Wai‘anae Field Trip

Wai‘anae literally means *mullet water*, presumably a reference to good mullet fishing here. Place name definitions and ‘ōlelo no‘eau (legends or sayings) come from Place Names of Hawaii by Pukui, Elbert, and Mookini, and from Sites of Oahu by Sterling and Summers. *"Ka lā kapakahi ma Wai‘anae" - the one-sided (or lopsided) sun of Wai‘anae, refers to the fact that the mountains are high on the east, so the sun mainly shines from the west.*

Field guide prepared by John Sinton and Scott Rowland, in support of a field trip by University of Hawai‘i at Mānoa, Department of Geology and Geophysics graduate students.

April, 2018.

Geology & Geophysics

The Geology of O‘ahu

The island of O‘ahu is dominated by two major mountain ranges that are the remnants of two major Hawaiian shield volcanoes (Wai‘anae and Ko‘olau - *windward*), in addition to younger rejuvenated-stage volcanism of the Honolulu Volcanics

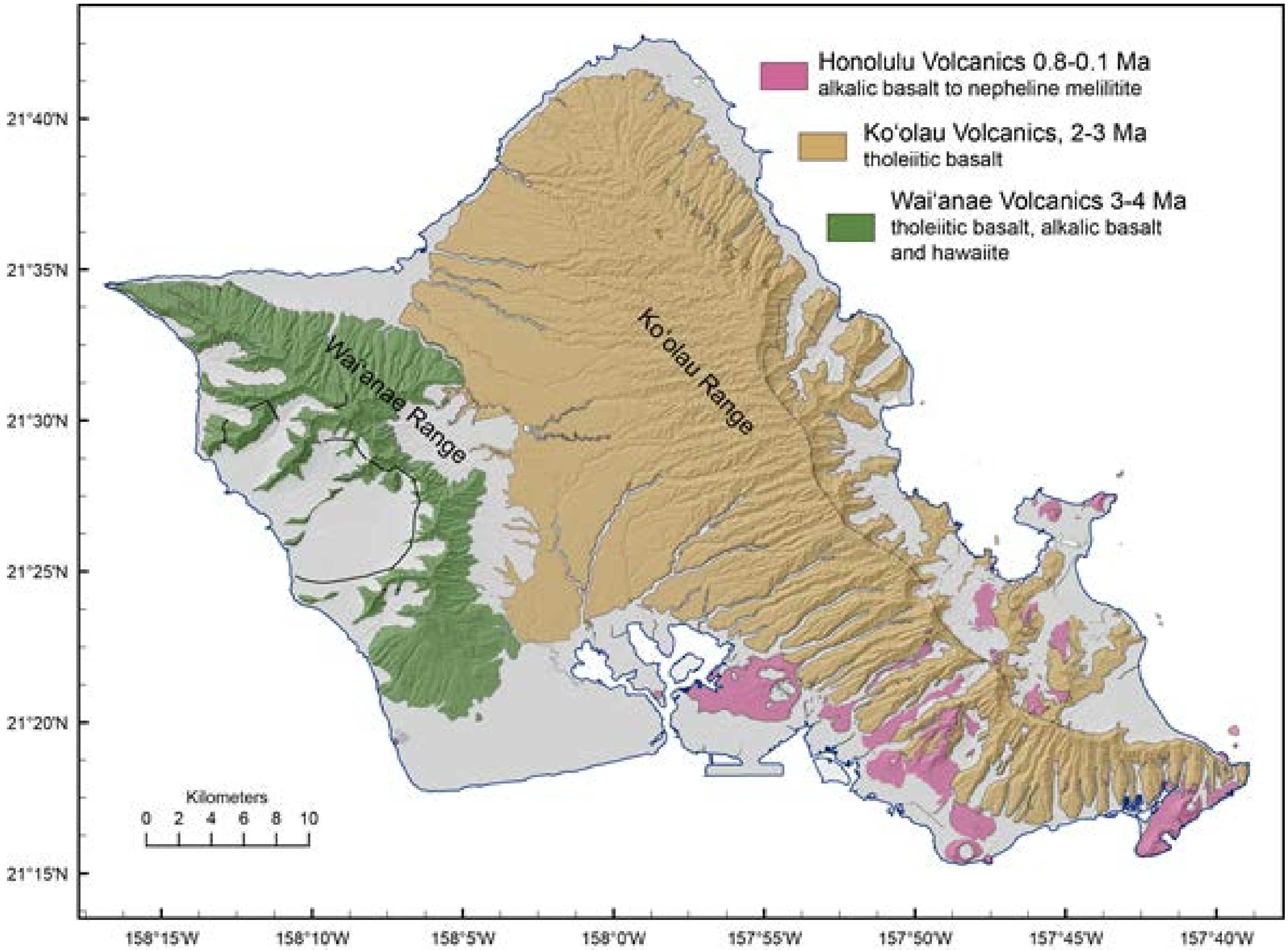

Figure 1. The island of O‘ahu, Hawai‘i, showing the distribution of principal physiographic and geological units. The Wai‘anae and Ko‘olau ranges represent the remnants of individual major shield volcanoes.

Study of the submarine region around O‘ahu (Figure 2) has revealed that Wai‘anae and Ko‘olau were built on the flanks of an earlier volcano called Ka‘ena (*the heat*), which was active from approximately 5 to ~3.5 Ma [*Sinton et al., 2014*]. Although now submerged, Ka‘ena reached a maximum elevation of ~1000 m above sea level near the end of its activity. The recognition of a precursor volcano of the island of O‘ahu explains aspects of the structures of the subaerial volcanoes as well as some enigmatic geochemical features of Wai‘anae.

Wai‘anae Volcano

Presently exposed lavas of Wai‘anae represent the subaerial shield and postshield stages of Hawaiian volcanism, and range in age from about 3.9 to 2.8 Ma. This period of Earth history is one of relatively closely spaced magnetic polarity reversals, spanning the Gilbert (>3.55 Ma) and Gauss (<3.55 Ma) Chrons, the latter including the Ka‘ena and Mammoth reversed-polarity subchrons (Figure 3). The rock units that make up the Wai‘anae Volcano are known as the Wai‘anae Volcanics, which has been divided into four sub-units or Members (Figures 3, 5).

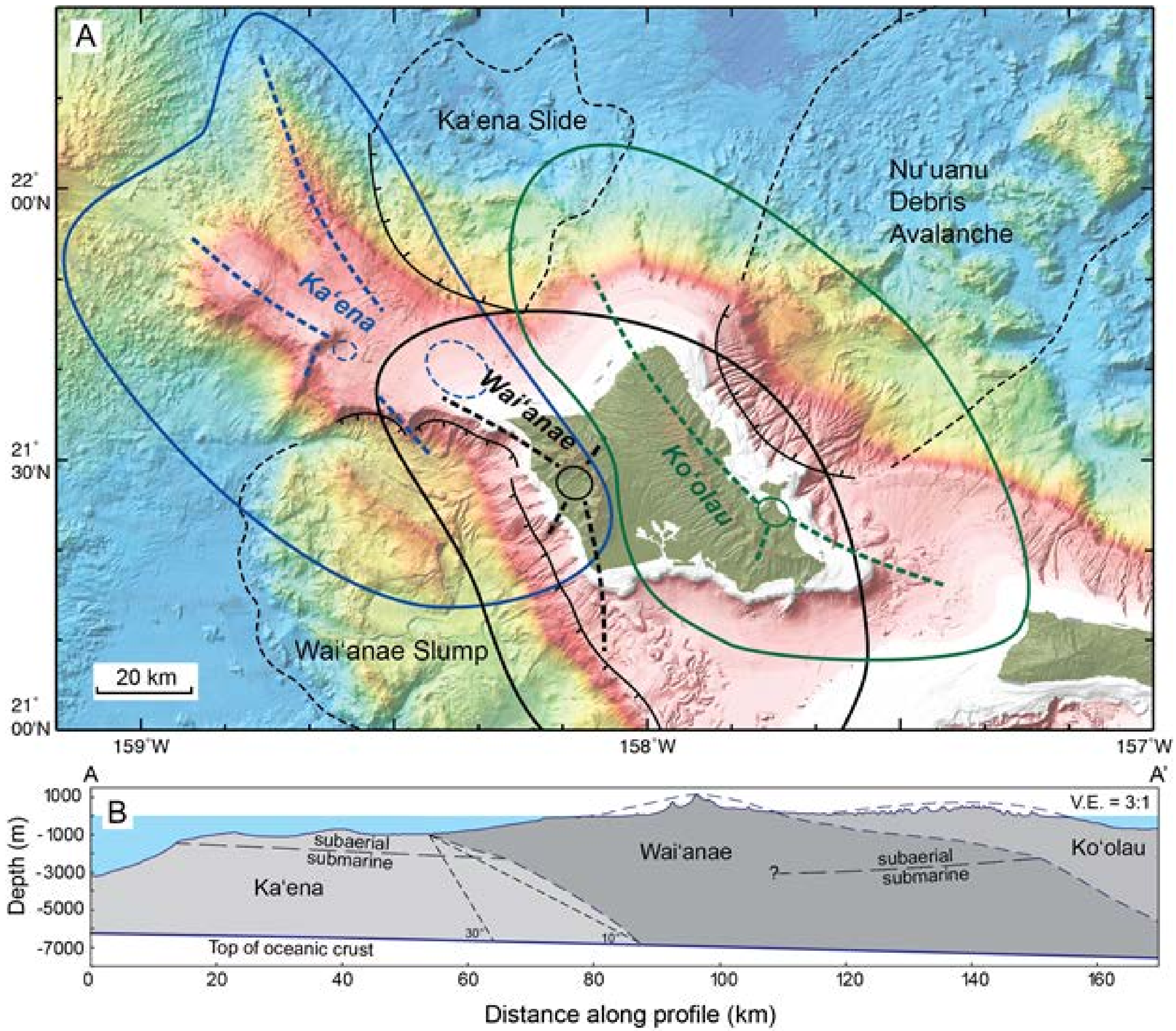

Figure 2. Map of the region around O‘ahu showing the island complex to consist of an assemblage of three separate but overlapping major shield volcanoes. Also shown are major landslide deposits. Figure from *Sinton et al.* [2014].

The oldest exposed lavas of the Wai‘anae Volcano comprise a shield-building stage dominated by the eruption of tholeiitic olivine basalts. These lavas are the reversely magnetized, ~3.9-3.55 m.y.-old Lualualei Member of the Wai‘anae Volcanics. A well-developed caldera in the vicinity of Lualualei Valley was present throughout this stage, along with one, well-developed rift zone trending approximately N60°W from near Kolekole Pass. To the south, dike orientations are less parallel and more radial (Figure 4).

A possible third, poorly developed rift zone has an orientation of approximately N65°E. Dikes of these three trends intersect near Pu’u Ka‘īlio near the back of Lualualei Valley. Lualualei lavas are mainly exposed near Pu‘u Heleakalā and Pu‘u o Hulu on the south side of Lualualei Valley, outside of the caldera boundary fault.

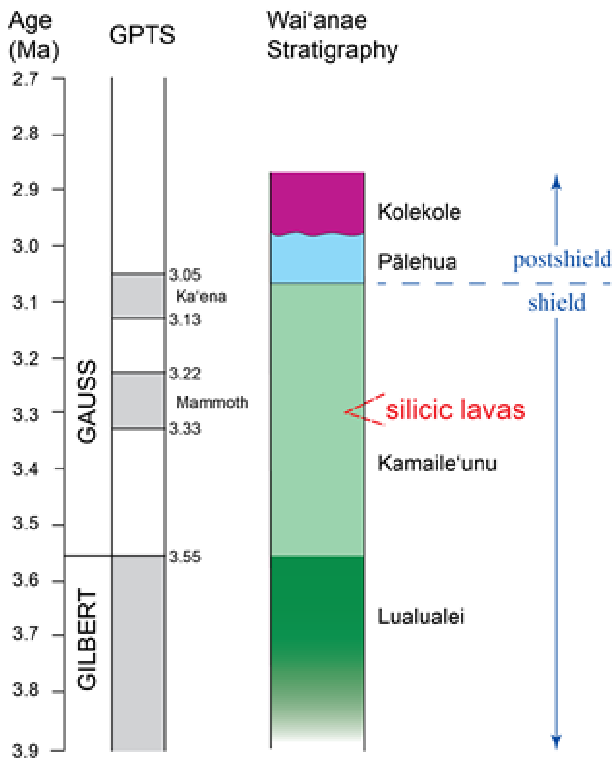

Figure 3. Wai‘anae stratigraphy, compared to the geomagnetic polarity time scale (GPTS) of *Cande and Kent* [1992], showing the age limits of the Ka‘ena and Mammoth reversed-polarity subchrons within the Gauss Normal-Polarity Chron.

A later shield-building stage (~3.55-~3.06 Ma) is characterized by increasing variability of lava compositions, including plagioclase-bearing tholeiitic and alkalic basalts, and basaltic hawaiites of the Kamaile‘unu Member of the Wai'anae Volcanics. Eruptions of Kamaile‘unu lavas occurred within the caldera and along rift zones. The caldera eventually was filled by Kamaile‘unu lavas, and this period can be viewed as a caldera-filling sequence. Kaua‘ō pu‘u, Mauna Kūwale, Pāhe‘ehe‘e, Mā‘ili‘ili and Kamaile‘unu ridges are built of lavas of this period. Near Mauna Kūwale and elsewhere toward the back of Lualualei Valley, silicic lavas are exposed as intracaldera dikes and flows, and constitute the only known silicic (icelandite and rhyodacite) lavas of the Hawaiian chain.

Postshield Volcanism

The postshield "alkalic cap" of Wai‘anae volcano includes alkalic hawaiites and rarer mugearites of the Pālehua Member of the Wai‘anae Volcanics. This sequence is exposed best on the NE and southern flanks of the volcano, particularly near Pālehua and above Mokulē‘ia, and represents eruptions along NW- and SSE-trending rift zones. Most Pālehua lavas are normally magnetized but the type locality for the Ka‘ena reversed-polarity subchron is a thick Pālehua hawaiite flow near Mokulē‘ia. The age of Pālehua Member lavas is approximately 3.06-2.98 Ma.

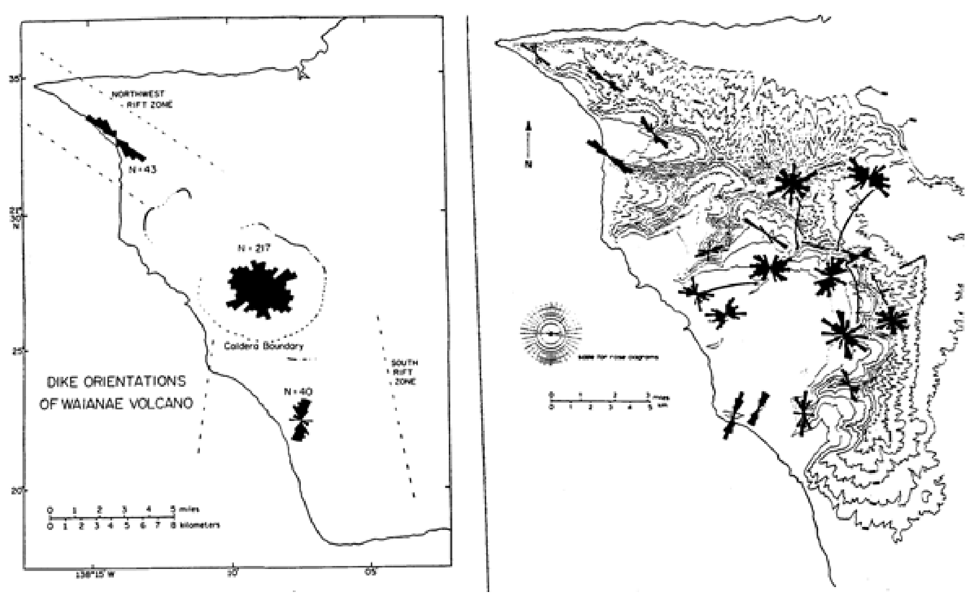

Figure 4. Dike orientations in Wai‘anae Volcano [*Zbinden and Sinton*, 1988]. The figure on the right shows orientations in individual localities; the figure on the left shows integrated orientations for the northwest rift zone, caldera region, and south rift zone

A major unconformity locally separates Pālehua hawaiites from the "last gasp" of the Wai‘anae volcano, which marks a return to generally basaltic eruptions of the Kolekole Volcanics. These lavas commonly contain xenoliths of lower crustal dunites, pyroxenites and gabbros. Kolekole volcanism extended from the young cones and flows of Pu‘ukapua‘i, Pu‘uku‘ua, Pu‘umakakilo, Pu‘upālailai and Pu‘ukapolei on the southern end of the Wai‘anae Range, a "post-erosional" flow at Kolekole Pass, the summit region of Mt. Ka‘ala (the highest point on O‘ahu), and Pahole and Kuaokalā regions in the northern part of the Wai‘anae Range. The age of Kolekole eruptions is barely distinguishable from the earlier Pālehua lavas, with the transition occurring about 2.98 m.y. ago. Although short-lived, the profound erosional event about 2.98 m.y. ago correlates with a significant change in the degree of differentiation of erupted lavas. This suggests that a catastrophic erosional event at this time led to substantial changes in the plumbing system of the volcano; this event may be associated with the offshore submarine landslide deposit present on the south side of Wai‘anae Volcano (Figs. 2 and 7).

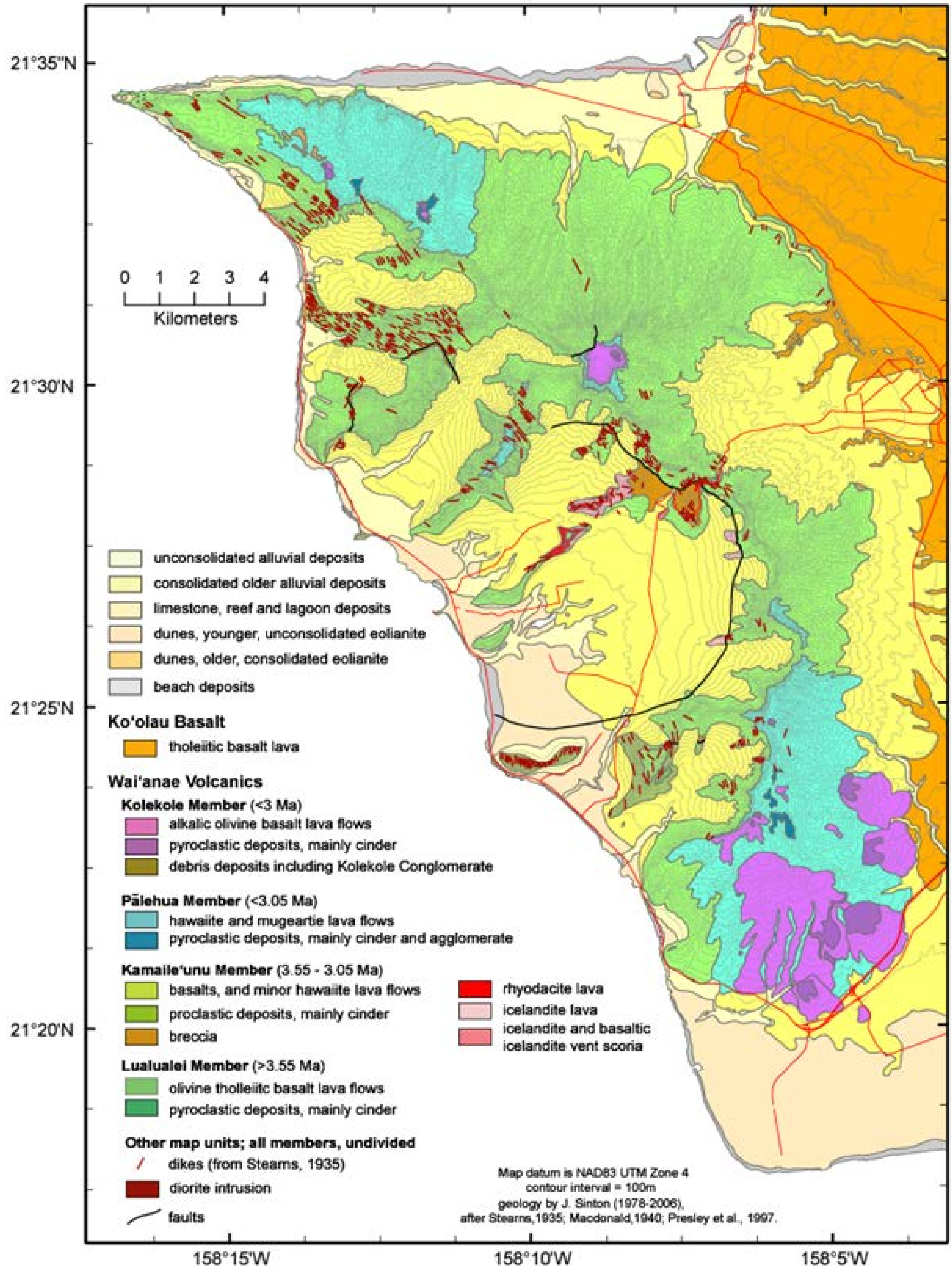

Figure 5. Geologic map of the Wai‘anae Range, modified after *Stearns* [1939], *Macdonald* [1940], *Sinton* [1986] and *Presley et al.* [1997].

Postshield Volcanism

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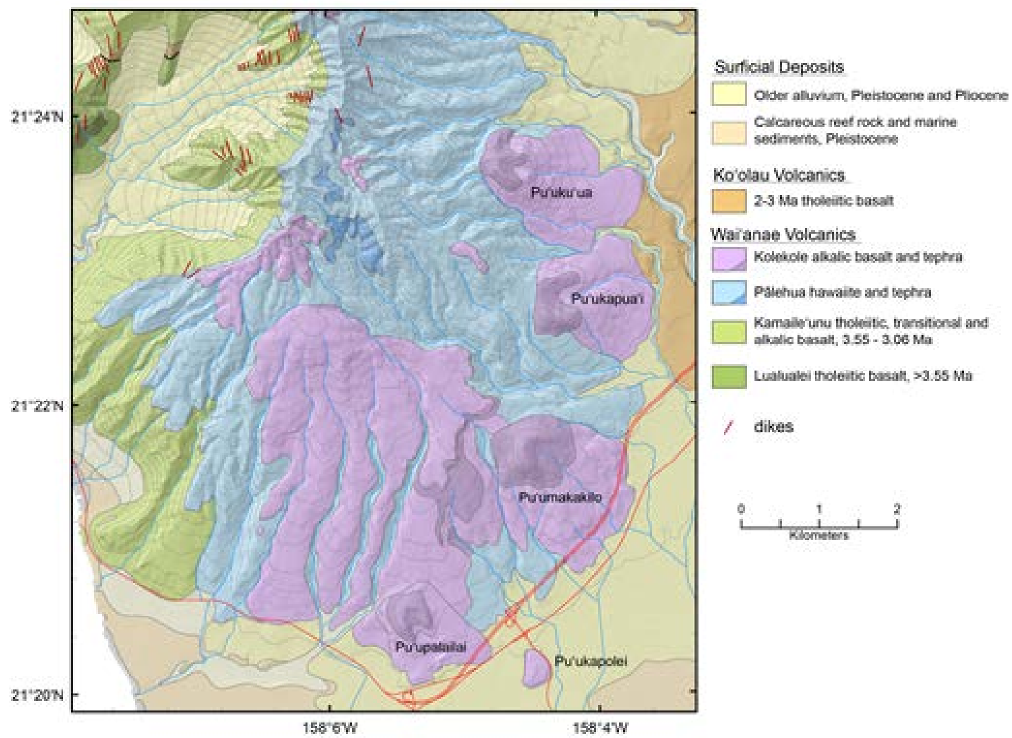

Figure 6. Geologic map of the southern end of the Waiʻanae Range, showing the distribution of postshield (Pālehua and Kolekole) volcanic units. The constructional morphology of the Kolekole cones and flows is well preserved, despite their ~3 Ma age. In contrast, underlying Palehua strata are much more eroded with more prominent and deeper gullies.

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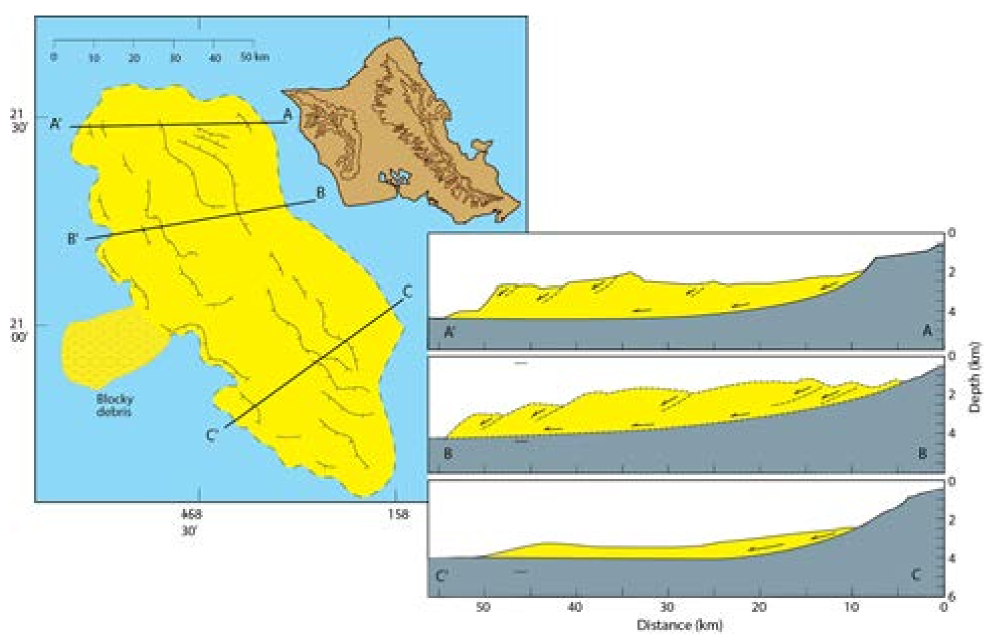

Figure. 7. Map and cross-sections through the Waiʻanae slump (after Presley et al., 1997]

Clastic Deposits

In addition to the above lavas, some clastic deposits are locally exposed. These include fault breccias, best exposed at Puʻu Kaʻīlio and in the saddle north of Puʻu Heleakalā. These breccias apparently were shed off of faults along the caldera boundary and other fault scarps, with caldera-filling lavas ponded against them. Mudflow deposits have been mapped in the saddle of Kolekole Pass and at the base of the ridge north of Kunia.

Magmatic Evolution

As in all Hawaiian volcanoes, the shield stage is dominated by high magma supply to magma chambers lying only a few km below the summit. By the end of Kamaileʻunu time Waiʻanae Volcano was no longer centered over the hotspot. Magmas became more alkalic as extent of mantle melting and the supply of magma into the volcano both decreased. Infrequently-fed, shallow magma chambers crystallized, and were replaced by deeper magma storage areas, perhaps near the base of the crust or the upper mantle. Eruption of magma from deep reservoirs was inhibited so that only differentiated magmas (hawaiites) were buoyant enough to find their way to the surface, a situation that apparently persisted throughout Pālehua time.

The end of Pālehua volcanism marks a fundamental change in the magmatic evolution of Waiʻanae volcano. Following the major erosional event separating Pālehua from Kolekole, the plumbing system was changed so that more mafic magmas from deep in the crust (Kolekole basalts) were erupted, carrying with them wall-rock fragments (xenoliths) of the deep crustal magma chamber.

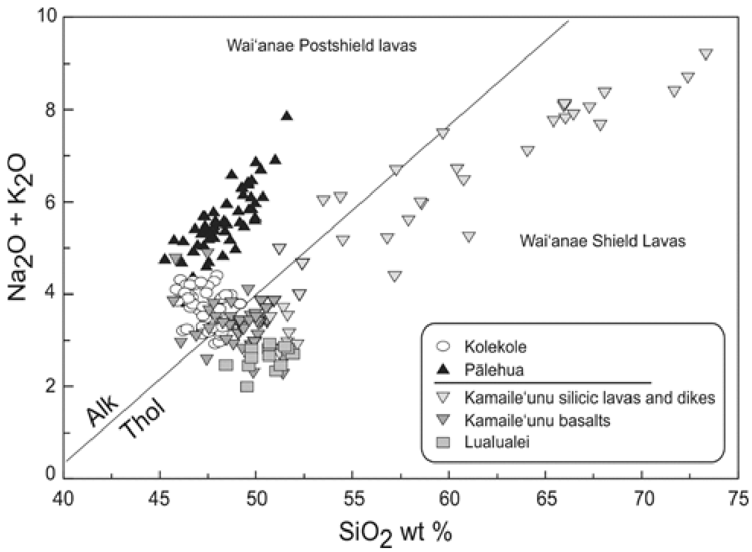

Figure 8. Alkali-silica diagram for Waiʻanae volcanic rocks. The line separating alkalic from tholeiitic compositions is from Macdonald [1968]

Pleistocene Deposits

Exposures of Pleistocene carbonates are widespread on Oʻahu, and especially so around the Waiʻanae coast. These deposits are mainly found 5-10 m above present sea level and are referred to in Hawaiʻi as the Waimānalo stand of the sea. This "stand" has been correlated with marine isotope stage 5e, dating to the last major inter-glacial period ~125,000 yrs ago.

Carbonates are also locally exposed at higher levels, most notably up to +28 ± 2 m; carbonates at this level are common around Kaʻena Point and these deposits are said to have formed from the Kaʻena stand of the sea. Modern interpretations have correlated the Kaʻena stand with an inter-glacial period about 500 ka.

There are many more exposures of "raised reef" on Oʻahu, than on any other Hawaiian Island. The reasons for this are unclear, but one explanation is that Oʻahu may have recently been uplifted, possibly as a flexural response to present-day loading on the Pacific Plate in the vicinity of the Big Island.

ʻEwa Plain, Kahe and Nānākuli Beach Parks

The entire ʻEwa Plain is a "raised reef" exposed either as the sea retreated to lower stands, and/or possibly by uplift of Oʻahu. This reef complex and associated eolian deposits (wind-deposited dunes) can be traced around much of the Waiʻanae coastline, including the beach parks at Kahe and Nānākuli, where excellent exposures of the fossiliferous reef complexes are best seen. These are all part of the so-called Waimānalo stand of the sea, dating to the last major inter-glacial period ~125,000 yrs ago.

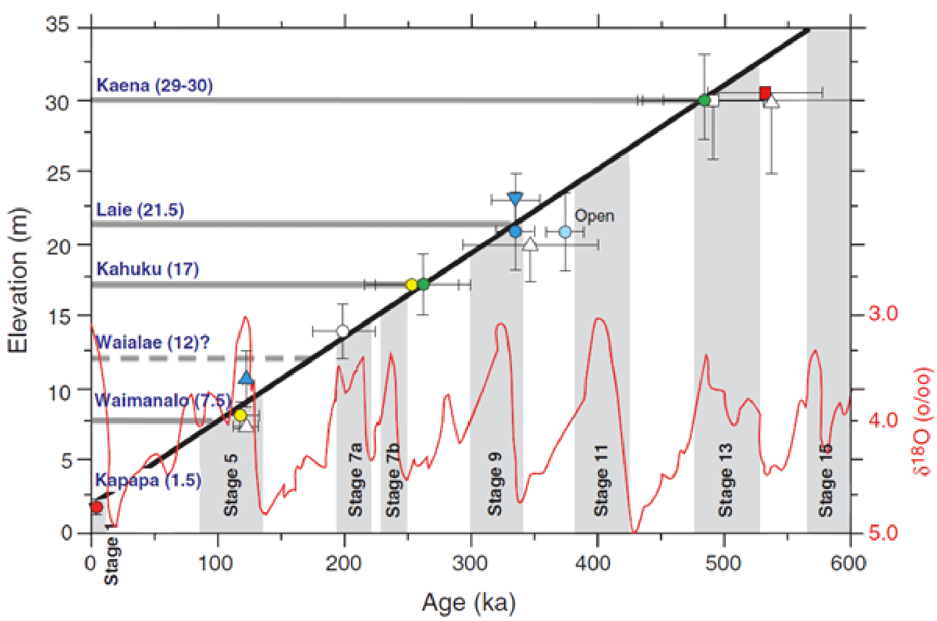

Figure 9 (from McMurtry et al. 2010). Graph of elevation above present mean sea level vs. age for coral samples on O‘ahu. The red line is benthic oxygen isotope data, and the grey bars indicate interglacial periods.

Slightly acidic rainwater has dissolved out sinkholes in the ‘Ewa plain. Bones of many species of prehistoric birds and shells of tree snails have been found in sinkholes at Barber’s Point. There is evidence for forty-five or more species, including ibises, two or three species of huge flightless geese, small or medium size flightless rails, the long-legged O‘ahu owl, crows similar to the severely endangered ‘alala, an eagle, ravens, and a plethora of songbirds including ‘ō‘ō and numerous finches, many of which vanished just prior to Polynesian colonization, apparently in response to rapid climate change.

ITINERARY

From Honolulu we will travel over shield lavas of the younger (2-3 Ma) Ko‘olau volcano. Even younger (<~0.7 Ma) lavas of the rejuvenation stage Honolulu Volcanics are exposed near Middle Street (Kalihi flow) and Āliamanu in Honolulu.

Pearl Harbor is a drowned river valley (estuary). The valleys were cut into Ko‘olau Volcanics and later coastal deposits during lower stands of the sea (or before O‘ahu subsided to its present level).

Ko‘olau lavas are exposed all the way to Honouliuli. These lavas presently lie more than 20 km from the axis of the Ko‘olau rift zone, from which they presumably were erupted. Most of the Ko‘olau lavas that ponded against older Wai‘anae lavas are dense pāhoehoe, similar to that emerging from lava tubes on the south flank of Kīlauea today. Lava tubes are an excellent way to insulate lava, thereby allowing it to travel great distances at high temperature. Many of the residual boulders exposed along Kunia Road are extremely olivine-rich Ko‘olau basalts or picrites.

Follow H-1 to the exit for Makakilo, Kapolei and KaLae (Barber’s Point). Turn south (toward Kapolei) on route 901; Just after crossing Farrington Hwy take the right turn into Kapolei Regional Park.

Stop 1. Kapolei Regional Park

Pu‘u-o-kapolei is the southern-most exposed outcrop of the Wai‘anae volcano. It is a Kolekole member cone and flow, and therefore part of the latest stage of the Wai‘anae Volcano. The lavas here contain abundant fragments of deep-seated rocks and minerals, including dunite, clinopyroxenite, gabbro, and single large crystals of pyroxene and feldspar. But we are here mainly for the views; best location for rock and mineral prospecting is in the drainage ditch along Fort Barrette Road. To the north lies the southern flank of the Wai‘anae Range, dominated by the Kolekole vents Pu‘umakakilo (observing eyes hill), now a residential area, and Pu‘upālailai (the young lai fish hill), once an important source of black glass used for cutting tools, but now largely modified by quarrying and later land-filling. The striking difference between heavily gullied Pālehua slopes and younger, nearly unmodified by erosion Kolekole vents and flows can be seen here. It really is a striking contrast, despite that the ages of the two units is barely discernible by the K-Ar dating method.
Puu-o-kapolei has seen many changes. Named for Kapo, a sister of Pele it used to be the site of the largest heiau in all of ‘Ewa, which was dismantled as a source for road metal during construction of Farrington Highway in the 1920’s. The pig-man Kamapua‘a established his grandmother here as queen after conquering most of O‘ahu.

Later, much of the cinder here was quarried away when the area was taken over by the U.S. Army, who renamed the site Fort Barrette. The area is now a district park under the jurisdiction of the City and County of Honolulu.

Return to H-1 westbound; right on Fort Barrette Road (901), again on Kamaaha Ave, and once again on Wakea St. Follow the signs to Rte 93and H-1 west.

The regional slope of the Wai‘anae Volcano and the boundary separating Kamaile‘unu and Pālehua lavas are visible to the east. Pālehua hawaiites occur as thick-bedded, light colored flows overlying thinner bedded, more mafic Kamaile‘unu basalts. The contact runs through Pōhākea Pass. *Pōhā* is short for *pōhaku* (stone or rock), and *kea* is the Hawaiian word for white; thus this pass is named for the light colored hawaiites present there. They are light colored and rich in plagioclase.

Near the Hawaiian Electric power plant at Kahe (*flow*), and for the next mile or so along Farrington Hwy, Kamaile‘unu member lavas dip generally to the south, characteristic of the southern flank of the former shield. The first large valley we come to along Farrington Hwy is Nānākuli. Nānākuli is the southernmost ahupua‘a of the Wai‘anae district, one of the original *moku* (districts) established by Ma‘ilikukahi, ruler of O‘ahu in the 1500’s. In the olden days this place was sparsely inhabited because of the scarcity of fresh water. Fishing was good but planting was poor. Because of the scarcity of water and vegetables, the inhabitants of Nānākuli were ashamed to greet passing strangers, and so would remain out of sight or look downward to avoid eye contact and the need to extend hospitality. Thus the place became known for the peculiar traits of the people there, as Nānākuli means “to look at knee or look deafly”.

All the hillsides and ridges around Nānākuli Valley were severely grazed in the 1800’s by wild goats and cattle, which caused increased erosion, flooding during the rainy season, and drought during the dry season. Introduced grasses and weeds moved in and now present a fire hazard. A few small remnants of native forest cling to life in the Wai‘anae Mtns., including at the top of Pu‘u Palikea.

The old name for the region between Nānākuli and Lualualei is Ulehawa, said to be the birthplace of Māui. The name (“filthy penis”) derives from the old Hawaiian practice of assigning unpleasant nicknames to newborns of high rank. It is said that this name was given to a king, as a means of providing protection.

The ridges surrounding Nānākuli Valley primarily dip to the south and southeast, indicating that we are on the south side of the old caldera region (Fig. 10). Lualualei lavas at the base of Pu‘u Heleakalā have been dated at ~3.7 Ma.

Figure 10. Photo looking NE from offshore, showing Pu‘u Heleakalā. Note that the lavas dip to the right (SE) and were thus erupted outside the caldera.

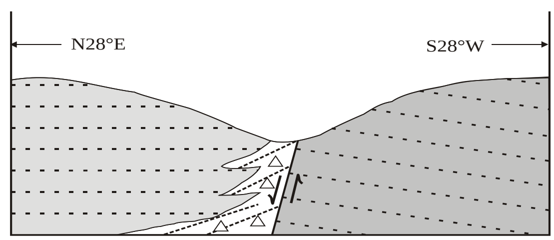

Figure 11. Cross section through the saddle north of Pu‘u Heleakalā. The fault marks the boundary between Lualualei lavas to the south (right) and Kamaile‘unu lavas to the north. Here the boundary is a normal fault, down to the north, with talus breccias and Kamaile‘unu lavas ponded against the fault scarp (Figure 11). Lavas on either side of this fault have been dated. A Lualualei lava on the south side of the fault is 3.62 ± 0.09 Ma; a Kamaile‘unu lava on the north is 3.11 ± 0.04 Ma [Guillou et al.,

The double bump hill (Puʻu o Hulu) between Māʻili and Nānākuli is composed of Lualualei member olivine basalts and dikes. This fellow *Hulu* (for whom the hill is named) was in love with *Māʻiliʻili*, who was one of twin sisters; because he could not tell the sisters apart, a *moʻo* changed them all to mountains, and he still looks at them. Puʻu Māʻiliʻili is an erosional remnant of intracaldera Kamaileʻunu lavas, as are also exposed on Puʻu Pāheʻeheʻe separating Lualualei and Waiʻanae Valleys.

Figure 12. Puʻu o Hulu Kai (right; lavas are dipping and therefore were erupted outside the caldera) and flat-lying Puʻu Pāheʻeheʻe (left) lavas erupted inside the caldera.

Just past Puʻu o Hulu turn right onto Kaukama Road.

Stop 2. Kaukama Road

Kaukama Road runs along the southern boundary of Lualualei Valley. Tholeiitic olivine basalt pāhoehoe lavas with reversed magnetic polarity (>3.55 Ma) here are part of the Lualualei member of the Waiʻanae Volcanics. Despite their age, glassy surfaces and well-developed pāhoehoe lobes are still evident in the road cuts, along with a few, nearly vertical dikes. Southerly dips indicate we are just outside the old caldera boundary. Views to the north and northeast include the prominent landforms Puʻu Pāheʻeheʻe and Puʻu Māʻiliʻili, both of which are built of intra-caldera eruptions of essentially flat-lying lava flow. The southern caldera boundary lies within Lualualei Valley.

The prominent peak to the northeast is Puʻu Kaʻīlio. It is composed of talus breccias cut by dikes. These breccias dip away from the main Waiʻanae crest into Lualualei valley. They were shed off of a fault scarp that runs just west of Puʻu Kaʻīlio (Figure 13). Lavas outside of it dip away from Puʻu Kaʻīlio, whereas those inside are generally flat lying. This fault can be traced around the SE side of Lualualei Valley where it cuts several of the ridges that protrude into the valley. Thus, this fault is one of the principal caldera-boundary faults. Flat-lying lavas making up Puʻu Māʻiliʻili, Puʻu Pāheʻeheʻe and Mauna Kūwale are intracaldera Kamaileʻunu lavas.

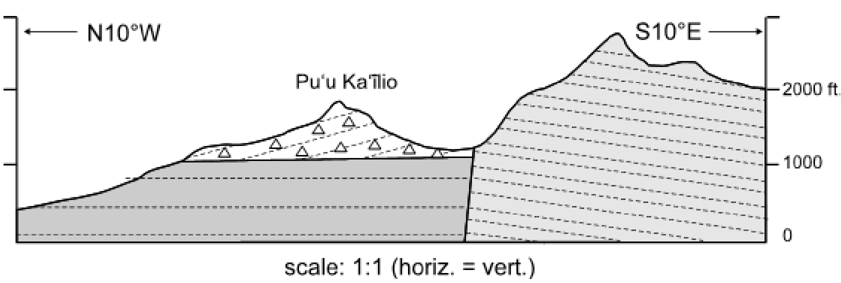

Figure 13. Cross-section running N10W from just south of Puʻu Kaʻīlio. Dashed lines indicate dip of beds. The Kaʻīlio breccia is shown by triangles. Note the thin-bedded dipping lavas outside the caldera and thicker, horizontal, intra-caldera lavas that are ponded against the caldera-bounding fault to the north of Puʻu Kaʻīlio.

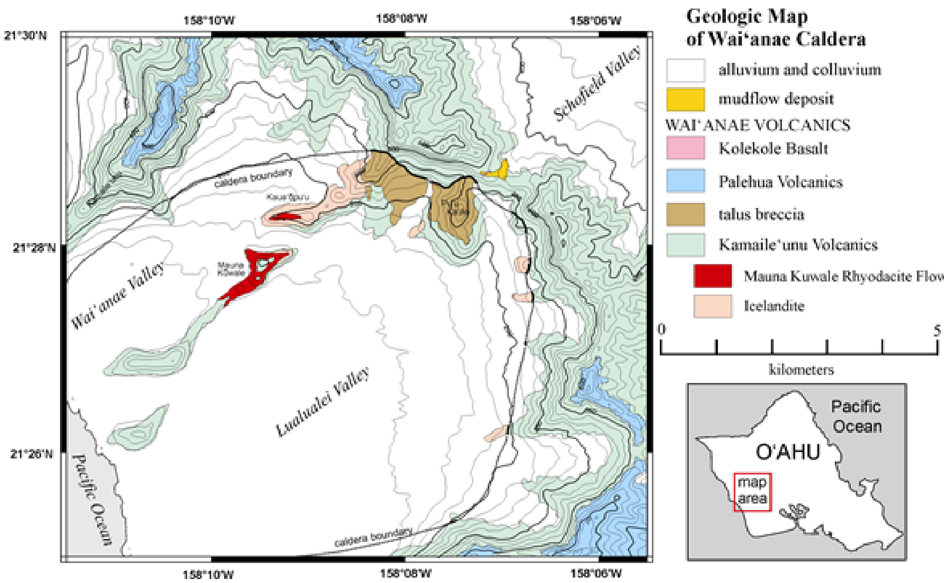

Figure 14. Geologic map of the caldera region. The caldera boundary fault is shown (dotted where covered).

Return to Farrington Hwy and proceed north. Turn right onto Wai'anae Valley Road and follow it until the prominent Y (about 2 miles from Farrington Hwy). There is a place to park at the base of Mauna Kūwale.

Stop 3. Mauna Kūwale (mountain standing alone; Fig. 15)

The section at Mauna Kūwale consists, from the base, of Kamaile'unu basalts overlain by augite-hypersthene tholeiitic andesite, which in turn is overlain by at least two flow lobes of hornblende-biotite-hypersthene rhyodacite (Figure 16). This sequence o is overlain by a thin flow of basaltic pāhoehoe, and mildly alkalic, flat-lying, very plagioclase-rich basaltic hawaiites that form the capping peak of Mauna Kūwale.

The section above the now-defunct dairy starts in icelandite. Several dikes and sills cut this sequence. The contact between the icelandite and rhyodacite is difficult to discern precisely in the field; apparently these two units were erupted in rapid succession. The overlying units are clearly much later, as a thin soil horizon occurs between the rhyodacite and overlying lavas

Figure 15. Mauna Kūwale, viewed from the west. The low place in the background ridge is Kolekole pass.

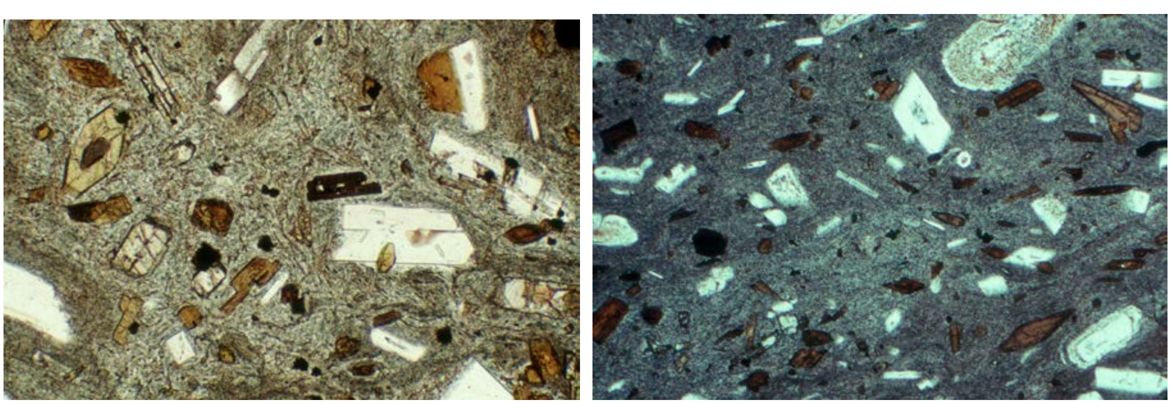

Figure 16. Photomicrographs of Mauna Kuwale rhyodacite. Each section ~2.5 mm across. Left hand slide contains conspicuous brown hornblende, very dark brown biotite, slightly pink hypersthene and colorless plagioclase. Right hand slide shows sieve-textured plagioclase crystals, indicating partial melting of the crystal following mixing between different magmas.

The "best"

age for the rhyodacite, consistent with the stratigraphic relationships and ages of surrounding flows, is about 3.3 m.y. [*Guillou et al.*, 2000]. Some of the enigmatic features of these remarkable rocks include dunite and gabbroic xenoliths and Ti-rich clinopyroxene xenocrysts in the rhyodacite, and a variety of disequilibrium, mixing textures in the rhyodacite and many (but not all) of the icelandites. The xenoliths presumably represent either early crystallization products of mantle-derived basaltic magmas, or random, disaggregated wall rock fragments entrained during ascent. Scattered tuff clasts in the rhyodacite, and local, ~1 m-thick tuff deposits indicate that the eruptions producing this sequence were, at least intermittently, pyroclastic (Fig. 17).

Figure 17. Ash bed at base of icelandite lava, north end of Mauna Kūwale ridge.

Silicic magmas can form by differentiation of basaltic magmas, and partial melting of (altered) crustal rocks. Van der Zander et al. [2010] argued that both processes were involved during Kamaileʻunu magmatic evolution (Fig. 18). Some icelandite dikes appear to be the result of extreme differentiation of shallow-level magmas, whereas others, including the Mauna Kūwale Rhyodacite Flow, probably formed by direct melting of hydrated lower crust. Although a crustal melting hypothesis explains many textural and chemical aspects of Waiʻanae silicic rocks, it does not explain why some of these silicic lavas have Pb isotope values unlike any Waiʻanae basalts.

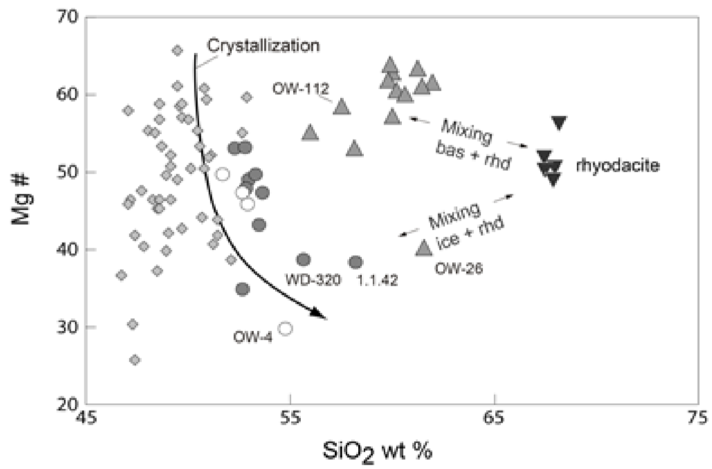

Figure 18. High Mg# of the Mauna Kūwale rhyodacite is inconsistent with it being a simple differentiate of Waiʻanae basaltic magma. For this reason, among others, van der Zander et al. [2010] favor a partial crustal melting of hydrated lower crust hypothesis. Silicic melts mixed with both basalt and icelandite magmas in shallow resorvoirs prior to eruption.

This paradox was resolved when samples collected from the off-shore Kaʻena volcano were analyzed for Pb, Sr and Nd isotopes (e.g., Fig. 2). Notably the silicic rocks (labeled Ws in Fig. 19) have Pb isotope values similar to those at one end of the Kaʻena trend. This result is consistent with the lower crust beneath Waiʻanae being Kaʻena, as depicted in Figures 2 and 17.

It is notable that the scenario outlined in Figure 20 is consistent with the eruptive sequence at Mauna Kūwale, with early formed icelandite overlain by rhyodacite. Following the eruption of the Mauna Kūwale rhyodacite, transitional shield volcanism continued for another ~200,000 years (Fig. 3), before Waiʻanae transitioned to a postshield volcano with a much deeper magma reservoir.

The view from the top of Mauna Kūwale offers an excellent panorama of the eroded-out center of the old Waiʻanae volcano. The broad flat-floored valley to the south is Lualualei valley, where ~125 ka carbonates have been quarried for cement. Lualualei is mostly occupied by the US Navy Magmazine and communication facilities. The prominent peak to the east is Puʻu Kaʻīlio (Figs. 13, 14), near the margin of the Waiʻanae caldera, but close to center of the gravity anomaly that signifies the long-term magmatic center of Waiʻanae volcano. To the north is the ridge that separates Waiʻanae and Mākaha valleys. The lower ~3/4 of the valley wall presents excellent exposures of Kamaileʻunu lavas, cut by a few obvious dikes. The uppermost part of the ridge is capped by post-shield alkalic Pālehua lavas, visible by a change in flow thickness, eroded slope, and depending on the amount of recent rainfall, a change in vegetation (Figure 20).

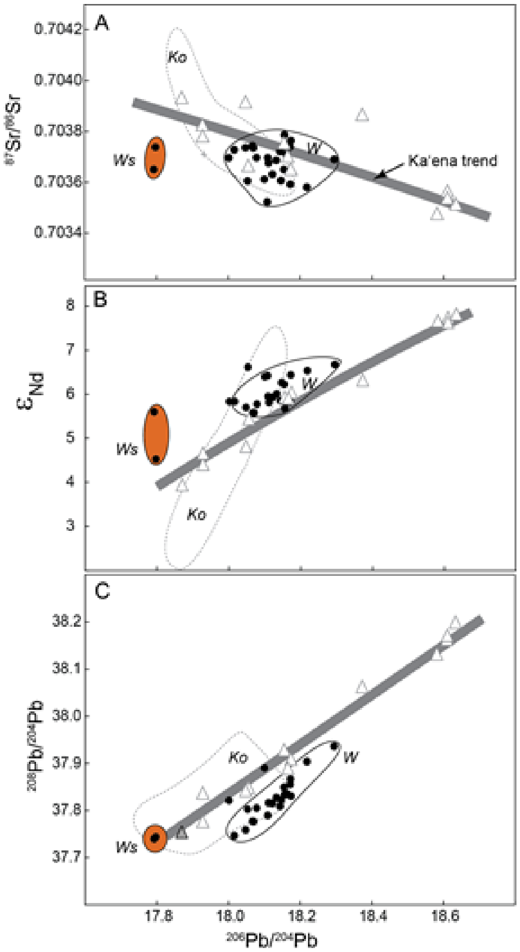

Figure 19 (left). Isotope ratios of Wai'anae (black circles, field labeled W) and Ka'ena (open triangles) volcanic rocks. Field of Ko'olau samples (Ko) is shown for comparison. Note that Wai'anae silicic lavas (those samples in the orange field) have isotopic compositions unlike any Wai'anae basalts, but similar to those at one end of the Ka'ena trend.

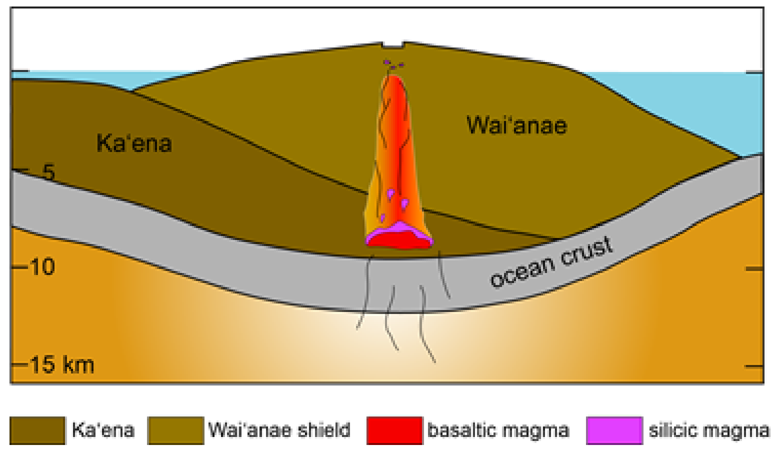

Figure 20. Origin of Wai'anae silicic magma by hydrous partial melting of the lower crust. Isotopic ratios of Wai'anae silicic lavas suggests the lower crust that melted is Ka'ena. At low magma supply the shallow chamber differentiates to make icelandite magma, while deeper ponded basalt heats up the lower crust until it begins to melt. Deep crustal silicic melts rise and mix with shallow magmas, erupting first icelandite, followed later by rhyodacite.

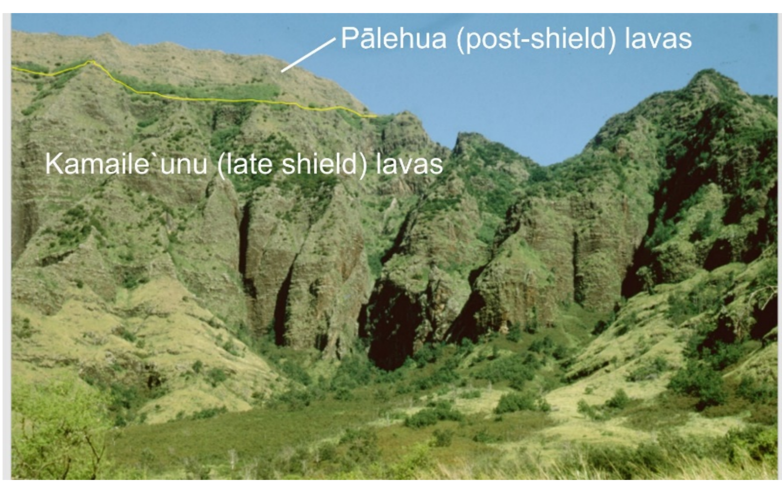

Figure 20. View of west wall of Wai'anae valley, showing contact (yellow) between Kamaile'unu and Pālehua lavas.

Return to Farrington Hwy., and proceed makai to Pōka'ī Bay where we will enjoy a brief lunch and bathroom break.

Pōka'ī Bay and Kū'īlioloa Heiau

Pōka'ī Bay is the former site of a great grove of coconut palms that dotted much of Kāne'īlio point and lined the back shore of the entire bay. This grove "Ka Uluniu o Pōka'ī" was famous in legend and noted by western sailors in the 1700's. Pōka'ī, The Navigator (lit. night of the supreme one) was reputed to have been a voyaging chief of Kahiki who is credited with bringing the versatile and valuable coconut palm to the Hawaiian people.

The south end of Pōkaʻī Bay is formed by Kāneʻīlio Point, a narrow peninsula composed of late shield-stage Kamaileʻunu basalts overlain by ~125 ka reef and dunes. The surmounting structure of Kūʻīlioloa Heiau has three terraced platforms and is believed to have been a temple of learning and training, mainly in the arts of fishing, navigation and other ocean-related skills. It might have served different functions during the nearly 1000 years that it has been in use. Its name (the long dog of Kū) is thought to reflect that the heiau was named after a legenday dog who protected travelers, …like us.

Return to Farrington Hwy and turn left (north) toward Makaha.

Waiʻanae to Mākua

The ridge separating Waiʻanae and Mākaha valleys is Kamaileʻunu Ridge, the type locality for this member of the Waiʻanae Volcanics. At the seaward end of the ledge is an obvious unconformity with a less obvious interpretation (Stearns & Vaksvik, 1935; Fig. 21). Essentially invisible beneath a cover of modern talus is a triangular-shaped remnant of old flows cut by numerous dikes. Both the west and east flanks of this remnant are erosional (or faulted), and the east flank is mantled by talus breccia. Banked against this talus breccia are (younger) Kamaileʻunu lavas which filled to the top of the triangular remnant before spilling over and draping steeply down to the west. The relationship of this fault to the overall structure of Waiʻanae volcano is unclear.

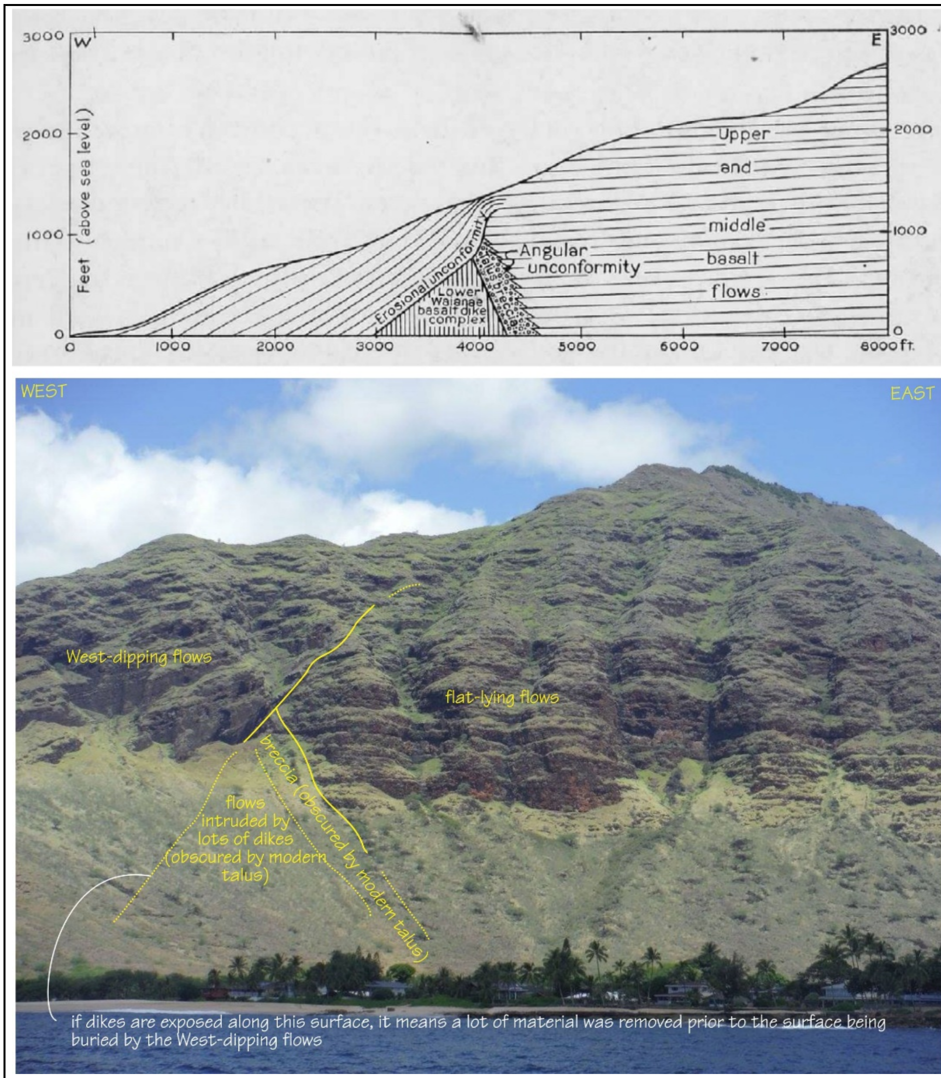

Figure 21. Diagram from Stearns & Vaksvik (1935; top) and photo from offshore (bottom) illustrating the unconformities within Kamaileʻunu ridge.

The Kamaile Heiau, said to be a luakini-class heiau where ruling chiefs prayed and human sacrifices were offered, is on Kamaile'unu Ridge at an elevation of about 400'. Puʻu Kawiwi, the tall peak behind Kamaileʻunu Ridge may have been a *puʻuhonua*, a place of refuge. After the failure of the Waipiʻo rebellion against Kahekili's occupation of Oʻahu, ʻEwa chiefs retreated to the safety of Puʻu Kawiwi. Their refuge was short-lived, however, when they were starved out by Kahekili.

Mākaha (lit. "fierce") is named for the gangs of bandits who once hid in caves as they waited to rob travelers. One translation of ʻŌhikilolo, a district just beyond Mākaha, means "prying out of brains" which may have been the unfortunate fate of travelers in this region.

Stop 4. Kāneana (the cave of Kāne)

Leave the car unlocked and take all valuables with you. This location is frequented by thieves.

According to Hawaiian legend, this cave is variously described as the place where Pele emerged on Oʻahu, traveling by undersea lava tube from Kauaʻi; where Maui and his grandmother lived; and a place where a shark man lived. According to Stearns, (Harold, not Nora) this cave was formed by the sea cutting back into the heart of the NW rift zone dike complex during a higher stand of the sea. The cave, in its present dimensions, was probably cut during the ~500 ka Kaʻena stand of the sea, which was about 30 m above present sea level. Part way up the left wall as you enter is a deposit of rounded beach boulders, cemented in place by lithified sand. The boulders are a remnant of a beach left high and dry during the cutting of the cave. The upper portion of the cave may have been cut by an even higher, earlier stand of the sea.

Many dikes are exposed at Kāneana, indicating that the cave lies in the center of the NW rift zone of Waiʻanae. The axis of this rift zone is not along the topographic axis leading to Kaʻena Point (Figure 4).

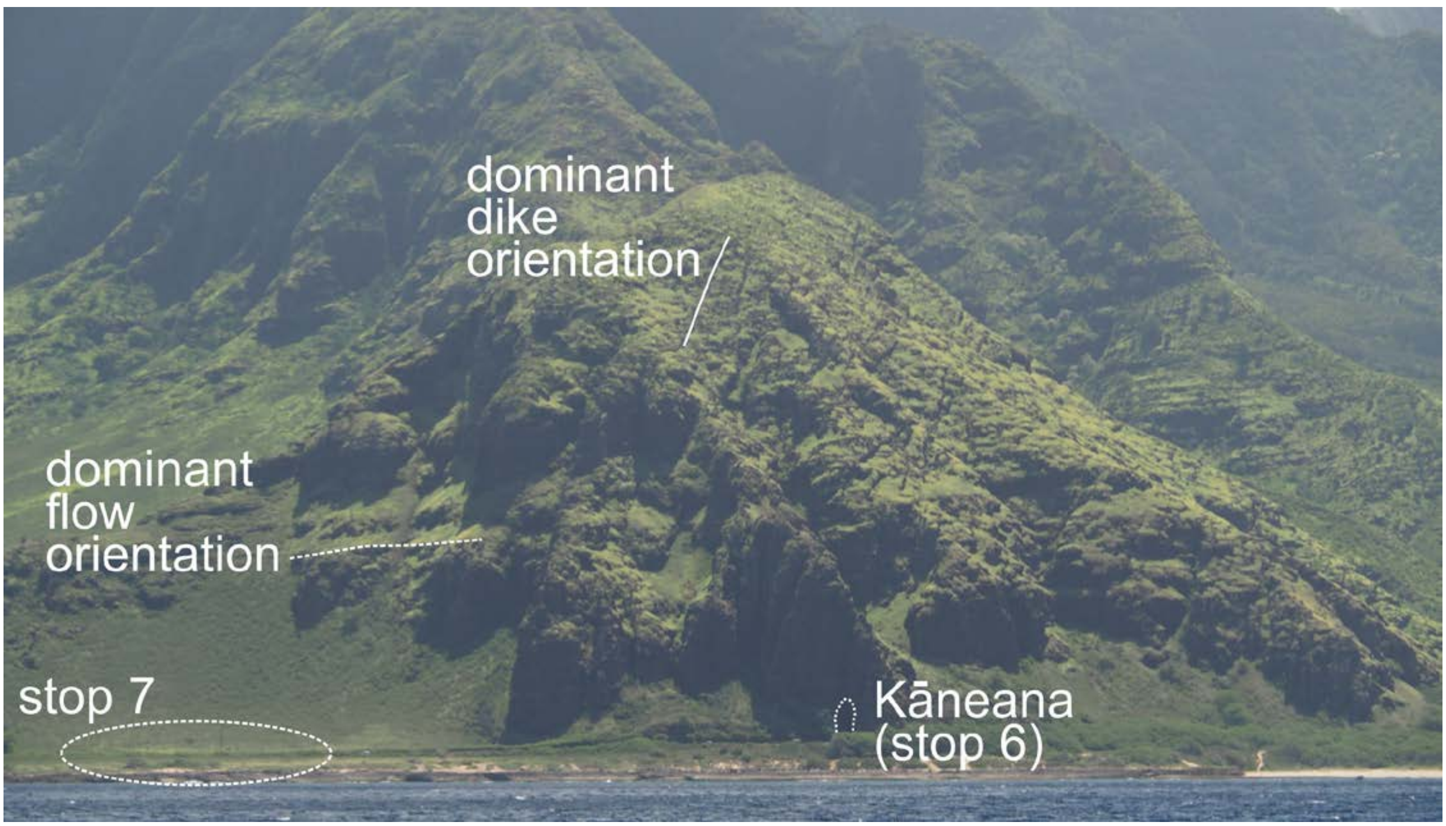

Figure 22. View to the East of Kāneana and the ridge in which it has been cut. Within the ridge are lava flows that dip gently West (left) as well as numerous dikes that dip steeply West. On this field trip Kāneana is Stop 4 (not 6), and roadcuts south of Mākua (labeled stop 7) are Stop 5.

Stop 5. Roadcuts just south side of Mākua Valley

An excellent section of Kamaileʻunu shield lavas truncated and overlain by carbonates is exposed in the roadcuts here (Fig. 23). This beautiful shoreline sequence contains at least two carbonate facies with *in situ* corals overlain by a well-sorted sand deposit, locally interrupted by pebbly horizons. This sequence is overlain by a paleosol with vertical structures that are either either root casts or evidence of burrowing.

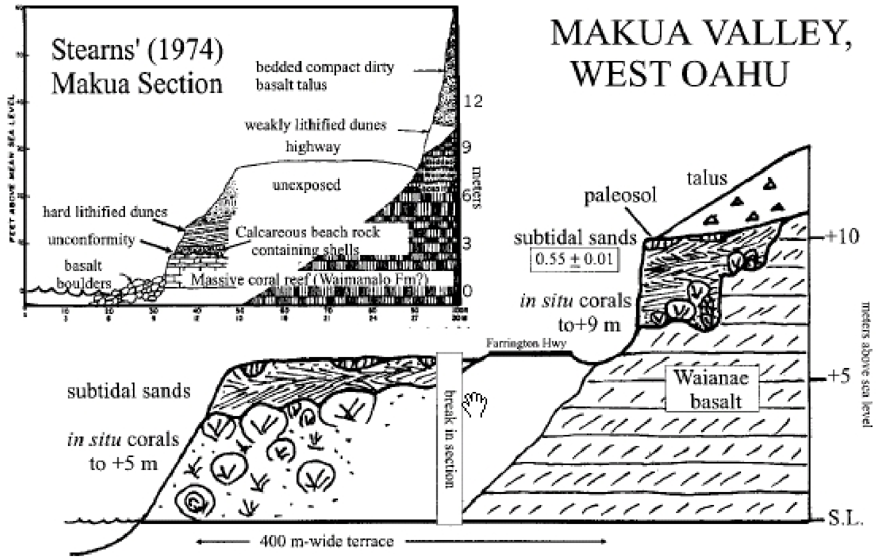

Figure. 23. Section on south side of Mākua Valley (from Hearty, 2002). The deposits here range from about +5 to +11 m above present sealevel. Their age is not well known. The inset shows Stearns' (1974) section and interpretation

Proceed along Farrington Hwy to Keavaʻula Beach Park

Stop 6. Keawaʻula

The Oʻahu narrow gauge railway used to stop here to let off fishermen, many of whom were of Japanese descent. Thus arose the slightly pejorative common reference of this place as Yokohama Bay; a summer surfing site here is called Yokohamas. Keawaʻula (lit. red harbor) refers to the large number of cuttlefish that colored the water red.

Lavas making up the ridges to the north consistently dip to the north, indicating that these lavas were erupted from the northwest rift zone that crossed the shoreline at Kāneana and lies to the south of Keawaʻula. A few dikes can be seen in the outcrops to the north, but not nearly as many as on the south side of Mākua Valley, near Kāneana.

Return south on Farrington Highway. On the way we will pass through the various regions of the Waiʻanae coast.

The sun is warm
At Mākua,
Then at Kūʻano and Keaʻau ,
A breath of air stirs,
A soft breeze touches Kamalama.
Night overtakes one at Pīkaʻi
A little dew from Kaʻala ,
There is Haleʻauʻau and Kauna,
Then Puleʻe and now the sea of ʻEwa,
ʻEwa is reached!

John Ii
in Stirling and Summers

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