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Geologic Map of the Southern Flank of Mauna Loa Volcano, Island of Hawai‘i, Hawaii

By Frank A. Trusdell and John P. Lockwood

Pamphlet to accompany
Scientific Investigations Map 2932–C

Photograph showing the Nīnole Hills—the oldest rocks found at the surface of Mauna Loa. The flat-topped hill in the center is Makanau. The Nīnole Hills range in age from 227,000 to 108,000 years. The ‘a‘ā flow in the foreground is the Keāpōhina flow, dated at 1,100 years before present.

2020

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
DAVID BERNHARDT, Secretary

U.S. Geological Survey
James F. Reilly II, Director

U.S. Geological Survey, Reston, Virginia: 2020

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Suggested citation:
Trusdell, F.A., and Lockwood, J.P., 2020, Geologic map of the southern flank of Mauna Loa volcano, Island of Hawai‘i, Hawaii: U.S. Geological Survey Scientific Investigations Map 2932–C, pamphlet 28 p., 2 sheets, scale 1:50,000, https://doi.org/10.3133/sim2932C.

ISSN 2932-1311 (print)
ISSN 2932-132X (online)

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Geologic Map of the Southern Flank of Mauna Loa Volcano, Island of Hawai‘i, Hawaii

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Mauna Loa

Mauna Loa, the largest volcano on Earth, has erupted 33 times since written descriptions became available in 1832. Some eruptions began with only brief seismic unrest, whereas others followed several months to a year of increased seismicity. Once underway, its eruptions can produce lava flows that may reach the sea in less than 24 hours (hr), severing roads and utilities. For example, lava flows erupted from the Southwest Rift Zone (SWRZ) in 1950 advanced at an average rate of 9.3 kilometers per hour (km/hr); all three lobes reached the ocean within approximately 24 hr (Finch and Macdonald, 1953). Near the eruptive vents, the flows must have traveled even faster. In terms of eruption frequency, pre-eruption warning, and rapid flow emplacement, Mauna Loa has great volcanic-hazard potential for the Island of Hawai‘i. Volcanic hazards on Mauna Loa may be anticipated, and risk substantially mitigated, by documenting the past activity to refine our knowledge of the hazards and by alerting the public and local government officials of our findings and their implications for hazards assessments and risk.

Mapping Project

The Mauna Loa mapping project is generating detailed geologic maps and associated digital databases for the subaerial volcanic rocks of Mauna Loa (fig. 1). The temporal and spatial records of eruptive activity, traceable to approximately 30,000 years before present (yr B.P.), provides a geologic framework for evaluating eruptive processes at large basaltic shield volcanoes and determining the long-term frequency and style of Mauna Loa eruptions. This framework can then be used as a guide for volcanic-hazard appraisals and land-use decisions (Trusdell, 1995).

The subaerial volcanic geology of Mauna Loa (fig. 1) is being mapped and digitally compiled on five maps at 1:50,000 scale to show the extent of surface flows. Approximately 500 flows have been identified and their attributes compiled in a large database. This temporal and spatial record of eruptive activity for the past 30,000 years provides a geologic framework to interpret the long-term frequency and style of Mauna Loa eruptions. These data permit quantitative analysis of the distribution of eruptive products through time and improve evaluation of volcanic risk (Trusdell, 1995).

Southern Flank Mauna Loa Map

The map of the southern flank of Mauna Loa shows the distributions and relations of volcanic and surficial sedimentary deposits. It incorporates previously reported work published in generalized small-scale maps (Lockwood and Lipman, 1987; Lockwood, 1995; Wolfe and Morris, 1996a).

Mapping Methods

Geologic mapping was done by using vertical aerial photographs taken in 1977 and 1978. Extensive fieldwork required walking the contacts to distinguish individual flow units and intraflow boundaries, including gradational morphologic transitions between pāhoehoe and ‘a‘ā flows. Where the terrain and jungle obscured contacts, we created a grid pattern of transects. The ensuing contacts were interpolated between transects from aerial photograph interpretation and from geological and botanical inferences. Details from aerial photographs were transferred to a 1:24,000-scale base, using a photogrammetric stereoplotter (Kern model PG–2), scanned, and digitized with ArcInfo software to create the digital database.

Reliably correlating discontinuous exposures through heavily vegetated areas is a major challenge on a volcano that consists entirely of compositionally similar basalt. Criteria for correlation include phenocryst size, morphology, and proportion; groundmass texture; vesicle shape; vesicle linings (magnesioferrite); flow morphology; paleomagnetic pole directions; rock chemistry; and varied evidence on relative and absolute ages. Paleomagnetic poles are an indispensable tool for making correlations among flows over large distances and, especially, through dense jungle. Individual flows typically change from pāhoehoe near the vent to ‘a‘ā downslope, especially for high-discharge eruptions; low-discharge eruptions may result in the distal emplacement of pāhoehoe through efficient lava-tube systems.

The pre-1868 lava flows and tephra deposits are divided into 15 age groups by several methods. The map is largely chronostratigraphic. About half the flows were dated directly (94 radiocarbon ages), using carbonized organic material recovered from beneath flows (Lockwood and Lipman, 1980). For undated flows, relative ages are assigned on the basis of

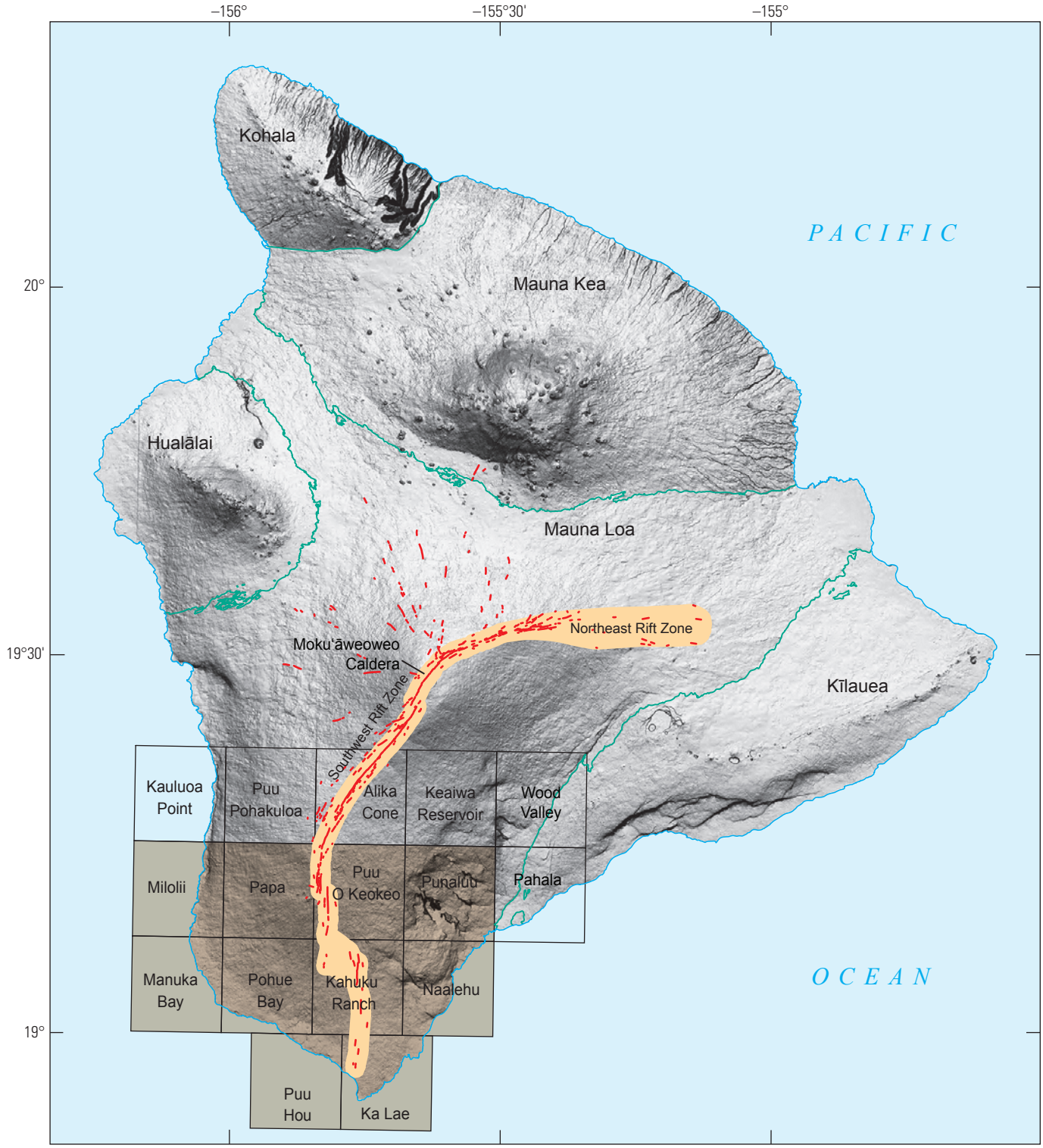

Figure 1. Shaded-relief map showing subaerial volcanoes (green boundary) forming Island of Hawai'i, main rift zones (orange) and fissures (red lines) on Mauna Loa, and 7.5-minute topographic quadrangles in (shaded) and adjacent to map area.

rock and mineral weathering or alteration, soil and tephra accumulation, vegetative cover, and stratigraphic relations with adjoining dated flows.

Surface color is an indirect indicator of age (Lipman, 1980; table 2). Young lava flows are initially black. As the rock is exposed to direct sunlight and becomes increasingly weathered, its color changes from black to dull black, then progresses to gray, brown, tan, orange, and, finally, reddish hues. The longer rock is weathered, the greater the color progression. Lipman and Swenson (1984) used this color scheme effectively to tentatively classify the ages of eruptive units within limited areas. The utility of this technique is influenced by elevation, rainfall, and shielding

by forest and tephra cover. Soil and tephra accumulation are also an indirect indicator of age. The thickness of tephra also varies with proximity to the contributing source(s).

Database

The digital database contains all information in the printed publication at 1:50,000 scale, but it is accurate to 1:24,000 scale. A unique three-digit Flow Identification Number (FID; for example, FID 831) is assigned to each flow unit mapped on Mauna Loa. The FIDs are unique descriptors in the database and are included in the Description of Map Units, as well as in the Correlation of Map Units. The database contains information on flow morphology, approximate age, exact age, mineralogy, data quality, unit names, rock chemistry, and any existing overburden type. Access the database for this map at https://doi.org/10.3133/sim2932C.

Acknowledgments

A great many individuals have contributed to the body of knowledge that has made this geologic map possible. We thank Meyer Rubin and Jack McGeehin and those who have worked in their laboratory for radiocarbon age determinations. Duane Champion conducted the paleomagnetic studies to test correlations of several geologic units. Assistants in geologic mapping of the southern flank include Ramona Navarette, George Roberts, Chris Corley, Elin Yoon, David Wilson, and Ichiban Tomodachi. People who worked as archivists of the geologic samples and charcoal samples include Toni Thompson and Vicki Taylor. The digital database containing the geologic map was initially constructed by Sandi Margriter. Superintendents of Hawaii Volcanoes National Park permitted work on the southwest rift. Thorough and helpful reviews of the map and text by Peter Lipman and Edward Wolfe as well as a careful edit by Monica Erdman resulted in many improvements in presentation.

Geology

Southern Flank of Mauna Loa

Although most Mauna Loa eruptions begin in the summit area at 12,000 feet (ft) (3,650 meters, m) elevation (Lockwood and Lipman, 1987), the SWRZ was the source of at least 10 flank eruptions since 1843 (table 1). The SWRZ extends from the summit towards Kalae (South Point) at sea level. The lowermost part of this rift zone, marked by Puʻuʻokeʻokeʻo to the north at 6,874 ft (2,095 m) elevation and extending to the sea, makes up the lower SWRZ (LSWRZ). The community of Hawaiian Ocean View Estates, with a population of about 2,500, is the largest in the region. The subdivision is built entirely on flows erupted from southern Mauna Loa, and some source vents are located within the subdivision. Approximately 25 percent of the subdivision is within Hazard Zone 1 (Wright and others, 1992).

The map area extends from 7,325 ft elevation at the crest of Mauna Loa's SWRZ. Lava erupted from the SWRZ typically flows to the west, east, or south (depending upon vent location relative to the rift crest) and generally produces narrow flow lobes. Both morphologic lava flow types—ʻaʻā and pāhoehoe—are present.

In general, the northern part of the mapped area is dominated by flows from the middle SWRZ, whereas the southern part contains flows from the LSWRZ and includes areas adjacent to, and downslope of, the rift zone. The exceptions are flows that originated from the upper SWRZ in the northeastern part of the Punaluu quadrangle. From east to west, the map covers the area from Punaluʻu to Miloliʻi and, from north to south, extends from north of Puʻuʻokeʻokeʻo to Kalae (South Point).

The LSWRZ trends south 180° and is about 36 kilometers (km) long. It is approximately 2 km wide in the north and becomes diffuse (5–7 km wide) near 5,400 ft (1,645 m) elevation. Below this elevation, the rift zone is en echelon (left-lateral-stepping) to the east from the main trend of the upper SWRZ by 5 km. Its constructional crest is marked by low spatter ramparts and spatter cones as high as 60 m. Subparallel eruptive fissures and ground cracks cut vent deposits and flows in and near the rift crest. Fissure vents are typically a few meters to several kilometers long. One exception is the 1950 eruptive fissure, which is nearly continuous for approximately 18 km.

The distal subaerial part of the rift zone extends toward Kalae, east of the Kahuku Fault. This part of the rift zone had been relatively inactive since 7,750 yr B.P. until an eruption occurred in 1868. The SWRZ continues for an additional 33 km below sea level.

Some ground cracks are, in places, extensions of eruptive fissures, whereas others may be unrelated to eruptive activity. Lipman and Swenson (1984) mapped a series of northeast-trending cracks at 5,600 ft (1,707 m) elevation, approximately 4.8 km east from the rift axis. Other than dilation (as much as 2 m), no other offset is noted. Presumably, the cracks are related to intrusive activity, similar to cracks documented by Swanson and others (1976) on Kīlauea. Lipman and Swenson (1984) attribute these cracks to intrusive activity associated with the 1950 eruption. It is not clear that all these cracks formed in 1950; the approximately magnitude 8 earthquake of 1868 occurred on this part of Mauna Loa, the largest in Hawaii. It was reported that ground cracks were pervasive in the region from Wood Valley to Waiʻōhinu. Therefore, although the 1950 eruption may have generated some of these ground cracks, we cannot exclude the 1868 earthquake as a source mechanism.

Several pit craters are found in the mapped area. The youngest is found adjacent to the upper Hapaimamo (unit a1b2, FID 499) vent area, just west of the 1907 fissure vent (unit a0k5, FID 492). Lava from this historical eruption flowed into the pit crater, and the crater rim cuts the Hapaimamo flows. Another is found within the Lua Nui flow (unit a2i3, FID 542) at 4,120 ft (1,256 m) elevation, approximately 0.5 km west of the eastern 1926 flow (unit a0b2, FID 489).

Three additional pit craters are found in the southern Kahuku Ranch quadrangle under the Pāhala Ash unit (unit pa; FID 389), east of the Kahuku Pali. The pit craters are Luapalalauhala, Luapōʻai, and Luapūʻali. Luapōʻai is unique

Table 1. Summary statistics of historical (after A.D. 1843) eruptions in the Lower Southwest Rift Zone of Mauna Loa, Island of Hawai‘i, Hawaii (adapted from Lockwood and Lipman, 1987).

(S, summit; SWRZ, Southwest Rift Zone).

Year	Eruption begins	Summit activity (days)	Flank activity (days)	Eruptive area of volcano	Area covered (km^2)	Volume erupted (km^3)	Error in estimated volume (percent)
1950	June 1	1	23	S, SWRZ	112	0.376	20–40
1926	April 10	<1	14	S, SWRZ	35	0.121	20–40
1919	September 26	<1	38	S, SWRZ	28	0.183	20–40
1916	May 19	0	12	S, SWRZ	17	0.031	20–40
1907	January 9	<1	15	S, SWRZ	28	0.121	20–40
1903	October 6	61	0	S, SWRZ	10	0.036	20–40
1887	January 16	<1	7	S, SWRZ	29	0.128	20–40
1868	March 27	<1	5	S, SWRZ	24	0.073	20–40
Total					**283**	**1.069**	

in that it may have been formed by explosive activity. Phreatic debris as thick as 1.5 m is found on its western rim (Stearns and Clark, 1930). It is overlain by Pāhala Ash, and its full extent cannot be determined. The other two craters probably formed in the usual manner through the withdrawal of lava.

Generally, flows on the east side of the map are older than those on the west side for several reasons. There was a westward migration of the rift zone (Lipman, 1980). The distance from the rift crest to the eastern shore is greater than the distance from the rift crest to the western shore. In addition, topographic barriers have prevented several areas from being inundated with lava. One of these zones is the region from Wai‘ōhinu to Honu‘apo; upslope from there is Puu Hoomaha. The other is the region near the upper end of the Kahuku Pali near Highway 11. This region has diverted flows both east and west of the pali crest; the end result is a region that has not been flooded by flows for approximately 7,000 years.

Volcanic Deposits

Flows

The map encompasses 1,163 square kilometers (km^2) of the southwest flank (fig. 1) of Mauna Loa, from 7,325 ft (2,233 m) elevation to sea level. It shows the distribution of eruptive units (flows), which are separated into 16 age groups, ranging from more than 100,000 yr B.P. to A.D. 1950.

Pāhoehoe is characterized by bulbous, smooth, and ropy surfaces, and the general topography can be described as hummocky. Lava tubes are common features in pāhoehoe flows. Most ‘a‘ā flows also start as pāhoehoe flow types near the vents and transition to ‘a‘ā downslope.

‘A‘ā flows, which cover more than half of the map area, are generally thicker and form broader units than pāhoehoe flows. ‘A‘ā flows are characterized by rubbly and (or) clinkery surfaces and have a rough texture; they are typically 3 to 15 m thick.

Effusion rates and slope influence lava morphology. High effusion rates, combined with steep slopes, usually generate ‘a‘ā. Moderate to low effusion rates typically produce pāhoehoe. Not surprisingly, ‘a‘ā is abundant in the region, which has the highest effusion rates and some of the steepest slopes of any sector of Mauna Loa (Trusdell, 1995). The relation between high effusion rates and steep slopes has momentous implications for volcanic hazards and flow-advance rates. Historical flows from the SWRZ have reached the sea in a matter of hours to days (see individual eruption narratives in the Age Group 0 section for specific details).

Vesicles are present in both pāhoehoe and ‘a‘ā flows. In ‘a‘ā flows, vesicles are generally fewer in number and volume (<35 percent), irregularly distributed, commonly deformed and subangular in shape, and larger in size than in pāhoehoe flows. In contrast, vesicles in pāhoehoe flows are smaller, more abundant, and voluminous (40–60 percent), moderately distributed to well distributed, and spherical to subrounded.

Age Groups

The age groups are arbitrary boundaries created by the authors. They are broken down into 1,000-year intervals until the older age groups. The larger age groups represent time periods greater than 1,000 years. The age groups are defined based on radiocarbon years. Unless the flows are dated, the reliability of age determinations decreases with increasing age.

Age Group 0 (Historical period: A.D. 1843 and younger)

Lava erupted from 1868 to 1950 covers 11 percent of the map area. Eruptions occurred in 1868, 1887, 1903, 1907, 1916, 1919, 1926, and 1950. Soil or ash cover is absent except in forested areas, and surficial glass is common. ‘A‘ā is common except near vents.

A.D. 1950—The largest historical eruption from the SWRZ occurred in this year. It was noteworthy in that lava from

a nearly continuous 18-km-long fissure fed three westbound flows that reached the sea in less than 24 hours. The high flux rate and rapid flow advance rate of 9.3 km per hour (Finch and Macdonald, 1953) are significant. The eruption began on June 1 and continued for 23 days; the eruptive volume is 376×10^6 cubic meters (m^3) (Lockwood and Lipman, 1987). The vents are distributed between 7,880 and 12,600 ft (2,402 and 3,840 m) elevation. All of the eruptive fissures are located north of the map area at higher elevations. A small lobe that entered the mapped area in the northeast part of the map was fed from the middle SWRZ. Most of the lava is ʻaʻā. The eruption was described in detail by Finch and Macdonald (1953).

A.D. 1926—The 1926 eruption began on April 10, after an increase in tilt and a swarm of earthquakes (Jaggar, 1926b; Finch, 1926). It lasted 14 days and produced an eruptive volume of 121×10^6 m^3 (Lockwood and Lipman, 1987). It originated in the summit and was followed by an outbreak high on the SWRZ near Lua Hou at 12,800 ft (3,901 m) elevation. On April 13, a fissure vent broke out at 7,840 ft (2,390 m) elevation and extended down to 7,240 ft (2,207 m) elevation, feeding flows that reached the sea in four days (Jaggar, 1926a; Jaggar, 1926c). The western lobe destroyed the coastal village of Hoʻōpūloa near Miloliʻi (Jaggar, 1926a).

A.D. 1919—The 1919 ʻĀlika eruption began at the summit of Mauna Loa on September 26. That same day, at 6 p.m. Hawaii standard time (HST), a new vent opened on the SWRZ at 7,843 ft (2,391 m) elevation. This vent, north of the mapped area, fed a flow that reached the sea in approximately 24 hours (Jaggar, 1919a, b, c). The eruption lasted for 38 days and produced 183×10^6 m^3 of lava (Lockwood and Lipman, 1987).

A.D. 1916—This eruption was preceded by a flurry of earthquakes, which began on May 14, and a change in tilt (T. Jaggar, quoted in the Hilo Tribune on May 23, 1916). The summit outbreak occurred on May 19, followed on May 21 by a flank eruption on the SWRZ at 6,580 to 7,455 ft (2,006 to 2,272 m) elevation (Wood, 1916). The flank eruption lasted 12 days and erupted 31×10^6 m^3 of lava (Lockwood and Lipman, 1987)—the least voluminous historical eruption on the SWRZ, producing only a small fraction (<10 percent) of the volume erupted in 1950. The fissure vents are north of the mapped area.

A.D. 1907—Preceded by an earthquake swarm that began on January 7 (anonymous quote in the Hilo Tribune on January 15, 1907), the 1907 eruption began on January 9 and continued for 15 days (anonymous quote in the Hilo Tribune on January 29, 1907). It erupted 121×10^6 m^3 (Lockwood and Lipman, 1987) of lava, much of which is ʻaʻā. The main fissure vents, which became active on January 10, were distributed along a 2-km segment of the SWRZ, upslope from Hawaiian Ocean View Estates, at 6,555 to 6,000 ft (1,998 to 1,829 m) elevation. The fissures fed two ʻaʻā flows that branched out 1.6 km from the distal end of the fissure. The west lobe traversed the mapped area in a southwest direction. The east lobe extended due south and came within 2 km of the sea. Additional fissures, adjacent to the east lobe, broke out at 3,000, 2,600, and 2,400 ft (914, 792, and 732 m) elevation within reach of now-populated areas.

A.D. 1903—The 1903 eruption began at 12:45 p.m. HST, on October 6 (S.C. Bidgood, quoted in The Pacific Commercial Advertiser on October 8, 1903). Sailors aboard an interisland ferry noticed a column of "smoke" from a point below the summit of Mauna Loa. The eruption continued for 61 days and produced 36×10^6 m^3 of lava on the LSWRZ. On October 7, two people hiked to Mokuʻāweoweo, where they found lava fountains 60–180 m high, feeding flows that covered the caldera floor. In addition, a fissure outbreak on the SWRZ between 7,600 and 8,100 ft (2,316 and 2,469 m) elevation fed seven flows that coalesced into two streams (anonymous quote in the Hawaii Herald on October 8, 1903, and R. Trent on October 11, 1903). These flows enter the northeast part of the mapped area. Throughout the flank eruption, the summit also remained active. The eruption ended on December 8 (anonymous quote in the Hawaii Herald on December 10, 1903).

A.D. 1887—The 1877 eruption began on January 16 and continued for about 7 days. Most of the erupted lava is ʻaʻā. The flows, which attained a volume of 128×10^6 m^3 (Lockwood and Lipman, 1987), entered the sea at Kākio approximately 29 hours after the onset of the eruption (Stearns and Macdonald, 1946). Vents are distributed along a 7-km segment of the SWRZ between 3,920 and 6,020 ft (1,195 and 1,835 m) elevation. The lowermost vents are within the Hawaiian Ocean View Estates subdivision.

A.D. 1868—Mauna Loa's most spectacular eruptive sequence in historical times began on Friday March 27, 1868, at 5:30 a.m. HST, with a dense column of fume illuminated by an eruption in Mokuʻāweoweo. The summit phase lasted for several hours before coming to an end. On March 28, a strong earthquake (with an estimated magnitude of 7.0) shook Kaʻū (Wyss and Koyanagi, 1992). It was followed on April 2, at 3:40 p.m. HST, by the largest earthquake ever recorded on the Island of Hawaiʻi, again in Kaʻū, with an estimated magnitude of at least 7.9 (Wyss and Koyanagi, 1992). The earthquake was felt throughout the islands, particularly on Maui and Lānaʻi, where houses shook. On the Island of Hawaiʻi, a large portion of the coastline, from Honuʻapo to Kapoho, sank. Former coastal villages were inundated by a tsunami and destroyed. People and animals were swept out to sea and drowned. A mud flow near Wood Valley buried people and farm animals under a layer of mud. In Kaʻū, the earthquake flattened every stone wall and dwelling, and ground cracks appeared throughout the district (Brigham, 1909).

Around 6 p.m. HST, on April 7, a 4-km fissure opened along Mauna Loa's LSWRZ, from 2,150 to 3,150 ft (655 to 960 m) elevation, from which lava surged and flowed south (Brigham, 1909). Within 3.5 hours, the flow had reached the sea, a distance of 13 km (Brigham, 1909). The eruption continued for five days and produced 123×10^6 m^3 of lava by the time it ended (Lockwood and Lipman, 1987). The olivine content of the lavas increased over time; the latest flows had model olivine abundances over 30 percent. The large earthquakes that accompanied the eruptive activity may have perturbed the rift zone to allow deeper access to the magmatic system and therefore greater abundances of olivine.

Age Group 1 (A.D. 1843–1,000 yr B.P.)

Spatter and flows are typically slightly weathered and have negligible overlying soil or tephra except in forested areas. Black surficial glass is commonly present. Eight flows have radiocarbon ages. Eruptions from this period cover approximately 23 percent of the map area.

Age Group 2 (1,000–2,000 yr B.P.)

Spatter and flows typically have some overlying soil or tephra at low elevations, and any surficial glass shows slight mechanical degradation and color lightening to gray hues. Six of 25 flows have radiocarbon ages. Eruptions from this period cover nearly 28 percent of the map area.

Age Group 3 (2,000–3,000 yr B.P.)

Spatter and flows are mildly weathered, and surficial glass is locally preserved. Seven of 18 flows have radiocarbon ages. Eruptions from this period cover nearly 10 percent of the map area.

Age Group 4 (3,000–4,000 yr B.P.)

Spatter and flows are moderately weathered, and surficial glass is preserved only in protected places. Five of 23 flows have radiocarbon ages. Eruptions from this period cover nearly 6 percent of the map area.

Age Group 5 (4,000–5,000 yr B.P.)

Spatter and flows are moderately weathered, surficial glass is rare, and upper surfaces have moderate mechanical degradation. These flows commonly have as much as 0.4 m of overlying soil or ash where in close proximity to Kīlauea. Four of 15 flows have radiocarbon ages. Eruptions from this period cover less than 7 percent of the map area.

Age Group 6 (5,000–6,000 yr B.P.)

These rocks are increasingly weathered, surficial glass is absent, and upper surfaces have open-vesicle texture. Units are typically covered by 0.2–0.3 m of ash or soil, especially at low elevations. One of eight flows has a radiocarbon age. Eruptions from this period cover less than 0.5 percent of the map area.

Age Group 7 (6,000–7,000 yr B.P.)

These rocks are increasingly weathered, surficial glass is absent, and upper surfaces less intact than younger units and have open-vesicle texture. Units are typically covered by 0.3–0.5 m of ash or soil, especially at low elevations. One flow was mapped and has a radiocarbon age. Eruptions from this period cover less than 0.5 percent of the map area.

Age Group 8 (7,000–8,000 yr B.P.)

The flows are weathered; upper surfaces have open-vesicle texture and are broken, and orange surfaces occur at high elevations. Ash accumulates in low-lying areas. One of two flows have radiocarbon ages. Eruptions from this period cover less than 5 percent of the map area. Flows from this age group are scattered in the Naalehu, Kahuku Ranch, and Ka Lae quadrangles.

Age Group 9 (8,000–9,000 yr B.P.)

The flows are deeply weathered, showing red-orange surfaces at high elevations; mechanical disintegration of upper surfaces is almost complete. Ash accumulates in low-lying areas. Two flows have been identified. Eruptions from this period cover less than 0.5 percent of the map area. Flows from this age range are found in areas southeast of Nāʻālehu.

Age Group 10 (9,000–10,000 yr B.P.)

These flows and all older age groups are found only in the southeastern part of the mapped area; they have been buried by younger flows closer to eruptive vents. Ash and soil fill low-lying areas; accumulations of as much as 0.5–1 m are common. Surface color approaches red. Two of four flows have radiocarbon ages. Eruptions from this period cover 3 percent of the map area. Flows from this age group are found in the northeast part of the Punaluu quadrangle.

Age Group 11 (10,000–15,000 yr B.P.)

These flows have few original surfaces left. Upper surfaces are commonly stained red-orange, probably owing to hydration of glass. In the wet, windward regions, the rock is soft and hammer impacts often leave a divot. Olivine is altered, yellow and (or) brown-green in color, and slightly flaky. Units of this age have 1–3 m of soil or ash cover. Partly altered groundmass is commonly a dull gray color and appears cryptocrystalline. Four units have radiocarbon ages. Eruptions from this period cover 3 percent of the map area. Flows from this age range are found upslope from Kāwā Bay, Honuʻapo, and Kaʻaluʻalu. Two additional kīpuka are found just east of the Kahuku Pali adjacent to the Pāhala Ash unit.

Age Group 12 (15,000–20,000 yr B.P.)

Flows of this age have no original surfaces left. Upper surfaces are commonly stained red-orange, probably owing to hydration of glass. In the wet, windward regions, the rock is yielding and mushy; hydrated glass has turned to clay. Olivine appears flaky and (or) cloudy and mostly altered. Units of this age have 2–4 m of soil and ash cover. Groundmass is altered and lined with alteration products (such as limonite). One of four units has a radiocarbon age. Flows of this age cover approximately 0.5 percent of the mapped area.

Age Group 13 (20,000–30,000 yr B.P.)

These flows are exposed in drainages and include the only surface exposures of Pāhala Ash southeast of Nāʻālehu at the coast near Kāhilipali Nui and at the crest of the Kahuku Pali. The flows have no remaining original surfaces. Boundaries between individual flows are blurred. In the wet, windward regions, the rock is mushy; olivine phenocrysts are altered. Three units have radiocarbon ages. Eruptions from this period compose more than 1 percent of the map area.

Age Group 14 (30,000–100,000 yr B.P.)

These flows are exposed in fault scarps, sea cliffs, and drainages around Nāʻālehu and in the Kahuku Pali. Flows are commonly overlain by as much as 6 m of ash. Flows have lost all original surfaces, and boundaries between individual flows are blurred. In wet, windward regions, the rock is mushy; olivine phenocrysts are mostly altered and generally soft. Eruptions from this period compose less than 1 percent of the map area. One unit

has a date that exceeds the upper detection limit of radiocarbon dating (>49,900 yr B.P.).

Age Group 15 (>100,000 yr B.P.)

Flows with dates of >100,000 yr B.P. were identified in fault scarps and drainages and in the Nīnole Hills. These flows are exposed in valley walls. The unit represents the oldest exposed rocks on Mauna Loa. These rocks are commonly overlain by as much as 6 m of ash and have no remaining original surfaces. In wet, windward regions, the rock is mushy; olivine phenocrysts are mostly altered and generally soft. Eruptions from this period compose 1 percent of the map area.

The Nīnole Hills consist of the oldest rocks found on Mauna Loa (Evernden and others, 1964; Lipman and Swenson, 1984; Lipman and others, 1990; Jicha and others, 2012). Lipman and others (1990) report a weighted mean age of 120,000±56,000 years for Nīnole Basalt, whereas Jicha and others (2012) constrain the Nīnole Basalts to have erupted from 227,000 to 108,000 years. The origin of these hills are an enigma. Originally, the Nīnole Hills were considered the remnants of a separate volcano—termed the Mohokea Caldera (Emerson, 1902). According to another hypothesis, the Nīnole Hills are old fault blocks (Stone, 1926). Lipman and others (1990) interpret the Nīnole Hills as preserved blocks of old Mauna Loa rocks displaced seaward and possibly tilted within a fault zone. Additional interpretation suggests that the Nīnole Hills are the faulted remnants of the old south flank of Mauna Loa, preserved by westward migration of the rift zone.

Alternatively, the Nīnole Hills may represent a failed rift zone or magma conduits feeding Mauna Loa's summit (Okubo and others, 1997; Stearns and Macdonald, 1946; Macdonald and others, 1983). Similar interpretations by Park and others (2007) demonstrate high seismic velocities beneath the Nīnole Hills consistent with the aforementioned interpretations. Kauahikaua and others (2000) used regional gravity survey and recent work by Zureck and others (2015) used an intensive microgravity survey to interpret the Nīnole Hills as the remnants of a failed Mauna Loa rift zone.

Surficial Sedimentary Deposits

Deposits were too small and transient to map. They consist chiefly of colluvial and alluvial deposits of basalt clasts and pebble- to cobble-sized gravel in drainages that occur locally within parts of the map area. We also include under this category unconsolidated sand along the coast.

Volcanic Ash

Pāhala Ash

Pāhala Ash includes beds of fallout and surge deposits that represent accumulation of deposits from numerous eruptions. Deposits include glassy ash and lapilli, now mostly altered to clay, crystals, and lithic fragments. Phenocryst abundance is difficult to estimate, owing to chemical decomposition, but ranges from aphanitic to moderately porphyritic, with as much as 8 percent olivine and fewer plagioclase phenocrysts. It is found chiefly in all quadrangles and in adjacent upslope areas, where it overlies lava flows ranging in age from 31,000 to 2,000 yr B.P.

There are two main subdivisions in this group: southern tephra (unit ts) and Pāhala Ash (unit pa). Southern tephra comprises beds of ashfall deposits in the map area. The source of the ashes is unknown but is considered to be primarily from Kīlauea, with likely contributions from Mauna Loa (Easton, 1987). All ash deposits ≤10,000 yr B.P. are included in this category.

The term "Pāhala Ash," named for the town Pāhala, was used with reference to ash deposits found along the northeast rift zone of Mauna Loa, northeast Kīlauea, and south and southwest of Kīlauea's summit, including the eastern flank of Mauna Loa. The bulk of the ash is presumed to be from Kīlauea, although Mauna Loa cannot be excluded as a source.

Pāhala Ash was described by Stone (1926), Stearns and Clark (1930), Wentworth (1938), Stearns and Macdonald (1946), Fraser (1960), Walker (1969), and Easton (1987). The term eventually came to be used for ashes from Kohala to Kalae at South Point. According to Easton (1987), Wolfe (verbal commun., 1986) determined that the ash deposits of North Kohala District, Waimea, Hāmākua District, and North Hilo District were derived locally and are chemically distinct from ashes near Kīlauea and on the east flank of Mauna Loa.

Wentworth (1938) and Stearns and Macdonald (1946) describe several sections of Pāhala Ash, yet a type section was not identified. Easton (1987) proposed two well-exposed sections on the south flank of Kīlauea for the type locality of the Pāhala Ash.

The ash is a mixture of yellow-brown palagonite, rare vitric shards, Pele's hair, pumice, and olivine phenocrysts. It is derived from airfall deposits, weathered and reworked ash, and sediments. The ash is composed of mostly sand and silt-sized fractions. Ancient soil horizons are present in some localities.

The appearance of the ash is greatly influenced by climate. In dry areas, it is friable, in places compact, but it is mostly sandy, loose, and dusty. In higher-rainfall areas, the ash appears clay like. The ash deposits from Ka'alu'alu to Kalae (or South Point) appear to be loess, reworked and redeposited by wind.

All ashes in the map area that are late Pleistocene or younger (<16,000 yr B.P.) are incorporated into unit ts, which identifies a mostly Holocene ash deposit that is of sufficient thickness to mask the underlying flow(s) or if the extent of the flow(s) cannot be mapped with a reasonable degree of certainty. In other places, where we are able to map ash-covered flows that are <16,000 yr B.P. in age with a high degree of certainty (see database for contact certainty), we chose to use a plus (+) pattern. The overlying ashes are grouped with unit ts.

Our mapping demonstrates—and previous investigators noted (Stearns and Macdonald, 1946; Easton, 1987)—that the Pāhala Ash was a catch-all term for all ash units from northeast Kīlauea, across Kīlauea's south flank, extending over Mauna Loa to (at least) Kalae (South Point) and Kahuku Pali. This included ashes of all ages (25,000–20,000 years); Stearns and Macdonald, 1946). The periodicity with respect to Pāhala Ash production was more infrequent than was previously recognized.

We are able to show that there have been at least eight ash-fall events, where lava flows separate the younger ash layers (unit ts). Most of the individual ash horizons have not been studied well

enough to be used as marker beds over a wide geographic area. We concur with previous investigators that the most likely source is Kīlauea, although Mauna Loa cannot be excluded as a source.

In order for Pāhala Ash to be recognized as a stratigraphic marker, its horizon needs to be recognizable over a large geographic region. Easton (1987) proposed a more restrictive age range of 25,000–10,000 years for Pāhala Ash. Our preference would be to restrict the Pāhala Ash age even further, to approximately 31,000–16,000 years, and possibly older, thereby providing a constraining period of time within which substantial ash accumulation occurred and is preserved, in places, on the flanks of Mauna Loa. The accumulated ash can then be used as a stratigraphic marker across a wide region. Unfortunately, this means that most type sections can only be found in drainages, arroyos, sea cliffs, and on top of Nīnole Hills above Punalu‘u.

Radiocarbon Data

Radiocarbon is obtained from under flow margins and usually dates the surface flow. This map includes some ages obtained from a vertical section (for example, from a waterfall). Flows dated by charcoal that are part of thick sections are represented by a solid black square on the map. In a few instances, we were able to obtain charcoal under the surface unit, but not at the contact between adjacent flows. The symbol is found inboard of the contact. In a few of these cases, heavy equipment broke through the flow (at a quarry), and we retrieved charcoal. In other instances, we obtained charcoal from arroyos, and the underlying outcrops were less than 5 square meters (m^2). Because of the limited exposure, we were not able to adequately characterize these units, and the map units were tiny; we do not show these units.

Table 2 reports 98 radiocarbon ages from 56 lava flows (Kelley, 1979; Kelley and others, 1979; Rubin and others, 1987; this study). Many are conventional ages determined at the U.S. Geological Survey (USGS) laboratory in Reston, Virginia. Forty-two accelerator mass spectrometer (AMS) ages were analyzed by USGS and other laboratories. For eruptive units at more locations, each age is weighted by the inverse of its variance to yield a mean age (Taylor, 1982).

All ages were calibrated to calendar years, using the CALIB 6.0 Radiocarbon Calibration Program (Stuiver and others, 1998; Stuiver and others, 2013). The calibrated age ranges in table 2 encompass the calendar years possible for a given radiocarbon age at two standard deviations; however, all ages shown on the map are radiocarbon yr B.P. Symbols indicate reliability of age for stratigraphic interpretations. Rejected ages are reported in appendix 1.

Fault Systems

The system of normal faults, which occurs on the southeast flank of the volcano, are the Honu‘apo Fault System. Faults shown on the map were adapted from Wolfe and Morris (1996a). Most faults within the map area are inactive and are draped by unfaulted, younger flows as old as 9,500 yr B.P. The concealed fault scarps are as much as 100 m high and traceable for as much as 10 km in an east-northeast direction.

The most prominent fault scarp in the mapped area is the Kahuku Fault, often referred to as the Kahuku Pali. This fault starts on land at 2,000 ft (610 m) elevation, with zero exposed displacement, and extends into the submarine environment for another 33 km. On land, the upslope part of the fault scarp is buried by younger Mauna Loa flows; downslope, it has a minimum displacement of 170 m (Stearns and Macdonald, 1946). The offshore part of the fault scarp has a maximum displacement of approximately 1.5 km. The Kahuku Fault is a product of large-scale collapse of the rift zone (Stearns and Clark; 1930) or slumping and (or) flank failure (Normark and others, 1979; Moore and Chadwick, 1995).

The Wai‘ōhinu Fault extends 7 km in a northwesterly direction, inland from Waikapuna Bay to Wai‘ōhinu. The last documented movement occurred along the fault in 1868. Historical accounts indicate both horizontal movements as much as 5 m and vertical displacements of 2–3 m (Wood, 1914). The maximum offset from this fault is less than 15 m. Lipman (1980) suggests that the Wai‘ōhinu Fault forms a structural boundary, or tear away zone, for seaward extension of Mauna Loa’s flank northeast of the fault.

DESCRIPTION OF MAP UNITS

[Small areas on the printed or plotted map are not labeled to avoid obscuring data; use unit color or the database (https://doi.org/10.3133/sim2932C) for unit identification. The simplified map unit label is not unique and provides quick access to flow morphology, flow age group, phenocryst mineralogy, and flow number in an age group (table 3, sheet 1); this non-unique unit label may be used for an entirely different unit on a different flank of Mauna Loa. We use the term “phenocryst” for any mineral >1 millimeter (mm) in maximum diameter. Pyroxene is not an abundant phenocryst in Mauna Loa lava flows and, therefore, it is not included in phenocryst mineralogy. Multiple labels for a unit are listed with the most abundant lithology first. In addition to the map unit label, a unique, three-digit flow identification number (FID; for example, FID 959) is assigned to each mapped flow unit to facilitate use of the database; therefore, the FID is essential as a unique descriptor for unit identification in the database]

SEDIMENTARY DEPOSITS

Qs **Surficial sedimentary deposits**—Deposits too small and transient to be a mappable unit. Deposits chiefly consist of colluvial and alluvial deposits of basaltic clasts, pebble- to cobble-sized gravel in drainages, which occur locally within parts of the map area. We also include sand

under this category. Sandy deposits include beach- and bay-filling deposits, gravel, and unconsolidated sand along and inland from the coast. In places, this sandy deposit has been remobilized by wind near Waikapuna and Kaʻaluʻalu.

VOLCANIC DEPOSITS

LAVA FLOWS AND VENT DEPOSITS

Kaʻū Basalt

The Kaʻū Basalt includes historic and prehistoric members. The prehistoric units range in age from 30,000 yr B.P to A.D. 1843. The Kaʻū Basalt consists of tholeiitic basalt, vent deposits, and lava flows. The flows are mostly aphanitic and some have variable amounts of olivine and plagioclase phenocrysts. Pyroxene is rare in hand specimen. Most of the map units are members of the Kaʻū Basalt.

Age Group 0 (A.D. 1843 and younger; Holocene)

m0b1, a0e1, m0e1, a0f1 — **A.D. 1950 flow**—ʻAʻā and minor pāhoehoe with variable amounts of olivine along the length of the fissure. The vents were distributed along the 18-km segment of the SWRZ between 7,880 and 12,600 ft (3,840–2,402 m) elevation. Most fissures are north of the map area at higher elevations, but a flow (Kahuku lobe) is at the north margin of the map area. Flows in the mapped area contain 5–15% olivine phenocrysts that are 1–10 mm in size. FID 488

a0b2, p0b2, s0b2 — **A.D. 1926 flow**—ʻAʻā and minor pāhoehoe in the northwest quadrant of the map. Contains 2% olivine phenocrysts and 0–1% plagioclase in a well-crystallized groundmass. Most of the fissure system is north of the map area. The downrift segment of the eruptive fissure is within the map area, at 7,240 ft (2,220 m) elevation. FID 489

a0b3, l0b3 — **A.D. 1919 flow**—ʻAʻā near the northwest boundary of the map. Contains 2% olivine phenocrysts and <1% plagioclase in a well-crystallized groundmass. The main eruptive fissure that fed this flow is located at 7,843 ft (2,391 m) elevation north of the map area. A flow entered the sea at ʻĀlika, north of Miloliʻi in south Kona. The flow is predominantly ʻaʻā; at the coast there is a littoral cone and associated deposits. FID 490

a0b4, s0b4 — **A.D. 1916 flow**—ʻAʻā and spatter ramparts near the northern boundary of the map, just south of the A.D. 1926 vents. Variable olivine content and size, ~0–5% subhedral phenocrysts and 0.5–6 mm in size. Olivine is light green in color and the groundmass is microcrystalline. The eruptive vents that fed flows in the mapped area are north of the map area, at 6,580 to 7,455 ft (2,006 to 2,272 m) elevation. FID 491

a0k5, s0k5 — **A.D. 1907 flow**—ʻAʻā and minor pāhoehoe near the center of the map and just south of the A.D. 1916 vents. Contains 3–8% plagioclase laths and 3–4% clear, subhedral olivine phenocrysts in a microcrystalline groundmass. This flow is the second-most plagioclase-rich historical eruption after the A.D. 1843 flow. The main eruptive fissure opened above Hawaiian Ocean View Estates subdivision at 6,555 ft (1,998 m) and extended 2.0 km to 6,000 ft (1,829 m) elevation. Additional eruptive fissures opened east of the subdivision at 3,000; 2,600; and 2,400 ft (914, 792, 732 m) elevations. Two lobes of ʻaʻā dissect the subdivision. The eastern lobe terminated approximately 2 km from the ocean. FID 492

a0i6, p0i6 — **A.D. 1903 flow**—ʻAʻā flow enters from the north edge of the map and extends ~10 km in a south-southeasterly direction across the map. The flow is due east of the A.D. 1926 and just south of the A.D. 1916 flow. Contains ~3% olivine and 0–3% plagioclase phenocrysts in a well-crystallized groundmass. FID 506

a0c7, s0c7 — **A.D. 1887 flow**—Massive dense rubbly ʻaʻā and minor spatter in the center of the map and just east of the A.D. 1907 vents. Contains 5–7% olivine phenocrysts as large as 7 mm in size and 0.5% plagioclase in a medium-gray microcrystalline groundmass. Also contains rare gabbroic microxenoliths. Eruptive fissures opened above Hawaiian Ocean View Estates and propagated down into the northeast part of the subdivision. FID 493

a0e8, p0e8, s0e8, l0e8 — **A.D. 1868 flow**—ʻAʻā, pāhoehoe, and spatter in the south-central part of the map. This flow forms the lowest elevation historical outbreak of lava on Mauna Loa's SWRZ. The vents were distributed along a 4-km segment of the SWRZ between 2,150 and 3,150 ft (655–960 m) elevation. Flows entered the sea in 2 hours! In addition, it created a large littoral cone, Puʻuhou. Contains 10–40% olivine phenocrysts (average 20%) as large as 10 mm in size and 0.5% plagioclase in a medium-gray microcrystalline groundmass. Unit also contains small xenoliths (1–2 cm) of dunnite, pyroxenite, and gabbro. FID 494

Age Group 1 (A.D. 1843–1,000 yr B.P.; Holocene)

a1j1, p1j1, s1j1 — **Manukā flow**—ʻAʻā, pāhoehoe, and spatter in the western part of the map. The eruptive vents are just west of the A.D. 1907 fissures and the flow extends ~20 km across the map in a southwest direction. Contains 7–10% subhedral to anhedral phenocrysts. Dull, light-green olivine ranges from 0.5 to 5 mm in size. Subhedral plagioclase is common at 3–4% abundance. The groundmass is medium gray and feldspathic. The surface color is dark brown. Age, 141±15 radiocarbon yr B.P. FID 497

a1b2, s1b2, p1b2, m1c2, s1c2, m1d2, l1f2, p1e2 — **Hapaimamo flows**—Impressive cinder cone and associated flows with large distributary channel systems. ʻAʻā and pāhoehoe near the northern boundary of Hawaiian Ocean View Estates. Variable olivine mineralogy forms ~2–25% euhedral to subhedral phenocrysts. Olivine is light green in color and ranges in size from 1 to 11 mm. The groundmass is microcrystalline. The initial-stage fissure vents are north of the main cinder cone, Hapaimamo, at higher elevations of 6,200 ft (1,890 m) and extend down 1 km to 5,820 ft (1,774 m) elevation. The flow is predominantly ʻaʻā. At the coast, there are several littoral cones; the largest is Nāpuʻuapele. This flow is the only Mauna Loa eruption documented in Hawaiian oral tradition in a legend called Na Puʻu a Pele (Westervelt, 1916). Age, 240±60 radiocarbon yr B.P. FID 499

p1i3, a1i3 — **Kīpāhoehoe flow**—Major flow on the southwest flank of Mauna Loa. The flow traverses from east to west in the northern part of Milolii and Papa quadrangles, flanking the lava flow of A.D. 1919. Most of the flow is tube-fed pāhoehoe. Tumuli are common, as are areas containing slabby pāhoehoe and fluid ʻaʻā. Contains 3–5% plagioclase phenocrysts that are commonly intergrown with olivine. Unit contains 2–4% olivine phenocrysts and microphenocrysts. Contains dense, well-crystallized, feldspathic groundmass. Surface is medium gray to black. Flow tops, locally glassy, are moderately weathered. Vesicles are subrounded, commonly distorted, and lined with magnesioferrite. Age, 402±33 radiocarbon yr B.P. FID 556

a1j4 — **Ke A Pele o Iki flow**—ʻAʻā in central part of Puu O Keokeo quadrangle, between the A.D. 1916 and A.D. 1926 flows. Contains ~8% subhedral olivine phenocrysts as large as 4 mm and 1% subhedral plagioclase phenocrysts. The groundmass is light gray and feldspathic. The surface color is gray. FID 495

p1f5 — **Kīpukanēnē flow**—Impressive tube-fed pāhoehoe that traverses the map from the northeast part of Puu O Keokeo quadrangle to the southeast where it reaches the sea. Variable olivine phenocrysts are ~2–25% abundant, euhedral to subhedral, light green, and 1–5 mm in size. The groundmass is microcrystalline. This flow, in places, is a prime example of olivine settling. Upper parts of the flow may have only 2–3% olivine whereas the core may have as much as 25%. Flow tops are black and glassy and ropey texture is well preserved. Lipman and Swenson (1984) originally spelled this flow name Kipuka Nene.[1] Weighted average age, 763±30 radiocarbon yr B.P. FID 547

p1l6, a1l6 — **Alapaʻi flow**—Pāhoehoe in contact with the distal lava flow of A.D. 1950 in Puu O Keokeo quadrangle. Contains dense, well-crystallized, feldspathic groundmass. Surface is medium gray to black. Flow tops, locally glassy, are mostly weathered; surface glass is broken up. Flow contains 7–20% subhedral olivine phenocrysts as large as 7 mm and 2–8% anhedral phenocrysts of plagioclase. Groundmass is medium gray and diktytaxitic. Vesicles are subrounded, commonly distorted, and may be lined by magnesioferrite. Age, 770±60 radiocarbon yr B.P. FID 548

p1b7 — **Waikapuna flow**—Pāhoehoe in the south-central part of Puu O Keokeo quadrangle that traverses the map in the south-southeast direction, extending to the coast at Waikapuna. Contains 1–5% olivine phenocrysts and <1% plagioclase in a well-crystallized diktytaxitic groundmass. Vesicles are subrounded and lined by magnesioferrite. Flow tops, locally glassy, are black in color. Age, 762±48 radiocarbon yr B.P. FID 549

p1i8, a1i8 — **Flow 550**—ʻAʻā and pāhoehoe in north central Puu O Keokeo quadrangle. Contains 5% plagioclase as blades and commonly intergrown with olivine. Unit contains 2% olivine phenocrysts and microphenocrysts. FID 550

p1b9, a1b9, s1b9 — **Kipuka Kanohina flow**—Massive ʻaʻā and spatter between the two lobes of the A.D. 1907 flow. Flow underlies much of the Hawaiian Ocean View Estates and enters the sea at Pōhue Bay. Flow contains 2–5% subhedral olivine phenocrysts in a light-gray, microcrystalline groundmass. Age, 750±60 radiocarbon yr B.P. FID 627

[1]We use the name Kipuka Nene (though update the spelling to Kīpukanēnē) to maintain consistency among published maps of Mauna Loa. Please note that, despite its name, this flow does not form a kīpuka.

a1j10, p1j10 **Halepōhāhā flow**—Thick ʻaʻā and minor pāhoehoe in central part of the map area. Flow runs parallel, on the west side, to the eastern lobe of the A.D. 1907 flow. Rock is characterized by 3–10% olivine and 2–5% plagioclase phenocrysts. The groundmass is well crystallized. Surface color is medium brown. Age, 926±53 radiocarbon yr B.P. FID 551

p1l11, a1l11 **Flow 565**—ʻAʻā and pāhoehoe near the northern edge of the map surrounded by the A.D. 1916 flow (unit a0b4, FID 491). A distinctive rock that contains 8–12% olivine and 5–8% plagioclase phenocrysts. Unit also contains minor (>1%) pyroxene and microxenoliths. Olivine, plagioclase, pyroxene, and microxenoliths are contrasted against a dark-gray crystalline groundmass. Surface color of this flow is dull black to medium gray. FID 565

a1l12, s1l12 **Flow 504**—Fissure vent and ʻaʻā flow south of Puʻuʻokeʻokeʻo in the northern central part of the map. Contains 7–12% olivine phenocrysts and microphenocrysts and 5–8% plagioclase mostly microphenocrysts and blades. Olivine and plagioclase commonly intergrown. The groundmass is gray in color and mildly feldspathic. Vesicles are subrounded and magnesioferrite lined. FID 504

Age Group 2 (1,000–2,000 yr B.P.; Holocene)

a2j1 **Keāpōhina flow**—Large ʻaʻā flow that traverses the Punaluu quadrangle from northwest to southeast in the central part of the quadrangle. Flow contains 10–15% olivine phenocrysts as large as 8 mm. Plagioclase phenocryst blades and laths make up as much as 2% of the unit. The groundmass is medium gray, dense, and microcrystalline. Age, 1,100±55 radiocarbon yr B.P. FID 496

a2i2, p2i2, s2i2, m2i2 **Kipuka Peehi flow**—Fissure vents and ʻaʻā in north central Puu O Keokeo quadrangle. Source vents surrounded by A.D. 1926 flow (unit a0b2, FID 489). Contains 2–6% subhedral plagioclase phenocrysts and blades. Unit contains 1–3% olivine phenocrysts and microphenocrysts in a medium-gray feldspathic groundmass. FID 546

a2i3, p2i3, m2i3 **Lua Nui flow**—Large ʻaʻā flow that traverses Puu O Keokeo quadrangle from north to south in the central part of the quadrangle. Contains 2–6% euhedral to subhedral olivine phenocrysts as large as 3 mm. Unit contains 1–3% plagioclase phenocrysts and microphenocrysts in a medium-gray feldspathic groundmass. Unit is covered by as much as 30 cm of ash. This unit, near its distal margin, has a large pit crater formed in the A.D. 1868 flow. Age, 1,190±150 radiocarbon yr B.P. FID 542

a2k4, m2k4, s2k4, p2k4 **Kīpukanoa flow**—ʻAʻā and pāhoehoe mostly found in western Kahuku Ranch and southeast Pohue Bay quadrangles. Contains 1–2% olivine phenocrysts and 4–10% subhedral plagioclase phenocrysts. The uppermost source vent is located northwest of the A.D. 1907 flow main fissure and the lowermost source vent is located in the northeast corner of Hawaiian Ocean View Estates at the quarry. Age, 1,290±50 radiocarbon yr B.P. FID 626

p2e5, a2e5, m2e5, s2e5 **Puu Ohohia flow**—ʻAʻā, pāhoehoe, and spatter in the west-central part of the map. The vent for this flow is Puu Ohohia at 5,524 ft (1,684 m) elevation. Flows from Puu Ohohia created the coastline from Kapuʻa to Manukā. Contains 12–25% olivine phenocrysts as large as 7 mm in size and minor amounts of plagioclase (0.5%) in a medium to light bluish-gray microcrystalline groundmass. Unit also contains microxenoliths. FID 553

p2i6, a2i6, m2i6, s2i6 **Puʻuʻokeʻokeʻo flow**—Major unit from Puʻuʻokeʻokeʻo cone. The flows traverse the map from Puʻuʻokeʻokeʻo cone in a west-southwest direction and from north to south in the central part of the map area. The north-south flow enters the sea in central Puu Hou quadrangle. Flow is most common as tube-fed pāhoehoe. Tumuli are common, as are areas containing slabby pāhoehoe and fluid ʻaʻā. Contains 1–10% plagioclase as blades and commonly intergrown with olivine. Unit contains 0–2% olivine phenocrysts and microphenocrysts. Age, 1,730±60 radiocarbon yr B.P. FID 545

p2b7 **Moaʻula flow**—Young-looking spongy pāhoehoe flow between Hiʻonamoa and Moaʻula Gulches in Pahala quadrangle. Flow originates from the Mauna Loa SWRZ. The pāhoehoe has 0–2% olivine in a well-crystallized groundmass. The flow tops are black and glassy. Flow overlain by ash in low-lying areas. Age, 1,827±17 radiocarbon yr B.P. FID 540

a2g8 **Flow 354**—ʻAʻā flow in northwest quadrant of Punaluu quadrangle. Flow is northeast of the A.D. 1950 flow. Contains 2% plagioclase phenocrysts and microphenocrysts and <1% olivine phenocrysts. Olivine commonly intergrown with plagioclase. The groundmass is dark gray, dense, and has abundant plagioclase microlites. Age, 1,860±70 radiocarbon yr B.P. FID 354

p2k9, a2k9 **Flow 570**—Pāhoehoe in northwest quadrant of Puu O Keokeo quadrangle surrounded by the A.D. 1903 and A.D. 1926 flows. Source vents are north of the mapped area. Contains 5–7% plagioclase as anhedral clusters. In addition, the unit contains 1–2% olivine phenocrysts in a light-gray, well-crystallized groundmass. FID 570

a2l10 **Flow 558**—ʻAʻā flow ~1.3 miles southeast of Manukā Bay. A distinctive rock that contains 8–10% subhedral plagioclase phenocrysts, 1–12% olivine phenocrysts, and 1% orthopyroxene.

Plagioclase, olivine, and orthopyroxene are contrasted against a medium-gray microcrystalline groundmass. Surface color of this flow is tan to chocolate brown. FID 558

a2a11 **Pāpā flow**—Major aphanitic ʻaʻā on the southwest flank of Mauna Loa. The flow traverses Papa and Milolii quadrangles from northeast to west-southwest in the northern part of the quadrangles, between the lava flows of A.D. 1919 and A.D. 1926. Contains <1% olivine phenocrysts in a well-crystallized and feldspathic groundmass that has obvious plagioclase microlites. Unit is covered by as much as 30 cm of ash. FID 557

a2i12 **Flow 625**—Rubbly ʻaʻā in northwest Puu O Keokeo quadrangle. Flow contains 1–3% subhedral, sugary olivine phenocrysts and ~2% plagioclase phenocrysts. Vesicles are subrounded to elongate and may be magnesioferrite lined. Surface color of this flow is orange tan and the flow is covered by as much as 10 cm of ash. FID 625

a2j13 **Flow 628**—ʻAʻā in the northeast corner of Pohue Bay quadrangle. The flow has ~6–8% subhedral blades and phenocrysts of olivine that have variable mineralogy. Olivine is clear, light green in color, and 1–6 mm in size. Glomerocrysts of plagioclase compose 2% of the flow. Anhedral clots of plagioclase and olivine are common. The groundmass is dark gray and feldspathic. The surface color is tan. FID 628

s2a14 **Cone 591**—Spatter ramparts near the apex of the A.D. 1907 flow and downslope of Keau flow (unit s4a21, FID 669) in Puu O Keokeo quadrangle. The spatter is aphanitic and has no visible phenocrysts. The surface color of the flow is tan orange. FID 591

a2i15 **Kiʻolakaʻa flow**—Dense ʻaʻā in north-central Kahuku Ranch quadrangle. Contains 1–4% subhedral olivine phenocrysts and ~1–2% plagioclase phenocrysts. The groundmass is medium-dark gray and feldspathic. FID 541

a2e16 **Pōhue Bay picrite flow**—ʻAʻā mostly in northeast Pohue Bay quadrangle; outliers in northwest Kahuku Ranch quadrangle. Late-stage fluid picritic ʻaʻā that fills channels and tubes of the Pōhue Bay flow (unit m2b24, FID 630). Rock contains 10–25% olivine phenocrysts and microphenocrysts and 0–1% plagioclase phenocrysts. The groundmass is microcrystalline. FID 629

m2i17, p2i17, s2i17 **Miloliʻi flow**—Major flow on the southwest flank of Mauna Loa. The vents are in the northern part of the Puu O Keokeo quadrangle and the flows traverse the map from northeast to west-southwest where they reach the sea in south Milolii quadrangle. This flow underlies the lava flows of A.D. 1916 and A.D. 1926. Flow contains 1–3% subhedral plagioclase phenocrysts and 0–3% olivine phenocrysts. The groundmass is microcrystalline and dark steely gray in color. Units also contain rare microxenoliths. FID 561

p2i18 **Kipuka Waiahuli flow**—Pāhoehoe near the northeastern margin of Pohue Bay quadrangle. Contains dark-gray groundmass, 4–5% subhedral olivine phenocrysts, and 1–2% subhedral plagioclase phenocrysts as large as 4 mm in size. Surface is broken and weathered yellow. Ash as thick as 0.1 m overlies this unit. FID 632

a2a19 **Flow 552**—Aphanitic ʻaʻā and minor pāhoehoe found in central Manuka Bay quadrangle. Rock is distinctive in that the groundmass is well crystallized and feldspathic, full of plagioclase microlites. FID 552

p2g20, a2g20 **Flow 567**—Pāhoehoe and dense, fine-grained rubbly ʻaʻā in northeast Puu O Keokeo quadrangle. Flow contains <1% widely scattered olivine phenocrysts and 2% subhedral plagioclase phenocrysts. FID 567

a2g21 **Flow 562**—ʻAʻā flow in north-central Papa quadrangle. Flow contains 0–1% olivine microphenocrysts and as much as 2% plagioclase phenocrysts. Plagioclase and olivine commonly intergrown. The groundmass is microcrystalline, dense, and has abundant plagioclase microlites. FID 562

p2c22 **Honomalino flow**—Tube-fed pāhoehoe found in the backshore of Honomalino Bay in Milolii quadrangle. Flow contains 7–10% olivine phenocrysts as large as 6 mm and microphenocrysts. The groundmass is microcrystalline and gray in color. FID 563

a2a23 **Kalihi flow**—Aphanitic pāhoehoe in the center of Milolii quadrangle that has ~1% small olivine phenocrysts and <1% plagioclase in a feldspathic, microlite-rich groundmass. Surfaces locally weathered to yellow orange, otherwise color is tan gray. FID 564

m2b24, p2b24, a2b24, l2b24 **Pōhue Bay flow**—Pāhoehoe and ʻaʻā that traverse Pohue Bay quadrangle from northeast to south-southwest. This flow has the largest tube and channels systems on the island. In addition, the littoral cones are some of the largest in Hawaii. Contains 4–5% olivine phenocrysts as large as 8 mm in a microcrystalline, dark-gray feldspathic groundmass. FID 630

a2k25 **Flow 691**—Tiny kīpuka of ʻaʻā along the northern boundary of Punaluu quadrangle. Contains 5–7% anhedral plagioclase phenocrysts and microphenocrysts in a well-crystallized groundmass. Flow has 1–2% olivine phenocrysts. Surfaces are orange stained and subdued owing to ash cover. Unit is blanketed by as much as 0.5 m of ash. FID 691

Age Group 3 (2,000–3,000 yr B.P.; Holocene)

a3a1 **Red Cone flow**—‘A‘ā flow of Keaīwa Gulch that has 0–1% olivine phenocrysts in a well-crystallized feldspathic groundmass. Prominent flow north and east of Pāhala town; planted with eucalyptus and macadamia trees. Age, 2,075±36 radiocarbon yr B.P. FID 295

a3g2 **Nīnole Gulch flow**—Massive ‘a‘ā in the southern part of Punaluu quadrangle in contact with the largest of the Nīnole Hills, Kaiholena and Makanau. Unit forms the southwest point of Punalu‘u Beach. Contains 2–5% plagioclase phenocrysts in a well-crystallized light-gray groundmass. Flow is covered by 5–10 cm of ash in places. Age, 2,312±57 radiocarbon yr B.P. FID 638

p3e3, a3e3, s3e3, l3e3 **Kā‘iliki‘i flow**—Pāhoehoe surrounded by A.D. 1868 flow mostly in central Kahuku Ranch quadrangle; outliers in Ka Lae and Puu Hou quadrangles. Flow has a weathered red-orange rind. Contains 10–15% olivine phenocrysts (as large as 8 mm) and microphenocrysts. The groundmass is mildly feldspathic. Age, 2,330±50 radiocarbon yr B.P. FID 543

a3i4, p3i4 **Nīnole flow**—Massive ‘a‘ā flow traverses through the middle of Punaluu quadrangle from northwest to southeast. Flow forms the northeastern side of Punalu‘u Beach. Contains 1–2% plagioclase phenocrysts and 0–1% olivine phenocrysts commonly intergrown with plagioclase. The groundmass is dense, finely crystalline, and feldspathic. Flow is covered by 5–10 cm of ash in places. Age, 2,349±19 radiocarbon yr B.P. FID 637

a3d5 **Hōkūkano flow**—Massive ‘a‘ā with large accretionary lava balls. Unit crosses the map from west to east across the southern part of Punaluu and northern Naalehu quadrangles. Contains 7–15% olivine phenocrysts as large as 7 mm in size and minor amounts of plagioclase (0.5%) in a medium-gray microcrystalline groundmass. Unit also contains rare pyroxene phenocrysts. Age, 2,405±24 radiocarbon yr B.P. FID 644

a3e6, p3e6, s3e6, l3e6 **Pu‘u 2847 flow**—Pāhoehoe and spatter ramparts in south-central Kahuku Ranch quadrangle; flows extend into Ka Lae and Puu Hou quadrangles. Main part of the unit is in contact with the A.D. 1868 flow along its west margin. Flow has a weathered red-orange rind. Contains 20–30% olivine phenocrysts (as large as 7 mm) and microphenocrysts. The groundmass is mildly feldspathic. Age, 2,630±50 radiocarbon yr B.P. FID 544

a3a7 **Flow 634**—Massive aphanitic ‘a‘ā east of northeast of Pu‘u‘enuhe, in the northeast corner of Punaluu quadrangle. Surface color is chocolate gray-brown. Contains 0–1% olivine phenocrysts in a bluish-gray groundmass. Plagioclase is rare, usually intergrown with olivine. Age, 2,920±60 radiocarbon yr B.P. FID 634

a3i8 **Puu o Lokuana flow**—Dense, weathered ‘a‘ā near the eastern margin of A.D. 1868 flow along South Point Road. Contains dark-gray groundmass, 2–3% olivine phenocrysts, and ~1% plagioclase phenocrysts. Groundmass is medium gray. Vesicles are subangular to subrounded and may be magnesioferrite lined. FID 639

a3k9, p3k9, s3k9 **Kipuka Kamiloaina flow**—Kīpuka in the west-central Pohue Bay quadrangle and tiny spatter ramparts in Puu O Keokeo quadrangle above the A.D. 1907 vents. Forms a distinctive coarse, plagioclase-rich, tube-fed pāhoehoe. Minor inconspicuous olivine phenocrysts form ~3% of the rock and are mostly intergrown with plagioclase. Abundant, large plagioclase crystals make up 5–6% of the rock. Groundmass is medium to dark gray and feldspathic; vesicles are small and poorly sorted. FID 659

m3i10, a3i10, p3i10 **Flow 652**—‘A‘ā located in southern part of Milolii and southwest Papa quadrangles. Contains 2–3% olivine and 1–3% fine plagioclase phenocrysts and microphenocrysts, commonly intergrown. Groundmass is light gray with many microlites of plagioclase. Flow is commonly covered by as much as 1 m of tan ash, especially at lower elevations; outcrops are fairly common. FID 652

p3a11 **Paikuahiwi flow**—Pāhoehoe that contains 1% olivine in a well-crystallized, feldspathic to diktytaxitic groundmass. Found in eastern Kahuku Ranch and southeastern Naalehu quadrangles. Outcrops are common; soil and (or) ash found in low spots. FID 633

p3d12 **Flow 645**—Pāhoehoe in the northeast corner of Kahuku Ranch and northwest Naalehu quadrangles. Contains 7–10% olivine phenocrysts as large as 10 mm in size in a bluish-gray feldspathic groundmass. Flow mantled by ~40 cm of ash. FID 645

s3b13 **Cone 661**—Spatter cones in southwestern Puu O Keokeo quadrangle. Contains 3–4% inconspicuous olivine phenocrysts in a well-crystallized groundmass. Rare plagioclase phenocrysts can be found. Unit is between the A.D. 1907 and A.D. 1887 flows, ~3 km north of Hawaiian Ocean View Estates. FID 661

m3b14 **Flow 656**—Pāhoehoe and ‘a‘ā in the Milolii quadrangle. Contains 1% olivine phenocrysts. Olivine is dull green in appearance and is small and inconspicuous. Plagioclase occurs as phenocrysts at <1% abundance. The groundmass is well crystallized and feldspathic, with abundant plagioclase microlites. Flow is located north of the large ‘a‘ā flow that forms Okoe Bay. FID 656

s3b15, a3b15, p3b15 **Ihuanu flow**—Spatter cone that has minor ʻaʻā and pāhoehoe in southwestern Puu O Keokeo quadrangle. Contains 2% olivine phenocrysts in a well-crystallized groundmass. Surfaces are deeply weathered and orange stained. Unit is between the A.D. 1907 and A.D. 1887 flows at the north end of Hawaiian Ocean View Estates. Unit is covered by 0.2–1 m of reticulite from Hapaimamo flow unit a1b2 (FID 499). FID 660

s3i16 **Cone 666**—Spatter cone kīpuka in Puʻuʻokeʻokeʻo flow unit p2i6 (FID 545) in the southwest quadrant of Puu O Keokeo quadrangle. The kīpuka is east of the A.D. 1887 flow. Contains 3–5% plagioclase and 1–2% olivine phenocrysts in a well-crystallized gray groundmass. FID 666

m3i17 **Flow 554**—Mixed ʻaʻā and pāhoehoe flow found in northeastern Punaluu quadrangle between Moaʻula and Hiʻonamoa Gulches. Contains 2–4% plagioclase as blades and microphenocrysts and 1–2% olivine phenocrysts and microphenocrysts. Olivine is light green and 1–3 mm in size. The groundmass is well crystallized and feldspathic. Flow is mantled by 0.3–1 m of ash. FID 554

a3j18 **Flow 698**—Olivine ʻaʻā in the Punaluu quadrangle. Rock is characterized by 15–20% olivine; sizes range from 1 to 6 mm and average 3.5 mm. Plagioclase phenocrysts form 1–2% of the rock and are equant (as large as 5 mm in size). The groundmass is microcrystalline and dull gray in color. FID 698

Age Group 4 (3,000–4,000 yr B.P.; Holocene)

p4a1 **Kauahāʻao flow**—Pāhoehoe flow underplates Waiʻōhinu and is home to Hāʻao Springs. Contains 0–1% olivine phenocrysts in a well-crystallized feldspathic groundmass. Unit is locally mantled by ash. Age, 3,393±57 radiocarbon yr B.P. FID 624

p4i2 **Flow 768**—Pāhoehoe and minor ʻaʻā in southwest Punaluu quadrangle. Contains 3–5% olivine and 3–4% plagioclase phenocrysts in a well-crystallized microlite-rich gray groundmass. Flow buried by 0.3–1 m of ash and (or) colluvium. Age, 3,506±48 radiocarbon yr B.P. FID 768

a4g3 **Flow 575**—ʻAʻā kīpuka in the north-central Puu O Keokeo quadrangle surrounded by the Alapaʻi flow unit p1l6 (FID 548). Contains 0–2% plagioclase and 0–1% olivine phenocrysts in a well-crystallized light-gray groundmass. The unit is covered by 0.2–0.5 m of ash. Age, 3,540±35 radiocarbon yr B.P. FID 575

a4h4, p4h4 **Flow 664**—ʻAʻā and pāhoehoe located in the northeast corner of Puu O Keokeo quadrangle. Unit contains 5–10% glomeroclasts of plagioclase. Groundmass is microcrystalline. Flow is covered by 0.1–0.5 m of ash. This flow overlies the Mountain House flow (unit m4j5, FID 751). FID 664

m4j5 **Mountain House flow**—Pāhoehoe and ʻaʻā that traverses south Punaluu quadrangle from west-southwest to east-southeast. Rock is characterized by 1–6% olivine and 1–7% plagioclase phenocrysts. The groundmass is well crystallized and full of plagioclase microlites. The unit is mantled with 0.1–0.2 m of ash. Age, 3,600±70 radiocarbon yr B.P. FID 751

a4g6 **Flow 655**—Dense ʻaʻā kīpuka in the northeast quadrant of Puu O Keokeo quadrangle and another in the northwestern quadrant of Naalehu quadrangle. Contains 1–2% plagioclase phenocrysts in a well-crystallized light-gray groundmass. Olivine is rare and commonly associated with plagioclase where it exists. The unit is covered by 0.2–0.5 m of ash. FID 655

p4b7 **Hiʻonaʻā flow**—Tube-fed pāhoehoe in the northern part of Naalehu quadrangle. Unit has a dull-black to gray, glassy rind top and is characteristically overlain by 0–0.3 m of ash. Contains 3–7% olivine as inconspicuous anhedral phenocrysts. The ground mass is gray, well crystallized, and diktytaxitic in places. Age, 3,680±25 radiocarbon yr B.P. FID 646

s4a8 **Kapoalaala cone**—Old spatter cone found encircled by the A.D. 1907 flow north of Hawaiian Ocean View Estates. The unit is aphanitic; no phenocrysts observed. This unit is found along the western boundary of the Puu O Keokeo quadrangle. FID 663

s4e9 **Cone 662**—Spatter cone in the northeast corner of the Hawaiian Ocean View Estates subdivision, located in the southeast corner of Puu O Keokeo quadrangle. Contains 20–35% olivine phenocrysts. FID 662

a4i10 **Flow 700**—Dense ʻaʻā west of western A.D. 1907 flow lobe in northeast Pohue Bay quadrangle. Rock is characterized by 1% olivine and 2% plagioclase phenocrysts. The groundmass is medium gray and microcrystalline. FID 700

a4k11 **Flow 657**—Small ʻaʻā kīpuka in the northwestern part of the Papa quadrangle surrounded by Kīpāhoehoe flow (unit p1i3, FID 556). Contains 5–7% plagioclase and 3–5% olivine phenocrysts in a gray microcrystalline microlite-rich groundmass. FID 657

a4h12 **Flow 667**—Kīpuka in the north-central Puu O Keokeo quadrangle. A coarse plagioclase-rich ʻaʻā. Contains 7–12% euhedral plagioclase laths as large as 6 mm in a gray microcrystalline groundmass. Upper surface is red-orange stained and weathered. Unit is covered by 0–30 cm of ash. FID 667

p4b13, s4b13 **Flow 699**—Tube-fed pāhoehoe in southeast Papa quadrangle in contact with the western A.D. 1907 flow lobe on the southeast side. Contains 3–7% olivine phenocrysts. Olivine is light green, clear, and 1 to 6 mm in size. The groundmass is dull gray and microcrystalline. Flow is mantled by tephra from Hapaimamo flow unit a1b2 (FID 499). FID 699

s4a14 **Cone 697**—Aphanitic spatter ramparts that cut Keau flow unit s4a21 (FID 669) on its south flank. Ramparts are located west of the highest elevation A.D. 1907 main flow and spatter ramparts in western Puu O Keokeo quadrangle. Rock is aphanitic and has microcrystalline groundmass. FID 697

a4g15 **Flow 689**—Tiny kīpuka in the northwest corner of Punaluu quadrangle and northeast of the A.D. 1950 flow. ʻAʻā contains 2% plagioclase phenocrysts and <1% olivine in a well-crystallized gray groundmass. The unit is covered by 0.2–0.5 m of ash. FID 689

a4j16, p4j16 **Flow 654**—Tube-fed pāhoehoe in Pohue Bay quadrangle, located at and near the Ocean View General Store. Flow has a weathered tan-orange rind. Rock contains 12–20% olivine phenocrysts and microphenocrysts and 0.5–3% plagioclase phenocrysts. The groundmass is microcrystalline. Ash as thick as 0.5 m overlies this unit. FID 654

a4b17 **Kīpukamālua flow**—ʻAʻā in southeast Manuka Bay quadrangle. Unit is ~1.5 km southeast of Manukā Bay. Contains ~2% widely scattered conspicuous olivine phenocrysts as large as 4 mm in a dark-gray feldspathic groundmass. ʻAʻā surface consists of angular blocks. FID 670

a4a18 **Flow 636**—Aphanitic ʻaʻā kīpuka in northwest and central Punaluu quadrangle. Rock contains 0.5% olivine phenocrysts and microphenocrysts (as large as 4 mm in size) in a microcrystalline groundmass. Vesicles are subangular to subrounded and magnesioferrite lined. FID 636

a4i19 **Flow 648**—ʻAʻā kīpuka in northeast corner of Naalehu quadrangle. Flow contains 2–4% anhedral plagioclase phenocrysts and 1–2% clear, inconspicuous olivine commonly intergrown with plagioclase. The groundmass is well crystallized and microvesicular. FID 648

p4j20 **Flow 622**—Flow in southern Puu O Keokeo and northern Kahuku Ranch quadrangles. Pāhoehoe containing 8% olivine phenocrysts and 4–5% plagioclase laths. Groundmass is dark gray and diktytaxitic. This unit harbors pockets of ash as thick as 40 cm in low-lying regions. FID 622

s4a21, p4a21 **Keau flow**—Aphanitic spatter cone located near the western boundary of Puu O Keokeo quadrangle near the apex of the A.D. 1907 flow. Rock is aphanitic with a microcrystalline groundmass. FID 669

p4l22, a4l22 **Kaulanamauna flow**—A distinctive plagioclase-bearing pāhoehoe flow containing 5–6% olivine phenocrysts and microphenocrysts and 8–9% plagioclase glomeroclasts in a diktytaxitic groundmass. Flow is overlain by ash as thick as 0.3 m. Unit traverses the map from northeast to southwest starting in south-central Papa quadrangle to the coast at Manukā Bay. FID 631

p4b23 **Flow 635**—Spongy tube-fed pāhoehoe contains 2–5% inconspicuous olivine phenocrysts in a well-crystallized groundmass. Olivine settling is present and cores of flows have concentrations as high as 10%. Surfaces are deeply weathered and orange stained. Flow is in contact with the southwest side of Puʻuʻenuhe in the Punaluu quadrangle. Flow is covered by 0.2–1 m of ash. FID 635

Age Group 5 (4,000–5,000 yr B.P.; Holocene)

p5c1 **Wailau flow**—Tan-orange stained, weathered pāhoehoe in southeast Punaluu quadrangle. Unit forms the coastline at the shore of Punaluʻu Harbor and Beach Park. Flow contains 7–10% olivine as light-green phenocrysts in a bluish-gray microcrystalline groundmass. Age, 4,028±33 radiocarbon yr B.P. FID 641

a5e2, s5e2 **ʻAkihi flow**—Picritic ʻaʻā originating from Kahuku Ranch quadrangle flowing southeast, creating Kaʻaluʻalu Bay of northeast Ka Lae quadrangle. Characterized by clear, large, subhedral to anhedral olivine as large as 10 mm that form 15–20% of the flow. Flow creates the coast from Kāhilipali Point to Kaʻaluʻalu. Age, 4,080±60 radiocarbon yr B.P. FID 623

a5a3 **Flow 555**—Dense aphanitic ʻaʻā in contact with Kaumaikeʻohu along its northeast flank in the northeast quadrant of the Punaluu quadrangle. Flow is characterized by 0.5% olivine and by its well-crystallized, medium-gray, feldspathic groundmass. Age, 4,575±35 radiocarbon yr B.P. FID 555

a5b4, p5b4 **Flow 750**—ʻAʻā with minor pāhoehoe in southwest Punaluu quadrangle. ʻAʻā contains 1–2% olivine phenocrysts and 0–1% plagioclase in a microcrystalline, medium-gray groundmass. Unit is blanketed by 0.1–0.3 m of ash. Age, 4,770±90 radiocarbon yr B.P. FID 750

a5l5, p5l5 **Flow 650**—Dense ʻaʻā with rare pāhoehoe in north-central Papa quadrangle. Contains 10–15% large, clear, olivine phenocrysts and 5–7% plagioclase as blades or anhedral clots. Groundmass is dull gray and mildly feldspathic. Gabbroic xenoliths are common. Vesicles are subrounded. FID 650

a5e6, p5e6 **Flow 715**—Flow in north-central Puu O Keokeo quadrangle. Mixed ʻaʻā and pāhoehoe containing 15% subhedral olivine phenocrysts as large as 6 mm. Groundmass is light gray and diktytaxitic. Surface is broken up and unit is deeply weathered orange-red in color. This unit is covered by ash. FID 715

s5k7 **Pu‘u 5680**—Oldest vent on the lower SWRZ, located ~2.5 km north of Hawaiian Ocean View Estates in western Puu O Keokeo quadrangle. Contains 5–6% plagioclase as subhedral phenocryst clusters. In addition, the unit contains 4–5% olivine phenocrysts in a well-crystallized groundmass. Upper surface is orange-stained and weathered. FID 668

a5b8, m5b8, p5b8 **Flow 778**—‘A‘ā and pāhoehoe kīpuka in the southeast A.D. 1907 flow on the eastern boundary of Pohue Bay quadrangle. Unit contains 1–2% olivine phenocrysts in a dense microcrystalline, medium-gray feldspathic groundmass. FID 778

a5e9, p5e9 **Kipuka Kalua o Kelii Waa flow**—Scattered picritic pāhoehoe and ‘a‘ā kīpuka within and adjacent to the A.D. 1887 flow in western Kahuku Ranch quadrangle. Unit is deeply weathered, covered by ash, and yellow-orange-tan on its surface. Contains large, euhedral olivine phenocrysts that form 25–40% of the rock. FID 759

p5g10 **Flow 741**—Pāhoehoe with minor ‘a‘ā in northeast Puu O Keokeo and northwest Punaluu quadrangles. Flow is between the Keāpōhina flow unit a2j1 (FID 496) and Kīpukanēnē flow unit p1f5 (FID 547). Contains 2–5% scattered plagioclase laths and phenocrysts; plagioclase ranges from 1 to 2 mm long. Flow contains <1% olivine. Groundmass is gray and microcrystalline. Flow has a thin mantle of 0–0.3-m-thick soil and (or) ash. FID 741

a5c11 **Flow 763**—Scattered ‘a‘ā and minor pāhoehoe kīpuka in the northwest part of the map, from northwestern Puu O Keokeo to Milolii quadrangle in the west. Flow at its distal end is in contact with the A.D. 1926 flow that destroyed the village of Ho‘ōpūloa. Contains 7–10% olivine as phenocrysts and microphenocrysts in a gray, mildly feldspathic, groundmass. FID 763

a5i12 **Flow 740**—‘A‘ā kīpuka in the southwest Puu O Keokeo and northwest Kahuku Ranch quadrangles. Flow contains 1–2% subhedral, clear olivine phenocrysts and ~1% plagioclase phenocrysts. Vesicles are subrounded to elongate and may be magnesioferrite lined. Flow is mantled by soil and (or) ash. FID 740

p5l13 **Flow 642**—Thick pāhoehoe (as thick as 5 m) in contact with the southeast margin of Makanau and forms the backshore of Kāwā Bay. Flow is located in southeast Punaluu and northeast Naalehu quadrangles. Rock is characterized by 5–8% olivine and 3–7% plagioclase phenocrysts. The groundmass is well crystallized, diktytaxitic, and full of plagioclase microlites. FID 642

a5d14, p5d14 **Flow 764**—‘A‘ā and minor pāhoehoe within eastern Pohue Bay quadrangle, south of Hawaiian Ocean View Estates. Unit is olivine-rich, has no surface glass, and is highly vesicular. Contains 10–15% clear, euhedral olivine phenocrysts (as large as 6 mm) that are commonly oxidized. FID 764

p5c15 **Flow 649**—Tan-yellow weathered pāhoehoe in north-central Naalehu quadrangle found as kīpuka near Hōkūkano flow unit a3d5 (FID 644). Flow contains 5–7% olivine phenocrysts in a light bluish-gray feldspathic groundmass. Flow mantled by 0.2–0.6 m of ash. FID 649

Age Group 6 (5,000–6,000 yr B.P.; Holocene)

p6a1 **Flow 745**—Large flow in northwestern Punaluu quadrangle northeast of Pu‘u‘enuhe. Unit sits under 0.3–0.5 m of ash and is a tube-fed pāhoehoe. Contains <1% olivine phenocrysts as large as 3 mm, mostly small and inconspicuous. The groundmass of this unit is feldspathic to diktytaxitic. Age, 5,414±29 radiocarbon yr B.P. FID 745

a6b2 **Flow 716**—Pāhoehoe that has no surface glass and lots of mechanical weathering in north-central Puu O Keokeo quadrangle, between the A.D. 1950 and A.D. 1903 flows. Contains 2–3% widely scattered olivine phenocrysts in a gray feldspathic groundmass. This unit is buried by ash, soil, and (or) colluvium. FID 716

p6f3 **Flow 767**—Pāhoehoe kīpuka in the southeast quadrant of Punaluu quadrangle. Content of subhedral to euhedral olivine phenocrysts ranges from 7–10% in center of flow to 1–4% near surface. Vesicles are subrounded to spherical, poorly to moderately sorted, and include rare pipe vesicles. Groundmass is gray, microcrystalline to diktytaxitic. Flow is covered by 0.2–0.4 m of ash. FID 767

p6e4, a6e4 **Flow 762**—Pāhoehoe and minor ‘a‘ā mostly in the north-central Papa quadrangle; outliers in north Milolii quadrangle. Flow has a weathered red-orange rind. Rock contains 7–25% olivine phenocrysts and microphenocrysts. The groundmass is mildly feldspathic to diktytaxitic. Sparse ash cover as thick as 0.1 m overlies this unit. FID 762

p6a5 **Flow 720**—Small kīpuka in the north-central Puu O Keokeo quadrangle, just east of the lowermost east-flowing A.D. 1950 flow lobe. Unit under 0.1–0.4 m of ash is a pāhoehoe. The groundmass of this unit is feldspathic, full of plagioclase microlites. FID 720

a6i6 **Flow 746**—Pāhoehoe in contact with Pu‘u‘enuhe on the downslope (makai) side in Punaluu quadrangle. Contains 3–4% olivine phenocrysts and 1–2% plagioclase. Vesicles are subrounded

to spherical, poorly to moderately sorted. Groundmass is gray and microcrystalline. Flow is covered by 0.2–0.4 m of ash. FID 746

s6d7 **Kamakapaa flow**—Tan-orange weathered spatter in central Kahuku Ranch quadrangle, observed as kīpuka adjacent to the A.D. 1868 flow above Highway 11. Unit contains 10–15% olivine phenocrysts in a gray groundmass. Unit mantled by ash. FID 777

p6a8 **Flow 769**—Tiny kīpuka in an arroyo upslope of Kāwā Bay in south Punaluu quadrangle. Flow is sparsely olivine-phyric tube-fed pāhoehoe. Contains 0–1% olivine phenocrysts in a light-gray, feldspathic to diktytaxitic groundmass. Unit overlain by 0.5–2 m of ash. FID 769

Age Group 7 (6,000–7,000 yr B.P.; Holocene)

p7b1 **Haleokāne flow**—Tube-fed pāhoehoe that has very little surface glass and lots of mechanical weathering because of agricultural activities in the eastern part of Naalehu quadrangle, near the scenic lookout above Honu‘apo Bay. Contains ~3% widely scattered olivine phenocrysts in a gray feldspathic groundmass. This unit is partly buried by ash and soil. Age, 6,246±35 radiocarbon yr B.P. FID 722

Age Group 8 (7,000–8,000 yr B.P.; Holocene)

a8c1, s8c1 **Puu Poo Pueo flow**—Olivine-bearing spatter ramparts and ‘a‘ā that traverse the middle of Ka Lae quadrangle. Flow contains 4–12% euhedral to subhedral olivine phenocrysts and microphenocrysts. The groundmass is well crystallized and full of plagioclase microlites. Flow is mantled by 0.4–1.2 m of ash. Age, 7,750±70 radiocarbon yr B.P. FID 747

p8e2, s8e2 **Kamakalepo flow**—Widespread picritic pāhoehoe below Wai‘ōhinu town in Naalehu quadrangle that extends to Ka‘alu‘alu Bay in Ka Lae quadrangle. Characterized by 15–35% large, clear, subhedral olivine phenocrysts. Flow is covered by variable amounts of ash. A large tube system is on the Ka‘alu‘alu side of the flow. FID 739

Age Group 9 (8,000–9,000 yr B.P.; Holocene)

p9e1, a9e1 **Kāhilipali Nui flow**—Widespread picritic pāhoehoe below Nā‘ālehu town in Naalehu quadrangle; an outlier of ‘a‘ā is near Hā‘ao Springs. Characterized by 15–35% large, clear, subhedral to anhedral olivine and 0–2% plagioclase phenocrysts, mostly intergrown with olivine. Vesicles are highly irregular in distribution, subrounded, and commonly magnesioferrite lined. Flow is commonly covered by as much as 1 m of tan ash; outcrops are fairly common. This flow has an extensive tube system. Xenoliths are common. Age, 8,870±56 radiocarbon yr B.P. FID 647

p9a2 **Alakaha flow**—Altered pāhoehoe close to the coast near Kāhilipali Nui, southeast of Nā‘ālehu town, east-central Naalehu quadrangle. Contains <1% olivine microphenocrysts. The groundmass is microcrystalline and feldspathic. Unit is buried by 45 cm of ash and is overlain by Kāhilipali Nui flow unit p9e1 (FID 647). FID 773

Age Group 10 (9,000–10,000 yr B.P.; Holocene)

p10b1 **Ka‘ū High School flow**—Tube-fed pāhoehoe that underlies the town of Pāhala. Contains 0–5% olivine phenocrysts in a well-crystallized groundmass. Flow tops are stained orange red. Flow is buried by 1.5–2 m of ash. Age, 9,121±46 radiocarbon yr B.P. FID 383

p10c2 **Lae‘opuhili flow**—Large regional pāhoehoe in Pahala quadrangle. Pāhoehoe contains 7–10% olivine phenocrysts in a light-gray diktytaxitic groundmass. Unit is covered by 0.3–1 m of ash. Age, 9,218±79 radiocarbon yr B.P. FID 742

m10k3 **‘Iliokōloa flow**—Flow in Pahala quadrangle. Unit has both ‘a‘ā and pāhoehoe phases, informally known as the “plagioclase-rich flow” of Pahala quadrangle. Plagioclase ranges from 3–8% as anhedral clots and laths. Also contains 1–8% olivine as green phenocrysts and microphenocrysts. Unit is overlain by 0.5–5 m of ash. FID 382

m10f4 **Flow 766**—‘A‘ā and pāhoehoe found in drainages of southeastern Punaluu quadrangle. Contains 3–7% olivine phenocrysts in a medium-gray, microcrystalline, feldspathic groundmass. Flow is covered by 0.2–1 m of ash. FID 766

Age Group 11 (10,000–15,000 yr B.P.; Holocene and Pleistocene)

p11f1 **Honu‘apo flow**—Sequence of tube-fed pāhoehoe and minor ‘a‘ā near Honu‘apo in the backshore of central-east Naalehu quadrangle. Flow is vesicular, generally oxidized to orange yellow, and has dark blue-gray groundmass where fresh. Contains 2–12% light-green, equant, altered olivine phenocrysts and microphenocrysts. Commonly overlain by 0.5–1.5 m of ash. Age, 10,678±56 radiocarbon yr B.P. FID 758

p11b2 **Flow 756**—Old tube-fed pāhoehoe found at the distal end of the Alapaʻi flow unit p1l6 (FID 548) above Nāʻālehu. Contains 1–3% inconspicuous olivine phenocrysts in a well-crystallized diktytaxitic groundmass. Surfaces are orange stained. Flow buried by 0.2–1.5 m of ash. Age, 10,995±40 radiocarbon yr B.P. FID 756

p11c3, s11c3 **Puu Poopaa flow**—Spatter cone and large tube-fed pāhoehoe found in southeast Kahuku Ranch and northeast Ka Lae quadrangles. Flow contains 10–12% olivine phenocrysts and microphenocrysts. The groundmass is well crystallized and feldspathic. Flow mantled by 0.5–1.5 m of ash. Age, 13,552±112 radiocarbon yr B.P. FID 749

p11a4, s11a4 **Flow 748**—Spongy tube-fed pāhoehoe contains <1% inconspicuous olivine phenocrysts and plagioclase in a well-crystallized groundmass. Surfaces are deeply weathered and orange stained. Flow as kīpuka is found in south-central Kahuku Ranch and west-central Ka Lae quadrangles. Unit is covered by 2 m of ash. Age, 13,940±110 radiocarbon yr B.P. FID 748

p11b5 **Kaʻalāiki flow**—Old pāhoehoe located along the south-central boundary of Punaluu quadrangle. This unit is characterized by 0–3% olivine phenocrysts in a microcrystalline dull-gray groundmass. Unit is buried by 1–3 m of ash. FID 753

m11i6, a11i6, p11i6 **Pohakuohau flow**—ʻAʻā located along Highway 11 between Honuʻapo and Nāʻālehu in east-central Naalehu quadrangle. This unit is characterized by 5% plagioclase and 1% olivine phenocrysts in a microcrystalline gray groundmass. Unit is buried by 0.1–1 m of ash. FID 771

s11c7 **Puu Kanikani cone**—Tiny spatter cone kīpuka in south-central Kahuku Ranch quadrangle, surrounded entirely by the Puu Poopaa flow unit p11c3 (FID 749). Contains 7–9% altered olivine phenocrysts and microphenocrysts. Flow is mantled by ash. FID 775

Age Group 12 (15,000–20,000 yr B.P.; Pleistocene)

p12k1 **Kaunāmano flow**—Weathered pāhoehoe, retaining little surface glass and stained red orange. Minor olivine phenocrysts form 1–4% of the rock and are mostly intergrown with plagioclase. Abundant plagioclase phenocrysts and microphenocrysts make up 7–15% of rock. Groundmass is well crystallized and diktytaxitic. Flow buried by 0.5–1 m of ash. Age, 16,445±80 radiocarbon yr B.P. FID 757

p12a2 **Flow 770**—Gully-exposed extremely altered pāhoehoe in Honuʻapo flow unit p11f1 (FID 758) of north-central Naalehu quadrangle. Contains 0–1% olivine phenocrysts and microphenocrysts. The groundmass is microcrystalline and feldspathic. Unit is buried by 3–4 m of ash. FID 770

p12b3 **Puu Hoomaha flow**—Old tube-fed sequence of faulted pāhoehoe located above Waiʻōhinu in central Naalehu quadrangle. Unit has an orange surface, is weathered, and is characteristically overlain by 1–3 m of ash. Contains 1–3% inconspicuous olivine as phenocrysts, commonly altered, in a medium-gray diktytaxitic groundmass. FID 760

s12c4 **Cone 776**—Tiny kīpuka in south-central Kahuku Ranch quadrangle between lobes of the A.D. 1868 flow in the ash unit ts (FID 959). Flow contains 7–10% olivine phenocrysts and microphenocrysts. Flow is mantled by ash. FID 776

Age Group 13 (20,000–30,000 yr B.P.; Pleistocene)

a13b1 **Flow 384**—Lava flow in section at Hiʻonamoa Gulch. ʻAʻā contains variable amounts (1–7%) of olivine phenocrysts in a bluish-gray microcrystalline groundmass. Flow is under the Kaʻū High School flow unit p10b1 (FID 383). Unit is covered by 0.5–1.0 m of ash. Age, 25,768±188 radiocarbon yr B.P. FID 384

p13e2 **Papakōlea flow**—Pāhoehoe surrounding Puāuāomahana (commonly referred to as "Green Sand beach") and overlies the Hāliʻi flow unit a14e4 (FID 761) in Ka Lae quadrangle. Rock contains 25–30% subhedral olivine phenocrysts and microphenocrysts as large as 10 mm in size. The groundmass is dense and feldspathic. Ash as thick as 1 m overlies this unit. Age, 27,155±328 radiocarbon yr B.P. FID 752

a13f3 **Lava flow of Hiʻonamoa Gulch**—ʻAʻā that lines the floor of Hiʻonamoa Gulch near Highway 11 in Pahala quadrangle. Contains variable amounts of olivine, ranging from 0 to 8% as phenocrysts in a bluish-gray microcrystalline groundmass. Flow is overlain by the Kaʻū High School flow unit p10b1 (FID 383). Unit is covered by 0.5–1.0 m of ash. Age, 28,140±590 radiocarbon yr B.P. FID 735

p13b4 **Flow 772**—Pāhoehoe exposed only in gullies above Nāʻālehu between Kaunāmano (unit p12k1; FID 757) and Puu Hoomaha (unit p12b3; FID 760) flows of Naalehu quadrangle. Contains 1–2% olivine phenocrysts and microphenocrysts in a light-gray microcrystalline groundmass. Unit is buried by 3–5 m of ash. FID 772

Kahuku Basalt

The Kahuku Basalt consists of units with an age range of 100,000 to 30,000 yr B.P. The Kahuku Basalt is composed of tholeiitic basalt, tuffs, vent deposits, and lava flows that rest unconformably on the Nīnole Basalt. The flows are mostly aphyric and some have variable amounts of olivine and plagioclase phenocrysts. The Kahuku Basalt type locality is the Kahuku Pali or Kahuku Fault near Kalae (South Point). Kahuku Basalt rocks are also exposed in scarps north of Waiʻōhinu and along the coast from Waikapuna to Honuʻapo, at Māniania Pali.

Age Group 14 (30,000–100,000 yr B.P.; Pleistocene)

m14f1 **Kahuku Pali section**—Vertical section of a stack of lava flows within the Kahuku Pali and includes the three pit craters at the northern extent of the fault. Units consist of mixed ʻaʻā and pāhoehoe flows. Rock contains variable amounts of olivine phenocrysts and microphenocrysts as large as 8 mm in size. The groundmass is gray and feldspathic. Ash as thick as 2 m overlies this unit. In section, several other ash beds are intercalated with flows. FID 721

p14h2 **Kipaepae flow**—Pāhoehoe observed in fault scarp at Māniania Pali southeast of Nāʻālehu. The flow contains about 1% olivine and plagioclase phenocrysts, commonly intergrown. Olivine is green and clear. Plagioclase is anhedral and as large as 3 mm in size. Groundmass is medium gray and diktytaxitic. This flow underlies the Pāhala Ash (unit pa; FID 389). FID 723

m14f3 **Undifferentiated basalt flows**—Undivided units found in fault scarps, sea cliffs, pit craters, landslide scars, and caldera walls. The flows are mostly deeply weathered and have variable amounts of olivine and possibly plagioclase phenocrysts. FID 754

a14e4 **Hāliʻi flow**—Rock contains 20–30% subhedral olivine phenocrysts and microphenocrysts as large as 8 mm in size. The groundmass is dense, dark gray, and feldspathic. Ash as thick as 2 m overlies this unit. A flow age of >49,900 radiocarbon yr B.P. (radiocarbon dead) was obtained for this unit. FID 761

s14e5 **Puāuāomahana**—Tuff/Surtseyan cone surrounded by Papakōlea flow unit p13e2 (FID 752) in Ka Lae quadrangle. This unit is commonly referred to as "Green Sand beach." The bay is eroded into a part of the cone, which is about 38 m high, but the true height is unknown because the base of the deposit is below sea level. Lithic and juvenile blocks in an ashy, palagonitic matrix compose the map unit. The blocks are as large as 0.5 m in size. Walker (1992) presents convincing evidence for the primary vent versus littoral origin of Puāuāomahana (Puʻu o Mahana). Rock contains 20–30% subhedral olivine phenocrysts and microphenocrysts as large as 8 mm in size. The groundmass is dense, dark gray, and feldspathic. Ash as thick as 2 m overlies this unit. Puāuāomahana is overlain by Hāliʻi flow unit a14e4 (FID 761) on its northeast flank, which is >49,900 radiocarbon yr B.P. FID 774

Nīnole Basalt

The Nīnole Basalt, the oldest exposed rocks on Mauna Loa, is >100,000 years old. These rocks are exposed in the Kaʻū District. The Nīnole Basalt consists of tholeiitic basalt, tuffs, vent deposits, and lava flows. The flows are mostly aphyric and some have variable amounts of olivine and plagioclase phenocrysts.

Age Group 15 (>100,000 yr B.P.; Pleistocene)

n **Nīnole Basalt**—Undivided units found in the valley wall of Wood Valley. Flows are mostly aphyric and deeply weathered and have variable amounts of olivine and plagioclase phenocrysts. Lipman and others (1990) report a weighted mean age of 120,000±56,000 years for the Nīnole Basalt, whereas Jicha and others (2012) constrain the Nīnole Basalts to have erupted from 227,000 to 108,000 years. FID 744

DISTAL TEPHRA DEPOSITS

Tephra (Holocene and Pleistocene)

ts **Southern tephra**—Beds of ashfall deposits in the map area are chiefly from Kīlauea Volcano and likely include contributions from Mauna Loa (Easton, 1987). All ash deposits ≤10,000 yr B.P. are included in this category. Kīlauea deposits include ^{14}C ages of 2,110±120 yr B.P., 2,265±50 yr B.P., and 2,770±70 yr B.P., all dating the Uēkahuna Ash Member of the Puna Basalt (Dzurisin and others, 1995; note that older publications spell this geographic name "Uwekahuna"). Other ages of 4,135±49 and 9,500±140 yr B.P. were obtained from ash layers on the east flank of the volcano. Distributions of ash near Kīlauea seem to be influenced by the inversion layer on the windward coast of the Island of Hawaiʻi. This meteoric phenomenon

appears to limit distribution of ash to lower elevations; therefore, overlay patterns for ash deposits may vary with elevation within flows or on flows of similar age. Possibly, ash deposited at higher elevations (alpine and above) lack vegetative cover that preserves it, allowing combined wind and rainfall to strip ash deposits from higher elevations. FID 959

pa **Pāhala Ash**—Deep Pāhala Ash 5–8 m thick exposed at the surface. Unit comprises several kīpukas in northwest-central Pahala quadrangle. Unit is older than surficial ash deposits (unit ts; FID 959). Unit comprises multiply bedded airfall deposits whose origin is unknown. Most likely, Pāhala Ash has Kīlauea Volcano origin, although Mauna Loa cannot be excluded as a source. Unit is overlain by flow units p11f1 (FID 758) and p9e1 (FID 647), dated at 10,678 and 8,870 radiocarbon yr B.P., respectively. Age, 31,020±310 radiocarbon yr B.P. FID 389

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Table 2. Radiocarbon ages of samples from the southern flank of Mauna Loa volcano, Island of Hawai‘i, Hawaii.

[All ages are reported in radiocarbon years before present (yr B.P., before the calendar year datum of A.D. 1950). Materials dated include charcoal, roots, twigs, vegetative litter, or unaltered wood (rarely). See figure 1 for quadrangle locations. ft, feet; yr, years; S.D., standard deviation]

Unit label[1]	FID[2]	Age[1] group	Unit name	Field No.	Lab No.[3]	Quadrangle name (1:24,000)
a1j1	497	1	Manukā flow	L-93-87	USGS3464	Pohue Bay
a1j1	497	1	Manukā flow	FT-90-03	W6271	Pohue Bay
m1f2	499	1	Hapaimamo flows	L-94-41	WW856	Puu O Keokeo
p1i3	556	1	Kīpāhoehoe flow	L-93-241	USGS3467	Milolii
p1i3	556	1	Kīpāhoehoe flow	L-93-40	WW337	Papa
p1f5	547	1	Kīpukanēnē flow	L-94-124	WW858	Puu O Keokeo
p1f5	547	1	Kīpukanēnē flow	77L-40	W4012	Punaluu
p1f5	547	1	Kīpukanēnē flow	77L-43	W4156	Punaluu
p1f5	547	1	Kīpukanēnē flow	77L-32	W4137	Punaluu
p1f5	547	1	Kīpukanēnē flow	78L-21	W4231	Punaluu
p1l6	548	1	Alapa‘i flow	L-94-121	WW857	Puu O Keokeo
p1b7	549	1	Waikapuna flow	L-93-283	WW853	Kahuku Ranch
p1b7	549	1	Waikapuna flow	L-90-16	W6415	Puu O Keokeo
p1b9	627	1	Kipuka Kanohina flow	L-93-02	WW232	Pohue Bay
a1j10	551	1	Halepōhāhā flow	L-91-194	W6463	Pohue Bay
a1j10	551	1	Halepōhāhā flow	L-94-12	USGS3484	Puu O Keokeo
a1j10	551	1	Halepōhāhā flow	L-91-206	AA10231	Pohue Bay
a2j1	496	2	Keāpōhina flow	L-98-528	WW1939	Punaluu
a2i3	542	2	Lua Nui flow	L-90-21c	W6420	Puu O Keokeo
a2k4	626	2	Kīpukanoa flow	L-94-10	WW855	Kahuku Ranch
p2i6	545	2	Pu‘u‘oke‘oke‘o flow	L-93-245	WW235	Kahuku Ranch
p2b7	540	2	Moa‘ula flow	77L-04[10]	W3850	Pahala
p2b7	540	2	Moa‘ula flow	L-91-525[10]	W6470	Pahala
p2b7	540	2	Moa‘ula flow	9P77C[10]	W5153	Pahala
p2b7	540	2	Moa‘ula flow	L-93-545	USGS3475	Punaluu
p2b7	540	2	Moa‘ula flow	L-93-596	USGS3478	Punaluu
p2b7	540	2	Moa‘ula flow	L-93-639	WW347	Punaluu
a2g8	354	2	Flow 354	77L-61	W4022	Punaluu
a3a1	295	3	Red Cone flow	77L-56[10]	W4161	Keaiwa Reservoir
a3a1	295	3	Red Cone flow	77L-57[10]	W4163	Keaiwa Reservoir
a3a1	295	3	Red Cone flow	L-91-186[10]	W6349	Keaiwa Reservoir
a3g2	638	3	Nīnole Gulch flow	77L-31	W4008	Punaluu
a3g2	638	3	Nīnole Gulch flow	77L-45	W4142	Punaluu
p3e3	543	3	Kā‘iliki‘i flow	L-93-254	WW236	Kahuku Ranch
a3i4	637	3	Nīnole flow	L-93-610E	SUERC-10375	Punaluu
a3i4	637	3	Nīnole flow	L-93-626	USGS3479	Punaluu
a3d5	644	3	Hōkūkano flow	77L-47-A	W4015	Naalehu
a3d5	644	3	Hōkūkano flow	L-93-642R	SUERC-10386	Naalehu

Latitude[4] (degree)	Longitude[4] (degree)	Elev (ft)	Age[5] (yr B.P.)	S.D.[5] (yr)	Weighted average[6] (yr B.P.)	S.D.[6] (yr)	Quality[7]	Age range[8] (calendar years)	Source[9]
19.115205	−155.854191	1,100	140	15	141	15	+	1674 to 1942	3
19.111910	−155.858947	620	190	90	141	15	+	1674 to 1942	3
19.179467	−155.740714	5,800	240	60			+	1481 to 1952	3
19.233316	−155.876104	1,520	385	40	402	33	+	1439 to 1634	3
19.214243	−155.871085	1,720	440	60	402	33	+	1334 to 1634	3
19.209735	−155.656127	5,860	650	60	763	30	+	−1267 to −1411	3
19.134818	−155.549561	1,000	740	60	763	30	+	−1166 to −1390	1
19.147783	−155.563181	1,550	740	60	763	30	+	−1166 to −1390	1
19.138550	−155.551826	1,250	890	200	763	30	+	−710 to −1422	1
19.168364	−155.598649	2,880	910	60	763	30	+	−1019 to −1251	1
19.195069	−155.675280	5,680	770	60			+	1054 to 1386	3
19.038482	−155.628017	980	640	60	762	48	+	1272 to 1413	3
19.185411	−155.673079	5,380	980	80	762	48	+	894 to 929	3
19.099242	−155.760807	2,630	750	60			+	1160 to 1389	3
19.072426	−155.752893	1,800	880	76	926	53	+	1019 to 1157	3
19.139228	−155.735349	4,400	860	120	926	53		1019 to 1157	3
19.058474	−155.760808	1,400	1,040	95	926	53	+	1019 to 1157	3
19.168190	−155.571840	2,105	1,100	55			+	780 to 1023	3
19.183137	−155.675677	5,325	1,190	150				586 to 1159	1
19.080338	−155.726064	2,280	1,290	50			+	652 to 867	3
19.091576	−155.699297	2,570	1,730	60			+	136 to 423	3
19.183767	−155.483063	450	1,810	80	1,827	17	+	31 to 405	1,2
19.183852	−155.481225	420	1,830	30	1,827	17	+	86 to 252	2
19.160780	−155.495431	175	1,500	70	1,827	17	0	421 to 655	2
19.196564	−155.518337	1,625	1,780	40	1,827	17	+	130 to 378	3
19.189404	−155.512131	1,320	1,885	30	1,827	17	+	61 to 219	3
19.193582	−155.505524	1,340	2,030	80	1,827	17	+	−352 to 132	3
19.245779	−155.610986	6,200	1,860	70			+	1 to 337	1
19.293844	−155.567445	6,760	2,000	70	2,075	36	+	−199 to 201	1,2
19.297790	−155.558647	6,680	1,980	80	2,075	36	+	−179 to 220	1,2
19.308173	−155.584640	7,520	2,150	50	2,075	36	+	−361 to −52	3
19.153398	−155.537812	1,035	2,300	60	2,312	57	+	−537 to −197	1
19.140196	−155.519567	175	2,440	200	2,312	57	+	−1004 to −45	1
19.057707	−155.687055	2,040	2,330	50			+	−727 to −209	3
19.169298	−155.539807	1,380	2,313	35	2,349	19	+	−484 to −210	3
19.169746	−155.557959	1,920	2,365	30	2,349	19	+	−511 to −391	3
19.114167	−155.572387	1,750	2,180	60	2,405	24	0	−386 to −60	1
19.121984	−155.555660	1,845	2,318	35	2,405	24	+	−505 to −215	3

Table 2. Radiocarbon ages of samples from the southern flank of Mauna Loa volcano, Island of Hawai'i, Hawaii.—*Continued*

Unit label[1]	FID[2]	Age[1] group	Unit name	Field No.	Lab No.[3]	Quadrangle name (1:24,000)
a3d5	644	3	Hōkūkano flow	L-93-642	WW854	Naalehu
a3d5	644	3	Hōkūkano flow	78L-236	W4377	Naalehu
p3e6	544	3	Pu'u 2847 flow	L-93-250	WW233	Kahuku Ranch
a3a7	634	3	Flow 634	L-93-598	WW346	Punaluu
p4a1	624	4	Kauahā'ao flow	L-93-181	WW239	Kahuku Ranch
p4a1	624	4	Kauahā'ao flow	HANSEN	W2016	Naalehu
p4a1	624	4	Kauahā'ao flow	MURATA	W856	Naalehu
p4i2	768	4	Flow 768	L-94-509	WW369	Punaluu
p4i2	768	4	Flow 768	L-93-721	WW348	Punaluu
a4g3	575	4	Flow 575	L-94-683[10]	WW624	Kauluoa
a4g3	575	4	Flow 575	L-94-683R[10]	WW1522	Kauluoa
m4j5	751	4	Mountain House flow	78L-19	W4223	Punaluu
p4b7	646	4	Hi'ona'ā flow	L-93-733	USGS3481	Naalehu
p5c1	641	5	Wailau flow	77L-34	W4152	Punaluu
p5c1	641	5	Wailau flow	77L-30A	W4132	Punaluu
p5c1	641	5	Wailau flow	L-93-604	SUERC-10384	Punaluu
a5e2	623	5	'Akihi flow	L-93-183	WW231	Kahuku Ranch
NAS[11]	NAS[11]	5		L-93-575	SUERC-10383	Punaluu
a5a3	555	5	Flow 555	L-93-556	USGS3476	Punaluu
a5b4	750	5	Flow 750	78L-20	W4224	Punaluu
p6a1	745	6	Flow 745	L-93-563	WW344	Punaluu
p6a1	745	6	Flow 745	L-93-691	WW1519	Punaluu
p6a1	745	6	Flow 745	L-93-583	WW345	Punaluu
NAS[11]	NAS[11]	6		77L-30B	W4135	Punaluu
NAS[11]	NAS[11]	6		L-93-605	SUERC-10385	Punaluu
p7b1	722	7	Haleokāne flow	77L-27	W3930	Naalehu
p7b1	722	7	Haleokāne flow	PG-04-04	SUERC-5415	Naalehu
p7b1	722	7	Haleokāne flow	77L-28c	W4117	Naalehu
a8c1	747	8	Puu Poo Pueo flow	77L-02	W4351	Ka Lae
p9e1	647	9	Kāhilipali Nui flow	L-16-499c	B483459	Naalehu
p9e1	647	9	Kāhilipali Nui flow	78L-225	W4372	Naalehu
p10b1	383	10	Ka'ū High School flow	L-93-101[10]	WW339	Pahala
p10b1	383	10	Ka'ū High School flow	L-91-50[10]	AA7656	Pahala
p10b1	383	10	Ka'ū High School flow	L-91-680[10]	W6482	Pahala
p10b1	383	10	Ka'ū High School flow	L-93-533	WW343	Punaluu
p10c2	742	10	Lae'opuhili flow	78L-18	W4201	Punaluu
p10c2	742	10	Lae'opuhili flow	9P70C1[10]	W4419	Pahala
NAS[11]	NAS[11]	11			W907	Naalehu
NAS[11]	NAS[11]	11		77L-44A	W4014	Punaluu

Latitude[4] (degree)	Longitude[4] (degree)	Elev (ft)	Age[5] (yr B.P.)	S.D.[5] (yr)	Weighted average[6] (yr B.P.)	S.D.[6] (yr)	Quality[7]	Age range[8] (calendar years)	Source[9]
19.121984	−155.555660	900	2,530	60	2,405	24	+	−804 to −417	3
19.114167	−155.572387	1,750	2,650	50	2,405	24	0	−916 to −674	3
19.107544	−155.696587	3,120	2,630	50			+	−910 to −594	3
19.177495	−155.529205	1,190	2,920	60			+	−1308 to −933	3
19.060514	−155.638725	1,680	3,360	60	3,393	57	0	−1870 to −1500	3
19.067752	−155.611573	1,070	3,620	250	3,393	57	+	−2847 to −1404	1
19.067261	−155.611752	1,070	3,740	250	3,393	57	+	−2872 to −1536	1
19.139828	−155.569587	1,635	3,500	80	3,506	48	+	−2031 to −1624	3
19.135724	−155.612890	2,960	3,510	60	3,506	48	+	−2014 to −1689	3
19.306380	−155.874038	1,200	3,570	50	3,540	35	+	−2107 to −1754	3
19.306380	−155.874036	1,240	3,510	50	3,540	35	+	−1522 to −1692	3
19.141048	−155.612685	3,225	3,600	70			+	−2140 to −1754	1
19.107015	−155.552083	480	3,680	25			+	−2137 to −1966	3
19.144761	−155.513941	275	3,800	200	4,028	33		−2866 to −1700	1
19.157535	−155.539572	1,220	3,900	90	4,028	33		−2623 to −2057	1
19.157708	−155.539573	1,235	4,056	36	4,028	33	+	−2849 to −2475	3
19.052019	−155.662781	1,815	4,080	60			+	−2869 to −2477	3
19.197590	−155.544230	2,355	4,146	38			+	−2878 to −2588	3
19.210914	−155.533878	2,400	4,575	35			+	−3497 to −3105	3
19.154218	−155.613174	3,425	4,770	90			+	−3710 to −3360	1
19.182935	−155.533837	1,880	5,420	60	5,414	29	+	−4339 to −4233	3
19.169712	−155.509997	640	5,390	40	5,414	29	+	−4339 to −4233	3
19.182935	−155.533837	1,860	5,460	60	5,414	29	+	−4339 to −4233	3
19.157969	−155.539544	1,220	5,160	200	5,492	38	+	−4443 to −3526	1
19.157859	−155.539561	1,235	5,505	39	5,492	38	+	−4450 to −4266	3
19.081974	−155.592038	1,860	6,160	110	6,246	35	+	−5310 to −5074	1
19.082109	−155.590541	1,795	6,250	37	6,246	35	+	−5310 to −5074	3
19.068247	−155.553895	70	7,300	500	6,246	35	0	−5310 to −5074	2
18.940805	−155.677179	320	7,750	70				−6747 to −6446	1
19.022514	−155.576840	100	8,840	30	8,870	56	+	−8220 to −7749	3
19.042758	−155.555540	120	9,080	80	8,870	56	0	−8703 to −7754	1
19.207847	−155.476969	980	8,720	70	9,121	46		−8166 to −7589	3
19.207824	−155.477039	975	8,955	115	9,121	46	+	−8425 to −7715	3
19.205090	−155.487983	1,160	9,960	170	9,121	46	+	−10171 to −8878	3
19.216798	−155.504659	2,115	9,540	80	9,121	46	+	−9213 to −8653	3
19.204503	−155.535279	2,140	9,170	100	9,218	79	+	−8694 to −8227	1,2
19.159658	−155.494753	210	9,300	130	9,218	79	+	−9118 to −8261	2
19.042758	−155.555540	200	10,140	300				−10667 to −8849	1
19.135201	−155.545958	750	10,820	90			+	−10966 to −10621	1

Table 2. Radiocarbon ages of samples from the southern flank of Mauna Loa volcano, Island of Hawai'i, Hawaii.—*Continued*

Unit label[1]	FID[2]	Age[1] group	Unit name	Field No.	Lab No.[3]	Quadrangle name (1:24,000)
p11f1	758	11	Honu'apo flow	77L-46	W4160	Naalehu
p11f1	758	11	Honu'apo flow	L-93-754	USGS3483	Naalehu
p11b2	756	11	Flow 756	L-93-761	USGS3457	Naalehu
NAS[11]	NAS[11]	11		77L-28B	W4121	Naalehu
p11c3	749	11	Puu Poopaa flow	L-06-02	SUERC-10387	Ka Lae
p11a4	748	11	Flow 748	L-93-359	WW341	Kahuku Ranch
NAS[11]	NAS[11]	11		PG-04-05	SUERC-5421	Naalehu
p12k1	757	12	Kaunāmano flow	L-93-770	USGS3458	Naalehu
p12k1	757	12	Kaunāmano flow	L-93-739	SUERC-10376	Naalehu
NAS[11]	NAS[11]	12	Mohokea	L-93-558	USGS3477	Punaluu
NAS[11]	NAS[11]	13		L-93-737	W349	Naalehu
a13b1	384	13	Flow 384	L-91-548	W6471	Punaluu
a13b1	384	13	Flow 384	L-91-564R	WW240	Pahala
a13b1	384	13	Flow 384	L-92-582	USGS3471	Pahala
NAS[11]	NAS[11]	13		77L-41	W4019	Punaluu
NAS[11]	NAS[11]	13		L-92-588[10]	USGS3473	Pahala
p13e2	752	13	Papakōlea flow	L-93-363	WW342	Ka Lae
p13e2	752	13	Papakōlea flow	78L-224	W4368	Ka Lae
a13f3	735	13	Lava flow of Hi'onamoa Gulch	L-91-555	WW321	Punaluu
NAS[11]	NAS[11]	13		77L-28A	W3935	Naalehu
a14e3	761	14	Hāli'i flow	L-03-526	WW4570	Ka Lae

[1]See table 3 for explanation of unit labels and definition of age groups.

[2]Unique, three-digit flow identification number assigned to each mapped surface-flow unit correlates with database (http://doi.gov/10.3133/sim2932C).

[3]Initial letter(s) identifies analytical laboratory: AA, University of Arizona, Tucson, Ariz.; B, BetaAnalytic, Miami, Fla.; SUERC, Scottish Universities Environmental Research Centre, NERC radiocarbon laboratory, Kilbride, Scotland, UK; USGS, U.S. Geological Survey ^{14}C laboratory, Menlo Park, Calif.; W, U.S. Geological Survey ^{14}C laboratory, Reston, Va. AMS ages have laboratory ID that start with letters of AA, B, SUERC, and WW (refers to AMS ages analyzed at U.S. Geological Survey ^{14}C laboratory, Reston, Va.)

[4]Decimal degrees; World Geodetic System of 1984.

[5]Calibrated ages are for two standard deviations.

[6]Weighted avg., each age is weighted by the inverse of its variance before averaging (for example, Taylor, 1982). A variance is reported as one standard deviation, in years.

[7]Quality: +, age considered meaningful; 0, age probably meaningful but accuracy may be poorer than indicated by the reported precision.

[8]Each age was calibrated to calendar years using CALIB 6.0 Radiocarbon Calibration Program (Stuiver and Reimer, 2011; Stuiver and others, 1998); calibrated ages are for two standard deviations. Entire age range of calendar ages is possible for a given sample. Unspecified ages, A.D.; negative (−) ages, B.C.

[9]Sources: 1, Kelley and others, 1979; 2, Rubin and others, 1987; 3, this study.

[10]Radiocarbon sample collected outside of mapped area: Pahala quadrangle (SIM 2932–B), and Kauluoa and Keaiwa Reservoir quadrangles (SIM 2932–D).

[11]NAS, flows not found at surface are exposed in drainages, fault scarps, and (or) sea cliffs.

[12]NAC, not able to calibrate ^{14}C age because too old for CALIB program.

Latitude[4] (degree)	Longitude[4] (degree)	Elev (ft)	Age[5] (yr B.P.)	S.D.[5] (yr)	Weighted average[6] (yr B.P.)	S.D.[6] (yr)	Quality[7]	Age range[8] (calendar years)	Source[9]
19.097014	−155.556264	610	10,290	150	10,678	56	+	−10709 to −9456	1
19.096224	−155.572765	1,578	10,740	60	10,678	56	+	−10911 to −10731	3
19.095220	−155.609436	2,340	10,995	40			+	−11120 to −10740	3
19.068247	−155.553895	50	13,210	300			+	−14943 to −13058	1
18.968647	−155.619615	20	13,552	112			+	−15739 to −12992	3
19.009510	−155.684053	1,165	13,940	110			+	−15466 to −14824	3
19.082066	−155.591043	1,825	13,945	177			+	−15582 to −14781	3
19.072106	−155.586624	1,220	16,400	90	16,445	80	+	−17879 to −17452	3
19.078822	−155.588188	1,600	16,606	171	16,445	80	+	−18157 to −17499	3
19.204358	−155.540561	2,280	17,910	810			+	NAC[12]	3
19.079504	−155.571593	1,175	20,370	250			+	NAC[12]	3
19.209769	−155.499810	1,610	25,570	600	25,768	188	+	NAC[12]	3
19.19938	−155.48648	990	25,000	460	25,768	188	+	NAC[12]	3
19.18879	−155.48278	575	25,970	220	25,768	188	+	NAC[12]	3
19.136925	−155.544884	600	26,410	390			+	NAC[12]	1
19.205142	−155.496453	1,400	26,450	120			+	NAC[12]	3
18.934265	−155.645985	6	26,650	570	27,155	328	+	NAC[12]	3
18.935802	−155.644663	30	28,150	800	27,155	328	+	NAC[12]	1
19.209662	−155.499829	1,605	28,140	590			+	NAC[12]	3
19.068247	−155.553895	5	31,100	900			+	NAC[12]	1
18.936150	−155.645339	8	>49,900				+	NAC[12]	3

Appendix 1. Rejected radiocarbon ages

This appendix contains radiocarbon ages that were rejected and not used in the study of the southern flank of Mauna Loa, Island of Hawai‘i, Hawaii. Reasons for rejection were because ages were inconsistent with stratigraphy or higher precision accelerator mass spectrometer (AMS) ages were determined.

[yr B.P., years before present; S.D., standard deviation; yr, years]

FID[1]	Field No.	Lab No.	Quadrangle name (1:24,000)	Age[2] (yr B.P.)	S.D.[2] (yr)	Data source[3]
626	L-94-12	USGS3484	Puu O Keokeo	860	120	3
749	L-75-61	W3487	Ka Lae	11,780	100	2
497	L-93-90c	WW338	Pohue Bay	190	60	3
499	L-93-63	WW238	Pohue Bay	50	60	3
742	L-93-694	USGS3480	Punaluu	120	45	1
497	78L-14	W4198	Papa	<200	0	3
630	L-93-152A	WW234	Pohue Bay	180	60	3
368	L-91-36	AA7655	Pohue Bay	200	85	3
630	L-93-58	WW237	Pohue Bay	260	60	3
764	L-91-207	AA8800	Pohue Bay	305	45	3
639	78L-24	W4238	Kahuku Ranch	330	70	2
623	78L-23	W4234	Kahuku Ranch	490	80	1
506	L-90-20C	W6416	Puu O Keokeo	490	60	3
	9P14C1	W4410	Pahala	660	70	2
545	78L-22	W4232	Kahuku Ranch	780	70	2
499	L-91-17	W6299	Pohue Bay	2,330	60	3
634	77L-33	W4009	Punaluu	3,900	80	2
496	77L-62A	W4025	Punaluu	640	45	3

[1]Unique three-digit flow identification number (FID) assigned to each mapped surface flow, vent, and ash unit is necessary to utilize database (https://doi.org/10.3133/sim2932C).

[2]Each age was calibrated to calendar years using CALIB 6.0 Radiocarbon Calibration Program (Stuiver and others, 2013); calibrated ages are for two standard deviations. Samples were processed at U.S. Geological Survey, ^{14}C Laboratory, Reston, Va.

[3]Sources: 1, Kelley and others (1979); 2, Rubin and others (1987); 3, this study.

Appendix 2. Geochemical analyses of the major units for the Geologic Map of the Southern Flank of Mauna Loa Volcano

Appendix 2 is available as an Excel table and may be downloaded from https://doi.org/10.3133/sim2932C.