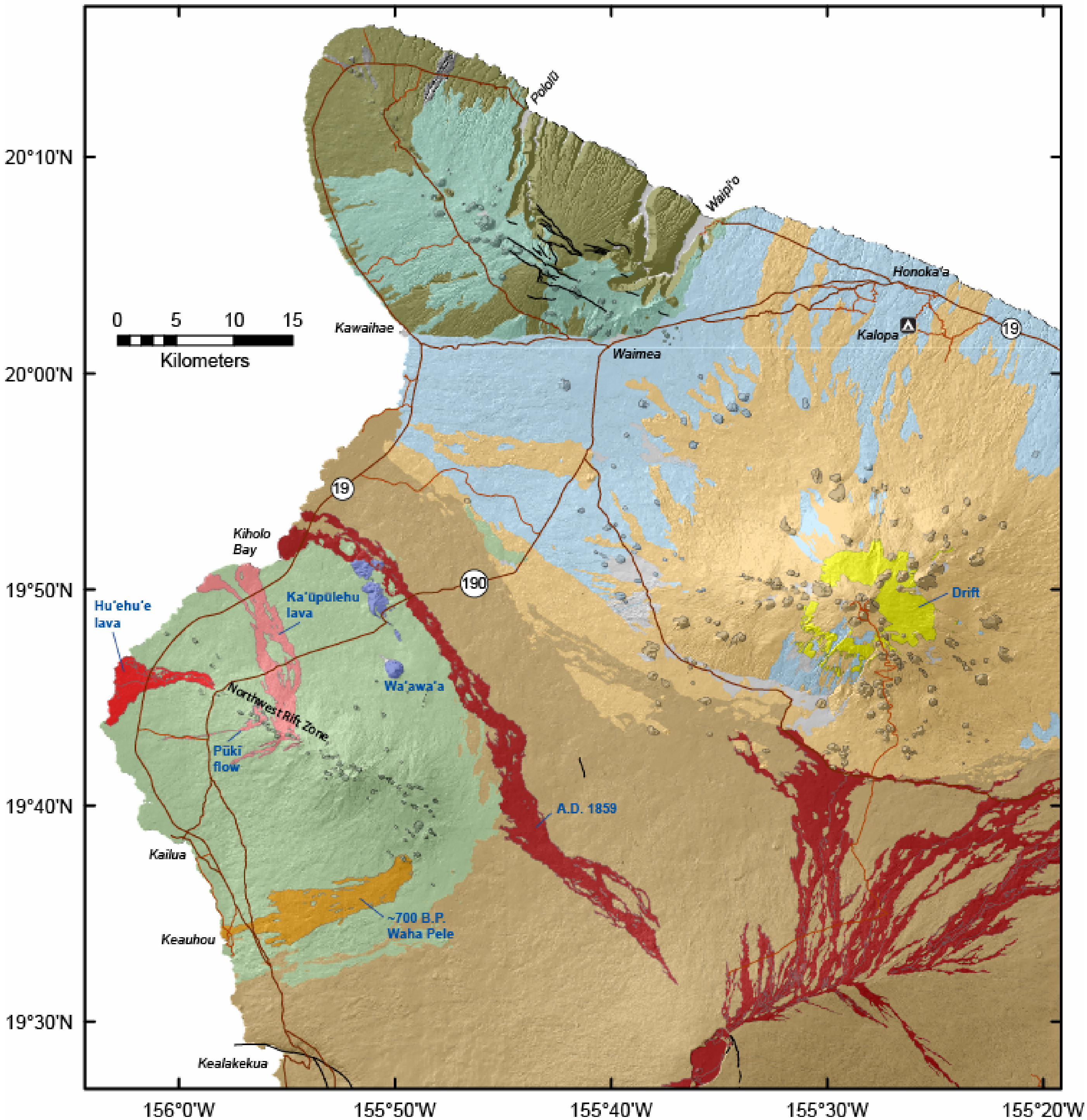
West Hawai'i Field Trip



University of Hawai'i
Department of Geology and Geophysics
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Field Guide by John Sinton
Department of Geology and Geophysics
University of Hawaiʻi at Mānoa
March, 2011

The life cycle of most Hawaiian volcanoes involves four main eruptive stages: 1) an early submarine stage (Lō'ihi is the only known, presently active, example); 2) the main subaerial shield-building stage; 3) an alkalic, postshield "capping" stage, making up no more than 3-5% of the total volume; and 4) after a period of inactivity and erosion lasting up to 500,000 years or more, a rejuvenation stage of alkalic basalts that generally accounts for <1% of the total volume. Not every Hawaiian volcano goes through every one of these stages, however.

The island of Hawai'i (Big Island) consists of 5 subaerial volcanoes: Kīlauea and Mauna Loa are active volcanoes in the subaerial shield stage, Mauna Kea and Hualālai are active (or dormant) volcanoes in the post-shield stage of activity, and Kohala is now inactive, having completed its shield and postshield stages of volcanism.

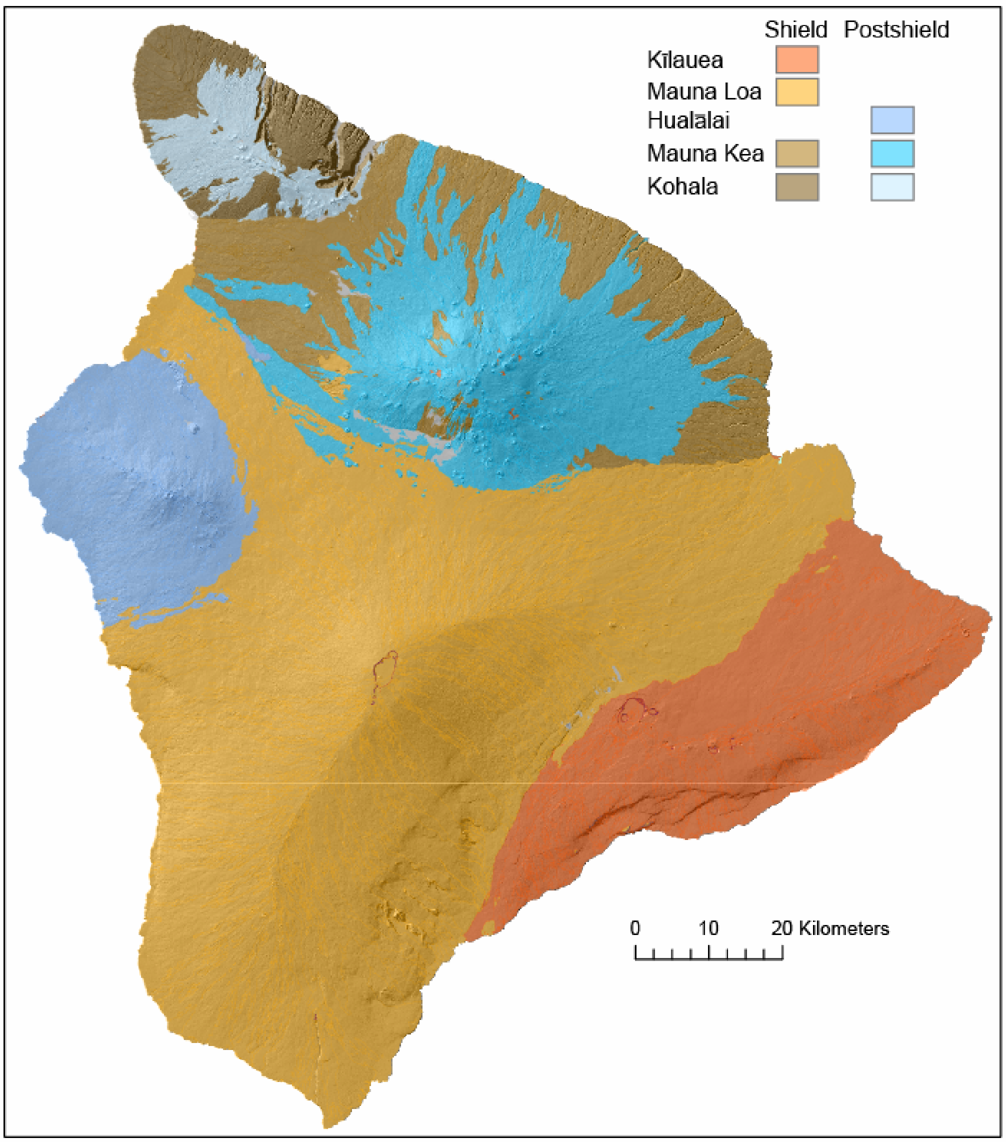


Figure 1. Map showing the volcanic formations of the five different volcanoes and their volcanic stages that make up the island of Hawai'i.

The early evolution of the island of Hawaiʻi is not fully known. For example, it is generally known that Kohala is the oldest of the present Big Island volcanoes, but it is unclear when it first began its activity. The oldest recovered samples of Big Island volcanic material come from the lower part of the Hawaiʻi Scientific Drilling Project drill core, yielding submarine tholeiitic basalts from Mauna Kea with an age of ~650 ka. Alkalic basalts collected from off-shore west Hawaiʻi are presumed to be representative of the early part of Hualālai Volcano [*Hammer et al.*., 2006]. Known stratigraphic relations of the five Big Island volcanoes are shown in Figure 2.

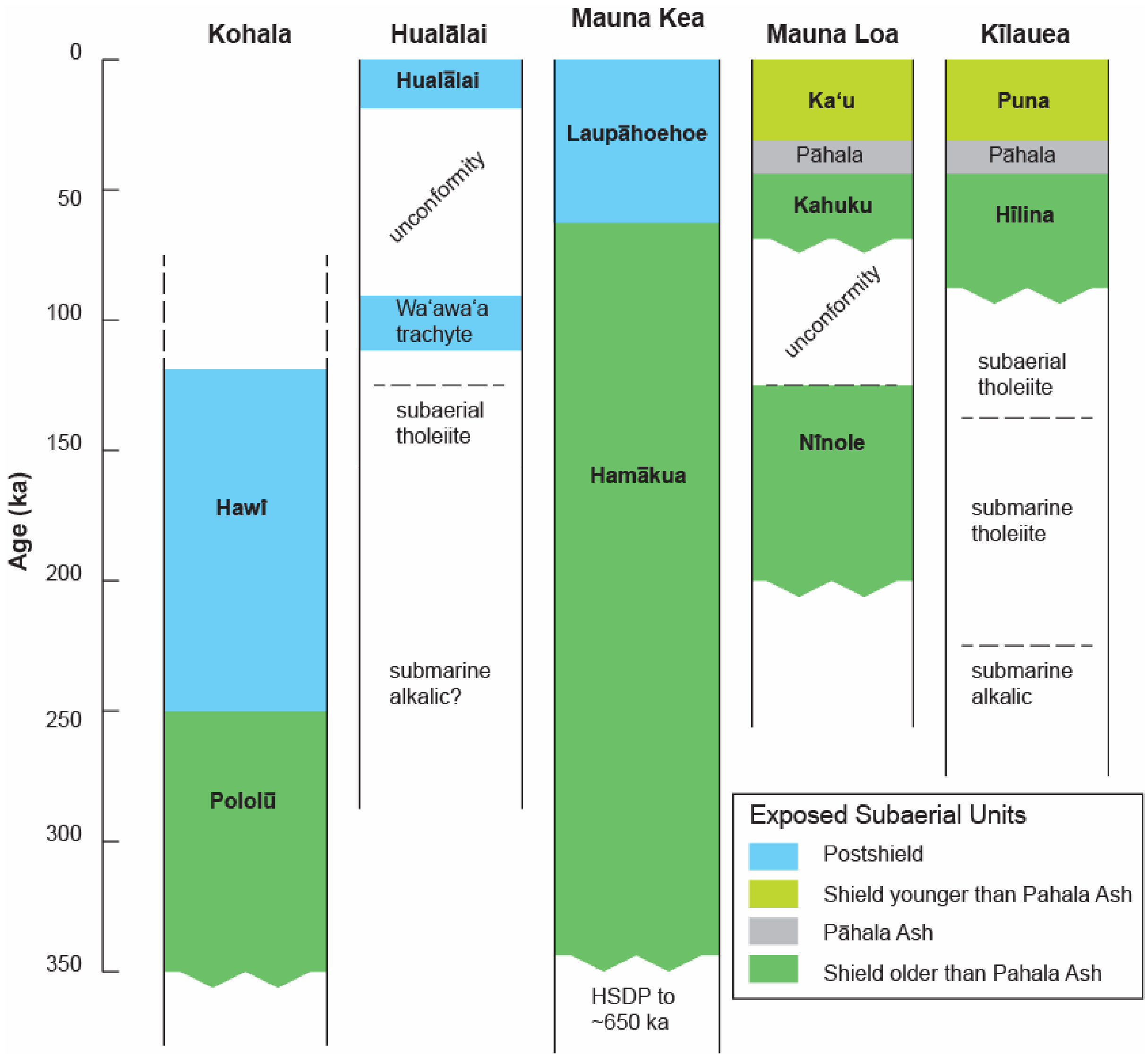


Figure 2. Stratigraphic relations for Big Island Volcanoes. Colored sections show subaerially exposed units only. Additional information from submarine regions and deep drilling are also shown, without color.

This guide covers the geology of the western part of the Big Island, including geological relations primarily associated with the three older volcanoes in west Hawaiʻi. The following briefly outlines aspects of the geology of each of these volcanoes. Specific localities are discussed further in the Itinerary section later in the guide.

Hualālai

The surface of Hualālai Volcano is dominated by alkalic basalts (Hulālai Volcanics) that are mostly younger than 11 ka. Tholeiitic basalts have been recovered from the near-shore submarine extension of the northwest rift zone [*Clague*, 1987; *Hammer et al.*, 2006], and also in a water well at a depth no more than ~75 m below the surface [*Clague*, 1987]. Tholeiitic volcanism persisted on Hualālai until sometime after 130 ka [*Moore and Clague*, 1992].

A widespread sequence of trachyte, the Waʻawaʻa Trachyte Member, is generally taken to mark the base of the Hualālai Volcanics, and the beginning of postshield volcanism on Hualālai. The only subaerial exposure of trachyte occurs at Puʻu Waʻawaʻa, a pumice cone on the north flank of Hualālai, and the associated Puu Anahulu trachyte lava flow, but trachytic material has also been penetrated by several water wells on the mountain. In addition, trachytic, syenitic and other leucocratic plutonic fragments are included as xenoliths or ejected blocks in vents from southeast of the volcano summit, suggesting that numerous other trachyte units must be buried near the northwest rift zone. Numerous radiometric ages indicate that trachyte was erupted sporadically for about 20,000 years, from ~114 to 92 ka [e.g., *Cousens et al.*, 2003]. An ~80 ka unconformity separates the Waʻawaʻa trachyte from the oldest of the surface basaltic flows with ages of ~11 ka, and the geologic history during this period remains unknown.

Hualālai is unusual, but perhaps not unique, in having a short period of highly evolved alkalic volcanism, followed by a return to more mafic activity. For example, the Waiʻanae Volcano on Oʻahu had an early period of postshield activity (Pālehua Member) dominated by hawaiite magmas that were increasingly differentiated with time, followed by a sudden change to much more mafic basaltic volcanism of the Kolekole Member [*Presley et al.*, 1997]. Similarly, early postshield activity on East Maui (Haleakalā) is dominated by hawaiites of the Kula Volcanics, followed by increasingly mafic lavas during the later postshield Hāna Volcanics [*Bergmanis et al*., 2000; *Sherrod et al.*, 2003]. But the chemical difference between the Waʻawaʻa trachytes and later alkali basalts of Hualālai is extreme, with the largest gap in composition known from any Hawaiian volcano.

Recent eruptions of Hualālai

Hualālai is one of several Hawaiian volcanoes known to have had highly explosive eruptions. About 700-800 yrs B.P. the Wahapele vent, at ~1600 m elevation, disgorged blocks of country rock, including plutonic syenites and dunites, and shed a layer of light gray to white ash with a thickness up to 3 m. Basaltic lava from this eruption reached the sea and currently underlies the golf course near Keauhou Bay. This eruption almost certainly was witnessed although there are no known accounts.

The most recent eruptions of Hualālai have been a matter of much interest and contradictory discussion in the literature. Macdonald et al. [1983] distinguished two “historical” flow fields, the Huʻehuʻe flow field which underlies the Kona airport near Keāhole Point, and the apparently older Kaʻūpūlehu flow field, both produced during eruptions along Hualālai’s northwest rift zone. Among the contentious issues include whether or not the flows were witnessed, whether or not there were casualties, how many actual eruptions there were and their respective ages, the viscosity of the lava and how rapidly it might have advanced. Most of these issues have been addressed by the comprehensive reappraisal of Kauahikaua et al. [2002], the source of most of the following information.

There are no actual first-hand accounts but there are several second-hand accounts, most of which relate the impressions of the Englishman John Young, who apparently was “impressed by the irresistible impetuosity” of the lava. There also are second-hand accounts of lava-water interaction at the coast and a historical story that Kamehameha, already the supreme Hawaiian leader at the time, was called on to stop flows near Mahaiʻula with a personal sacrifice. Kauahikaua et al. [2002] conclude that these accounts refer to the Huʻehuʻe lava activity, which probably mainly took place during the period A.D. 1800-1801. The timing of the earlier and larger Kaʻūpūlehu lava is unclear, other than that it apparently preceded the emplacement of the Huʻehuʻe lava. This lava could have been emplaced as early as 1774; an account by Kamakau suggests that Luahinewai, an anchialine pond currently on the north edge of Kaʻūpūlehu flow already existed in 1791. Although both flow fields contain xenoliths, primarily of lower crustal dunites, pyroxenites and gabbros, the Kaʻūpūlehu lava is world famous for the abundance of xenoliths locally concentrated into spectacular beds.

A report from 1841, several decades after the end of eruptive activity, said that a mother and child were surrounded by the Huʻehuʻe flow and killed, but it is notable that earlier reports of this activity do not mention any deaths, and one earlier interview specifically says there were none (*Kauahikaua and Camara*, 2000).

Huʻehuʻe lava flow field. The main Huʻehuʻe flow field comprises two main eruptive units: the mostly ʻaʻā Puhi-a-Pele flow and the later, mostly pāhoehoe Maniniʻowali flow (Figure 3). Kauahikaua et al. [2002] also included the tiny flow unit at Kileo Cone into the Huʻehuʻe flow field. The Puhi-a-Pele eruption began from a 0.7-km long fissure system that produced a 40-m high agglutinated spatter rampart. Later phases of this eruption allowed pāhoehoe lava to reach the coast. It is clear that the coastline was significantly

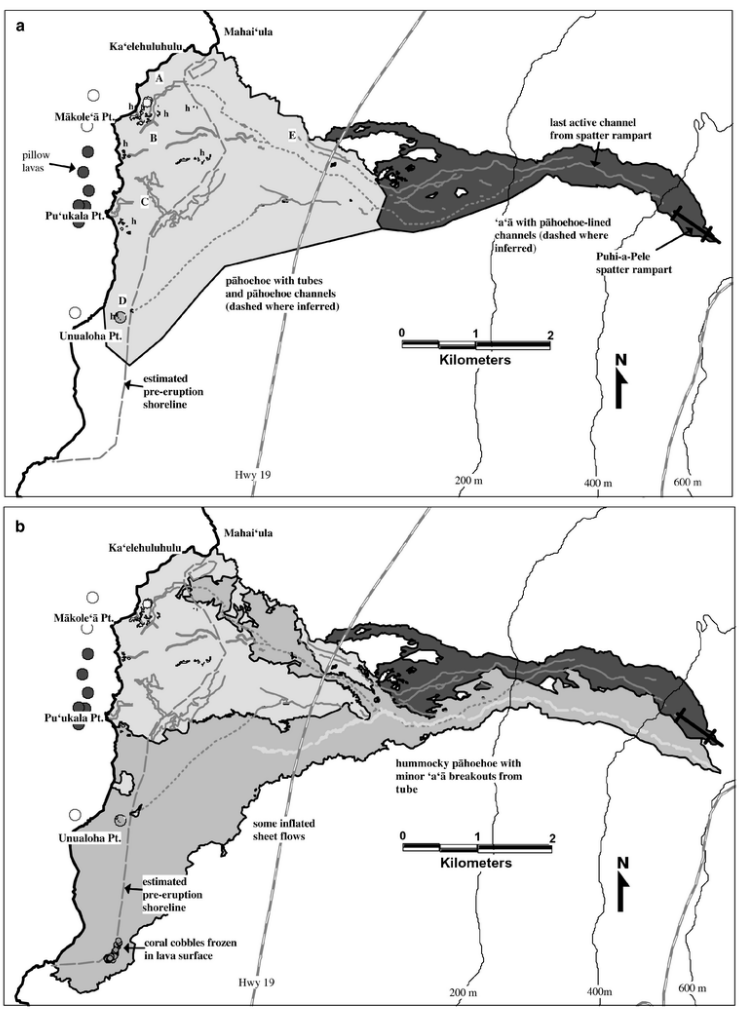


Figure 3. Development of the Huʻehuʻe lava flow field (from Kauahikaua et al., 2002]. Note estimated location of former shoreline.

modified by lava from this activity, which over-ran the Paʻaiea fishpond. Most likely the flow that Kamehameha was called on to stop was the one that produced the Puhi-a-Pele pāhoehoe. The Maniniʻowali flow overlies both the ʻaʻā and pāhoehoe phases of the Puhi-a-Pele flow. The Maniniʻowali lava emerged as a sheet-like pāhoehoe from a pre-existing tube system just south of the spatter vents at Puhi-a-Pele (Fig. 3). Thus the original vent for this flow is unknown, but might have started up slope at Kileo Cone.

The exposed Huʻehuʻe lava probably represents only 50-70% of the total erupted volume; pillow lava has been found ~ 400 m offshore, and lavas chemically equivalent to Huʻehuʻe have been found 8 km off shore in water depths of 1000 m. Kauahikaua et al [2002] estimate the total erupted volume of the Huʻehuʻe flows to be as high as 60×10^6 m^3 and the eruption duration ~120 days. Although the exact dates of the eruptions cannot be precisely determined, the activity probably ended in 1801.

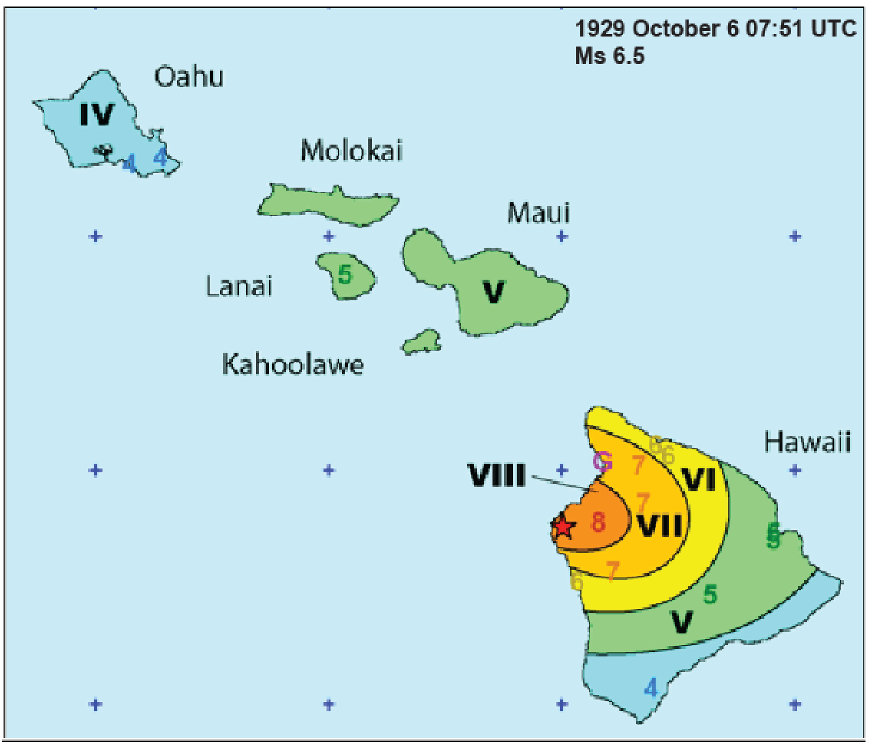
Kaʻūpūlehu lava flow field. This ~160×10^6 m^3 lava field also comprises three different flow units: the Kaʻūpūlehu Crater flow, the main Kaʻūpūlehu flow field, and the Pūkī flow. The Kaʻūpūlehu flow field was emplaced in three distinct phases; the first major phase of the eruption is a xenolith-bearing ʻaʻā, although scattered xenoliths also are present in lavas from later phases. The most spectacular of the xenolith beds is on private land, ~3 km upslope from the highway, where tens of thousands of xenoliths, 10-20 cm across have accumulated like a "heap of potatoes" [*Macdonald et al.*, 1983, Fig. 4]. Notably, the study of Kauahikaua et al. [2002] found no evidence to support either the rapid emplacement of this flow field or unusually low viscosities of the lava.

Figure 4. Xenolith beds in the Kaʻūpūlehu lava ~3 km mauka of Rte 190. Arrow points at backpack for scale. These xenoliths are coated with glassy lava; they were deposited in a small depression, after which the lava drained away.

Although the last eruption of Hualālai appears to have been more than 200 years ago, it is still generally considered to be active, with a hazard rating of 4 on a scale of 1 (highest) to 9 (lowest) based on surface coverage of lavas less than 1,000 years old. In the last 1500 years, Hualālai has experienced 8 eruptive episodes which shed lava over 174 km^2 [*Sherrod et al.*, 2006]. Furthermore, in late 1929 Hualālai experienced a period of unrest that is generally considered to represent magma intrusion into the northwest rift zone. A burgeoning population in close proximity to Hualālai's active rift zones makes this region one of particular concern.

The 1929 seismic crisis

Accounts of the 1929 events were recorded by T. A. Jaggar in his weekly reports as Volcanologist in Charge of the Hawai‘i Volcano Observatory [*The Volcano Letter*, 1996, p.248-252]. The first tremors began just after noon on 19 September, 1929 near Pu‘u Wa‘awa‘a Ranch and increased in frequency and intensity for the next several weeks. A recorder set up on a veranda at Pu‘u Wa‘awa‘a Ranch recorded 220-599 shocks/day from 9/26-9/30. Particularly strong shocks were recorded on September 25 and "one quite disastrous event" on October 5. The stronger shocks displaced furniture, threw down and overturned loose objects, moved buildings, cracked masonry, collapsed stone walls and produced slides on steep slopes. Recent analysis of the Oct 5 event estimate its magnitude as 6.5 with a maximum intensity of VIII [*Hopper et al.*, 2007] (Figure 5), comparable to the 2006 Kiholo Bay earthquake, the strongest earthquake in Hawaii since 1975. Jaggar argued that "in the quality of growing gradually to a maximum from tremor to bumping shocks, and from bumping shocks to oscillations of longer period, this seismic crisis in Hawai‘i is … volcanic, and marks the shift of magma underground", and that a "lava outbreak is expectable". By late October the seismic crisis had declined considerably although locally felt events continued throughout the rest of the year.



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE Resistant Structures	none	none	none	V. Light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy
POTENTIAL DAMAGE Vulnerable Structures	none	none	none	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy	V. Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
ESTIMATED INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Figure 5. Earthquake intensity map for the 1929 October 5 earthquake [Hopper et al., 2007]. This map was created by carefully compiling the contemporary accounts of effects from this earthquake and then assigning intensities to them. Map provided by David Wald, USGS. Compare to figure 20.

Mauna Kea

Mauna Kea emerged from the sea ~400 ka, during the tholeiitic shield stage of activity. Since ~350 ka Mauna Kea has produced a range of tholeiitic to alkalic basalts of the Hāmākua Volcanics [*Stearns and Macdonald*, 1946; *Wolfe et al.*, 1997]. Post-shield Laupāhoehoe Volcanics are younger than about 65 ka, and range in composition from hawaiite to benmoreite (Figure 6).

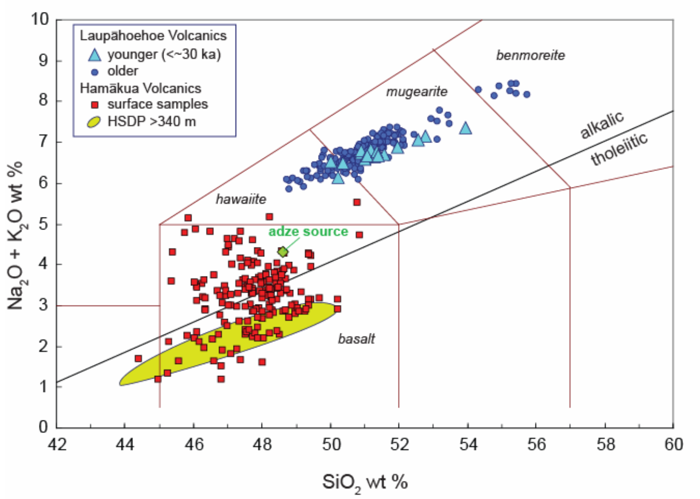


Figure 6. Alkali-silica variation diagram for Mauna Kea samples. Yellow field shows range of compositions for samples below 340 m in Hawai'i Scientific Drilling Project core. Green diamond shows the composition of the source rock for the Mauna Kea adze quarry.

Mauna Kea contains geological evidence for three principal periods of glaciation that are bracketed by various lava units. Evidence of glaciation includes extensive moraine deposits, steep lava flow fronts with crude pillow lava forms, local hyaloclastite, glacial polish and local striae on ʻaʻā lava flows that have had their upper clinker layers removed. Efforts to document the ages and durations of the various glacial periods are complicated by large analytical uncertainties. The oldest event, the Pōhakuloa, is clearly older than the Hāmākua to Laupāhoehoe transition, and is thought to correspond to marine isotope stage (MIS) 6, about 180 – 130 ka. The Waihū Glacial Member probably occurred during MIS 4, roughly 80-60 ka, close to the transition from Hāmākua to Laupāhoehoe volcanism. The youngest, the Mākanaka, was clearly underway by 40 ka. Two ice-contact lava flows have been dated at 33 ± 12 and 31 ± 9 ka. The end of Mākanaka glaciation is generally taken to be about 13 ka, when Lake Waiau became an ice-free depression capable of accumulating sediment [*Peng and King*, 1992]. Cosmogenic exposure ages of till deposits have been obtained in the range 16-21 ka, generally consistent with this chronology.

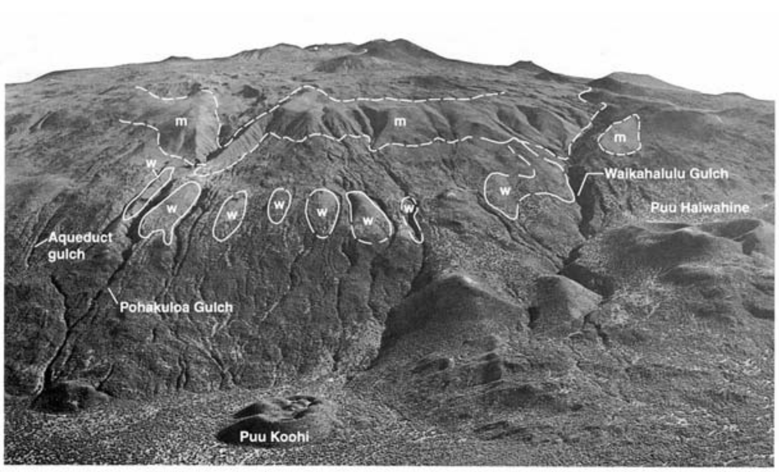


Figure 7. View of Mauna Kea showing the distribution of drift deposits from the Mākanaka (m) and Waihū glacial periods. (from Wolfe et al. [1997]).

The age of the last volcanism on Mauna Kea is most likely about 4500 yrs B.P. Nine charcoal ages from beneath six stratigraphic units [*Porter*, 1979; *Wolfe et al.*, 1997] yield calibrated dates from about 4500 to 8200 years before present [*Sherrod et al*., 2007]. Arguments for activity less than 4000 yrs B.P. [e.g., *Porter*, 1979, *Porter et al.*, 1987], based on depth-age relations for tephra layers in sediment cores from Lake Waiau [*Woodcock, et al.*, 1966], suffers from large analytical errors of the ages of the bounding sedimentary strata and assumptions of uniform accumulation rates. Sherrod et al. [2007] note that the permissible range of calibrated ages for these tephra, 3130-5380 yrs B.P., overlaps with the ages of known eruptions from dated lava flows, and cite an age of ~4.6 ka for the youngest volcanism on Mauna Kea, in concurrence with Wolfe and Morris [1996].

Kohala

Kohala is the oldest of the volcanoes on the island of Hawai‘i. Its exposed lava flows are all normally magnetized and younger than 0.78 Ma. Kohala has an axial rift zone that was active in both shield and postshield time. The trace of the southeast rift zone passes beneath Mauna Kea, and reappears farther southeast as the submarine Hilo Ridge. The Hilo Ridge has bulk magnetic character that indicates it is built chiefly by reversed-polarity volcanic rocks, evidence that much of the ridge is older than 0.78 Ma (*Naka, et al*., 2002).

Kohala shield-stage strata are assigned to the Pololū Volcanics, with radiometric ages mostly in the range 0.45 to 0.32 Ma [(*McDougall*, 1964; *Lanphere and Frey*, 1987; see also *Sherrod et al.*, 2007]. Overlying the Pololū Volcanics are the postshield-stage Hāwī Volcanics, which range in composition from hawaiite to trachyte. Most Hāwī ages range from 0.26 to 0.14 Ma. The end of Hāwī volcanism is taken to be about 120 ka by Wolfe and Morris [1996] although there are a few reported ages in the range 60-80 ka. Some of these younger ages have been challenged on stratigraphic grounds, e.g., relation to Mauna Kea lavas of known age, but others remain to be rigorously evaluated.

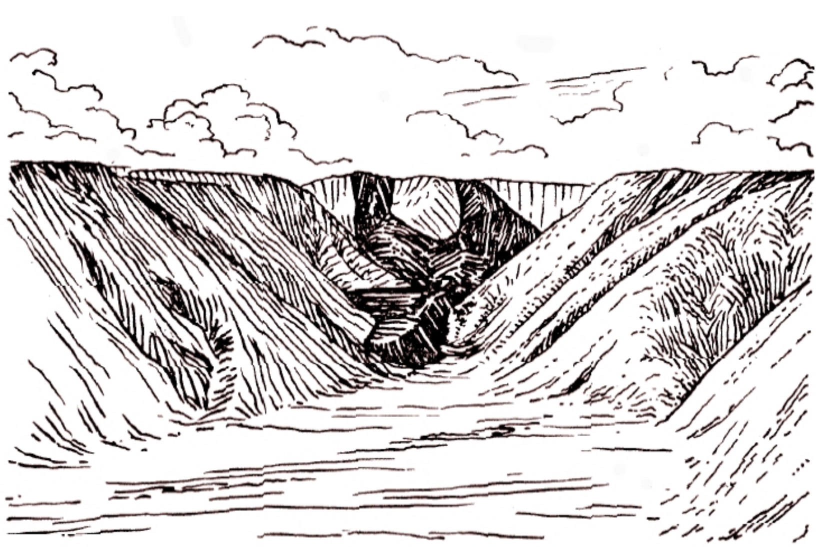


Figure 8. Drawing of post-erosional Hāwī lava flowing down into Pololū Valley (from Stearns and Macdonald, 1946).

Kohala is notable for several geomorphic features, all of which may be related to a large landslide or slump from its northeast side late in Pololū time (*Moore et al.*, 1989). In plan view, the northeast coast has a prominent indentation extending along 20 km of shoreline from Waipi‘o to Pololū Valleys. Large stream valleys have cut deeply into the volcano, likely a consequence of stream gradients thrown out of equilibrium when the landslide severed their paths.

The summit of the volcano has faults that parallel the indented northeast coastline. Stearns and Macdonald [1946] emphasized the importance of the graben structure in this region in controlling the distribution of Hāwī lava flows on Kohala. Moore et al. [1989] considered the structural depression near the summit to be a "pull-apart graben developed at the head of the landslide." In contrast, Sherrod et al. [2007] argued that the landslide head scarp is at the coast and the graben formed as a far-field response to changes in stress precipitated by the landslide. Regardless, post-erosional volcanism was well documented on Kohala by Stearns and Macdonald [1946], with Hāwī lava flows draping the valley walls and one late lava that flowed down into Pololū Valley (Fig. 8). This flow is known to host a prehistoric adze quarry [*Lass*, 1994].

Itinerary

Kona Keahole Airport to Waimea

From Kona Keahole Airport turn south

Turn left on Kalaoa Road

Moore and Clague [1991] and Wolfe and Morris [1996] showed a narrow finger of the Pūkī flow extending along this road (see cover map). Interestingly, Kauahikaua et al. [2002] limit the end of this flow to just above Rte 190. We will look for evidence for the extension of this lava while driving up the road.

Turn left (north) on Rte 190

Optional Stop – Hu'ehu'e vents
After about 5 km, Rte 190 passes just mauka of the spatter ramparts that fed the Hu'ehu'e lava flow field.

After another 5 km, we cross the contact into the Ka'ūpūlehu lava.

Stop 1. Ka'ūpūlehu lava channels

In this region are several prominent lava channels, some of which host lower crustal xenoliths. Xenolith lithologies in the Ka'ūpūlehu lava include dunite, wehrlite and gabbro. Some xenoliths contain contacts between two or more lithologic types. Although many of these xenoliths have metamorphic textures, their compositions suggest that they represent lower crustal cumulates, rather than mantle lithologies. Hawaiian volcanoes develop steady-state magma reservoirs early in their development. As the volcano grows the reservoir also rises, surmounting a pipe-like conduit of the early crystallization products of these magmas. During the post-shield stage, as magma supply wanes, the thermal state of the volcano can no longer sustain a shallow magma reservoir; rather magma accumulates at progressively deeper levels within the pre-existing cumulate pipe. Eruptions from deep reservoirs during post-shield activity commonly carry fragments of early cumulates, like this one.

Continue north on RTE 191.

Turn right toward Pu'u Wa'awa'a

Stop 2. Pu'u Wa'awa'a

This is the only vent structure in the Hawaiian Islands characterized as a pumice cone. It has distinctive fluted erosion on its sides (Figure 9), for which it is named (Pu'u Wa'awa'a is

Hawaiian for “furrowed hill”, and many local folks refer to this feature as “cupcake hill”). Stearns and Macdonald [1946] speculated that much of this erosion might have originated “from landslides soon after the cone was formed and only subsequently enlarged by steam erosion.” The internal structure of the 140-m high cone consists of bedded pumice including fragments of relatively massive trachytic obsidian. Volcanic glass in reasonable sizes is relatively rare in Hawaiʻi and it is therefore not surprising that this source was exploited by pre-contact tool makers. Scrapers fabricated from Puʻu Waʻawaʻa obsidian have been found in burial caves near Kaʻūpūlehu [*Stearns and Macdonald*, 1946], and elsewhere on the Big Island [*McCoy et al.*, 2011], and also in Hālawa Valley, on Oʻahu [*K. T. M. Johnson, pers. Comm.*. 2000].

Figure 9. Puʻu Waʻawaʻa showing the distinctive fluted erosion pattern on its slopes. Photo courtesy of the NASA Virtually Hawaiʻi Project

Stearns and Macdonald [1946] established the relationship between the Puʻu Anahulu trachyte flow and its source vent at Puʻu Waʻawaʻa, despite the fact that these two features are now separated and partially buried by younger basalts (Figures 10, 11). At more than 270 m thick, with an estimated total erupted volume of ~5.5 km^3, this eruption is the largest known single eruption in all of Hawaiʻi nei.

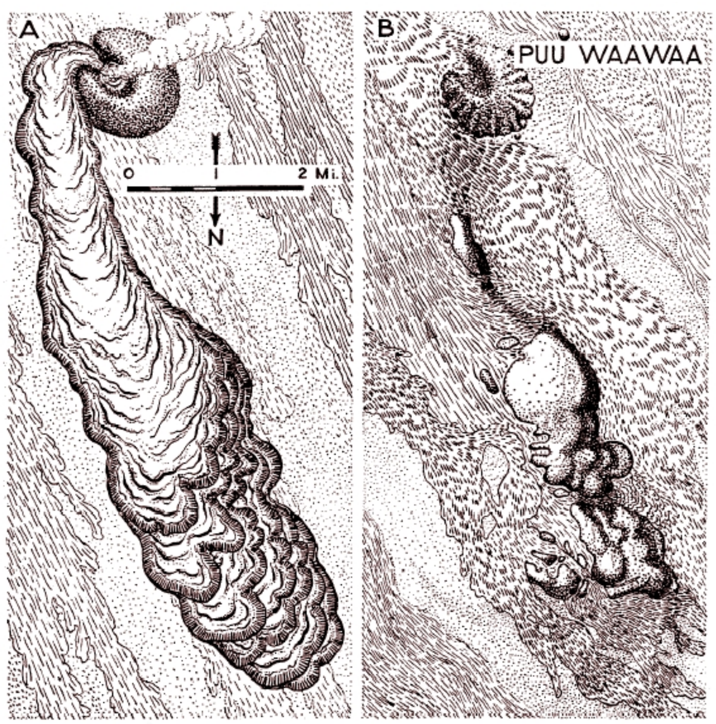


Figure 10. Sketch map showing relations between Puu Waʻawaʻa pumice cone and Puu Anahulu trachyte flow. A. at the end of the eruption, and B. present configuration with much of the trachyte flow now buried by later basalt flows. From Stearns and Macdonald [1946]. Note north is toward bottom of figures.

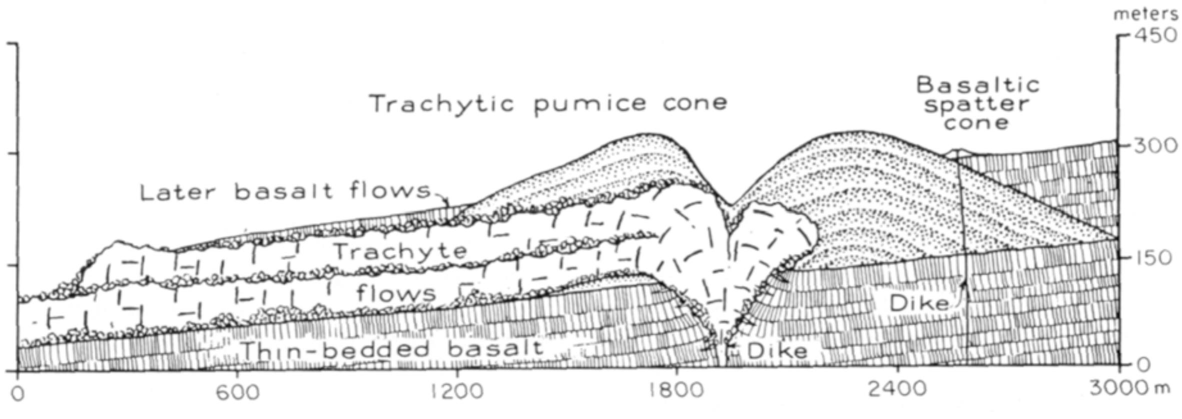


Figure 11. Relationship between Pu'u Wa'awa'a pumice cone and Pu'u Anahulu trachyte flow. Figure also shows the presence of younger basalt, both as flows and spatter cones near Pu'u Wa'awa'a. Figure from Stearns [1946], after Stearns and Macdonald [1946].

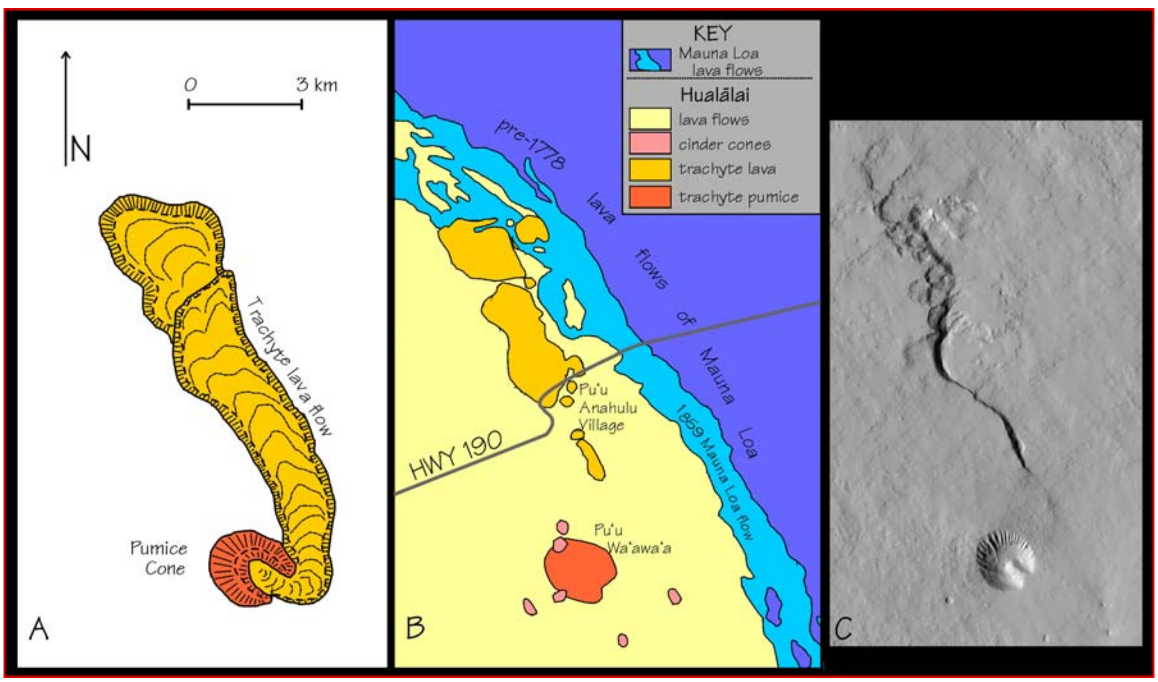


Figure 12. The region around Pu'u Wa'awa'a and Pu'u Anahulu; Left two figures after Stearns and Macdonald [1946](see Fig. 9). Middle panel also shows the relationship to the 1859 Mauna Loa lava, which partially buries the distal end of the trachyte flow. Figure by S. Rowland.

Return to Rte 190

The road climbs up onto the Pu'u Anahulu trachyte flow.

Optional Stop – Pu'u Anahulu

The total thickness of the Pu'u Anahulu trachyte flow is more than 270 m. It is thought to comprise at least two individual flows, each at least 90 m thick, separated by a screen of pumice and clinker.

Stop 3. Mauna Loa 1859 lava

The 1859 eruption of Mauna Loa volcano is remarkable for a number of reasons. First, it was erupted from neither the summit nor one of the rift zones, but rather from one of several east to northeast-trending radial vents (see cover map). Vents for the 1859 eruption are located along a 9 km-long fissure trending 335° from elevation of 3400 to 2600 m. Second, it is one of several distinctly "paired" eruptions, in which a short period of high discharge produced ‘a‘ā lava, followed by a longer period of low discharge producing pāhoehoe lava [*Rowland and Walker*, 1990]. The initial ‘a‘ā phase occurred over a 16-day period, characterized by high lava fountains at the vent. The 1859 ‘a‘ā flow is 51 km long, the longest historic lava flow in the Hawaiian islands; the first lava flow advanced at an average of 270 m/hr and reached the sea in about 7 days. Its estimated volume is 270 x 10^6 m^3, with an average discharge rate of ~ 200 m^3/s. After the initial phase the eruption rapidly shifted to vents lower down on the mountain, where a 47-km-long pāhoehoe lava flow was erupted at an average discharge rate of ~ 5 m^3/s for another 285 days.

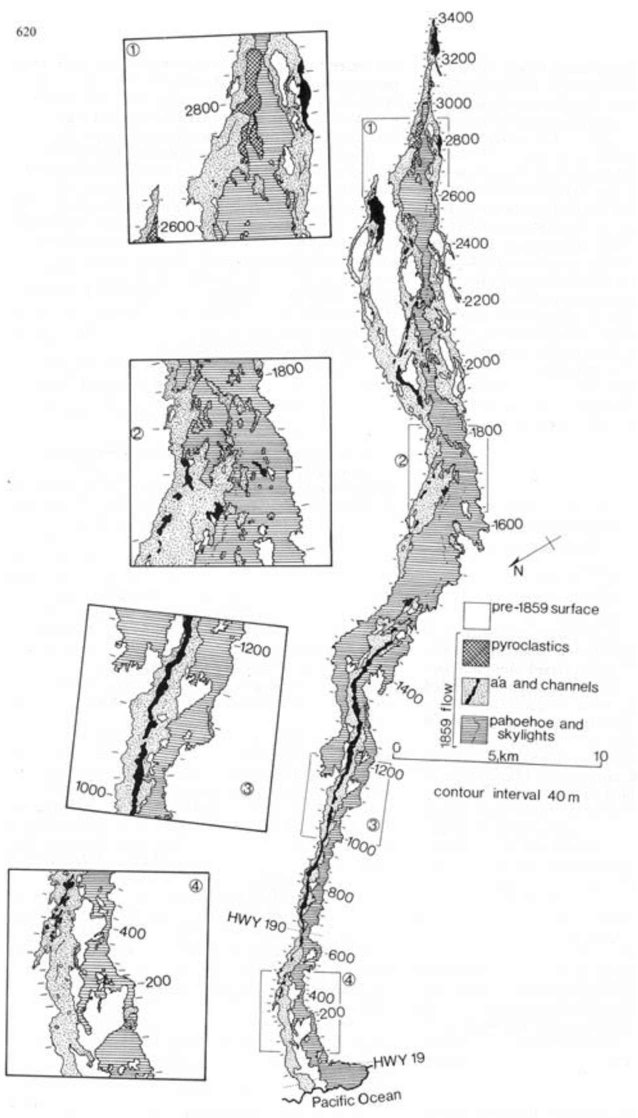


Figure 14. Map of the Mauna Loa 1859 lava flow field (from Rowland and Walker, 1990), showing the distribution of early ‘a‘ā and later pāhoehoe lavas. Note position of Hwy 190.

Thus the paired eruption of 1859 provided critical information used by Rowland and Walker [1990] to quantify differences in discharge rate and lava advance rates between Hawaiian ‘a‘ā and pāhoehoe lava flows. Those authors showed that degassing associated with high-discharge lava fountains promoted an increase in viscosity and the development of ‘a‘ā lava flows, which then advanced rapidly, riding on the roller-bearing clinker that characterize this lava type. The relatively rapid ~40x reduction in discharge rate observed for this eruption has important implications for the magmatic processes that fed it. Average eruption rates determined in this classic paper are now used worldwide to estimate eruption durations. The total volume of the 1859 pāhoehoe is estimated to be 113 x 10^6 m^3 [*Rowland and Walker*, 1990].

At this locality only the pāhoehoe is observed (see location of Hwy 190 on Figure 14).

Waimea (Kamuela Post Office)

Fine views of Mauna Kea and Kohala are available on clear days from Waimea. Most of the region south of town is Hāmākua Volcanics (Mauna Kea late shield lavas) covered by ash mainly derived from Mauna Kea. Puʻu Pā cinder cone ~5 km south of Waimea contains loose, well-formed crystals of augite and olivine [*Stearns*, 1978].

Honokaʻa

This charming town is mainly built on Mauna Kea Hāmākua lavas with lots of covering ash.

Kukuihaele (Waipiʻo Valley overlook)

Waipiʻo Valley is a classic Hawaiian stream valley with steep walls, an amphitheater head and a flat, alluvium-filled floor. This is the southern extent of a region of spectacular sea cliffs that extends northwestward for ~15 km to Pololū Valley. The enigmatic geomorphology of this region of incised shoreline, steep cliffs and deep stream valleys is now generally ascribed to processes associated with the Pololū landslide [e.g., *Moore et al.*, 1989]. It is another example (Nuʻuanu and Waiʻanae palis on Oʻahu are other classic examples) of accelerated on-shore erosion precipitated by changing stress conditions following major off-shore submarine landsliding. The initiation of the Pololū landslide is thought to be ~350-370 ka, based on the age of a reef terrace that cuts across the landslide. This puts the landslide as occurring in late- Pololū (shield) time.

An excellent section of Pololū lavas, capped by a single flow of postshield Hāwī volcanics, is exposed along the road down the southeastern side of Waipiʻo Valley. Lava from Mauna Kea spilled into the valley at Hiʻilawe falls, said to be the highest free-fall waterfall in Hawaiʻi, with a single vertical drop of >360 m. The total relief of these falls is >460 m.

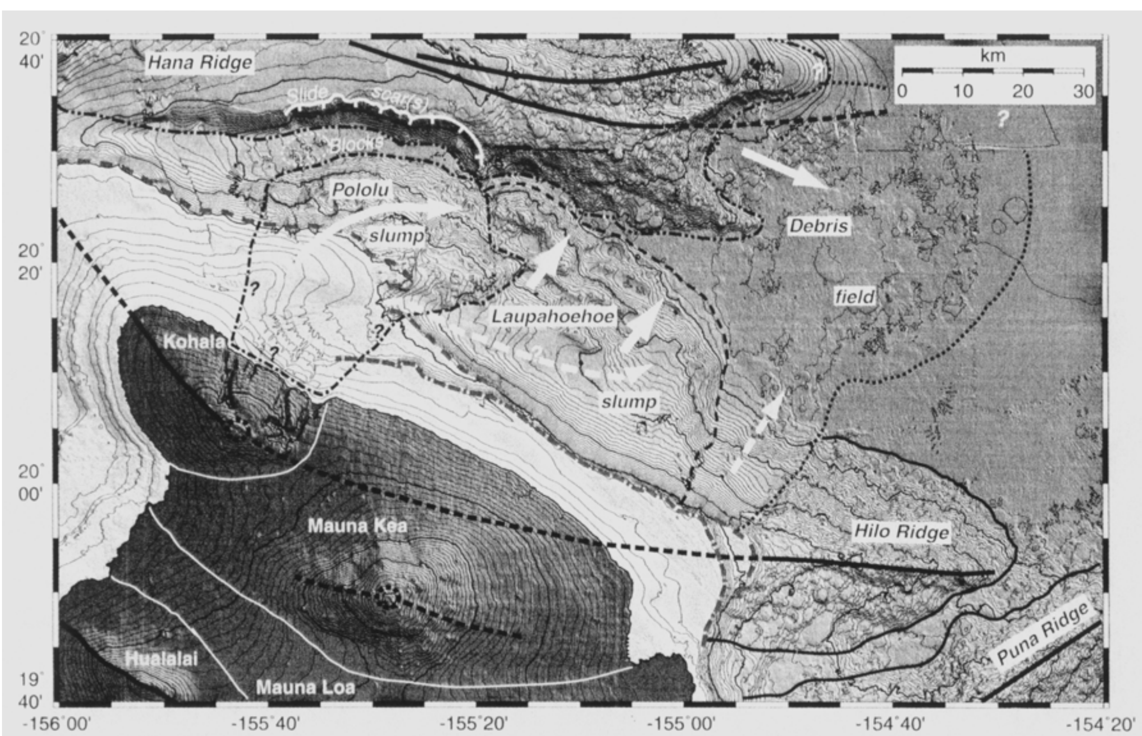


Figure 15. Map showing the location of landslide deposits north of Hawaiʻi. Note the relationship between the incised section of north Kohala and the Pololū Slump deposit. Also note that Hilo Ridge is considered to be an extension of a Kohala rift zone. (from Smith et al. [2002].

Mauna Kea[1]

Mauna Kea kuahiwi ku haʻo i ka mālie
Mauna Kea is the astonishing mountain that stands in the calm – Pukui, 1983, 2147.

The road up Mauna Kea leaves the Humuʻula Saddle Road near Puʻu Huluhulu (Hairy Hill), a Mauna Kea cinder cone, partially surrounded by 1935-6 Mauna Loa lavas. This cone has been extensively quarried, which exposes a dike cutting through the cone. A 1.5 m-high wall of loose stones built during the late 19th century west and northwest of Puʻu Huluhulu was partially inundated by fluid pāhoehoe in 1935. This wall was sufficiently strong to stop forward movement of the pāhoehoe in several places, attesting to the limited momentum of Hawaiian pāhoehoe. This location has been cited as evidence, both pro and con, the controversial question about the effectiveness of artificial barriers for lava diversion.

Hale Pōhaku

At an elevation of 2880 m is the Mauna Kea Visitor Information Station. The prominent cinder cone across from the visitor's center contains abundant "cored bombs". These are spindle bombs erupted during strombolian activity of this Laupāhoehoe vent, which formed around large, primarily gabbroic xenoliths. Pre-historic Polynesians fabricated sinkers and lures from these xenoliths in a nearby "workshop".

Mauna Kea Summit

The summit of Mauna Kea is dominated by cones and flows of the Laupāhoehoe Volcanics. At least three of these units contain evidence of contact with glacial ice (Figure 16).

Take the walking trail down through one of the sub-glacial lava flows, with evidence of ice contacts and crude pillow structure. Gabbroic xenoliths are locally present.

Lake Waiau. Lake Waiau (swirling water, also the name of the goddess who protects this place) is bound on one side by Waiau cone and on the other by a steep-fronted, ice-contact lava (Figure 17). The lava margin consists of crude pillows typical of ice-contact lava flows. Lake Waiau, at an elevation of approximately 3700 m, is a perched water body lying more than 3000 m above the water table of the Big Island. Although a layer of massive lava cannot be precluded as the impermeable layer on which the lake is perched, the more likely explanation is that it is a layer of permafrost [*Woodcock*, 1974] which likely persists today.

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[1] Although the name Mauna Kea is commonly said to be derived from *mauna keokea* "white mountain", alluding to the presence of snow that intermittently covers the upper reaches of the mountain, an alternate interpretation is that the name is a shortened version of *mauna a Wakea* (the mountain of Wakea). This latter name also is fitting for the highest point in the Pacific because Wakea represents the sky. Indeed Wakea (Sky Father) and Papa (Earth Mother) are the first parents of all human life on earth, i.e., the 'first ancestors of the Hawaiian people, both chiefs and commoners. Wakea (Atea or Vatea in East Polynesia, Rangi in New Zealand) generally means sky; Wakea appears as the primary generative force throughout Polynesia and the name is a symbol for the upper regions of the air, whence descend the sunshine and rain to fertilize Earth. To Polynesians the functions of sky and earth are themselves direct analogues of the process of human reproduction.

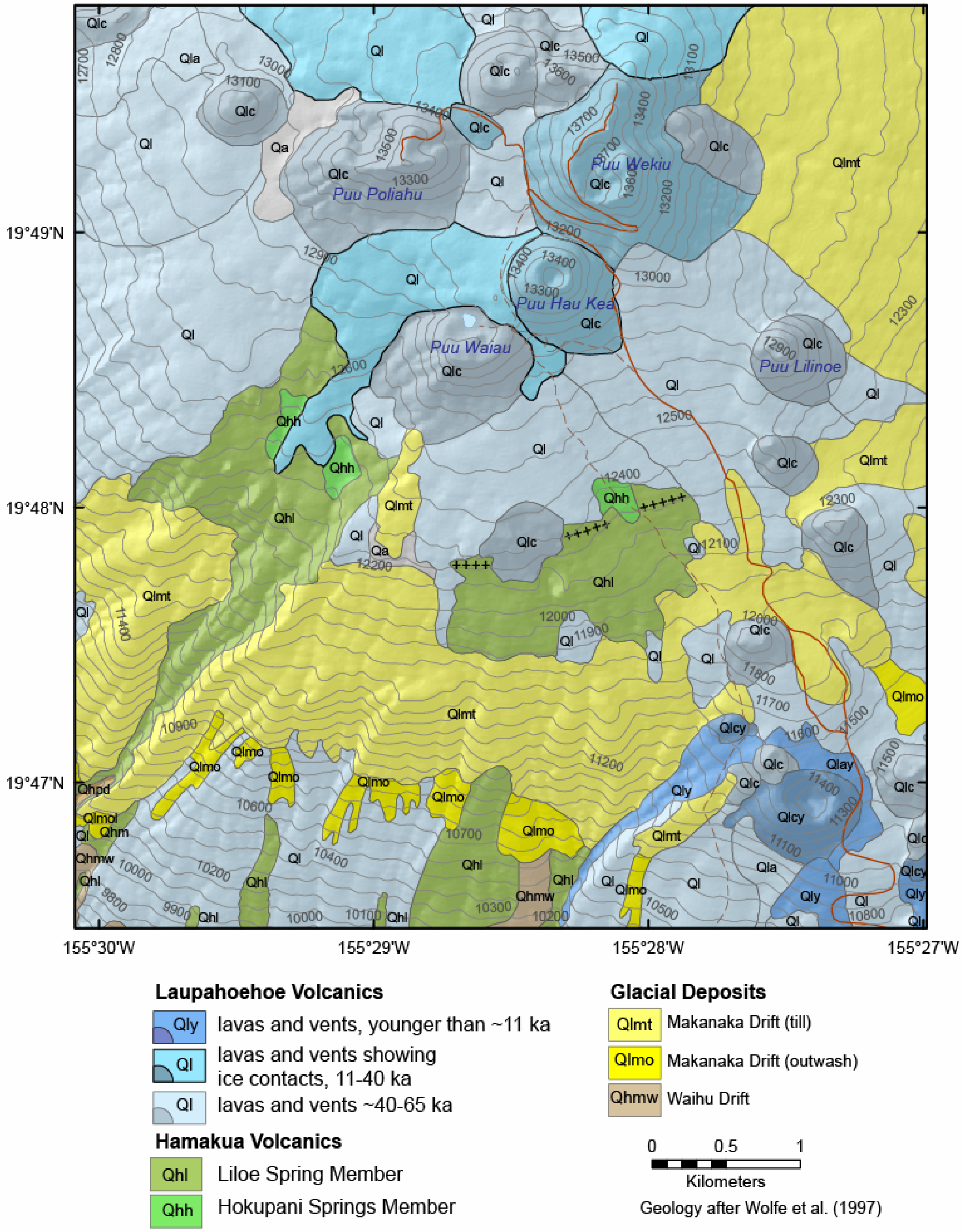

Figure 16. Geologic map of Mauna Kea summit and south side, based on geology of Wolfe et al. [1997]. Laupāhoehoe ice-contact lavas are shown with a darker outline.

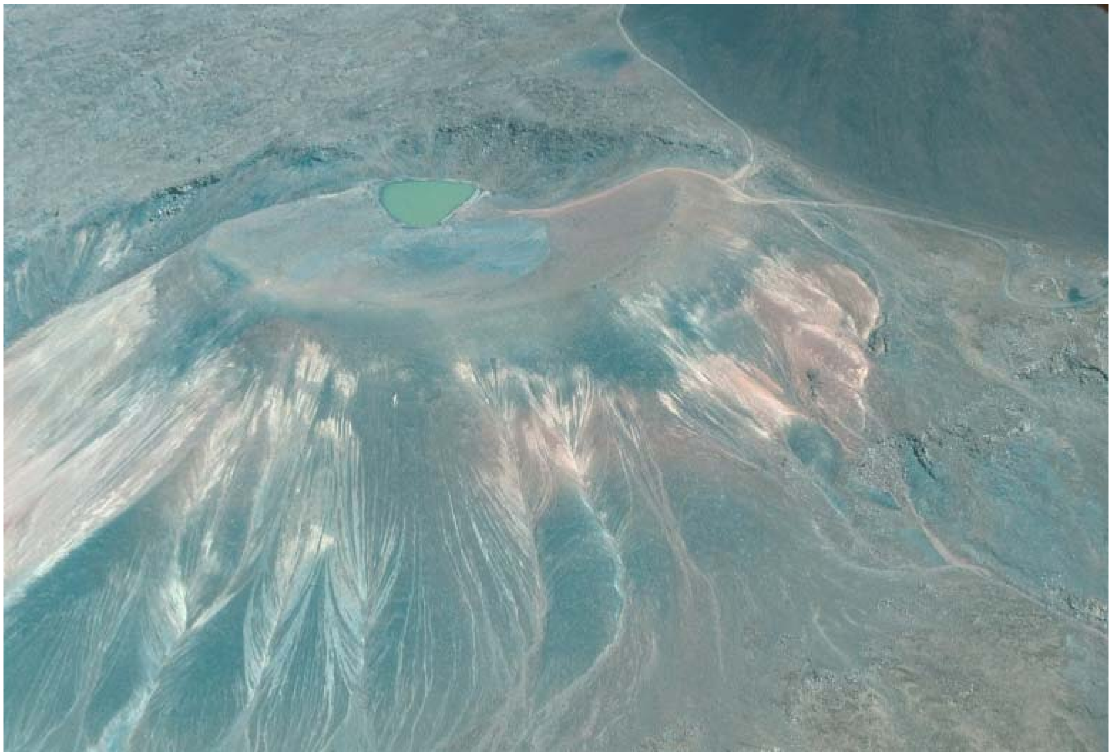

Figure 17. Lake Waiau sits between Waiau cone to the south and a steep-fronted, ice-contact Laupāhoehoe lava flow.

Continue walking down trail

Along the way, watch for evidence of glacial action, including the presence of moraines, and both glacial polish and glacial striae on ‘a‘ā lava flows that have had their upper clinker layers removed by glacial action.

Figure 18. Examples of glacial striae in Mauna Kea lavas affected by Mākanaka glaciation.

The Mauna Kea Adze Quarry

The Mauna Kea adze quarry complex is by far the largest known quarry used by pre-historic Polynesians for the extraction of raw stone for the fabrication of tools used in everyday life. The entire complex extends over an area of almost 20 km^2, although the most intensive use was confined to an area of about 4 km^2 between 3350-3780 m elevation, including extraction areas and chipping stations along with religious shrines, habitation rock shelters, and overhang and open air shelters. The principal extraction area lies along an escarpment running close to the 3750 m elevation in an alkalic basalt of the Liloe Spring Member of the Hāmākua Volcanics. Porter [1979; 1987] argued that this escarpment represents an ice-contact terminus. In contrast, Wolfe et al. [1997] suggested that the escarpment might mark the location of a buried eruptive fissure. In either case, it is clear that early Hawaiians found these outcrops to be especially suited for adze production, so much so that they were willing to spend considerable effort to reach and work outcrops >30 km from any known permanent habitation sites, and at high elevations under conditions that must have lacked for most comforts of the time.

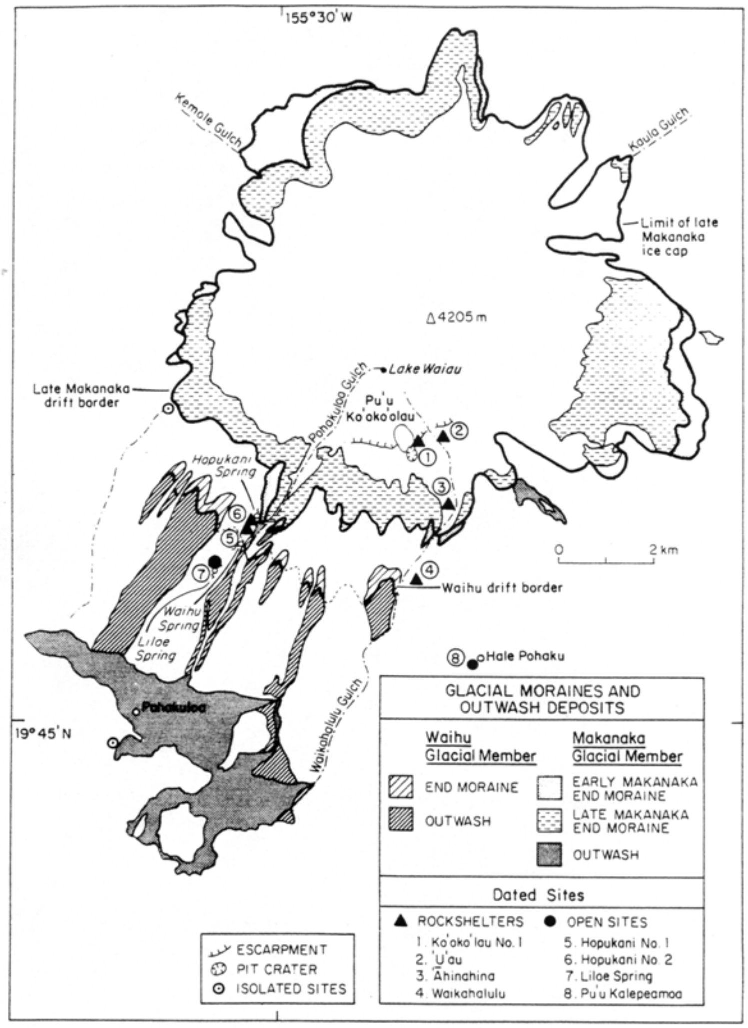

Figure 19. Summit region of Mauna Kea showing possible distribution of Pleistocene glaciers and archeological features (from McCoy [1990]).

McCoy [1990] pointed out that quarrying activities were not restricted to the local escarpment, but occurred over a wide range of elevations. However, these secondary sources also are tool-quality lavas that generally contain evidence for ice contact and glacial drift. The reasons why these ice-contact lavas were exploited so extensively are describe below. The first two features are essentially textural, while the third relates to macroscopic fabric.

1. The Liloe Springs member of the Hāmākua Volcanics represents late-shield volcanism when slightly alkalic magmas were beginning to reach advanced differentiation at moderate pressures. This led to the eruption of degassed, aphyric lavas, i.e., rocks

devoid of large crystals and vesicles, features which constitute defects in tool-grade materials.

2. Ice contact also imparts a fine-grained, interlocking texture reflecting the unique cooling environment. Texture, including the lack of phenocrysts and vesicles described above, is one of the most important characteristics of tool-grade stone. The material must be easily fabricated without frequent breaking and the finished tool must be able to hold a fine edge. Mauna Kea adze material has groundmass grain size <0.01 mm; microphenocrysts of plagioclase and rare olivine are typically < 1mm in size [*Cleghorn et al*., 1985].

3. Ice contact produces a mosaic pattern of cooling joints along the flow margin. This feature is of paramount importance because it allows for easy initial extraction of a volume of massive rock that already has the general form of a large tool, a huge labor saving feature of ice-contact lavas.

Wolfe et al. [1997] documented 4 summit Laupāhoehoe flows with ice-contact, mosaic jointed margins (three are shown in Fig. 16). These lavas were not extensively quarried however, presumably because they lacked one or other of the textural characteristics of those that were.

The sheer scale of the quarry operations here argue for this being an export quarry, an interpretation supported by the widespread presence of Mauna Kea adze material in acheological sites throughout Hawai‘i island and also on Maui and O‘ahu. Most of the 23 radiocarbon dates on archeological materials within the Mauna Kea quarry complex cluster between A.D. 1300-1800, but three older ages suggest possible use as early as ~AD 1100.

High-level Carbonates on Kohala

Stearns and Macdonald [1946] described the widespread presence of “fossiliferous marine conglomerates” along the western side of Kohala. Most are within ~8 m of present sea level, although at least one occurrence just south of Mahukona was described at an elevation of 80 m above present sea level. Although Stearns [1978] generally attributed the presence of such units on Kohala, as well as those on the leeward sides of West Maui, Lāna‘i and East Moloka‘i, to various glacioeustatic marine high sea-level stands, substantial uplift is required to explain some of these deposits at these altitudes, especially those on Lāna‘i and Moloka‘i, by this mechanism. An alternate hypothesis that has gained some level of acceptance is that these deposits are a consequence of catastrophic giant waves (megatsunami) generated by prehistoric large submarine landslides [e.g., *Moore and Moore*, 1984; 1988].

The megatsunami hypothesis remains especially controversial for the islands of Lāna‘i and Moloka‘i, where geochronologic and sedimentological studies dispute the catastrophic deposition interpretation [*Rubin et al*., 2000; *Felton et al*., 2000], and where the uplift history is questionable [e.g., *Grigg and Jones*, 1997]. However, the deposits on Kohala are somewhat less controversial because the question of uplift is made moot by the ongoing subsidence that has characterized Hawai‘i Island since its emergence. McMurty et al. [2004] employed corrections based on modern rates of subsidence, lithofacies analysis, and U-series ages of partially recrystallized carbonate to argue for original deposition altitudes 350-390 m higher than presently found. Those authors attribute the Kohala deposits to a megatsunami with a runup

>400 m, >6 km inland, possibly associated with the ~120 ka Alika 2 landslide from Mauna Loa volcano.

Outcrops of marine carbonate are well developed in the vicinity of Keaweʻula Bay, in a gully near Keawanui Bay, and deposits up to 60 m elevation, ~0.75 km inland in Paoʻo gulch.

Kawaihae to Keāhole via Rte 19

Kawaihae is close to the contact between Kohala (Hāwī) and Mauna Kea.

The junction between Rtes 270 and 19 occurs in 64-300 ka (Hāmākua) lavas from Mauna Kea. Mileages given below are from this intersection.

2.1 miles, turnoff to Hāpuna Bay State Recreation Area

5.5 miles, the road crosses the contact with 11-64 Ka Laupāhoehoe lavas from Mauna Kea.

6.3 miles, boundary of lavas from Mauna Loa, mostly in the range 3000-5000 years old with locally younger (1500-3000 year-old) Mauna Loa lavas near the road to the Mauna Lani resort and Puakō Petroglyph Preserve.

8.0 miles, junction with Waikoloa Road on prehistoric, 3000-5000 year old Mauna Loa lavas

9.1 miles, turnoff to ʻAnaehoʻomalu Bay and a bunch of hotels. ʻAnaehoʻomalu beach used to be a nice place.

~11.1 miles, road crosses contact with ʻaʻā of the 1859 Mauna Loa lava, which is about 0.5 miles wide here. See discussion and map on p. 16.

11.6 miles, contact of 1859 ʻaʻā with 11,000 – 30,000 year-old Mauna Loa lavas

12.1 miles, contact with the younger pāhoehoe lava of the 1859 Mauna Loa eruption. Along this stretch there are pieces of the older prehistoric pāhoehoe surface that became incorporated into, and rotated up onto the 1859 pāhoehoe [*Rowland*, 1987].

14.1 miles, Scenic Lookout **STOP** (mileage marker 82)

This area is close to a contact between older (5000-11,000 year-old) and younger (3000-5000 year-old) Mauna Loa lavas. Excellent views of Kohala, Hualālai and Haleakalā. Kiholo Bay is bound on the north by the Mauna Loa 1859 lava, and on the south by the Hualālai Kaʻūpūlehu lava.

Whole Lotta Shakin' Goin' On

There are nine Hawaiian earthquakes in the historical record with magnitudes of 6.5 or greater. Four of these, including the 3 biggest with magnitudes between 7.0 and 7.9, are associated with slumping on the southeast sides of Kīlauea and Mauna Loa; there also was a M=6.7 event on the Kaʻōiki fault system in 1983. All of the remaining five occurred either in the Kona region (Figure 20) or farther to the northwest (M=6.8 north of Maui in 1938, and M=6.8, near Lānaʻi in 1871).

Just after 7 AM (local time) on Sunday October 15, 2006 the state of Hawaiʻi received yet another reminder that strong earthquakes can affect regions well beyond the island of Hawaiʻi. The M=6.7 earthquake was unusually deep, at almost 40 km, centered near Kiholo Bay. Unlike the 1929 events, which were likely associated with magma intrusion into Hualalai's northwest rift zone, the 2006 event, and earlier strong earthquakes in Kona and the Maui region, were probably associated with forces related to island subsidence. The intensity and shake maps for the 2006 event are generally similar to the reconstructed intensities of the 1929 event (Figure 20). Structural damage was especially severe in the Kona and Kohala regions of the Big Island, including collapse of walls in a 1855 church in Hāwī, damage to hospital and school in Kapa'au, condominiums and a school in Waikoloa, the Mauna Kea Beach Resort, and severe cracking of the 1838 Hulihe'e Palace in Kailua Kona. Power outages plagued much of the state for the remainder of the day. Total estimated damages from this event are ~$200 million.

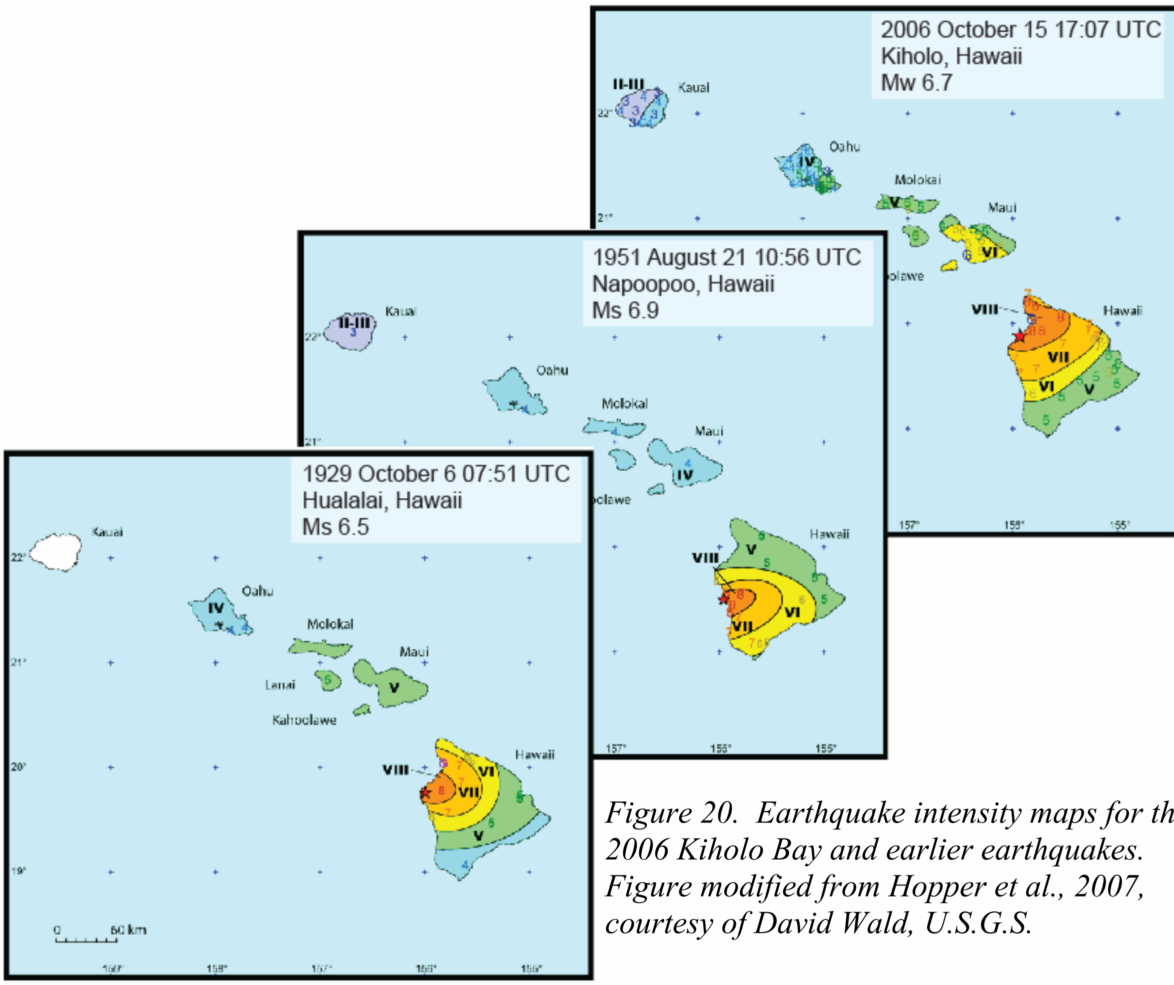

Figure 20. Earthquake intensity maps for the 2006 Kiholo Bay and earlier earthquakes. Figure modified from Hopper et al., 2007, courtesy of David Wald, U.S.G.S.

Optional Side Trip: Kiholo Bay and Luahinewai anchialine pond on edge of Ka'ūpūlehu lava field (q.v.)

~15.9 miles, here we are on the late-18th century(?) Ka'ūpūlehu lava erupted form the northwest rift zone of Hualālai. This location also is known to host xenoliths within the prominent lava channel. Want some?

23.4 miles – **Optional Stop**: lava tube in Hu'ehu'e lava. Just before here is road leading down to Kekaha Kai (Kona Coast) State Park, and Mahai'ula

27.9 airport access road

Optional Stop: Kaloko-Honokōhau State National Historic Park. Coastal areas, fishponds, archeological remnants, Hale o Mano heiau and other good cultural stuff.

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