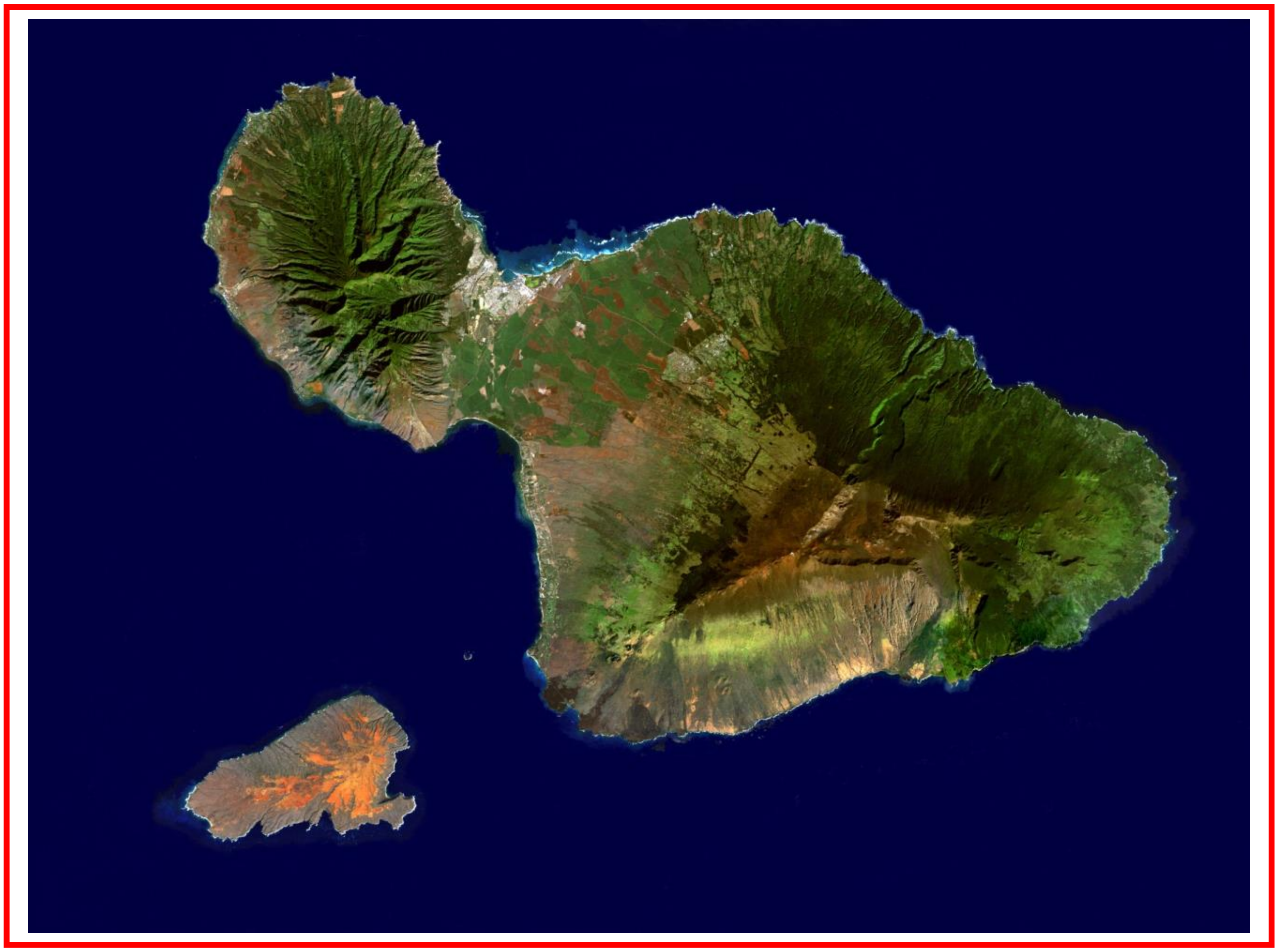
MAUI FIELD TRIP



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Cover image: Landsat 7 mosaic; courtesy of NASA Hawai‘i Infomart Project

Introduction

The following describes field excursions of geological interest on the island of Maui, Hawaiʻi. These excursions can be done in almost any sequence or direction of travel. Aspects of Hawaiian volcano evolution, structure, and petrology are emphasized. To do all of the excursions requires four or more full days, depending on the speed, energy and enthusiasm of the field tripper. A circle trip around West Maui, the older of the two volcanoes that make up the island, is described in the first excursion, along with notes on the Quaternary deposits found on the isthmus that separates West Maui and East Maui volcanoes. Trips on East Maui Volcano include Haleakalā Crater, the upper SW rift zone, and the lower SW rift zone. Other stops of geological interest, particularly along the road from Kahului to Kaupō via Keʻanae and Hāna (E. Maui) are accessible by private automobile. Suggested stops along this road are given in *Stearns* [1942a]. This guide relies heavily on work by *Stearns and Macdonald* [1942], *Macdonald and Katsura* [1964], *Macdonald and Powers* [1968], *Macdonald* [1978], *Kyselka and Lanterman* [1980], *Pukui et al.* [1981], *Diller* [1982], *Sinton et al.* [1987], *Bergmanis* [1998], *Sterling* [1998], *Bergmanis et al.* [2000], *Sherrod et al.* [2003; 2007] and unpublished data from a variety of sources.

The life cycle of most Hawaiian volcanoes is generally considered to involve four main eruptive stages: 1) an early submarine (seamount) stage (Lōʻihi is the only known presently active example); 2) the main subaerial shield-building stage; 3) an alkalic, postshield "capping" stage, and 4) in some cases a rejuvenated stage of alkalic basalts that generally accounts for <1% of the total volume. Not every Hawaiian volcano goes through all of these stages, however. It was previously thought [e.g. *Stearns and Macdonald*, 1942; *Macdonald et al.*, 1983] that both Maui volcanoes went through all three of these stages. Later study of East Maui [*Sherrod et al.*, 2003] showed that there was no discernible quiescent period separating the Kula and Hāna Volcanics, which also appear to share similar magma compositions, and therefore the status of Hāna Volcanics has been revised from rejuvenated-stage to a later, post-erosional period of postshield volcanism.

Geology of Maui

The island of Maui is part of a large complex of volcanic edifices that includes West and East Maui, Lānaʻi (~1.5-1.2 Ma), Kahoʻolawe (~1.4-0.9 Ma), West Molokaʻi and Penguin Bank (2.1-1.6 Ma) and East Molokaʻi (1.8-1.3 Ma) (Fig 1). This large complex, commonly referred to as Maui Nui (greater Maui), would have been a single emergent island prior to recent subsidence and during low stands of the sea accompanying glacial maxima. Its maximum areal extent was about 1.2 million years ago, when it was larger in areal extent than the present-day Big Island (Price and Elliot-Fisk, 2003). The island of Maui consists of two separate volcanoes.

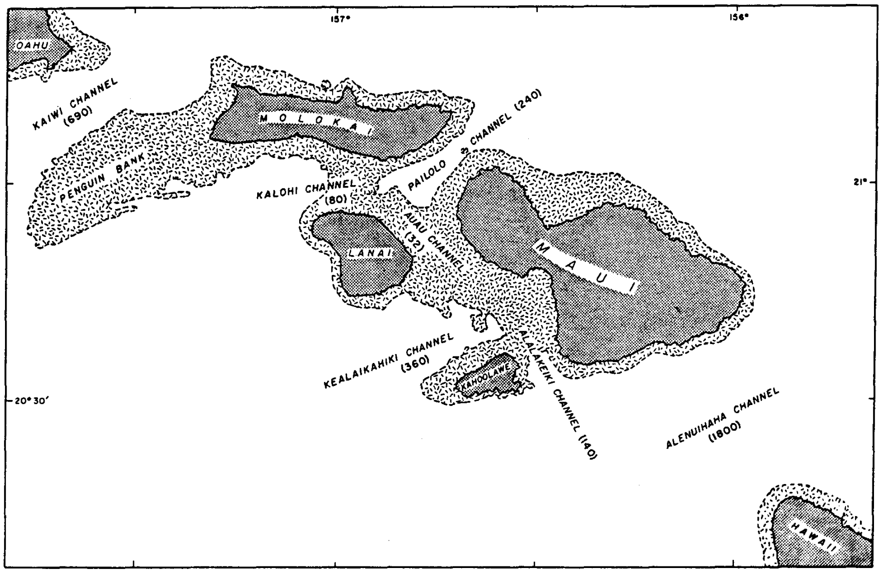

Figure 1. Map of Maui Nui, showing the individual islands of the Maui Group (from *Macdonald et al.*, 1983). The shaded region shows areas shallower than 180 m depth.

West Maui is the older of the two volcanoes that make up the island of Maui. Shield lavas comprise the Wailuku Basalt, ranging in age from about 1.6 – 1.3 Ma; postshield lavas of West Maui are the Honolua Volcanics, ~1.3 – 1.1 Ma [*McDougall*, 1964; *Naughton et al.*, 1980; *Sherrod et al.*, 2007]. A period of quiescence of approximately 0.5 Ma separates Honolua Volcanics from the rejuvenated-stage, post-erosional lavas of the Lahaina Volcanics (~0.6-0.4 Ma [*Tagami et al.*, 2003]).

Exposures of shield lavas of East Maui Volcano (Honmanū Basalt) are mainly limited to deep valleys on the northern side of the volcano; limited age data suggest that the shield stage had ended by about 0.95 Ma. [*Chen et al*., 1991], beginning a protracted period of postshield activity. *Stearns and Macdonald* [1942] distinguished post-erosional Hāna Volcanics from earlier Kula Volcanics, and assigned the Hāna to the rejuvenated stage, suggesting a volcanic quiescence of several hundred thousand years. However, K-Ar data by *Sherrod et al*. [2003] indicate that, although postshield activity on East Maui declined after about 0.65 Ma, it continued without significant hiatus to the present. Thus, both Kula and Hāna are now considered to be early and later manifestations of postshield activity of East Maui Volcano.

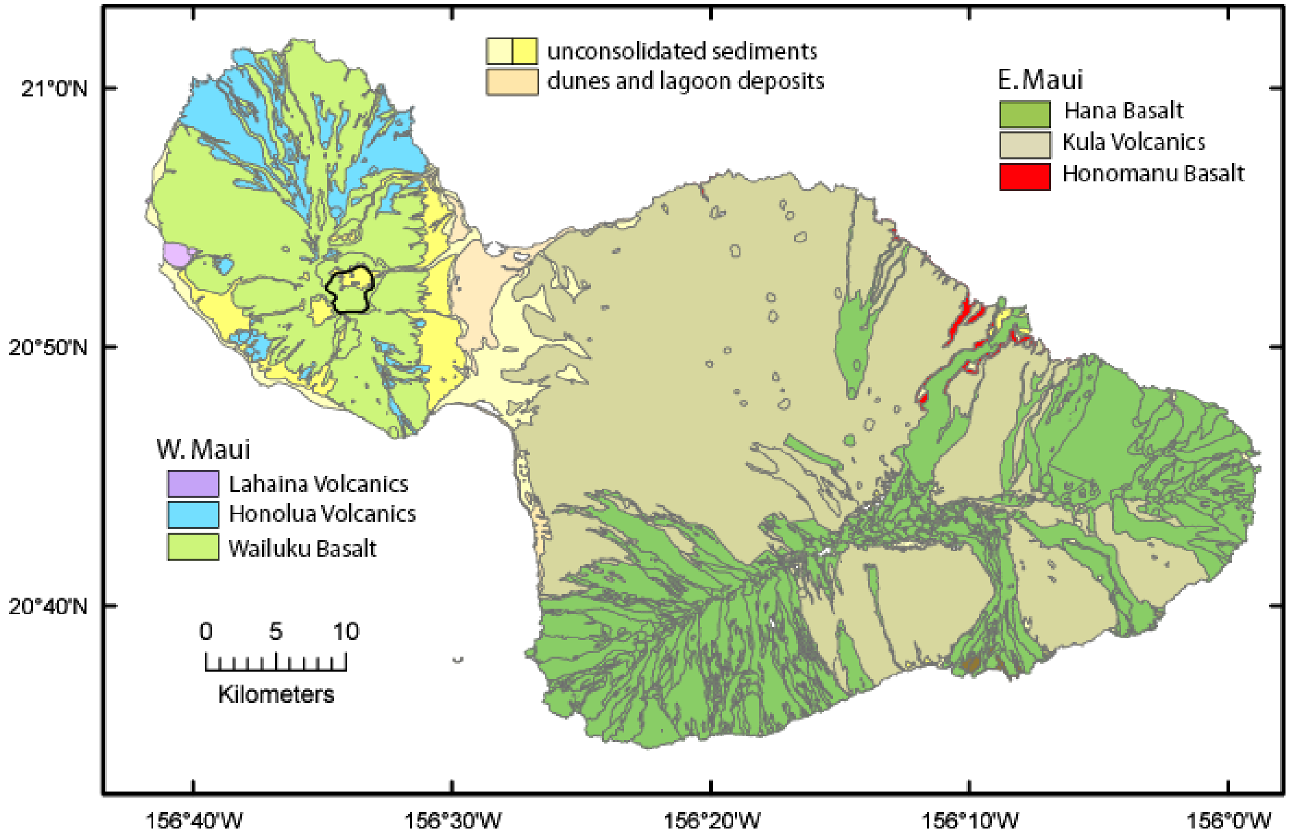

Figure 2. Geologic map of Maui, after Sherrod et al. [2007b], modified from *Stearns and Macdonald*, [1942] and *Bergmanis et al*. [2000].

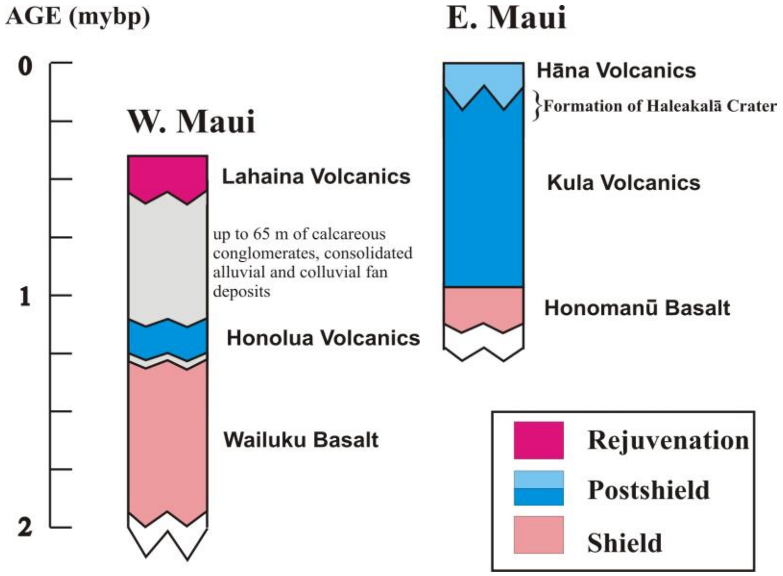

Figure 3. Stratigraphic time lines for Maui, based on data from *Macdougall* [1964], *Naughton et al*. [1980], *Chen et al*. [1991], *Sherrod and McGeehin* [1999], *Bergmanis et al*. [2000], *Sherrod et al*. [2003] and *Tagami et al*. [2003].

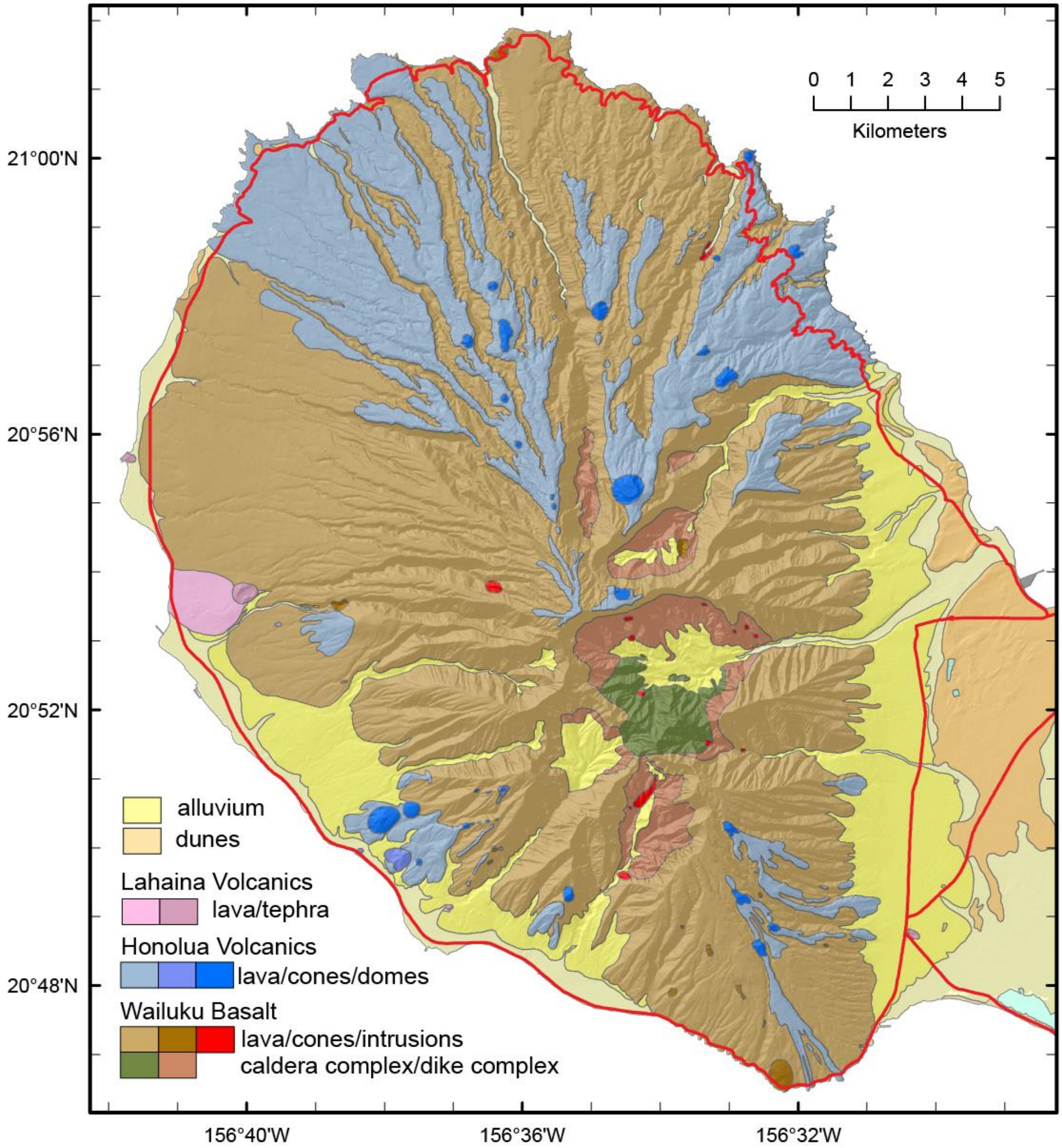

Figure 4. Geologic map of West Maui Volcano (after *Stearns and Macdonald* [1942].

Structure and Geologic History of West Maui Volcano

West Maui volcano is an asymmetric dome, elongated NW-SE (Fig. 4). *Stearns and Macdonald* [1942] mapped a central caldera, roughly coinciding with ‘Iao Valley. Lava flows dip outward from the caldera region at angles of 10-20°, somewhat steeper than is typical for most Hawaiian shield volcanoes. Although a few faults not associated with the caldera are locally exposed, such faulting is of limited extent and insignificant to the development of the volcano. *Stearns and Macdonald* [1942] identified two rift zones, extending NW and SE from the caldera region, and *Macdonald and Abbott* [1970] suggested the existence of a third rift zone extending NE from the caldera (Fig. 5). The NW and SE rift zones are defined by an abundance of basaltic dikes striking parallel to those zones and by the overall morphology of the edifice. The NE rift zone marks the location of Honolua dikes and vents that are distributed in two broad, cone-shaped regions radiating generally to the NE and SW of the caldera.

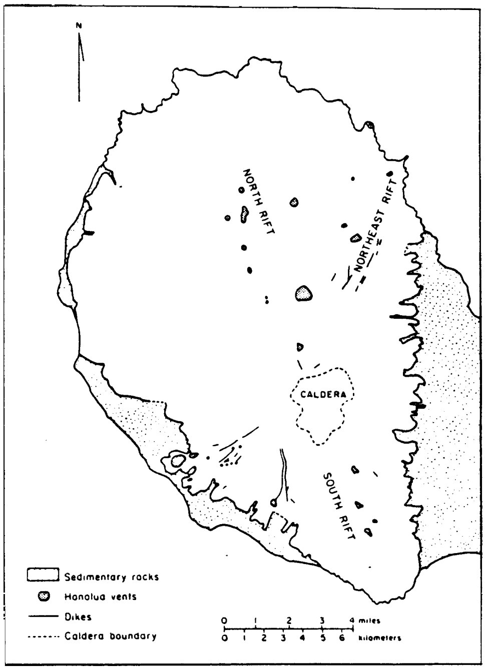

Figure 5. Principal rift zones of West Maui as defined by dike and vent concentrations (from Macdonald et al., 1983)

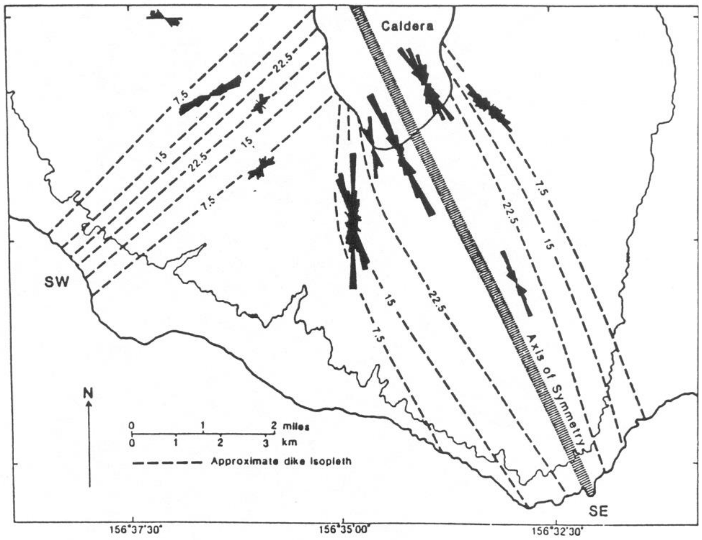

Figure 6. Dike isopleths in intervals of 7.5 dikes/100 m along traverses in the SW part of West Maui. Rose diagrams for various areas indicate dike orientations scaled according to the number of measurements taken, not the number of dikes present (from *Diller* [1982]).

Diller (1982) undertook a detailed investigation of the southwestern part of West Maui, where thousands of dikes are exposed. Dike abundances can be approximated by isopleths that define two prominent zones, a wider and better developed SE rift, and a SW zone (Fig. 5), the latter one complementary to the NE rift zone suggested by *Macdonald and Abbott*. Although the SW zone is clearly defined by the dike data, the lack of a pronounced topographic expression suggests that this zone constituted only a minor locus of activity during most of the history of the volcano. The abundance of late Honolua trachytes and benmoreites distributed along the NE and SW zones (Fig. 4) suggests that this orientation might have been increasingly favored for magma injection and eruption in the later stages of postshield activity. *Diller*, invoking the model of *Fiske and Jackson* (1972) for the development of Hawaiian rift zones, suggested that the rift zones of West Maui evolved from NW-SE during early growth of the volcano, to NE-SW in later stages as the least principal stresses migrated in response to buttressing by growing neighbor volcanoes, principally East Maui (Fig. 7).

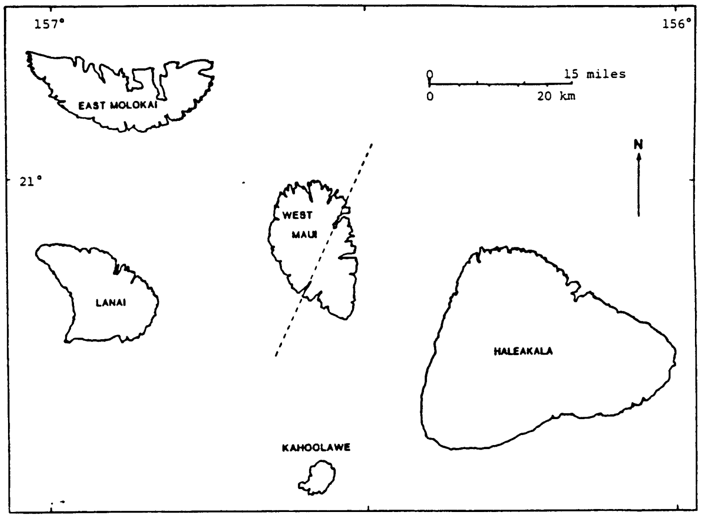

Figure 7. The 1000' (305 m) topographic contour of the islands of the Maui group. The dashed line across West Maui shows the preferred rift orientation once East Maui started to grow. This orientation roughly corresponds to the NE-SW zone of West Maui (from *Diller*, 1982).

Radiometric ages from the Wailuku Basalt range about 2 to 1.3 Ma (Fig. 8). Most Wailuku Basalt have reversed polarity magnetization, suggesting that the exposed section is likely younger than the Olduvai Normal-Polarity subchron, ~1.8 Ma. Postshield Honolua Volcanics range from 1.3 to 1.1 Ma. Of the four Lahaina Volcanics eruptions, two were erupted ~0.6 Ma, and the other two ~0.3 Ma (Tagami et al., 2003) (Fig. 8).

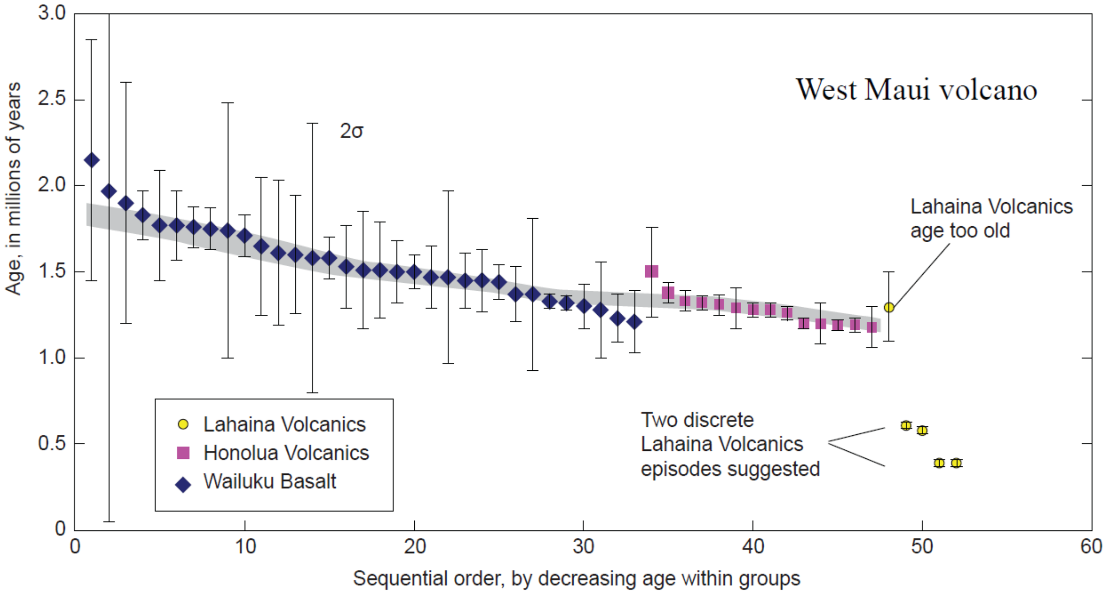

Fig. 8. Radiometric ages from West Maui volcano, from Sherrod et al., 2007b. Gray band shows likely range of ages across the suite. Data from McDougall, 1964; Naughton et al., 1980; Tagami et al., 2003; and Sherrod et al., 2007a.

Petrological Evolution of West Maui Volcano

The shield stage of West Maui is represented by the **Wailuku Basalt**, mainly consisting of thin-bedded pāhoehoe flows comprising more than 90% of the subaerial shield. ‘A‘ā flows and discontinuous beds of vitric tuff are dispersed throughout the exposed section, but become increasingly common in the later stages of shield activity. Lowermost Wailuku Basalts are aphyric to moderately olivine-phyric tholeiitic basalts. Total phenocrysts and the relative proportions of plagioclase and clinopyroxene as phenocryst phases increase in the uppermost Wailuku flows. *Diller* [1982] identified a ~50 m-thick Upper Member of the Wailuku Basalt, based mainly on phenocryst assemblages. The upper member has larger and more abundant olivine and plagioclase phenocrysts, accompanied by an increasing proportion of clinopyroxene phenocrysts greater than 1 mm in size. He also noted an increase in the number of ‘a‘ā flows nearly coinciding with the appearance of clinopyroxene as a phenocryst phase, along with an increase in the abundance of vitric tuffs, alkalic lithologies including hawaiites, and ultramafic xenolith-bearing flows (Fig. 8).

Three chemical “types” defined on the basis of variations in alkalicity and degree of silica saturation occur within the Wailuku Basalt. (Table1). The transition from tholeiitic to alkalic basalts occurs in the Upper Member. Although there is a general tendency for an increase in alkalic lithologies up-section, tholeiitic, transitional, and alkalic basalts are randomly interbedded in the Upper Member. Increasing FeO, TiO_2 and alkali concentrations with decreasing Mg# from tholeiitic to alkalic (Table 1), as well as the increase in phenocryst abundances and proportions of ‘a‘ā flows indicate that alkalic lavas are more differentiated and had lower eruption temperatures than did tholeiitc lavas. The generally less differentiated and more uniform nature of the tholeiitic lavas suggest eruption from moderately large, more-or-less homogenized, probably steady-state magma chamber(s). Evidence for significant time breaks between eruptions of the lower Wailuku Basalt is lacking; the early shield stage is characterized by high eruption frequencies and by high magma supply rates to crustal magma chambers.

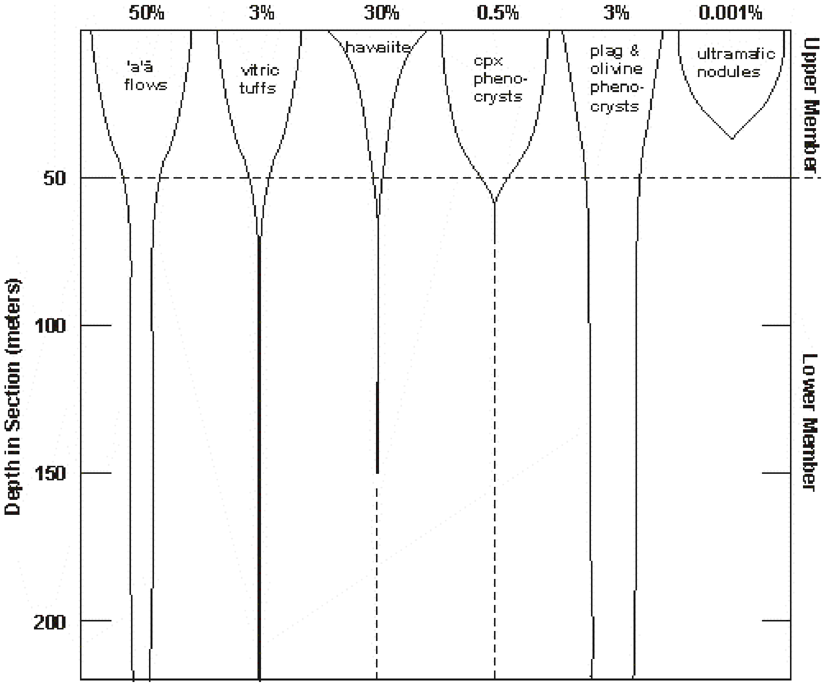

Figure 9. Schematic profiles through the upper part of the Wailuku Basalt, depicting changes in the relative abundances of ‘a‘ā flows, tuff beds, hawaiite, phenocryst phases and ultramafic xenoliths in the upper 50 m. Approximate maximum absolute values are indicated at the top of each profile. These variations constitute the basis for designating the Upper Member of the Wailuku Basalt (from *Diller*, 1982; *Sinton et al.*, 1987).

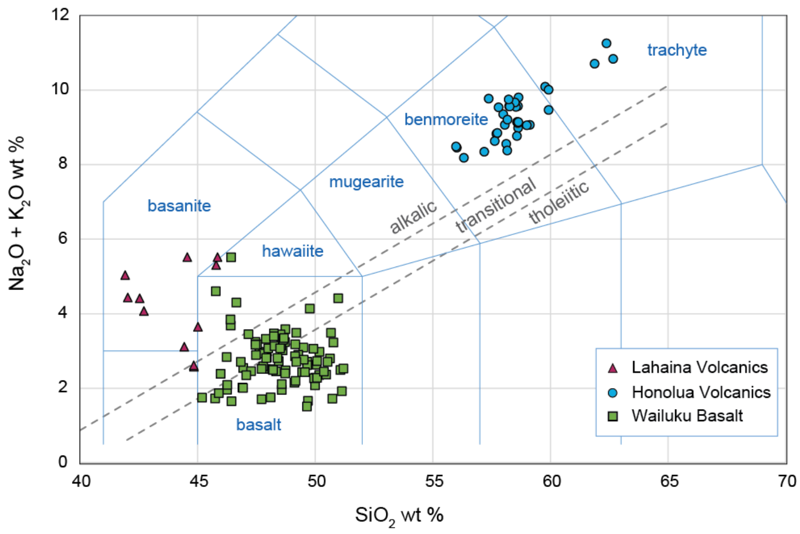

Figure 10. Alkali-silica diagram for West Maui volcanic rocks. Data from Macdonald and Katsura, 1964, Macdonald, 1968; Diller, 1982; Tagami et al., 2003; Gaffney et al., 2004; Sherrod et al., 2007; and Sinton (unpublished)

Olivine in Wailuku basalts are in the range Fo 81-88 (Fig. 11). Most plagioclase in Wailuku basalts are An 70-80, but Na-rich rims on these feldspars extend the range of analyzed plagioclase to An 51 (Fig. 11). Augite in Wailuku tholeiites have composition $\mathrm{Wo}_{36-42}\mathrm{En}_{46-51}\mathrm{Fs}_{10-16}$. Transitional Wailuku basalts have slightly more calcic compositions, ranging from $\mathrm{Wo}_{40-45}\mathrm{En}_{42-48}\mathrm{Fs}_{9-17}$ (Fig. 11).

The transition to alkalic lithologies in the Upper Member likely represents a decrease in the extent of partial melting of upwelling mantle during this time. Field evidence indicates a decrease in eruption frequency and an increase in explosivity of late Wailuku eruptions relative to earlier shield activity. Thus the latest shield-building activity at West Maui Volcano can be generally characterized by:

1. A decrease in the extent of melting giving rise to lower volumes of relatively incompatible element-enriched magmas, and
2. Longer residence times in smaller, probably deeper, magma bodies, along with less frequent eruptions from these reservoirs yielding more variable, but generally more differentiated erupted lithologies.

Stearns and Macdonald [1942] suggested that a significant erosional unconformity separates Wailuku from postshield **Honolua Volcanics** at West Maui. Although local unconformities are present, *Diller* [1982] suggested that a time break between the Wailuku and Honolua lavas may be no longer that the increasingly common eruptive hiatuses in the Upper Wailuku, a conclusion supported by radiometric dating of *Sherrod et al*. [2007].

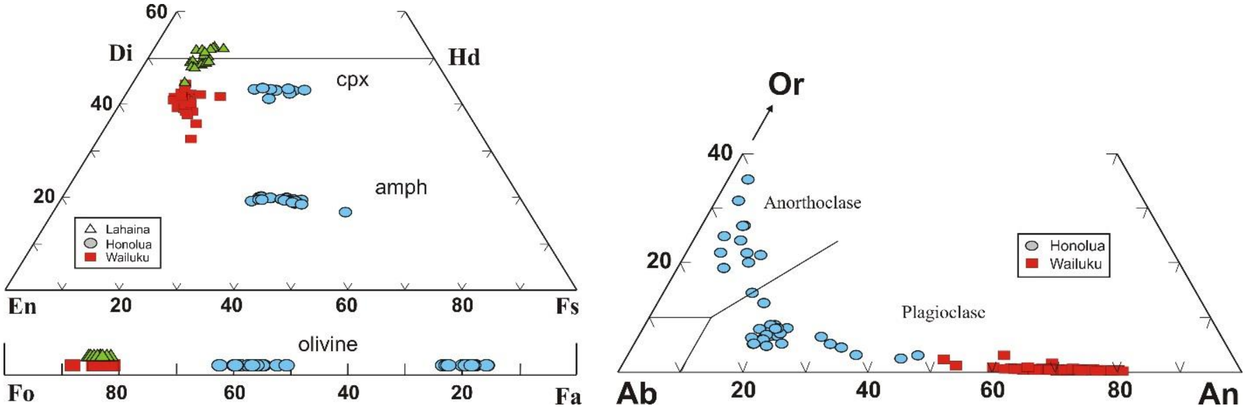

Figure 11. Olivine, clinopyroxene and amphibole (left) and feldspar (right) mineral compositions in West Maui volcanic rocks. (analyses by E.Lohnert)

Honolua Volcanics are lithologically distinct from Wailuku lavas. Analyzed Honolua lavas are benmoreites and trachytes with differentiation indices (D.I.) >65. Olivine compositions in two analyzed Honolua lavas range from Fo16 - 62, and clinopyroxene compositions are in the range $Wo_{41-43}En_{27-34}Fs_{23-30}$ (Fig. 11). Plagioclase ranges from andesine (An 46) through oligoclase to anorthoclase (Fig. 11). Despite their highly differentiated compositions, most Honolua lavas lack hydrous minerals, containing only olivine, clinopyroxene, feldspar and iron oxides. However, some highly differentiated trachytes contain a pale brown igneous amphibole, (see notes for the Kahakuloa stop, below). Trachytes are relatively rare in Hawaiʻi. Other than West Maui, only Hualālai contains significant trachyte, although one trachyte dike also is known from East Maui. In general, West Maui is the most uniformly differentiated postshield cap in the Hawaiian Islands.

Honolua lavas typically are massive ʻaʻā or block lava flows ranging from about 10 to 50 meters thick. A well-developed flow foliation is apparent in most flows, indicating generally high magma viscosities. Many Honolua eruptions produced endogenous domes and plugs. Pyroclastic deposits surrounding Honolua vents are not extensive, but would be easily eroded. Presumably dome emplacement was accompanied by at least moderately explosive activity.

Analysis of the outcrop pattern of Honolua Volcanics (Fig. 4), and allowing for removal by erosion of a significant number of exposures, suggests that this unit could have been formed by as few as 40-60 eruptions. The range of dated Honolua Volcanics spans about 150,000 years, indicating a crude eruption frequency of approximately one every 2,500-3,800 years. Despite considerable uncertainties in estimating the total number of Honolua eruptions, the exercise suggests a decrease of at least two orders of magnitude in eruption frequency from shield to postshield time. The generally high degrees of differentiation attained by Honolua magmas prior to eruption largely reflects this low eruption rate, and indicates moderately long residence times of fractionating magmas prior to eruption. Obviously these fractionating magma batches were not frequently replenished during this residence and thus, Honolua time represents a waning magmatic stage in which lower magma production rates, infrequent eruptions and long residence times of magma batches led to the development of highly differentiated, alkalic magmas.

Table 1. Average Compositions of West Maui Volcanic Rocks

	WAILUKU LAVAS			HONOLUA LAVAS	LAHAINA LAVAS			
	Tholeiitic Basalts	Transitional Basalts	Alkalic Lavas		Pu‘u Hele	Pu‘u Kīlea	Laina	Keka‘a Pt.
SiO_2	49.51	47.82	46.90	56.69	42.72	45.69	44.90	41.76
TiO_2	2.68	2.80	3.99	1.38	3.14	2.28	2.00	2.76
Al_2O_3	13.83	13.11	14.19	17.29	11.42	13.53	11.89	11.66
FeO*	11.77	12.57	14.48	7.34	13.77	12.21	12.96	14.09
MnO	0.17	0.18	0.20	0.21	0.18	0.19	0.18	0.21
MgO	7.31	9.68	6.29	1.23	12.69	10.17	14.39	11.78
CaO	10.94	10.19	9.44	3.60	11.74	9.64	10.90	11.58
Na_2O	1.59	1.66	2.32	6.22	2.82	3.78	2.00	3.26
K_2O	0.29	0.40	0.72	2.50	1.25	1.52	0.61	1.15
P_2O_5	0.32	0.38	0.58	0.86	0.48	0.59	0.27	0.85
LOI	1.37	1.05	0.58	1.58	0.01	0.21	0.12	0.65
Total	99.78	99.83	99.68	99.50	100.21	99.81	100.22	99.74
trace elements (ppm)								
Sc	33	30	27	5	25	22	26	23
V	279	269	316	6	332	215	266	297
Cr	357	492	149	5	600	471	703	591
Ni	157	287	112	10	367	272	446	316
Zn	121	126	150	154	126	139	112	154
Sr	373	425	545	1158	707	932	409	1092
Zr	173	202	283	719	193	253	117	209
Nb	12	17	24	84	49	61	22	52
Ba	111	141	216	752	584	859	272	801

The **Lahaina Volcanics** consists of the products of four small basanitic, post-erosional eruptions at Pu‘u Hele (no longer visible), 4.5 km NNE of McGregor Point, Pu‘u Kīlea in Olowalu Valley, Pu‘u Laina near Lahaina, and at Keka‘a Point on the coast about 6 km north of Lahaina (Fig. 4). The flow from Pu‘u Laina has the greatest volume, is the least differentiated, and has substantially lower normative nepheline than the other three. Lahaina volcanism represents a volumetrically insignificant phase of activity at West Maui. The distribution of known vents bears no relation to the rift zones along which Wailuku and Honolua eruptions were concentrated, as is typical for rejuvenation stage volcanics in the Hawaiian Islands. K-Ar dates [*Tagami et al*., 2003] indicate that the four Lahaina eruptions all occurred between 385,000 and 610,000 yrs ago. Lahaina Volcanics do not contain plagioclase; olivine ranges from Fo 81-85. Clinopyroxenes are extremely calcic, ranging to salite compositions (Fig. 11). As is the case for most rejuvenation stage volcanics in Hawai‘i, Lahaina Volcanics formed by melting of mantle sources with lower $^{87}Sr/^{86}Sr$ than that for shield and postshield volcanics (Fig. 12).

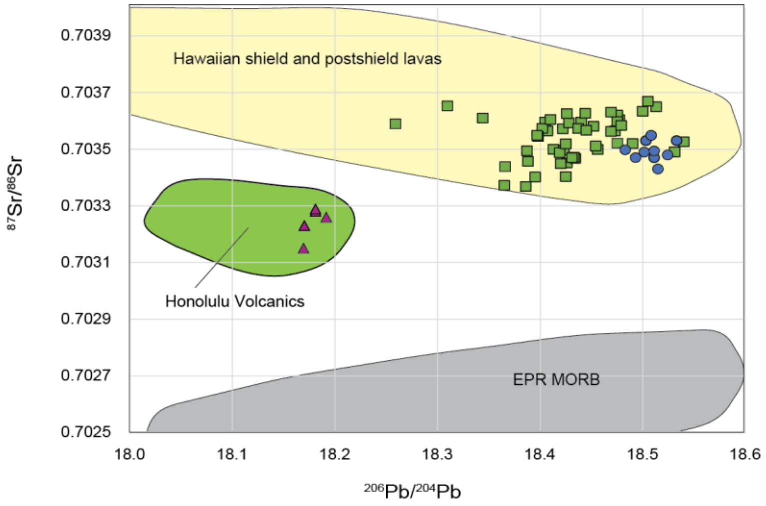

Figure 12. $^{87}Sr/^{86}Sr$ versus $^{206}Pb/^{204}Pb$ for West Maui volcanic rocks, compared to similar data from elsewhere in the Hawaiian chain. Data from *Tatsumoto et al*. [1987]; Gaffney et al., 2003; and *Chen and Sinton* [unpublished].

TABLE 2. Chemical Analyses of Selected West Maui Volcanic Rocks

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
SiO_2	58.08	45.08	45.69	58.07	41.76	54.96	47.38	46.55	48.50	62.15
TiO_2	1.06	2.65	2.28	1.20	2.76	1.61	4.39	4.76	3.88	0.62
Al_2O_3	18.59	12.02	13.53	17.74	11.66	17.60	13.47	14.47	13.56	17.52
FeO*	6.46	12.80	13.21	6.33	14.09	8.23	15.08	15.23	14.00	4.94
MnO	0.24	0.18	0.19	0.27	0.21	0.18	0.20	0.19	0.19	0.27
MgO	1.95	12.75	10.17	1.33	11.78	1.36	5.36	5.52	6.38	0.52
CaO	3.33	9.42	9.64	3.27	11.58	4.26	9.74	8.72	9.93	1.64
Na_2O	6.75	1.39	3.78	7.03	3.26	5.99	2.46	2.78	2.09	7.38
K_2O	2.80	0.22	1.52	2.68	1.15	2.31	0.78	0.97	0.37	3.37
P_2O_5	0.54	0.36	0.59	0.58	0.85	1.15	0.59	0.72	0.55	0.17
LOI	0.28	2.93	0.21	0.86	0.65	1.89	0.16	0.00	0.49	0.82
Sum	100.08	99.78	99.81	99.37	99.74	99.53	99.61	99.51	99.95	99.39
Trace elements (ppm)										
Sc	6	32	22	6	23	5	30	23	31	2
V		245	215		297	10	383	318	350	0.1
Cr		930	471		591	11	37	8	160	11
Ni	2	462	272	2	316	15	52	65	124	4
Zn	133	127	139	118	154	166	159	158	153	150
Sr	1096	413	932	1076	1092	1251	504	585	454	478
Nb	85	18	61	83	52	79	24	29	23	103
Ba		152	859		801	846	206	243	133	865

FeO* = total Fe as FeO
LOI = loss on ignition at 900°C

1. Honolua lava, McGregor Point; C-92
2. Wailuku basalt, McGregor Point, WM-2
3. Lahaina basanite, Pu‘u Kīlea, WM-4
4. Honolua benmoreite, Launiupoko, WMLP-100
5. Lahaina basanite, Keka‘a Point, WM-7
6. Honolua mugearite, Līpoa Point, WM-24
7. Wailuku basalt, Honoanana Gulch, WM-32
8. Wailuku basalt, Hononana Gulch, WM-34
9. Wailuku basalt, Hononana Gulch, WM-36
10. Honolua trachyte, Pu‘u Koa‘e, WM-21

Itinerary

The following itinerary starts at Kahului Airport, **mile x** refers to mileage of the field trip.

mile 0 - Kahului Airport

From Kahului Airport, follow Route 380 west toward Kahului. Turn right on Route 37 and then merge left onto Route 36 (**mile 1.6**). Merge left onto Ka‘ahumanu Avenue, Route 32. Ka‘ahumanu Avenue cuts through Pleistocene semi-lithified calcareous dune deposits near Maui Community College.

mile 5.6

The road enters ‘Iao Valley at an elevation of 300 meters. There are two alluvial terraces in the valley, the first formed when the sea stood about 30 meters higher than it does today. Later, when sea level began dropping, ‘Iao Stream cut down into its own alluvial deposits, leaving the lower terrace. Farther along this road are cuts through lava flows of the Wailuku Basalt, the main shield-building member of West Maui volcano.

mile 7.3 Kepaniwai

Caldera-fill talus breccias with steep dips are here plastered onto the ancient caldera walls. Kepaniwai is the site of a battle between two powerful Hawaiian chiefs in 1790. Kalanikupule was ruling Maui while his father, Chief Kahekili, was on O‘ahu attempting to put control of all the islands under his command. However, the young upstart from Kona, Kamehameha, aided by recently arrived haole ships and guns, landed on Maui and defeated Kalanikupule at Kepaniwai. ‘Iao Stream was choked with human bodies after the slaughter there, and hence the name *Kepaniwai* (the water dam). Kalanikupule escaped by climbing the steep trail at the western head of ‘Iao Valley, and descending the other side into Olowalu. He fled by canoe to O‘ahu. In 1795 Kamehameha and Kalanikupule met once more, this time at Nu‘uanu on O‘ahu, and Kalanikupule was once again defeated, and this time killed. Wailuku (*water of destruction*), where the battle began, derives its name from this battle.

mile 7.7 - ‘Iao Needle - STOP 1

The visitor’s parking lot is situated near the intersection of ‘Iao Stream and Black Gorge, inside the remnant of the old West Maui caldera. ‘Iao Valley is a spectacular, amphitheater-headed valley that roughly marks the old caldera, enlarged by erosion.

Conglomerates are exposed in the stream below the footbridge leading to the observation shelter, with its excellent views of ‘Iao needle. The needle is actually a narrow ridge viewed head-on. It is an erosional remnant of Wailuku basalt flows cut (and probably supported) by dikes. *‘Iao* means supreme point or reaching (to the) sky. Probably this name is post-missionary in origin, as the earlier Hawaiian name for ‘Iao needle, Kūkae moku, can be translated loosely as “broken turd”. Apparently the ancient Hawaiians recognized the residual nature of this landform.

An intrusive gabbro is exposed in the east wall of Black Gorge. The discordance between south-dipping talus breccias and northeast-dipping lava flows is evident when looking east from the observation shelter. Several dikes are exposed on the south wall of ‘Iao Valley. Polynesian-introduced kukui (candlenut) and native ‘ōhi‘a lehua trees are abundant in ‘Iao Valley.

Return east on Route 32, back toward Wailuku. Wailuku sits on the alluvial fan from ‘Iao Valley. Turn right on Route 30 (High Street, **mile 10.7**) and proceed to the south along the western edge of the isthmus. Excellent views of East Maui to the east as well as Honolua volcanics (postshield alkalic cap member) domes, flows and cinder cones of West Maui on the skyline to the west, are available from this road.

Waikapū is another deep valley incised into the West Maui volcano. When sea level was lower, Waikapū Stream flowed northward into the ocean at Kahului Bay. Eventually that route was blocked by sand dunes piled up by the wind (probably ~ 100,000 yrs ago), and the stream was diverted southward into Mā‘alaea Bay. Now days, water from Waikapū rarely reaches the ocean; most is diverted for irrigation and the rest simply sinks into the ground. *Waikapū* means “water of the conch”. It is said that Kamehameha the Great once assembled his troops by sounding a conch here.

mile 15.7 (optional side trip)

Just past the junction of Route 38 with Route 30 is the former site of Pu‘u Hele, a 385,000 year-old [*Tagami et al.*, 2003], Lahaina volcanics (rejuvenated stage) cinder cone. It once was about 20 m high but has been extensively quarried. Now it is a hole in the ground twice as deep as it once was high.

mile 18.63 - McGregor Point - STOP 2

McGregor Point is named for Daniel McGregor, a sea captain involved in interisland trade, who made an emergency anchorage in the small sheltered cove here one stormy night, sometime between 1875 and 1887. McGregor Point is the southern end of the south rift zone of West Maui Volcano.

The Honolua lava at McGregor Point is a massive flow of trachytic benmoreite [following *Coombs and Wilkinson* 1969], a differentiated alkalic lava flow of the Honolua volcanics (Analysis 1, Table 2), showing well-developed flow foliation. The vent for this flow is at an elevation of 715 m, about 4 km to the NNW. Petrographically it is typical of Hawaiian benmoreites with abundant microphenocrysts of olivine, oligoclase and rare magnetite, in a trachytic matrix of oligoclase, anorthoclase, and magnetite. This lava has been dated at 1.32 Ma [Sherrod et al., 2007]. At the shore, the benmoreite unconformably overlies Wailuku tholeiitic olivine basalt pāhoehoe flows (Analysis 2, Table 2).

E. Maui, the Maui isthmus, and the single-volcano islands of Kahoʻolawe and Lānaʻi are visible (some days) from McGregor Point; in winter humpback whales can often be seen between here and Lānaʻi. Molokini Islet is an East Maui volcano tuff cone, ~150 ka old. The prominent cinder cone at the coast on the south flank of East Maui is Puʻu Ōlaʻi, a Hāna Volcanics vent.

The next few features are exposed in roadcuts along the highway. Unfortunately there are no safe places to stop along here - traffic is often heavy and is always fast.

<u>mile 19.1</u>

An ash bed up to 1 m thick separates tholeiitic plagioclase-phyric basalt below from alkalic olivine basalt above. This outcrop was originally mapped as interbedded Wailuku and Honolua flows [*Stearns and Macdonald*, 1942], but *Macdonald and Katsura*, [1964] later suggested that the ash bed marks the boundary between the Wailuku and Honolua Volcanics. *Diller* [1982] included both flows in his Upper Member of the Wailuku Basalt. Both flows contain groundmass olivine. These outcrops are typical of late-shield basaltic lavas of many Hawaiian volcanoes, where alkalic lavas and ash beds are increasingly common.

<u>mile 19.3</u>

The road cuts through thin, slabby flows of the Papawai Point lava cone, a Wailuku Basalt vent on the south rift zone of West Maui Volcano.

Figure 13. Thin slabby basaltic layers of the Papawai Point lava cone. This cone section is almost entirely devoid of tephra, suggesting that the eruption lacked significant pyroclastic activity.

<u>mile 19.9</u>

Wailuku lava flows here probably were erupted from the Papawai Cone vent. They contain scattered inclusions of cumulate-textured dunite and olivine megacrysts. The rock is olivine-phyric with microphenocrysts and groundmass grains of hypersthene, along with abundant groundmass olivine.

<u>mile 21.3</u>

The massive olivine basalt ʻaʻā flow here is typical of the Wailuku Basalt Upper Member. It contains large phenocrysts of olivine with less abundant clinopyroxene and rare orthopyroxene. It is transitional to ankaramite; its chemical composition indicates that this flow is tholeiitic to transitional in chemical affinity.

<u>mile 22.9</u> - Ukumehame Valley - STOP 3 (optional)

Ukumehame Valley is a large river-cut valley, the head of which has cut into the West Maui caldera complex to expose a spectacular dike complex. A large, vent-filling trachyte dome and feeder dike are clearly visible (some days) in the west wall of Ukumehame Valley. The remnants of a heiau occur at the mouth of the canyon. An inclined "Maui-type" (inclined shaft) well near the mouth of the canyon yields water with a temperature of 33°C. This, along with 25.5°C water from Olowalu, indicates that there is residual heat in West Maui Volcano.

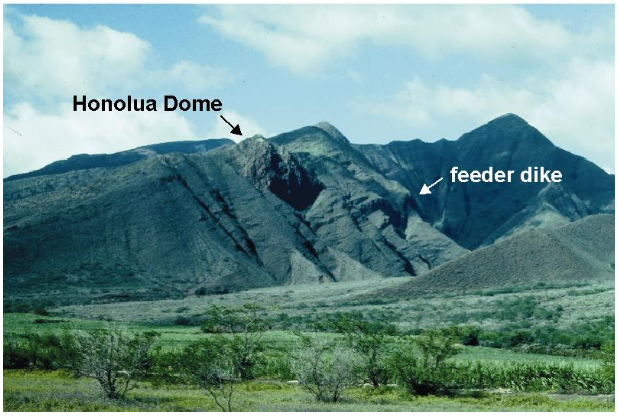

Figure 14. West wall of Ukumeham Valley, showing Honolua trachyte dome and feeder dike, intruding Wailuku basalts.

mile 25.9- Olowalu Turn northeast (ma uka) onto the access road behind the store at Olowalu.

mile 26.6 - Pu'u Kīlea - STOP 4

Olowalu is a wide V-shaped valley cut into the mountains by Olowalu Stream, which built a broad alluvial fan. Later, Lahaina volcanism shattered the fan to build Kīlea cinder cone and its massive basanite lava flow (Analysis 3, Table 2). The rock contains abundant olivine and smaller Ti-augite phenocrysts in a very fine-grained matrix that includes tiny nepheline. The lava has a normal magnetic polarity; *Tagami et al*. [2003] obtained an age of 610,000 yrs for this lava. The "post-erosional" nature of this eruption is evident; it occurs within the mouth of a large valley, and there is thick soil with residual boulders beneath the lava flow. There is a tree mold within the spatter at the base of the cone. The massive character of the lava provides an excellent fracture surface for the production of pre-historic petroglyphs and historic graffiti; examples of both are preserved at this locality. The large, walled Kawaialoa Heiau, measuring 156 x 110 feet used to exist on the rising ground south of Pu‘u Kīlea.

A trail once led past Kīlea cone and up through Olowalu Canyon, across the divide and down into ‘Iao Valley. It was this trail that Kalanikupule used in escaping (temporarily) from Kamehameha after his defeat in ‘Iao Valley. The trail has become all but obliterated, primarily from landslides in more recent times. On orders from Captain Simon Metcalfe in 1790, more than 80 Hawaiians were treacherously killed here and many more were wounded.

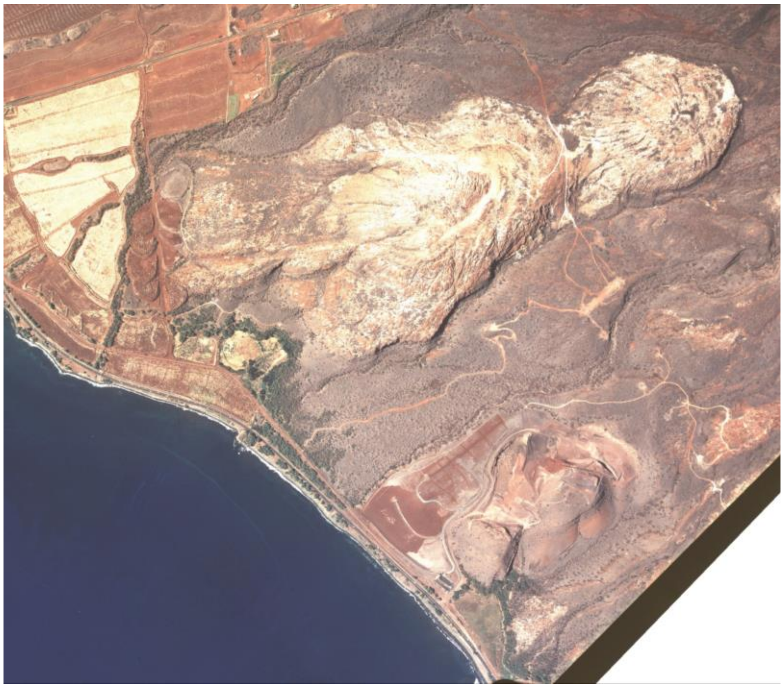

Figure 15. Aerial photograph of region around Launiupoko showing typical, white-weathering Pu‘u Māhanaluanui trachyte dome that formed simultaneously over a SW-trending fissure with another, unnamed dome. See Fig. 15 for flow planes.

mile 27.3

Return to Route 30. Proceed northwest.

mile 28.2 - Launiupoko - optional STOP

A small outcrop of trachyte (Analysis 4, Table 2) that erupted from Pu‘u Māhanaluanui (large twin hills) is exposed on the beach side of the road here. This is part of the possible SW rift zone of West Maui Volcano identified by *Diller* [1982], which is complementary to the NE rift zone suggested by *Macdonald et al*. [1983].

Pu‘u Māhanaluanui trachyte is typical of the late eruptives from the SW rift zone of West Maui Volcano and at 1.19 ± 0.02 Ma [Sherrod et al., 2007] is the youngest West Maui postshield lava yet dated. It contains extremely rare, cumulate dunite xenoliths as well as rare plagioclase and amphibole phenocrysts in a groundmass of oligoclase, anorthoclase, olivine, magnetite, apatite and pale brown amphibole.

Launiupoko is well known for its sharks; local fishermen say this area is a shark breeding ground.

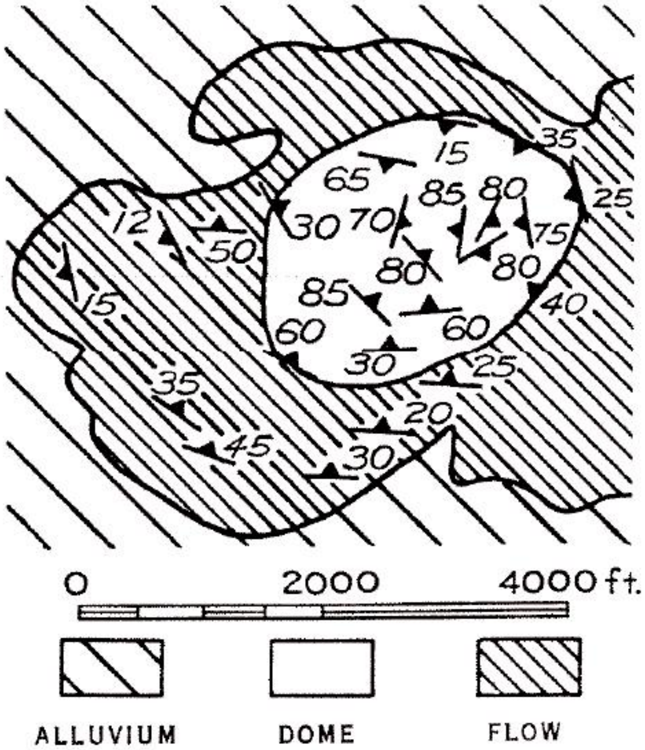

Figure 16. Survey map of flow planes of the Launiupoko dome and flow of Pu‘u Māhanalua Nui. Survey by G. A. Macdonald (from *Stearns and Macdonald* [1942]).

mile 33.0 - Lahaina

Tradition tells of powerful chiefs living here in ancient times. Lahaina was an important whaling port that was the capital of Hawai‘i from 1820 to 1845. American missionaries arrived in 1825 and established the Lahainaluna School, the first school in the islands and the oldest school west of the Mississippi, in the hills to the east in 1831. A well near Lahaina yields 28°C water.

Three heiau, Wailehua, Helekumukalani, and Halulukoakoa, all dating back to (or just prior to) the reign of Kahekili, were built at Lahaina.

About 1.5 miles north of Lahaina the road passes west of Pu‘u Laina, a Lahaina volcanics basanite vent, dated by *Tagami et al*. [2003] at 388,000 years. For a short time it was the home of Pele. More recently the crater has been used as an irrigation reservoir. A lava flow issuing from this cone poured into the ocean to form Pu‘unoa Point at Māla. The flow is rich in olivine.

Keka‘a Point (optional stop)

To get to Keka‘a Pt, take the first Kā‘anapali turnoff (mile 35.9) and proceed north. Keka‘a Point is the site of a Lahaina volcanics cinder and spatter cone, as well as a modern tourist hotel. A cross section through the cone is well exposed along the walkway near the beach. Cinder, bombs, spatter and flow fragments (Analysis 5, Table 2) are exposed along the path. Stearns noted that the cone was not nipped at the 8-meter level by the Waimānalo stand of the sea, thought to have occurred about 125,000 years ago, but *Tagami et al*. [2003] obtained an age of 580,000 years for this feature. There is a bench cut into the rock 55 meters below present sea level, presumably cut during the last glacial period. Although currently at the coast, this spatter cone is the result of a “dry” magmatic eruption that did not encounter the ocean. As such it must have been some distance inland at the time of eruption.

This cone used to be a man named Moemoe, who unwisely insulted the demigod Māui. After lassoing the sun, Māui chased and killed Moemoe, who turned into this rock. It also is known as a *leina a ka ‘uhane*, “the leaping place of the soul”. When a person lay on his deathbed, his soul would leave his body and find its way to Keka‘a. If he has a friend there, who had previously died, the friend’s soul would drive it away and the spirit would re-enter the body and cause it to live again. If the dying person has no friends’ spirits at Keka‘a, he’s history. Only the souls of subjects (makaainana) go to Keka‘a; those of chiefs go to the volcano, whereas those of farmers (lopa), lacking aumakua to aid them, are doomed to a wandering friendless sphere [*Sterling*, 1998]. Every island had at least one, if not several, locations designated as *leina a ka ‘uhane*.

Beyond Kā ‘anapali

From Kā‘anapali to Kapalua are examples of what happens to a Hawaiian island when no one is paying attention. Beyond Kapalua deep valleys have provided a temporary respite from modern construction run amok. The region is dominated physiographically by six bays that formally were under the rule of Chief Pi‘ilani. Route 30, along which we have been traveling, is known as Honoapi‘ilani - “the bays [acquired] by [Chief] Pi‘ilani”. The six bays are Honokōwai, Honokeana, Honokahua, Honolua, Honokōhau and Hononana. Pi‘ilani ruled the bays and the islands of Lāna‘i , Moloka‘i and Kaho‘olawe, which he could see from them.

At Honokōwai the shoreline is a long curve of calcareous "beach rock" or lithified modern beach sand. Honokeana is a small cove cut into the south side of Hāwea Point, as is Nāpili. Latitude 21°00' N runs just north of Nāpili (Fig. 1). The 3-km stretch from Hāwea Point to Līpoa Point is a large embayment, with four small bays lying within it. The two long, straight, north-facing bays of Oneloa and Honokahua are separated by Makāluapuna Point, consisting of a Honolua lava flow that was erupted from a vent lying about 10 km up the mountain.

Makāluapuna - STOP 6

Makāluapuna ("Spring Hole") Point is composed of differentiated Honolua alkalic lava issued from a vent at least 10 km uphill. The remarkable upturned lava spires here (Dragon's Teeth, Fig. 16) show the orientation of near-vertical flow folia, which have been accentuated by weathering and erosion. Vertical flow directions attest to the highly viscous nature of the lava when it was emplaced. In several places rubbly material is exposed that appears to represent intra-flow breccias.


Figure 17. Dragon's teeth at Makāluapuna, sub-vertical flow planes in viscous benmoreite Honolua lava.

Excellent views of the east end of East Moloka'i can be seen from Makāluapuna Point. The grassy area between the beach park and Makāluapuna covers a series of dune deposits that are the site of pre-contact Hawaiian burials, some of which were inadvertently excavated during ground preparation for a new tourist hotel. Upon discovery of the remains, hotel construction was terminated and eventually relocated to a site apparently free from burials. Presently this area is preserved from further construction.

Līpoa Point

On the north side of Honolua Bay is Līpoa Point, the type locality of the Honolua volcanics, more or less on the northern rift zone of West Maui Volcano. The road from Honolua Bay to Līpoa Point travels up through pāhoehoe flows of the Upper Member of the Wailuku basalts. These are overlain by about 30 m of Honolua mugearite (Analysis 6, Table 2). The Honolua volcanics here consist of at least two thick, slightly olivine-phyric flows separated by about 1 m of red, ashy soil.

Honokōhau

The fifth of the bays of Pi'ilani, Honokōhau, lies at the mouth of West Maui's longest stream, which flows 15 km straight north from just below Pu'u Kukui, the highest point on West Maui. The waterfall at the head of Honokōhau is said to drop 520 m, making it the sixth tallest in the world, and second, after Yosemite Falls, in the United States. On the north side of Honokōhau is Pu'u Ka'eo, a bright red Wailuku Basalt cinder cone. This cone has been partially buried by later Wailuku basalts and Honolua lava flows.

Directly behind Honokōhau, Honolua, and Honokahua is Waiuli Pit, a deep pit used as a burial place for bodies of the common people from Lahaina to Kahakuloa. According to Kamakau [*Sterling*, 1998] it was as much as a mile deep (!) with water at the bottom.

The road turns back to the south near Kanounou and Nākālele Points. Wind is commonly strong here, so strong that you can lean into it (*Nākālele* means "the leaning"). Along this section of road are exposures of Wailuku basalts that were never covered by the younger Honolua volcanics. Lacking the protection of these postshield flows, they became deeply weathered. Many of the landforms here, stained red and buff, are characteristic of wind erosion, and are typical of so-called "badlands" weathering.

Papanalahoa Pt. (optional stop)

A short, scenic trail has recently been opened here by the State of Hawai'i Nā Ala Hele program. It features shoreline views and an assortment of native coastal plants including 'ulei, 'akoko, 'a'ali'i and the endangered 'ohai, as well as sea birds, turtles and whales (in season).

Hononana Bay

The section here is in the Upper Member of the Wailuku basalt (Figure 17; Analysis 7, 8, Table 2). From the north, the road descends down through two transitional basalt flows, the lower one is about 6-7 m thick. These flows unconformably overlie about six ‘a‘ā flows, each about 2 m thick. The upper surface of the lower flows is truncated by an unconformable surface, marked by a 15-50 cm-thick, discontinuous conglomerate layer. The lower, thinner-bedded basalts overlie a 50 cm-thick, red ash bed. Below the ash bed, flows are mostly thin-bedded and basaltic, containing phenocrysts of plagioclase, olivine and clinopyroxene. A walled heiau at Hononana is now used as a cattle pen.

Just beyond Hononana is Pōhaku Kani, “the bell stone”, which is a 3 meter boulder that rings when struck. However, this rock is not a phonolite (ringing rock, “klinkstein” in German), which also are famous for making sonorous sounds when struck.

Kahakuloa (STOP 7)

The fishing and farming village of Kahakuloa has long been inhabited by Hawaiians who prefer to live off the beaten track. At least four heiau are located here. The region is dominated by two magnificent trachyte domes, the 194 m Pu‘u Koa‘e (also known as Kahakuloa - “the tall lord”) and 165 m Pu‘u Kāhuli‘anapa (“overturned hill [that] shines”). These domes are part of the NE rift zone of West Maui. The trachytic lavas that make up these domes are among the most differentiated alkalic lavas in Hawai‘i. The magma was so viscous that it welled up to form endogenous domes, rather than effusive lava. Trachyte from Pu‘u Koa‘e contains oligoclase (An24), anorthoclase, olivine (Fo16-23), Na-rich clinopyroxene, and an unusual amphibole (Table 3, Fig. 9). The structural formula of this amphibole can be expressed as $Ca_{2.0}(Na_{1.2}K_{0.2})(Fe_{2.3}Mg_{2.5}Ti_{0.2})[Si_{7.5}Al_{0.5}O_{22}](OH)_2$.

Table 3. Amphibole in WM-21

SiO_2	49.19
TiO_2	1.44
Al_2O_3	3.02
FeO	18.15
MnO	1.08
MgO	11.13
CaO	7.36
Na_2O	4.02
K_2O	1.17
H_2O	1.97
Sum	98.53

Exposed on the northeast side of Pu‘u Koa‘e are some well-bedded scoria layers. Not very much is known about the eruptions that produced these domes, but dome-building eruptions elsewhere can involve very explosive phases. Extensive air-fall ash beds are interlayered with trachyte lava on the north and east sides of the domes (Fig. 18).

Thin-bedded ankaramites of the Wailuku Basalt, Upper Member crop out around the base of Pu‘u Koa‘e and on the east side of Kahakuloa Stream. The latest activity in this region produced a small scoria cone that mantles the northern dome.

Figure 18. Pu‘u Koae (right) and Pu‘u Kāhuli‘anapa, two bulbous domes of trachyte on the NE rift. Red-weathering horizons are ash beds. Photo courtesy of NASA Virtually Hawai‘i Project.

Makamaka‘ole Gulch

On the north side of Makamaka‘ole Gulch are two Honolua benmoreites separated by a red weathering horizon. The lower lava is about 6 m thick. Eruption frequency was low in Honolua time, probably several thousands of years between eruptions. Daring folks used to climb to Eke Crater near the summit of West Maui from near here. The name *Makamaka‘ole* (friendless), might derive from the legend about a party that was attacked by robbers here.

Just beyond Makamaka‘ole Gulch is the turnoff to Camp Maluhia Boy Scout Camp. Between Makamaka‘ole and Waihe‘e are several weathered outcrops of Honolua benmoreites, displaying some of the best spheroidal weathering you will ever have the privilege to see in person (Fig. 19).

Figure 19. Spheroidal weathering of Honolua benmoreites, on road between Makamaka‘ole and Waihe‘e.

Waihe‘e

There are many ghosts near Waihe‘e.

At the intersection of Routes 33 and 340, follow 340 to the left.

STOP 8 (optional)

Lithified to semi-lithified, cross-bedded calcareous dune deposits are exposed in roadcuts along Route 340 between Wailuku and Waiehu. These eolian deposits lie on alluvial fan deposits and extend inland across the easterly edge of the isthmus. They locally attain a thickness of 60 m and extend below sea level [*Macdonald et al.*, 1983].

Figure 20. Semi-lithified calcareous eolianite (wind-deposited) dunes.

EAST MAUI

The Age of Haleakalā Crater and the Reinterpretation of East Maui Geologic History

Interpretations of the geologic history of East Maui are closely tied to understanding the formation of Haleakalā Crater. *Stearns* [1942a] established the erosional origin of Haleakalā Crater, suggesting that it formed during a quiescent period between Kula and Hāna activity. *Stearns and Macdonald* [1942] showed that the crater is cut into alkalic lavas typical of postshield volcanics on other volcanoes, and that post-erosional lavas of the Hāna Volcanics were erupted after the crater had formed. This led to the classic division of East Maui rock units into shield (Honomanū), postshield (Kula) and rejuvenated (Hāna) stages. The assumption, consistent with available age data of the 20th Century, was that Hāna volcanics followed a significant period of volcanic quiescence, while Haleakalā Crater formed by stream erosion. Until recently the youngest known age for Kula Volcanics was 360,000 yrs [*Chen et al*., 1991] and the oldest Hāna about 50,000 years [*Bergmanis et al*., 2000], allowing a period of up to 300,000 years for formation of Haleakalā Crater. More extensive dating by *Sherrod et al*. [2003] extended the age of "Kula" lavas forward and the age of Hāna Volcanics back in time so that there no longer is evidence for a quiescent period in the history of East Maui Volcano. Dated sections in the walls of Haleakalā Crater indicate that the crater did not form before about 150,000 years ago. Within the crater the division between Kula and Hāna Volcanics is easily made on the basis of the post-erosional character of the latter. However, outside of the crater this division is more difficult to make. Chemical data don't help much because younger Kula and older Hāna volcanics overlap in chemical composition (see below). *Sherrod et al*. [2003] consider the formation of Haleakalā Crater to be about 120,000 to 150,000 years ago and, following *Stearns and Macdonald* [1942], draw the boundary between Kula and Hāna Volcanics at about this time, i.e., lavas older than 150,000 years are Kula while those younger than 120,000 years are Hāna. These new ages are an important advance because if the volcano never died, it hardly could have become rejuvenated. In light of these new data, Hāna Volcanics must now be interpreted to represent a later period of post-erosional, postshield volcanism, similar to the Kolekole Volcanics of Wai‘anae Volcano on O‘ahu [*Presley et al*., 1997]. Hāna Volcanics were always an anomalous sort of rejuvenated sequence, including the only known such suite erupted along previously active rift zones, and chemically similar to earlier postshield volcanics. Thus, these previous enigmas of Maui geology are now replaced by a new one – why the postshield of East Maui has lasted more than 900,000 years (!), more than three times longer than any other Hawaiian postshield.

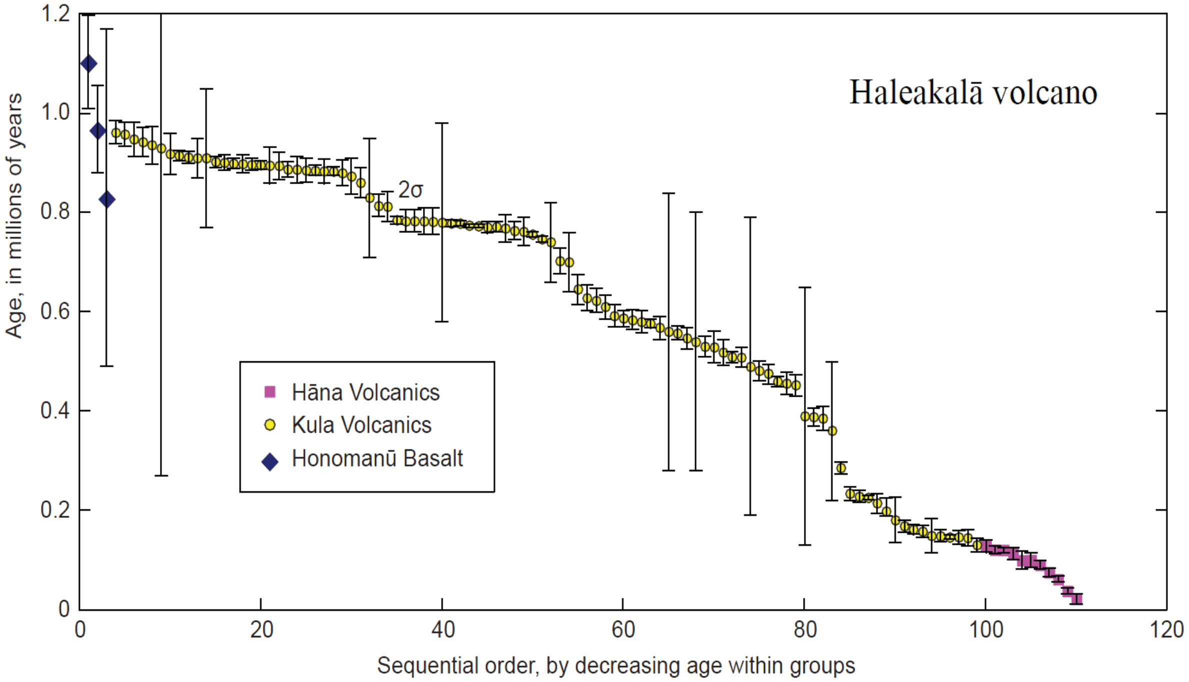

Figure 21. Radiometric ages for East Maui volcano (from Sherrod et al., 2007b). See Sherrod et al., 2007b for sources of data. The Kula-Hāna boundary at ~150 ka is the age of formation of Haleakalā Crater.

Volcanic and Petrologic Evolution of East Maui

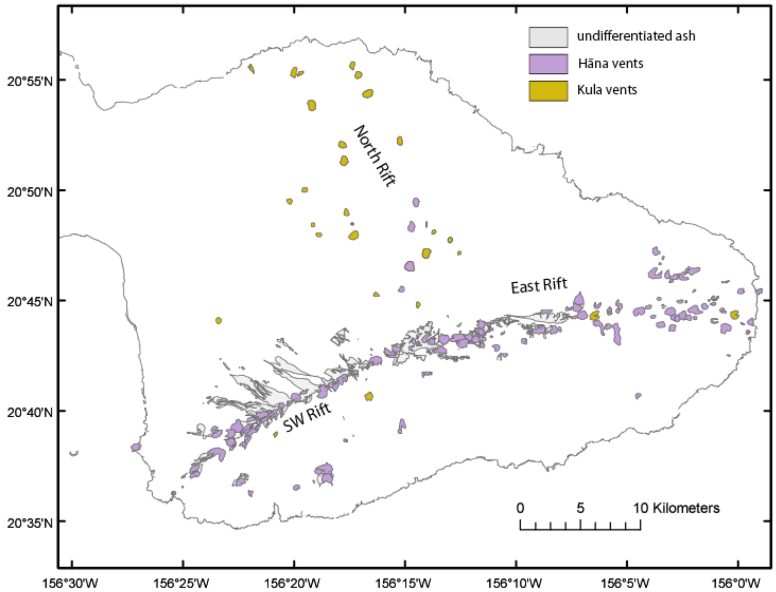

Figure 22. Vent distribution defines three rift zones that intersect near the present summit of East Maui.

During shield and early postshield activity on East Maui eruptions occurred from three principal rift zones radiating away from the summit region (Fig. 22). The shield stage of East Maui Volcano is represented by the Honomanū Basalt, a suite of lavas that vary from tholeiitic to alkalic basalt in composition (Fig. 24). Postshield Kula Volcanics began about 0.95 Ma with the eruption of alkalic basalts and hawaiites. After about 0.65 Ma, following a period of apparently low extrusion rate, the composition of Kula Volcanics became increasingly alkalic, including substantial basanite eruptions (Fig. 24), changes *Sherrod et al.* [2003] used to distinguish Lower Kula Volcanics older than 0.7 Ma from younger, more strongly alkalic Upper Kula lavas. Hāna Volcanics less than 0.12-0.15 Ma are mainly basanites, with lesser nepheline hawaiites, similar in composition to Upper Kula lavas. Hāna Volcanics were primarily erupted from only two of East Maui's 3 rift zones (the east or Hāna rift, and the SW rift zone), with only very minor activity on the north rift [*Sherrod et al*., 2003], in contrast to earlier postshield times. The increase in alkalicity with time likely reflects declining extents of partial melting of upwelling mantle beneath East Maui, i.e. waning melting as the island moves farther and farther from the hotspot center.

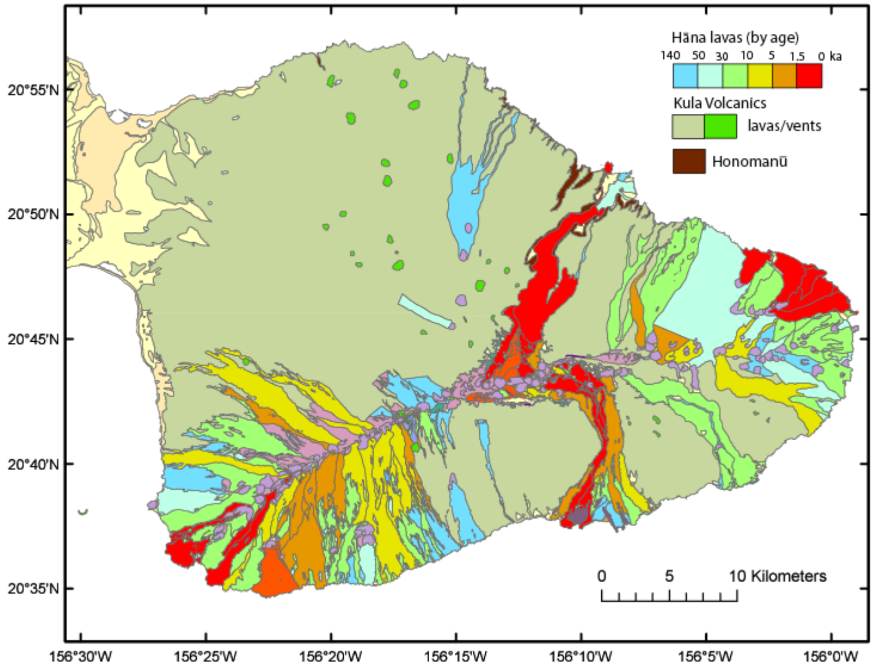

Figure 23. Geologic map of East Maui (from *Sherrod et a*l., 2007b; after *Stearns and Macdonald* [1942] and *Bergmanis et al.* [2000]).

Hammer et al. [2016] *Bergmanis et al*. [2000] and Hammer et al. [2016] determined that East Maui postshield magmas evolved at depths of 9-12 km below the volcano summit.

Carbon dating and geological evidence suggests that there have been approximately 5-6 eruptions along the SW Rift Zone in the last ~960 years [*Bergmanis et al*., 2000] and at least six additional lava flows younger than 1000 yrs in age are known from the east rift zone in Haleakalā Crater and near Hāna [*Sherrod and McGeehin*, 1999; *Sherrod et al*., 2003]. Thus, there is evidence for about 12 eruptions on East Maui in the last 1000 years. East Maui is the only volcano other than those on the youngest island of Hawai‘i for which any quasi-historical record of volcanic activity exists. There is some uncertainty as to when the last eruption on East Maui took place, but it probably occurred between 1450 and 1790 A.D (see notes to Honuaula, later in this guide). Recent eruptive activity on East Maui occurred in episodes lasting as much as 1,000 yrs separated by periods of quiescence 500-800 yrs long (Fig. 24). East Maui seems to be presently in one of those quiescent periods.

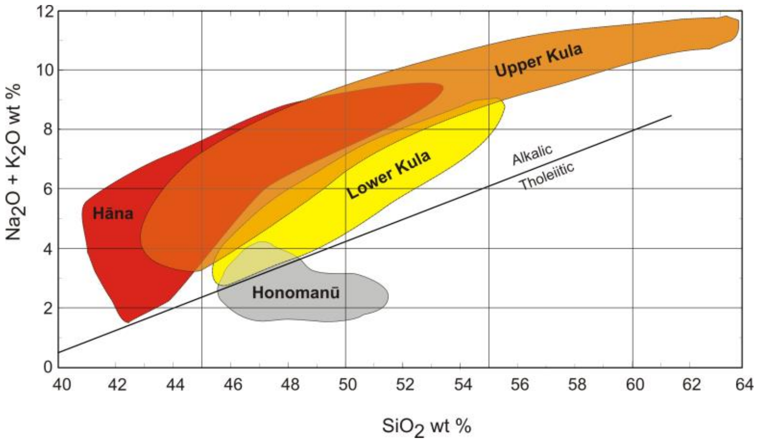

Figure 24. Total alkalis versus SiO_2 for East Maui Volcanic rocks (*Sherrod et al*., 2003). Alkalic-tholeiitic dividing line is from *Macdonald and Katsura* [1964]. Honomanū lavas range from tholeiitic to alkalic basalt; Lower Kula lavas are mainly alkali basalt and hawaiite; upper Kula rocks range from basanite to trachyte; Hāna volcanics are mainly basanites with subordinate hawaiite.

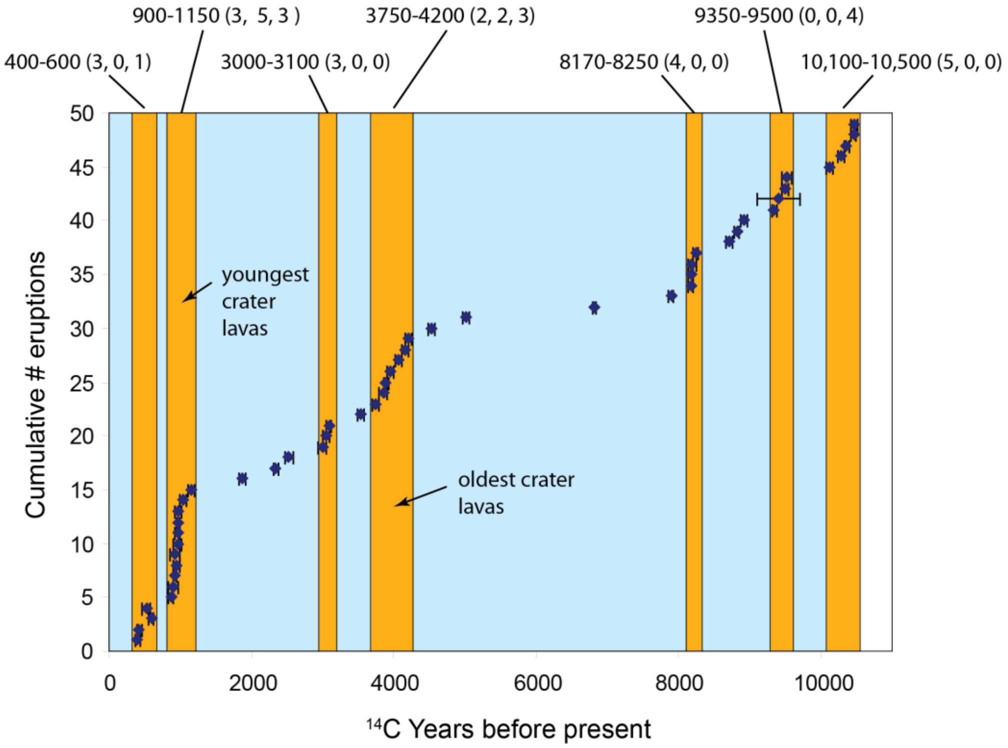

Figure 25. Plot showing the episodic eruptive character of East Maui in the last 11,000 years. Existing data suggest a pattern of relatively active periods lasting 100-1200 years, separated by periods of 800 – 1800 years in which eruptions are relatively infrequent. Data are from *Sherrod and McGeehen* [1999], *Bergmanis et al.* [2000] and *Sherrod et al.* [2003].

A Note on Carbon Dating

Charcoal can be dated by the ^{14}C method with a precision of about ± 50 years. However, the ^{14}C "clock" is not exactly linear, due to variable cosmic production of ^{14}C through time. ^{14}C ages can be corrected to "real" or calibrated ages based on correlation studies with tree rings and annular cycles in deep cores drilled in the polar ice caps. In this report, all ^{14}C ages have been corrected to "real" ages, back to about 10,000 years, after which the correlations are not well constrained. By convention, ^{14}C ages are typically reported as B.P. (before present), where present has been arbitrarily defined as 1950 A.D. Thus, in 2019, 69 years must be added to calendar ages B.P. to get the actual age. Some more recent lavas have been assigned to an actual year A.D.

Road Log: Kahului to Haleakalā Crater

This guide outlines a driving log from Kahului to the summit of Haleakalā. The driving log is mainly after *Easton and Easton* [1987].

mile 0

Junction of Routes 36 and 37; proceed on Route 37. For the next 10 miles or so the road passes through sugar cane fields planted on alluvium-covered land that forms the isthmus between East and West Maui volcanoes. Thick red soils are exposed locally in roadcuts.

mile 7.1

Junction of Routes 37 and 365; continue on Route 37.

mile 7.5

Junction of Routes 37 and 377; turn left on Route 377.

mile 9.5 - 10.5

Roadcuts expose weathered Kula volcanics lava flows with thick alluvial cover.

mile 11.5

A Kula cinder cone to the right of the road has been quarried for road metal. On the left, 0.1 mile on up the road, a younger Kula volcanics flow overlies soil.

mile 13.5

Junction of Routes 377 and 378; turn left on Route 378.

mile 17.5

Pullouts along the road afford excellent views of West Maui, and the islands of Molokaʻi, Lānaʻi, Kahoʻolawe, and Molokini Islet.

mile 19.0

Kula hawaiite ʻaʻā flows here are interbedded with ash erupted from Puʻu Pahu, a Kula volcanics cinder cone.

mile 20.8

Puʻu Pahu cinder cone is on the right. The road cuts through Kula ʻaʻā flows for the next 1 1/2 miles.

mile 22.2

Ash from Puʻu ʻŌʻili cinder cone (a Kula volcanics vent) overlies Kula volcanics ʻaʻā flows in roadcuts.

mile 22.9 - Optional Stop: Puʻu Nianiau. This cone was previously considered to be a Kula volcanics cinder cone. A K-Ar age of 113 ka [*Sherrod et al.*, 2003] is consistent with it being an early Hāna cone. Good examples of bedding, bomb sags, gullying, and reworking of cinder have been exposed by quarrying.

mile 23.6

Haleakalā National Park boundary. **Collecting is by permit only.** Permits must be obtained from the Director, Haleakalā National Park, P.O. Box 369, Makawao, Maui, Hawaiʻi 96768.

mile 23.9

Road on left leads to Hosmer Grove Campground and Nature Trail.

mile 24.7

Park Headquarters. Literature, camping permits and rest rooms are available inside. Various native plants and Nēnē (the state bird, a goose thought to be related to Canadian Geese) are outside where they belong.

mile 28.2

Halemauʻu trailhead, elevation about 8000 feet.

mile 30.9 - Leleiwi Overlook - Optional Stop

Roadcuts on the NW side of the road expose a composite Kula volcanics lava flow consisting of a 150 cm-thick ankaramite upper part overlying a lower 25 to 60 cm-thick alkali olivine basalt. The two parts of the flow grade into one another over about 20 cm. *Macdonald* [1972] interpreted this flow as having been erupted from a zoned magma chamber in which the lower alkali basalt represents early eruption from the crystal-poor upper part of the chamber, followed by later eruption of the crystal-rich, anakaramitic lower part. The latter over-rode the earlier crystal-poor lava while both were hot and still active.

mile 32.4 - Kalahaku Overlook

A large area of silverswords is present in the enclosure here. This rare plant is restricted to the upper slopes of Haleakalā, Mauna Kea, and Mauna Loa. It used to be subject to predation by goats and people, but goats have nearly been eliminated from the park, and silverswords are slowly making a comeback. The other predatory mammals are still a problem, however. Silverswords are *Compositae*, related to sunflowers and chrysanthemums. They live 7 to 20 years, flower once and then die. The flowering season is from June through October. Near here is an important quarry for stone materials used in the fabrication of adzes by ancient Hawaiians.

mile 34.1 - Haleakalā Summit Observatory

Haleakalā Crater is an oval-shaped depression about 12 km long by 4 km wide and almost 1000 m deep. Although many cultural miscreants use the name Haleakalā (house of the sun) as the name of the whole volcano or mountain, it originally was used to refer only to the summit and crater area. The name ʻAhelelā can be found in ancient Hawaiian chants in reference to the mountain as a whole. The rim is broken in two places: Kaupō Gap, lying at the far eastern end of the depression, and Koʻolau Gap, opening into Keʻanae Valley on the northern side. On the south side of the crater, just west of Kaupō Gap at an elevation of 2523 meters is a peak known as Haleakalā (house of the sun). Stone shelters, platforms and a heiau have been found on the rim. This was obviously an important place, perhaps the place where Māui stood when he snared the sun.

HALEAKALĀ CRATER

Figure from *Roelofs* [1993b]

Long ago the sun moved quickly across the sky and the day was short. Hina, the mother of the demigod Māui, was unhappy that she had too little time to dry her tapas. So Māui made a strong fiber cord and climbed the slopes of Haleakalā to snare the sun. When the sun (Lā) rose above the mountain Māui lassoed one of the sun's rays and broke it off, then another, and another. He then said "Now I shall kill you for hurrying so fast." But the sun answered, "Let me live and you shall see me go more slowly from now on." That is why the sun moves so slowly now, and there is enough time for completing daylight tasks and the drying of tapas in the warmth of the sun.

- based on the account of Thomas Maunupau in *Sterling* [1998]

Haleakalā has been called the largest extinct volcanic crater in the world. This statement is correct except for three things. As pointed out by *Macdonald et al.* [1983], "Haleakalā is far-smaller than many volcanic craters (calderas); there is an excellent chance that it is not extinct, but only dormant; and strictly speaking it is not of volcanic origin, beyond the fact that it exists in a volcanic mountain." *Stearns* [1942a] established the erosional origin of Haleakalā Crater, now known to have formed about 0.12-0.15 Ma [*Sherrod et al*., 2003]. Post-erosional Hāna volcanics eruptions, mainly less than 4500 yrs old [*Sherrod and McGeehin*, 1999] produced the youngest volcanic features in the crater.

The following notes describe a day trip through the crater, descending Keonehe'ehe'e Trail (Sliding Sands Trail), crossing the crater, and ascending Halemau'u Trail. Various alternative routes are possible. Appropriate provisions include water (at least 2 liters), comfortable shoes (boots not required), daypack, waterproof rain jacket and pants, sweater or sweatshirt, sunscreen and hat. The temperature can be between 30° and 70° F (0°-20° C), so be prepared for a wide variation.

The trailhead for Keonehe'ehe'e Trail is at the west end of the parking lot for the Pakao'ao (White Hill) Observatory. Mileages shown below are approximate, beginning at the trailhead.

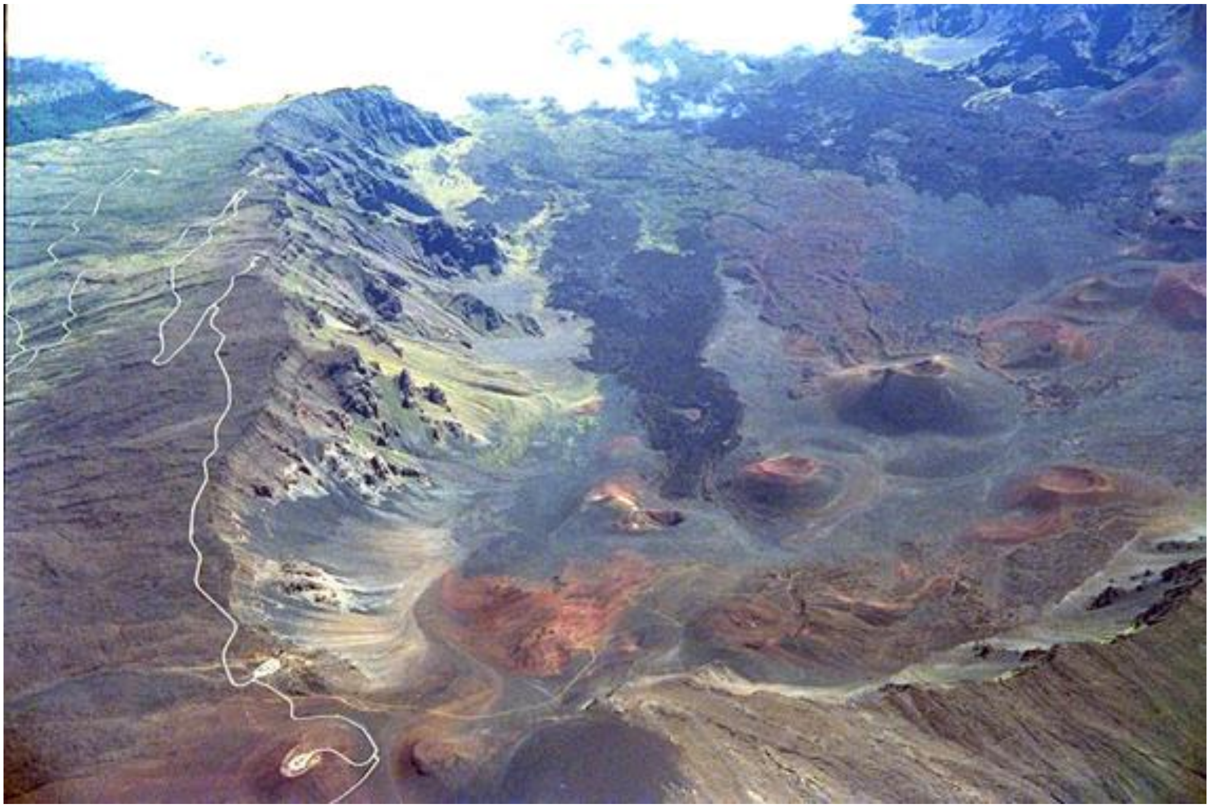

Figure 26. Air view of Haleakalā Crater looking northeast (image courtesy of NASA Virtually Hawai'i Project). The two dark-colored flows in the center of the picture and along the far side of the crater have been dated by ^{14}C to 970 ± 50 and 940 ±50 yrs B.P, respectively. [*Sherrod and McGeehin*, 1999].

<u>mile 0</u> - Keonehe'ehe'e (Sliding Sands) Trail

The trail commences near the intersection between the SW and East (Hāna) Rift zones of East Maui volcano, in a blanket of cinder shed from Pakao'ao cone, a Kula volcanics ankaramite cone, ~214 ka [*Sherrod et al*., 2003]. This lava has the highest ^{3}He/^{4}He ratio of any analyzed terrestrial rock, a characteristic attributed to an influx of cosmic radiation that bombards this high altitude location [*Kurz*, 1986]. The mugearite flow that underlies the ankaramite also is interesting in that it contains phenocrysts of hornblende, the only known occurrence of this mineral as a phenocryst phase in East Maui. The trail winds around Pakao'ao and Magnetic Peak (named for the effect it exerts on a compass needle) before entering the crater.

The trail descends into the crater in a series of long switchbacks through Hāna volcanics cinder and ash, most of which has been reworked and redeposited by the wind. Views of the entire crater are best along this section of trail. On clear days it is possible to see down Ko'olau Gap to the north, down Kaupō Gap to the southeast, and across to the wet windward part of the crater at Palikū.

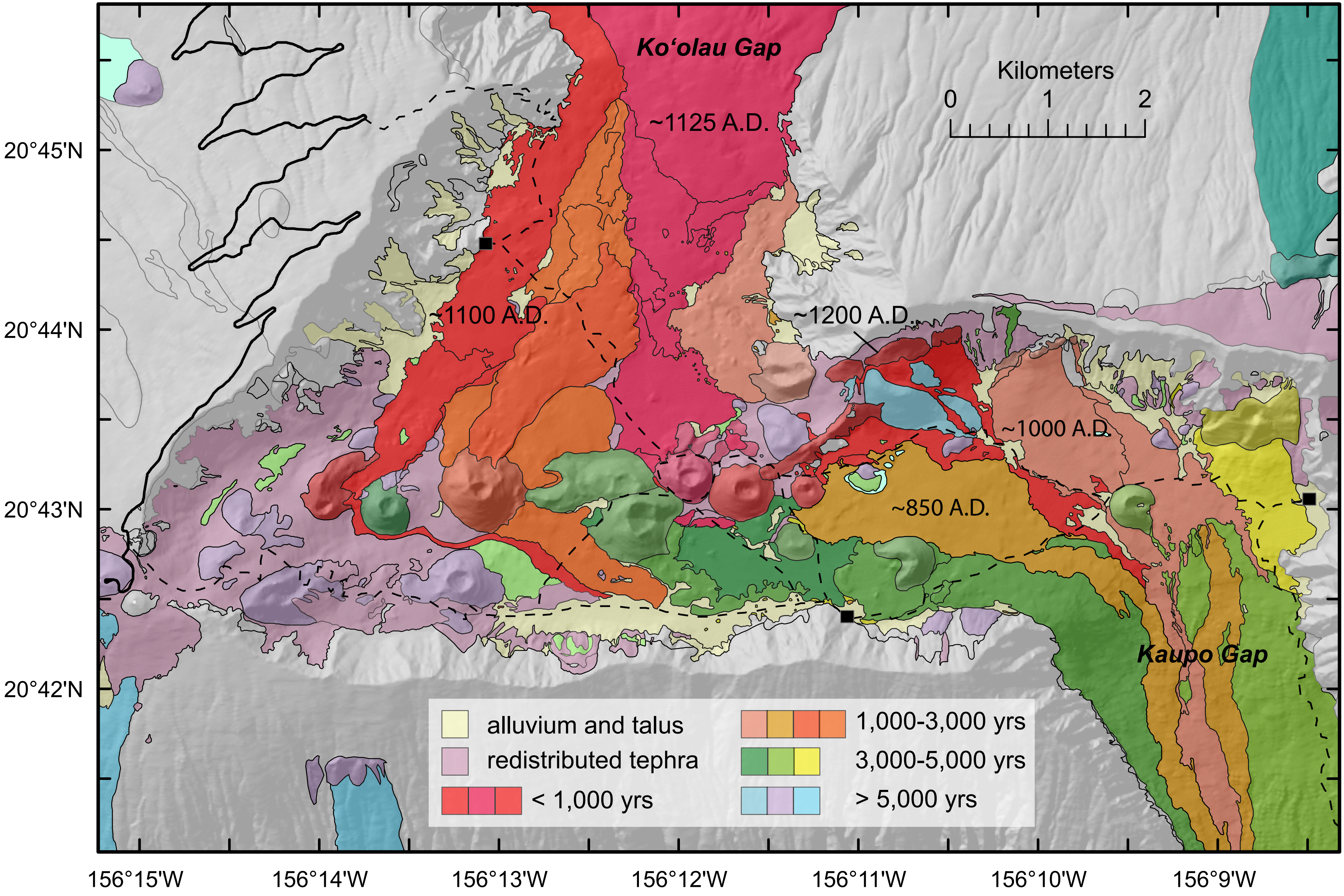

Figure 27. Map showing the distribution of individual Hana lavas and vents; mapping by D. Sherrod after G. A. Macdonald [1978]

mile 1.35

Indurated breccias are exposed just to the north of the trail as it switches back from north to southeast.

mile 2.0

Intersection of Keonehe‘ehe‘e Trail with a subsidiary trail leading to Kalu‘u o ka ‘ō‘ō (the plunge of the digging stick), a Hāna volcanics cinder cone. This very young cone (970±50 ^{14}C yrs B.P., *Sherrod and McGeehin*, 1999) produced a nearly aphyric basanitoid lava.

mile 2.1

The trail crosses a Hāna volcanics olivine-phyric basalt or basanitoid lava flow.

mile 3.1

To the left is Pu‘u O Pele cinder cone, one of the many abodes of Pele during her sojourn on Maui.

mile 3.8

Intersection of Keonehe‘ehe‘e Trail with one leading to Pele’s Pig Pen and Hōlua Cabin. Turn left (north) toward Hōlua Cabin. This trail traverses Hāna volcanics flows including nearly aphyric olivine basalt or basanitoid issuing from Pu‘u Kama‘oli‘i.

mile 4.4

The trail ascends the western shoulder of Ka Moa O Pele (the chicken of Pele), a Hāna volcanics cinder cone on the East Rift Zone. Views to the west of the cones, Pu‘u o Pele, Pu‘u O Maui and Kama‘oli‘i are realized along this trail.

mile 4.7

As the trail reaches the saddle between Ka Moa o Pele and the cinder blanket to the north, Ka Pua‘a o Pele can be seen to the east.

mile 5.0 - Ka Pua‘a o Pele (Pele's Pig Pen)

This small spatter rampart and associated alkali olivine basalt flow issuing to the northwest is said to have been a place of high kapu (prohibition) in ancient times. Natural levees along this flow produced the “pig run.”

Follow Halemau‘u Trail toward Hōlua Cabin. Take the optional side trip to Bottomless Pit, a ~20 m-deep spatter vent adds about 1.2 km. The relatively small amount of spatter present indicates that it mainly discharged superheated gases. This pit is part of a group of NE-aligned vents that strike back toward Ka Pua‘a o Pele; this trend is ~30° oblique to the overall strike of the East Rift Zone. The Bottomless Pit is a *nā piko haua* (a hiding place of navel cords). Umbilical cords, wrapped in kapa and tied with fiber cord, were hidden in rock crevices that were then sealed with wedged stones. This was done by Hawaiians of old to ensure safe protection and growing strength for the newborn child.

mile 5.3

The trail leaves the rift zone axis and traverses the plain leading to Hōlua Cabin. At this locality the trail crosses the youngest phase of an olivine- and augite-phyric flow erupted from Halāli‘i. Charcoal collected from a location ~1 km to the north yielded an age of 940±50 ^{14}C yrs B.P. [*Sherrod and Mcgeehin*, 1999].

mile 6.3 - Silversword Loop

Here the Silversword Loop side trail leaves Halemau‘u Trail in Hāna volcanics porphyritic olivine basanitoid from Pu‘u O Maui. The loop trail adds about 500 m to the hike. Silverswords are highly adapted to life in high altitude, often fog-enshrouded environments. Flat, concave, and numerous silvery hairs on the leaves reflect ultraviolet radiation in addition to catching droplets of water from the air, and give the plant a patina expressed in the Hawaiian name ‘Āhinahina (very silvery gray).

Although Haleakalā has a somewhat hostile environment and rises over 3 km above sea level, there is an ancient Hawaiian highway running through the crater in this area. Built by Kihapi‘ilani, the highway runs toward Halāli‘i. Only parts of it remain visible now, as it has been almost completely covered with drifting sand. It must have been a link between Wailuku and Hāna, which, despite its hardships, might have been preferred to routes at lower levels through rain forests, nasty gulches, and deep valleys.

mile 7.1

The trail here crosses the nearly aphyric basanitoid flow from Kaluʻu o ka ʻōʻō. This flow is the same age (~800 yrs B.P.) as the Hanamanioa lavas [*Bergmanis et al*., 2000] erupted from four separate vents lying 17-20 km down the southwest rift zone. The lavas from the two units are close in composition, although not identical, especially in Al_2O_3 and Cr (Table 4, Anal. 1, 2).

mile 7.3

Good pāhoehoe flow features are exposed along the trail in Hāna volcanics basalts. A small pit crater or spatter vent also occurs here, which was another *na piko haua* (hiding place of navel cords).

Near here a trail heads uphill to the south, leading to the entrance to Hōlua cave, a lava tube in Kaluʻu o ka ʻōʻō lava that served as a shelter before the cabin was built. There are radiocarbon dates indicating that the cave was in use shortly after it formed about 1150 A.D. Inside, the tube is dark and footing is uneven; flashlights are required. Common features of lava tubes, including remelted ceilings, subsidiary branches, multiple tube levels and carbonate precipitates all are to be found (Fig. 27). The tube "exit" is marked by a particularly exquisite example of *Artemessia haleakalaensis,* a relative of wormwood, also called *hinahina*.

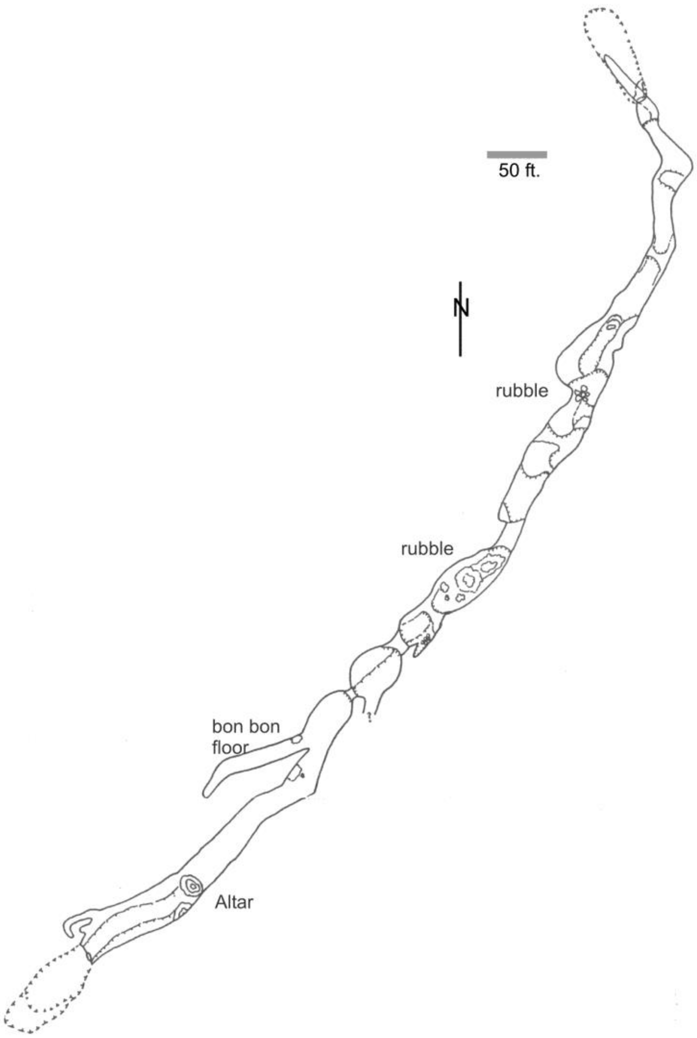

Figure 28. Hōlua lava tube, Haleakalā. [Sinton, Johnson and Mallonee, unpublishable

A short walk leads to a 6 m-thick dike exposed above a horse pasture. This Kula volcanics dike is the only known trachyte from East Maui volcano. It contains large anorthoclase phenocrysts.

mile 7.4 - Hōlua Cabin

Kula volcanics flows and dikes make up the crater walls to the west.

From Hōlua Cabin, Halemauʻu Trail crosses older Hāna volcanics basalts and alluvium.

mile 8.4

Kula volcanics alkalic olivine basalt is exposed at the gate. From here it is about 3.3 miles to the Halemauʻu trailhead, all uphill. The crater wall is composed of Kula lavas that contain a paleomagnetic record of the Brunhes-Matuyama polarity reversal. Lavas at the base are reversed (Matuyama, >0.78 Ma), while those at the top have normal magnetic polarity [*Coe et al*., 1984]. Those in between have a varied assortment of non-systematic orientations [*Coe et al.*, 1985]. Many of the flows have been so highly magnetized by lightning strikes that they will deflect a compass needle held a few feet away.

West and Leeman [1987, 1994] divided the Halemauʻu Trail section into 13 discrete magma batches (Fig. 28). The first eruptive products in each batch tend to be highly differentiated hawaiites or mugearites; the final products tend toward more mafic compositions. West and Leeman proposed that interbatch variations reflect periods of low magma recharge combined with significant fractional crystallization, whereas intrabatch variations reflect open system magmatic processes in which magma mixing of evolved residual magma with more primitive recharge magma during periods of high eruption rates was a dominant process.

On (rare) clear days, good views of Koʻolau Gap down to the sea can be had from north-facing switchbacks. The flat floor of the gap is due to partial infilling by Hāna volcanics lava flows. At least one Hāna volcanics lava flow erupted from the crater area flowed all the way down Keʻanae valley and entered the ocean to form the Keʻanae peninsula. Halemauʻu Trail gets its name from the common amaʻumaʻu ferns, some with reddish fronds.

mile 10.3

The trail leaves the steep section in undifferentiated Kula volcanics flows and passes into Kula hawaiites.

mile 10.8

Take the left trail leading to the summit road. The right hand trail leads down to Hosmer Grove. Along the trail, watch for examples of the endangered native geranium, also called *hinahina,* with silvery gray leaves.

mile 11.7

Trail end, intersection with summit road.

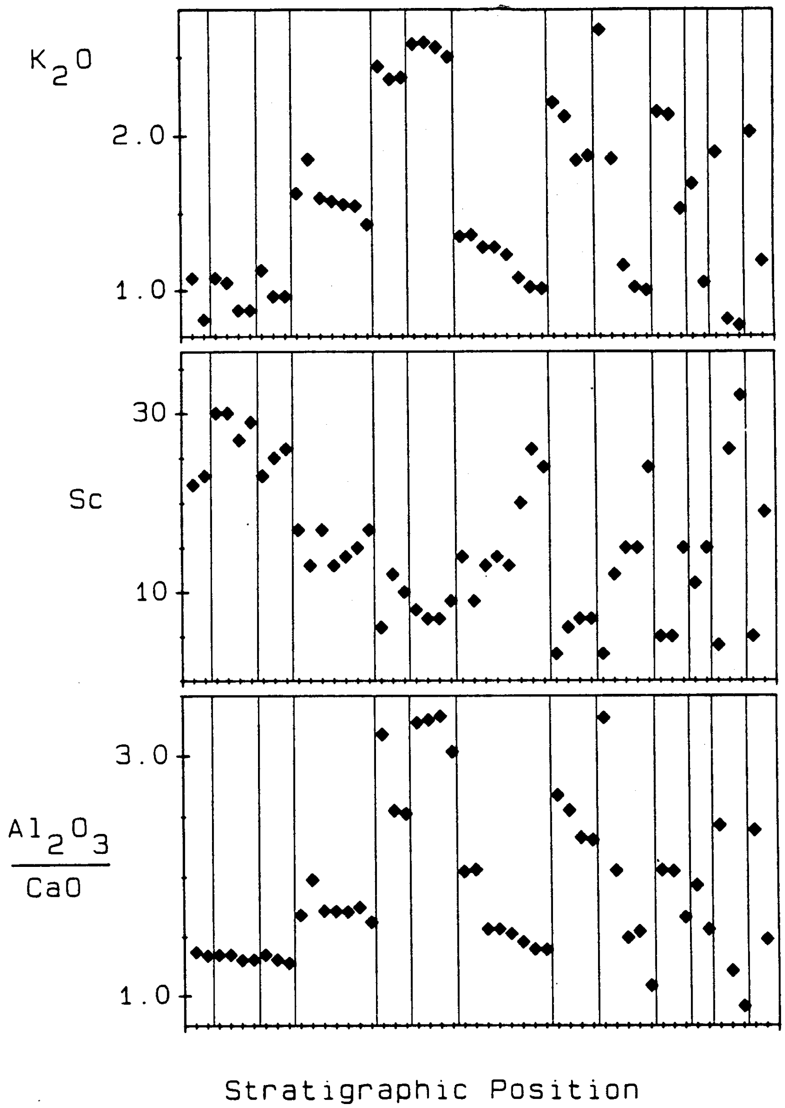

Figure 29. Up-section variations in K_2O, Sc and Al_2O_3/CaO for Kula lavas from the Halemau'u trail section. Vertical lines indicate geochemical discontinuities that reflect individual magma batches. (from *West et al.*, 1987).

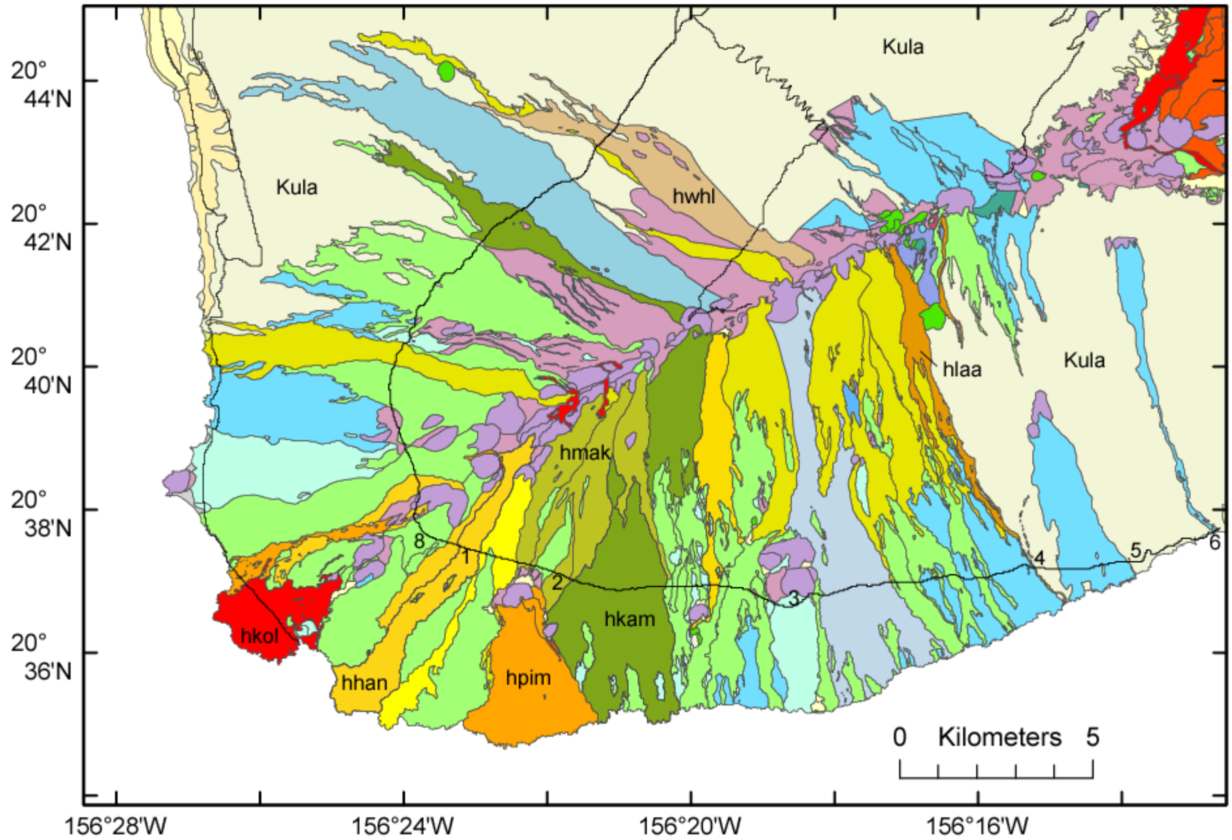

Figure 30. Geologic map of the southwest rift zone, East Maui, (after *Bergmanis et al*. [2000] and *Sherrod et al*. [2007]. Numbers indicate stops referred to in the field guide.

Take the Kula Hwy toward ʻUlupalakua.

Kēōkea

The village of Kēōkea is situated in a Kula kīpuka, between the Hāna flows of Waiohuli (Fig. 30, hwhl, ~9500 yrs. B.P.) and Kamole (hkam, ~4550 yrs B.P.), erupted from the SW Rift Zone. The area around Kēōkea was once part of a thriving Chinese community in upcountry Kula. Chinese first came to Hawaiʻi in the 1840s, and mainly grew potatoes, shipped to California during the gold rush. The Fong Store and nearby Ching Store continue to be operated in Kēōkea today. Just beyond Kēōkea, a statue of Dr. Sun Yat Sen, father of the Chinese republic, stands on ranch land once operated by his brother, Sun Mi.

From Kēōkea the road crosses several different, generally felsic, Hāna flows erupted from the SW rift zone (hpae, hwai, hkea, Fig. 30). Pyroclastic deposits are much thicker on this side of the mountain, owing to the prevailing winds. These deposits produce more subdued topography and improved grazing lands.

ʻUlupalakua

The owner of ʻUlupalakua Ranch is a descendent of the Dillingham family of Oʻahu; his father has a degree in geological engineering. The ranch office is located on ankaramite erupted from Keonenelu. Near the old churchyard this ankaramite is overlain by Waiokawa felsic lavas.

About 1 km beyond the ʻUlupalakua Ranch office the road crosses the first flow of the Hanamanioa eruptive sequence (hhan, Fig. 29). This eruption produced four separate lava flows from four vents aligned along a 3 km-long fissure along the southwest rift zone, about 1170 A.D. One of the two carbon ages for this sequence was obtained on a charcoal from a tree mold in this flow. This flow is close in age to the Ka luʻu o ka ōʻō lava in Haleakalā Crater containing the Hōlua lava tube.

The road bends around the topographic axis of the SW Rift Zone, marked by cinder deposits and lava erupted from Puʻu Mahoe, just mauka of the road.

STOP 1. Hanamanioa lavas.

This stop is located in the upper southwest rift zone flows of the ~1170 A.D., Hanamanioa eruptive sequence. Looking ma uka, you can see the vents. Ma kai reveals views downrift over Honuaula. On the north side of La Pérouse Bay is Cape Kinaʻu, consisting of lava from Ka lua o lapa. The south side of the bay is Cape Hanamanioa, formed by the flow lying under your feet. The Ka lua o lapa lava is the youngest lava flow on Maui, variably estimated to have formed between the 15th and 18th centuries, A.D. Another young flow to the southeast was erupted from the off-axis cone, Puʻu Pīmoe.

STOP 2. Kanaio.

This stop is on ʻaʻā lava erupted from the Mākua vents (hmak, Fig. 30). Charcoal collected from beneath the Mākua lava yields a ^{14}C age of ~3800 yrs B.P. It is another example of the numerous eruptions of moderately differentiated lava that characterize the middle SW Rift Zone. The first lava flow produced during the Mākua eruption was pāhoehoe, and contains numerous lava tubes, one of which is said to contain a canoe showing marks of fabrication by ancient stone adzes. Later eruptions produced ʻaʻā lavas with well-developed lava channels like those present here. Below the road is the cone of Pīmoe. Although the eruption of Pīmoe has not yet been dated, tephra from the cone can be found to extend beneath Hanamanioa [*D. Sherrod*, written comm., 2001]; Pīmoe lava probably is about 1000 yrs old.

The Pīmoe eruption is an interesting example of syn-eruptive cone collapse. During the eruption, a large section of the eastern part of the cone collapsed and became rafted along the eastern margin of the flow. Collapsed cone debris can be traced almost to the small cone of Pohakea. Similar debris avalanches also are present around some of the Hanamanioa flows.

From Kanaio the road first crosses the large lobe of ~4550 yr-old Kamole lava erupted from near Polipoli, and then into older Hāna lavas. Kamole lava is characteristically very rough ʻaʻā with excellent channel structures.

STOP 3. Lualaʻilua Hills

The Lualaʻilua Hills comprise cinder cones erupted in this location ~7 km from the SW rift zone. According to Sherrod [2004] the most makai cone is the youngest of four discrete cones, and the one likely responsible for the olivine basalt pāhoehoe that became ponded here. The nearly circular collapse structures present on both sides of the road mark the locations of these former lava ponds. The collapse pits now are home to native Wiliwili and the very rare ʻOhe makai trees.

From Lualaʻilua Hills the road crosses in succession, an older ankaramite, a small lobe of Alena ankaramite, a 2 km-wide lobe of nearly aphyric ʻaʻā lava erupted about 9,130 yrs B.P., and then into olivine basalt Hāna lavas, about 53,000 yrs old [*Sherrod et al.*, 2004].

STOP 4. Kepuni Gulch

Another young lava from the SW rift zone is the Laʻau ankaramite (hlaa, Fig. 34; Table 4, anal. 8) erupted ~3,250 yrs B.P. from a small vent lying just south of the topographic axis of the SW rift zone at an elevation of ~2,500 m. At an elevation of about 800 m, it flowed into a pre-existing stream channel, where it was confined for the rest of its sojourn to the sea. Below the road you can see the sharp boundaries of the flow along the old channel. A short walk up the flow provides exceptional exposures of the post-erosional nature of the flow. Laʻau lava also is notable for the scattered, large plagioclase crystals in it, along with crystal clots and gabbroic xenoliths. Feldspar almost certainly was not a liquidus phase in the Laʻau magma under the conditions of its evolution, about 9-11 km deep beneath the volcano [*Bergmanis et al.*, 2000]; as such these feldspar crystals and gabbroic inclusions can be considered to be xenoliths, most likely entrained material from the cooler mush zone surrounding the Hāna magma reservoir that fed the eruption.

The adjacent gulch to the east contains a much older Kula, intra-canyon flow, which displays excellent columnar jointing pattern on its surface.

The road briefly traverses older Kula lavas and then into one of the older Hāna lavas of the area, issuing from Puʻu Pane. Puʻu Pane vent also is off of the main SW rift zone axis; it is about 96,000 yrs old [*Sherrod et al.*, 2003].

Beyond the limit of Pane lava the road moves into older Kula lavas.

STOP 5. Manawainui Gulch

Big gulch, big wind. Looking across the gorge, one can see a marked angular unconformity within Kula lavas, first described by *Stearns and Macdonald* [1942, Plate 15b]. *Sherrod et al*. [2003] dated lavas on either side of the unconformity. The lower, truncated lavas are 0.703 ± 0.013 Ma, while the lowermost draping lava yielded a K-Ar age of 0.481 ± 0.010 Ma. This locality was one of several examples of post-erosional relationships documented by *Stearns and Macdonald* [1942] within the postshield Kula Volcanics.

Figure 31. Post-erosional Hāna lava filling canyon cut into older Kula lavas at Wai‘ōpai Gulch.

STOP 6. Wai‘ōpai Gulch

Dense, columnar jointed lavas here are in unconformable relationship with earlier Kula lavas. *Stearns and Macdonald* [1942] considered this locality to be another example of post-erosional relations within the Kula. Because eruption frequency during the postshield stage is probably on the order of thousands of years, in any single area the recurrence interval can be several tens to hundreds of thousands of years, as we saw at Manawainui Gulch. Thus, significant erosion can separate lava flows during this stage. Examples like this one are further justification for discarding the term “post-erosional” as a stage name, but retaining it to describe local geological relations. The term “rejuvenated” is preferred for the secondary eruptions that follow several hundreds of thousands to millions of years of quiescence. Dave Sherrod traced the flow back up to its vent, Pu‘u Ali‘i at an elevation of about 2460 m (Fig. 29), and *Sherrod et al*. [2003] report a K-Ar age for this lava of about 75,000 yrs placing it within the period of Hāna Volcanics. Most Hana lavas at this time were “trapped” inside Halekala Crater. However, because the vent for this lava is outside the crater (Fig 29), its lava poured down the south flank, and into pre-existing gullies cut into older Kula lavas.

Just past Huakini Bay, the road crosses ~4500 yr old lava erupted from Pu‘u Maile in Haleakalā Crater (hmai, Fig. 32). This lava is chemically and chronologically identical to the Kamole lavas near Polipoli (Table 4, Anal. 5, 6). Kamole is the largest Hāna eruption on the southwest rift zone (0.40 km^3 - Bergmanis et al. [2000]). If Pu‘u Maile is co-eruptive with Kama‘ole, as suggested by the age and chemical data, this is easily the largest Hāna eruption yet identified anywhere on East Maui.

The Pu‘u Maile lavas are overlain by lavas erupted from Pu‘u Nole (hnole, Fig. 32; 1,160 ^{14}C yrs. B.P. [*Sherrod and McGeehin*, 1999]). This lava is the youngest lava from Haleakalā Crater that flowed all the way to the sea.

STOP 7. Mane‘one‘o Hill - Kaupō Gap

Several hundred thousand years ago Ke‘anae, Kīpahulu and Kaupō rivers cut back into East Maui volcano, progressively working their way uphill by headwall erosion. Eventually, ~120,000 – 150,000 years ago, they converged to form Haleakalā Crater. Kaupō Gap marks the valley of one of these rivers. As you look up at Kaupō Gap, you will note that the valley is not V-shaped. That is because it has been partially filled by later Hāna lava flows, mainly erupted in the last 5,000 yrs, and also by a large clastic deposit that has been called the Kaupō Mudflow. There has been little detailed study of this unit; the term “debris avalanche” probably is more appropriate than “mudflow”.

Figure 32. Kaupō Gap, viewed from the south. The gap is now partially filled with debris avalanche deposits and Hāna lava flows.

The deposit contains fresh, angular and subangular lava fragments, irregularly arranged in a rather sparse, sandy matrix. One characteristic of mudflow deposits is that they are matrix supported rather than clast supported. Puʻu Maneʻoneʻo is composed of weathered breccia of the clastic unit. The deposit has an exposed thickness of 355' in the sea cliff at Puʻu Maneʻoneʻo, but it must be thicker as it extends below sea level.

There are many things not known about the Kaupō debris deposit. There is some speculation that this deposit might be related to a jökullaup, a massive flood formed from failure of a glacial ice dam. Whether or not glaciers ever existed on East Maui is unknown. Evidence for glacial action is restricted to elevations above ~11,000 ft on Mauna Kea, slightly above the present summit of East Maui. To date, evidence for subglacial Hāna eruptions has not been found, nor have glacial striae or moraines. As such, this intriguing idea is presently without supporting evidence of any kind.

A thin sliver of Hāna lava erupted from Puʻu Nole in Haleakalā cuts the mudflow deposit near here.

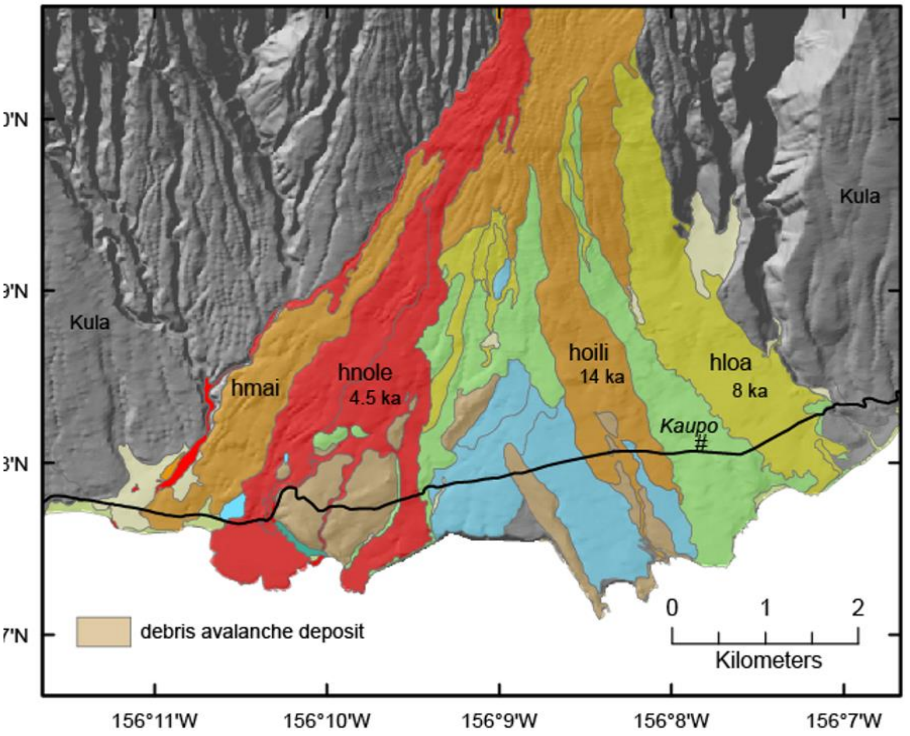

Figure 33. Geologic map of the Kaupō area, showing the distribution of lava flows (pretty colors, all erupted inside Haleakalā Crater and flowed down through Kaupō Gap) and the Kaupō debris deposit.

Return toward ʻUlupalakua

STOP 8. Māhiehie

A deep collapse pit in 13,000-30,000 yr-old lava erupted from the Mahoe cone complex is present ~40 m below the road. This pit is now sequestered behind barbed wire fences on private land.

UPPER SOUTHWEST RIFT ZONE

The intersection of the SW and East rift zones is in Haleakalā Crater, near Pu'u Māmane. The summit of the mountain is a complex of cones, fissures and spatter vents, possibly part of the Kula Volcanics. The trail between the summit region and Polipoli State Park is the Skyline Trail, which crosses through various complexes of Hāna and Kula cones, craters, flows, and spatter ramparts. The upper-most Hāna vents were erupted about 3200 yrs B.P. Below these are a series of spatter ramparts at Kalepeamoa, considered to be Kula age by *Stearns and Macdonald* [1942]. The vent for the youngest lava eruption from the upper southwest rift zone (^{14}C ages of 3,015 and 3,070 years B.P) is between Kalepeamoa and Kanahau. Kanahau (lit. remarkable) is the largest topographic feature on the southwest rift zone and is clearly visible from the isthmus region of Maui around Kahului and Wailuku. The region around Kanahau was a major eruptive center during later Hāna time, mainly during the period around 9200-9500 B.P. [Sherrod et al., 2004]. The view from Kanahau (2662 m) truly is marvelous (some days). When clear, it is possible to see Kohala, Hualālai, Mauna Kea and Mauna Loa on the Big Island, the lower SW rift zone all the way to La Pérouse Bay and beyond to Kaho‘olawe and Molokini to the southwest, and Lāna‘i, West Maui and E. Moloka‘i to the west. The steep break in slope below Kanahau marks a dramatic change in vegetation from little or none above, to mostly native, scrub lands below, including pukiawe, kukaenene, māmane, ohelo (not nearly as tasty as the Kīlauea variety), and a relative of silversword (*dubautia*) that goes by the Hawaiian names kupaoa (mainly on the Big Island and by some also for the Maui variety) or na‘ena‘e.

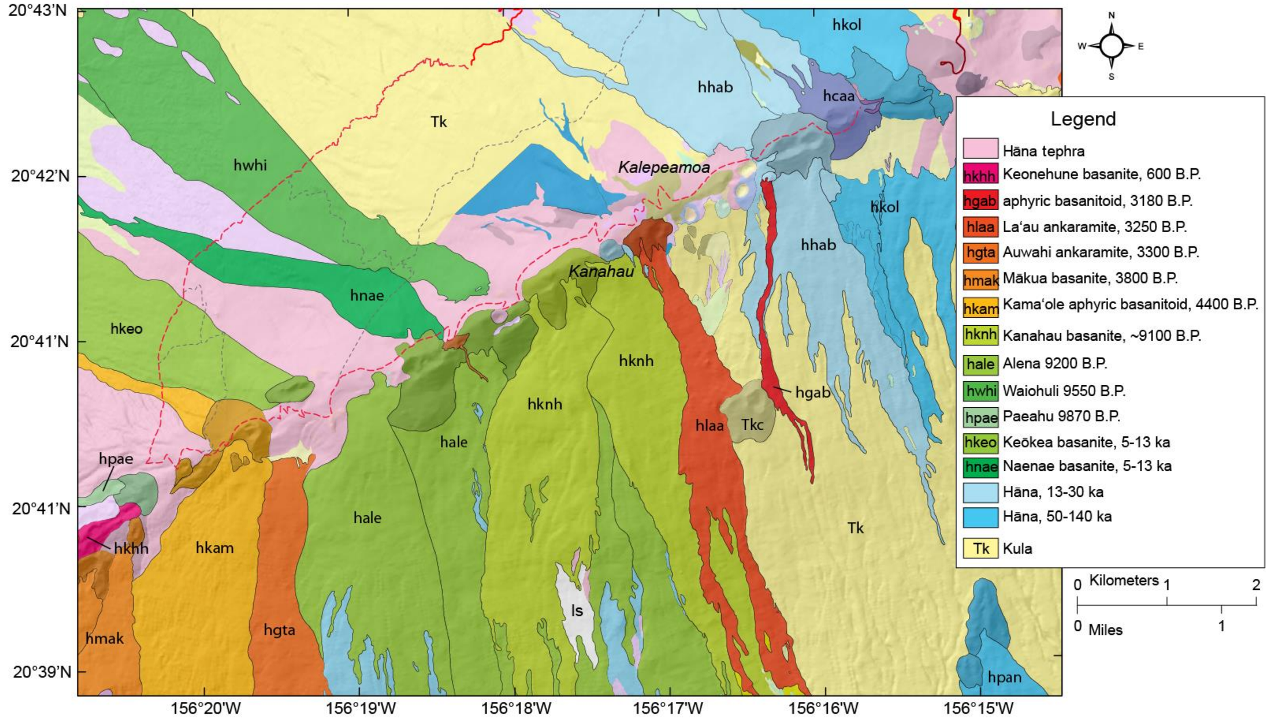

Figure 34. Geologic map of the upper southwest rift zone. Map data of Sherrod et al., 2007b, based on geologic mapping of Bergmanis et al., 2000 and Sherrod et al., 2004.

Na‘ena‘e/Alena

The Na‘ena‘e/Alena complex produced at least four different lava flows from a fissure system extending approximately 2 km along axis. One of these (hnae) flowed to the north, where it has been over-run by ~9550 B.P. Waiohuli lavas above Waipoli Road. Na‘ena‘e crater is the southernmost of the Na‘ena‘e vents and produced the large Alena flows (Table 4, Anal. 3), which flowed to the south around the Luala‘ilua Cones at about 500 m elevation. The vent area (Na‘ena‘e Crater) now is the deepest depression on the Southwest Rift Zone. The massive rock unit visible in the NE crater wall is ankaramite that was part of a lava pond in the vent area. This large depression formed by collapse, exposing the older ponded lava, following the main eruptive activity. Post-eruptive collapse is due to a combination of cooling and contraction of the underlying magma body and in-filling following expulsion of the large volume of magma. The magnitude of this depression is a manifestation of the large amount of magma that was present here. Just below the large crater is an alignment of low-lying spatter cones. These cones probably are “rootless”, i.e. were not part of the primary vent structure but rather mark the site of secondary explosions, possibly as the lava flowed over swampy ground. Farther down this flow are other “rootless” vent structures including a most fetching hornito (Fig. 35).

Just below Naʻenaʻe the trail leaves Hāna Volcanics and enters an older region of Kula cinder and lava covered by somewhat thicker soil horizons. Pigs enjoy the deep soil and abundant vegetation in this Kula kīpuka and devastation from their activity is especially prominent in this region.

Ballpark Junction

In the 1920s a major reforestation and conservation program was begun by the Territory of Hawaiʻi; it was continued in the 1930s by the federal Civilian Conservation Corps (see notes about Polipoli State Park later in this guide). The guys involved in these projects used the alluvium-filled depression, occurring within nested tephra cones for ball games. This area is still known as Ballpark Junction, as it occurs at the junction of the Skyline Trail with the jeep road leading to the hunters' shelter at Kahua. Two separate cones define the limits of the ballpark. The northern one produced a lot of hawaiite spindle bombs, many showing excellent bread-crust cooling patterns. The southern cone consists of much more fluid basaltic spatter. Naʻenaʻe/Alena lava flows occur along the southern and eastern edge of Ballpark, wrapping around the eastern side of the southern cone.

Ballpark to Polipoli

In addition to the lava flows from Naʻenaʻe and Alena that flowed into the area from the north, three other Hāna eruptions occurred in this area. Pu'u Kēōkea is an older Hāna vent, now modified by erosion and partially covered by cinder from the younger Hāna cone just above Polipoli. Cinder deposits exposed along the jeep track indicate that the Kēōkea eruption was a spectacular fire fountain of spatter. The next youngest eruption occurred ~4550 years ago, producing the Kamaʻole lavas; this is one of the largest eruptions known from the Southwest Rift Zone.

The youngest lava in this region (Auwahi - hgta, Fig. 34; Table 4, Anal. 4), erupted ~3300 B.P. Although this flow has a rather rough surface, it includes a large inflationary structure resembling a tumulus, and some collapse structures more typical of pāhoehoe lava. The flow is best classified as transitional between ʻaʻā and pāhoehoe. Its vent area is not a cone at all, but rather a low-lying, slightly collapsed lava pond area lying just below 2000 m elevation. The so-called giant tumulus is an inflationary structure showing a characteristic longitudinal crack in its rough surface. An extremely rare, native red geranium has found a surviving niche in this crack, presumably as a haven from voracious ungulates that are common in this region.

A large cinder cone and associated spatter vents about 1 km NE of Puʻu Polipoli produced the Kamaʻole series of lava flows. Kamaʻole lavas are somewhat unusual for Hāna Volcanics in being rather felsic (Table 4., Anal. 5), transitional to hawaiites, indicating that the magma was stored and cooled significantly prior to eruption. This flow is chemically identical to lava of the same age erupted from Puʻu Maile in Haleakalā Crater (Table 4, anal 6). The eruption here must have been quite a spectacle. Early phases of the eruption produced pāhoehoe lava from a now partially collapsed lava lake. The latest activity built a large cinder cone that partially buried the eastern rim of the lake. A small lava tube is present about 500 m south of the cone.

Figure 35. Hornito structure on west side of Alena ankaramite, close to the contact with older lavas and alluvium.

Polipoli State Park

In the 1800s and on into the last century much of the native forest of koa, ʻōhia and māmane was destroyed by cattle, goats, fires and lumbering. During the 1920's a major reforestation and conservation project was begun by the Territory of Hawaiʻi, and continued in the 1930s by the federal

Civilian Conservation Corps. The result of these efforts was the planting of hundreds of redwoods, eucalyptus, cypress, junipers, ash, sugi, cedar and various pines. The region around Polipoli spring now is a state park with an overnight campground, complete with spring water, flush toilets and parking lot, and a cozy cabin (reservations through DLNR-State Parks).

Along the Haleakalā Ridge Trail you can (some days) gain marvelous views down to the lower SW Rift Zone, Cape Kīnaʻu, Keoneʻōʻio, La Pérouse Bay and off-axis Pīmoe cone and flows. Further down the Ridge Trail leads to a dry cave cut into the Kula age Polipoli cinder cone. Massive ankaramite lava and a 30-cm dike can be observed in this cave. Trails heading north lead to an old Ranger's cabin and CCC bunkhouse, where an abundance of fuschia and hydrangea have been planted. The small native bird, ʻapapane loves fuschia nectar. You also might see ʻalauahio, the Maui creeper - a small greenish bird that gives a single chirp in this area. The forests of East Maui are the only known home to this bird. There also are vestiges of Methley plum trees planted earlier this century. These trees have all but been replaced by more aggressive species, however.

Although the forest around Polipoli State Park is not native, it is beautiful nonetheless. The commonly cloud-enshrouded Redwood Trail is as beautiful and magical as any in the world. The redwoods (*Sequoia sempervirens*) were planted in 1927; many have grown to heights of about 90 feet. Hiking in and around Polipoli is commonly damp and cool, and many of the trails are muddy.

Waipoli Road leads from Polipoli State Park down to Kula. Along the upper region of the road are isolated occurrences of ʻōhia, ʻiliahi (sandalwood) and native red geranium. The open grasslands below the forest are a popular area for hang- and para-gliding.

HONUAULA - LOWER SW RIFT ZONE, EAST MAUI VOLCANO

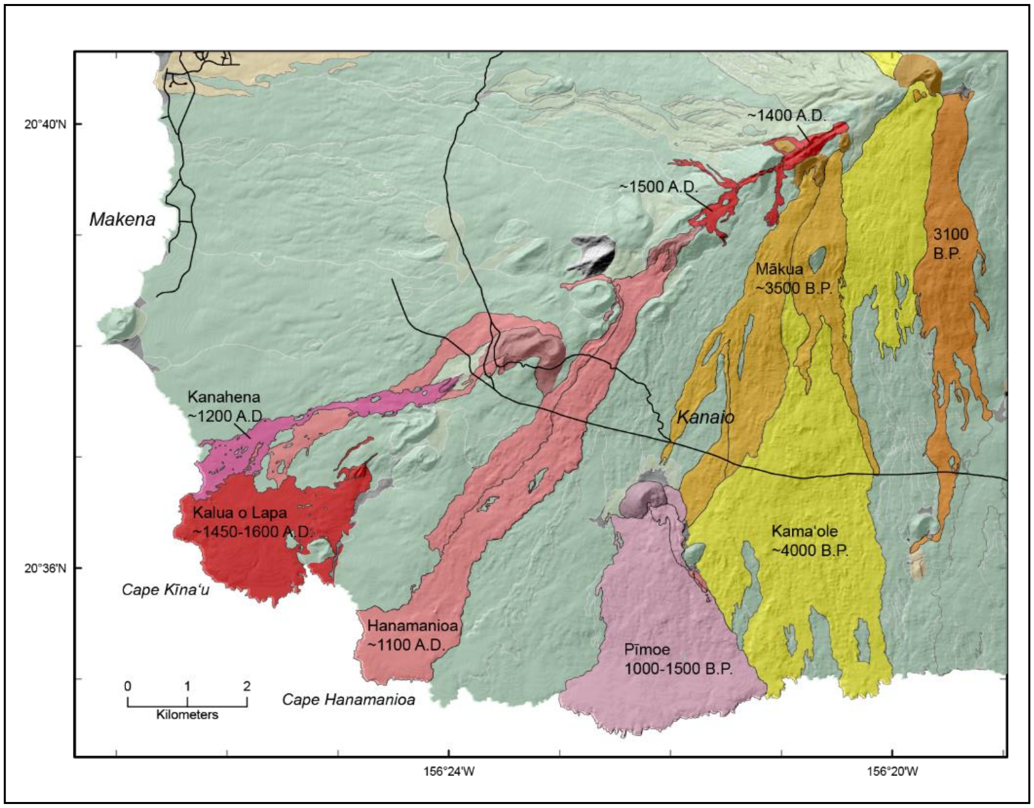

Figure 36. Geologic map of Honuaula area (after *Bergmanis et al.* [2000] and *Sherrod et al.* [2007b].

From Kahului take Route 350 toward Kīhei. Although the area of Waikapū is famous in song for the home of "Maui Girl", the most desirable are known to have come from Kīhei in earlier times. Take Route 31, which bypasses some of the more unfortunate aspects of modern Kīhei, toward Wailea and Mākena. This region is the driest on Maui, receiving less than 30 cm of rainfall each year, mostly between November and April. Road cuts along the road expose Kula volcanics hawaiites.

The southwest corner of East Maui is known as Honuaula (red land). Just beyond an unforgivable hotel near Mākena, the road passes behind Puʻu ʻŌlaʻi (see below).

Cape Kīnaʻu

Ankaramite lavas of Cape Kīnaʻu are almost certainly the youngest on Maui. In 1924, Lorrin Thurston, noting the young appearance of the lava at Cape Kīnaʻu, accumulated historical accounts in an attempt to determine its age. He found two accounts that are relevant. The first was one by J. D. Dana in his report for the U.S. Exploring Expedition:

> ***“I asked the natives if they knew when that flow occurred, and they told me that their grandparents saw it. They also told me that a woman and child were surrounded by the flow, but escaped after it cooled.”***

From this Thurston reasoned that the eruption must have occurred around 99 years prior to 1841, or about 1742 A.D., assuming 33 years for the length of a generation, and ages of ~33 years for the natives who told the story. However, *Stearns and Macdonald* [1942] suggested that Thurston’s use of 33 years as the length of a Hawaiian generation is too long, and that 23 years is better. Using 23 years, this account would suggest an age of **1772 A. D.**

In 1906 Thurston was camped on Haleakalā when he encountered a cowboy named Charlie Ako. Ako told Thurston:

> ***“I married a woman from Honuaʻula, and my father-in-law, of Honuaʻula, who died last year, at the age of 92 years, told me that when the flow at Keoneʻōʻio ran out, his grandfather saw it, and that, at that time, he (the grandfather) said he was old enough to carry two coconuts from the sea to the upper road.”***

From this Thurston reasoned that the eruption occurred about 1757 A.D., but using a 23-year generation length yields a somewhat younger “age.” Ako’s father-in-law was 92 in 1905, and hence was born in 1813. His father, perhaps born 23 years earlier in 1790, was the son of the boy who carried the coconuts (or maybe not - see below). A boy old enough to carry the coconuts “from the sea to the upper road” must have been at least 10 years old at the time. Hence, 1790-13 = **1777 A.D.**

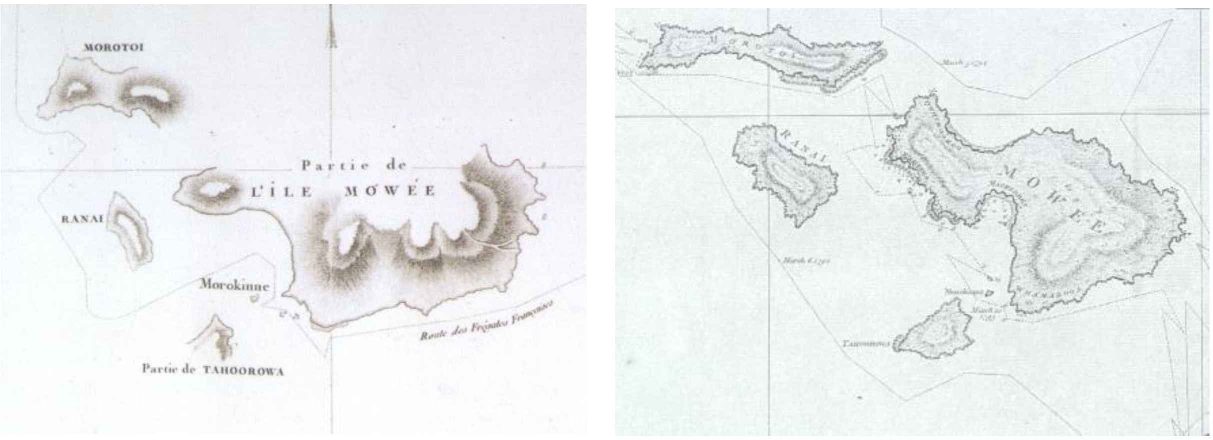

Figure 37. Maps produced during the expeditions of La Pérouse in 1786 (left) and Vancouver in 1792 (right) (from *Fitzpatrick,* [1986]. Cape Kīnaʻu is clearly evident in the 1792 map.

Here the matter rested until *Oostdam* [1965] studied maps made by some early western explorers (Fig. 36). In May of 1786, a French expedition consisting of two ships, *La Boussole* and *L'Astrolabe*, under the command of Captain Jean François de Galaup, Comte de La Pérouse anchored here and mapped a long, shallow bay from Cape Hanamanioa, about 4 km to the southeast, to Puʻu ʻŌlaʻi. La Pérouse and a landing party went ashore on 30 May, 1786, becoming the first non-Hawaiians to set foot on Maui. In 1792 Vancouver mapped the region and showed a large peninsula of lava in the bay. *Oostdam* [1965] thus reasoned that the eruptions that produced the lavas of Cape Kīnaʻu must have occurred between the visits of La Pérouse and Vancouver, and hence are dated at ~1790 A.D. The Hawaiian name for La Pérouse Bay is Keoneʻōʻio (bonefish beach). Kīnaʻu was the daughter of Kamehameha I and Kaheiheimalie, the wife of Kekuʻanaoʻa, and the mother of Kamehameha IV, Kamehameha V, Victoria Kamamalu and Kekuaiwa.

There actually are two lava flows making up Cape Kīnaʻu. From the maps of La Pérouse and Vancouver, it is clear that the younger lava making up Cape Kīnaʻu (Table 4, Anal. 9) probably was erupted before 1792. The age for the more westerly one, erupted from a vent about 3.7 km up on the SW rift zone, is not discernible in these maps. The younger flow to the southeast was erupted from Kalua o Lapa, a spatter cone about 2.5 km uprift. Both flows are ankaramites with large clinopyroxene and olivine phenocrysts, and rare, scattered xenocrysts of plagioclase; the two lavas are slightly different chemically.

Reber [1959] published a ^{14}C age that suggested that the younger flow was emplaced between 1670 and 1790 A.D. This more or less corresponds to the dates inferred by Thurston and Stearns and Macdonald. However, in 1959 the method of carbon-14 dating was still in its infancy and some researchers have suggested that this age might not be trustworthy. More recently, however, Sherrod and others have produced two additional ^{14}C ages for the Kalua o Lapa flow that suggest that this eruption may have taken place between 1450 and 1600 A.D. Taken together, the conflicting evidence makes it unclear exactly when the last eruption on East Maui took place. It almost certainly did not happen any later than Vancouver's visit in 1792 A.D., and it may have occurred as early as 1450 A.D. One issue that might explain the apparent discrepancy between the latest ^{14}C ages and oral histories compiled by Thurston is that in the Hawaiian language the same word (*kupuna*) is used for grandfather and more generally for ancestor. Whether or not the oral accounts were referring to persons two-generations removed from the storyteller, or more distant ancestors is unclear. According to *Sherrod* [written comm., 2001] the older lava making up Cape Kīnaʻu (hkan) is more than 900 yrs old.

The road crosses the Cape Kīnaʻu lavas, emerging at Keoneʻōʻio where there is a prehistoric cone at the head of La Pérouse Bay. Nearby lava is chemically different from the cone deposits and probably represents younger lava from Puʻu Naio. From Keoneʻōʻio a trail leads onto younger lavas (820 yrs B.P.) making up Cape Hanamanioa. This trail is known as the King's (Hoapiʻilani) Highway, which was used by high chiefs and royalty (and perhaps others); it previously ran all the way to Hāna. Built of fitted boulders and chunks of cinder, it is exceptionally well preserved along the south coast of East Maui.

Pu'u ʻŌlaʻi and Oneloa

Puʻu ʻŌlaʻi (earthquake hill) is another, slightly off-axis, Hāna volcanics vent. It erupted ankaramite lavas with rather coarse phenocrysts of olivine and clinopyroxene. There is a notch and terrace with sea shells about 8 m above present sea level. Pu'u ʻŌlaʻi is believed to be the head of a moʻo (lizard) who angered Pele by becoming the wife of Lohiʻau (her beloved). The tail of the moʻo became Molokini Islet. Molokini is the remnant of a tuff cone produced by hydromagmatic explosions during an offshore eruption about 150,000 yrs ago [*D. Sherrod*, written comm., 2001], making it late Kula or early Hāna in age.

On the south side of Puʻu ʻŌlaʻi is a long beach, locally known as Big Beach or Oneloa. During the 1960s this area became a preferred destination for alternative lifestyle practitioners of the time. By 1970 about 100 persons were living here in tents and shanties, but without adequate sanitation or water facilities, and it became known as Hippie Beach. By 1972, Maui police had evicted most of the transients from the area.

A short walk and climb over lava from Pu'u ʻŌlaʻi leads to the more secluded Puʻu ʻŌlaʻi Beach (Little Beach).

pau

Table 4. Chemical analyses of selected East Maui Hāna Volcanics

	1	2	3	4	5	6	7	8	9
	800 yrs B.P.				4550 yrs B.P.				
SiO_2	41.94	42.86	42.64	42.67	45.29	46.25	43.70	43.56	42.73
TiO_2	3.88	3.63	3.49	3.10	3.39	3.24	3.36	3.07	2.95
Al_2O_3	14.18	12.99	14.50	13.57	17.36	17.15	15.17	14.43	12.41
Fe_2O_3*	15.59	14.94	15.52	15.65	13.35	13.19	15.31	15.26	15.08
MnO	0.20	0.19	0.20	0.19	0.20	0.20	0.19	0.20	0.18
MgO	6.93	8.20	8.00	9.59	4.74	4.50	7.50	8.09	11.42
CaO	11.26	12.50	11.11	11.25	8.36	8.00	10.84	11.08	11.73
Na_2O	3.74	3.17	3.29	2.98	4.47	4.94	2.72	2.75	2.40
K_2O	1.45	1.28	1.02	0.68	1.80	1.71	1.19	1.10	0.87
P_2O_5	0.60	0.52	0.49	0.42	0.73	0.64	0.49	0.48	0.34
Sum	99.74	100.28	100.26	100.40	99.69	99.82	100.47	100.01	99.76
LOI			-0.46	-0.62	- 0.38		-0.50	-0.45	0.16
Trace elements (ppm)									
Sc	24	29	27	27	13	14	26	26	27
V	410	395	411	369	190	202	367	364	357
Cr	44	265	199	352	< 2	9	187	211	549
Ni	68	129	80	123	10	0	83	98	277
Zn	128	110	115	110	115	109	113	114	103
Rb	34	29	27	24	41	40	29	26	22
Sr	890	763	755	632	1179	1031	750	686	532
Y	23	27	28	26	33	30	29	27	25
Zr	261	234	206	191	264	252	196	210	165
Nb	57	50	42	38	69	63	46	43	34
Ba		518				739			417

Fe_2O_3* = total Fe as Fe_2O_3
LOI = loss on ignition at 900°C
All analyses by U. Hawai‘i XRF except anal. 6 (XRF at WSU).

1. Kalu‘u o ka‘ō‘ō basanite, Haleakalā Crater, EMH-60
2. Hanamanioa ankaramitic basanite, SW Rift Zone, ave of 4 analyses [Bergmanis et al., 2000]
3. Na‘ena‘e ankaramitic basanite; Middle SW Rift Zone, EMH-86
4. hgta ankaramitic basanite, near Polipoli, EMH-91
5. Kama‘ole aphyric basanite, BEM-66
6. Pu‘u Maile lava at charcoal locale; S97-HC65 [Sherrod, written comm., 1999]
7. Pīmoe olivine basanite, BEM-63
8. La‘au sparsely phyric ankaramitic basanite, Kepuni Gulch, BEM-8a
9. Ka lua o lapa ankaramitic basanite, Cape Kīna‘u; EMH-18

REFERENCES

Bergmanis, E. C., *Rejuvenated Volcanism Along the Southwest Rift Zone, East Maui, Hawaii: Eruptive History of the Hana Volcanics,* M. S. thesis, U. Hawaii, 1998.

Bergmanis, E. C., J. Sinton, and F. Trusdell, Rejuvenated Volcanism Along the Southwest Rift Zone, East Maui, Hawaii *Bull. Volcanol. 62,* 239-255, 2000

Chen, C-Y., F. A. Frey, and M. O. Garcia, Evolution of alkalic lavas at Haleakala volcano, East Maui, Hawai‘i, *Contr. Mineral. Petrol., 105*, 197-218, 1990.

Chen, C-Y., F. A. Frey, M. O. Garcia, G. D. Dalrymple, and S. R. Hart, The tholeiite to alkalic basalt transition at Haleakala volcano, Maui, Hawai‘i, *Contr. Mineral. Petrol., 106,* 183-200, 1991.

Clark, J. R. K., *The Beaches of Maui County,* Univ. Hawaii Press, Honolulu, 161 pp, 1980.

Coe, R. S., V. Hsu, S. Rowland, and D. Miller, Brunhes-Matuyama transition recorded in lavas on Maui, *Eos Trans. Amer. Geophys. Union, 65,* 869, 1984.

Coe, R. S., V. Hsu, and F. Theyer, Matuyama-Brunhes record from Maui: transitional directions, *Eos Trans. Amer. Geophys. Union, 66,* 872, 1985.

Coombs, D. S., and J. F. G. Wilkinson, Lineages and fractionation trends in unsaturated volcanic rocks from the East Otago Volcanic Province (New Zealand) and related rocks, *J. Petrol., 10,* 440-501, 1969.

Crandall, D. R., Potential hazards from future volcanic eruptions on the island of Maui, Hawaii, *U. S. Geol. Surv. Misc. Invest. Series, Map I-1442*, 1983.

Diller, D. E., *Contributions to the geology of West Maui Volcano, Hawaii*, M.S. thesis, Univ. Hawaii, Honolulu, 237 pp., 1982.

Easton, R. M., and M. G. Easton, *Highway Geology of the Hawaiian Islands*, Brampton, Ontario, Canada, 168 pp., 1987.

Fitzpatrick, G. L., *The Early Mapping of Hawaiʻi*, Editions Ltd., Honolulu, 160 pp., 1986.

Hammer, J., S. Jacob, B. Welsch, E. Hellebrand, and J. Sinton, Clinopyroxene in postshield Haleakala ankaramite: 1. Efficacy of thermobarometry, Contr. Mineral. Petrol., 171, 2016.

Kurz, M., Cosmogenic helium in a terrestrial igneous rock, *Nature, 320*, 435-439, 1986.

Kyselka, W., and R. Lanterman, *Maui, How it Came to Be*, Univ. Hawaii Press, Honolulu, 159 pp., 1980.

Macdonald, G. A., Composition and origin of Hawaiian lavas, *Geol. Soc. Amer. Mem*., *116*, 477-522, 1968.

Macdonald, G. A., Composite lava flows on Haleakala Volcano, Hawaii, *Geol. Soc. Amer. Bull., 83,* 2971-2974, 1972.

Macdonald, G. A., Geologic map of the crater section of Haleakala National Park, Maui, Hawaii, *U. S. Geol. Surv. Misc. Invest. Ser., Map 1088*, 1978.

Macdonald, G. A., A. T. Abbott, and F. L. Peterson, *Vocanoes in the Sea*, 2nd edition., Univ. Hawaii Press, Honolulu, 517 pp., 1983.

Macdonald, G. A., and T. Katsura, Chemical composition of Hawaiian lavas, *J. Petrol., 5,* 82-133, 1964.

Macdonald, G. A., and H. A. Powers, A further contribution to the petrology of Haleakala Volcano, Hawaii, *Geol. Soc. Amer. Bull., 79*, 877-888, 1968.

McDougall, I., Potassium-argon ages from lavas of the Hawaiian Islands, *Geol. Soc. Amer. Bull., 75*, 107-128, 1964.

Naughton, J. J., G. A. Macdonald, and G. A. Greenberg, Some additional potassium-argon ages of Hawaiian rocks: the Maui volcanic complex of Molokai, Maui, Lanai and Kahoolawe, *J. Volcan. Geotherm. Res., 7*, 339-355, 1980.

Oostdam, B. L., Age of lava flows on Haleakala, Maui, Hawaii, *Bull. Geol. Soc. Amer., 76*, 393-394, 1965.

Presley, T. K., J. M. Sinton, and M. Pringle, Postshield volcanism and catastrophic mass wasting of the Waianae volcano, Oahu, Hawaiʻi, *Bull. Volcanol., 58*, 597-616, 1997.

Price, J. P. and D. Elliot-Fisk, Topographic history of the Maui Nui complex, Hawaiʻi, and its implications for biogeography, *Pac. Sci*., in press, 2003.

Pukui, M. K., S. H. Elbert and E. T. Mookini, *Place Names of Hawaii*, Univ. Hawaii Press, Honolulu, 289 pp., 1974.

Reber, G., Age of lava flows on Haleakala, Hawaiʻi, *Geol. Soc. Amer. Bull., 70*, 1245-1246, 1959.

Roelofs, F., *In the Land of Na Wai ʻEha, Waiheʼe Trail and Halekiʼi*, Moanalua Gardens Foundation, Honolulu, 36 pp., 1993a.

Roelofs, *High and Wild, Waikamoi and Halemauʼu Trail*, Moanalua Gardens Foundation, Honolulu, 24 pp., 1993b.

Sherrod, D. R., and J. P. McGeehin, New radiocarbon ages from Haleakala Crater, island of Maui, HawaiʻI, *U.S. Geol. Surv. Open-File Rept. 99-143*, 14 pp, 1999.

Sherrod, D. R., t. Murai, and T. Tagami, New K-Ar ages for calculating end-of-shield extrusion rates at West Maui volcano, Hawaiian island chain, *Bull. Volcanol., 69*, 627-642, 2007a.

Sherrod, D. R., Y. Nishimitsu and T. Tagami, New K-Ar ages and the geologic evidence against rejuvenated-stage volcanism at Haleakalā, East Maui, a postshield-stage volcano of the Hawaiian island chain, *Bull. Geol. Soc. Amer*., 115, 683-694, 2003.

Sherrod, D. R., J. M. Sinton, S. E. Watkins, and K. M. Brunt, Geologic Map of the State of Hawaiʻi, *U.S. Geol. Surv. Open File Rept. 2007-1089*, 2007b.

Sinton, J. M., Geologic history of Maui, p. 1-12 in Sinton, J. M., (editor), *Field Trip Guide to Maui, Geol. Soc. Amer. 83rd Cordill. Sect. Mtg*, 83 pp., 1987.

Sinton, J. M., D. E. Diller and C-y. Chen, Geology and petrological evolution of West Maui Volcano, p. 13-30 in Sinton, J. M., (editor), *Field Trip Guide to Maui, Geol. Soc. Amer. 83rd Cordill. Sect. Mtg*, 83 pp., 1987.

Stearns, H. T., Map of the island of Maui, Hawaii, showing points of geological interest, Supp. *Haw. Div. Hydrogr. 7*, 1942a.

Stearns, H. T., Origin of Haleakala Crater, island of Maui, *Hawaii, Haw. Div. Hydrogr. Bull., 53*, 1-14, 1942b.

Stearns, H. T., and G. A. Macdonald, Geology and groundwater resources of the island of Maui, Hawaii, *Haw. Div. Hydrogr. Bull., 7,* 344 pp., 1942.

Sterling, E. P., *Sites of Maui*, Bishop Museum, Honolulu, 285 pp., 1998.

Tagami, T., Y. Nishimitsu, and D. R. Sherrod, Rejuvenated-stage volcanism after 0.6-m.y. quiescence at West Maui Volcano, Hawaiʻi: new evidence from K-Ar ages and chemistry of Lahaina Volcanics, *J. Volcanol. Geotherm. Res., 120*, 207-214, 2003.

Tatsumoto, M., E. Hegner, and D. M. Unruh, Origin of the West Maui volcanic rocks inferred from Pb, Sr and Nd isotopes and a multicomponent model for oceanic basalts, *U.S.G.S. Prof. Paper 1350*, 723-744, 1987.

West, H. B., and W. P. Leeman, Petrology and geochemistry of lavas from Haleakala Crater, Hawaii: an overview, p. 45-66 in Sinton, J. M., (editor), *Field Trip Guide to Maui, Geol. Soc. Amer. 83rd Cordill. Sect. Mtg*, 83 pp., 1987.

West, H. B., and W. P. Leeman, The open-system geochemical evolution of alkalic cap lavas from Haleakala Crater, Hawaiʻi, USA, *Geochem. Cosmochim. Acta, 58*, 773-796, 1994.