevations. On January 1, tube-fed pāhoehoe was spreading slowly over the 1977 flow just south of Pu‘u Kia‘i at 1,800-ft elevation, and fume from the surface lower on the slope indicating the tube system was active again down to 1,600-ft elevation. By January 8 and again on January 12, pāhoehoe lava reached 1,200-ft elevation, but all other activity

Figure 155. Oblique aerial photograph of the Kalapana flow on December 19, 1986, showing a dark ʻaʻā flow and later thin pāhoehoe flows crossing Highway 130 and moving through the Kalapana Gardens subdivision. Nine homes were destroyed as the flow advanced toward the scarp at upper right (beneath the smoke), which later deflected the flow toward the more densely populated part of Kalapana village (top center). Photograph by J.D. Griggs, U.S. Geological Survey.

remained at higher elevations until February 16, when once again tube-fed pāhoehoe advanced slowly toward the coast. From February 20 to 27, several narrow fingers of lava moved downslope on and alongside the episode 18 (April 1984) flow. One of these lobes eventually reached 380-ft elevation, 2.6 km from the sea, igniting grass fires and threatening homes in the Royal Gardens subdivision, 800 m west.

The level of the lava lake remained high during the second half of January (<6 m below the rim; fig. 148) apparently owing to reduced capacity of the downslope tube, resulting in frequent pāhoehoe breakouts on the east side of the shield. These multiple extrusions constructed a satellite shield. Two small lava lakes formed on top of this shield and numerous tumuli, 8–10 m across and 2–3 m high, were produced by intrusion and inflation beneath the uppermost flows. Lava oozed through cracks, stagnating soon after exposure and leaving oblong mounds scattered over much of the composite shield surface. The slopes of the main shield ranged from 4 to 12 degrees as it grew laterally, whereas its summit increased only slightly above its 45-m height in the months ahead.

An unusual event occurred in early February 1987, when a new crack opened downrift of Puʻu Kiaʻi, 3.9 km northeast of the lava lake. Opening of the crack was not detected seismically. The crack extended through a Puʻu ʻŌʻō flow from episode 12 (November–December 1983) and partway through the 1977 Puʻu Kiaʻi flow (figs. 156 and 157). Helicopter pilot David Okita was the first to see the new crack, on the afternoon of February 1, and transported an HVO observer to the site. The steaming crack was about 600 m long and generally less than 1 m wide. At its downrift end, viscous, crusted pāhoehoe was visible 2–3 m below the surface. The gases emitted from the crack consisted mainly of steam, with no sulfur odor.

Earlier on the same day, pāhoehoe breaking out of the lower east flank of the shield had flowed northeastward around the north side of Puʻu Kiaʻi and stagnated when its terminus was 4.2 km from the lava lake. The upper reaches of the flow remained active and poured into an old crack of indeterminate age, 2 km from the vent, and just uprift of the new steaming crack. The new crack had extended to its full length of 1.1 km by the next day (February 2), and pāhoehoe continued to issue from its lower end, which was as much as 2 m wide. The small pad of pāhoehoe extruded from the crack eventually covered about 75,000 m^2 (fig. 157). By February 4, extrusion from the crack had ended, and after February 5, all movement of the flow had ceased.

Our interpretation of this event is that the lava originated at the shield, flowed into a pre-existing crack and followed the crack for about 800 m before reappearing at the surface. The lava may have extended the original crack downrift, or, assuming the crack was buried by the 1977 ʻaʻā, may have broken new ground only where the lava intruded upward through the overlying 1977 flow.

Activity through the first half of March was characterized primarily by overflows from the Kupaianana lake, though there were a few other sluggish breakouts elsewhere along the tube system. On March 24, a breakout from mid-way up the Pūlama pali began to advance downslope alongside and on top of the November–December 1986 Kapaʻahu flow, reaching Highway 130 and burying Queens Bath on March 31. The flow, blocked by several north-facing fault scarps on its seaward side, then turned southwest, filling in low ground on both sides of the National Park boundary and covering parts of Highway 130 and Chain of Craters Road (fig. 153). Finally, on April 9, the flow reached the ocean, establishing a weak, intermittent ocean entry that lasted until April 22. It was succeeded by new flows that broke out from the tube system on the Pūlama pali. These flows gradually advanced downslope along the same general path as the breakout in late March. They reached the coastal plain and Highway 130 by the end of April, which concludes the period covered by this report. A simplified chronology of the later part of episode 48C is described by Heliker and Mattox (2003).

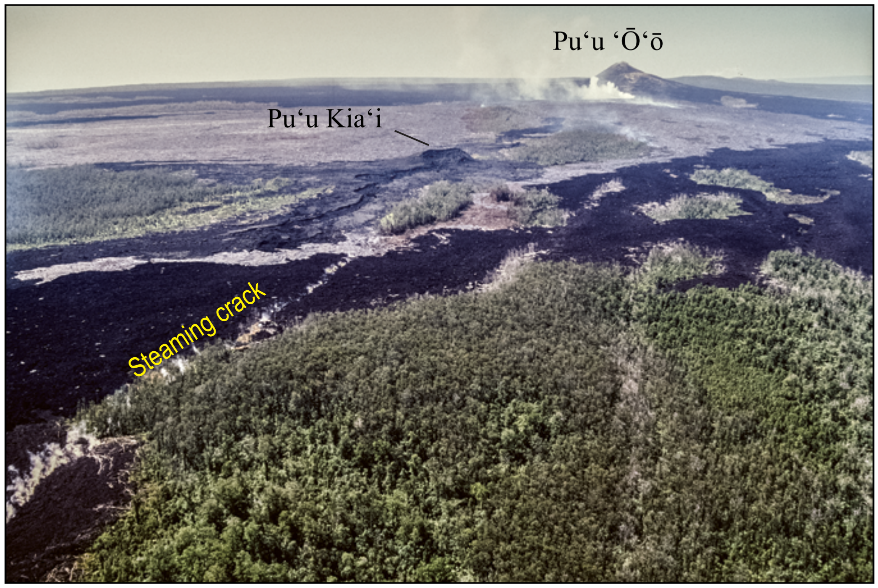


Figure 156. Oblique aerial photograph of the steaming crack, seen crossing the image from near the center to the lower left, that formed February 1, 1987, and through which lava extruded on February 2–3. Pu‘u ‘Ō‘ō is about 8 kilometers southwest on the horizon. The heavy white fume below Pu‘u ‘Ō‘ō marks the Kupaianaha shield. Lava from the near side of Kupaianaha enters an old fissure at the edge of the forested kīpuka directly below Kupaianaha in the image (smoky area) and resurfaces in the steaming crack. The crack first opened across the dark ‘a‘ā flow (episode 12) and extended beyond the image to the lower left. Photograph by J.D. Griggs, U.S. Geological Survey, February 2, 1987.

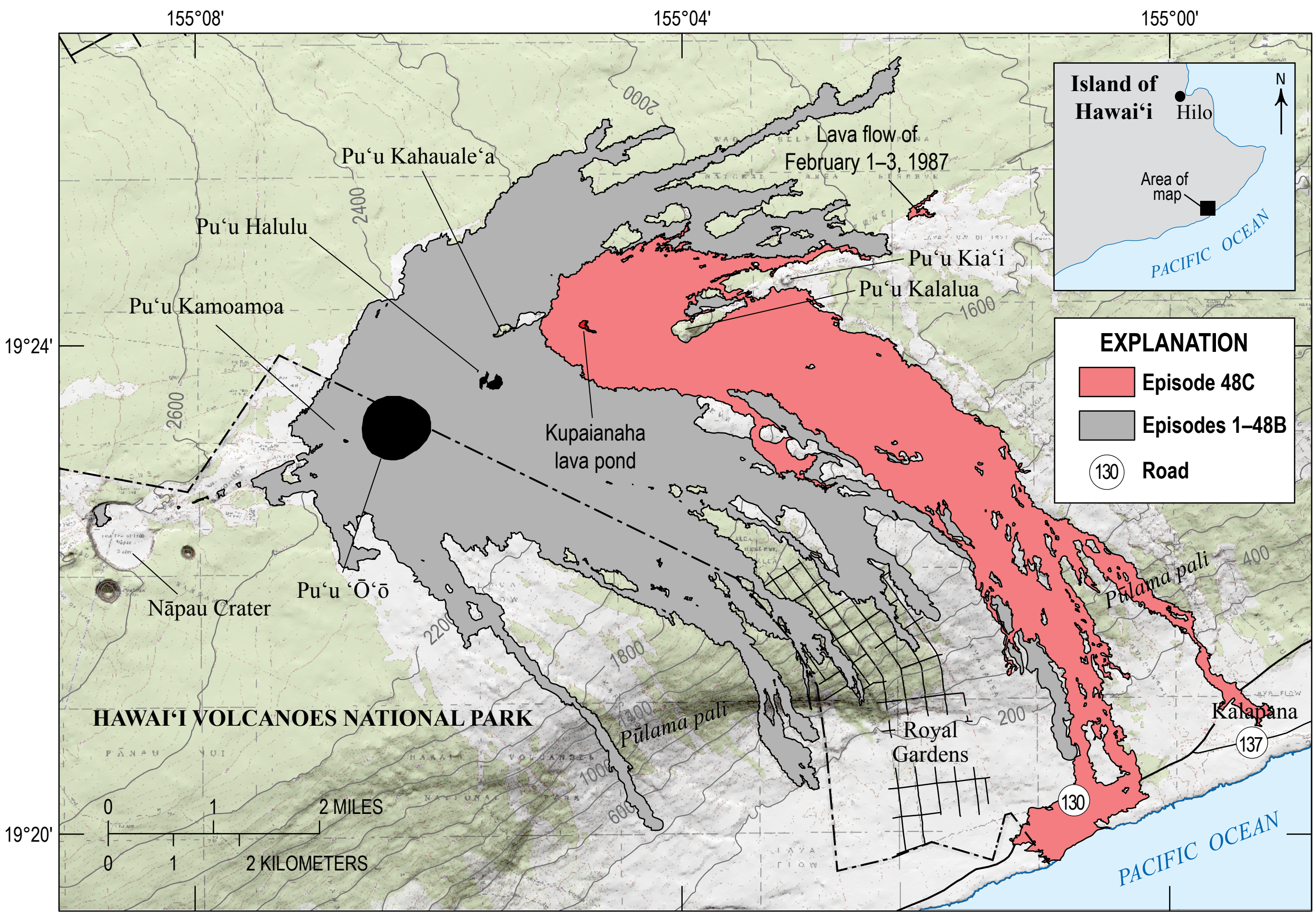


Figure 157. Map showing the distribution of episode 48C lava flows (Kupaianaha flow field) from July 20, 1986, through April 24, 1987, compared to earlier Pu‘u ‘Ō‘ō flows.

Summary

Episode 48 (table 1, fig. 157), which started with two short-lived fissure outbreaks (episodes 48A and 48B), marked the transition from episodic high fountains to nearly continuous effusion. By the end of April 1987—a duration of 285 days—episode 48C had constructed the Kupaianaha lava shield and covered about 18.5 km^2. The Kupaianaha lava shield grew to a height of about 45 m and hosted a small lava lake, which fed lava directly into a lava tube system. Flow-field volume estimates are difficult to determine because of the lack of thickness control on the composite, tube-fed flow field. However, using the previously determined DRE effusion rate of 4 m^3/s established for the period between days 15 and 95 of the episode yields an approximate volume of 98×10^6 m^3 (~0.1 km^3).

The relatively slow-moving but relentless flows reached long distances from the vent by establishing lava tubes. Flows advanced into the Kalapana Gardens and Kapaʻahu areas, destroying 28 homes and other primary structures. Lava also reached the ocean for the first time during the eruption, building a small lava delta near Kapaʻahu. Episode 48C went on to erupt for several more years (Heliker and Mattox, 2003), eventually ending in 1992, when the focus of activity shifted back to Puʻu ʻŌʻō.

Acknowledgments

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