Selected Images of the Pu‘u ‘Ō‘ō–Kūpaianaha Eruption, 1983–1997

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Abstract

The 100 images in this CD–ROM have been selected from the collections of the Hawaiian Volcano Observatory as enduring favorites of the staff, researchers, media, designers, and the public over time. They represent photographs of a variety of geological phenomena and eruptive events, chosen for their content, quality of exposure, and aesthetic appeal. The number was kept to 100 to maintain the high resolution desirable. After 1997, digital imagery has been the main method of photographically documenting the eruption. Many of these photos, from 1998 to the present, can be viewed on the website: http://hvo.wr.usgs.gov/kilauea/update/archive/.

Episode numbers are given as E-numbers in parentheses before each caption that pertains to the Pu‘u ‘Ō‘ō–Kūpaianaha eruption; details of the episodes are given in table 1. Hawaiian words and place names are listed below to facilitate searching. All images included in this collection are owned by the U.S. Geological Survey, Hawaiian Volcano Observatory, and are in the public domain. Therefore, no permission or fee is required for their use. Please include photo credit for the photographer and the U.S. Geological Survey. We assume no responsibility for the modification of these images.

Introduction

The eruption has progressed through three main epochs: 3.5 years of episodic fountaining, mainly from the Pu‘u ‘Ō‘ō central vent, producing a cinder-and-spatter cone and ‘a‘ā flows; 5.5 years of continuous effusion from the Kūpaianaha vent, producing a shield and tube-fed pāhoehoe flows; and over 11 years (as of January 2003) of nearly continuous effusion from flank vents on Pu‘u ‘Ō‘ō, again producing a shield and tube-fed pāhoehoe flows.

Episodes

1983–1986: The Rise of Pu‘u ‘Ō‘ō–Episodic Lava Fountains Build Massive Cone

The Pu‘u ‘Ō‘ō–Kūpaianaha eruption began on January 3, 1983. For the first six months (episodes 1–3), fissures erupted intermittently along the middle east rift zone from Nāpau Crater to Kalalua. In June 1983, the activity became localized at the Pu‘u ‘Ō‘ō vent, which straddles the boundary of Hawai‘i Volcanoes National Park. For the next three years (episodes 4–47), Pu‘u ‘Ō‘ō erupted approximately every three to four weeks, usually for less than 24 hours. Spectacular lava fountains that catapulted lava as high as 470 m above the vent characterized these eruptive episodes.

The high fountains produced mainly ‘a‘ā flows, the more viscous and gas-poor of the two types of Hawaiian lava. ‘A‘ā flows from Pu‘u ‘Ō‘ō were typically 3–5 m thick and advanced at speeds of 50–500 m/h, picking up speed and narrowing on steep slopes.

Because of the short duration of each eruptive episode, none of these flows reached the ocean or the coastal highway. The flows posed an immediate threat, however, to the sparsely populated Royal Gardens subdivision, located on a steep slope 6 km southeast of the vent. ʻAʻā flows reached the subdivision in as little as 13 hours during several eruptive episodes and destroyed 16 houses in 1983 and 1984.

Fallout from the towering lava fountains built a cinder-and-spatter cone 255 m high, over twice the height of any other cone on the east rift zone. The cone was strikingly asymmetrical, because the prevailing trade winds caused most of the airborne fragments to pile up on the southwest side of the conduit.

1986–1992: Continuous Eruption of Kūpaianaha Sends Lava to the Sea

In July 1986, the vertical conduit of Puʻu ʻŌʻō ruptured, and the eruption shifted to a new vent, Kūpaianaha, 3 km northeast of Puʻu ʻŌʻō. This event marked the end of episodic high fountaining and the beginning of five-and-a-half years of nearly continuous, quiet effusion (episode 48). A lava pond formed over the new vent, and its frequent overflows resulted in a broad, low shield that reached its maximum height of 56 m in less than a year.

After weeks of continuous eruption, the main channel exiting the pond gradually developed a roof as crust at the sides of the channel extended across the lava stream. This was the beginning of a lava tube that would eventually extend to the ocean. Lava tubes insulate rivers of lava from both heat and gas loss. Flows that break out of tubes are usually pāhoehoe, a type of lava more fluid than ʻaʻā. The surface of a cooled pāhoehoe flow can be flat and smooth, ropy, shelly, or undulating.

A broad field of tube-fed pāhoehoe spread gradually from Kūpaianaha to the ocean, 12 km to the southeast, taking three months to cover the same distance that ʻaʻā from Puʻu ʻŌʻō traveled in less than a day. By early November 1986, the flows were visible on the steep slope above the small community of Kapaʻahu, and their leisurely pace was no longer reassuring.

On November 28, 1986, flows from Kūpaianaha reached the ocean, cutting a swath through Kapaʻahu and closing the coastal highway. A few weeks later, the lava took a more easterly course and overran 14 homes on the northwest edge of Kalapana in a single day. Fortunately for the rest of the village, this flow abruptly stagnated when the tube became blocked near the vent.

Over the next three years, lava destroyed a few homes on either side of the ever-widening flow field. Initially, the course of pāhoehoe flows was strongly influenced by topography, but, eventually, even the highest ground was inundated. The depth of the lava increased as flows covered many areas repeatedly and the tube-fed flows grew from within, inflating as more lava was intruded under the already solid crust of the flow front.

From mid-1987 through 1989, most of the lava that erupted from Kūpaianaha flowed directly to the sea. Steam explosions at the ocean entry fragmented the lava, creating black

sand that collected to form new beaches in protected bays down-current of the lava entry. New, albeit unstable, acreage was added to the island as lava deltas built seaward over a steep submarine slope of fragmented lava.

The long-lived tube system delivering lava to the ocean began to break down in the spring of 1989, and surface flows were a common sight, particularly on the steep slope (pali) above the coastal plain. Lava flows encroached on new territory, overrunning the Waha‘ula Visitor Center and adjoining residences in Hawai‘i Volcanoes National Park.

The eruption began to change in 1990, when a series of nine pauses, lasting from one to four days, interrupted the steady effusion of lava. At the same time, the eruption entered its most destructive phase. In March 1990, the flows turned toward Kalapana, an area cherished for its historic sites and black sand beaches. By the end of the summer, the entire community, including a church, store, and 100 homes, lay buried under 15–25 m of lava. In May 1990, a Federal Disaster Declaration was issued for Kalapana and all other areas previously affected by the eruption.

As the flows advanced eastward, they took to the sea, covering the palm-lined Kaimū Bay with a plain of lava that extends 300 m beyond the original shoreline. In late 1990, a new lava tube diverted lava away from Kalapana and back into the national park, where flows again entered the ocean.

During the five-and-a-half years that Kūpaianaha reigned, repeated collapses of the Pu‘u ‘Ō‘ō conduit gradually formed a crater approximately 300 m in diameter. A lava pond appeared sporadically at the bottom of the crater starting in 1987; after 1990 it was present most of the time.

The volume of lava erupted from Kūpaianaha steadily declined in 1991. Concurrently the level and activity of the Pu‘u ‘Ō‘ō lava pond rose. In November 1991, fissures opened between Pu‘u ‘Ō‘ō and Kūpaianaha and erupted for three weeks. Kūpaianaha continued to erupt during this event (episode 49), but its output was waning. On February 7, 1992, the Kūpaianaha vent was dead.

1992–1997: The Return to Pu‘u ‘Ō‘ō

Ten days later, the eruption returned to Pu‘u ‘Ō‘ō. Lava erupted in low fountains along a fissure on the west flank of the massive cone. This was the first in a series of flank vents that were active for the next five years (episodes 50–53). As at Kūpaianaha, the style of the eruption was nearly continuous, quiet effusion.

Episodes 50–53 built a lava shield 45 m high and 1 km in diameter that banked up against the western flank of Pu‘u ‘Ō‘ō. In November 1992, lava crossed the Chain of Craters Road in Hawai‘i Volcanoes National Park and entered the ocean at Kamoamoa, 11 km from the vents. Over the next month, tube-fed pāhoehoe flows buried the Kamoamoa archaeological site, the National Park’s campground and picnic area, and the black sand beach formed earlier in the eruption by flows from Kūpaianaha entering the ocean farther east. From the end of 1992 through January 1997, tubes fed lava to the ocean almost

continuously, broadening the episode 50–53 flow field, which lies mostly within the National Park.

Beginning in 1993, collapse pits appeared on the west flank of Pu‘u ‘Ō‘ō as the magma feeding the flank vents undermined that side of the cone. Collapse pits had engulfed most of the west flank by the end of 1996.

January 1997: Cone Collapse Heralds Fissure Eruption

On the night of January 30, 1997, Pu‘u ‘Ō‘ō cone changed dramatically. Magma drained from the Pu‘u ‘Ō‘ō conduit, causing first, the, crater floor, then the west wall of the cone, to collapse. Shortly thereafter, new fissures broke open and erupted briefly in and near Nāpau Crater. The fissure eruption, designated episode 54, lasted 22 hours.

The collapse at Pu‘u ‘Ō‘ō left a large gap in the west side of the cone. The rubble-lined crater was now 210 m deep.

February 1997 to Present: Eruption of Pu‘u ‘Ō‘ō Flank Vents Resumes

Episode 54 was followed by the longest eruptive hiatus in more than 10 years. Twenty-four days passed before episode 55 began on February 24, 1997, when lava rose through the rubble on the floor of the crater to form a new pond. Lava erupted outside the crater a month later, when new vents opened on the west and southwest flanks of the cone.

In April 1997, a single vent on the west side of the crater replaced the active lava pond in Pu‘u ‘Ō‘ō. Flows from this vent intermittently ponded at the crater’s east end. In June 1997, the lava rose until it overtopped the gap in the west wall of Pu‘u ‘Ō‘ō formed by the January 1997 collapse. Lava spilled from the crater for the first time in 11 years. Subsequent crater overflows overtopped the east crater rim and extended as far as 1.5 km downrift. The spillovers were brief events, ending when the pond drained through conduits in the crater floor.

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

Table 1. Details of episodes 1–55

Episode no.	Episode start date	Episode start time (H.S.T.)	Episode end date	Episode end time (H.S.T.)	Repose interval (days)	Episode duration (days)
1	1/3/83	0:31	1/23/83	0:00	0	4.1
2	2/25/83	9:00	3/4/83	14:51	33	7.3
3	3/28/83	1:00	4/9/83	2:57	23.5	12.1
4	6/13/83	10:25	6/17/83	14:13	65.3	4.2
5	6/29/83	12:51	7/3/83	7:15	11.9	3.8
6	7/22/83	15:30	7/25/83	16:30	19.3	3.0
7	8/15/83	7:41	8/17/83	16:00	20.6	2.3
8	9/6/83	5:11	9/7/83	5:26	19.5	1.0
9	9/15/83	15:41	9/17/83	19:20	8.4	2.2
10	10/5/83	1:06	10/7/83	16:50	17.2	2.7
11	11/5/83	23:50	11/7/83	18:45	29.3	1.8
12	11/30/83	4:47	12/1/83	15:45	22.4	1.5
13	1/20/84	17:24	1/22/84	11:23	50.1	1.8
14	1/30/84	17:45	1/31/84	13:18	8.3	0.8
15	2/14/84	19:40	2/15/84	15:01	14.3	0.8
16	3/3/84	14:50	3/4/84	22:31	17	1.3
17	3/30/84	4:48	3/31/84	3:24	25.3	1.0
18	4/18/84	18:00	4/21/84	5:33	18.6	2.5
19	5/16/84	5:00	5/18/84	0:50	25	1.8
20	6/7/84	21:04	6/8/84	6:25	20.8	0.4
21	6/30/84	10:28	6/30/84	18:27	22.2	0.3
22	7/8/84	19:30	7/9/84	10:17	8	0.6
23	7/28/84	12:00	7/29/84	5:40	19.1	0.8
24	8/19/84	21:52	8/20/84	17:25	21.7	0.8
25	9/19/84	16:04	9/20/84	5:32	29.9	0.6
26	11/2/84	11:40	11/2/84	16:36	43.3	0.2
27	11/20/84	0:05	11/20/84	10:06	17.3	0.4
28	12/3/84	19:05	12/4/84	9:41	13.4	0.6
29	1/3/85	13:15	1/4/85	5:04	29.1	0.7
30	2/4/85	5:46	2/5/85	2:46	31	0.9
31	3/13/85	6:00	3/14/85	4:55	36.1	1.0
32	4/21/85	15:16	4/22/85	9:06	38.4	0.8
33	6/12/85	23:06	6/13/85	4:53	51.6	0.3
34	7/6/85	19:03	7/7/85	8:50	23.6	0.6
35	7/26/85	2:52	7/26/85	9:52	18.8	0.3
35a	7/27/85	4:14	8/12/85	4:30	0.7	16.0
36	9/2/85	14:00	9/2/85	23:35	21.1	0.4
37	9/24/85	18:08	9/25/85	6:19	21.8	0.5
38	10/21/85	3:00	10/21/85	11:24	25.9	0.4
39	11/13/85	15:34	11/14/85	1:24	23.2	0.4
40	1/1/86	13:09	1/2/86	2:38	48.5	0.6
41	1/27/86	20:35	1/28/86	7:57	25.8	0.5
42	2/22/86	15:15	2/23/86	4:20	25.3	0.5
43	3/22/86	4:50	3/22/86	15:56	27.1	0.5
44	4/13/86	20:54	4/14/86	7:56	22.2	0.5
45	5/7/86	22:41	5/8/86	11:06	23.6	0.5
46	6/2/86	2:29	6/2/86	13:20	24.6	0.5
47	6/26/86	4:19	6/26/86	16:35	23.6	0.5
48a-b	7/18/86	12:05	7/19/86	9:30	21.8	0.9

Table 1 (continued).

Episode no.	Episode start date	Episode start time (H.S.T.)	Episode end date	Episode end time (H.S.T.)	Repose interval (days)	Episode duration (days)
48	7/20/86	8:30	2/7/92	ND	1	2,028.0
49	11/8/91	4:45	11/26/91	ND	0	17.8
50	2/17/92	~19:30	3/3/92	1:30	10	14.3
51	3/7/92	12:45	9/27/92	~6:00	4.5	197.7
52	10/3/92	~3:30	2/20/93	14:50	5.9	140.5
53	2/20/93	14:50	1/29/97	18:52	0	1,439.2
54	1/30/97	2:40	1/31/97	0:33	0.3	0.9
55	2/24/97	7:00	ongoing		24.3	ongoing

References

Heliker, C.C., and Mattox, T.N., *in press*, Pu‘u ‘Ō‘ō—the first two decades: chronology and selected bibliography: U.S. Geological Survey Professional Paper.

Takahashi, T.J., and Griggs, J.D., 1987, Hawaiian volcanic features: a photoglossary, chap. 36 *of* Decker, R.W., Wright, T.L., and Stauffer, P.H., eds., Volcanism in Hawaii: U.S. Geological Survey Professional Paper 1350, v. 2, p. 845–902.

Ulrich, G.E., Heliker, C.C., and Hoffmann, J.P., *in preparation*, The Pu‘u ‘Ō‘ō–Kūpaianaha eruption of Kīlauea Volcano, Hawai‘i: episodes 21 through 48, June 1984 through February 1987: U.S. Geological Survey Open-File Report.

Weisel, Dorian, and Stapleton, Frankie, 1992, Aloha o Kalapana: Honolulu, Hawaii, Bishop Museum Press, 154 p.

Wolfe, E.W., ed., 1988, The Pu‘u ‘Ō‘ō eruption of Kīlauea Volcano, Hawaii: episodes 1 through 20, January 3, 1983, through June 8, 1984: U.S. Geological Survey Professional Paper 1463, 251 p., 5 pls. in pocket, map scale 1:50,000.

Wright, T.L., Takahashi, T.J., and Griggs, J.D., 1992, Hawai‘i volcano watch: a pictorial history: University of Hawaii Press and Hawaii Natural History Association, 162 p.

Image Collection

Hawaiian words and place names used in the captions:

ʻaʻā

Hākuma (horst)

Halemaumau (Crater)

Hawaiʻi

heiau

Hōlei sea arches

Kaimū (Bay, beach)

Kalalua

Kalapana

Kamoamoa

Kapaʻahu

Kīlauea (Volcano, caldera)

Kūpaianaha

Kupapaʻu (Point, village)

Laeʻapuki

lei

limu o Pele

Lokelani Street

Mauna Kea

Mauna Loa

Nāpau Crater

ʻōhiʻa

Pāʻao

pāhoehoe

Pauahi Crater

Poupou

Pūlama pali

Punaluʻu

Puʻu Halulu

Puʻu Kahaualea

Puʻu Kamoamoa

Puʻu ʻŌʻō

Uwēkahuna (bluff, overlook)

Wahaʻula (Visitor Center, heiau)

Waiʻākōlea Park

References cited forHawaiian words are listed below. An exception has been made for "Halemaumau," where glottal stops have been removed to accommodate both modern pronunciations (with and without the glottal stops) of the name of the pit crater at the summit of Kīlauea.

Pukui, M.K., and Elbert, S.H., 1986, Hawaiian dictionary: Honolulu, University of Hawaii Press, 572 p.

Pukui, M.K., Elbert, S.H., and Mookini, E.T., 1974, Place names of Hawaii: University of Hawaii Press, 289 p.

1 (E-1). Aerial view, from the southwest, of flow near Puʻu Kamoamoa, a prehistoric cone approximately 3,500 m northeast of Nāpau Crater, in Kīlauea's middle east rift zone. Episode 1 (January 3–23, 1983) was characterized by eruptions from fissures several hundred meters long. The fountains from these eruptions produced a series of low spatter ramparts (photo by J.D. Griggs, 1/3/83, JG132A).

2 (E-1). Aerial view of fountains from eruptive fissures south of Puʻu Kahaualea, approximately 2,350 m northeast of what is now Puʻu ʻŌʻō. Note single ʻōhiʻa tree burning in front of the fissures (photo by J.D. Griggs, 1/5/83, JG349).

3 (E-1). Forest of lava trees resulting from eruption of a 1-km-line of vents east of Pu‘u Kahaualea. The bulbous top of each lava tree marks the high stand of the lava flow as it spread through the trees. As the fissure eruption waned, the flow continued to spread laterally; its surface subsided, leaving pillars of lava that had chilled against tree trunks. Spattering is from fissure out of view to the left. Note blob of spatter adhering to the top of the stripped ‘ōhi‘a tree (photo by J.D. Griggs, 1/7/83, JG653).

4 (E-2). Arching fountain approximately 10 m high issuing from the western end of the 0740 vents, a series of spatter cones 170 m long, south of Pu‘u Kahaualea. Episodes 2 and 3 were characterized by spatter and cinder cones, such as Pu‘u Halulu, which was 60 m high by episode 3 (photo by J.D. Griggs, 02/25/83, JG928).

5 (E-4). Lava boulder large enough to fill the back of a pickup truck rolls off the top of an ʻaʻā flow in Royal Gardens subdivision. Puʻu ʻŌʻō was now the primary vent (photo by J.D. Griggs, 6/16/83, JG2236).

6 (E-4). Surging flow front traveling approximately 33 m per minute down the central channel of ʻaʻā flow west of Royal Gardens subdivision. The flow was erupted from Puʻu ʻŌʻō during episode 4 (photo by R.W. Decker, 6/16/83, RD68309).

7 (E-5). View at dusk of the young Pu‘u ‘Ō‘ō cinder-and-spatter cone, with fountain approximately 40 m high, during episode 5 (photo by G.E. Ulrich, 6/29/83, GU6830A).

8 (E-5). Aerial view, to the northwest, of channelized pāhoehoe flow from Pu‘u ‘Ō‘ō. The flow moved southeastward over the sloping terrain and entered Royal Gardens subdivision, destroying seven homes and cutting off four from road access (photo by J.D. Griggs, 7/1/83, JG2451).

9 (E-5). Aerial view, at dusk, of Pu‘u ‘Ō‘ō. During episode 5, Pu‘u ‘Ō‘ō had two adjacent vents, separated by a wall of spatter (photo by J.D. Griggs, 7/1/83, JG2430).

10 (E-5). Concerned scientists observe an ‘a‘ā flow from Pu‘u ‘Ō‘ō as it advances down a street in Royal Gardens subdivision (photo by J.D. Griggs, 7/2/83, JG2511).

11 (E-5). Scientists pace out and mark known distances in front of the advancing flow to document its speed. The top of an ʻaʻā flow rides on the underlying mass and rolls over it like a tractor's tread, advancing to the front of the flow (photo by J.D. Griggs, 7/2/83, JG2514).

12 (E-5). Accretionary lava ball comes to rest on the grass after rolling off the top of an ʻaʻā flow in Royal Gardens subdivision. Accretionary lava balls form as viscous lava is molded around a core of already solidified lava (photo by J.D. Griggs, 7/2/83, JG2562).

13 (E-5). ʻAʻā flow approaches stop sign in Royal Gardens subdivision (photo by J.D. Griggs, 7/2/83, JG2551).

14 (E-8). Low fountain, approximately 50 m high, from Puʻu ʻŌʻō, viewed from the north. Lava issuing from the breach in the northeast rim of the crater produced an ʻaʻā flow that extended for more than 4 km (photo by J.D. Griggs, 9/6/83, JG2879).

15 (E-8). Close-up of Pu‘u ‘Ō‘ō lava fountain, episode 8 (photo by J.D. Griggs, 9/6/83, JG2895).

16 (E-8). Pu‘u ‘Ō‘ō fountain approximately 100 m high during episode 8. Dark clots of spatter land near the base of the fountain, contributing to the growth of the cone. Less dense cinder, visible in upper right, is carried downwind of the cone (photo by J.D. Griggs, 9/6/83, JG2939).

17 (E-8). Jetting fountains, fluctuating in height from tens of meters to 200 m, playing in Pu‘u ‘Ō‘ō crater (episode 10). These fountains varied greatly in height and trajectory and occasionally alternated with a single sustained high fountain (photo by J.D. Griggs, 10/5/83, JG3144).

18 (E-8). High (over 200 m) fountain from Pu‘u ‘Ō‘ō in early morning light. Fountains feed ‘a‘ā flows to northeast. The characteristic rough, blocky surface of a cooled ‘a‘ā flow is visible at the margins of the flow. The river of lava inside the channel travels at a much greater speed than the front of the flow advances (photo by R.W. Decker, 10/5/83, RD108333).

19 (E-13). Dome fountain, 5 m high, in Pu‘u ‘Ō‘ō crater (viewed from north rim), feeds lava flowing over spillway during episode 13 (photo by E.W. Wolfe, 1/20/84, EW18409).

20 (E-13). Sunset seen through the fume from Pu‘u ‘Ō‘ō; view is from Pauahi Crater (photo by R.W. Decker, 1/21/84, RD18430).

21 (E-14). Aerial view of Pu‘u ‘Ō‘ō fountain, approximately 100 m high. Flow from breached northeast rim feeds bifurcating channels (photo by J.D. Griggs, 1/31/84, JG4036).

22 (E-21). Aerial view from the northeast of Pu‘u ‘Ō‘ō fountain and ‘a‘ā flow during episode 21. The broad, fan-shaped front of the flow in the foreground is typical of ‘a‘ā flows on low-angle slopes (photo by J.D. Griggs, 6/30/84, JG4472).

23 (E-23). Aerial view of Pu‘u ‘Ō‘ō fountain from the north during episode 23. Theodolite measurements of high fountains, which played throughout the day, ranged from 150 to 305 m (photo by J.D. Griggs, 7/28/84, JG4605).

24 (E-25). Pu‘u ‘Ō‘ō fountain, approximately 450 m high, produces clouds of black cinder that are carried downwind (southwest) of the vent. Low fountains play from fissure at base of cone. View is from northeast, at Pu‘u Halulu. Pu‘u ‘Ō‘ō gained 12 m in height during episode 25. By the end of October 1984, Pu‘u ‘Ō‘ō’s height was 155 m above the pre-1983 surface (photo by C.C. Heliker, 9/19/84, CH98435).

25 (pre-E-25). Drainback of lava into Pu‘u ‘Ō‘ō conduit; Mauna Loa, to the northwest, is in the background. The low-level activity took place the day before episode 26 began. A 42-day repose period, the longest since December 1983, preceded episode 26, the briefest (5 hours long) of the episodes of 1983–1984 (photo by G.E. Ulrich, 11/1/84, GU118420).

26 (E-32). Pu‘u ‘Ō‘ō plume with inversion layer, viewed from Kīlauea’s summit during episode 32. The warm air has not dispersed due to the absence of tradewinds. Volcanic fume consists primarily of water vapor, carbon dioxide, and sulfur dioxide (photo by J.D. Griggs, 4/22/85, JG5351).

27 (E-32). Aerial view, from the east, of waning fountain from Pu‘u ‘Ō‘ō at end of episode 32. Pu‘u ‘Ō‘ō rose 209 m above the pre-1983 surface (928 m above sea level) (photo by J.D. Griggs, 4/22/85, JG5363).

28 (E-35a). Spattering (less than 5 m high) from episode 35a fissure near the west side of Pu‘u ‘Ō‘ō. About 3.5 hours after the fountains of episode 35 died on July 26, ground cracks at the base of the cone propagated uprift, accompanied by booming noises. At 0414 H.s.t. on July 27, the new fissures, which extended 2.5 km uprift, began to erupt along the 1-km stretch closest to Pu‘u ‘Ō‘ō. This activity persisted for 16 days (photo by J.D. Griggs, 7/27/85, JG5600).

29 (E-38). Sun seen through fume cloud from Pu‘u ‘Ō‘ō, viewed from Uwēkahuna overlook at the summit of Kīlauea. Fountain heights at Pu‘u ‘Ō‘ō reached a maximum of 295 m around the time this photo was taken during episode 38 (photo by J.D. Griggs, 10/21/85, JG5935).

30 (E-39). Pu‘u ‘Ō‘ō fountain and flow at sunset; view, to the southwest, is from Pu‘u Halulu during episode 39 (photo by G.E. Ulrich, 11/13/85, GU118533).

31 (E-46). Jetting fountain and eruption plume, viewed from north side of Pu‘u ‘Ō‘ō during episode 46 (photo by J.D. Griggs, 6/2/86, JG7348).

32 (E-46). Round-topped fountain, viewed from north side of Pu‘u ‘Ō‘ō. The cone grew 2 m during episode 46 to its maximum height of 257 m above the pre-1983 surface (photo by J.D. Griggs, 6/2/86, JG7356).

33 (E-48). Aerial view, from the northeast, of pāhoehoe flow from the fissure eruption at the site of the Kūpaianaha vent. New flows are overriding dark ‘a‘ā flows from Pu‘u ‘Ō‘ō, 3 km uprift (in background). The Pu‘u ‘Ō‘ō conduit failed on July 18, triggering fissure eruptions both up- and downrift of the cone. On July 20 (beginning of episode 48), the fissure at this site began to erupt, initiating 5.5 years of near-continuous effusion from the Kūpaianaha vent. The high-fountaining episodes of Pu‘u ‘Ō‘ō were over (photo by J.D. Griggs, 7/20/86, JG7632).

34 (E-48). Aerial view of flow from Kūpaianaha that demolished a residence near an orchid farm at Kapa‘ahu. Farmers continue to work on what is left of the farm. Flows from Kūpaianaha moved through the village of Kapa‘ahu, cut off the coastal highway, and reached the sea in late November 1986 (photo by J.D. Griggs, 12/16/86, JG8502).

35 (E-48). Aerial view to southeast of tube-fed pāhoehoe flow blocking Highway 130 at the entrance to Kalapana Gardens subdivision on Lokelani Street. The flow demolished 14 homes on the northwestern edge of Kalapana in a single day, then stagnated when the tube became blocked near the vent (photo by J.D. Griggs, 12/19/86, JG8610).

36 (E-48). Aerial view of thin pāhoehoe flow advancing through mango trees toward a house in Kalapana Gardens subdivision (photo by J.D. Griggs, 12/19/86, JG12367).

37 (E-48). Aerial view of flow (marked by smoke from burning vegetation) moving into Kalapana Gardens subdivision. Pu‘u ‘Ō‘ō is visible on skyline at center. In the foreground are the Mauna Kea Congregational Church (right of center) and fishponds (lower left) bounded by the Hakuma horst, the uplifted, elongate block at lower left. View is to the northwest (photo by J.D. Griggs, 12/19/86, JG8632).

38 (E-48). Aerial view from the northeast, looking across the Kūpaianaha lava pond to Pu‘u ‘Ō‘ō. The lava pond is covered by a thin, mobile crust. The pond is at the top of a broad, low shield 1 km in diameter and about 56 m high. Frequent overflows from the pond in its first year built the shield (photo by J.D. Griggs, 1/13/87, JG8728).

39 (E-48). Aerial view of Kūpaianaha lava pond. A vent beneath the broad area to the left supplies lava to the pond, which then flows down the long neck to the right. A lava tube at the end of the neck carries lava downslope. The entrance to the lava tube is visible at the end of the neck (photo by J.D. Griggs, 2/2/87, JG8948).

40 (E-48). Pu‘u ‘Ō‘ō fumes in the background, with ‘ōhi‘a trees and tree ferns in foreground. In the middle distance is Pu‘u Halulu. View is uprift from Kalalua, a prehistoric cone (photo by J.D. Griggs, 3/11/87, JG9139).

41 (E-48). Queens Bath, a fresh-water filled graben that was a popular bathing spot in Kapa‘ahu, before being filled by lava from the Kūpaianaha vent (photo by J.D. Griggs, 3/31/87, JG9319).

42 (E-48). Bystanders watch steam rising from Queens Bath as lava flow enters the water. Lava overran Highway 130 at 0748 H.s.t. on the same morning at the western margin of the Kapa‘ahu flow. By the end of the day, Punalu‘u heiau was overrun, and Queens Bath was filled with lava (photo by J.D. Griggs, 3/31/87, JG9470).

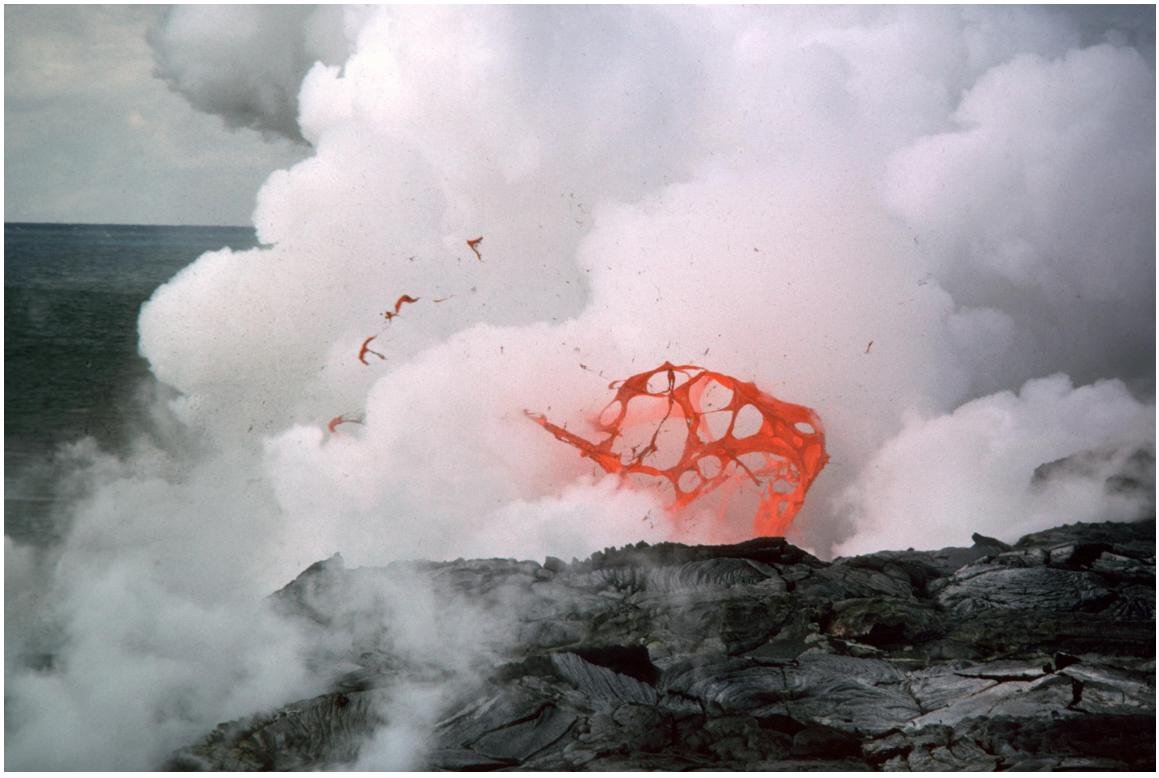
43 (E-48). Billowing steam plume marks the spot where tube-fed lava from Kūpaianaha enters the ocean east of Kupapa‘u Point. The plume contains a mixture of hydrochloric acid and concentrated saltwater that is created when lava reacts with seawater. Steam explosions (also called littoral explosions because they occur at the shoreline or littoral zone) spray fragments of lava into the air (photo by J.D. Griggs, 2/3/88, JG10760).

44 (E-48). Glow of lava is reflected in steam plume at water's edge east of Kupapa'u Point. A littoral cone formed by spatter from steam explosions sits on top of the sea cliff to the right (photo by T.J. Takahashi, 2/10/88, TT028807).

45 (E-48). Littoral explosion east of Kupapa'u Point produces thin sheets of spatter known as "limu o Pele" (Pele's seaweed) (photo by T.J. Takahashi, 2/10/88, TT028838).

46 (E-48). New black sand beach at Kamoamoa. Lava is fragmented into sand-sized pieces by steam explosions as it enters the ocean. Currents carry the sand until it reaches a protected bay where the sand accumulates, forming a new black sand beach (photo by J.D. Griggs, 3/3/88, JG11546).

47 (E-48). Lava drapery and bench east of Kupapa‘u Point. The drapery was formed when lava flowed over a sea cliff onto the new land forming at its base. New land forms as lava deltas build seaward over steep submarine slopes of spatter, black sand, and pillow lava. These slopes are unstable and prone to slumping, which removes support for the active, leading edge of the lava delta, or “bench.” Benches and deltas can collapse unexpectedly (photo by J.D. Griggs, 4/13/88, JG11606).



48 (E-48). A thin-walled lava bubble expands and bursts. These “bubble bursts” occur when seawater infiltrates the lava tube system near the shore (photo by J.D. Griggs, 10/5/88, JG12367).

49 (E-48). Lava bubble bursts near shoreline where lava enters the ocean. Such bubble bursts produce translucent sheets of spatter, or limu o Pele (photo by J.D. Griggs, 10/5/88, JG12364).

50 (E-48). Waha‘ula Visitor Center before being destroyed by lava flows from Kūpaianaha. Groundbreaking for the visitor center in 1966, coincided with the 50th anniversary of the founding of Hawai‘i Volcanoes National Park on August 1, 1916 (photo by T.J. Takahashi, 2/10 /87, TT28711).

51 (E-48). Lava oozes from within an already crusted flow and forms ropy pāhoehoe near Waha‘ula Visitor Center (photo by J.D. Griggs, 6/15/89, JG12539).

52 (E-48). Lava flow ignites Waha‘ula Visitor Center. The flow moved under the structure despite the Park Service crews’ and volunteers’ efforts to cool it and stop its advance (photo by J.D. Griggs, 6/22/89, JG12788).

53 (E-48). Aerial view of remains of Waha‘ula Visitor Center, with heiau (temple site) still intact in foreground. The Waha‘ula heiau was said to have been built in the eleventh century by the high priest Pā‘ao (photo by J.D. Griggs, 6/28/89, JG13089).

54 (E-48). Steel structural members are all that remain of Waha‘ula Visitor Center after it was destroyed by fire from lava that flowed under the structure and ignited it (photo by J.D. Griggs, 10/12/89, JG13336).

55 (E-48). Lava pours from tube into sea at Poupou west of Kupapa‘u Point and east of the Waha‘ula heiau. The single tube feeding the entry was exposed when the sea cliff beneath the Poupou littoral cone calved off. The lava stream was referred to as a “fire hose” (photo by J.D. Griggs, 11/27/89, JG13424).

56 (E-48). Aerial view from the eastern coast of Kīlauea, looking across Hawaiian Paradise Park subdivision toward Pu‘u ‘Ō‘ō and Kūpaianaha (where plume rises) on the horizon (photo by J.D. Griggs, 12/27/89, JG13581).

57 (E-48). Aerial view of ocean entry at Poupou and the Kūpaianaha flow field. Pu‘u ‘Ō‘ō fumes on the horizon; streets of Royal Gardens subdivision lie on the slopes of Pūlama pali above the coastal plain (photo by J.D. Griggs, 12/27/89, JG13655).

58 (E-48). Aerial view of pāhoehoe from Kūpaianaha overriding earlier channeled ʻaʻā flows, flowing down Pūlama pali through ʻōhiʻa forest on its way to the sea (photo by J.D. Griggs, 2/15/90, JG13956).

59 (E-48). Aerial view of the "Quarry" flow that crossed Highway 130 west of Kalapana. This flow entered the sea on February 20, 1990 (photo by J.D. Griggs, 2/21/90, JG14246).

60 (E-48). Aerial view of lava encroaching on Kalapana community. Hākuma horst, a raised fault block, is on the left. To the right of the point are fishponds, and to their right, Walter's Kalapana Store and Drive Inn. In the large trapezoidal plot are Mauna Kea Congregational Church and hall. The white structure across the street from the Congregational Church is St. Mary's Star of the Sea Catholic Church (photo by J.D. Griggs, 4/3/90, JG14496; see also JG15634 (5/2/90), 16102 (5/16/90), 16454 (5/31/90), and 16718 (6/3/90).

61 (E-48). A three-story house in Kalapana Gardens is ignited by a lava flow, which entered the subdivision on April 17, 1990. By the 24th, more than a dozen houses were destroyed. The total number of homes destroyed by the eruption was 121 by the end of April 1990 (photo by J.D. Griggs, 4/22/90, JG14665).

62 (E-48). Children in Kalapana Gardens watch lava moving into their neighborhood. Some of the people whose land was covered by lava were tenth generation residents of Kalapana (photo by J.D. Griggs, 4/22/90, JG14710).

63 (E-48). A lei is offered to appease Pele, goddess of the volcano (photo by J.D. Griggs, 4/22/90, JG14805).

64 (E-48). Aerial view of lava advancing through Kalapana Gardens. The edge of the flow follows the inland contours of Hakuma horst, the fault block to the left (photo by J.D. Griggs, 5/2/90, JG15634).

65 (E-48). Lava enters Harry K. Brown Park, originally called "Wai‘ākōlea Park." It was renamed "Harry Ka‘ina Brown Memorial Park" in 1953 after Brown, a county auditor, whose ancestral home was in Kalapana. By the end of May 1990, 35 more homes were destroyed; a total of 157 homes had been destroyed since 1983 (photo by D. Weisel, 5/2/90, 59017).

66 (E-48). St. Mary's Star of the Sea Catholic Church in its original setting in Kalapana. The "Painted Church" was completed by April 19, 1931 (photo by J.D. Griggs, 4/22/90, JG14853).

67 (E-48). The Painted Church is finally moved to a safe location at dawn (photo by D. Weisel, 5/4/90, DW59004).

68 (E-48). Aerial view of Kalapana community inundated by tube-fed lava flows (photo by J.D. Griggs, 5/16/90, JG16102).

69 (E-48). Aerial view of flow field in Kalapana. The Mauna Kea Congregational Church (lower right) burned down on May 7 (photo by J.D. Griggs, 5/31/90, JG16454).

70 (E-48). Aerial view of lava flow entering the ocean at Kalapana (photo by J.D. Griggs, 6/3/90, JG16718).

71 (E-48). Lava surrounds sign at Walter Yamaguchi's Kalapana Store and Drive Inn, "the oldest water well in Puna." The store burned down on June 6, the 161st structure overrun by lava (photo by J.D. Griggs, 6/3/90, JG16763; see also JG16888, 6/8/90, and JG17085, 6/13/90).

72 (E-48). Lava rises around Walter's Drive Inn sign. Concrete walls of the store and roof of the post office are in the background (photo by J.D. Griggs, 6/6/90, JG16888).

73 (E-48). Lava rises to the base of the sign at Walter's Store and Drive Inn. The sign, with its eight-inch high concrete blocks, was one of the means used to measure inflation of the lava flow (photo by J.D. Griggs, 6/13/90, JG17085).

74 (E-48). Lava surrounds family grave sites in Kalapana (photo by J.D. Griggs, 6/13/90, JG17225).

75 (E-48). "Court rules" superseded by lava at the remains of Harry K. Brown Park, Kalapana (photo by J.D. Griggs, 6/30/90, JG18003).

76 (E-48). Lava enters Kaimū Bay, site of renowned black sand beach and coconut grove northeast of Kalapana village (photo by J.D. Griggs, 8/2/90, JG18072).

77 (E-48). Aerial view of lava lake in Pu‘u ‘Ō‘ō crater. The crater is about 250 m in diameter (photo by J.D. Griggs, 8/30/90 JG18426).

78 (E-48). Marine life washed ashore after being killed by hot, sediment-filled water where lava entered the ocean in Kaimū Bay. Seabirds and other animals came to feast on the remains each day (photo by J.D. Griggs, 10/11/90, JG18928).

79 (E-48). Bus imbedded in lava with remains of a roof in the background at Kalapana. By this time, an entire community lay buried beneath 15–25 m of lava (photo by J.D. Griggs, 12/4/90, JG19238).

80 (E-48). Vertical aerial-photo mosaic of Kalapana and Kaimū Bay before being filled with lava (see nos. 76 and 81). The flow, advancing eastward, had inundated most of Kalapana before reaching Kaimū Bay (photo by D. Weisel, 8/20/90, DW120A7 and DW120A11).

81 (E-48). Vertical aerial-photo mosaic of Kalapana and Kaimū Bay after the bay was filled with lava. The lava extended the shoreline 500 m beyond its original location (photo by D. Weisel, 12/7/90, DW120I15 and DW120I16).

82 (E-52). Littoral explosion at Kamoamoa produces black cloud of spatter at base of billowing white steam plume during episode 52 (photo by L.P. Keszthelyi, 2/5/93, LK020593.11).

83 (E-53). Geologist collects spatter samples while fountains play southwest of the episode 53 vent at the base of Pu‘u ‘Ō‘ō. The vent began to erupt on February 20 (beginning of episode 53), producing 1–4 m-high fountains that increased in height to 15 m by the 21st (photo by C.C. Heliker, 2/21/93, CH022193.31).

84. Holei sea arches, approximately 30 m high. The arches, formed by constant wave action, were eroded from flows erupted more than 500 years ago from Kāne nui o Hamo, a vent in the middle east rift zone (photo by J. Kauahikaua, 3/4/95, JK030495.18).

85 (E-53). Lava bubbles burst at the shoreline at Kamoamoa. These “bubble bursts” occur when seawater infiltrates the lava tube system near the shore. Note two littoral cones, formed by explosion debris, in background (photo by T.N. Mattox, 3/9/94, TM030994.24).

86 (E-53). Skylight in the roof of a lava tube inland of Kamoamoa. Littoral cone and steam plume in the background mark the point where lava enters the ocean (photo by J. Kauahikaua, 3/10/94, JK031094.03).

87 (E-53). Broken lava bubbles in glassy surface of solidified lava from Highcastle flow on the coastal plain (photo by C.C. Heliker, 4/14/95, CH01495.28).

88 (E-53). Incandescent crack in roof of lava tube in the Highcastle flow on the coastal plain (photo by L.P. Keszthelyi, 4/27/95, LK042795.4).

89 (E-53). Littoral explosion at Kamokuna hurls spatter approximately 50 m high during episode 53. Five new littoral cones formed in January. Bench collapses over a 6-hour period on January 30, 1996, resulted in explosions that threw blocks nearly 1 m in diameter up to 250 m inland (photo by C.R. Thornber, 1/28/96, CT012896.10).

90 (E-53). Dome fountains, the largest of which was 7.6 m high, formed over the skylight of a lava tube during an eruptive surge at Pu‘u ‘Ō‘ō. The surge fed a channelized flow down the steep slope of Pūlama pali (photo by C.R. Thornber, 2/1/96, CT020196.27).

91 (E-53). Pāhoehoe flow draining into skylight of lava tube on upper flow field (photo by C.C. Heliker, 2/2/96, CH020296.16).

92 (E-53). Aerial view of channelized ʻaʻā flow from episode 51 vent advancing down steep slope of Pūlama pali. Terminus of flow burns rainforest (photo by C.C. Heliker, 6/4/96, CH060496.22).

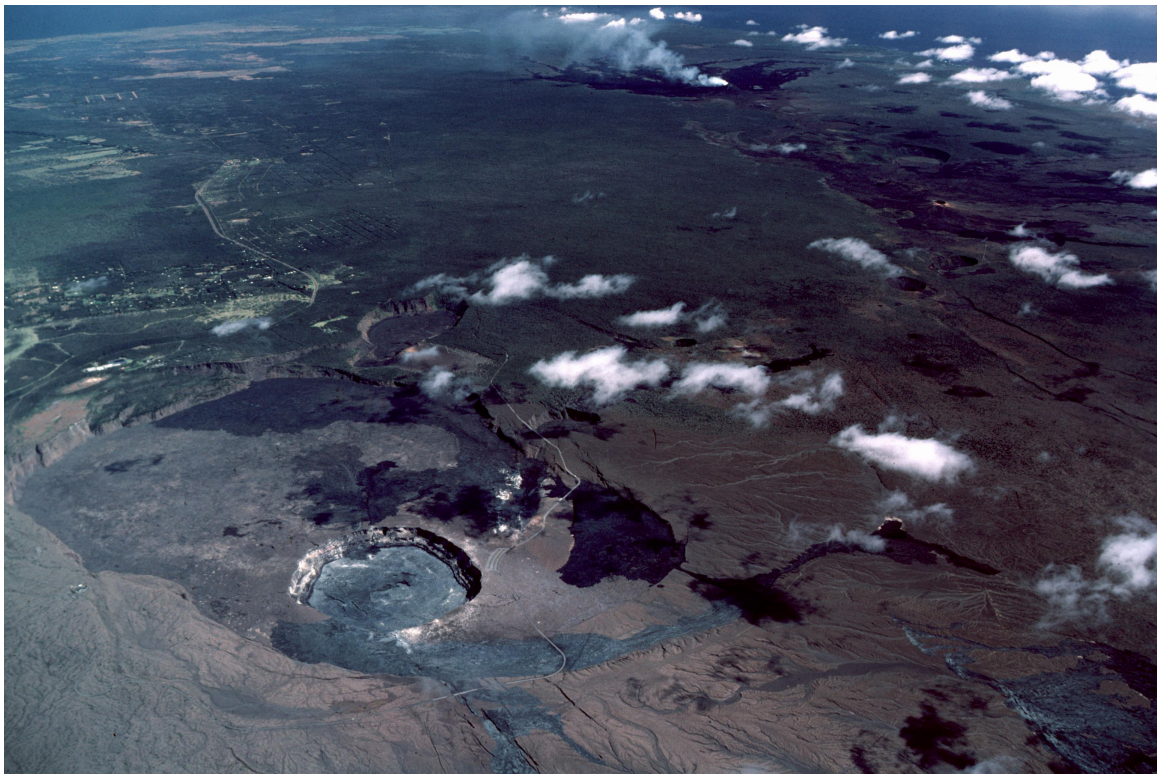
93 (E-54). Aerial view of “west gap” in the Pu‘u ‘Ō‘ō cone that formed on the night of January 29, 1997. The lava pond in the Pu‘u ‘Ō‘ō crater drained, the crater floor collapsed, and the west flank of the cone caved in, creating a gap 150–200 m wide. The collapse resulted in a crater 210 m deep and produced a spectacular blanket of red rock dust (photo by C.R. Thornber, 1/30/97, CT0-13097.3).

94. Lava trees uprift of Pu‘u ‘Ō‘ō. The ground is covered by cinder from the high-fountaining episodes of Pu‘u ‘Ō‘ō from 1983 to 1986 (photo by C.C. Heliker, 1/30/97, CH013097.13).

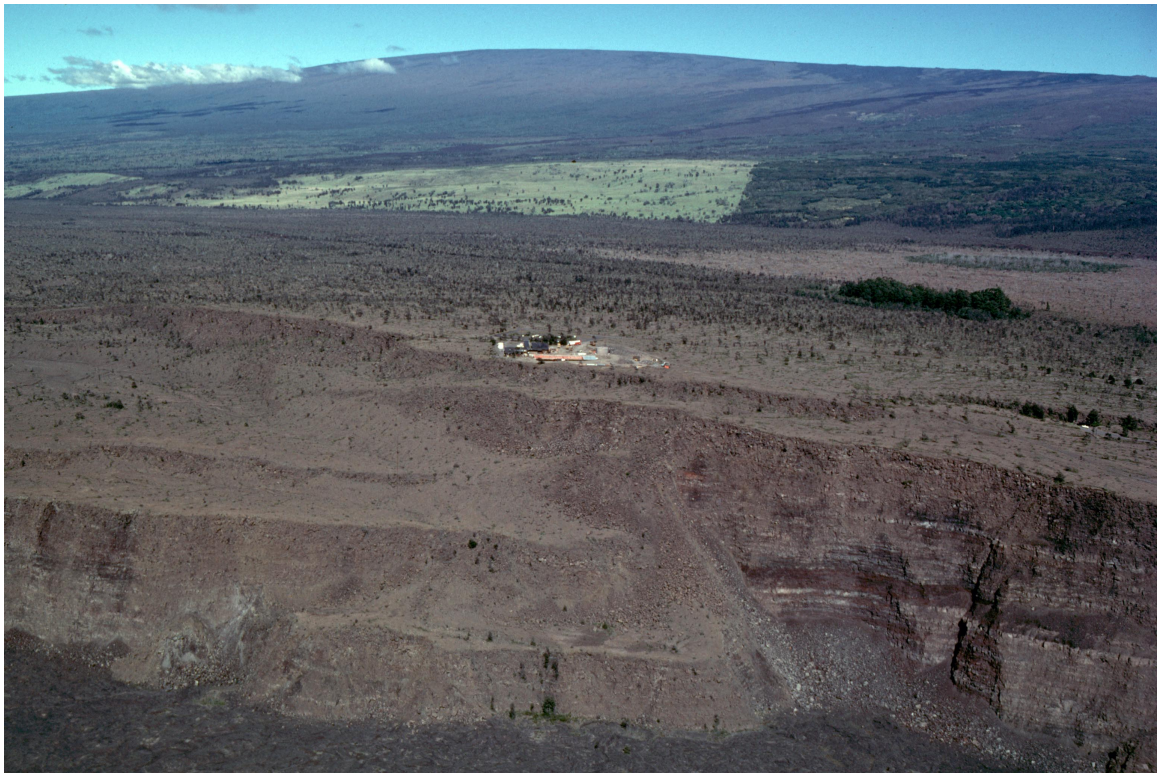
95 (E-53). Aerial view of Lae‘apuki lava delta, which extends 275 m beyond the earlier shoreline defined by the sea cliff 15–18 m above the delta (photo by C.C. Heliker, 1/30/97, CH013097.32).

96 (E-54). Dark lava from episode 54 eruptive fissures flowed into old cracks uprift of Pu‘u ‘Ō‘ō. The cone is coated with red rock dust from the collapse of the crater and west flank. Five closely spaced fissures in, and downrift of, Nāpau Crater were active during the 22-hour-long episode 54 (photo by C.C. Heliker, 1/31//97, CH013197.21).

97 (E-55). Aerial view of lava from flank vents on the west slope of Pu‘u ‘Ō‘ō early in episode 55. Lava is ponding in a series of collapse pits (photo by C.R. Thornber, 4/1/97, CT040197.26).



98. Aerial view looking across summit caldera of Kīlauea toward Pu‘u ‘Ō‘ō on the east rift zone. Kīlauea caldera, containing Halemaumau Crater, is in the lower left, with Hawaiian Volcano Observatory (HVO) on the caldera's rim to the left of Halemaumau. Pu‘u ‘Ō‘ō fumes in the distance on the east rift zone (photo by J.D. Griggs, 1/10/85, JG18537).



99. Aerial view of Hawaiian Volcano Observatory (HVO) situated on Uwēkahuna bluff atop a series of step faults on the northwest rim of Kīlauea caldera. Mauna Loa is in the background (photo by J.D. Griggs, 8/22/85, JG88519).

100. Aerial view of HVO. The newest wing (with the observation tower) was built in 1986 and dedicated on the 75th anniversary of HVO on January 18, 1987 (photo by J.D. Griggs, 10/23/86, JG40238).