Geologic Map of the Northwest 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–E

Photograph of fissure 4 from the A.D. 2022 eruption high on the Northeast Rift Zone of Mauna Loa, Island of Hawai‘i, at approximately 8 a.m. on November 29, 2022. View is to the west-southwest. Flat-topped cone in the background is Dewey Cone, the source of the A.D. 1899 eruption.

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Mauna Loa

Mauna Loa, the largest active volcano on Earth, has erupted 34 times since written descriptions became available in A.D. 1832. The most recent eruption of Mauna Loa occurred on November 27, 2022, after a 38 year hiatus; it lasted for 12 days. Some eruptions began with only brief seismic unrest, whereas others followed several months to a year of increased seismicity. Once underway, Mauna Loa's eruptions can produce lava flows that may reach the sea in less than 24 hours, severing roads and utilities. For example, lava flows that erupted from the Southwest Rift Zone in 1950 advanced at an average rate of 9.3 kilometers per hour (5.8 miles per hour); all three lobes reached the ocean within ~24 hours (Finch and Macdonald, 1953). Near the eruptive vents, the flows likely 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 Hawaiʻi. Volcanic hazards on Mauna Loa can be anticipated, and risk substantially mitigated, by documenting its 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.

Physiography

Most of the population within the mapped area is clustered below 2,400 feet (ft) (732 meters [m]) elevation. The northwest flank of Mauna Loa is sparsely populated except for the coastal areas in the region, where tourist hotels and condominiums are located. Approximately 850 people live in the coastal region below Highway 19. Above 2,400 ft (732 m), the population is near zero. Most of the land is protected for conservation or used for ranching and farming, which is concentrated at higher elevations in the west. At lower elevations (2,400 ft [732 m] and below) are coffee, farming, and residential lands; approximately (~) 6,200 people reside in this region. In the saddle region between Mauna Loa and Mauna Kea is the Pōhakuloa Training Area, the largest U.S. Army training facility in the Pacific, that encompasses more than 132,000 acres.

State Highway 200 (Daniel K. Inouye Highway), a major east-west transit corridor across the Island of Hawaiʻi, skirts the map area in the north, in the saddle region between Mauna Loa and Mauna Kea. Two other highways, 190 and 19, transect the northwest part of the map area, from northeast to southwest, at lower elevations. Highway 190 dissects the map area at ~2,000–2,500 ft (610–762 m) elevation; Highway 19 is closer to the coastline and is considered the coastal road. A few four-wheel-drive roads transect the middle elevations, but the map area is largely devoid of any roads, trails, or other access routes. Most of the field-work area was accessed on foot (after driving as far as possible on four-wheel-drive roads) or by helicopter.

The high-elevation regions, from ~8,000 to 13,040 ft (2,438 to 3,975 m) on the map, is subalpine terrain, devoid of any vegetation. Rainfall is between ~10 and 20 inches per year (254–508 millimeters per year [mm/yr]; fig. 1, Giambelluca and others, 2013). Between ~7,000 and 8,000 ft (2,134 to 2,438 m) elevation is mixed scrubland, a sparse mixture of shrubs and trees; rainfall is between 20 and 25 inches per year (508–635 mm/yr) and rock outcrops are easily discovered. The forest thickens, primarily on the west side of the map, at ~7,000 ft elevation. The land on the west side of the map has been used for cattle ranching for more than 100 years and the area has been deforested and reduced to pastureland. Ranches extend down the flank of the volcano to about 2,400 ft. From 2,400 to 7,000 ft elevation, rainfall ranges from 25 to 50 inches per year (635–1,270 mm/yr). Outcrops in this part of the northwest flank are masked by grasslands and the flows have been bulldozed for pasture growth. Because of orographic effects, the higher rainfall along the lower slopes—from 2,400 ft to just below Highway 19, known as the coffee belt—is ~50–60 inches per year (1,270–1,524 mm/yr). Lava-flow contacts are buried by vegetation or obscured by ground disturbance from agricultural activity.

Rainfall on the northwest flank is greatly influenced by the rain shadow created by the >13,000-ft (>4,000-m) volcanoes Mauna Loa and Mauna Kea. Rainfall in the saddle region between these volcanoes is ~25 inches per year (635 mm/yr) across the broad plain to the west to Highway 190, a distance of 35 kilometers (km) (21.7 miles [mi]). Below Highway 190, rainfall drops from 25 to 10 inches per year (635 to 254 mm/yr) near the coast. This arid region contains remnants of dryland forest and outcrops are abundant.

Mapping Project

The subaerial volcanic geology of Mauna Loa (fig. 2) is being mapped and digitally compiled on five maps at 1:50,000 scale (Trusdell and Lockwood, 2017, 2019, 2020) to show the extent of surface flows. Approximately 500 flows have been identified and their attributes compiled in a large geographic information system (GIS) database. The temporal and spatial record of eruptive activity, traceable to ~30,000 years before the 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).

Map of the Northwest Flank of Mauna Loa

The map of the north and west flanks of Mauna Loa shows the distribution and relation of volcanic and surficial sedimentary deposits. It incorporates previously reported work published as generalized small-scale maps (Stearns and Macdonald, 1946; Lockwood and Lipman, 1987; Wolfe and Morris, 1996; Trusdell and others, 2006) and a more detailed map (Moore and Clague, 1991).

Mapping Methods

Geologic mapping was accomplished by analyzing vertical aerial photographs taken in 1977 and 1978. Extensive fieldwork required walking many contacts to distinguish individual eruptive units, intraflow boundaries and relative age relations, including gradational morphologic transitions between pāhoehoe and ‘a‘ā flows. Where the terrain, forest, and agricultural development obscure contacts, we created a grid pattern of transects. The ensuing contacts were interpolated between transects from interpretation of aerial photographs 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), then scanned and digitized using ArcInfo software to create the digital database.

Reliably correlating discontinuous exposures of older lava flows is a major challenge on a volcano that consists entirely of compositionally similar basalt. Criteria for correlation include phenocryst size, morphology, and percentage; groundmass texture; vesicle shape; vesicle linings (for example, magnesioferrite); flow morphology; paleomagnetic pole directions; rock chemistry; and assorted evidence on relative and absolute ages. Cooling lava flows record the Earth’s magnetic field direction at the time of eruption. Accordingly, paleomagnetic measurements are indispensable for making correlations among flows over large distances. Individual flows commonly change from pāhoehoe near their source vents to ‘a‘ā downslope, especially for high-discharge eruptions (larger than 100 cubic meters per second [m^3/s]). Low-discharge eruptions (less than 10 m^3/s) may result in the distal emplacement of pāhoehoe through efficient lava-tube systems.

The map is largely chronostratigraphic. The pre-1843 lava flows and tephra deposits are divided into 15 age groups. About 28 percent of the flows were dated directly (72 radiocarbon ages out of 144 units), using carbonized organic material recovered beneath flows (Lockwood and Lipman, 1980). For undated flows, relative ages are assigned on the basis of 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 (table 2 of Lipman, 1980). 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 progressively to gray, brown, tan, orange, and, finally, reddish hues. The longer the rock is weathered, the greater the color progression. Lipman and Swenson (1984) used this color scheme 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. Vegetation size, diversity (of native species), and soil and tephra accumulation are also indirect indicators of age. The thickness of tephra varies with proximity to the contributing source(s) and degree of reworking.

Database

The digital GIS database contains all information in the printed publication at 1:50,000 scale and 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 (leading zeros omitted). 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. The database for this map is available at https://doi.org/10.3133/sim2932e.

Map Unit Label and Flow Identification Number (FID)

Map unit labels identify flow morphology, flow age group, phenocryst mineralogy, and flow number in the age group (table 1). For example, unit p10e1 is a pāhoehoe flow (p) dated to 10,000 to 9,000 radiocarbon yr B.P. (10) that contains >15 percent olivine phenocrysts (e) and is the youngest flow in Age Group 10 (1). Only the dominant morphology (abbreviated as s, p, a, or m; see table 1) is listed on the map and correlation diagram, even though morphology commonly varies within a single unit. Phenocrysts are olivine and plagioclase crystals ≥1 mm in diameter. Phenocrystic pyroxene is sparse in Mauna Loa flows and therefore not listed in the map unit label.

The map unit label is not unique, and may be used for another unit on a different flank of Mauna Loa. Accordingly, in addition to the map unit label, a unique three-digit Flow

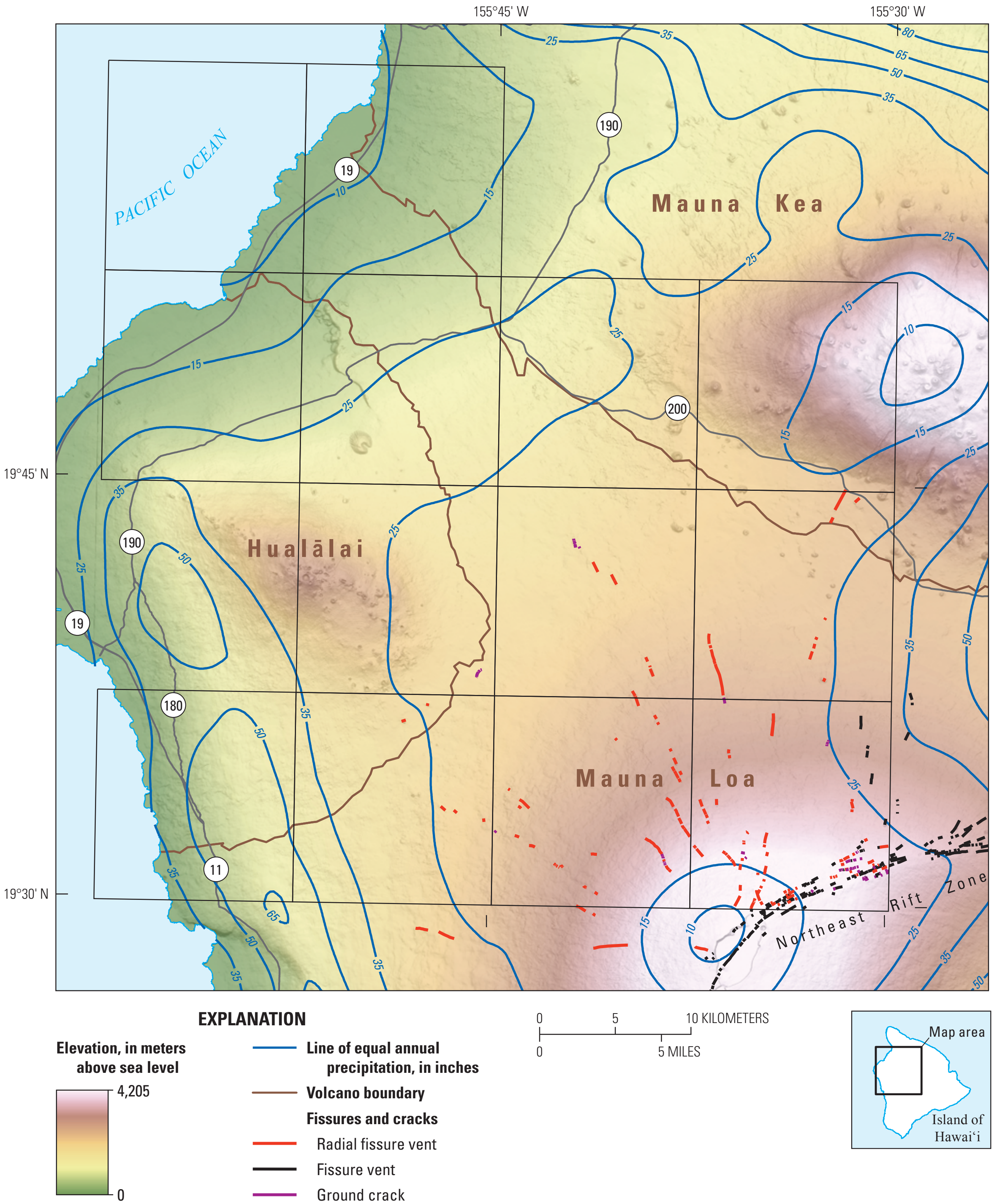

Figure 1. Color shaded-relief map showing annual rainfall on the Island of Hawai'i. The mapped area ranges in elevation from sea level to >13,000 feet (3,962 meters) and in rainfall from <10 to 60 inches per year (arid to rain forest). Squares show the 7.5-minute quadrangles that cover the mapped area.

Identification number (for example, FID 488) is assigned to facilitate use of the GIS database.

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).

Undated flows are correlated with dated flows using superposition, surface exposure, color change caused by weathering, extent of weathering, tree height and girth, diversity of native plant species, and soil and ash accumulation.

Acknowledgments

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Geology

Northwest Flank of Mauna Loa

Within the mapped area, lava has flowed from three different source regions: the Northeast Rift Zone (NERZ), the summit, and the radial vents (fig. 3). All three have different points of origin which, in turn, affect the flow characteristics and periodicity of activity.

Most of the map area—about 64 percent—is covered by flows originating from the summit of Mauna Loa. Twenty-two percent of the map area comprises flows from the NERZ, and 14 percent of the surface is inundated by radial-vent flows (fig. 3).

The map area includes the uppermost part of the NERZ and extends from the highest elevation—13,040 ft (3,975 m)

Table 1. Explanation of map unit labels for lava flows and vent deposits on Mauna Loa, Island of Hawai‘i.

[Map unit labels for lava flows and vent deposits consist of four parts that identify flow morphology, flow age group, phenocryst mineralogy, and flow number in the age group. All ages are reported in radiocarbon years before present (yr B.P.; before the calendar year A.D. 1950). %, percent]

Symbol	Explanation
Flow morphology (letter; for example p1b2)	
s	Spatter, tephra, and cinder-fall deposits
p	Pāhoehoe
a	‘A‘ā
m	Mixed ‘a‘ā and pāhoehoe
l	Littoral deposit
Flow age group (number; for example p1b2)	
0	A.D. 1843 and younger
1	150–1,000 yr B.P.
2	1,000–2,000 yr B.P.
3	2,000–3,000 yr B.P.
4	3,000–4,000 yr B.P.
5	4,000–5,000 yr B.P.
6	5,000–6,000 yr B.P.
7	6,000–7,000 yr B.P.
8	7,000–8,000 yr B.P.
9	8,000–9,000 yr B.P.
10	9,000–10,000 yr B.P.
11	10,000–15,000 yr B.P.
12	15,000–20,000 yr B.P.
13	20,000–30,000 yr B.P.
14	30,000–100,000 yr B.P.
15	>100,000 yr B.P.
Phenocryst mineralogy (letter; for example p1b2)	
a	Aphanitic (<1% of any mineral)
b	1–5% olivine
c	5–10% olivine
d	10–15% olivine
e	>15% olivine
f	Variable amounts of olivine (2–30%)
g	1–5% plagioclase
h	>5% plagioclase
i	Mixed, 1–5% olivine + 1–5% plagioclase
j	Mixed, >5% olivine + 1–5% plagioclase
k	Mixed, 1–5% olivine + >5% plagioclase
l	Mixed, >5% olivine + >5% plagioclase
Flow in age group (number, for example p1b2)	
1	Youngest flow in an age group
2	Next youngest flow in an age group
3	Number increases as age increases

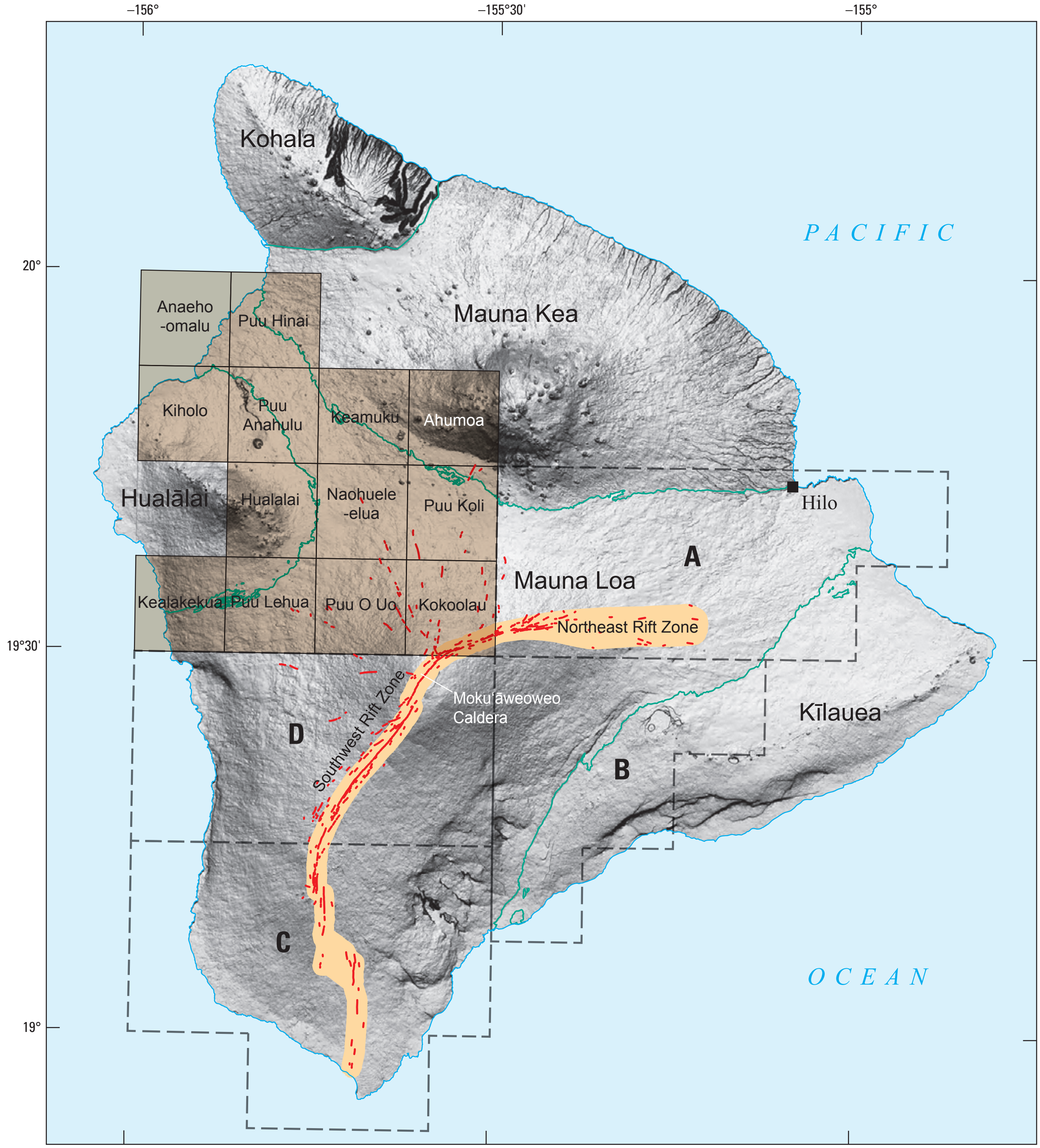

Figure 2. Shaded-relief map showing subaerial volcanoes (green boundary) that form the Island of Hawaiʻi, main rift zones (orange) and fissures (red lines) on Mauna Loa, 7.5-minute topographic quadrangles (shaded boxes) in the map area, and adjacent areas mapped as part of this series (dashed outlines).

at the south end of the Kokoolau quadrangle, just below the summit caldera—to the sea northwest and west of the summit. Lava that erupts from the north and west flanks typically flows to the west, northwest, or north, depending on the vent location. Both morphologic lava flow types—ʻaʻā and pāhoehoe—are present. Pāhoehoe units tend to spread out or widen in low-slope regions, such as in the saddle regions between Mauna Loa and Mauna Kea or between Mauna Loa and Hualālai. In comparison, ʻaʻā flows generally produce narrower flow lobes that have higher relief.

Lava flows from the upper NERZ go either north or in an east-southeast direction, away from the rift zone. Flows that make it downslope to the broad plateau between Mauna Loa and Mauna Kea are influenced by topography there. The crest of the saddle is near the east boundary of the mapped area. A few flows, like that of A.D. 1843, entered the region and headed west. Other flows along this east boundary, like that of A.D. 1935, entered the region and flowed east out of the mapped area (see fig. 2 of U.S. Geological Survey Scientific Investigations Map [SIM] 2932–A by Trusdell and Lockwood [2017]). This region defines the divide between east-west drainages.

Westward flows that originate from the summit of the volcano are influenced by topography and have different inclinations because of the presence of Hualālai, a topographical impediment, splitting the direction of their movement into two predominant drainages. Flows heading to the north and east of Hualālai are dominated by flowage to the northwest, whereas flows to the south and southwest of Hualālai are predominantly diverted in westerly and southwesterly directions.

The distribution of radial-vent flows is determined by location of vent openings. Radial vents are scattered across the upper flanks of the volcano, and their flows simply follow the topographic relief relative to their position with respect to Hualālai.

According to the geologic record observed from mapping and local drill holes, interfingering of lava flows between Mauna Kea and Mauna Loa along the north boundary of the map is rare. Two exploratory water wells were drilled near the north boundary of the Mauna Loa map, and in neither drill hole was any Mauna Loa flow encountered. Along the west boundary of the map, however, where Mauna Loa flows encroach onto Hualālai, interfingering of flows goes back to at least ~14,000 yr B.P.

Flows on the west side of Mauna Loa are generally older than those on the northwest and north flanks for several reasons. The east flank of Mauna Loa has been inundated by flows from the upper NERZ, whereas north and west flank flows were derived from Mokuʻāweoweo, the summit caldera, and from radial vents. Rift zones erupt an order of magnitude more frequently than do other parts of the volcano.

Summit-initiated flows are sporadic and controlled by specific conditions for lava to inundate these slopes. The caldera, with its high northwest wall, currently prevents the northwest flank from being inundated by lava. The north and south portions of the caldera have low relief, and lava from eruptions would preferentially drain out of the caldera in these low spots. Radial-vent flows are fissure eruptions that occur at all elevations in the map area; the most recent significant radial vent eruption occurred in A.D. 1859.

Nearly all historical Mauna Loa eruptions began in the summit region, defined by Lockwood and Lipman (1987) as that portion of the volcano above 12,000 ft (3,658 m) elevation, including Mokuʻāweoweo. About half of these initial breakouts were followed by related eruptive phases on Mauna Loa's rift zones or flanks. In the mapped area, the NERZ was the source of eight historical eruptions since A.D. 1843 (table 1) and two radial-vent eruptions.

The east margin of the mapped area is dominated by flows from the upper NERZ. Rift zones erupt more frequently there than in the other source regions, with eruptions occurring every 5–50 years. To the southeast, flows from the upper NERZ may inundate areas adjacent to and downslope from the rift zone. To the north is the contact with Mauna Kea. To the northwest, the flows extend down to the ocean, ~50 km (~31 mi) away, between Hualālai and Mauna Kea.

The upper NERZ trends N. 65° E. and extends beyond the mapped area into that of SIM 2932–A (fig. 2; Trusdell and Lockwood, 2017). Within the mapped area, the rift segment is 8.5 km (5.3 mi) long and ~2 km (1.2 mi) wide. Its constructional crest is marked by low spatter ramparts, and by spatter and tephra cones as high as 65 m (213 ft). Subparallel eruptive fissures and ground cracks cut vent deposits and flows in and near the rift zone. Fissure vents, commonly en echelon, are typically a few meters to several kilometers long. Around the fissures, agglutinated lava commonly accumulates to form ramparts. The ramparts are a few meters to tens of meters high, averaging 3–7 m (10–23 ft).

Some ground cracks are extensions of eruptive fissures, whereas others may be unrelated to eruptive activity. Most cracks are related to intrusive activity, similar to cracks documented by Swanson and others (1976) on Kīlauea, although some may be related to tectonic stresses. One pit crater within the summit, Lua Ioane, at 12,640 ft (3,853 m) elevation, demarcates the caldera-NERZ boundary in the mapped area. This constitutes a departure from Lockwood and Lipman's (1987) definition of the summit region as at or above 12,000 ft (3,658 m) elevation.

Off-axis or oblique to orthogonal vents are located along the north side of the NERZ. These differ from radial vents in that the dikes from these off-axis vents originally propagated down the rift zone (fig. 4). As they encountered a compressive stress regime, they turned at right angles—in all documented cases to the north—to the trend of the rift. A prime example of this is the A.D. 1843 eruption.

Flows erupted along the upper NERZ are typically aphanitic with a few olivine and rarer plagioclase phenocrysts. This is most likely the result of crystal settling within the magma reservoir and (or) homogenization of the input magma chemistry by the large magma reservoir at depth (Klein and others, 1987). Eruption duration at each vent is customarily short lived as the eruption progresses and feeder dikes propagate to lower elevations. All the historically active vents in the region erupted for 24 hours or less. The effusion rates have characteristically been high, in the range of a few hundred cubic meters per second (100–500 m^3/s), in contrast to Kīlauea, where the average effusion rates were 2–3 m^3/s during the Puʻuʻōʻō eruption. Because of the high effusion rates, the flows are initially ʻaʻā. As the eruption stabilizes and effusion rates drop, the vents tend to erupt pāhoehoe. Many examples of this behavior are evident in the map area that include the A.D. 1935 and A.D. 1843 flows. The A.D. 1859 flow is a radial-vent example of the process of ʻaʻā giving way to pāhoehoe as the eruption approaches steady state and effusion rates decline.

Summit flows represent long-term steady state activity, similar to what was observed during the Puʻuʻōʻō eruption (A.D. 1983–2018), with a fixed vent region, sustained magma supply, and moderate-to-low effusion rates. The region is dominated by pāhoehoe lavas with lesser amounts of ʻaʻā.

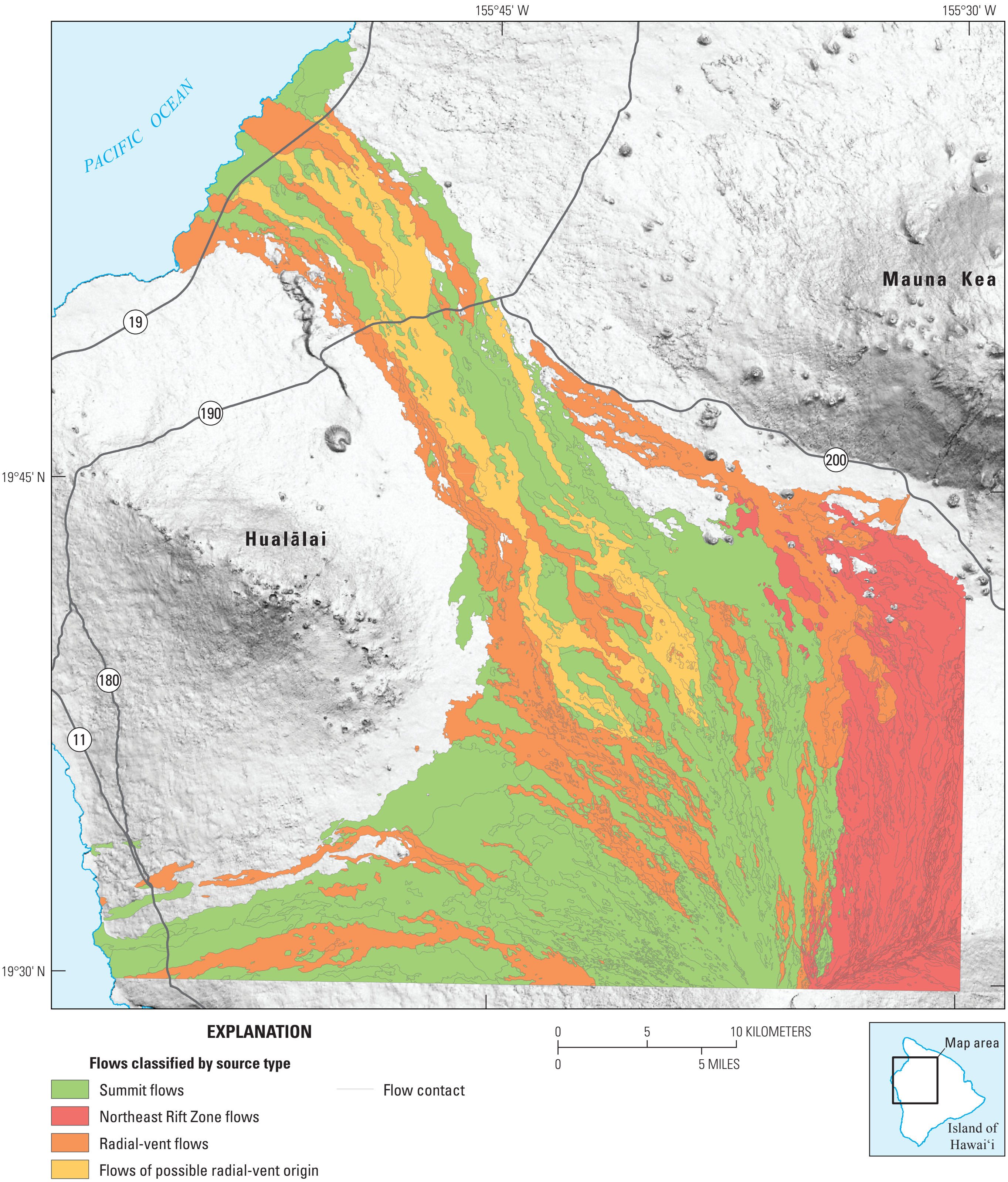

Figure 3. Map showing lava flows by source location for the mapped area of the northwest flank of Mauna Loa, Island of Hawaiʻi. Green represents flows originating from the volcano's summit. Red flows are from the Northeast Rift Zone. Orange flows are sourced from radial vents. Light-orange flows may have originated from radial vents. The sources of these units are buried, so the absolute determination of their source is speculative.

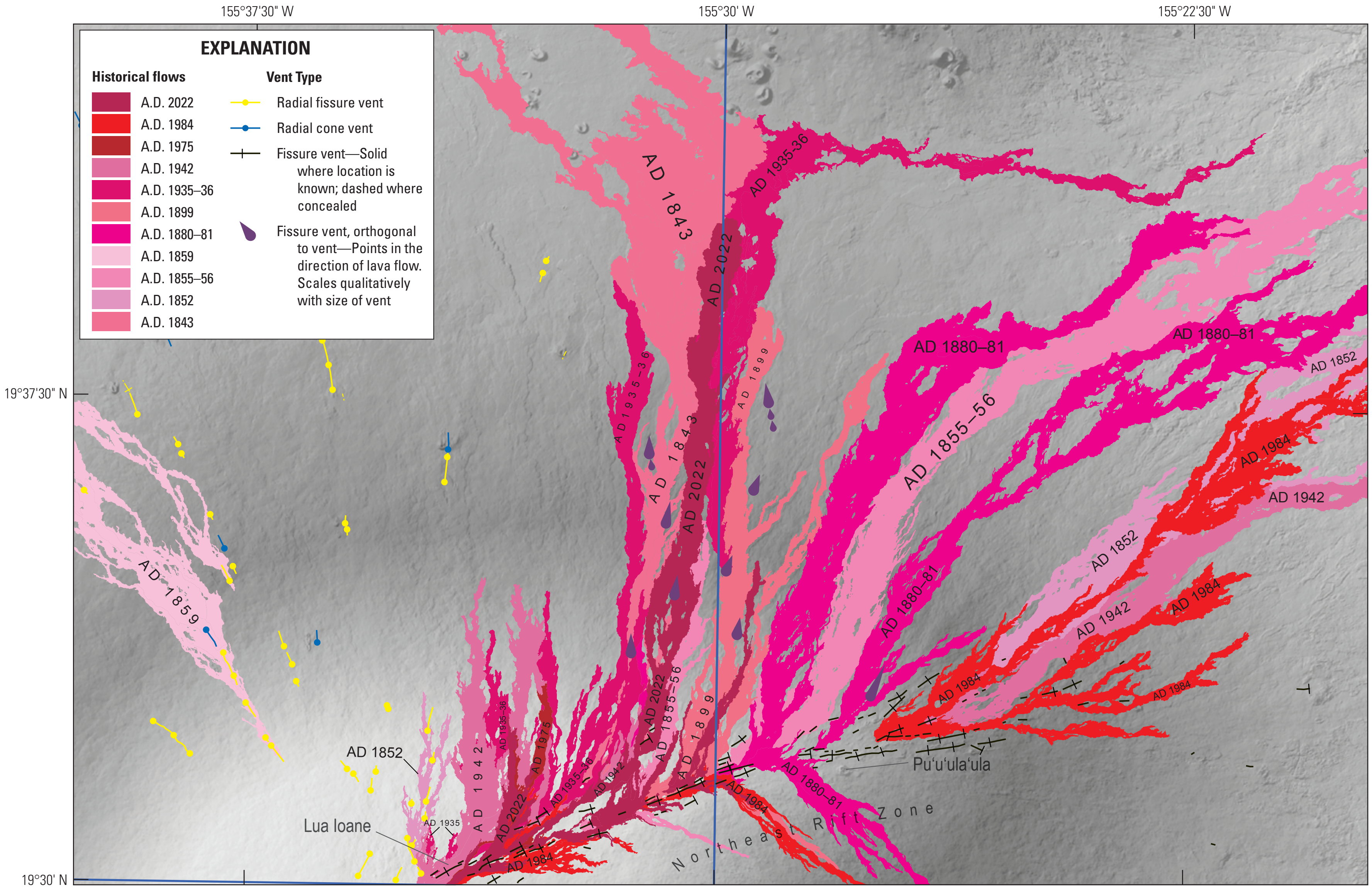

Figure 4. Map showing the upper part of the Northeast Rift Zone (NERZ) and the historical erupted lavas of Mauna Loa, Island of Hawaiʻi. Most historical lavas from the NERZ are located outside of the mapped area for this publication, except for the A.D. 1843 flow, most of which is within the mapped area (west of the blue line). Also shown are the historical lavas present in part of the area mapped in U.S. Geological Survey Scientific Investigations Map 2932–A (east of the blue line; Trusdell and Lockwood, 2017).

Owing to the nature of pahoehoe-flow behavior, the middle elevation region (the saddle between the volcanoes) and the broad, high plains in the interior sections of the island have gentle topography. As it progresses, pāhoehoe, being the more fluid flow type, tends to fill all depressions before the flow advances. This process results in a slow, steady filling of the surroundings and the construction of broad plains. The regions between Mauna Loa and Mauna Kea and between Mauna Loa and Hualālai typify this behavior. The average slopes in these regions are shallow, from 0 to 3 percent grades.

To the northwest, lava flows have reached the coast, on average, every 1,000 years. The age of the flows ranges from 6,000 to 376 yr B.P. If the source of the flow were the summit, the distance travelled would range from 55 to 60 km (34–37 mi) to reach the coast. The flows in this region have extended the coastline of the island outward as much as 2.5 to 3.5 km (1.6 to 2.2 mi). There are five distinct flows in the coastal region: two are pāhoehoe, two are ʻaʻā, and one has both ʻaʻā and pāhoehoe types. The strictly pāhoehoe flows are tube fed and summit derived. One ʻaʻā and the mixed (ʻaʻā and pāhoehoe) flows are from radial vents. The remaining flow vent is unknown; as the flow is ʻaʻā, it most likely originated from a radial vent.

One of the most significant findings, based on detailed geologic mapping and radiocarbon ages (table 2), is that vast sheets of pāhoehoe originated from the summit of the volcano over a long period before the formation of the present caldera. Sustained activity sent flows repeatedly to the north and west, which, conservatively speaking, lasted for about 750 years (fig. 5). A more expansive interpretation is that this long period of continuous summit activity occurred between B.C.E. 50 and A.D. 1270. Flows from this period blanketed the north and west flanks and reached the sea near Puʻuohau (west) and from Kīholo to Puakō to the northwest. Another period of sustained summit activity appears to have occurred around 3,000 yr B.P. (1,000 B.C.E.).

On the northwest flank, 7 out of 18 units consist mostly of ʻaʻā. Of the seven, two entered the ocean: one from the A.D. 1859 radial-vent eruption and an older flow whose upslope extent is buried by younger flows. If these ʻaʻā flows originated from the summit of Mauna Loa, the distance travelled ranges from 57 to 64 km (35 to 40 mi). Of ʻaʻā flows that originated from the NERZ, the longest historical ʻaʻā flows range in length from 25 to 32 km (15.5 to 20 mi) and the longest prehistoric flows are 45 to 52 km (28 to 32 mi) long (Trusdell and Lockwood, 2017). It is likely that most of the ʻaʻā flows on the northwest flank are the products of radial vents whose sources are buried by younger flows. To put this in perspective, the A.D. 1859 radial-vent flow is ~52 km (32 mi) long and originated from a vent at 11,090 ft (3,380 m) on the northwest flank. South of Hualālai are two radial-vent eruptions that produced flows that reached the sea; one of these flows traveled ~34 km (21 mi) from the vent.

The flows to the southwest are the oldest in the mapped area, partially owing to eruptive activity in the region, which has been more sporadic there than in other sections of the mapped area. The flow ages range from 14,000 to 500 yr B.P. The average eruption frequency is between 2,000 to 5,000 years. Ten flows originated from radial vents, and the rest (20) are summit flows. The wide range of ages is a testament to the paucity of eruptive activity when compared to the northwest or the upper NERZ regions.

Another physiographic factor that may have contributed to the wide range of ages in the region is the presence of the distal south-southeast rift zone of Hualālai (Moore and others, 1987). The construction of the rift zone in the Puʻulehua region predates much of the most recent summit activity of Mauna Loa. The southern rift zone of Hualālai created a topographic barrier—a low ridge that prevented younger flows from moving downslope—causing flows, especially pāhoehoe, to pond against the rift zone on the upslope side. The ridge enhanced the pooling of flows, thereby augmenting the construction of the broad plain between Hualālai and Mauna Loa. Periodically, a few flows were able to flow beyond Hualālai's rift zone and downslope toward the sea.

Because of the episodic nature of flows from the summit of the volcano (concentrated at 3,000 yr B.P. and 1,000 yr B.P.), a shallow trough very likely existed between Hualālai and Mauna Kea to the northwest of Mauna Loa. This topographic low was a natural corridor for channeling flows to the northwest. It seems that the northwest flank of Mauna Loa was lower in elevation than the west flank: 16 flows reached the upper highway (versus 7 flows on the west flank), the eruption frequency on the northwest flank is higher than in the west (every 600–2,000 years versus every 2,000–5,000 years), and flows are generally younger in the northwest (whereas young flows are essentially absent on the west flank).

Radial vents within Hawaii are unusual and only form on Mauna Loa. They occur over a wide area on Mauna Loa's north and west flanks outside the well-defined rift zones and summit region. These vents originate at all elevations from the summit of the volcano, at more than 13,000 ft (3,962 m) elevation to 5,249 ft (1,600 m) below sea level on the submarine flanks (Wanless and others, 2006). The dikes feeding these vents emanate from the magma reservoir like spokes on the wheel of a bicycle radiating away from the hub.

We have documented more than 45 subaerial radial-vent eruptions volcano-wide. Three of those eruptions occurred in the last 150 years, and flows from two reached the sea. Within the mapped area are two of the three historical radial-vent eruptions: A.D. 1852 and A.D. 1859. The third radial-vent eruption occurred in A.D. 1877 and resulted in a submarine eruption in Kealakekua Bay (south of the map area; fig. 2).

Thirty-four radial vents have been identified in the mapped area. Prehistoric radial vents range in age from 13,000 to 200 yr B.P. The radial vents can be grouped into two categories: either the eruptions were gas-rich, producing the usual near-vent tephra and spatter products, or the vents were gas-poor and produced only fluid (low-viscosity) flows with no near-vent tephra deposits. The gas-poor radial vents are preserved as cracks from which degassed lava emerged.

The origin of radial vents on Hawaiian volcanoes is not fully understood. One hypothesis posits that because of the enormous mass of Mauna Loa, at higher elevations, compressive forces of the adjacent volcanoes do not impede the intrusion of a dike, leading to the formation of a radial vent. Another explanation is that the opening of the two non-parallel main rift zones of Mauna Loa promotes the local circumferential extension necessary to develop the radial dikes on the northwest flank (La Marra, 2016; fig. 6).

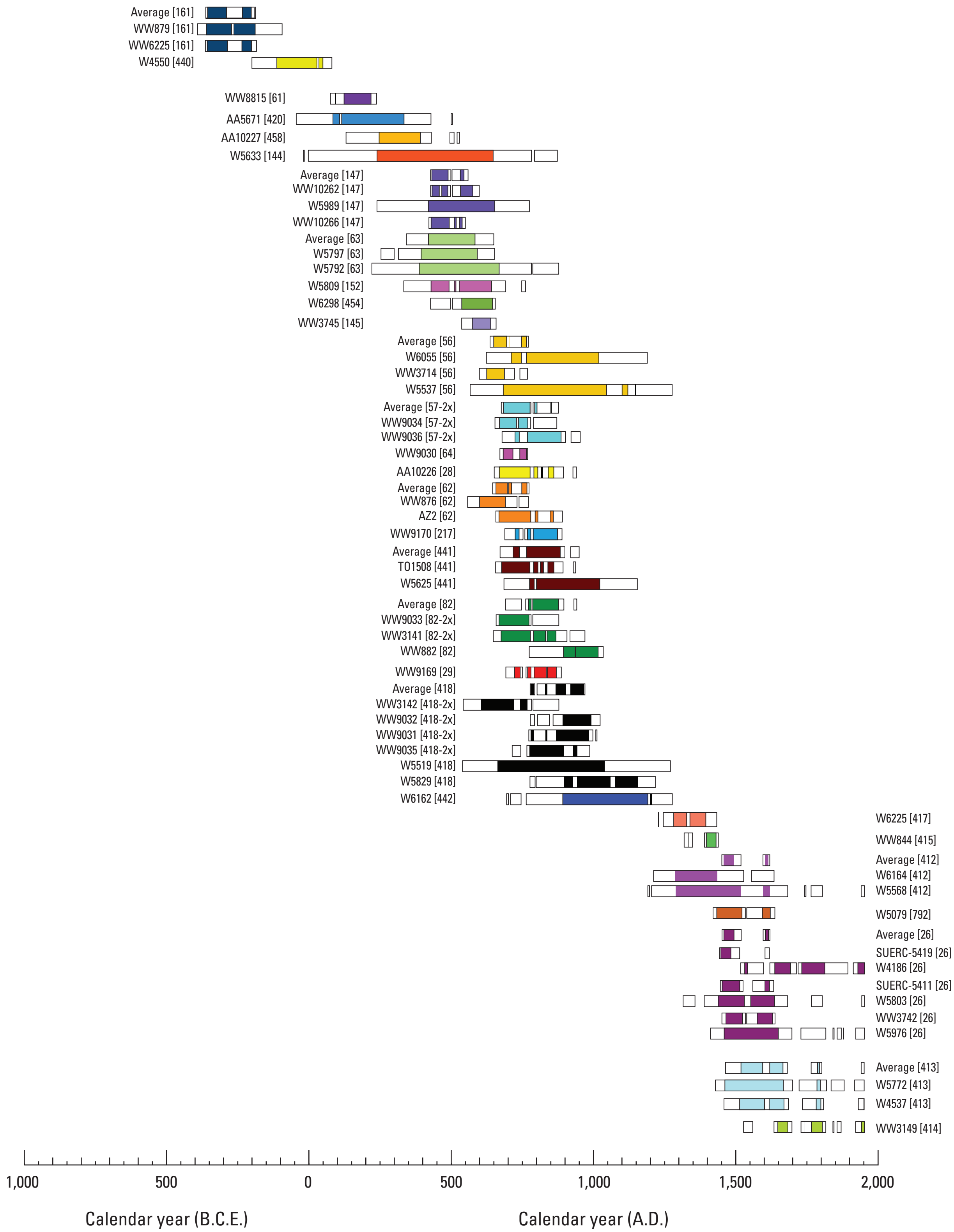

Figure 5. Plot of radiocarbon ages from lava flows on the northwest flank of Mauna Loa, Island of Hawai‘i, chronicling about 1,300 years of eruptive activity (conservatively, 750 years). Colors represent different flow units, some with multiple ages. The colored parts of the bar show the age range within one standard deviation of the mean; the total length of the bar (including the uncolored segments) shows the age range within two standard deviations of the mean. Where multiple ages are given, an average age is also shown. Labels are the laboratory sample number (appendix 2); flow identification numbers are given in brackets.

The presence of radial vents on the flanks of Mauna Loa reveals a different scenario of lava-flow hazards. The public's response time associated with eruptions that occur within the map area on rift zones and at the summit ranges from several days to several months, whereas the response time for radial-vent eruptions that could open near or within populated areas low on the volcano's flanks can be substantially shorter (minutes to hours). Such a short response time poses a serious potential risk to property and persons living there (Trusdell, 2012).

Volcanic Deposits

Flows

The map encompasses 1,131 square kilometers (km^2) of the north and west flanks (figs. 1 and 3) of Mauna Loa, from sea level to 13,040 ft (3,975 m) elevation. The map shows the distribution of eruptive units, which are separated into 13 age groups ranging from more than 20,000 yr B.P. to A.D. 2022.

Pāhoehoe flows are characterized by bulbous, smooth, and ropy surfaces, and much of the terrain can also be described as hummocky. Subsurface lava tubes are common features in pāhoehoe flows. Most ʻaʻā flows also start as pāhoehoe near their vents and transition to ʻaʻā flows downslope.

Covering more than half of the map area, ʻaʻā flows are generally thicker and form broader units than pāhoehoe flows. Flows of ʻaʻā have rough textures with rubble and (or) clinker at their surfaces; they are typically 3–15 m thick.

Effusion rates and slope influence lava morphology. High effusion rates combined with steep slopes typically generate ʻaʻā, whereas moderate to low effusion rates typically produce pāhoehoe. A prime example of this is the A.D. 1859 eruption, where an ʻaʻā flow reached the ocean in ~8 days, and the subsequent pāhoehoe flow reached the sea in ~120 days.

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

Age Groups

We assigned the lava flows into 12 age groups. The youngest age group represents those erupted in the period from A.D. 1832 to the present, and the rest of the age groups are separated into 1,000-year intervals, except for age groups older than 10,000 yr B.P., which represent time periods greater than 1,000 years. The age groups are defined by 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)

Eruptions in this age group occurred in A.D. 1832, 1843, 1852, 1855–56, 1859, 1880–81, 1899, 1935–36, 1942, 1975, 1984, and 2022 (see table 3; fig. 4). Lava erupted from the A.D. 1859 to 2022 flows covers 15 percent of the map area. Soil, or tephra cover, is absent except in forested areas, and surficial glass is common on pāhoehoe. Most historical lava flowed north and south from the NERZ. Exceptions are the radial-vent eruptions of A.D. 1852 and A.D. 1859.

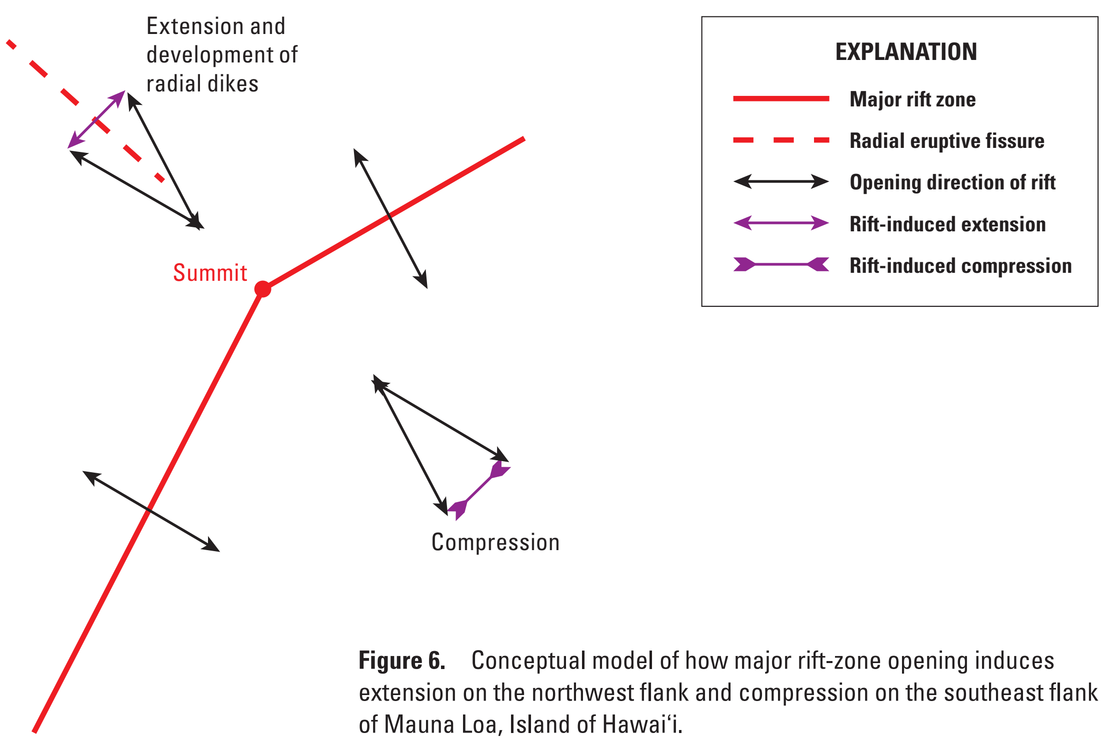

Figure 6. Conceptual model of how major rift-zone opening induces extension on the northwest flank and compression on the southeast flank of Mauna Loa, Island of Hawaiʻi.

Table 3. Summary statistics of historical (after A.D. 1843) eruptions on the northwest flank of Mauna Loa, Island of Hawaiʻi.

[Adopted from Lockwood and Lipman (1987). S, summit; NERZ, Northeast Rift Zone; NF, north flank; RV, radial vent; km^2, square kilometer; km^3, cubic kilometer; %, percent; n.d., not determined]

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 (%)
2022	November 27	0	12	S, NERZ	38.5	0.15	20
1984	March 25	<1	22	S, NERZ	48	0.22	20
1975	July 5	1	0	S	13	0.03	20
1942	April 26	2	13	S, NERZ	34	0.176	20
1935–36	November 21	6	40	S, NERZ, NF	33	0.087	20–40
1899	July 1	4	21	S, NERZ	23	0.081	20–40
1880–81	November 5	0	280	NERZ	51	0.13	20–40
1880	May 1	6	0	S	5	0.01	n.d.
1859	January 23	<1	~300	S, RV	91	0.383	>40
1855–56	August 11	<1	~450	S, NERZ	66	0.28	>40
1852	February 17	1	20	S, RV	33	0.182	20–40
1843	January 10	5	~90	S, NERZ, NF	45	0.202	>40
Total					**480**	**1.931**	

A.D. 2022—The A.D. 2022 eruption began on November 27 and continued for 12 days. The erupted volume is about 150×106 cubic meters (m^3). Approximately half (51 percent) of the lava is within the mapped area and is predominantly ʻaʻā. The vents were distributed along a 7.8-km (4.8-mi) segment of the NERZ between 11,000 and 12,780 ft (3,353 and 3,895 m) elevation. The main fissure is located at ~11,640 ft (3,548 m) elevation. Flows from this eruption came within 2.5 km (1.5 mi) of Highway 200.

A.D. 1984—The 1984 eruption began on March 25 and continued for 22 days. It was Mauna Loa's fifth longest historical NERZ eruption; the erupted volume is 220×10^6 m^3 (Lockwood and Lipman, 1987). Most (>85 percent) of the lava is east of the mapped area (figs. 2 and 4; Trusdell and Lockwood, 2017) and is ʻaʻā. The vents were distributed along a 15-km (9.3-mi) segment of the NERZ between 9,350 and 12,720 ft (2,850 and 3,877 m) elevation. The main fissure is located at ~9,600 ft (2,926 m) elevation, east of the mapped area. Flows from this eruption came within 7 km (4.3 mi) of the greater city limits of Hilo (Kaūmana City; Trusdell and Lockwood, 2017).

A.D. 1975—At 10:51 p.m. on July 5, the seismometers at the summit of Mauna Loa began to record harmonic tremor, and shortly before midnight, USGS Hawaiian Volcano Observatory scientists observed a bright glow across the summit area. Lava erupted from fissures extending from the upper NERZ (figs. 2 and 4), across the floor of Mokuʻāweoweo (figs. 2 and 4; south of the mapped area), and into the upper Southwest Rift Zone. Fountaining in the caldera and upper Southwest Rift Zone waned within 4 hours and by dawn was restricted to the upper NERZ. All eruptive activity ceased within 22 hours of its commencement. The eruption was the first since 1950, and the 25 years of inactivity was, at the time, the longest period of quiescence in the recorded history of Mauna Loa. This was one of the briefest eruptions in historical times. The area covered was ~13 km^2, and the volume erupted was 30×10^6 m^3 (Lockwood and Lipman, 1987).

A.D. 1942—The eruption began at the summit on April 26. When it ended on May 9, a lava flow extended 26 km (16 mi) from the main vent at 9,350 ft (2,850 m) elevation, east of the mapped area (figs. 2 and 4; Trusdell and Lockwood, 2017), and came within 5 km (3.1 mi) of Hilo. Within the mapped area, ʻaʻā erupted on the north flank, and extended to the northeast beyond Puu Koli quadrangle. Vents were distributed along a 3.5-km (2.2-mi) segment of the NERZ between 11,880 and 12,880 ft (3,621 and 3,926 m) elevations, but most of the lavas (61 percent; Trusdell and Lockwood, 2017) were erupted from vents below 10,000 ft (3,048 m) elevation (fig. 2; Trusdell and Lockwood, 2017). During this eruption, the local government tried to divert the lava from its course toward Hilo by bombing it.

A.D. 1935–36—The A.D. 1935–36 eruption began near the summit on November 21. Vents were distributed along a 6.5-km (4.0-mi) segment of the NERZ between 11,160 and 12,880 ft (3,402 and 3,926 m) elevations. On November 27, a new vent opened on the north flank at 8,805 ft (2,684 m) elevation outside the mapped area (figs. 2 and 4; Trusdell and Lockwood, 2017). The eruption, which lasted 40 days, produced about 87×10^6 m^3 (Lockwood and Lipman, 1987) of lava. During this eruption, the local government attempted bombing to divert the advancing flow, the first such attempt in Hawaii.

A.D. 1899—The A.D. 1899 eruption began with a summit outbreak in Mokuʻāweoweo (figs. 2 and 4) on July 1, followed on July 5 by a flank eruption on the NERZ at Dewey Cone, at the 11,405 ft (3,476 m) elevation. The flank eruption, which lasted 21 days, produced about 80×10^6 m^3 of lava (Lockwood and Lipman, 1987), the least voluminous historical eruption on the NERZ at only one-third the volume of the A.D. 1984 eruption.

A.D. 1880–81—The eruption of A.D. 1880–1881 began on May 1, 1880, when a small, short-lived eruption of 6 days at Mauna Loa's summit heralded the beginning of an eruptive sequence that was followed 6 months later by a voluminous flank eruption, which would eventually threaten Hilo. The flank phase of the eruption began on November 5. The outbreak was located at 11,000 ft (3,353 m) elevation. High lava fountains fed an ‘a‘ā flow that moved swiftly down the north flank. Another branch of ‘a‘ā flowed southeast, stopping ~3 km from Kīlauea (figs. 2 and 4; Trusdell and Lockwood, 2019). As fountains waned, a new vent opened downrift, east of the mapped area (99 percent of the lava is outside of the mapped area; figs. 2 and 4; Trusdell and Lockwood, 2017), about 450 m (0.28 mi) northwest of Pu‘u‘ula‘ula (fig. 4). From this new vent, lava simply oozed up from an earth crack as pāhoehoe and flowed steadily northeastward.

A.D. 1859—The A.D. 1859 eruption of Mauna Loa began in the evening of January 23. Following a brief summit eruption in Moku‘āweoweo, an outbreak occurred high on Mauna Loa’s northwest flank at 11,090 ft (3,380 m) elevation. The initial ‘a‘ā flow reached the coast in 8 days, and the ensuing pāhoehoe flow in 120 days. The eruption ultimately destroyed a coastal village and fishponds at Wainānāli‘i and Kīholo, on the northwest coast of the island. During the initial stage of the A.D. 1859 radial-vent eruption, two sets of subparallel fissures issued ‘a‘ā lava. On the evening of January 30, the villagers of Wainānāli‘i were awakened by sounds of advancing lava and scrambled to remove personal belongings from the path of the flows. An ‘a‘ā flow reached the sea on the morning of January 31, 8 days after the eruption started. By March 7, ‘a‘ā flows gave way to pāhoehoe in the high plateau between Mauna Loa and Hualālai. The eruption stabilized, effusion rates dropped, and open channels were supplanted by lava tubes as the flow field matured and the eruption developed toward a steady state. Pāhoehoe eventually entered the sea 158 days after the eruption commenced. This eruption is notable for several reasons: it was the most voluminous eruption in the historical period, producing a 52-km-long (32-mile-long) lava flow, the longest in the State, and, at 300 days, had the second longest duration of all Mauna Loa eruptions in Age Group 0. Lava effused from two sub-parallel fissure systems. The main fissure originated at 11,135 ft and propagated downslope 4.6 km to an elevation of 8,890 ft. The second fissure system opened 1.3 km northeast of the first at an elevation of 8,695 ft and extended 1.1. km downslope to 8,380 ft elevation. Both systems fed flows simultaneously that joined downslope and formed one flow field. The volume produced was 383×10^6 m^3 (Lockwood and Lipman, 1987).

A.D. 1855–56—The A.D. 1855–56 eruption began in August 1855 and continued for about 450 days. It was Mauna Loa’s longest lasting historical eruption. It included many episodes of high fountaining and was characterized by highly variable rates of lava production. Most of the lava erupted as pāhoehoe, with minor amounts of ‘a‘ā. A lava-tube system never formed, but the flows, which attained a volume of 280×10^6 m^3 (Lockwood and Lipman, 1987), came within 10 km (6.2 mi) of Hilo Bay. The main vent, called Steaming Cone, is located at 11,787 ft (3,593 m) elevation in the southeasternmost corner of this map. The bulk of the flow is outside the mapped area (89 percent; figs. 2 and 4; Trusdell and Lockwood, 2017). It is exposed south of Saddle Road (Highway 200) at 5,000 ft (1,524 m) elevation and north of the road near 2,400 ft (732 m) elevation.

A.D. 1852—The A.D. 1852 eruption began on February 17 and continued for 20 days. Much of the lava is ‘a‘ā; the erupted volume is 182×10^6 m^3 (Lockwood and Lipman, 1987). The vents were distributed along an 18-km (11-mi) segment of the NERZ, which is mostly buried by younger lava flows. The uprift vents, active for ~1 day, are radial to the caldera, and the flows extend 4 km (2.5 mi) downslope to the area now occupied by the National Oceanic and Atmospheric Administration (NOAA) Mauna Loa Observatory. The higher elevation flows are aphanitic and the lower elevation flows are picritic. Flows from the lower elevation vents came within 6 km (3.7 mi) of Hilo.

A.D. 1843—The A.D. 1843 eruption began on January 10 and continued for ~90 days. This eruption produced both ‘a‘ā and pāhoehoe flows. Surface relief on the A.D. 1843 ‘a‘ā flow is more than 8 m (26 ft) in places. The eruptive sequence demonstrates a common situation: younger pāhoehoe covering older ‘a‘ā of the same eruption. The volume erupted is about 202×10^6 m^3 (Lockwood and Lipman, 1987). Vents were distributed along a 5-km (3.1-mi) segment of the NERZ; the lowest elevation vent is orthogonal to the trend of the rift zone. A small section of this unit is shown on the adjacent geologic map (5 percent; figs. 2 and 4; Trusdell and Lockwood, 2017) to the east of the mapped area.

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. Flows from this period cover approximately 12 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 accumulating within low depressions in flows, and any surficial glass shows slight mechanical degradation and color lightening to gray hues. Twenty of 52 flows have radiocarbon ages. Flows from this period cover nearly 45 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. Four of 18 flows have radiocarbon ages. Flows from this period cover nearly 7 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. Four of 22 flows have radiocarbon ages. Flows from this period cover nearly 12 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 can have as much as 0.4 m of overlying soil or tephra where they are in close proximity to Mauna Kea or Hualālai. None of the six flows in this group have been dated using the radiocarbon method. Flows from this period cover 3 percent of the map area.

Age Group 6 (5,000–6,000 yr B.P.)

These rocks are weathered, surficial glass is absent, and upper surfaces are eroded and expose the interior open-vesicle texture. Units are typically covered by 0.2–0.3 m of tephra or soil, especially at middle elevations (4,000–8,000 ft; 1,219–2,438 m). None of the four flows in this group have been dated using the radiocarbon method. Flows from this period cover less than 1 percent of the map area.

Age Group 7 (6,000–7,000 yr B.P.)

There are five flows in this age group. They are weathered, surficial glass is absent, and upper surfaces are less intact than younger units and have an open-vesicle texture. Units are typically covered by 0.3–0.5 m of tephra or soil, especially at middle elevations. Flows from this period cover about 3 percent of the map area.

Age Group 8 (7,000–8,000 yr B.P.)

There is only one flow in this age group. It is weathered, with orange surfaces that occur at high elevations (>8,000 ft; 2,438 m); upper surfaces have an open-vesicle texture and are broken. Tephra has accumulated in low-lying areas. Outcrops are scattered as small kīpuka near the border between the Kokoolau and Puu Koli quadrangles. The flow covers less than 0.1 percent of the map area.

Age Group 9 (8,000–9,000 yr B.P.)

These flows are deeply weathered, showing red-orange surfaces at high elevations; mechanical disintegration of upper surfaces is almost complete. Tephra has accumulated in low-lying areas. One of two flows has a radiocarbon age. Flows from this period cover about 1.3 percent of the map area. They are located in the southwest section of the map.

Age Group 10 (9,000–10,000 yr B.P.)

These flows (and all older age groups) are located only in the southwest part of the map area; they have been mostly buried by younger flows. Tephra and soil fill low-lying areas; accumulation of as much as 0.5–1 m is common. Surface color approaches red. One of two flows has a radiocarbon age. Flows from this period cover ~0.6 percent of the map area, chiefly in Kealakekua 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 wet regions, the rock is soft, and hammer impacts commonly leave divots. Olivine is altered, yellow and (or) brown-green in color, and slightly flaky. Units of this age group have 1–3 m of soil or tephra cover. Partly altered groundmass is commonly a dull gray color and appears cryptocrystalline. One of three units has a radiocarbon age. Flows from this period cover 0.9 percent of the map area. Outcrops are scattered as kīpuka in Puu Lehua and Kealakekua quadrangles.

Age Group 12 (15,000–20,000 yr B.P.)

There are no flows from this age group in the mapped area.

Age Group 13 (20,000–30,000 yr B.P.)

One flow is exposed as a small kīpuka in the northwest section of the map (northwestern Puu Anahulu quadrangle). It has no remaining original surfaces. The flow covers less than 1 percent of the map area.

Age Group 14 (30,000–100,000 yr B.P.)

There are no flows from this age group in the mapped area.

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

There are no flows from this age group in the mapped area.

Surficial Sedimentary Deposits

These deposits are too small and local to map at this scale. They consist chiefly of colluvial and alluvial deposits of basaltic clasts and pebble- to cobble-sized gravel in drainages that occur locally within parts of the mapped area. We also include unconsolidated coastal sand under this category.

Volcanic Ash

Volcanic ash in this region is poorly characterized and, for the most part, unconstrained temporally and spatially; its source is unknown. Ash includes beds that represent accumulation of deposits from numerous eruptions. Deposits include vitric ash and glassy lapilli (some altered to clay), crystals, and lithic fragments. Phenocryst abundance is difficult to estimate owing to chemical decomposition, but ranges from aphanitic to moderately porphyritic. Vitric ash and other tephra are located in most quadrangles near source vents. Older altered ash occurs chiefly on older flows in the northwest and west, where it overlies lava flows ranging in age from 20,000 to 3,000 yr B.P. The appearance of the ash is greatly influenced by climate. In dry areas, it is friable, less altered, and in places compact, but it is mostly sandy, loose, and dusty. In areas that receive more rainfall, the ash appears clay-like.

Radiocarbon Data

Carbonaceous material for radiocarbon dating can be obtained from under flow margins or from beneath flows where bases are exposed by erosion. The dates usually apply to the surface flow

(Lockwood and Lipman, 1980). Some ages were obtained from vertical sections (for example, stacked flows in an open ground crack). Flows dated by charcoal that are part of thick sections are represented by a solid black square on the map. In a few places, we were able to obtain charcoal under the surface unit but not at the contact between adjacent flows. In those places, the symbol on the map is located inboard of the contact. In a few of these cases, flow bases were exposed in roadcuts or quarries, where charcoal was preserved.

Table 2 reports 68 radiocarbon ages from 39 lava flows (Kelley, 1979; Kelley and others, 1979; Rubin and others, 1987; this study). Most are accelerator mass spectrometer (AMS) ages, and the rest are conventional ages determined at the U.S. Geological Survey (USGS) laboratory in Reston, Virginia. Thirty-seven AMS ages were analyzed by USGS and other laboratories. For eruptive units with more than one dated charcoal sample, each age is weighted by the inverse of its variance to yield a mean age (Taylor, 1982).

In table 2, there are multiple ages used to calculate a weighted mean average for a given flow unit. We interpret the breadth of ages as reflective of the nearly continuous eruptive activity on these flanks over multiple centuries. In the field, we may identify overlapping relations between flow units, the ages for which are indistinguishable according to the f-test (statistical fitness test; Stuiver and others, 1993). This is a further testament to the nearly continuous nature of summit-derived flows, reflective of a period of sustained activity.

All ages were calibrated to calendar years, using the CALIB 7.1 Radiocarbon Calibration Program (Stuiver and others, 1993, 1998). 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 ages in years before present. Symbols indicate reliability of age for stratigraphic interpretations. Rejected ages are reported in appendix 1.

Fault Systems

One normal fault cuts the northwest flank of Mauna Loa at 5,200 ft (1,585 m) elevation, 4.8 km (3.0 mi) east of the A.D. 1859 flow. This fault is inactive and draped by unfaulted younger flows as old as 3,300 yr B.P. The maximum offset from this fault is less than 10 m. In addition, several large cracks trend parallel to topographic contours. The origin of the cracks is unknown.

Baher and others (2003) analyzed earthquakes at 5–13 km depth preceding the A.D. 1984 Mauna Loa eruption, and they interpreted the focal mechanisms to be consistent with a northwest rift zone. There are no other geophysical or geological data to support this interpretation; that is, no gravity (Kauahikaua and others, 2000) or magnetic (Godson and others, 1981) data are consistent with a rift zone. No lineations or clustering of eruptive fissures or other structures that are usually found in rift zones occur in the field. Yet it is possible that the contour-following cracks are a direct result of the seismicity.

Map Unit Labels and Flow Identification Number (FID)

Each map unit is designated by a four-part label that identifies flow lithology, flow age group, phenocryst mineralogy, and flow number in an age group or defined stratigraphy (table 1; see Description of Map Units). Only the dominant lithology type (indicated by the letters s, p, a, m, or l; table 1) is listed on the map (sheet 1) and in the Correlation of Map Units (sheet 2), even though morphology of a single unit may vary, as described in the Description of Map Units. We use the term phenocryst for any mineral ≥1 mm in maximum diameter. Pyroxene is not an abundant phenocryst in Mauna Loa lava flows, therefore no code for its presence is assigned.

In addition to the map unit label, a unique three-digit Flow-Identification Number (for example, FID 838) is assigned to facilitate use of the database for the entire Mauna Loa edifice. The simplified map unit label is a non-unique label given to a unit so the user can readily obtain information about the morphology, age, mineralogy, and stratigraphy. This non-unique unit label may be used for an entirely different unit on a map of a different flank of Mauna Loa. Therefore, the FID is essential as a unique descriptor for unit identification in the database.

DESCRIPTION OF MAP UNITS

[Small areas on the printed or plotted map are unlabeled, to avoid obscuring data; use unit color or the database (https://doi.org/10.3133/sim2932e) 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 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

These deposits were too small and transient to map at this scale. 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 unconsolidated sand along the coast.

VOLCANIC DEPOSITS

LAVA FLOWS AND VENT DEPOSITS

Kaʻū Basalt

The Kaʻū Basalt includes historical 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 basalts, vent deposits, and lava flows. The flows are mostly aphanitic, and some have small amounts of olivine and plagioclase phenocrysts. Pyroxene is rare in hand specimen.

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

a0a0, p0a0, s0a0 — **A.D. 2022 flow**—Aphanitic ʻaʻā with minor pāhoehoe and spatter near the eruptive fissures. Vents distributed along 18.5-km segment across the summit (out of the mapped area) and along the NERZ between 11,000 and 12,780 ft. All the NERZ fissures are along the southern boundary of the mapped area. Contains <1% olivine phenocrysts 1–2 mm in size. FID 1

p0a1, a0a1, s0a1 — **A.D. 1984 flow**—Aphanitic ʻaʻā with <1% olivine phenocrysts 1–2 mm in size. Vents distributed along 15-km segment of NERZ between 9,350 and 12,750 ft elevation. Most fissures along the south boundary of the mapped area. FID 783

a0a2, p0a2, s0a2 — **A.D. 1975 flow**—Aphanitic ʻaʻā with <1% plagioclase phenocrysts 1–2 mm in size. Vents distributed along 2.5-km segment of NERZ between 12,140 and 12,790 ft elevation. Some fissures south of map area within the caldera. Uppermost NERZ fissures fed a 6.5 km ʻaʻā flow; the longest of these flowed in a northerly direction. FID 7

a0a3, m0a3, p0a3, s0a3 — **A.D. 1942 flow**—Massive ʻaʻā containing <1% olivine phenocrysts and abundant plagioclase microphenocrysts in a microcrystalline groundmass. Vents distributed along 3.5-km segment of NERZ between 11,880 and 12,860 ft elevation. Distinguished from A.D. 1984 flow by abundant plagioclase microphenocrysts. Makai (distal) vents erupted ʻaʻā near Mauna Loa access road and flowed northeast. FID 784

a0a4, m0a4, p0a4, s0a4 — **A.D. 1935–36 flow**—Flow is aphanitic with fine crystalline groundmass. Vents distributed along 6.5-km segment of NERZ between 11,160 and 12,880 ft elevation. Toothpaste ʻaʻā flow, commonly mixed with slabby pāhoehoe, along east border of Kokoolau quadrangle. Vesicles are subrounded and lined with magnesioferrite in places. Vent just east of the mapped area (fig. 4) is orthogonal to trend of rift zone. FID 785

a0a5, p0a5, s0a5 — **A.D. 1899 flow**—Nearly aphanitic ʻaʻā contains fine crystalline groundmass with <1% olivine phenocrysts and 1–3% plagioclase microphenocrysts. Located along east border of Kokoolau quadrangle. Eruption began with a summit outbreak followed by a flank eruption on NERZ. Vents distributed along 2-km segment of NERZ between 10,875 and 11,410 ft elevation; main eruptive vent called Dewey Cone. FID 786

a0b6 — **A.D. 1880–81 flow**—Flow is fresh and glassy with 1–3% clear olivine phenocrysts and abundant inconspicuous plagioclase microphenocrysts. Both ʻaʻā and pāhoehoe morphologies occur. FID 787

p0b7, a0b7, s0b7 — **A.D. 1859 flow**—Flow fresh and glassy with 1–3% clear olivine phenocrysts and abundant inconspicuous plagioclase microphenocrysts. Radial vents distributed along 4.6-km segment of Mauna Loa’s north flank between 8,890 and 11,135 ft elevation; a second sub-parallel system erupted 1.3 km northeast of this at an elevation of 8,380 to 8,695 ft, extending 1.1 km. An ʻaʻā part of the flow entered the sea north of Keawaiki in just 8 days. Pāhoehoe reached the sea in

120 days at the north side of Kīholo Bay. Both flows traverse almost the entire mapped area. Groundmass is diktytaxitic and light to medium gray in color. Vesicles well to moderately sorted. FID 410

p0j8, a0j8, s0j8 — **A.D. 1855–56 flow**—Pāhoehoe, ‘a‘ā, and spatter morphologies present. Contains 2–8% clear subhedral olivine and 1–5% plagioclase phenocrysts. FID 788

a0a9, s0a9 — **A.D. 1852 flows**—Aphanitic ‘a‘ā and near-vent pāhoehoe erupted from radial vents along upper NERZ. Eruption is noteworthy for its bimodal distribution of olivine phenocrysts. Vents that erupted early at higher elevation tended to produce more spatter and erupt olivine-poor (<<1%) lava, whereas lower elevation vents (outside map area; Trusdell and Lockwood, 2017) erupted lavas that have 15–20% olivine phenocrysts in a fine crystalline groundmass. FID 789

p0k10, a0k10, m0k10, s0k10 — **A.D. 1843 flow**—Pāhoehoe and ‘a‘ā flows along east border of mapped area in Kokoolau and Puu Koli quadrangles. NERZ vents are distributed along a 2.3-km segment between 10,720 and 11,480 ft elevation. Lower elevation vents, orthogonal to NERZ, are between 9,600 and 9,900 ft elevation on Mauna Loa’s north flank. Flow has 1–3% brownish-green olivine phenocrysts and 8–10% plagioclase phenocrysts. Some olivine present as discrete crystals; others intergrown with plagioclase. Surface relief on ‘a‘ā flow >8 m locally and pāhoehoe tumuli reach 30 m tall. Lowest elevation vent oblique to trend of rift zone. FID 790

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

a1i1, s1i1 — **Radial vent 414 flow**—Small ~1.5-km-long ‘a‘ā flow issued from radial vent in west-central part of Puu O Uo quadrangle. Flow contains ~4% subhedral, sugary olivine phenocrysts and 0–2% plagioclase phenocrysts as long as 4 mm. Feldspathic groundmass. Age, 220±40 radiocarbon yr B.P. FID 414

a1b2, p1b2, s1b2 — **Ke‘āmuku flow**—Massive ‘a‘ā and pāhoehoe originating from large radial vent at Ko‘oko‘olau cone. Flow flooded Mauna Loa’s north flank and traversed Kokoolau, Puu Koli, Keamuku, and Ahumoa quadrangles. Contains 0–2% olivine phenocrysts in medium-gray, fine-grained, feldspathic groundmass. Weighted average age, 278±41 radiocarbon yr B.P. FID 413

p1a3 — **Landing Zone flow**—Massive pāhoehoe with minor ‘a‘ā that flooded Mauna Loa’s north flank near boundary with Mauna Kea in northeastern Puu Koli quadrangle. Contains <1% rare olivine phenocrysts in medium-gray, fine-grained, feldspathic groundmass. Flow surfaces vesicular to dense and glassy. Weighted average age, 376±15 radiocarbon yr B.P. FID 26

a1a4, s1a4, p1a4, m1a4 — **Pohaku‘ohanalei flow**—Prominent vent on upper NERZ of Mauna Loa, bisected by the A.D. 1984 fissure. Vents distributed along 2.0-km segment of NERZ between 11,940 and 12,480 ft elevation. Flow of ‘a‘ā and pāhoehoe in the east part of Kokoolau quadrangle. Contains rare olivine (<<1%) phenocrysts in medium-gray, cryptocrystalline groundmass. FID 18

p1a5, a1a5, s1a5 — **Flow 803**—Aphanitic ‘a‘ā near east boundary of Kokoolau quadrangle; probable source vent buried near 11,400 ft elevation. Dense, medium-gray, nearly feldspathic groundmass with 10–15% subangular magnesioferrite-lined vesicles. FID 803

p1a6 — **‘Āinahou flow**—Dense pāhoehoe to vesicular pāhoehoe in kīpuka along east boundary of map area in northeastern Kokoolau and southeastern Puu Koli quadrangles. Well-crystallized, bluish-gray, feldspathic groundmass with 0–1% light-green olivine phenocrysts and microphenocrysts of plagioclase. Age, 410±60 radiocarbon yr B.P. FID 792

p1a7, s1a7 — **Radial vent 415 flow**—Short ~800-m-long ‘a‘ā flow issued from radial vent in southwestern Puu O Uo quadrangle. Groundmass sparkly, gray, and feldspathic. Small plagioclase phenocrysts (<1%) widely scattered; plagioclase microphenocrysts present as fine laths. Age, 530±60 radiocarbon yr B.P. FID 415

a1a8, s1a8 — **Pu‘u‘ouo flow**—Prominent radial vent eruption on west flank of Mauna Loa. Flow reached the sea north of Kealakekua Bay (fig. 2). Massive ‘a‘ā with minor pāhoehoe located in southern Puu O Uo quadrangle. Fissures occur in adjacent Sulphur Cone quadrangle outside of the mapped area to the southeast. Contains 0–1% olivine phenocrysts in medium-gray, fine-grained, feldspathic groundmass. Weighted average age, 553±94 radiocarbon yr B.P. FID 412

p1a9, a1a9, m1a9, s1a9 — **Ke A Po‘omuku flow**—Massive pāhoehoe and ‘a‘ā that flooded Mauna Loa’s flank northeast of the caldera and southeast of NERZ in southwestern Kokoolau quadrangle. Eruptive fissures extend into NERZ in south-central Kokoolau quadrangle. Contains <1% olivine phenocrysts in medium-gray, fine-grained, feldspathic groundmass. Weighted average age, 599±57 radiocarbon yr B.P. FID 274

a1j10, s1j10 — **Radial vent 417 flow**—Two-kilometer-long ‘a‘ā in west-central Puu O Uo and east-central Puu Lehua quadrangles that erupted from a radial vent. Radial vent between 6,120 and 6,140 ft elevation. Flow has moderately feldspathic groundmass with subrounded to subangular vesicles. Contains

5–7% subhedral olivine phenocrysts and 1–2% fine, anhedral plagioclase phenocrysts and microphenocrysts, generally intergrown with olivine. Age, 640±80 radiocarbon yr B.P. FID 417

a1a11, m1a11, p1a11, s1a11 — **NOAA flow**—ʻAʻā and pāhoehoe flows in central Kokoolau quadrangle erupted from radial vents and overlain by A.D. 1852 flow (unit a0a9; FID 789). Radial vents distributed along 4-km segment of the north flank between 10,720 and 12,640 ft elevation. Contains <1% olivine and plagioclase phenocrysts and microphenocrysts. Flows and vents within the lava diversion structure of the National Oceanic and Atmospheric Administration (NOAA) Mauna Loa Observatory. FID 424

m1a12, a1a12 — **Flow 804**—Nearly aphanitic mixed ʻaʻa and pāhoehoe flows in south-central Kokoolau quadrangle. Located between A.D. 1942 (unit a0a3; FID 784) and A.D. 1852 (unit a0a9; FID 789) flows. Has <1% subhedral olivine phenocrysts and <1% plagioclase in well-crystallized, fine-grained, feldspathic groundmass. Plagioclase is more conspicuous than olivine. FID 804

a1a13 — **Flow 854**—ʻAʻā in northeastern Kokoolau and southeastern Puu Koli quadrangles. Just west of A.D. 1935–36 flow (unit a0a4; FID 785). Unit nearly aphanitic; contains 0.5% olivine phenocrysts. Groundmass light gray and feldspathic; vesicles angular and moderately sorted. FID 854

a1a14, p1a14 — **Flow 16**—Unit from summit region of Mauna Loa; extends 6 km from the south boundary of Kokoolau quadrangle. Dense, nearly aphanitic ʻaʻā contains <1% widely scattered plagioclase phenocrysts. Rare pāhoehoe contains 1–2% plagioclase and <1% plagioclase-olivine glomerocrysts. FID 16

a1g15 — **Flow 815**—Young-looking ʻaʻā flow just south (upslope) of Puʻukoli. The flow contains 1–2% anhedral plagioclase phenocrysts 1–3 mm in size in a well-crystallized, light-gray, feldspathic groundmass. Olivine and plagioclase glomerocrysts common. Unvegetated. FID 815

a1a16 — **Flow 816**—Nearly aphanitic ʻaʻā contains fine crystalline groundmass with <1% olivine phenocrysts and plagioclase microphenocrysts. Unit overlain by flow 804 (unit m1a12; FID 804). FID 816

a1a17, s1a17 — **Flow 798**—ʻAʻā flow in north-central Kokoolau and south-central Puu Koli quadrangles. Traverses quadrangle from south to north, ending northeast of Koʻokoʻolau cone (unit a1b2; FID 413). Vent at 12,600 ft elevation along NERZ. At higher elevations, unit buried by A.D. 1942 (unit a0a3; FID 784) and A.D. 1975 (unit a0a2; FID 7) flows. Aphanitic ʻaʻā has 0–1% olivine phenocrysts and microphenocrysts in a well-crystallized feldspathic groundmass. Microlites of plagioclase common in dense groundmass. FID 798

p1i18, s1i18 — **Keʻāmoku Kīpukakulalio west flow**—Pāhoehoe in southeastern Kokoolau quadrangle. Vent at 11,080 ft elevation. Flow contains 3–8% subhedral, sugary olivine phenocrysts and 0–2% plagioclase phenocrysts. Vesicles subrounded to elongate and lined with magnesioferrite in places. FID 838

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

a2d1 — **Radial vent 442 flow**—Radial vent and flow along west-central border of Puu O Uo quadrangle, extending into central Puu Lehua quadrangle. Contains ~12% olivine subhedral blades and phenocrysts. Olivine phenocrysts clear, light green, and 1–7 mm in diameter. Medium-gray and feldspathic groundmass. Surface color tannish brown; surface glass preserved on some surfaces. Age, 1,000±150 radiocarbon yr B.P. FID 442

a2c2, p2c2 — **Honey Bee flow**—Major radial flow in central part of Puu Lehua quadrangle, extending into Kealakekua quadrangle. Vent is both spectacular and unique. It seems a ~150-m-long rift opened parallel to the contour from which lava erupted. No spatter present. Blocks as large as 8 m across displaced downslope of vent. Lava probably rafted or floated large blocks from the rift downslope. Flow consists of rubbly ʻaʻā and slabby pāhoehoe. Contains medium-gray, diktytaxitic groundmass that has 5–8% clear subhedral olivine phenocrysts. Upslope side of vent stands 15–20 m tall. Vent forms a slope-parallel radial fissure at 5,960 ft elevation. Age, 1,100±110 radiocarbon yr B.P. FID 441

p2k3, a2k3, s2k3 — **Keauhou Two flow**—Major radial vent in central part of Puu O Uo quadrangle, between A.D. 1859 (unit p0b7; FID 410) and Puʻuʻouo (unit a1a8; FID 412) flows. Vents from 2.8-km radial fissure between 9,340 and 10,900 ft elevation. Both pāhoehoe and ʻaʻā common and extend down to saddle between Mauna Loa and Hualālai. Contains ~5–7% subhedral plagioclase phenocrysts as long as 2 mm and 3–4% subhedral olivine phenocrysts. Olivine and plagioclase intergrowths common. Light gray and feldspathic groundmass. Gray surface color. Weighted average age, 1,153±15 radiocarbon yr B.P. FID 418

p2i4, a2i4 — **Flow 29**—Major unit from summit region of Mauna Loa. Traverses from southeast to northwest in south-central Puu O Uo quadrangle. Flow most common as tube-fed hummocky pāhoehoe. Tumuli common, as are areas containing slabby pāhoehoe and fluid ʻaʻā. Contains 1–3% plagioclase as anhedral clots commonly intergrown with olivine. Contains 1–2% olivine as small inconspicuous phenocrysts and microphenocrysts. Feldspathic and dark gray groundmass. Tephra from unknown sources accumulates in some low spots. Overlies flow 28 (unit p2k9; FID 28) and Poopaaelua flow (unit p2d22; FID 144). Age, 1,225±30 radiocarbon yr B.P. FID 29

p2e5, s2e5 **Radial vent 423 flow**—Radial vent flow in southwestern Kokoolau quadrangle. Vents discontinuous across 0.9 km starting at 11,760 ft elevation. Longest flow is 1 km long. Pāhoehoe, approximately 20 cm thick, contains 10–30% olivine and ~1% plagioclase phenocrysts in a cryptocrystalline groundmass. Phenocryst abundances vary depending on whether flow or spatter is sampled and where in the section the sample is collected from. FID 423

p2l6, s2l6 **Radial vent 448 flow**—Radial vent with pāhoehoe and ʻaʻā in southwestern Kokoolau quadrangle. Vents form 0.7-km-long radial fissure between 12,750 and 12,970 ft elevation. Appears as crack-oozed lava without near-vent structures in places. Contains 6–8% olivine phenocrysts, 7–10% plagioclase phenocrysts, and 5–6% olivine-plagioclase intergrowths. ʻAʻā flows have slightly higher mineral abundances. Plagioclase is more conspicuous than olivine. FID 448

m2a7, s2a7 **Radial vent 444 flow**—Radial vent with two en echelon segments spanning 0.8 km between 11,570 and 11,925 ft elevation. Aphanitic ʻaʻā with rare olivine in southwest corner of Kokoolau quadrangle, ~1.7 km west of the NOAA Mauna Loa Observatory. Contains <<1% olivine phenocrysts in well-crystallized and feldspathic groundmass that has obvious plagioclase microlites. FID 444

p2a8, s2a8 **Radial vent 426 flow**—Radial vent spanning 0.24 km between 10,960 and 11,110 ft elevation in southwest corner of Kokoolau quadrangle. Source vents between radial vent 444 flow (unit m2a7; FID 444) and flow 16 (unit a1a14; FID 16). Contains 0–1% olivine phenocrysts and microphenocrysts in medium-gray feldspathic groundmass. FID 426

p2k9, a2k9, m2k9 **Flow 28**—Flow from summit region of Mauna Loa. Traverses southwest corner of Kokoolau and southern Puu O Uo quadrangles from southeast to northwest. Contains 3–6% olivine phenocrysts and microphenocrysts and 7–9% anhedral plagioclase clots. Some plagioclase forms radiating intergrowths with olivine. Dark gray and microcrystalline groundmass. Weighted average age, 1,255±44 radiocarbon yr B.P. FID 28

p2i10, a2l10, a2i10, p2h10, m2j10, a2g10, m2i10 **Flow 82**—Flow from summit region of Mauna Loa. Flow traverses Kokoolau and Puu O Uo quadrangles from southeast to northwest along their common border. Large pāhoehoe flow with minor ʻaʻā. Contains 2–3% subhedral olivine phenocrysts as large as 2 mm. Contains 5–7% plagioclase phenocrysts as large as 4 mm and plagioclase microphenocrysts in medium-gray feldspathic groundmass. Some phase abundances vary by 2–3%. Weighted average age, 1,250±17 radiocarbon yr B.P. FID 82

p2a11, a2a11 **Flow 64**—Flow from summit region of Mauna Loa. Traverses southeast part of Puu O Uo quadrangle from southeast to northwest. Aphanitic ʻaʻā and pāhoehoe groundmass well crystallized and feldspathic, full of plagioclase microlites. Flow older than flow 82 (unit p2j10; FID 82) and younger than flow 57 (unit p2d12; FID 57). Age, 1,280±25 radiocarbon yr B.P. FID 64

p2c12, a2c12, a2d12 **Flow 57**—Massive flow from Mauna Loa summit. Pāhoehoe flowed down northwest flank of Mauna Loa to flood northwestern Puu O Uo, southeastern Hualalai, eastern Puu Lehua, and Kealakekua quadrangles. Distinctive in that flow contains olivine with two habits—equant phenocrysts and laths. Flow has variable amounts of olivine, ranging from 3 to 15%; flow tops have lower amounts of olivine and are black and glassy. Groundmass is light gray, well crystallized, and microcrystalline. Weighted average age, 1,248±35 radiocarbon yr B.P. FID 57

p2f13, p2d13, a2d13, a2f13, m2d13, a2a13, m2f13, p2c13 **Pōhakuloa flow**—Tube-fed pāhoehoe flow from summit region of Mauna Loa. Traverses Kokoolau, Puu O Uo, Puu Koli, Naohueleelua, Keamuku, and Puu Anahulu quadrangles from southeast to northwest. Large pāhoehoe flow with minor ʻaʻā; tumuli common. Variable amounts of olivine, ranging from 3 to 30%; flow tops have lower amounts of olivine and are black and glassy. Interiors of flows display dramatic olivine settling in places. Groundmass is light gray, well crystallized, and microcrystalline to diktytaxitic in texture. Weighted average age, 1,323±42 radiocarbon yr B.P. FID 62

p2a14 **Hōkūkano flow**—From summit region of Mauna Loa. Located along southeast border of Puu Lehua quadrangle. Pāhoehoe with 0–1% olivine phenocrysts in well-crystallized feldspathic groundmass. Most of flow is south of mapped area. Weighted average age, 1,337±42 radiocarbon yr B.P. FID 56

p2d15 **Flow 145**—From summit region of Mauna Loa. Located along south-central border of Puu Lehua quadrangle. Pāhoehoe with 10–15% olivine phenocrysts in well-crystallized feldspathic groundmass. Defining characteristic is large olivine crystals (<6 mm), averaging 4–5 mm. Most of flow is south of mapped area. Age, 1,460±40 radiocarbon yr B.P. FID 145 p2e16, s2e16 **Radial vent 454 flow**—Radial-vent flow in southwestern Puu O Uo quadrangle. Vents discontinuous across 0.45 km between 7,700 and 7,860 ft elevation. Pāhoehoe originates from radial fissure with no spatter. Flow is picritic with 15–18% olivine phenocrysts. Inconspicuous olivine phenocrysts (<3 mm) average 1.5 mm in size. Olivine laths or blades common. Groundmass contains plagioclase microlites. Vesicles subrounded and poorly sorted. Longest flow is 250 m. Age, 1,480±60 radiocarbon yr B.P. FID 454

a2b17, p2b17 **Flow 152**—Massive flow from summit of Mauna Loa. ʻAʻā flowed 39 km down northwest flank of Mauna Loa in northwesterly direction through Naohueleelua, Hualalai, Keamuku, Puu Anahulu, Puu Hinai, and Anaehoomalu quadrangles. Contains 3–5% olivine as light-green phenocrysts in a microcrystalline groundmass. Age, 1,500±100 radiocarbon yr B.P. FID 152

p2i18, a2i18 **Flow 63**—Pāhoehoe and ʻaʻā flows originating from NERZ of Mauna Loa. Traverses south to north along the east parts of Kokoolau and Puu Koli quadrangles. Crosses the Redleg Trail. Flow most common as tube-fed pāhoehoe. Tumuli common. Contains 2–3% large olivine phenocrysts and ~1% plagioclase phenocrysts and microphenocrysts in feldspathic groundmass. Weighted average age, 1,548±83 radiocarbon yr B.P. FID 63

a2b19 **Flow 850**—ʻAʻā commonly in small, isolated patches surrounded by younger flows (A.D. 1942 flow [unit a0a3; FID 784] and A.D. 1975 flow [unit a0a2; FID 7]) in central Kokoolau quadrangle. Originates from upper part of NERZ. Contains 1–2% subhedral olivine phenocrysts that are olive green in color and 1–3 mm, averaging 1.5 mm. Plagioclase present at ~1% and commonly intergrown with olivine. Medium gray, microcrystalline, and sparkly groundmass. Vesicles subrounded to subangular in form, deformed, and lined by maghemite. Surface color light- to medium-chocolate brown to tan. FID 850

p2a20, a2a20 **Flow 147**—Flow from upper NERZ region of Mauna Loa. Traverses south to north in north-central Kokoolau quadrangle. Aphanitic pāhoehoe with <<1% olivine phenocrysts. Olivine crystals dull green in appearance, small, and inconspicuous. Groundmass is medium gray and feldspathic with abundant plagioclase microlites in core and microcrystalline flow tops. Color is tan to light gray. Soil and (or) tephra occur in low spots. Weighted average age, 1,550±19 radiocarbon yr B.P. FID 147

s2c21 **Radial vent 451 flow**—Radial-vent flow in south-central Puu O Uo quadrangle, north of Puʻuʻouo flow (unit a1a8; FID 412). Vents discontinuous across 230 m starting at 8,760 ft elevation. Kīpuka just 380 m long. Flow contains 7–10% subhedral olivine phenocrysts and blades; color is green and clear. Sizes range from 1 to 7 mm, averaging 2 mm. Groundmass microcrystalline and medium gray. Vesicles subrounded and poorly sorted. Surface color tan. FID 451

p2d22, a2d22, m2d22, p2c22, a2b22 **Poopaaelua flow**—Pāhoehoe and ʻaʻā flows originating from Mauna Loa summit. Located in southwest corner of Puu O Uo quadrangle and as scattered kīpuka in northwestern Puu O Uo and Puu Lehua quadrangles. Distinctive, containing 10–18% olivine phenocrysts. Interiors of pāhoehoe flows contain as much as 25–30% olivine phenocrysts. Groundmass well crystallized. Overlain by flow 57 (unit p2c12; FID 57). Age, 1,600±200 radiocarbon yr B.P. FID 144

p2c23, s2c23 **Radial vent 458 flow**—Two small radial-vent flows in southwest corner of Puu O Uo quadrangle. Vents discontinuous, separated by 2.7 km; upper vent and flows at 9,080 ft elevation and lower flow at 7,880 ft elevation. Longest flow is 170 m. Contains approximately 5–10% olivine as subhedral phenocrysts (<4 mm). Most olivine phenocrysts small and inconspicuous, averaging 2 mm in size; unit also has olivine laths as long as 5 mm. Feldspathic groundmass. Age, 1,720±65 radiocarbon yr B.P. FID 458

a2b24, p2b24, m2b24, s2b24 **Radial vent 420 flow**—Radial unit in central part of Naohueleelua quadrangle; flowed southeast to northwest. Main crater vent at 6,960 ft elevation. Flows skirt northeast border of Kīpukaʻalalā. Contains 2–4% olivine phenocrysts. Groundmass light to medium gray and microcrystalline. Vesicles subangular and poorly sorted. Surface color orange-tan to brown-tan. Olivine and plagioclase intergrowths common at ~1%. Age, 1,810±105 radiocarbon yr B.P. FID 420

a2a25 **Flow 61**—Aphanitic flow crossing center of boundary between Puu Koli and Kokoolau quadrangles. ʻAʻā has a well-crystallized groundmass that contains plagioclase microlites that sparkle. Surface tan to light chocolate color. Age, 1,855±35 radiocarbon yr B.P. FID 61

p2i26, a2i26, s2i26 **ʻĀinakahiko flow**—ʻAʻā and pāhoehoe commonly in small, isolated patches surrounded by younger flows in eastern Kokoolau quadrangle. Main eruptive vent orthogonal to NERZ at 10,120 ft elevation on Mauna Loa's north flank. Majority of flow outside mapped area in central Puu O Uo quadrangle. Flow very sparsely phyric, with approximately 1% olivine phenocrysts and 0–2% plagioclase microphenocrysts. Groundmass light gray with some diktytaxitic and open vuggy textures. Vesicles elongate, spheroidal, and subangular. Surface broken and weathered to red, tan, or orange. Black lichen commonly on surface. Age, 1,880±200 radiocarbon yr B.P. FID 867 p2k27, a2k27, p2j27, a2j27, m2k27 — **Flow 74**—Large pāhoehoe in western Kokoolau quadrangle. From summit of Mauna Loa. Variable olivine mineralogy (~1–10%) as subhedral phenocrysts. Anhedral clots of plagioclase and olivine common at 2–8%. Medium gray and feldspathic groundmass. Surface color tannish gray. FID 74

p2a28, a2a28 — **Flow 70**—Pāhoehoe and ‘a‘ā commonly in small, isolated patches surrounded by younger flows (NOAA flow [unit a1a11; FID 424]) in central Kokoolau quadrangle. Just downslope of A.D. 1852 flow (unit a0a9; FID 789). Contains 0–1% olivine phenocrysts in feldspathic groundmass. FID 70

p2g29, a2g29 — **Flow 20**—‘A‘ā and pāhoehoe commonly in small, isolated patches surrounded by younger flows in south-central Kokoolau quadrangle. Surrounded by A.D. 1852 (unit a0a9; FID 789), A.D. 1942 (unit a0a3; FID 784) and A.D. 1935–36 (unit a0a4; FID 785) flows. Contains 1–2% anhedral plagioclase phenocrysts that are 1 mm in size and <1% olivine as small 1 mm anhedral phenocrysts. Olivine commonly intergrown with plagioclase. Groundmass microcrystalline with abundant plagioclase microlites. Surface color dull gray; upper surfaces somewhat broken down though some ropey surfaces are preserved. FID 20

p2d30, a2d30 — **Flow 845**—Traverses from south to north in eastern Kokoolau quadrangle in small, isolated patches surrounded by younger flows. Source vents were mapped as discontinuous across 2.8 km between 11,320 and 12,000 ft elevation but were since completely buried by the A.D. 2022 flow. Pāhoehoe and ‘a‘ā common. Contains olivine with two habits—equant phenocrysts and laths. Flow has variable amounts of olivine (2–15%); flow tops have lower amounts of olivine and are black and glassy. Groundmass light gray, well crystallized, and microcrystalline. Lower elevation units tend to be less phyric and full of tumuli. FID 845

a2j31 — **Flow 113**—‘A‘ā flow in southeast corner of Naohueleelua quadrangle. Contains 5–7% olivine and 1–2% plagioclase phenocrysts. Groundmass medium gray, microcrystalline, and sparkly. Vesicles angular and poorly sorted. Surface color medium to light chocolate tan. FID 113

a2i32, m2i32 — **Flow 848**—Scattered ‘a‘ā flows and minor pāhoehoe in east-central Kokoolau quadrangle. Vent was mapped at 10,840 ft elevation but was since buried by the A.D. 2022 flow. Contain about 1% olivine and 1% anhedral plagioclase phenocrysts as large as 3 mm. Plagioclase and olivine commonly intergrown. Groundmass light gray and sparsely feldspathic. Vesicle abundance 20–40%, subrounded to subangular in form, and well sorted. FID 848

p2a33, a2a33, m2a33, s2a33 — **Radial vent 455 flow**—Radial vent between 9,560 and 9,720 ft elevation in west-central Kokoolau quadrangle. Aphanitic ‘a‘ā with rare olivine. Contains <1% yellow-green olivine phenocrysts in well-crystallized microcrystalline groundmass. Flow surface tan in color. FID 455

p2d34, a2d34, a2f34, p2f34, m2d34, a2b34 — **Flow 58**—Pāhoehoe and ‘a‘ā commonly in isolated patches surrounded by younger flows in central Kokoolau quadrangle. A few kīpuka are in southern Puu Koli quadrangle. Contains ~10–15% olivine phenocrysts and blades. Cores of pāhoehoe flows have as much as 30% olivine. Olivine crystals 4–6 mm, clear and euhedral. Groundmass sparsely feldspathic; vesicles subrounded and contain zeolites in places. FID 58

a2a35, p2a35, m2a35, m2b35, s2a35, a2b35 — **Crack flow**—Radial vents discontinuous across 8.3 km between 6,450 and 8,560 ft elevation. Lower part of vent system are ground cracks that effused lava. Originates in northwestern Kokoolau quadrangle and traverses southwestern Puu Koli and east-central Naohueleelua quadrangles. Aphanitic with rare olivine as large as 2 mm. Groundmass well crystallized, mildly feldspathic, and full of plagioclase microlites. Flow surface tan in color. FID 445

a2a36 — **Flow 60**—‘A‘ā kīpuka flanked by younger flows (NOAA flow [unit a1a11; FID 424] and A.D. 1935–36 flow [unit a0a4; FID 785]) in central Kokoolau quadrangle. Toothpaste form of ‘a‘ā common. Flow just downslope of A.D. 1852 flows (unit a0a9; FID 789) and NOAA Mauna Loa Observatory. Contains 0–1% olivine phenocrysts in feldspathic groundmass. FID 60

a2a37 — **Flow 853**—‘A‘ā flow in eastern Kokoolau quadrangle. Traverses quadrangle from south to north, ending just east of Pu‘ukoli cone (unit p7b1; FID 473). Aphanitic ‘a‘ā has <1% olivine phenocrysts and microphenocrysts in well-crystallized groundmass, which is dense, medium gray, and plagioclase rich. Surface color chocolate brown. FID 853

m2a38, s2a38 — **Flow 902**—Off-axis NERZ vent with two en echelon segments spanning ~0.8 km between 8,450 and 8,690 ft elevation. Aphanitic ‘a‘ā with rare olivine in northeast corner of Kokoolau quadrangle. Contains <<1% olivine phenocrysts in medium gray, moderately feldspathic groundmass. Surface color light brown to tan. FID 902

s2a39 — **Radial vent 452 flow**—Radial fissure 0.7 km long between 8,900 and 9,190 ft elevation in east-central Kokoolau quadrangle. Comprises spatter ramparts and ‘a‘ā and pāhoehoe flows. Aphanitic with <1% olivine microphenocrysts. Groundmass light gray, abundantly feldspathic, and has both olivine and plagioclase microphenocrysts. Vesicles subspherical and well sorted. Surface color light chocolate-brown to tan. FID 452 p2a40, a2a40 **Flow 59**—Pāhoehoe kīpuka in north-central Kokoolau quadrangle. Flow just downslope of flow 60 (unit a2a36; FID 60). Contains 0–1% olivine phenocrysts in a feldspathic groundmass. FID 59

a2a41, p2a41 **Flow 148**—Aphanitic ʻaʻā and pāhoehoe flows in northern Puu Koli quadrangle beyond distal end of A.D. 1843 flows (FID 790). Contains rare scattered (<1%) olivine phenocrysts in a well crystallized and feldspathic groundmass. ʻAʻā characterized by numerous accretionary lava balls. FID 148

p2h42 **Flow 76**—Pāhoehoe commonly in small, isolated patches surrounded by younger flows in northwestern Kokoolau and southwestern Puu Koli quadrangles. Distinctive coarse, plagioclase-rich, tube-fed pāhoehoe. Contains 7–8% plagioclase phenocrysts. Plagioclase forms aggregates of euhedral plagioclase laths (to 3 mm) to form glomerocrysts in a gray groundmass. Upper surface stained orange, weathered, glassy, and speckled by coarse plagioclase. FID 76

a2a43, m2a43, p2a43, s2a43 **Radial vent 419 flow**—Radial vent flow in northeast corner of Puu O Uo quadrangle. Vents discontinuous across 4.4 km between 7,280 and 8,580 ft elevation. Contains <1% olivine microphenocrysts and phenocrysts in well crystallized and feldspathic groundmass with obvious plagioclase microlites. FID 419

s2a44, p2a44 **Radial vent 456 flow**—Radial vent surrounded by A.D. 1859 flow (FID 410). Small unit only ~750 m long issued from radial vent at 7,180 ft elevation in north-central Puu O Uo quadrangle. Aphanitic, frothy, bulbous pāhoehoe with large blisters. Groundmass feldspathic; microgabbros common. Vesicles angular to subangular and poorly sorted. Surface color yellow orange. FID 456

s2a45 **Pukauahi flow**—Vents along NERZ discontinuous across 0.8 km between 10,960 and 11,125 ft elevation. Spatter from Pukauahi aphanitic with <1% light-green, subhedral olivine as large as 4 mm in medium-gray, moderately feldspathic groundmass. Vesicles subangular, poorly sorted, and 15–20% of rock. FID 835

s2a46 **Flow 851**—Solitary cone in midst of NERZ at 11,400 ft elevation. Aphanitic with 0–1% olivine phenocrysts, dull green in color and subhedral in form. Olivine crystals as large as 3 mm. Groundmass medium gray, microcrystalline, and sparkly. Surface color ranges from dull black to dark gray to oxidized red and consists of welded spatter. FID 851

s2g47 **Radial vent 450 flow**—Radial vent with no flows in southwestern Kokoolau quadrangle at 12,160 ft elevation. Contains 3–5% plagioclase as anhedral clots as large as 3 mm. Contains <1% olivine as small, inconspicuous phenocrysts and microphenocrysts. Groundmass feldspathic and dark gray. About 1 km downslope of A.D. 1852 (unit a0a8; FID 789) fissure. FID 450

p2a48, s2a48 **Radial vent 446 flow**—Flow from radial vent discontinuous across 1.7 km between 9,340 and 10,200 ft elevation in west-central Kokoolau quadrangle. Aphanitic, frothy, shelly pāhoehoe with large blisters. Other parts of flow have dense black glass and non-oxidized surfaces. Groundmass microcrystalline. FID 446

p2a49 **Flow 65**—Hummocky pāhoehoe with minor ʻaʻā in south-central Puu O Uo quadrangle. Nearly aphanitic pāhoehoe with 0–1% light-green olivine phenocrysts and microphenocrysts and rare <<1% plagioclase. Groundmass well crystallized, dark gray, and diktytaxitic. FID 65

p2i50 **Flow 852**—Pāhoehoe commonly in small, isolated patches surrounded by younger flows (A.D. 1942 [unit a0a3; FID 784] and A.D. 1975 [unit a0a2; FID 7]) in central Kokoolau quadrangle. One of oldest units in area. Contains 1–2% olive-green olivine phenocrysts as large as 3 mm, averaging 1.5 mm. Contains 2% anhedral plagioclase, generally associated with olivine. Groundmass medium gray and microcrystalline. Vesicles elongate, lined by maghemite, and subspheroidal to subangular in form. FID 852

a2b51, p2b51 **Flow 849**—ʻAʻā and pāhoehoe commonly in tiny, isolated patches surrounded by younger flows (A.D. 1942 [unit a0a3; FID 784] and A.D. 1852 [unit a0a8; FID 789]) in south-central Kokoolau quadrangle. Slightly porphyritic lava with 1–5% olivine. Groundmass microcrystalline. FID 849

a2d52, p2d52, s2d52 **Waterhole kīpuka flow**—Vents along NERZ discontinuous across 0.5 km between 11,560 and 11,640 ft elevation in southeast corner of Kokoolau quadrangle. Pāhoehoe and minor ʻaʻā contain 10–15% olivine phenocrysts in light-gray microcrystalline groundmass. Olivine phenocrysts as large as 7 mm; some oxidized to black. Flow surface tan to orange stained. Rubbly tops. FID 846

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

p3i1 **Kaʻawaloa flow**—Radial-vent flows in kīpuka within Puʻuʻouo flow (unit a1a8; FID 412). Contains 1–4% subhedral to anhedral olivine phenocrysts. Dull, light-green olivine 0.5 to 3 mm. Subhedral plagioclase common at 1–5% abundance. Surface color light gray. Age, 2,030±60 radiocarbon yr B.P. FID 440 a3b2, p3b2, a3a2, m3b2 **Flow 156**—Originates from Mauna Loa summit. ‘A‘ā flowed down northwest flank of Mauna Loa, travelling northwesterly for 39 km through Kokoolau, Puu O Uo, Naohueleelua, Keamuku, and Puu Anahulu quadrangles. Contains 0–3% olivine as light-green phenocrysts and microphenocrysts. Sizes range from 0.5 to 4 mm; average 2 mm. Groundmass medium gray and microcrystalline. Surface color tan to tannish orange. FID 156

p3a3, a3a3 **Flow 161**—Flow originates from Mauna Loa summit. Pāhoehoe flowed down northwest flank of Mauna Loa, traversing in a northwesterly direction for 43 km through Kokoolau, Naohueleelua, and Keamuku quadrangles. Flow is aphanitic. Groundmass light gray and contains plagioclase microlites. Surface color dull black to gray. Weighted average age, 2,194±27 radiocarbon yr B.P. FID 161

p3k4 **Pu‘ukahiliku flow**—Pāhoehoe flow in southeast corner of Puu Koli quadrangle. Originates from two discontinuous radial vent fissures upslope. Contains 0–2% anhedral, dark-green olivine and 2–8% anhedral plagioclase phenocrysts. Conspicuous intergrowths of olivine and plagioclase form 1–2% of rock. Groundmass light gray and feldspathic, with diktytaxitic vugs. Subrounded to subangular vesicles form large, open pockets at surface and are lined by magnesioferrite in places. Age, 2,240±150 radiocarbon yr B.P. FID 866

a3a5 **Flow 174**—Aphanitic ‘a‘ā in southwestern Puu Koli quadrangle that carries <<0.5% small olivine phenocrysts in dense, dark-gray, microcrystalline groundmass. Surfaces locally weathered to tan-brown color. FID 174

p3d6, p3e6, m3d6, a3d6, a3e6 **Flow 150**—Originates from summit of Mauna Loa. ‘A‘ā flowed down northwest flank of Mauna Loa, traversing northwesterly through southwestern Puu Koli, north-central Naohueleelua, Keamuku, and Puu Anahulu quadrangles. Contains 20–30% olivine phenocrysts (average 20%) as large as 10 mm in medium-gray microcrystalline groundmass. Age, 2,693±39 radiocarbon yr B.P. FID 150

a3a7 **Flow 106**—Originates from upper NERZ. ‘A‘ā flowed down north flank of Mauna Loa, traversing northwesterly through north-central Kokoolau and Puu Koli quadrangles. ‘A‘ā flow flanks Pu‘ukoli on south and west sides. Contains 0–1% each of olivine and plagioclase phenocrysts in a well-crystallized feldspathic groundmass. Plagioclase is more conspicuous than olivine. Plagioclase ranges from 4 to 7 mm, averaging 2 mm. Plagioclase occurs as solo grains and form is anhedral but commonly intergrown with olivine. Olivine crystals are small and inconspicuous. Surface color light chocolate brown. FID 106

a3a8, m3a8, p3a8 **Flow 149**—‘A‘ā and pāhoehoe flows originating from summit of Mauna Loa. Located in north-central Kokoolau quadrangle in scattered kīpuka. Aphanitic with medium-gray groundmass. Rock is vesicular, and accretionary lava balls are common. Surface color is tan to reddish tan. FID 149

p3g9, a3g9 **Flow 176**—Pāhoehoe and ‘a‘ā in kīpuka in northwestern Puu Koli quadrangle surrounded by Ke‘āmuku flow (unit a1b2; FID 413). Contains 3–5% plagioclase laths and clusters in anhedral form, as large as 3 mm. Rare olivine phenocrysts present at <1% abundance. Surface color tannish gray. FID 176

a3a10 **Flow 151**—Originates from upper NERZ. ‘A‘ā flowed down north flank of Mauna Loa, traversing through north-central Kokoolau and south-central Puu Koli quadrangles. Contains 0–1% anhedral plagioclase phenocrysts and clear, inconspicuous olivine that is commonly intergrown with plagioclase and occurs as separate minerals locally. Groundmass moderately feldspathic; plagioclase microlites common. FID 151

p3i11 **Flow 178**—Tube-fed pāhoehoe in northwest corner of Puu Koli quadrangle near southwest margin of Ke‘āmuku flow (unit a1b2; FID 413). Contains 2–3% olivine phenocrysts and ~5% subhedral plagioclase phenocrysts as large as 4 mm. Large tumuli common in shallow slope regimes. Surface color tan. FID 178

a3b12 **Flow 202**—‘A‘ā flows in northwestern Puu Anahulu, southwestern Puu Hinai, and southeastern Anaehoomalu quadrangles between the A.D. 1859 eruption pāhoehoe and ‘a‘ā flows (units p0b7 and a0b7; FID 410). Contains 1–2% olivine phenocrysts as large as 5 mm. Groundmass microcrystalline and medium gray. Surface color tan. Characterized by accretionary lava balls. FID 202

s3i13 **Flow 905**—Partly buried vent structures along NERZ at 11,240 ft elevation. Comprises spatter ramparts and ‘a‘ā and pāhoehoe flows <50 m long. Contains 2–4% anhedral clots of plagioclase and ~1% olivine phenocrysts. Plagioclase as large as 3 mm and olivine averages 1 mm. Olivine commonly intergrown with plagioclase. Groundmass medium gray and full of plagioclase microlites. FID 905

m3a14, a3a14, s3a14, p3a14 **Flow 847**—Mixed ‘a‘ā and pāhoehoe containing <1% olivine phenocrysts as large as 3 mm in size. Groundmass light gray and sparsely feldspathic. Vesicles subspherical to subangular and well sorted. Located in eastern Kokoolau quadrangle. Vents along NERZ are buried. One off-axis vent located at 10,680 ft elevation. Surface color tan to orange-tan. Upper surfaces eroded with most primary surfaces destroyed. FID 847 s3a15, p3a15 **Puu Keanui flow**—Radial vent at 5,200 ft elevation in northeast corner of Puu Lehua quadrangle. Composed of a small spatter cone and tiny pāhoehoe flows. Entirely surrounded by flows from Hualālai volcano. Aphanitic with <1% olivine microphenocrysts. Composed of frothy, bulbous pāhoehoe with large blisters. Groundmass feldspathic. Vesicles angular to subangular and poorly sorted. Surface yellow orange. FID 457

p3a16 **Flow 167**—Pāhoehoe flows originating from Mauna Loa summit. Located in southeast corner of Puu O Uo quadrangle in scattered kīpuka. Contains rare olivine microphenocrysts and phenocrysts in diktytaxitic groundmass. Surface color tan to orange-tan. FID 167

s3b17 **Radial vent 453 flow**—Radial fissure 0.32 km long at 5,560 ft elevation in east-central Puu Lehua quadrangle. Composed of spatter ramparts. Flow has 2–3% olivine phenocrysts and locally as much as 15%. Olivine as large as 6 mm with subhedral form. Groundmass medium gray and cryptocrystalline. Vesicles subrounded and well sorted. Surface color tannish gray. FID 453

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

p4e1, a4e1 l4e1 **Moinui Point flow**—Picritic tube-fed pāhoehoe and ʻaʻā from summit region of Mauna Loa. Flow traverses east to west along south border of Puu Lehua quadrangle as well as in scattered and isolated kīpuka. Most of unit is south of mapped area. Large pāhoehoe flow with abundant tumuli. Minor ʻaʻā has variable amounts of olivine, ranging from 3 to 30%, commonly 15–30% green and clear phenocrysts. Crystal sizes as large as 3.5 mm; average 2.5 mm. Flow tops have lower amounts of olivine and are black and glassy. Flow interiors show olivine settling locally. Groundmass light gray and microcrystalline to diktytaxitic. Large littoral cone, 60 m (200 ft) high, at coast. Weighted average age, 3,051±16 radiocarbon yr B.P. FID 139

a4a2, p4a2 **Flow 158**—Dense aphanitic ʻaʻā with accretionary lava balls. Traverses Naohueleelua quadrangle from southeast to northwest. Also in scattered kīpuka in central Puu Anahulu quadrangle. Characterized by 0–1% olivine phenocrysts and microphenocrysts. Groundmass well crystallized, feldspathic, and medium to dark gray in color. Microgabbroic clusters present. FID 158

p4d3, a4d3 **Flow 231**—Pāhoehoe and minor ʻaʻā as scattered kīpuka in northeastern Puu O Uo and southwestern Naohueleelua quadrangles, northeast of A.D. 1859 flow (unit a0b7; FID 410). Contains 8–18% olivine phenocrysts and blades. Orange tops covered by as much as 25 cm of ash and cinders (source unknown). Olivine as large as 2.5 mm; groundmass contains plagioclase microphenocrysts. Weighted average age, 3,063±39 radiocarbon yr B.P. FID 231

p4e4 **Flow 141**—Picritic tube-fed pāhoehoe from summit region of Mauna Loa. Traverses south border of Puu Lehua quadrangle from east to west in scattered and isolated kīpuka. Has 20–25% subhedral, inconspicuous, olivine phenocrysts as large as 3 mm. Differs from other picrites by its smaller, inconspicuous olivine and lack of olivine blades or laths. No surface glass. Age, 3,330±80 radiocarbon yr B.P. FID 141

p4i5, a4i5 **Flow 206**—Tube-fed pāhoehoe in northeast corner of Puu Anahulu quadrangle, with a few kīpuka in west-central Keamuku quadrangle. Contains 2–5% plagioclase as rhombs and blades as large as 9 mm, averaging ~1 mm. Contains ~1% light-green, subhedral olivine phenocrysts, 2 mm in size. Groundmass medium gray and abundantly feldspathic. Surface color tan to light chocolate brown. FID 206

p4a6 **Flow 209**—Pāhoehoe flow in northeastern Puu Anahulu quadrangle, upslope of highway. Nearly aphanitic, with 0–1% olivine phenocrysts as large as 3 mm. Groundmass light gray and diktytaxitic. Surface light brown; some surface glass remains intact. FID 209

a4a7 **Flow 171**—Massive ʻaʻā widespread in central Naohueleelua quadrangle. Flow is aphanitic; common to see only one grain per hand-specimen face. Subhedral olivine crystals average 1 mm in size. Groundmass medium gray and moderately feldspathic. Surface color tan to grayish tan. FID 171

p4i8, a4i8 **Flow 154**—Pāhoehoe and minor ʻaʻā as scattered kīpuka in northern Naohueleelua, southwestern Keamuku, northeastern Puu Anahulu and central Puu Hinai quadrangles. Contains 2–6% plagioclase phenocrysts as large as 2 mm. Olivine and plagioclase phenocrysts commonly intergrown. Olivine present at 1–5% as green and clear phenocrysts. Groundmass medium gray and mildly feldspathic. Main flow lobe south of Puʻuhānaʻi, a Mauna Kea cinder cone. FID 154

a4c9, p4c9, s4e9, a4e9, p4e9 **Kanikū flow**—Radial vent flow in central Naohueleelua, northeastern Puu Anahulu, and Puu Hinai quadrangles. Vents continuous across 720 m starting at 5,480 ft elevation. Contains 7–15% olivine as green and clear subhedral phenocrysts and blades. Sizes from 1 to 7 mm, averaging 2 mm. Groundmass microcrystalline and medium gray. By comparison, flanking Kanimoe flow (unit p5e3; FID 159) at coast is much more olivine rich (20–35%) and olivine is larger (3–12 mm) with no blades. Surface color of Kanikū flow is tan. FID 421 a4a10 **Flow 214**—Aphanitic ‘a‘ā flow in north-central Puu Anahulu and central Puu Hinai quadrangles. Contains <1% subhedral olivine as large as 3 mm, averaging 1 mm. Groundmass feldspathic and light to medium gray. Vesicles angular to subangular and poorly sorted; 10% of rock. Rare plagioclase generally associated with olivine. Surface color medium chocolate brown and gives impression of being younger than its stratigraphic age. FID 214

a4a11, s4a11 **Flow 901**—‘A‘ā flows in scattered kīpuka near east border of Kokoolau quadrangle and flanking Pu‘ukoli in Puu Koli quadrangle. Vent for eastern flows at 11,080 ft elevation along NERZ. Vent for flows that flank Pu‘ukoli buried at higher elevations under younger flows. Nearly aphanitic ‘a‘ā characterized by rare equant, light green and clear olivine phenocrysts. Groundmass well crystallized and feldspathic. Surface color tan to light-chocolate-brown tan. FID 901

p4j12, m4j12 **Flow 170**—Mixed ‘a‘ā and pāhoehoe flowed down north flank of Mauna Loa traversing through northwestern Kokoolau, southwestern Puu Koli, and southeastern Naohueleelua quadrangles. Contains 15–18% large, clear olivine phenocrysts and 1–2% plagioclase phenocrysts and fine laths in feldspathic groundmass. Olivine as large as 8 mm. Surface color orange tan. FID 170

a4e13 **Flow 205**—‘A‘ā in two kīpuka in south-central Puu Hinai quadrangle in contact with Mauna Kea flows. Contains 15–20% subhedral olivine phenocrysts. Phenocrysts as large as 6 mm; also contains olivine blades. Groundmass dark gray and microcrystalline. FID 205

p4a14, s4a14, m4a14, a4a14 **Flow 895**—‘A‘ā and pāhoehoe flows originating from spatter ramparts along NERZ discontinuous for 3.6 km between 11,360 and 12,205 ft elevation in the southeast corner of Kokoolau quadrangle. Nearly aphyric, with rare phenocrysts of olivine and plagioclase. Groundmass medium gray, microcrystalline, and mildly feldspathic with abundant plagioclase microlites. Very large tube system lies within pāhoehoe. Surface color tan. FID 895

p4a15 **Flow 844**—Tiny pāhoehoe kīpuka in southeast corner of Kokoolau quadrangle. Unit is aphanitic. Pāhoehoe contains 0–1% olivine phenocrysts in well-crystallized, light-gray groundmass. FID 844

a4d16, p4d16, s4d16 **Pōhakuloa camp flow**—Prominent radial vent on north flank of Mauna Loa near Highway 200. ‘A‘ā and pāhoehoe flows originate from spatter ramparts that are discontinuous across 2.7 km between 6,320 and 6,485 ft elevation. Forms the northernmost radial vent from Mauna Loa. Traverses Puu Koli, northeastern Naohueleelua, and Keamuku quadrangles near boundary with Mauna Kea. Characterized by clear, subhedral olivine as large as 10 mm that form 8–12% of flow. Groundmass medium gray and microcrystalline. Rare plagioclase phenocrysts present. Surface color orange-tan. FID 460

p4k17, p4j17, a4k17 **Flow 163**—Pāhoehoe with minor ‘a‘ā in scattered kīpuka in southwestern Kokoolau quadrangle. Most of unit in northeast part of Puu O Uo quadrangle, south of the A.D. 1859 flow (unit a0b7; FID 410). Originates at summit of Mauna Loa. Contains 8–12% glomerocrysts of plagioclase as large as 5 mm and averaging 3 mm. Contains 2–4% olivine phenocrysts, commonly intergrown with plagioclase. Groundmass dark gray. Flow surface tan-orange and bumpy owing to glomerocrysts of plagioclase. One part of this flow has >5% olivine and 3–5% plagioclase. FID 163

a4c18 **Flow 177**—‘A‘ā surrounded by Ke‘āmuku flow (unit a1b2; FID 413) in north-central Puu Koli quadrangle. Yellow-tan-stained unit contains 5–6% olivine as subhedral phenocrysts in microcrystalline groundmass. Plagioclase observed at <1% as laths. FID 177

p4d19, a4d19 **Flow 173**—Flows in west-central Puu Koli quadrangle. Mixed pāhoehoe and ‘a‘ā containing 5–15% subhedral olivine phenocrysts as large as 3 mm. Contains 0–1 % plagioclase generally associated with olivine. Groundmass microcrystalline. Surface color tan-orange. FID 173

p4i20, m4i20 **Flow 180**—Pahoehoe with minor ‘a‘ā in scattered kīpuka in southwest corner of Puu O Uo and southeastern Puu Lehua quadrangles. Flow contains 3–5% light-green to brown-green olivine phenocrysts. Sizes as large as 8 mm, averaging 3 mm; subhedral form. Olivine commonly intergrown with plagioclase. Plagioclase present as phenocrysts and microphenocrysts at 2–3%, but white color contrasted against gray groundmass gives impression of greater abundance. Groundmass medium gray and microcrystalline. Surface color tannish orange to tannish gray. FID 180

p4a21 **Flow 210**—Pāhoehoe in two kīpuka in east-central Puu Anahulu quadrangle. Contains rare olivine phenocrysts in a finely crystalline, mildly feldspathic groundmass. FID 210

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

a5b1 **Flow 160**—‘A‘ā in west-central Naohueleelua quadrangle, in contact with A.D. 1859 flow (unit a0b7; FID 410). ‘A‘ā contains 2–4% olivine phenocrysts in feldspathic, medium-gray groundmass. Surface orange-tan color. FID 160 p5a2, a5a2, m5a2 — **Flow 155**—Aphanitic pāhoehoe and ʻaʻā in scattered kīpuka in eastern Puu Anahulu and southwestern Puu Hinai quadrangles. Characterized by rare olivine and well-crystallized, medium-gray, feldspathic groundmass. ʻAʻā locally has more olivine than pāhoehoe. Surface tannish orange to whitish tan. FID 155

p5e3, a5e3, p5f3, m5e3 — **Kanimoe flow**—Picritic flow originating from summit of Mauna Loa traverses northwestern Naohueleelua, Puu Anahulu, Puu Hinai, and Anaehoomalu quadrangles. At one time, this unit formed the coastline from Weliweli Point to Puakō. ʻAnaehoʻomalu Bay formed as result of this eruption. Characterized by clear, large, subhedral to anhedral olivine as large as 10 mm that form 15–35% of flow. Both pāhoehoe and ʻaʻā occur. Pāhoehoe flow tops locally have lower abundances of olivine; flow interiors contain as much as 40% olivine. Plagioclase abundances range from 0 to 4% as phenocrysts. Groundmass dull gray. FID 159

a5g4 — **Flow 175**—ʻAʻā in west-central Puu Koli quadrangle. Surrounded by Pōhakuloa flow (unit p2f13; FID 62). Contains 1% scattered plagioclase phenocrysts as large as 2 mm. Contains <<1% olivine. Microcrystalline groundmass. Surface color tannish brown. FID 175

p5a5, a5a5, m5a5 — **Flow 251**—Both pāhoehoe and minor ʻaʻā flows in dispersed kīpuka in north-central Kokoolau and south-central Puu Koli quadrangles. Contains microphenocrysts of plagioclase and golden-green olivine. Both minerals <1 mm and <<1% abundance. Groundmass gray, sugary, well crystallized, and contains abundant plagioclase microlites. Flow cores locally have higher abundances of olivine. Color orange to reddish orange; soils located in low spots. FID 251

m5h6, a5h6 — **Flow 233**—Mixed ʻaʻā and pāhoehoe in one small kīpuka in southwest corner of Puu Hinai quadrangle. Contains 12–20% plagioclase phenocrysts as large as 9 mm. Groundmass medium gray to dark gray with microlaths of plagioclase. Vesicles subangular and poorly sorted. Rare olivine as large as 4 mm. Surface color orange-tan to tan. Possibly a flow from Hualālai volcano. FID 233

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

p6e1, a6e1 — **Radial vent 472 flow**—Pāhoehoe and minor ʻaʻā in scattered kīpuka in northeastern Kokoolau and east-central Puu Koli quadrangles. Crops out between A.D. 1935 (unit a0a4; FID 785) and A.D. 1843 (unit a0k9; FID 790) flows in Kokoolau quadrangle and east of the A.D. 1843 flow in Puu Koli quadrangle. Flow has weathered red-orange rind. Rock contains 15–20% olivine phenocrysts and microphenocrysts. Groundmass mildly feldspathic. Surface color orange red; no surface glass present. FID 472

a6b2, s6b2, a6c2, a6d2, a6e2, m6b2 — **Radial vent 422 flow**—Flow from radial vent on northwest flank of Mauna Loa, with flows in central Naohueleelua quadrangle. Vents discontinuous across 1.3 km between 6,400 and 6,720 ft elevation. Flow has variable amounts of olivine phenocrysts from 2–18%. Cores of flows are richer in olivine. Olivine phenocrysts as large as 3 mm, inconspicuous and average 1.5 mm in size. Laths or blades of olivine common. Groundmass medium gray and microcrystalline. FID 422

p6d3, m6d3, a6d3 — **Flow 226**—Tube-fed picritic pāhoehoe in northwest part of Naohueleelua quadrangle. Characterized by 12–15% clear, subhedral olivine and 0–1% plagioclase phenocrysts, mostly intergrown with olivine. Blades of olivine common. Flow commonly covered with cinders of unknown origin. Groundmass light gray and diktytaxitic. Surface color reddish tan in the open and gray in shade. Upper surface of flow is almost warty owing to abundant olivine phenocrysts. FID 226

p6b4 — **Flow 234**—Pāhoehoe with minor ʻaʻā in southwestern Puu Hinai quadrangle. Pāhoehoe has no surface glass and lots of mechanical weathering. Contains 1–2% light-green to brown-green olivine phenocrysts. Subhedral crystals as large as 5 mm, averaging 2 mm. Groundmass dark gray and microcrystalline. Vesicles subrounded to subangular and poorly sorted. Contains large, perched channel in northwest part of mapped area near coast. Surface color orange tan to whitish tan. FID 234

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

p7b1, a7b1, s7b1, m7b1, a7f1 — **Puʻukoli flow**—Flows of prominent radial vent eruption on north flank of Mauna Loa. Massive pāhoehoe and ʻaʻā located in central part of Puu Koli quadrangle. Large cinder and spatter cone at 7,320 ft elevation. Rock contains 1–2% olivine phenocrysts and microphenocrysts. Subhedral olivine crystals range from 1 to 7 mm, averaging 2 mm. Groundmass medium gray and cryptocrystalline. Vesicles subangular to subrounded, poorly sorted, as large as 2 cm wide, and deformed; secondary minerals fill some vesicles. Tephra from this eruption mantles older flows. FID 473 p7b2, a7b2, s7b2 **Radial vent 459 flow**—Radial vent in southwestern Puu Koli quadrangle. Actual vent buried by younger flows; cinder and spatter cone at 7,440 ft elevation. Pāhoehoe and ʻaʻā flows extend north through central Puu Koli and into east-central Naohueleelua quadrangles. Contains approximately 2–3% olivine as subhedral to anhedral phenocrysts as large as 4 mm. Contains plagioclase microlaths in medium-gray groundmass. Surface color light orange to orange tan and flow tops eroded. FID 459

p7d3, p7f3, p7c3, m7f3, p7e3, p7a3, a7d3, a7e3, m7d3 **Keawaiki flow**—Picritic flow originating from summit of Mauna Loa. Traverses north-central Puu O Uo, southwestern Naohueleelua, northwestern Hualalai, Puu Anahulu, southwestern Puu Hinai, and southeastern Anaehoomalu quadrangles. Reaches sea at Keawaiki. Characterized by 7–20% olivine phenocrysts that are clear, subhedral, and as large as 5 mm, averaging 4 mm. Pāhoehoe associated with minor ʻaʻā. Pāhoehoe flow tops locally have lower abundances of phenocrysts; flow interiors contain as much as 20% olivine. Olivine settling common. Groundmass light gray and diktytaxitic. Surface color tannish brown to dull black. Upper surface well preserved, and color indicates youthful age, yet it is one of the oldest units in the lowlands. FID 229

p7b4, a7b4, s7b4, m7b4 **Radial vent 474 flow**—Flow and spatter from old radial vent in south-central Puu Koli quadrangle, 2 km northwest of Puʻukoli cone. Source vents nearly buried by younger flows; discontinuous across 1.5 km between 6,610 and 6,820 ft elevation. Tube-fed pāhoehoe bulbous with large cavities. Flow extensively weathered; no surface glass. Contains ~0–3% widely scattered olivine phenocrysts in gray feldspathic groundmass. Sparse plagioclase commonly intergrown with olivine. Unit partly buried by tephra, ash, and soil. FID 474

p7b5, m7b5, a7b5 **Flow 236**—Flow in dispersed kīpuka in west-central Puu Koli and northeastern Naohueleelua quadrangles. Contains 1–2% olivine phenocrysts as large as 1.5 mm and plagioclase laths in groundmass. Groundmass feldspathic and medium gray. Vesicles spheroidal, maghemite lined, and well sorted. Surface color tan; upper surfaces mostly intact. FID 236

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

p8k1 **Flow 253**—Flow in north-central Kokoolau and south-central Puu Koli quadrangles. Pāhoehoe with minor ʻaʻā that flanks Puʻukoli cone. Plagioclase ranges from 5 to 8% as subhedral phenocrysts as large as 4 mm, averaging 3 mm. Contains 0–2% olivine as green subhedral phenocrysts as large as 2 mm. Groundmass light gray, feldspathic, and rich in plagioclase microlites. Locally phenocryst abundances vary by as much as 2%. Vesicles subrounded, well sorted, and 40–50% of rock; contain secondary minerals locally. Overlain by 10–20 cm of ash. Flow covered by polygonal blocks of broken flow tops and tan soil and tephra. FID 253

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

p9e1 **Flow 219**—Picritic flow originating from summit of Mauna Loa. Traverses along south border of Puu Lehua and Kealakekua quadrangles. Mantles lava flows in section at Palikapuokeōua (south of mapped area) at Kealakekua Bay. Characterized by 15–25% olivine phenocrysts that are clear, subhedral, and as large as 14 mm, averaging 5 mm. Pāhoehoe flow tops locally have lower abundances of phenocrysts; flow interiors as much as 30% olivine. Groundmass light gray and vesicles well sorted. No original surfaces preserved. Weighted average age, 8,909±41 radiocarbon yr B.P. FID 219

a9b2, p9b2 **Konawaena High School flow**—ʻAʻā with minor pāhoehoe in southwestern Puu Lehua and southeastern Kealakekua quadrangles. ʻAʻā contains variable amounts of olivine from <1 to 3%, mostly as inconspicuous phenocrysts in light-gray, microcrystalline groundmass. FID 224

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

p10e1 **Painted Church flow**—Picritic flow originating from summit of Mauna Loa. Traverses southwest corner of Puu Lehua quadrangle and southeast corner of Kealakekua quadrangle. Pāhoehoe contains ~20% olivine phenocrysts that appear as aggregates of tiny grains. Olivine crystals as large as 2 mm. Pāhoehoe flow tops mostly destroyed, eroded away, and deeply weathered. Rare plagioclase commonly intergrown with olivine. Age, 9,250±80 radiocarbon yr B.P. FID 225

m10k2 **Kanakau flow**—Mixed ʻaʻā and pāhoehoe in south-central Kealakekua quadrangle, at the coast, and 1 km south of Puʻuohau littoral cone. Contains approximately 7–8% subhedral plagioclase phenocrysts as large as 3 mm. Olivine also present at 2–3% as phenocrysts and blades as large as 4 mm, averaging 1 mm. Most olivine small and inconspicuous as groundmass phase. Groundmass gray and moderately feldspathic. Vesicles subrounded to subangular and poorly sorted. Surface covered by ash. FID 257

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

p11f1 **Kīkī‘ae‘ae flow**—Radial-vent flow traverses central Puu Lehua and Kealakekua quadrangles from east to west in scattered and isolated kīpuka. Enters sea 1.5 km north of Hualālai contact. Vent outside mapped area. Pāhoehoe contains 1–10% olivine phenocrysts as large as 3 mm. Groundmass dark gray and microcrystalline. Age, 13,800±300 radiocarbon yr B.P. FID 471

p11e2 **Flow 235**—Pāhoehoe with minor ‘a‘ā in central Kealakekua quadrangle. Contains 10–30% light-green to brown-green subhedral olivine phenocrysts. Sizes range from 1 to 5 mm, averaging 2 mm. Groundmass dark gray and microcrystalline. FID 235

a11a3, p11a3 **Flow 220**—‘A‘ā and pāhoehoe contain 0–1% inconspicuous olivine phenocrysts in well-crystallized groundmass. Surfaces deeply weathered and orange stained. Covered by ash as thick as 30 cm in some places. Flow traverses Puu Lehua and Kealakekua quadrangles from east to west in scattered and isolated kīpuka along or near south boundary of the map. FID 220

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

[No units of this age group are located at the surface in the map area]

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

p13c1 **Flow 254**—Pāhoehoe flow in contact with Mauna Kea in northwestern Puu Anahulu quadrangle. Flow tops contain 2–5% olivine phenocrysts as large as 5 mm. Core of flow contains 7–10% subhedral olivine phenocrysts and microphenocrysts. Groundmass medium gray and ranges from feldspathic to diktytaxitic. Overlain by hawaiite flow from Mauna Kea. FID 254

Kahuku Basalt

The Kahuku Basalt consists of units with an age range of 100,000 to 30,000 yr B.P. The Kahuku Basalt comprises 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).

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

[No units of this age group are located at the surface in the map area]

Nīnole Basalt

The Nīnole Basalt, the oldest exposed rocks on Mauna Loa, is >100,000 years old. These rocks are exposed in the Ka‘ū 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)

[No units of this age group are located at the surface in the map area]

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

[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 map sheet 1 for quadrangle locations. ft, foot; yr, year; cal. yr, calendar year]

Unit label[1]	FID[2]	Age group[1]	Unit name	Field no.	Lab no.[3]	Quadrangle name (1:24,000)	Latitude[4] (degree)	Longitude[4] (degree)
a1i1	414	1	Radial vent 414 flow	L-00-12C	WW3149	Puu O Uo	19.56466	−155.73364
a1b2	413	1	Ke‘āmuku flow	L-79-66b	W4537	Puu Koli	19.62707	−155.55936
a1b2	413	1	Ke‘āmuku flow	W86H5-61C	W5772	Ahumoa	19.74835	−155.60305
a1b2	**413**	**1**	**Weighted avg. (yr B.P.)[6]**					
p1a3	26	1	Landing Zone flow	L-78-19	W4186	Puu Koli	19.70856	−155.54938
p1a3	26	1	Landing Zone flow	L-86-136	W5976	Puu Koli	19.71456	−155.53489
p1a3	26	1	Landing Zone flow	L-86-136R	WW3742	Puu Koli	19.71454	−155.53486
p1a3	26	1	Landing Zone flow	L-86-15R	SUERC-5411	Puu Koli	19.71224	−155.54835
p1a3	26	1	Landing Zone flow	L-86-15c	W5803	Puu Koli	19.71225	−155.54839
p1a3	26	1	Landing Zone flow	PG-04-03	SUERC-5419	Puu Koli	19.71225	−155.54840
p1a3	**26**	**1**	**Weighted avg. (yr B.P.)[6]**					
p1a6	792	1	‘Āinahou flow	L-81-58	W5079	Puu Oo[11]	19.65778	−155.46305
p1a7	415	1	Radial vent 415 flow	L-90-98c	WW844	Puu O Uo	19.53313	−155.72080
a1a8	412	1	Pu‘u‘ouo flow	L-88-38A	W6164	Puu Lehua	19.52664	−155.81620
a1a8	412	1	Pu‘u‘ouo flow	L-84-93A	W5568	Puu Lehua	19.52816	−155.76612
a1a8	**412**	**1**	**Weighted avg. (yr B.P.)[6]**					
p1a9	274	1	Ke A Po‘omuku flow	L-80-10012	W4790	Kipuka Pakekake[11]	19.43715	−155.39977
p1a9	274	1	Ke A Po‘omuku flow	L-87-07	W6001	Kipuka Pakekake[11]	19.40651	−155.38265
p1a9	**274**	**1**	**Weighted avg. (yr B.P.)[6]**					
a1j10	417	1	Radial vent 417 flow	L-89-05	W6225	Puu O Uo	19.56726	−155.74128
a2d1	442	2	Radial vent 442 flow	L-88-29	W6162	Puu Lehua	19.55696	−155.75404
a2c2	441	2	Honey Bee flow	L-84-106	W5625	Puu Lehua	19.55967	−155.78569
p2k3	418	2	Keauhou Two flow	CC86F4-56	W5829	Puu O Uo	19.58900	−155.69535
p2k3	418	2	Keauhou Two flow	L-11-29b12	WW9032	Puu O Uo	19.59286	−155.69086
p2k3	418	2	Keauhou Two flow	L-11-2712	WW9031	Puu O Uo	19.59286	−155.69097
p2k3	418	2	Keauhou Two flow	MH-84-167	W5519	Puu Lehua	19.62122	−155.75254
p2k3	418	2	Keauhou Two flow	L-11-97d12	WW9035	Naohueleelua	19.62679	−155.74176
p2k3	418	2	Keauhou Two flow	L-99-58212	WW3142	Puu O Uo	19.56717	−155.66949
p2k3	**418**	**2**	**Weighted average (yr B.P.)[6,12]**					
p2i4	29	2	Flow 29	L-11-06c	WW9169	Sulphur Cone[11]	19.48648	−155.70028
p2k9	28	2	Flow 28	L-88-23	TO1508	Puu Lehua	19.54934	−155.76534
p2k9	28	2	Flow 28	L-90-88	AA10226	Puu O Uo	19.53832	−155.74074
p2k9	**28**	**2**	**Weighted avg. (yr B.P.)[6]**					
p2i10	82	2	Flow 82	L-12-58c	WW9170	Puu O Uo	19.60241	−155.65674
p2i10	82	2	Flow 82	L-99-57512	WW3141	Puu O Uo	19.56988	−155.66459
p2i10	82	2	Flow 82	L-11-32c12	WW9033	Puu O Uo	19.57172	−155.69840
p2i10	**82**	**2**	**Weighted avg. (yr B.P.)[6]**					
p2a11	64	2	Flow 64	L-11-16c	WW9030	Puu O Uo	19.54506	−155.66218

Elev (ft)	Age[5] (yr B.P.)	S.D.[5] (yr)	Quality[7]	Age range[8] (cal. yr)	Age range[9] highest probability (cal. yr)	Age range[9] mid probability (cal. yr)	Age range[9] lowest probability (cal. yr)	Source[10]
6,445	220	40	+	1525 to 1949	1726 to 1813 (48)	1632 to 1694 (36)	1918 to 1949 (12)	3
7,360	270	60	+	1458 to 1949	1458 to 1684 (81)	1733 to 1807 (15)	1929 to 1949 (3)	2
5,670	300	100	+	1429 to 1949	1429 to 1699 (78)	1721 to 1817 (15)	1916 to 1949 (4)	3
	278	**41**		**1464 to 1949**	**1464 to 1680 (90)**	**1763 to 1801 (8)**	**1939 to 1949 (2)**	
6,278	220	60	+	1516 to 1949	1716 to 1890 (47)	1618 to 1710 (29)	1516 to 1596 (12)	1, 2
6,435	330	100	+	1410 to 1949	1410 to 1695 (86)	1726 to 1813 (10)	1918 to 1949 (3)	3
6,435	360	40	+	1450 to 1636	1537 to 1636 (52)	1450 to 1533 (48)		3
6,270	381	30	+	1444 to 1631	1444 to 1524 (65)	1558 to 1631 (35)		3
6,270	390	100	+	1314 to 1949	1388 to 1680 (94)	1314 to 1356 (3)	1764 to 1801 (2)	3
6,255	401	22	+	1441 to 1616	1441 to 1512 (91)	1601 to 1616 (9)		3
	376	**15**		**1450 to 1618**	**1450 to 1517 (77)**	**1594 to 1618 (23)**		
6,755	410	60	+	1419 to 1636	1419 to1532 (63)	1537 to 1636 (37)		2
7,100	530	60	+	1320 to 1440	1391 to 1440 (80)	1320 to 1350 (20)		3
4,620	580	120	+	1212 to 1633	1212 to 1527 (95)	1554 to 1633 (5)		3
5,780	510	150	+	1192 to 1949	1205 to 1681 (98)	1762 to 1802 (2)		2
	553	**94**		**1265 to 1618**	**1265 to 1518 (98)**	**1594 to 1618 (2)**		
5,280	540	70	+	1285 to 1464	1285 to 1464 (100)			2
4,350	720	100	+	1048 to 1422	1149 to 1422 (95)	1048 to 1087 (4)	1123 to 1138 (1)	3
	599	**57**		**1285 to 1422**	**1285 to 1422 (100)**			
5,970	640	80	+	1229 to 1434	1247 to 1434 (100)			3
5,800	1000	150	+	695 to 1277	765 to 1277 (97)	708 to 747 (2)		3
5,240	1100	110	+	687 to 1154	687 to 1154 (100)			3
6,840	1020	100	+	776 to 1216	798 to 1216 (98)	776 to 794 (2)		3
6,760	1100	25	0	777 to 1022	85 to 1022 (91)	803 to 844 (6)	777 to 792 (3)	3
6,775	1135	25	0	772 to 1011	772 to 997 (99)	1007 to 1011 (1)		3
5,410	1150	200	+	539 to 1268	539 to 1268 (100)			2
5,475	1170	25	0	714 to 986	765 to 986 (95)	714 to 744 (5)		3
7,900	1360	40	0	542 to 781	542 to 781 (92)	787 to 877 (8)		3
	1153	**15**		**777 to 969**	**801 to 969 (92)**	**777 to 793 (8)**		
8,475	1225	30	+	690 to 885	761 to 885 (73)	690 to 749 (27)		3
5,640	1250	60	+	658 to 938	658 to 894 (99)	930 to 938 (1)		3
6,310	1260	65	+	652 to 940	652 to 895 (99)	928 to 940 (1)		3
	1255	**44**		**669 to 878**	**669 to 782 (70)**	**786 to 878 (30)**		
7,325	1220	35		762 to 747	762 to 887 (78)	692 to 747 (22)		
7,880	1250	40	+	672 to 878	672 to 782 (69)	786 to 878 (31)		3
7,080	1270	25	+	671 to 773	671 to 773 (100)			3
	1250	**17**		**678 to 772**	**680 to 777 (97)**	**843 to 856 (2)**	**793 to 802 (1)**	
8,720	1280	25	+	672 to 769	672 to 769 (100)			3

Table 2. Radiocarbon ages of samples from the northwest flank of Mauna Loa, Island of Hawaiʻi.—Continued

Unit label[1]	FID[2]	Age group[1]	Unit name	Field no.	Lab no.[3]	Quadrangle name (1:24,000)	Latitude[4] (degree)	Longitude[4] (degree)
p2c12	57	2	Flow 57	L-12-27c12	WW9036	Puu Lehua	19.60774	−155.78326
p2c12	57	2	Flow 57	L-11-78c12	WW9034	Naohueleelua	19.64155	−155.73519
p2c12	**57**	**2**	**Weighted average (yr B.P.)[6,12]**					
p2c13	62	2	Pōhakuloa flow	L-86-55	AZ2	Naohueleelua	19.72381	−155.62981
p2c13	62	2	Pōhakuloa flow	L-95-537	WW876	Naohueleelua	19.73522	−155.66584
p2c13	**62**	**2**	**Weighted avg. (yr B.P.)[6]**					
p2a14	56	2	Hōkūkano flow	L-84-24	W5537	Sulphur Cone[11]	19.47597	−155.70772
p2a14	56	2	Hōkūkano flow	L-87-168	W6055	Puu Lehua	19.49907	−155.74722
p2a14	56	2	Hōkūkano flow	L-84-24R	WW3714	Sulphur Cone[11]	19.47597	−155.70772
p2a14	**56**	**2**	**Weighted avg. (yr B.P.)[6]**					
p2d15	145	2	Flow 145	L-88-61R	WW3745	Puu Lehua	19.49908	−155.79128
p2e16	454	2	Radial vent 454 flow	L-90-118c	W6298	Puu O Uo	19.52040	−155.70504
a2b17	152	2	Flow 152	W86G4-150	W5809	Naohueleelua	19.68212	−155.70513
p2i18	63	2	Flow 63	L-86-37	W5792	Puu Koli	19.69535	−155.54434
p2i18	63	2	Flow 63	L-86-119	W5797	Puu Koli	19.68352	−155.54929
p2i18	**63**	**2**	**Weighted avg. (yr B.P.)[6]**					
p2a20	147	2	Flow 147	L-86-273	W5989	Puu Koli	19.63595	−155.54712
p2a20	147	2	Flow 147	L-12-185B	WW10262	Kokoolau	19.60280	−155.55506
p2a20	147	2	Flow 147	L-13-562d	WW10266	Puu Koli	19.62452	−155.55938
p2a20	**147**	**2**	**Weighted avg. (yr B.P.)[6]**					
p2d22	144	2	Poopaaelua flow	L-84-102	W5633	Puu Lehua	19.53916	−155.80795
p2c23	458	2	Radial vent 458 flow	L-90-119	AA10227	Puu O Uo	19.52110	−155.70377
a2b24	420	2	Radial vent 420 flow	L-90-43	AA5671	Naohueleelua	19.65314	−155.68772
a2a25	61	2	Flow 61	L-88-66R	WW8815	Puu Koli	19.63089	−155.55799
p2i26	867	2	ʻĀinakahiko flow	L-87-93	W5949	Puu Oo[11]	19.63649	−155.45793
p3i1	440	3	Kaʻawaloa flow	L-79-27	W4550	Honaunau[11]	19.48398	−155.93522
a3a3	161	3	Flow 161	L-95-634	WW879	Naohueleelua	19.73182	−155.66477
a3a3	161	3	Flow 161	L-06-21c	WW6225	Keamuku	19.76043	−155.69928
a3a3	**161**	**3**	**Weighted average (yr B.P.)[6,12]**					
p3k4	866	3	Puʻukahiliku flow	L-84-32	W5566	Puu Oo[11]	19.69904	−155.38711
p3d6	150	3	Flow 150	L-84-62R	AA95722	Puu Anahulu	19.83476	−155.78430
p4e1	139	4	Moinui Point flow	L-87-273	AA4381	Honaunau[11]	19.45240	−155.90795
a4e1	139	4	Moinui Point flow	L-97-566c	WW1937	Kealakekua	19.51813	−155.91988
p4e1	139	4	Moinui Point flow	L-12-75d	WW9172	Puu Lehua	19.55576	−155.76039
a4e1	139	4	Moinui Point flow	L-87-17	W6297	Kealakekua	19.51764	−155.92092
a4e1	139	4	Moinui Point flow	L-97-566R	SUERC-5424	Kealakekua	19.51813	−155.91988
p4e1	**139**	**4**	**Weighted avg. (yr B.P.)[6]**					
p4d3	231	4	Flow 231	L-84-87R	AA95723	Puu O Uo	19.60373	−155.66975
p4d3	231	4	Flow 231	L-84-87	W5542	Puu O Uo	19.60373	−155.66975
p4d3	**231**	**4**	**Weighted avg. (yr B.P.)[6]**					

Elev (ft)	Age[5] (yr B.P.)	S.D.[5] (yr)	Quality[7]	Age range[8] (cal. yr)	Age range[9] highest probability (cal. yr)	Age range[9] mid probability (cal. yr)	Age range[9] lowest probability (cal. yr)	Source[10]
5,100	1210	25	+	679 to 952	679 to 901 (95)	920 to 952 (5)		3
5,390	1285	25	+	654 to 870	654 to 779 (85)	789 to 870 (15)		3
	1248	**35**		**676 to 876**	**676 to 780 (70)**	**787 to 876 (30)**		
5,665	1267	60	+	655 to 888	655 to 888 (100)			3
5,088	1380	60	+	556 to 769	556 to 729 (91)	736 to 769 (9)		3
	1323	**42**	**+**	**644 to 771**	**644 to 771 (100)**			
8,200	1120	200	+	568 to 1274	568 to 1274 (100)			2
6,550	1150	150	+	624 to 1206	631 to 1187 (100)			3
8,200	1365	45	+	598 to 770	598 to 723 (90)	739 to 770 (10)		3
	1337	**42**		**634 to 775**	**634 to 775 (100)**			
5,700	1460	40	+	537 to 658	537 to 658 (100)			3
7,845	1480	60	+	428 to 655	505 to 655 (81)	428 to 497 (19)		3
5,200	1500	100	+	255 to 653	316 to 653 (96)	255 to 301 (4)		3
6,365	1500	150	+	223 to 877	223 to 782 (97)	786 to 877 (3)		3
6,380	1570	100	+	225 to 653	313 to 653 (96)	255 to 301 (4)		3
	1548	**83**		**344 to 650**	**344 to 650 (100)**			
7,100	1500	130	+	240 to 774	240 to 774 (100)			3
8,160	1530	30	+	428 to 598	504 to 598 (58)	428 to 498 (42)		3
7,445	1565	25	+	422 to 550	422 to 550 (100)			3
	1550	**19**		**428 to 559**	**428 to 499 (65)**	**503 to 559 (35)**		
4,755	1600	200	+	−18 to 869	0 to 799 (98)	789 to 869 (2)		3
7,845	1720	65	+	132 to 527	132 to 429 (98)	494 to 509 (1)		3
5,890	1810	105	+	−42 to 503	−42 to 428 (100)			3
7,240	1855	35	+	−43 to 121	−43 to 88 (96)	102 to 121 (4)		3
6,855	1880	200	+	−362 to 550	−265 to 550 (95)	−360 to −267 (5)		3
200	2030	60	+	−197 to 82	−197 to 82 (100)			2
6,310	2190	60	+	−390 to −93	−390 to −93 (100)			3
4,380	2195	30	+	−363 to −183	−363 to −183 (100)			3
	2194	**27**		**−361 to −186**	**−361 to −191 (100)**			
5,715	2240	150	+	−759 to 47	−673 to 27 (94)	−759 to −678 (6)		2
2,480	2693	39	+	−911 to −801	−911 to −801 (100)			3
255	2885	85	+	−1367 to −842	−1290 to −842 (99)	−1367 to −1367 (1)		2
1,560	3000	50	+	−1396 to −1058	−1396 to −1107 (97)	−1103 to −1080 (2)		3
5,635	3040	25	+	−1393 to −1220	−1324 to −1220 (65)	−1393 to −1335 (35)		3
1,560	3070	60	+	−1490 to −1129	−1452 to −1188 (96)	−1181 to −1158 (2)	−1145 to −1129 (2)	3
1,560	3094	28	+	−1426 to −1283	−1426 to −1283 (100)			3
	3051	**16**		**−1393 to −1235**	**−1324 to −1259 (52)**	**−1993 to −1336 (47)**	**−1242 to −1235 (1)**	
6,990	3058	40	+	−1416 to −1216	−1416 to −1216 (100)			3
6,990	3200	200	+	−1945 to −934	−1945 to −970 (99)	−961 to −934 (1)		2
	3063	**39**		**−1416 to −1222**	**−1416 to −1222 (100)**			

Table 2. Radiocarbon ages of samples from the northwest flank of Mauna Loa, Island of Hawai‘i.—Continued

Unit label[1]	FID[2]	Age group[1]	Unit name	Field no.	Lab no.[3]	Quadrangle name (1:24,000)	Latitude[4] (degree)	Longitude[4] (degree)
p4e4	141	4	Flow 141	L-90-35	W6422	Kealakekua	19.50030	−155.87268
p9e1	219	9	Flow 219	L-90-34R	WW3746	Kealakekua	19.49858	−155.88044
p9e1	219	9	Flow 219	L-90-34C	W6421	Kealakekua	19.49858	−155.88044
p9e1	**219**	**9**	**Weighted avg. (yr B.P.)[6]**					
p10e1	225	10	Painted Church flow	L-87-235	TO1512	Puu Lehua	19.53669	−155.81019
p11f1	471	11	Kīkī‘ae‘ae flow	MH-79-2	W4392	Kealakekua	19.54582	−155.93118

[1]See table 1 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 (https://doi.gov/10.3133/sim2932e).

[3]Initial letter(s) identifies analytical laboratory: AA and AZ, University of Arizona, Tucson, Ariz.; SUERC, Scottish Universities Environmental Research Centre, NERC radiocarbon laboratory, Kilbride, Scotland, UK; W or WW, U.S. Geological Survey ^{14}C laboratory, Reston, Va.; TO, IsoTrace Laboratory, Toronto, Canada. Initial letter(s) for accelerator mass spectrometry (AMS) ages: AA, AZ, TO, SUERC, WW.

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

[5]Age determination and one standard deviation (S.D.) reported by the respective laboratories.

[6]Weighted average, 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, samples passed the f-test of statistical significance; 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 7.0 Radiocarbon Calibration Program (Stuiver and others, 1993, 1998); calibrated ages are for two standard deviations. Entire age range of calendar ages is possible (not probable) for a given sample. Positive ages, A.D.; negative (−) ages, B.C.

[9]Age range probability given in calendar years for two standard deviations (numbers in parenthesis are ranked by relative area under the probability curve, with 100 meaning 100%). Note that a calibrated ^{14}C age is probabilistic, not an absolute calendar date.

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

[11]Radiocarbon sample collected outside of mapped area: Puu Oo quadrangle (USGS Scientific Investigations Map [SIM] 2932–A), Kipuka Pakekake quadrangle (SIM 2932–B), and Honaunau and Sulphur Cone quadrangles (SIM 2932–D).

[12]Ages calibrated using twice the standard deviation (for example, if the reported S.D. = 25 years, we used 50 years).

Elev (ft)	Age[5] (yr B.P.)	S.D.[5] (yr)	Quality[7]	Age range[8] (cal. yr)	Age range[9] highest probability (cal. yr)	Age range[9] mid probability (cal. yr)	Age range[9] lowest probability (cal. yr)	Source[10]
3,080	3330	80	+	−1872 to −1434	−1777 to −1434 (97)	−1872 to −1844 (2)		3
2,885	8890	45	+	−8239 to −7843	−8239 to −7937 (95)	−7897 to −7843 (4)		3
2,885	9000	100	+	−8450 to −7818	−8450 to −7818 (100)			3
	8909	**41**		**−8241 to −7956**	**−8241 to −7956 (100)**			
4,710	9250	80	+	−8700 to −8292	−8644 to −8292 (98)	−8700 to −8677 (2)		3
1,440	13800	300	+	−15591 to −13916	−15591 to −13916 (100)			2

Appendix 1. Rejected Radiocarbon Ages

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

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

FID[1]	Field no.	Lab no.[2]	Quadrangle name (1:24,000)	Age (yr B.P.)	S.D. (yr)	Source[3]
20	L-86-288	W5997	Puu Koli	200	100	2
412	L-88-63	W6172	Puu Lehua	450	140	2
Hualālai	L-12-15c	WW11026	Puu Lehua	770	25	2
28	CC86F4-4	W5818	Puu O Uo	940	100	2
166	L-96-525	WW882	Puu O Uo	1,090	60	2
441	MH-88-2	W6054	Puu Lehua	1,540	120	1
211	L-86-34	AZ1	Puu Koli	1,891	99	2
217	L-88-61	W6167	Puu Lehua	2,050	160	2
144	L-90-115	W6457	Puu O Uo	2,068	85	2
61	L-88-66	TO1509	Puu Koli	2,580	320	2
141	L-88-35b	TO1510	Puu Lehua	2,840	60	2
150	L-84-62	W5536	Puu Anahulu	3,360	200	2

[1]Unique, three-digit flow identification number assigned to each mapped surface-flow unit correlates with database (http://doi.gov/10.3133/sim2932e).

[2]Initial letter(s) identifies analytical laboratory: AZ, University of Arizona, Tucson, Ariz.; TO, IsoTrace Laboratory, Toronto, Canada; W or WW, U.S. Geological Survey 14C laboratory, Reston, Va. Initial letter(s) for AMS ages: WW.

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

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Appendix 2. Geochemical Analyses of the Major Units for the Geologic Map of the Northwest Flank of Mauna Loa Volcano

Appendix 2 is available as an Excel table and may be downloaded from https://doi.org/10.3133/sim2932e.

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