HOFSTRA UNIVERSITY
GEOLOGY 280F - FIELD TRIP GUIDEBOOK

Geology of Hawaii

Summer Session Two – 23 July to 02 August 2007

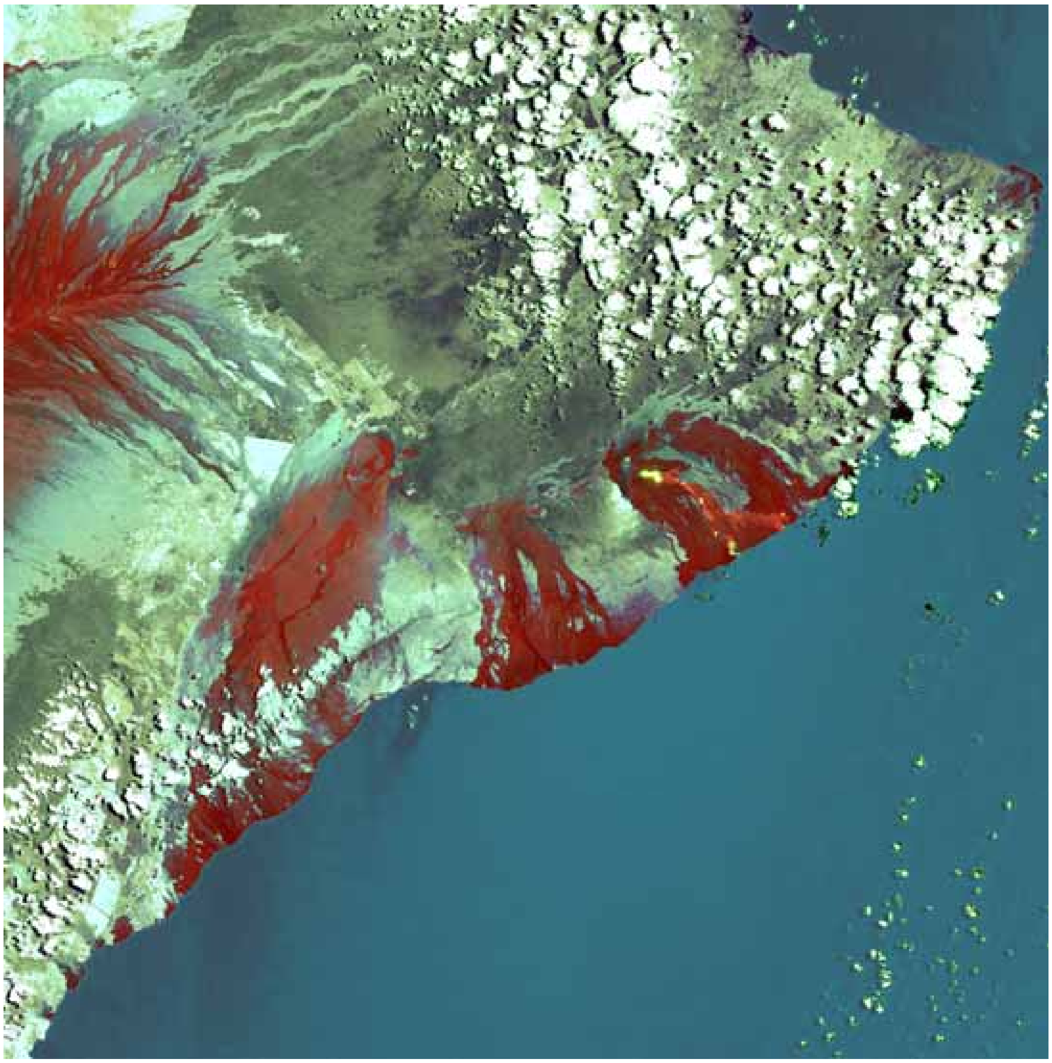

Figure 1 - False color infrared satellite image of the SE coast of Hawaii showing the plumose structure of modern and ancient lava flows which have emanated from the summit of Mauna Loa (upper left) and from lava tubes on the flanks of Kilauea volcano. (NASA image.)

Field Trip Guide by Charles Merguerian and Steven Okulewicz

Hofstra University Geology Department

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Geology For Teachers and Travelers: The Geology of Hawaii
Hofstra University - Geology 280F

23 July to 02 August 2007

Field Trip Guide by:
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Introduction

Luxurious vegetation, spectacular beaches, surfers, hula skirts, and umbrella drinks are most people's lasting impression of the Hawaii. Indeed, a paradise for landlubbers from the continent but also a unique field experience for geologists and students of geology. Last year's trip to the Yellowstone hot spot in Wyoming provided a continental view of what happens on our planet when a thick continental lithospheric plate slides for many centuries over a relatively stationary hot plume in the Earth's mantle, one of 47 known on earth. This summer's geology field trip by contrast will focus on what occurs when thin oceanic lithosphere is dragged with purpose and majesty across a more distant oceanic hot plume and what the geological products and landscape development of such an interaction have created over a relatively brief period of time. Although our trip will certainly focus on volcanism and volcanic products, evidence for glaciation, earthquake activity, groundwater interactions, and coastal processes will be discussed in the field. The guidebook will present a brief overview on the geology of the Hawaiian Islands and Hawaii in particular and provide specific background information on our planned itinerary. Appendix 1 provides a primer of geological terms and concepts deemed central to our field trip and should probably be read before the guide itself. Appendix 2 is a glossary of volcanic and geologic terms.

Geological Background

Presiding over the central Pacific Ocean and over 3,000 km from the nearest continent, the island of Hawaii extends from the sea floor to produce a small island roughly 122 x 150 km in size that marks only the very tip of a huge shield volcano, so named for the overall outline in the shape of a badge or shield (Figure 2). Listed by decreasing age, Hawaii actually consists of five large coalesced volcanoes known as Kohala, Mauna Kea, Hualalai, Mauna Loa, and Kilauea (Table 1). By far the largest volcanic construct on Earth, Hawaii is the youngest of a roughly 44 Ma (million year old) line of genetically related volcanic islands that stretch over 2,400 km in a southeasterly direction from the dogleg bend in the Emperor Seamount – Hawaiian Island chain

(Figure 3). From oldest to youngest (and NW to SE) they are known as Kure Island, Midway Island, Pearl and Hermes Reef, Lisianski Island, Laysan Island, Gardner Island, the French Frigate Shoals, Necker Island, Nihoa Island, Niihau, Kaula, Kauai, Oahu, Molokai, Lanai, Maui, Kahoolawe, and Hawaii. The islands diminish in size from SE to NW and are mostly submerged, the result of subsidence and the erosive effects of wave-action as they drift away from the tumescent hot plume that created them. The newest Hawaiian Island (Loihi) has begun to sprout in the subterranean realm of the Pacific Ocean to the SE of Hawaii.

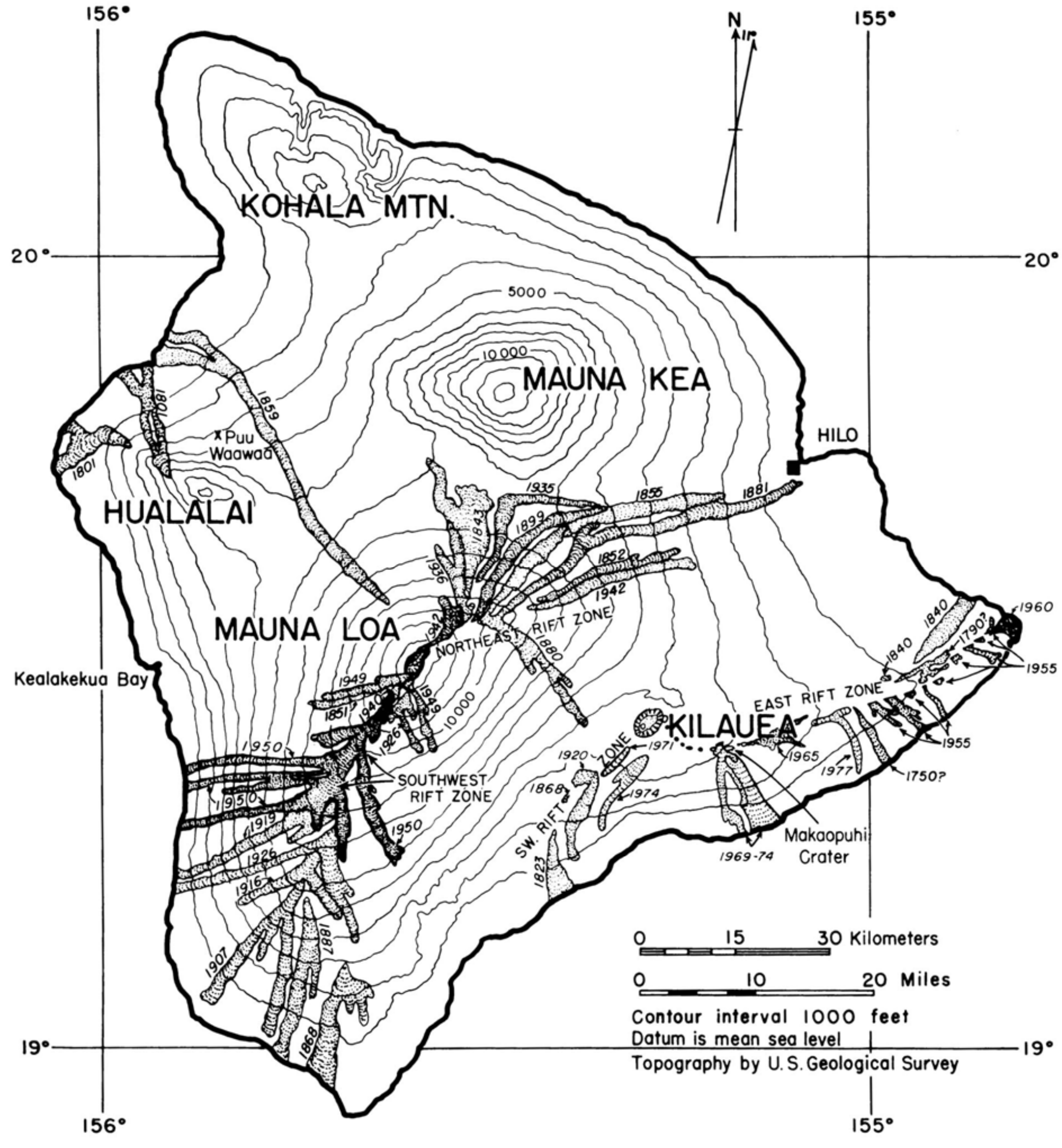


Figure 2 – Topographic map of the island of Hawaii showing the five major volcanoes that constitute the island and the major historic lava flows that have been extruded. (From Macdonald and others, 1983, Fig 3.2, p. 59.)

Table 1 – Geographical data for the Hawaiian Islands. (From Macdonald and others, 1983, p. 3, Table 1.)

Island	Length (km)	Width (km)	Area (square km)	Length of shoreline (km)	Name of mountain	Altitude (meters above sea level)
Hawaii	150	122	10,451	504	Mauna Kea	4,205
					Mauna Loa	4,169
					Hualalai	2,521
					Kohala Mountain	1,670
					Kilauea	1,248
Maui	77	42	1,902	240	Red Hill (Haleakala)	3,055
					Puu Kukui (West Maui)	1,764
Oahu	71	48	1,600	336	Kaala (Waianae Range)	1,225
					Puu Konahuanui (Koolau Range)	960
Kauai	53	40	1,446	177	Kawaikini	1,598
Molokai	61	16	683	171	Kamakou (East Molokai)	1,515
					Puu Nana (West Molokai)	436
Lanai	30	21	366	84	Lanaihale	1,027
Niihau	30	10	182	81	Paniau	390
Kahoolawe	18	10	119	58	Lua Makika	450
TOTAL	—	—	16,749	1,650	—	—

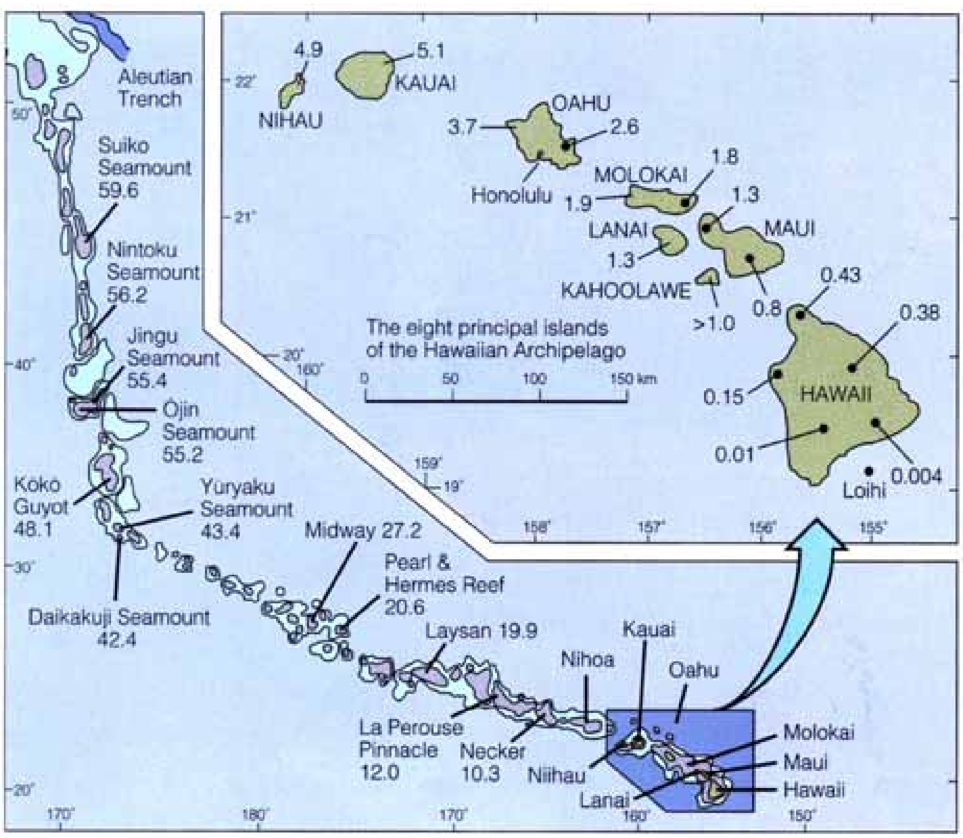


Figure 3 – Map showing the relationship of the eight principal islands of the Hawaiian archipelago to the vast island and seamount chain with which they are genetically related. Ages of radiometrically dated volcanic rocks are shown. Note that the Hawaiian Islands are less than ~5 million years old (5 Ma).

The image below (Figure 4) is a shaded "Bathymetric map" of Loihi Seamount as it now looks, following the July 1996 eruption and coseismic events. "Bathymetry" refers to the depth from the ocean's surface to features on the seafloor. As you might expect, low numbers on a depth map refer to shallow regions, or the high point on a submarine mountain such as Loihi. Shallow regions are given in warm colors on this map; cool colors are the deep regions. The 3 depressions in the summit area are pit craters; the lower-left most crater was formed in July 1996.

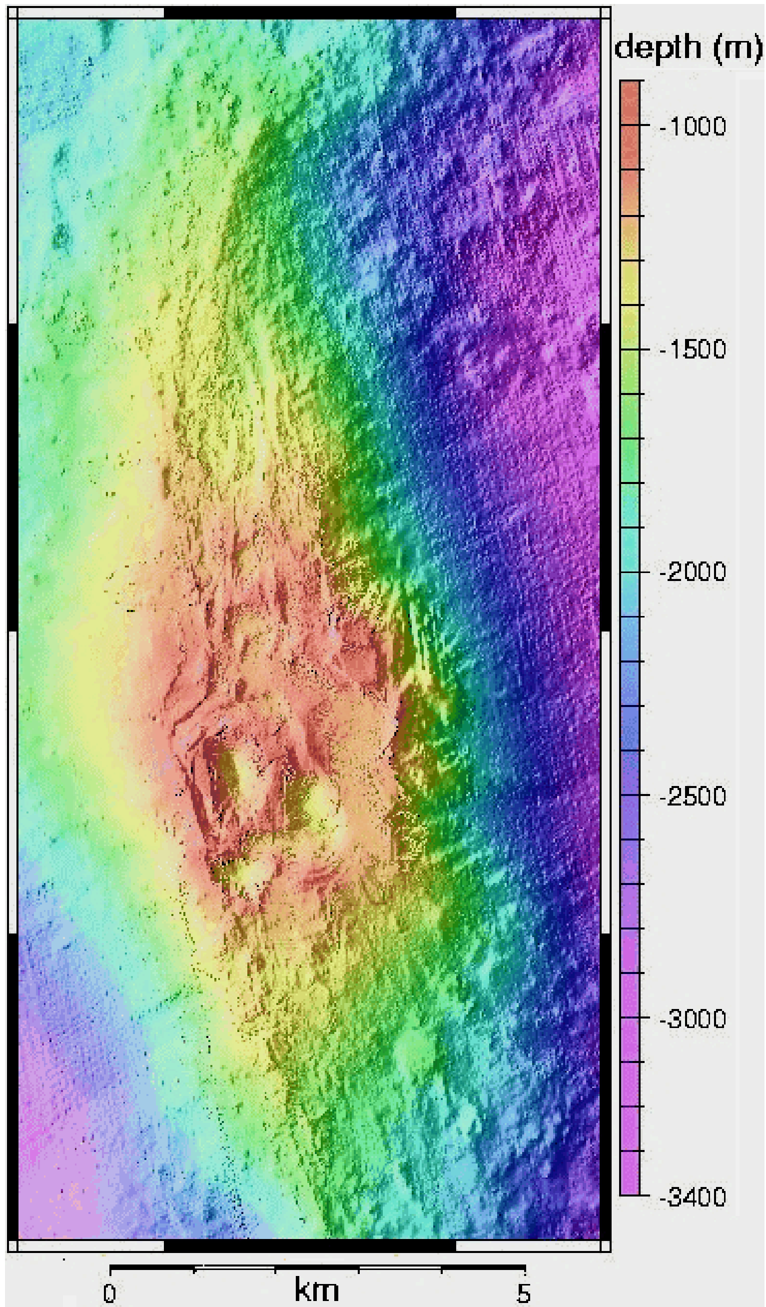


Figure 4 – Shaded bathymetric relief map of the Loihi Seamount whose growth is the result of suboceanic hot spot volcanism to the southeast of Hawaii. Map made by UH graduate student Nathan Becker using 1997 seabeam bathymetry and the GMT program.

Hawaii, the focus of our 2007 Geology IDEAS field trip offering, is the youngest island in the archipelago and is a volcanologists hot dream as modern volcanism and the products of recent volcanic activity are wonderfully preserved there for all to walk over, see, and experience. As we all know from reading the back of cereal boxes, the Hawaiian Islands were produced by northwestward drift of the Pacific Ocean plate at the rate of about 3.2 to 4 inches/year (8-10 cm/yr) over a relatively stationary hot plume roughly 50 miles in diameter in the Earth's mantle (Figure 5).

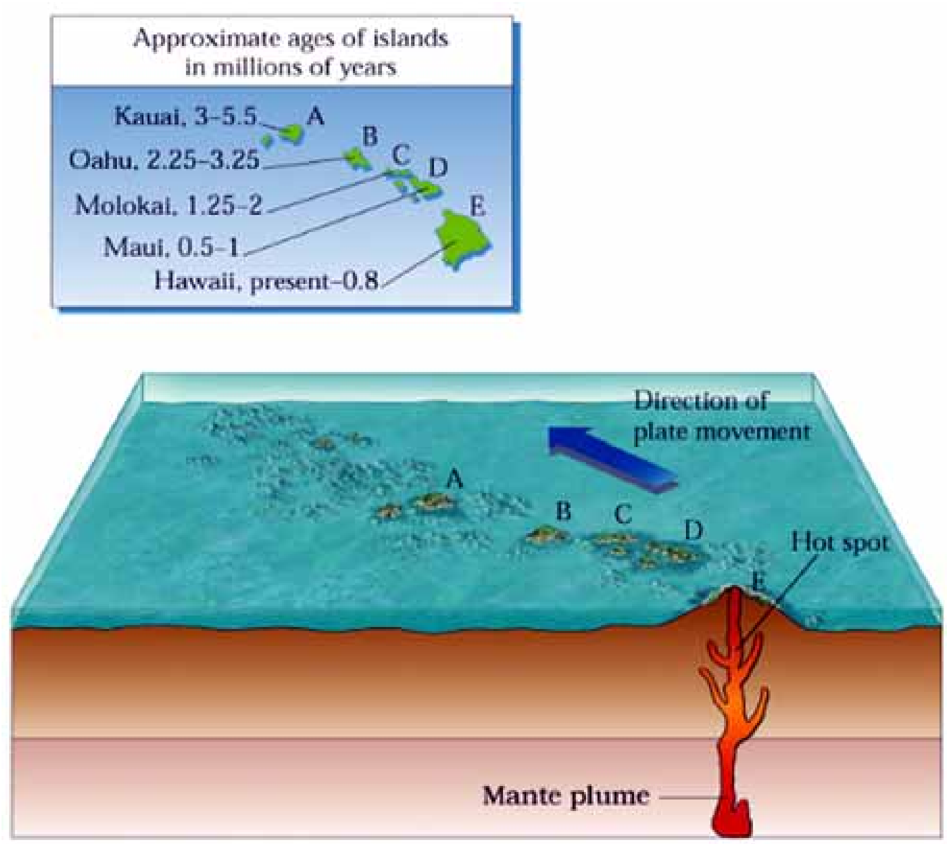


Figure 5 – Diagram illustrating the growth of the Hawaiian volcanic islands as they drift across a hot spot on the Earth's mantle.

The lower part of the ~100 km thick oceanic lithosphere consists of ultramafic rocks (peridotites, etc.) belonging to the uppermost mantle. Above that occur gabbroic rocks which grade eventually into a thin, 4-8 km thick veneer of oceanic crust. This layer consists of basal gabbro overlain by a sequence of vertical sheeted basaltic dikes with chilled margins which feed into a thick stack of pillow basalts that cap the ocean crust. King, Queen and Standard pillow sizes have been reported in the literature. Passage of the oceanic lithosphere over the concentrated blowtorch that is a mantle plume creates wholesale (and in some cases, retail) melting at the base of the lithosphere which, in turn, produces rising plumes of basaltic magma. Indeed, seismic evidence and petrogenetic studies suggest that Hawaiian magmas originate 50 to 80 km deep and that the magma rises along roughly cylindrical conduits to pool 2 to 5 km beneath their respective volcanic summits (Figure 6). A self-fulfilling prophecy, fracturing of the brittle basaltic crust by periodic rising magma allows faulting and localized volcanism which empties the shallow magma chambers. Recharge by the hot plume mechanism affords a steady supply of juicy basalt which, over the last million years or so has creates the overlapping outpourings of basalt that have built the Hawaiian shield volcano over 31,000’ from the base of the ocean floor (Figure 7) and have produced a broad arch (the Hawaiian arch) in the ocean.

Growth of the islands by purely igneous mechanisms has been interrupted from time to time by massive earthquakes and significant downslope movement of loose volcanic materials to develop submarine fans (Figure 8). A great volume of material has been displaced into the ocean in this fashion and over time the islands have fanned outward in extent. This is very depressing for oceanic lithosphere – having not as yet heard about the uplifting effects of Prozac or Tequila it eventually started to sink. Thus, as we will experience first hand at Hilina Pali, faulting and large scale downslope movement have had an important erosional effect on pre-existing volcanic materials. Remember from previous trips the effects of mean old Mr. Gravity – it’s the Law! And it’s a good one!

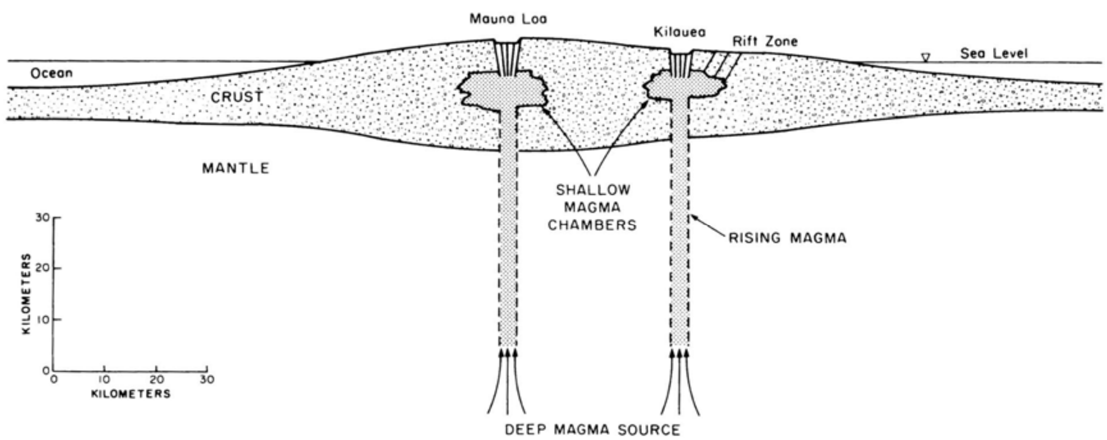


Figure 6 – Diagrammatic section through the outer part of the earth at Hawaii showing the magma source for Mauna Loa and Kilauea and the relative position of shallow magma chambers that control the volcanic activity. (From Macdonald and others, 1983, p. 10, Fig. 2.3.)

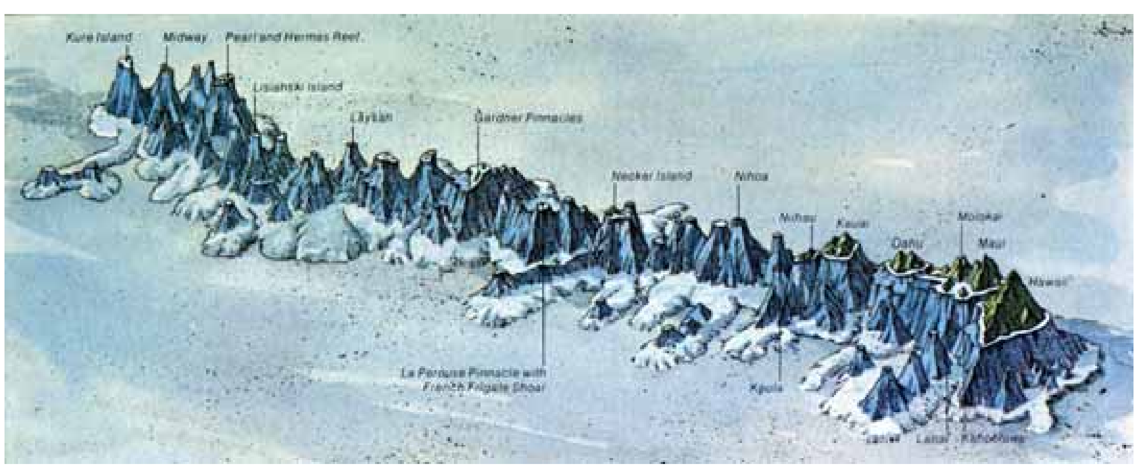


Figure 7 – Physiographic diagram showing the submerged ~30 Ma Hawaiian volcanoes atop the Hawaiian arch.

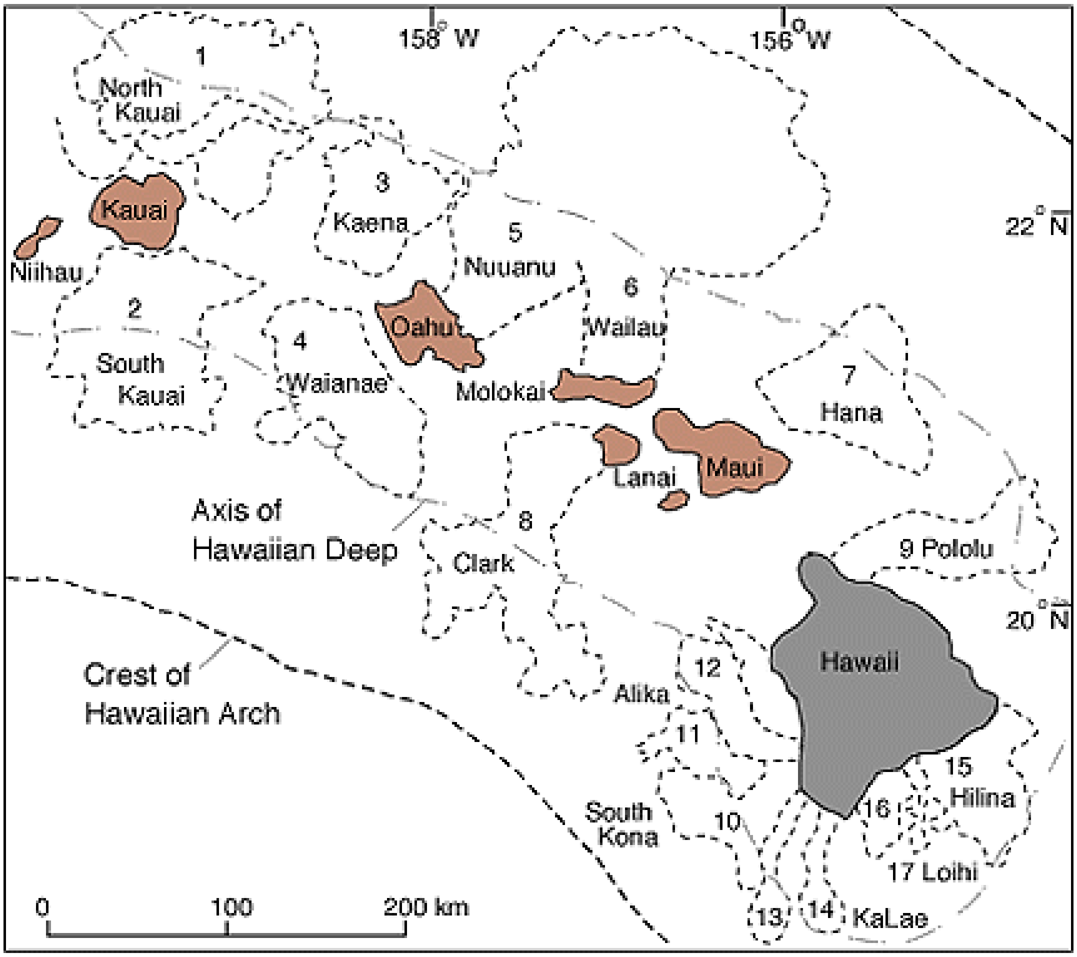


Figure 8 - Drawing from side scan sonar data showing submarine landslides off the Hawaiian Islands. (From www.uhh.hawaii.edu/~kenhon/GEOL205/petrology/default.htm.)

A location map showing the linear distribution of basaltic volcanic islands and seamounts in the Pacific Ocean (Figure 9) indicates that the geometry of the Emperor-Hawaii bend is mimicked by the Marshall-Ellice Island – Austral seamount chain, the Line Island – Tuamoto chain, and also partially in the Cobb seamount chain. The volcanic island chains (red in Figure 9.) are all the result of a similar hot plume mechanism and thus locate active hot plumes in the Pacific basin. No one knows what causes hot plumes in the Earth's mantle but CM often advances the idea that they may represent fossil asteroid scars of dense meteorites (*Remember folks, you heard it here first!*).

Obviously a change in the geometry of Pacific plate motion took place coincident with the age of the bend in the Emperor seamount-Hawaiian island chain. Such a fundamental shift (~120°) in plate motion can be accurately dated since we know the age of the volcanic rocks preserved at the dogleg bend in the Emperor-Hawaiian chain, roughly 44 Ma (Figure 10).

The sharper angle of the Emperor-Hawaii chain (~120°) compared to other chains in the Pacific (~160° to 170°) could be the result of latitudinal variations in north Pacific plate motion associated with loss of the northern spreading ridge of the East Pacific Rise beneath the western North American Cordillera. As we witnessed on our Geology 280 trip to California (to be repeated in 2008, by the way!), the western Cordillera experienced nearly continuous subduction for ~ 200 Ma until what started out life as the "mid-ocean ridge" of the Pacific approached the west coast subduction zone.

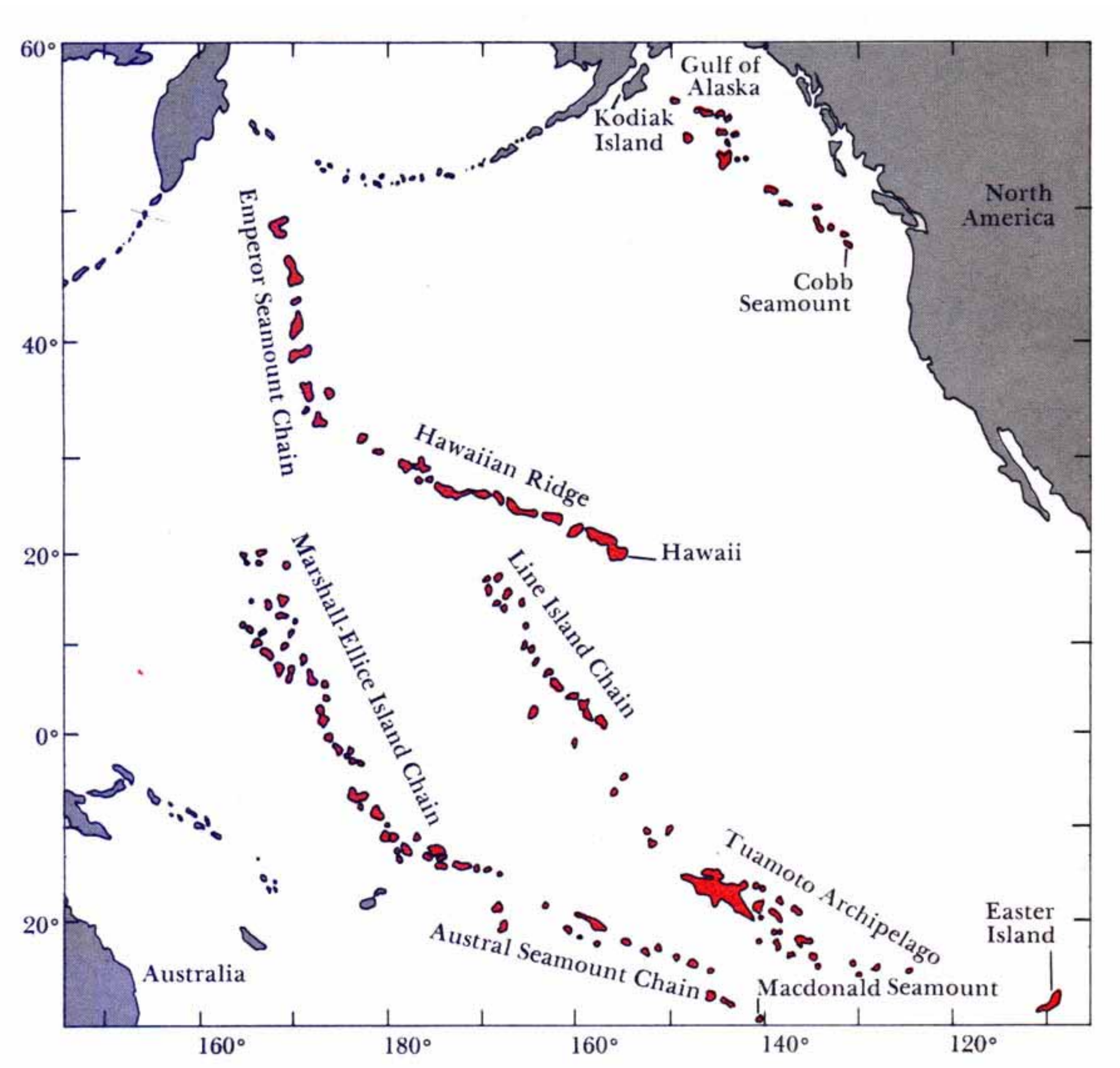


Figure 9 – Location map showing the distribution of volcanic islands and seamounts (in red) in the Pacific Ocean.

The timing is good for our suggestion, since we know that about 44 Ma impingement of the East Pacific Rise and generation of the San Andreas transform system began. This may have resulted in major jostling of lithospheric plates in the north half of the Pacific and created the angular difference in the island chains noted above. Soon, in the northern Pacific, it will be party time again! Note that the northernmost volcanos in the Emperor Seamount chain are on course for northwestward subduction into the Aleutian and/or Kamchatka trenches. It will only be a few Ma in the future but no one can predict constancy of plate motion. Any bets on the table? How about under the table?? At present rates, Hawaii is on schedule to plunge into the Aleutian trench in roughly 40 Ma.

Volcanism has been a continuous friend to the Hawaiian volcanoes, creating real estate like no tomorrow. Table 1 lists the dimensions of length, width, area, length of shoreline, major mountains, and altitudes for the chain. Note the SE to NW decrease in area and subsequent length of shoreline in response to contraction cooling, densification, and subsidence with passage away from the active plume area.

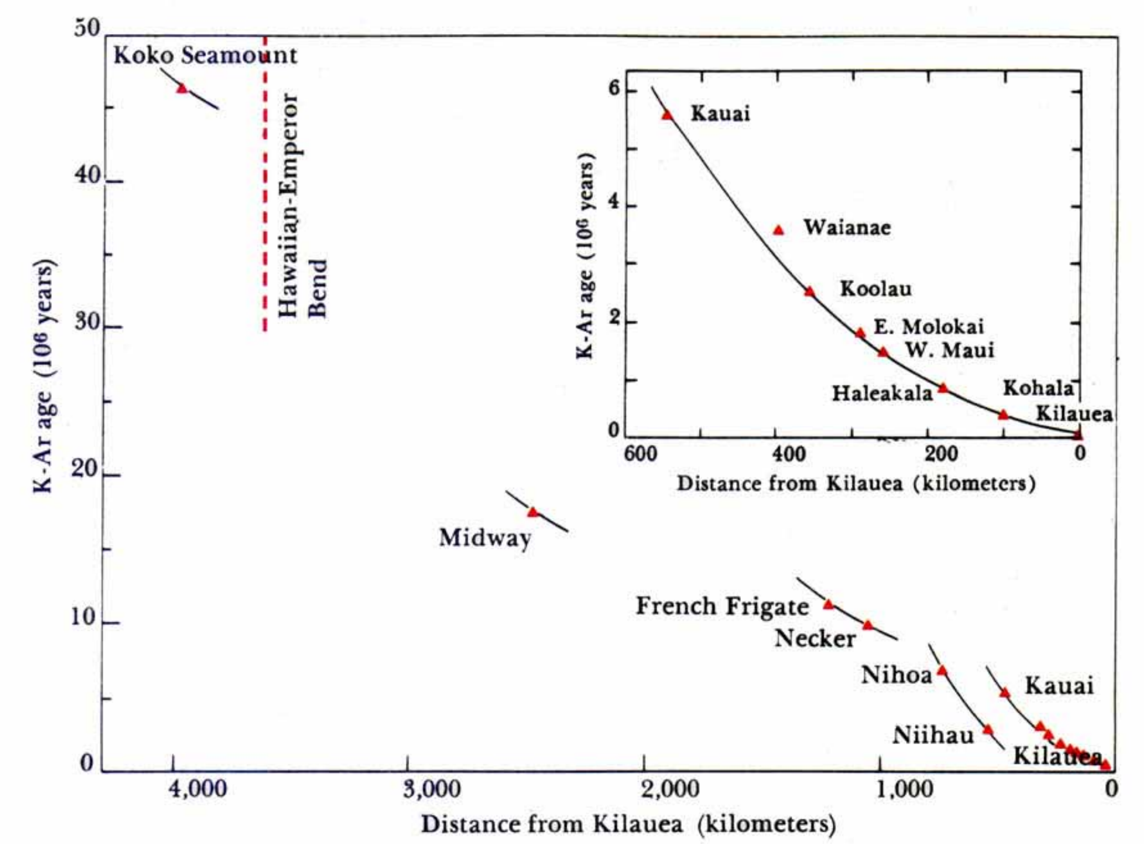


Figure 10 – Graph showing age vs. distance from Kilauea for the Emperor-Hawaiian chain. Note that the age of the bend in the Emperor-Hawaiian Seamount chain is roughly 30 Ma. Inset shows age-distance relationships of the nearby "Hawaiian" islands.

The symbiosis between seismicity and volcanism has been well established. As earthquakes and related fractures in the earth occur in response to abnormal stress in volcanic districts, magma and lava can move upwards to fill the openings. The force of moving magma can introduce stress that, before the effects of igneous heat permeate the rock mass and decrease brittle response, creates more earthquakes. Naturally this provides more openings for more lava or magma to intrude and invigorates the process toward repetition.

Monitoring devices at Kilauea summit indicate that during the interval 15 January to 20 February 1974, shallow focus earthquakes increased to hundreds per day and tiltmeters showed maximum departure just preceding an eruption (Figure 11). At Mt. St. Helens in May 1980 harmonic earthquakes (*they got rhythm, baby!*) heralded the flank eruption that killed "I ain't leaving" Harry Truman and vaporized his rocking chair, porch, and multicultural cat collection. In addition, plots of Kilauean tilt over longer time periods (1957-1981) show a marked correlation between tilt, eruptions, and intrusion (Figure 12).

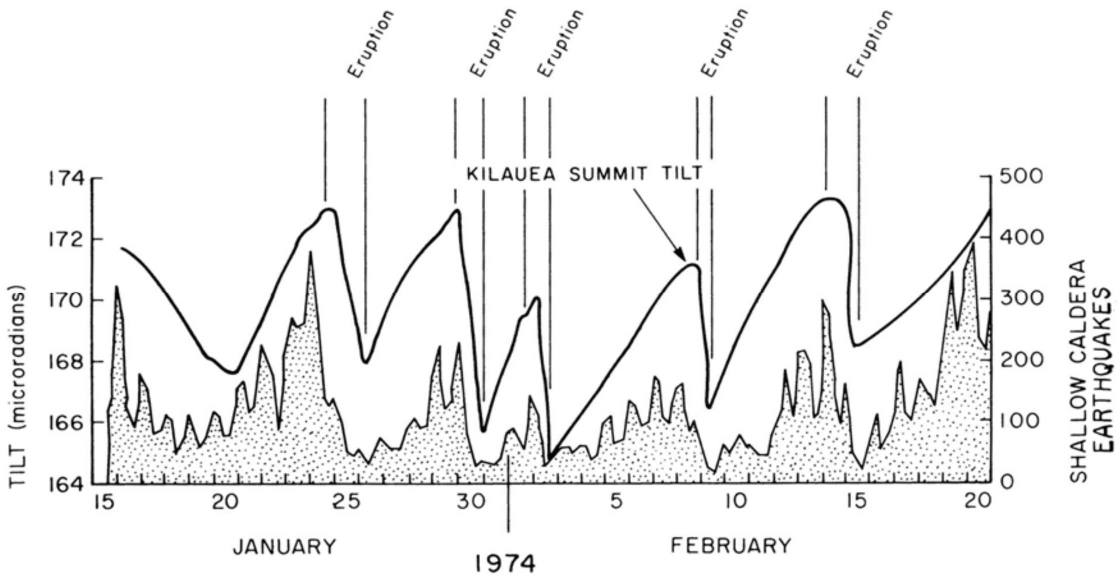


Figure 11 – Summit tilt and earthquake frequency (shaded area) from 15 January to 20 February 1974 at Kilauea volcano. (Source of data: U.S. Geological Survey Hawaii Volcano Observatory.)

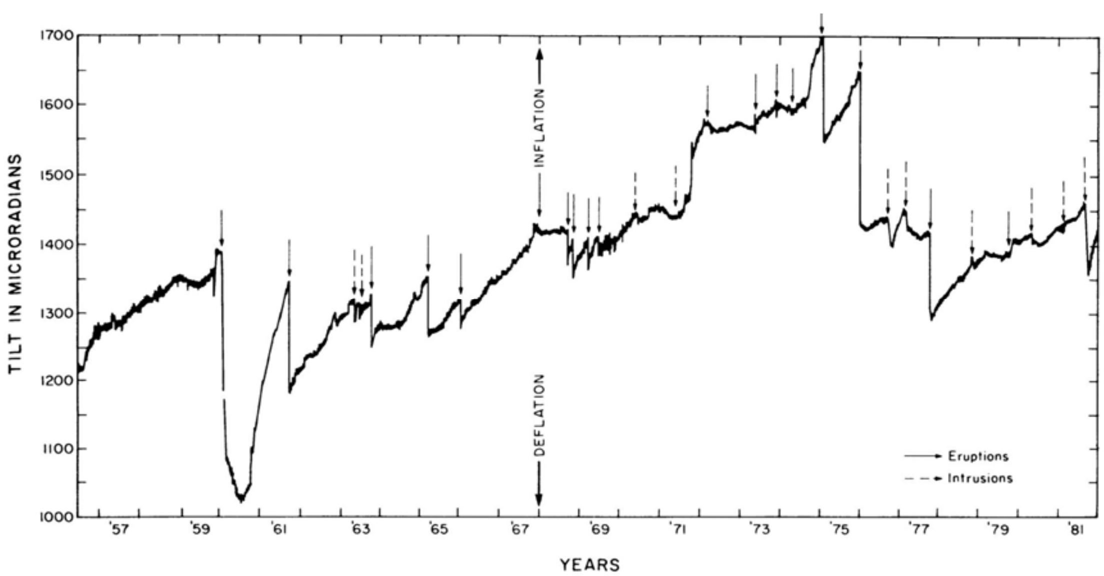


Figure 12 – Record of Kilauea summit tilt from 1957 to 1981. Increasing tilt indicates inflation and decreasing tilt deflation. Note that intrusions and eruptions are preceded by episodes of increasing tilt. (Source of data: U.S. Geological Survey Hawaii Volcano Observatory.)

Clearly the graphs above are records of the heartbeat of an active volcano, with its surface heaving and issuing forth lava on a periodic basis. Over the past 800,000 years, this process has created the island of Hawaii, the focus of our field trip. The rest of this guidebook will focus on the specific places that we plan to visit on our 10-day excursion. Figure 13 is a map of the island of Hawaii showing many of the place names mentioned in the itinerary. But before we get to the itinerary and information on specific stops, let's chat a bit about basalts.

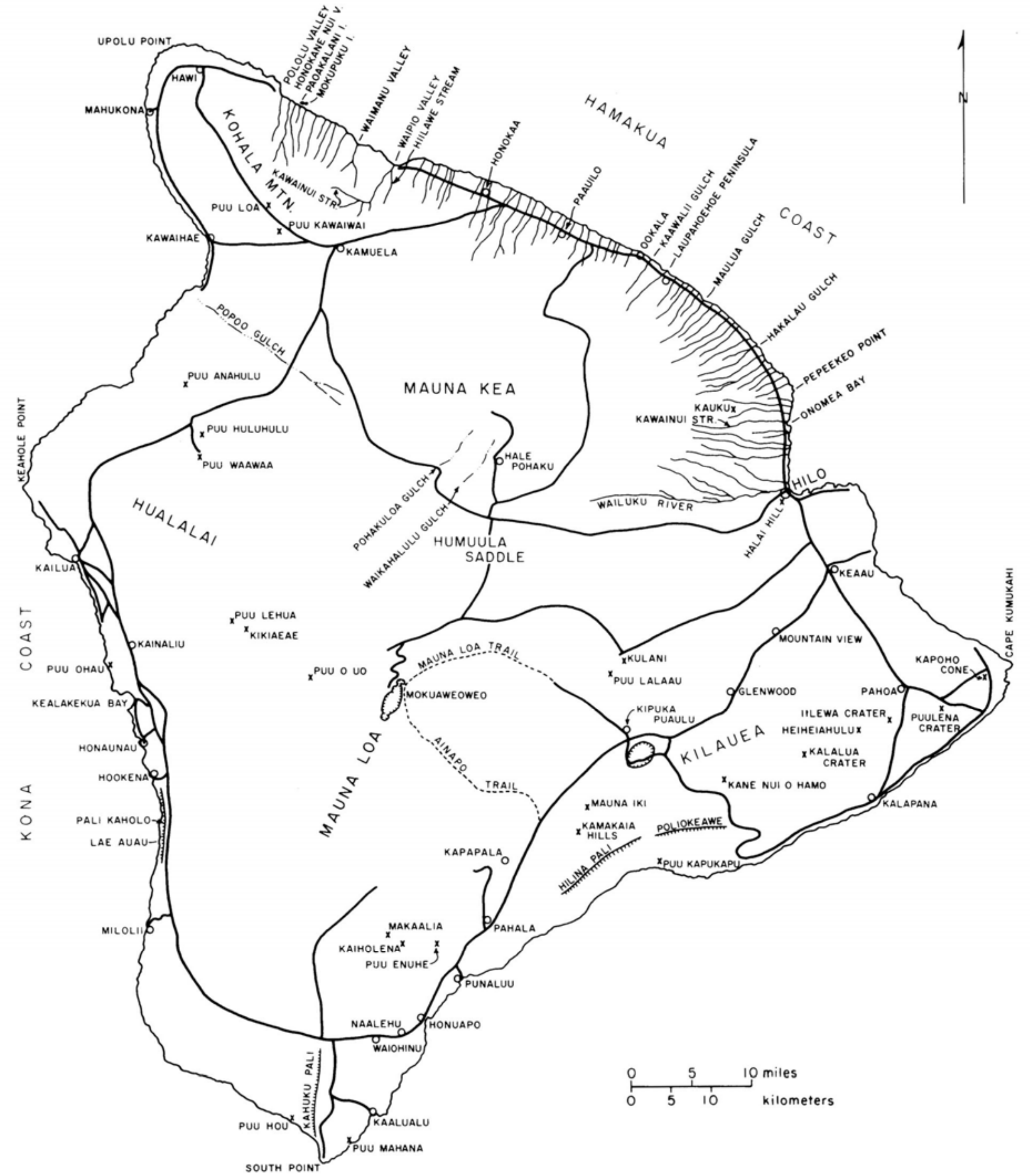


Figure 13 – Map of Hawaii with place names. (From Macdonald and others, 1983, Fig 19.2, p. 347.)

Origin of Basalts

The Earth's surface can be divided into two general silicate rock types: low density and light colored **granite** which makes up the continents and high density dark-colored **basalt** which underlies the ocean basins. Granites are relatively easy to study since they are readily accessible on land but basalt is more difficult to access because it mostly lies beneath deep oceans and is covered by varying amounts of sediment. The chemistry of both types is variable, depending upon location and how much melting of parental rock has occurred prior to its formation.

Basalt is typically derived from various degrees of melting of the Earth's upper mantle, whose initial composition is thought to be that of a **peridotite**. Peridotite generally contains the minerals calcium feldspar, pyroxene, and olivine and perhaps some minor chromite and magnetite. As a result, this dark rock has a density higher than basalt. The partial melting of peridotite can form relatively shallow magma chambers of basalt beneath active plate boundaries such as the north-south trending Mid-Atlantic Ridge of the Atlantic Ocean. This is a **divergent plate boundary** where new ocean floor basalt is created as a result of active seafloor spreading. Because the oldest basaltic sea floor is only about 180 to 200 Ma and the Earth is approximately 4.6 Ga (billion years old), the seafloor must have been recycled many times along **convergent plate boundaries** or **subduction zones**. This "recycled" basalt process produces a unique chemistry to the resulting basaltic oceanic crust and it is referred to as mid ocean ridge basalt or **MORB**; they are also known as **tholeiites**, named after a type-locality in Iceland. To describe and compare the chemistry of "recycled" versus "not recycled" basalt, chemical analyses are given in the form of percentages of mostly metallic oxides such as SiO_2, Al_2O_3, FeO, MgO, CaO, Na_2O, K_2O, MnO, TiO_2, and P_2O_5, whose sum equals about 100%. Refer to Table 2 for some selected average chemical silicate rock analyses. SiO_2 is chemical shorthand notation for silicon dioxide or silica and generally, igneous rocks contain between 30% to 80% silica. By comparison, a continental granite is rich in SiO_2, K_2O, TiO_2, and P_2O_5. while being low in FeO, MgO, and CaO. These oxide amounts reflect the types of minerals present in granite such as quartz, potash feldspar, micas, and perhaps some hornblende. A MORB tholeiite is characterized by having lesser amounts of SiO_2 and K_2O, with higher FeO, MgO, and CaO, which corresponds to the presence of pyroxene, calcium feldspar and rare olivine; minerals that are very different from those in granite.

Table 2 – Selected Average Basalt Compositions

Oxide	Kilauea Tholeiite	Hawaiian Alkali Basalt	Mid-ocean Ridge Basalt	Continental Hornblende Granite
SiO_2	50.5	46.4	48.8	71.1
Al_2O_3	13.5	14.2	15.9	14.1
FeO	11.2	12.6	9.8	2.6
MgO	7.4	9.5	9.7	0.3
CaO	11.2	10.3	11.2	1.6
Na_2O	2.3	2.9	2.4	3.0
K_2O	0.05	0.09	0.01	6.1
MnO	0.02	0.02	0.02	0.2
TiO_2	2.6	2.4	1.2	0.4
P_2O_5	0.03	0.03	0.03	0.1
Totals	99.7	99.7	99.6	99.5

Basalt that forms away from plate boundaries or on "hot spots" within an oceanic plate are known as oceanic island basalts or **OIB**s. Their chemistry is slightly different than those of MORBs. Partial melting of deeper mantle beneath Hawaii, produces a basalt known as a **Hawaiian tholeiite**. Compared to a **MORB**, a Hawaiian tholeiite is richer in SiO_2, FeO, and K_2O and poorer in Al_2O_3, and MgO. This corresponds to the abundance of calcium feldspar and pyroxene with minor olivine phenocrysts. As Hawaii sits atop the hotspot, the chemistry of the basalt does not change much. However, as the island moves away from this area, the degree of partial melting of the mantle decreases due to an increased distance from the heat source and melting occurs at shallower depths. As a result, a new type of basalt (**alkali basalt**) is created. This type is lower in SiO_2 and CaO, while higher in Na_2O and K_2O. Correspondingly, there are more sodium+calcium (plagioclase series) and potash feldspars present and overall the magma is much more sticky or viscous.

Viscosity is described as the resistance to flow for fluids. For example, water has a very low viscosity since it flows readily, while ketchup has a very high viscosity, since it flows with great difficulty when poured from its container (unless you pound on the 57). Molten lava behaves in a similar manner. The ability of a lava to flow *increases with decreasing silica content* and increasing temperature; or conversely, the *higher the silica content, the higher the viscosity* and the more difficult it will be for it to flow. Alkalic lavas formed from older volcanoes on Hawaii are very viscous. At the Kohala volcano on the north shore of the Big Island of Hawaii, two types of unusual alkali basalts are known as **benmoreite and hawaiite.** The former has weathered brown olivine crystals, sodium feldspar crystals, thin black hornblende needles, and is gray in color. The latter is red brown with alkali feldspar in the form of sodium-rich plagioclase and some type of amphibole. Although not shown on any of the diagrams, it represents a type of alkali basalt that is very high in alkalis with about 50% SiO_2 present usually indicative of very old volcanoes fed by very shallow magma source or reduced melting of a tholeiite basalt.

Plotting the chemical abundances of a combination of alkalis (sodium [Na_2O] and potassium [K_2O]) versus overall silica (SiO_2) content from different types of basalt produces a diagram as that shown in Figure 14. Examination of this diagram shows the compositional difference between each type of basalt and the effect of melting and crystallization of the magma and resulting lava. As crystallization increases, the silica content increases slightly and the alkali content decreases forming a tholeiite. As the degree of melting decreases, the alkali content increases and the silica content decreases, forming alkali basalt.

Therefore, Hawaiian tholeiites have not been recycled as much as the MORB tholeiites, probably from sampling different depths with the mantle; MORBs sampling shallower mantle depths, while Hawaiian tholeiites sample deeper mantle depths. One way to determine this is to compare the abundance of certain radioactive elements that occur in trace amounts in certain minerals of the basalt. Two well known and used elements are generally combined isotopes of neodymium (Nd) and strontium (Sr). A plot of their abundances also illustrates the differing compositions and origins of these basalts. Refer to Figure 15 for a plot of neodymium versus strontium isotopes. The composition of the Hawaiian tholeiite is not too different from that of Earth's original mantle composition which has a relatively high abundance of strontium isotopes and lower amounts of neodymium, similar to very old stony meteorites. This suggests the upper mantle away from plate boundaries is fairly primitive in composition and has not been recycled much if any, while the alkalic basalts occupy a transitional location with low amounts of strontium and MORBs even a lower amount, meaning they have been recycled (melted) many times or only partially melted. Use of these diagrams serve as good tools for geologists to use in determining the origin of particular rocks, in this case basalts.

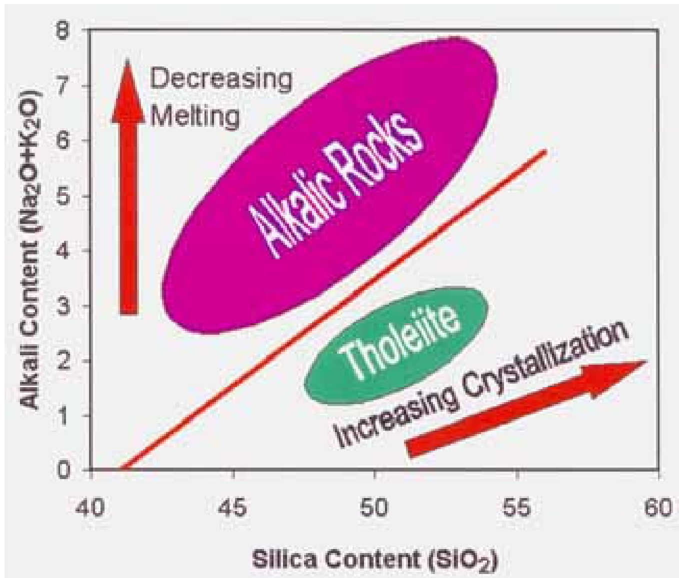


Figure 14 – Silica vs. alkali content of basaltic rocks. (From www.uhh.hawaii.edu/~kenhon/GEOL205/petrology/default.htm.)

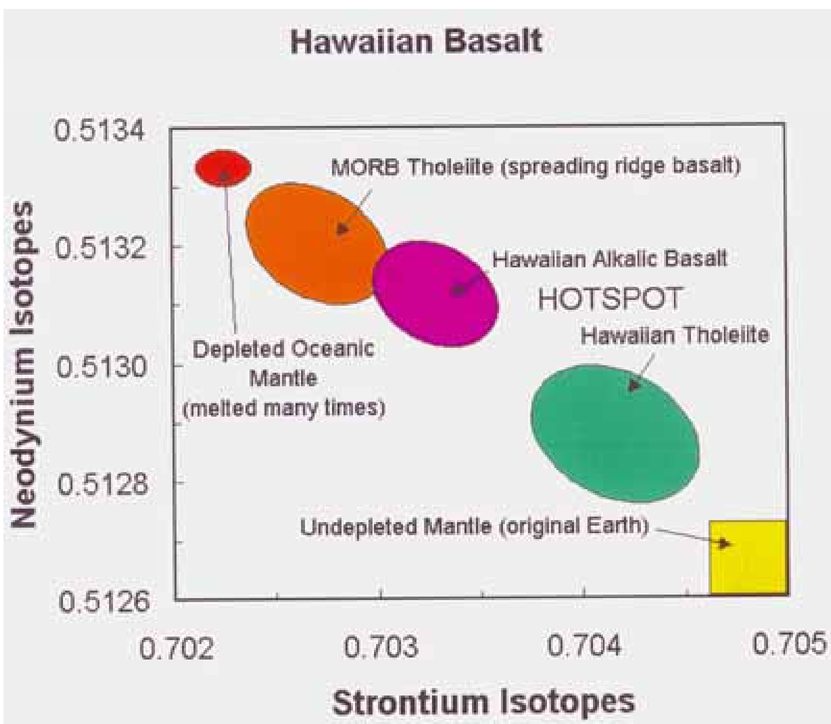


Figure 15 - Trace element isotope concentration of basalts. (From www.uhh.hawaii.edu/~kenhon/GEOL205/petrology/default.htm.)

Final Itinerary

Geology 280F - Summer Session II, 2007
Trip Leaders: Charles Merguerian and Steven Okulewicz

Day 01 - Monday 23 July – Hofstra private bus departs at 3:00 AM to Newark Airport
Depart Hofstra University Gittleson Parking Lot by Armored Car
Depart Newark on America West/U.S. Air Flight 522S @ 6:55 AM – Arrive Phoenix 9:10 AM
Depart Phoenix on America West Flight/U.S. Air 20S @ 10:28 AM – Arrive Honolulu 2:06 PM
Depart Honolulu on Hawaii Airlines Flight 262 @ 4:20 PM – Arrive Hilo 5:11 PM
Pick up van, secure lodging at Hilo Hawaiian Hotel (808 935-9361), adjust to time change for evening

Day 02 - Tuesday 24 July – Hawaii Volcano National Park (HVNP)
Thomas A. Jaggar Museum (USGS speaker)
Kilauea Overview (Volcanic Features)
Halema'uma'u Pit Crater (Overview)
Sulfur Bank and Steaming Bluff (Geothermal features)
Southwest Rift Zone (Structure and flow features)
Keanakako'i Crater

Day 03 - Wednesday 25 July - HVNP
Waldron Ledge Earthquake Hike (Structure)
Kilauea Iki Crater and Thurston Lava Tube Hikes
Devastation Trail [Time Permitting] (Cinder Cone)

Day 04 - Thursday 26 July – Puna District
Pahoa Dump (Volcanic rocks and ash layers)
Lava Tree State Park (Preserved trees)
Pu'u Laimana Volcanic Area (Volcanic rock collecting)
MacKenzie State Recreational Area (Lunch)
Kaimu Black Sand Beach (Hike over pahoehoe lava flow)
Destroyed Village of Kalapana (Possible lava viewing) [Time Permitting]
Ahalanui County Park Hot Tub and Active Steam Lava Tubes (Geothermal features)
Nanawale Sand Hills [Time permitting]

Day 05 - Friday 27 July – Saddle Road Excursion to Kohala
Rainbow Falls, Boiling Pots (Lava tube hydrology, Tropical forest, Flow features)
Kaumana Cave (Ancient Lava Tube; historic pahoehoe flow)
Mauna Kea
Pu'u Huluhulu Preserve (Mauna Kea Cinder Cone Cut by Mauna Loa Dikes)
Onizuka Observatory Visitors Center (Mauna Kea Overview)
Kohala Mountain (Lava Dome, Benmoreite locality, Structure)
Hualalai Volcano [Time Permitting]

Day 06 - Saturday 28 July – Hamakua Coast Excursion to Waipi'o Valley
Hawaii Tropical Botanical Garden
Kahuna and Akaka Falls (Hydrology)
Laupahoehoe Point (1946 Tsunami Effects)
Waipi'o Valley (Hydrology, Tsunami, Weathering)

Day 07 - Sunday 29 July – HVNP
Kilauea Caldera - Halema'uma'u Crater hike (Volcanic features)
Hilina Pali Road Excursion (Structure)
Lua Manu and Pauahi Craters (Volcanic explosion and pit craters)
Mauna Ulu hike (Lava shield volcano) [Time Permitting]

Day 08 - Tuesday 31 July – HVNP
Basalt Petroglyphs and Sea Cliffs (Coastal geomorphology)
Hike to Active Lava Flows and Evening Lava Watch [If possible]

Day 09 - Monday 30 July – Local Hilo Area and Lava Tube Spelunking
Kazumura Cave Exploration (Lava Tube)
Chain of Craters Road Excursion to Pit Craters and Sea Arch

Day 10 - Wednesday 01 August – Kau Desert and Punaluu Harbor
Kau Desert Hike (Volcano-aeolian processes, Human footprints)
Punaluu Harbor Turtle Swim
South Point Olivine Sand Beach [Time permitting]
Town for packing, shipping specimens and gift shops
Day rooms have been secured for last minute showers and packing

Day 10 - Return Travel Arrangements:
Depart Hilo on Hawaiian Airlines Flight 391 @ 8:43 PM – Arrive Honolulu 9:30 PM
Depart Honolulu on America West/U.S. Air Flight 125S @ 10:55 PM – Arrive Phoenix 7:51 AM
Set watches back to New York time.
Depart Phoenix on America West Flight/U.S. Air 687S @ 9:09 AM – Arrive Newark 5:19 PM (02 Aug)
Private bus taking students to Hofstra Campus (est. arrival 8:00 PM)

Bomb's Away!

Day 02 - Tuesday 24 July 2007 – Hawaii Volcano National Park (HVNP)

Through prior arrangement we will have a speaker greet us at the Jaggar Museum (no relation to Mick Jagger, rock heads!). The purpose of today's introduction to the geology of Hawaii is to get right into it, namely into the volcanic features of Kilauea volcano (Figure 16) including the Southwest Rift Zone, Halema'uma'u Pit Crater, Keanakako'i Crater, Sulfur Bank, and Steaming Bluff.

Thomas A. Jaggar Museum

Thomas A. Jaggar, who from MIT, founded the Hawaiian Volcano Observatory in 1912 and was the director until 1940. HVNP was established in 1916 and the museum became part of the U.S. Geological Survey 1947. The HVO monitors activity on Kilauea and Mauna Loa using 50 seismographs on each volcano. They record 100,000 temblors per year, roughly 3-4 quakes per week. They also use tiltmeters which are sensitive to 1 part in 10 million meaning having 3,000 foot level to detect a piece of paper under one end. Tiltmeters are used to measure inflation and deflation of the summit.

1. What is the location of the current source of magma? Do you think the composition of the magma within these chambers are different?

2. Why is the Thomas A. Jaggar Museum located here?

3. Is there any danger of eruption for the museum?

4. From examination of the museum's exhibits, what are the precursors of a volcanic eruption?

5. From the exhibits, describe five products of a volcanic eruption.

6. List several volcanic hazards created by this volcano.

7. What is the significance of volcanic harmonic tremors?

8. Compare earthquakes here in Hawaii with those generated on the mainland. How do they differ?

9. From the museum exhibit, how does a tiltmeter work?

10. Why is their use important?

11. Sketch two simple diagrams of a volcano: one showing volcanic inflation and one showing volcanic deflation with respect to a pending volcanic eruption.

Kilauea Volcano and Hawaii Volcano National Park

Hawaii is perhaps the most famous shield volcano in the world and certainly the most visited. Starting in 1916, the Hawaii Volcano National Park which is located at Kilauea has drawn spectators from all over the world. Showing constant eruption beyond recorded history, surely it was noticed by at least a few inhabitants and voyeurs. Not the highest peak in Hawaii at 1,248 m (See Table 1.), the activity at Kilauea has produced a plethora (**Note:** I am contractually obligated to use this word at least once a year and I am covering myself.) of volcanic features of great interest to students of geology. Kilauea is a broad shield-type volcano built upon the southeast slope of Mauna Loa, the "big mountain". The lavas of Mauna Loa lap against the northwestern margin of Kilauea (compare Figure 2 with Figures 16 and 17.) The summit of Kilauea is marked by an elongate caldera 4 km long by 3.2 km wide and 120 m deep along its western side. The caldera walls decrease to zero toward the south and within the caldera lies a circular crater known as Halema'uma'u (Figure 18), the site of magnificent basaltic volcanicity for the past century. Two rift zones extend southwestward and eastward from Kilauea caldera and these have localized flank eruptions. The eastern rift zone bends sharply extending 8 km southeastward from the caldera then bends extending east-northeastward toward Cape Kumukahi and onward toward the ocean floor.

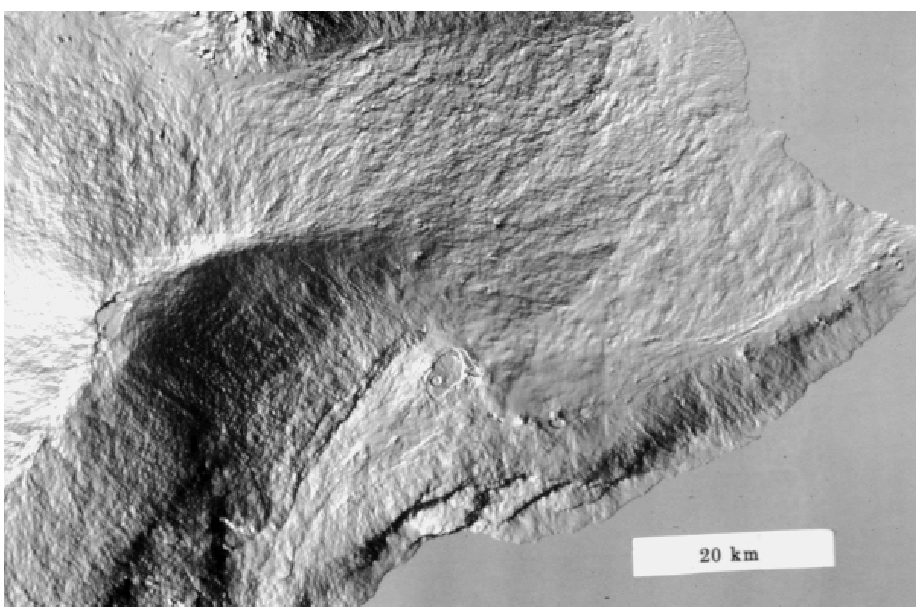


Figure 16 - Digital elevation map of Mauna Loa and Kilauea showing Kilauea's Summit. Note the oval-shaped collapse structure in the bottom center of the image, a huge caldera perched on the top of the summit. (From www.uhh.hawaii.edu/~kenhon/GEOL205/petrology/default.htm.)

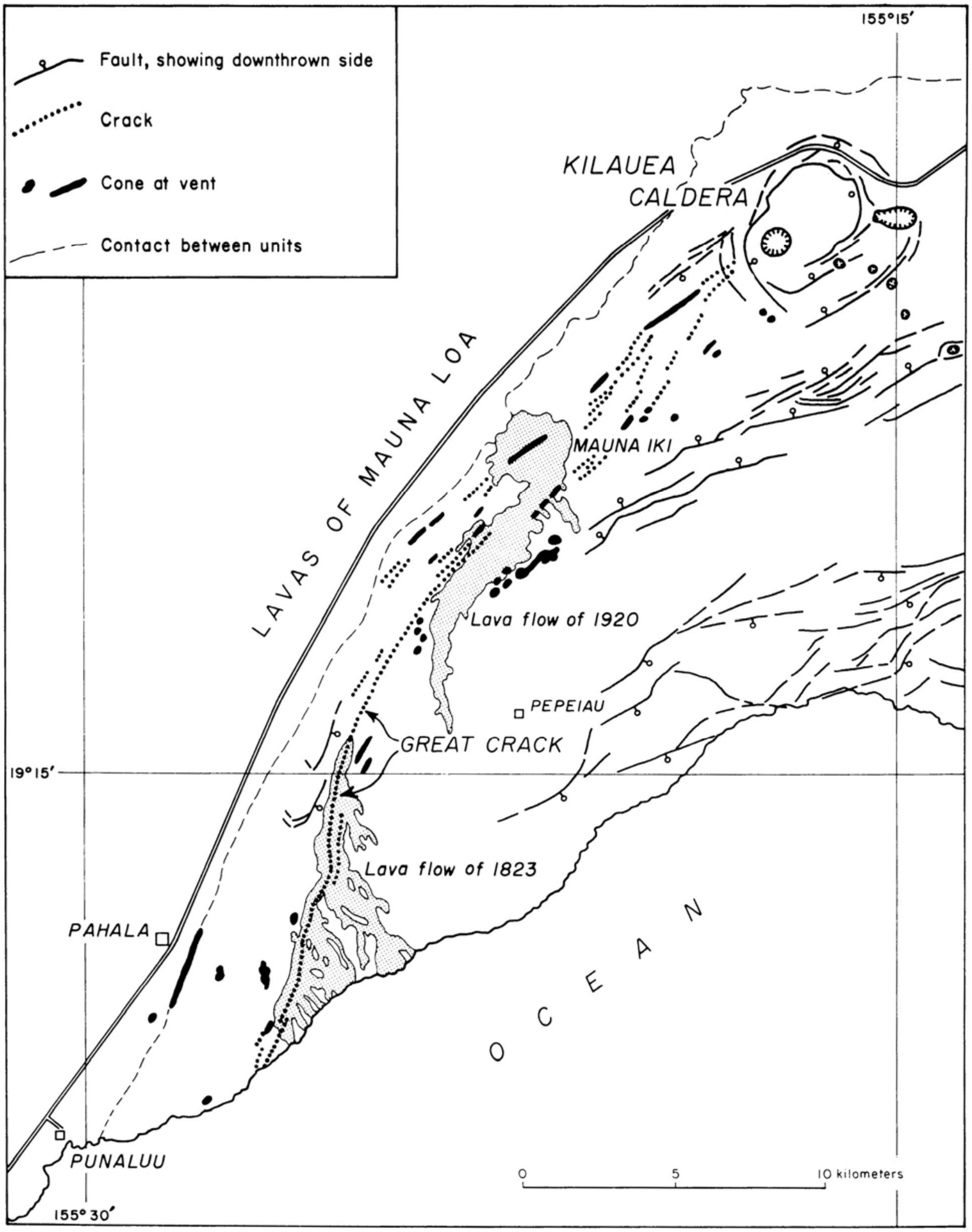


Figure 17 - Map of the western part of Kilauea volcano showing faults, fractures, and cones along the Southwest Rift Zone and the position of lava flows from 1823 and 1920. (From Macdonald and others, 1983, Fig. 3.12, p. 78.)

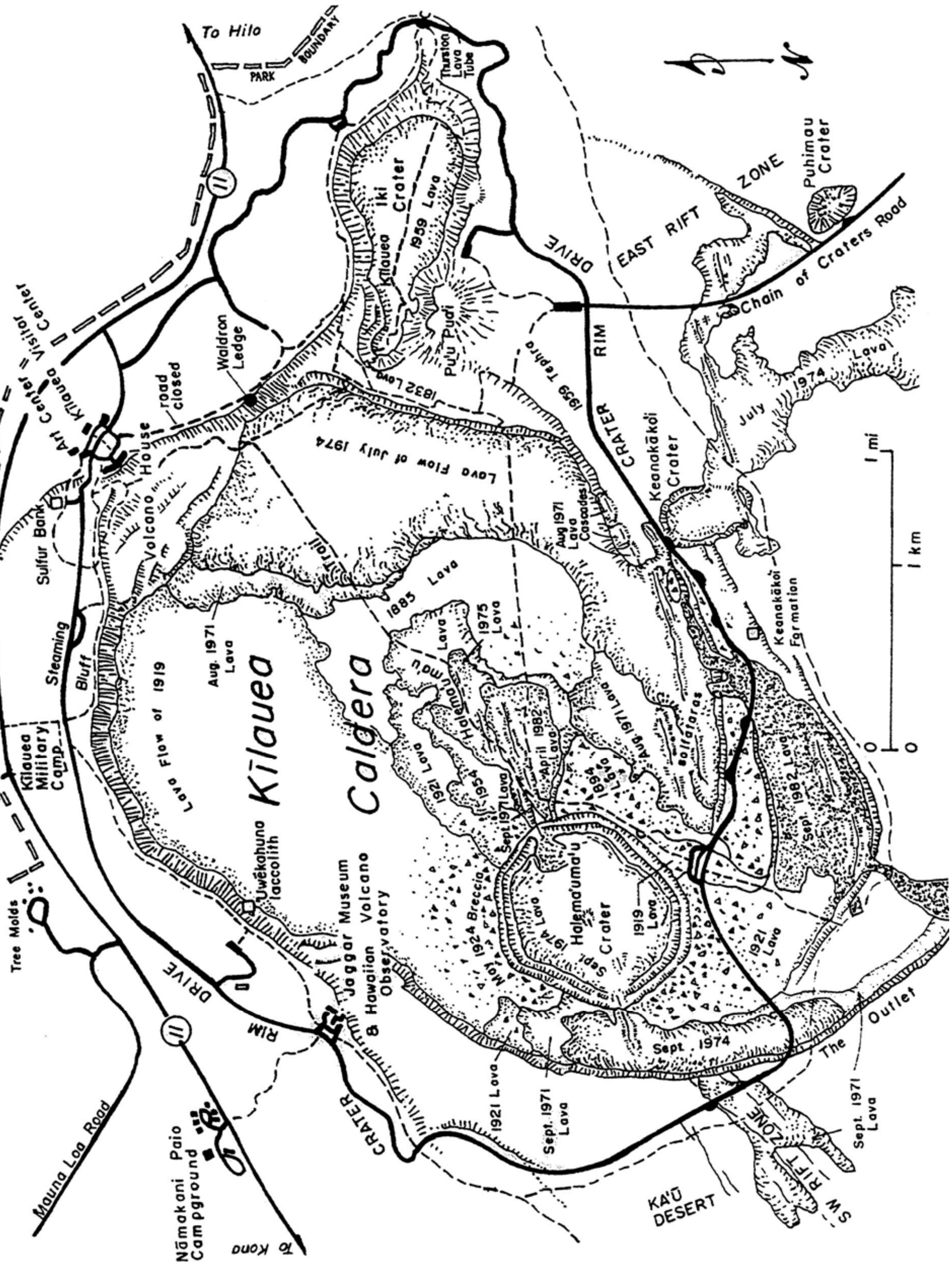


Figure 18 – Road map and diagram of Kilauea caldera. (Modified from Eaton and Murata, 1960.)

Thirteen pit craters are distributed along the rift within 16 km of the caldera (Figure 19). Eruption pairs have been suggested by many workers for both Mauna Loa and Kilauea with a summit eruption followed by a flank eruption but analysis by Klein (1982) indicates that the eruptions of Kilauea are random with little evidence for summit-flank pairing. Yet, eruption pairing can certainly be demonstrated for the 1954-55 and 1959-60 eruptions.

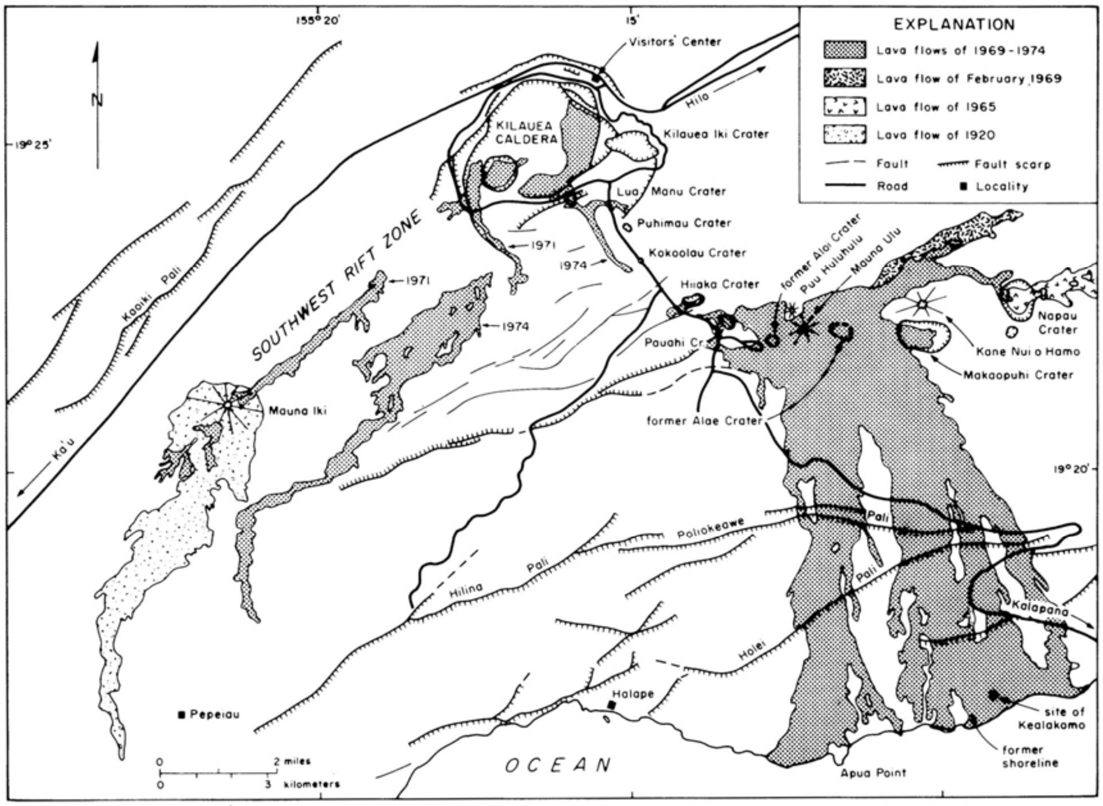


Figure 19 – Map of Kilauea caldera and the upper parts of the southwest and eastern rift zones of Kilauea Volcano and lava flows active since 1964. Aloi and Alae craters on the east rift zone have been buried by lava flows from Mauna Ulu, a small shield volcano active from 1969 to 1974. Lava from that vent entered the ocean at the south coast after cascading down the Poliokeawe and Holei palis, destroying the ancient Hawaiian city of Kealakomo. The Hilina, Poliokeawe, and Holei palis are fault scarps produced by a 600 m drop of landscape to the south. Halape sank about 4 m during the 29 November 1975 earthquake. (From Macdonald and others, 1983, p. 109, Fig. 3.29.)

Kilauea Caldera

Calderas are produced when a shallow magma chamber is evacuated and a void develops below a volcanic summit. A series of circular inward dipping ring fractures develop and coalesce and eventually the tip of the volcano can subside into the voided chamber leaving a caldera in its wake. Maps and sections across the Kilauea caldera (Figures 20, 21, 22, and 23) indicate major changes in a relatively short period of time geologically speaking. The multitude of thin flows that constitute Kilauea are clearly visible on the walls of the caldera. Pahoehoe flows predominate in the vicinity of the caldera but farther away from the caldera and the rifts aa becomes more abundant and near the coast aa flows predominate.

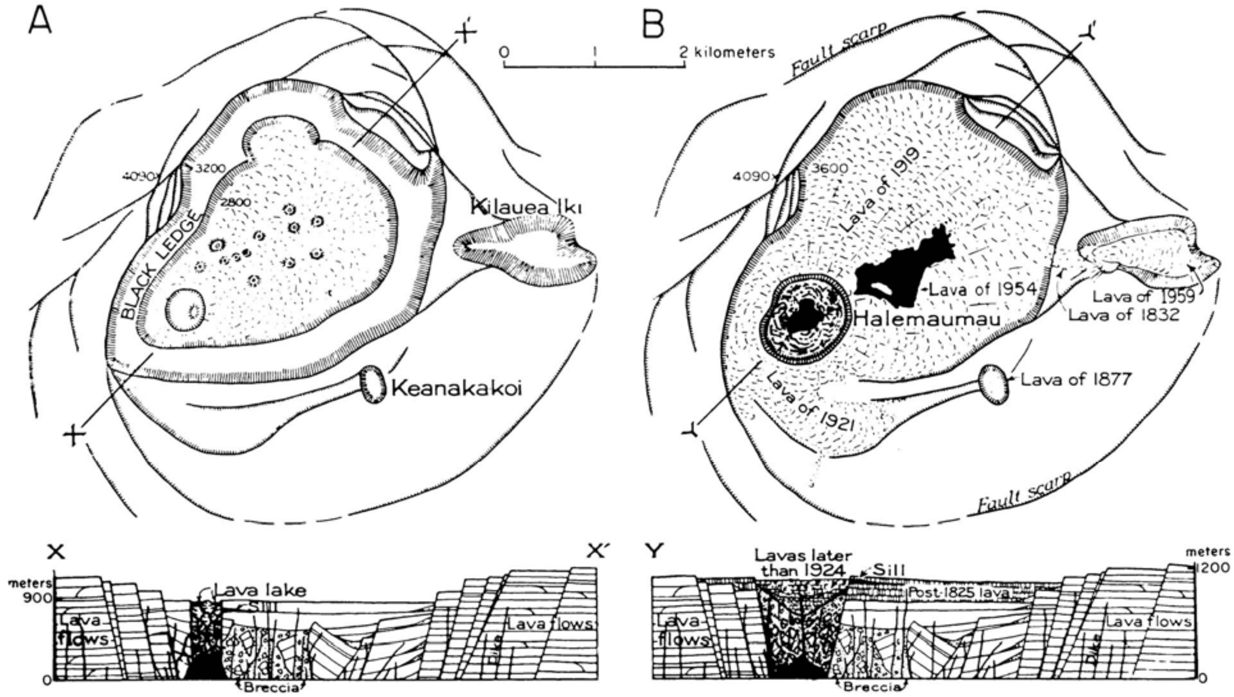


Figure 20 – Maps and sections of Kilauea caldera. A. in 1825 and B. in 1960. The large central pit that existed in 1825 had been filled in entirety before 1900. Structure beneath the caldera (sections) is interpretive. (From Macdonald and others, 1983, Fig 3.11, p. 76.)

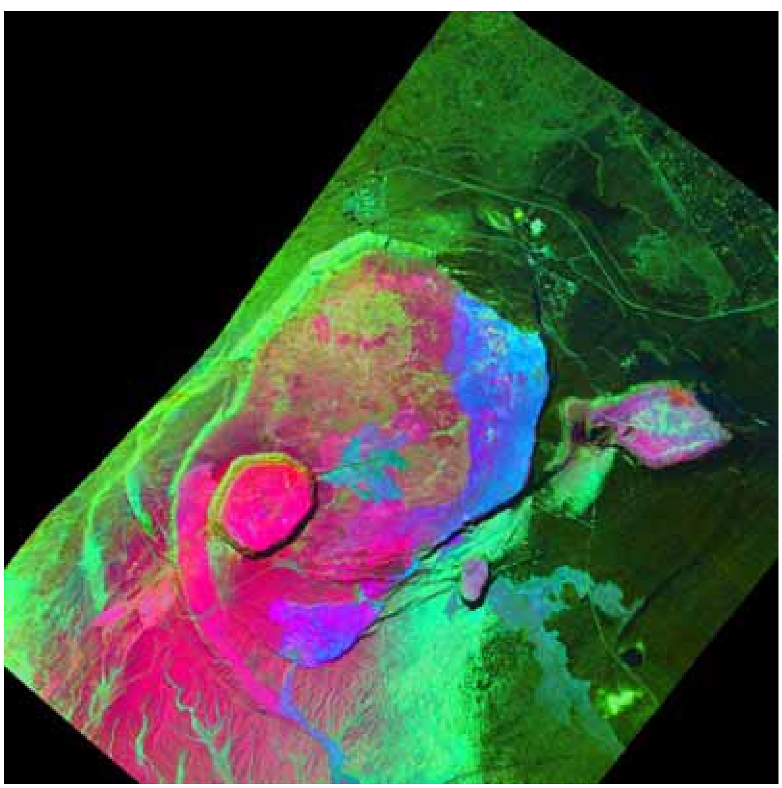


Figure 21 - False color satellite image showing the same general area as Figure 20.

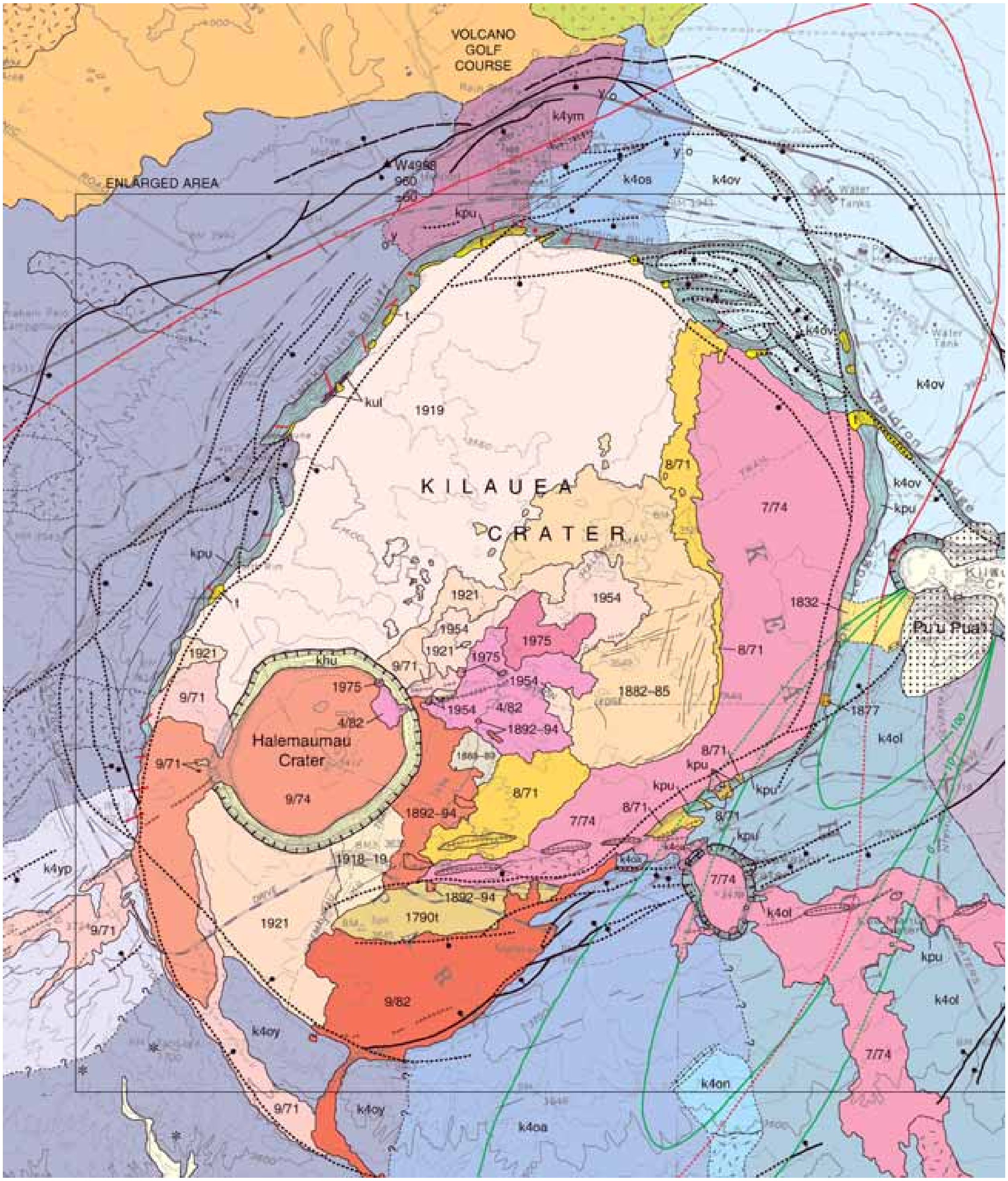
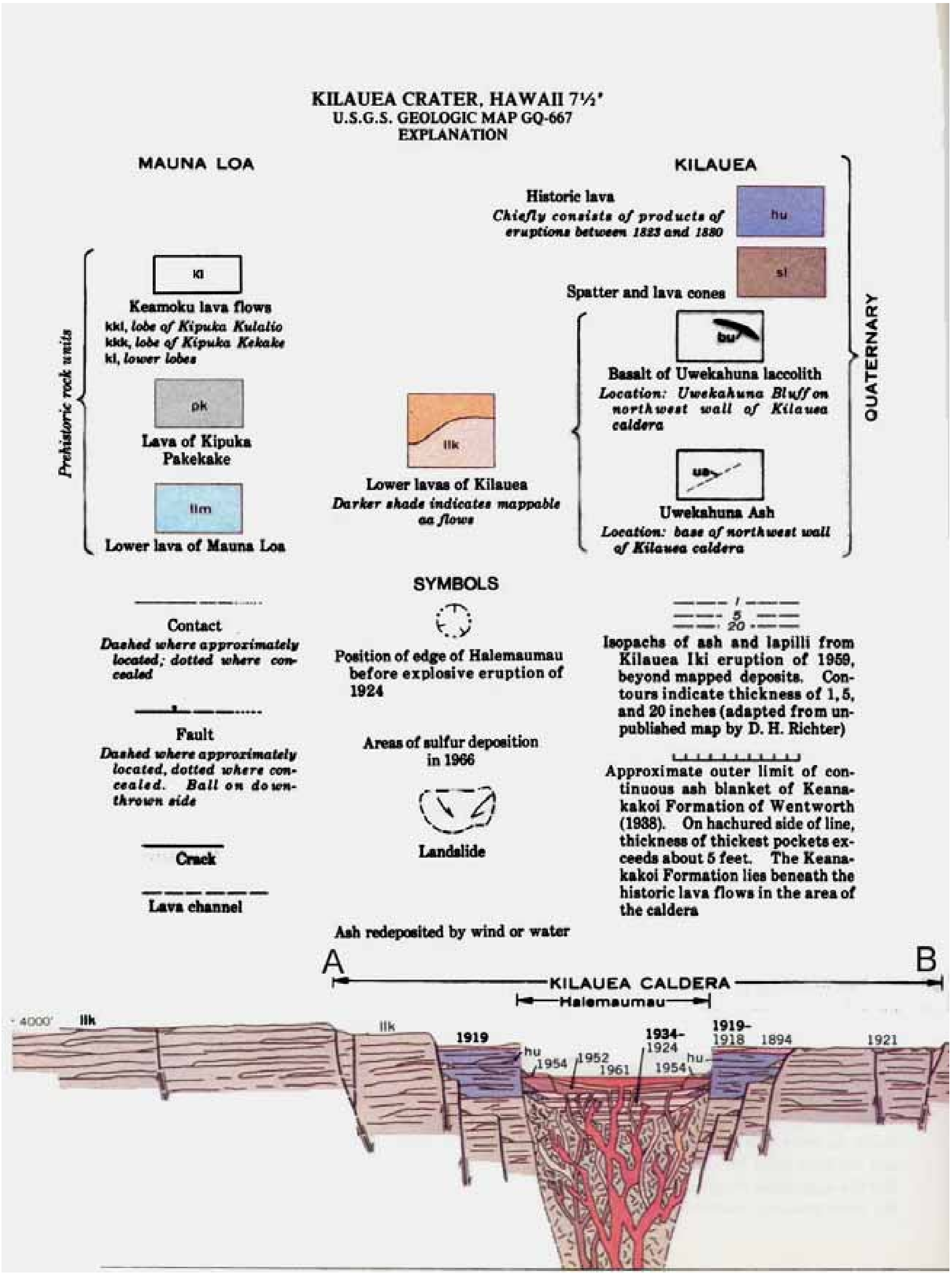


Figure 22 – Geological map, explanation, and section across Kilauea caldera (below). (From U. S. Geological Survey.)


KILAUEA CRATER, HAWAII 7½'
U.S.G.S. GEOLOGIC MAP GQ-667
EXPLANATION
MAUNA LOA
KILAUEA
Historic lava
Chiefly consists of products of eruptions between 1823 and 1880
hu
sl
Spatter and lava cones
kl
Keamoku lava flows
kkl, lobe of Kipuka Kulalio
kkk, lobe of Kipuka Kekake
kl, lower lobes
bu
Basalt of Uwekahuna laccolith
Location: Uwekahuna Bluff on northwest wall of Kilauea caldera
QUATERNARY
Prehistoric rock units
pk
Lava of Kipuka Pakekake
llk
Lower lavas of Kilauea
Darker shade indicates mappable aa flows
ua
llm
Uwekahuna Ash
Location: base of northwest wall of Kilauea caldera
Lower lava of Mauna Loa
SYMBOLS
Contact
Dashed where approximately located; dotted where concealed
Position of edge of Halemaumau before explosive eruption of 1924
1
5
20
Isopachs of ash and lapilli from Kilauea Iki eruption of 1959, beyond mapped deposits. Contours indicate thickness of 1, 5, and 20 inches (adapted from unpublished map by D. H. Richter)
Fault
Dashed where approximately located, dotted where concealed. Ball on downthrown side
Areas of sulfur deposition in 1966
Approximate outer limit of continuous ash blanket of Keanakakoi Formation of Wentworth (1938). On hachured side of line, thickness of thickest pockets exceeds about 5 feet. The Keanakakoi Formation lies beneath the historic lava flows in the area of the caldera
Crack
Landslide
Lava channel
Ash redeposited by wind or water
A
B
KILAUEA CALDERA
Halemaumau
4000'
llk
llk
1919
hu
1954
1952
1961
1934-
1924
1954
hu
1919-
1918
1894
1921

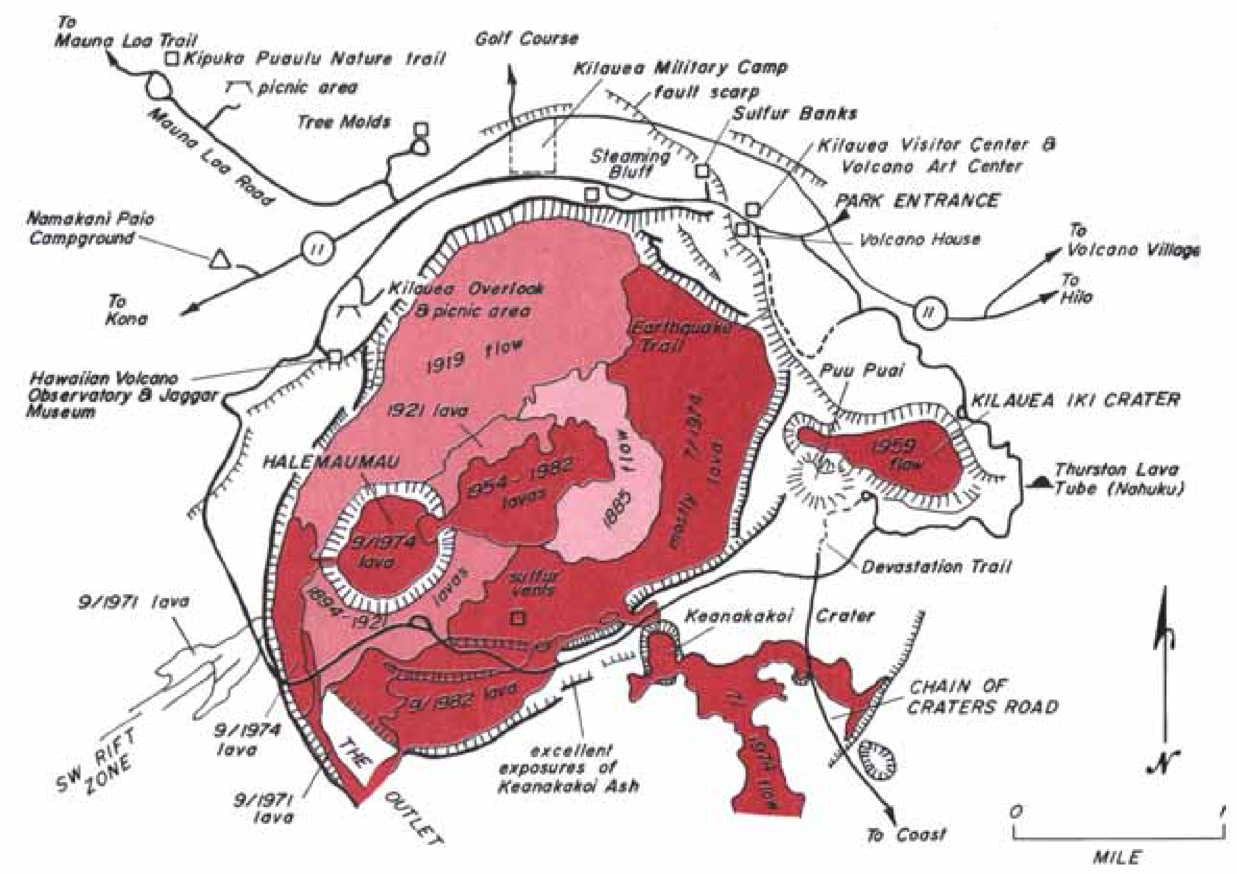


Figure 23 – Geological sketch map of Kilauea caldera and vicinity. (From Hazlett and Hyndman, 1996, p. 70.)

To discuss in the field:

1. Locate yourself on the above map and from the viewing area behind Volcano House, explain the shape and structure of Kilauea.

2. How old is the present day caldera?

3. What is the difference between a caldera and a crater?

4. What are the approximate dimensions of the caldera?

5. What is the geologic feature that bounds the caldera?

6. What are the ages of the youngest/oldest lava exposed on the caldera floor?

7. The two zones where eruptions have recently occurred are:

   1. ______________________________ 2. ___________________________________

Halema’uma’u Pit Crater

Halema’uma’u is the pit crater located inside Kilauea caldera, which is believed to be the house of the goddess, Pele. A pit crater and caldera are craters of different sizes as exemplified by Halema’uma’u pit crater inside Kilauea caldera. As you walk inside the caldera, you can smell and taste the gases released from the still active volcano. The main odoriferous gas is sulfur dioxide. Halema’uma’u is about 1440 m across and 640 m deep. It is sometimes called "The House of Everlasting Fire" because of an active lava lake within it for over a hundred years (Figure 24).

Figure 24 – Two views of Halema’uma’u pit crater stolen with flowery glee from Al Gore’s internet.

Halema'uma'u crater lies on the southwestern side of the main Kilauea caldera. (See Figure 22). For the past century, Halema'uma'u has been the principal site of volcanic activity at Kilauea's summit. There has also been frequent activity along the Southeast Rift Zone (such as the presently active Pu'u 'O'o eruption, which started in 1983). The thin pahoehoe flows that built Kilauea can be seen in the walls of the caldera. As mentioned earlier, pahoehoe flows predominate in the caldera region because they are close to the vents in which they were issued. With the increasing distance from the caldera and rift zones, aa becomes more abundant, particularly nearer the coast. Clearly, significant volcanic activity has been recorded at Kilauea volcano (Figure 25).

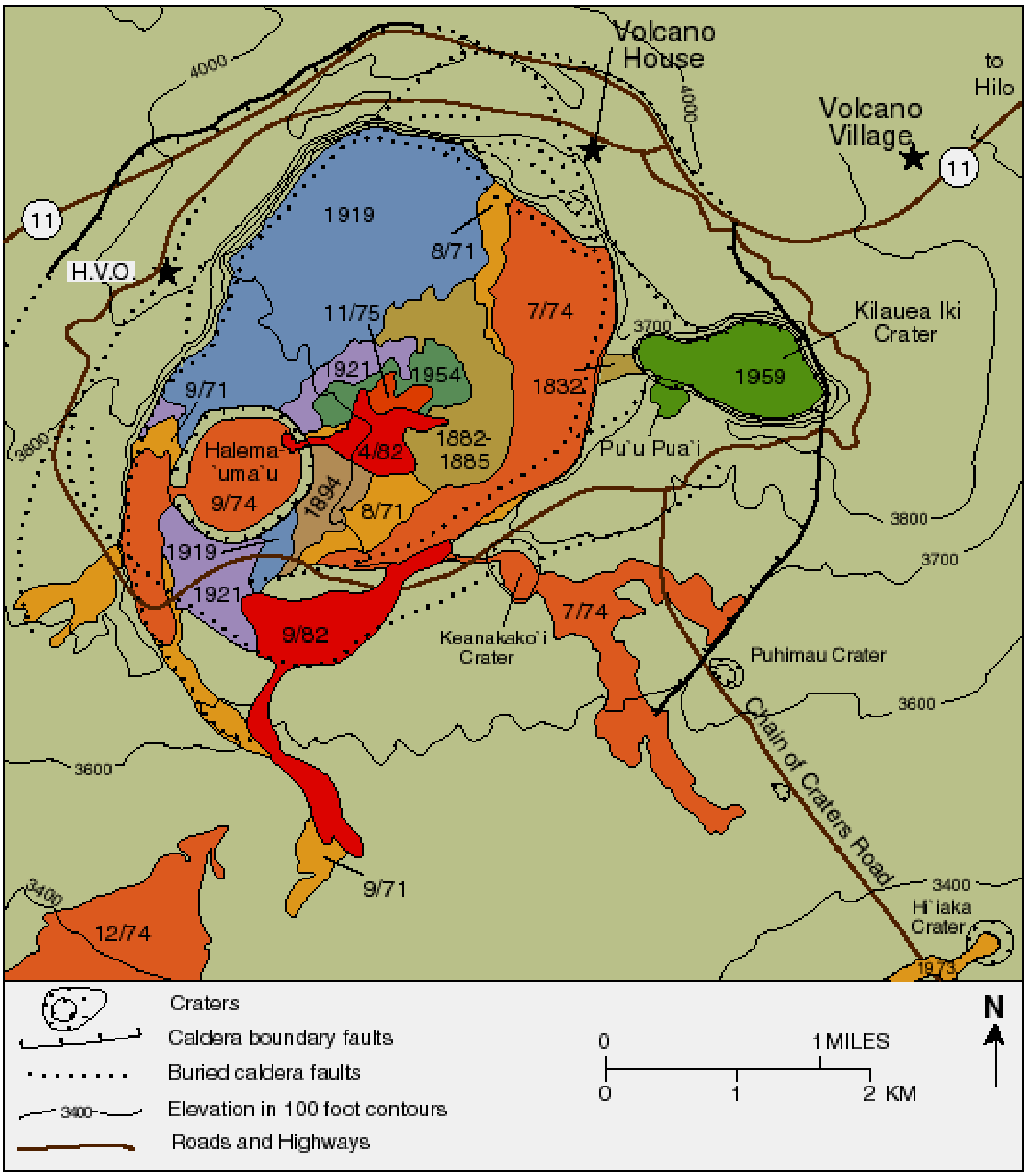


Figure 25 - Lava flows within the Kilauea caldera.
(From www.uhh.hawaii.edu/~kenhon/GEOL205/petrology/default.htm.)

From 1823 to 1924 Halema’uma’u was an active lava lake of molten lava. One could look into the crater and see the flowing liquid lava, which would sometimes overflow into the caldera. However, in 1924, the lava drained back into the crater, leaving it empty and lonely-hearted but not for long. Quiescence resulted in a phreatic explosion (Figure 26) because the sudden draining of the lava lake caused cool ground water to enter the crater and be quickly heated. The mixing of the water and hot lava caused a high, explosive steam eruption, which threw out blocks of rocks and debris. Even though, the blocks were hot when they were thrown out of the crater, they were not new. The blocks were actually cooled magma of a previous eruption from the inner walls of the crater. One death resulted from this dangerous explosion - a photographer who had gotten a little to close was struck by a piece of falling debris and killed.

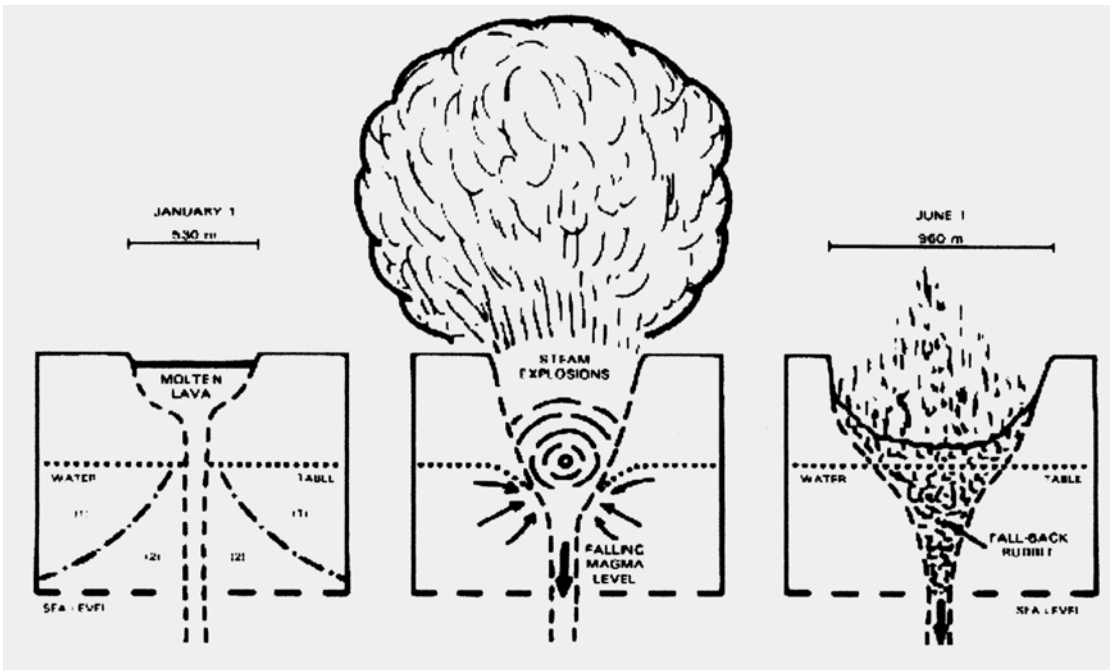


Figure 26 - Diagram of possible phreatic eruption of Kilauea volcano. (From www.uhh.hawaii.edu/~kenhon/GEOL205/petrology/default.htm.)

The Powerful Halema’uma’u Eruptions of 1924

Approximately 83 years ago, the final chapter of one of Kilauea's most alarming displays of volcanic power came to a close. Halema`uma`u, the fire pit nestled in Kilauea's summit caldera, ended a 10-day-long outburst of violent steam explosions on 24 May 1924. For nearly two decades prior to 1924 an immense lake of molten lava churned and bubbled at the bottom Halema`uma`u Crater. Travelers from across the world were drawn to the rim of Halema`uma`u to witness the spectacular array of volcanic pyrotechnics. In February 1924, however, a curious thing happened. A giant molten whirlpool formed on the lake's surface. Over two days' time, lava drained away like water in a bathtub, leaving behind a dully glowing pit 112 m (370 feet) deep and 520 m across (1,700 feet). Halema`uma`u remained in this ominously quiet state for almost two months.

In April 1924, attention was diverted from the unusual happenings at Halema`uma`u by an earthquake swarm that rattled the summit of Kilauea. The swarm migrated 45 km (28 miles) down the volcano's East Rift Zone to the eastern tip of the island near Kapoho. On April 22 and 23, Kapoho residents felt more then 200 earthquakes. Cracks opened, and a stretch of land 6.4 km (4 miles) long and 1.6 km (a mile) wide subsided. The area just north of Cape Kumukahi dropped 4 m (14 feet) and the sea washed inland a kilometer (half a mile) past the shoreline. Such swarms typically herald the start of an eruption, but no eruption came-or so it seemed. A few days later, attention again turned to Halema`uma`u. The floor of the pit began to sink rapidly. Incandescent slabs of rock peeled from the walls and crashed down into the pit. Hot ash and pebbles swirled out over the rim as the rocks hit bottom. Undaunted by ash storms that "stung like hail," some 400 visitors from a Thomas Cook steamship tour were thrilled by the awesome sight.

On the morning of May 11, a ranger from Hawaii National Park noticed several hot boulders on the rim of Halema`uma`u. Evidently, a small explosion had occurred in the pit overnight. The park superintendent, Thomas Boles, put up roadblocks 0.8 km (a half a mile) from the crater and ventured out to investigate with two other observers. Boles was within 3 m (10 feet) of rim when he heard a "thud" followed by a "prolonged whooosh." Thousands of red-hot boulders shot up amidst a fury of black ash. The ash column rose 915 m (3000 feet) above the crater as the party ran for cover. Fortunately, all three made it back to their vehicle, sustaining only a few cuts and bruises. They found that a boulder weighing nearly 45 kg (100 pounds) had sailed over the vehicle during the explosion, landing more than 600 m (2,000’) from the crater. Superintendent Boles pushed the roadblocks back 2.2 km (2 miles) from the crater. Similar events followed, with each explosion more intense than the last. At night, the white-hot rocks that were hurled from the crater looked like rockets trailing sparks.

The largest explosion occurred on May 18. With a resounding BOOM, an ash column shot up 6.5 km (4 miles) in the air while a hurricane-force rush of gas and ash spread across the caldera floor. To Superintendent Boles, the dark, mushrooming column "loomed up like a menacing genie from the Arabian Nights." Static electricity generated between ash particles produced streaks of blue lightning and condensed steam mixed with the ash to create a rainstorm of gray mud. A young man from a nearby sugar plantation had slipped past the road blocks set up by the Superintendent and was within 600 m (2,000’) of the rim when the explosion occurred. He was hit by a boulder and severely burnt by the falling ash. Rescuers hurried in to the caldera when the explosion ended some 20 minutes later, but the unfortunate man died on the way to the hospital.

After the deadly blast of May 18, the explosions continued, but with waning intensity. When the dust finally settled on May 24, Kilauea caldera was littered with huge boulders. Rocks weighing as much as 8,000 kg (8 tons) were found 500 m (1,600’) from the rim of Halema`uma`u. The pit itself was almost twice as wide as it had been and eight times deeper.

The cause of the 1924 explosions can be deduced from seismic and geodetic measurements made by HVO scientists before, during, and after the event. April's earthquake swarm indicates a massive draining of magma from Kilauea's summit reservoir into the East Rift Zone. The considerable ground cracking and subsidence in Kapoho suggests that magma moved out into the submarine portion of the rift where it very likely fed an eruption on the ocean floor. The summit of the volcano sagged inward and cracked as the magma drained. Groundwater rushed through the developing crack system where it encountered incandescent rock at temperatures close to 980°C (1,800°F). The water flashed violently to steam at the sudden encounter, releasing sufficient power to excavate over a thousand-million kilograms (a million tons) of rock. HVO scientists estimate that approximately 400 million cubic meters (520 million cubic yards) of magma shuttled down the east rift zone conduit in 1924. That's enough magma to fill 265,000 Olympic swimming pools!

Source: http://hvo.wr.usgs.gov/volcanowatch/1998/98_05_21.html

Some questions to ponder in between sunscreen applications:

1. Is Halema'uma'u still active? List three observations that support your answer.

2. What is the origin of the massive volcanic chunks along the path from the parking lot?

3. What is the origin of the light-colored "bath tub ring" around the inside of Halema'uma'u?

4. What is the significance of the large surficial cracks around the crater's rim?

5. What is the origin of the pile of basalts observed around the sides and base of this crater?

6. Referring to the geologic maps above, what is the age of the latest eruption to occur here?

7. What is the yellow-white material that coats several areas within Halema'uma'u?

8. Since elemental sulfur has little smell, what causes the pungent odor in the air?

9. Who was Pele and why is she so significant to the Hawaiian people?

Sulfur Bank and Steaming Bluff

Our walk in HVNP around sulfur bank and steaming bluff will find a 70 feet high fault scarp, part of fractured monocline of ash on top. The fracturing allows gases from buried magma to escape. Fresh magma is enriched in CO_2 but old magma is depleted in CO_2 but enriched in H_2O, SO_2, with minor H_2S. The lava is chemically weathered to clay minerals by H_2SO_4 and stained red by hematite and yellow with limonite. Common lava weathering products include native sulfur, gypsum, opal, hematite, and limonite. Here, by contrast to Yellowstone (Geology 280C – 2006), the lava is too porous to form hot springs and geysers.

At steaming bluff we are situated above the Kilauea caldera boundary. Steam is produced by interaction of percolating rain water with a buried magma intrusive. Not spectacular in terms of visible geology, it is more fun here to watch the bus tourists interact with the steam.

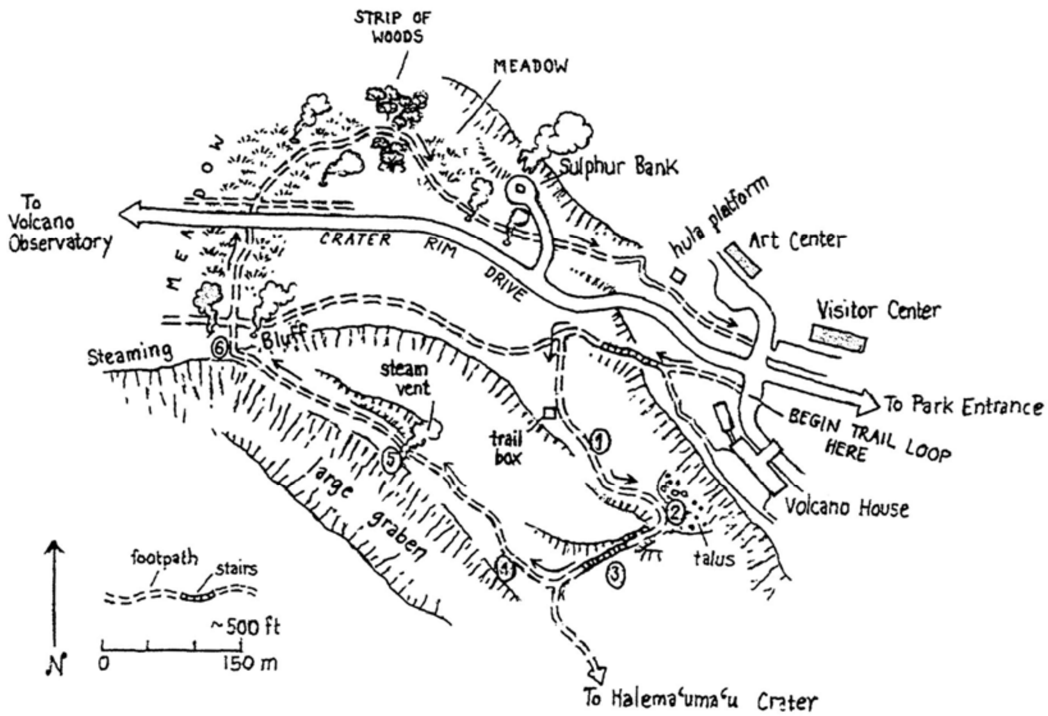


Figure 27 – Map showing roads, structural, and geothermal features near Sulfur Bank and Steaming Bluff. (From Hazlett, 2002.)

1. Examine Figure 27 (above). What geologic feature is Sulfur Bank associated with?

2. At the Sulfur Bank, list the four (4) minerals that can be found. Why are only these minerals found here?

3. What is the significance of volcanic gases and what gas is most abundant in volcanic eruptions?

4. Sulfur dioxide gas (SO_2) reacts with water to make sulfuric acid (H_2SO_4). What is the affect of this corrosive liquid upon the lava at this site?

5. What is the yellow mineral seen encrusting the steam vents, bluff, and nearby volcanic rocks?

6. What does the existence of Sulfur Bank and the Steaming Bluff suggest about the location of Kilauea's magma source?

Southwest Rift Zone

Most Hawaiian volcanoes have 3 rift zones emanating from their summit. The southwest rift zone extends radially from the Kilauea caldera. The entire rift zone was active for 250 years and outlines an 11-mile drive around the caldera. The southwest rift does not have a distinct ridge and is only 21 miles long but extends into Kau Desert. The rifts are caused by forcible dike intrusion into the rift zone which follows the Koa'e Fault Zone. The dikes are < 1.8 miles below surface and have created most of the faults. Overall, the rifting pushes the flank of volcano seaward. Pit craters and rift zone grabens develop from subsidence from their associated intrusives. All pit craters are younger than 550-600 years old

Here we examine, with the hell-fire and brimstone smell of sulfur in the air, an active rift in tephra that is overlain by lava. The tephra consists of well-stratified, cross-bedded, and chaotic deposits of fine ash that locally includes lapilli, bombs, and blocks.

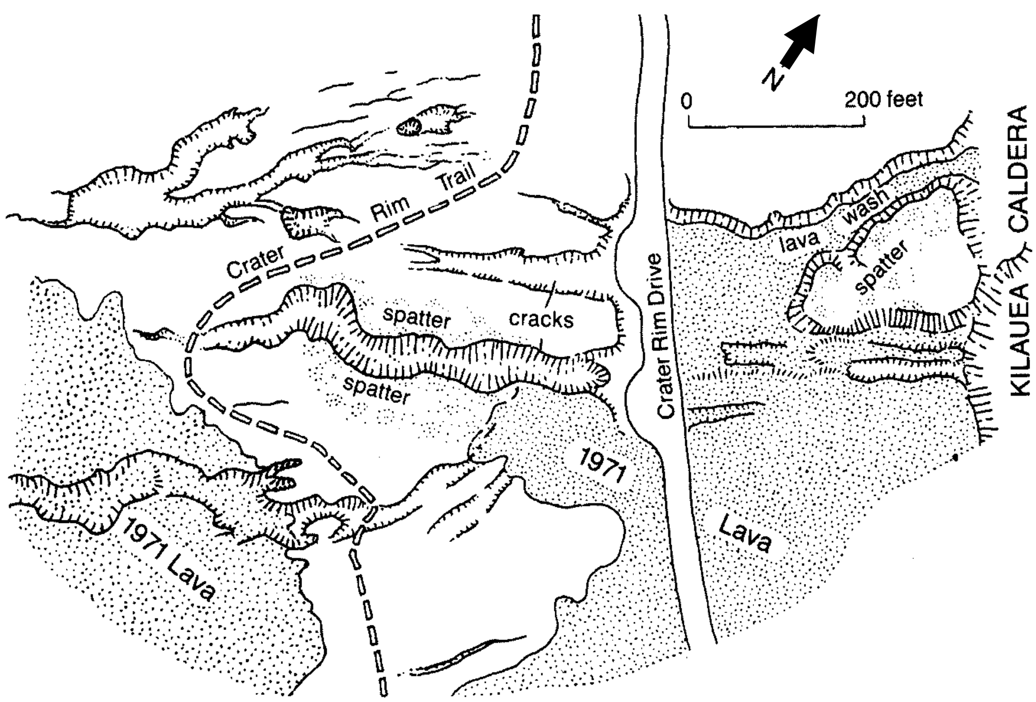


Figure 28 - Map of the Southwest Rift Zone. (From Decker, Decker, and Hazlett, 1997.)

Some questions to rift the brain cells:

1. What is the origin of this rift zone and what type of forces created it?

2. What are pyroclastics and what is the significance of the color of the pyroclastics?

3. What is the origin of the large blocks in the ash deposit?

4. What is the association of vesicles to the gas and silica content of the ash?

5. Refer to the map of the rift zones below (Figure 29). Why are there no rift zones to the north of Kilauea?

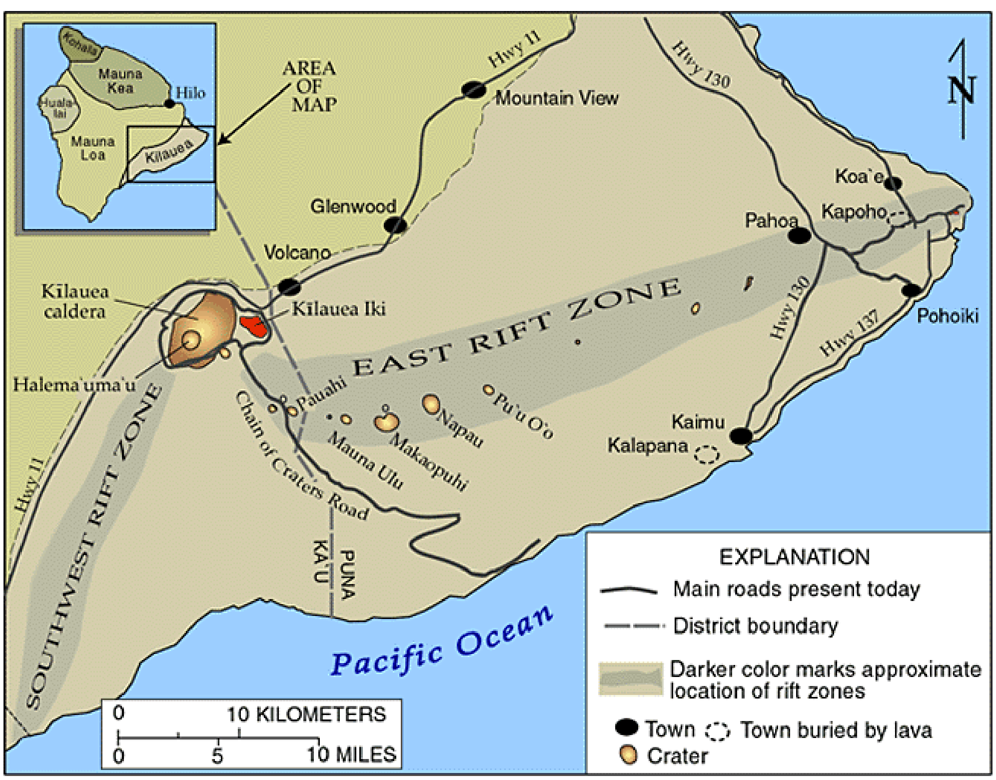


Figure 29 - Sketch map of Southwest and East Rift Zones associated with the Kilauea Volcano.

Keanakako'i Crater

Keanakako'i crater is 115' deep and 1,500' wide. It originated as a pit crater meaning that it was not formed by lava but instead was produced when magma below the ground suddenly drained out causing the ground to drop and form a circular pit. Many pit craters have a lava tube at their base - part of the remnant plumbing structure that drained the magma.

Keanakako'i Crater lies on boundary faults which encircle the collapsed summit of Kilauea volcano. The crater was the source of stone made by the Kapo'e Kahiko people into tools. The name Keanakako'i literally means "Place of the Adze" and glassy basalt was used to make adzes prior to 1877 when the adze source was covered by lava flows from Aila'au. The 1971 and 1974 lava flows from a fissure flow near Lua Manu entered the crater and covered the crater floor as well as the lava tube and Adze quarry. Note the lava swash from the July 1974 eruption of Kilauea fissure flow which flowed toward the Kau desert. Such lava also flowed that way in 1921, 1971, 1974 and 1982. The vertical walls result from gravitational collapse – note the talus deposits. Although it would create more room in the van for the ride back, be careful here because the crater edge is brittle and we could easily fall in. Refer to Figures 30 and 31 for a map and view of this field stop.

The crater is also viewable from Crater Rim Drive (**Note:** we still can't figure out how that dreamed up the name for this road?). Where you are standing now, looking across, is the visitor overlook to the crater. You will probably see people pull up and take pictures and drive on. You will be tiny dots in those pictures taken from those standing on the opposite rim of the crater. Watch out, you'll be easy to crush with two fingers from that distance.

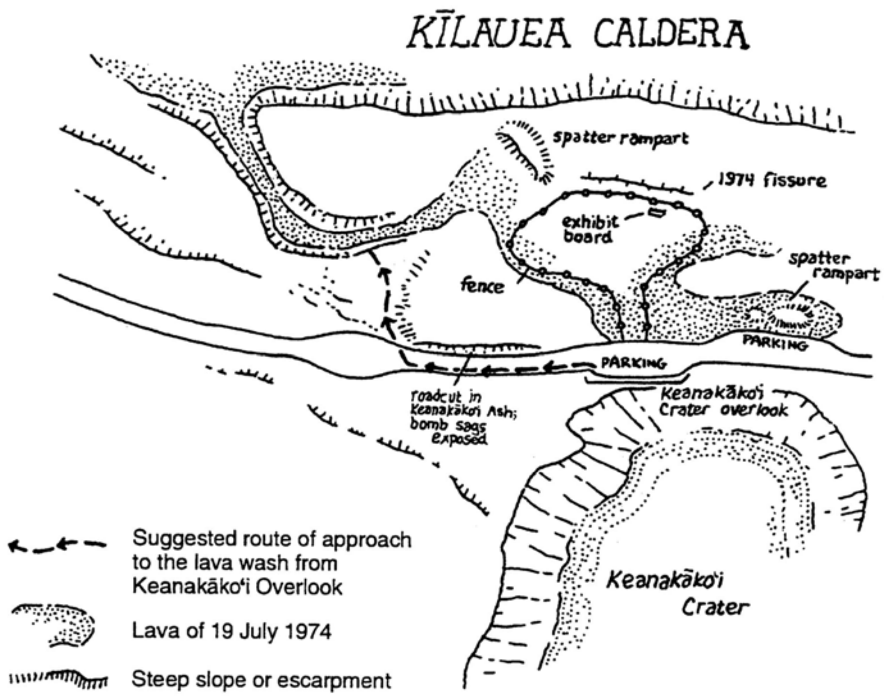


Figure 30 – Path map to the lava wash from Keanakako'i overlook. (From Hazlett, 2002, Fig 26, p. 87.)

Figure 31 – View of Keanakako'i crater showing spatter rampart in center. (CM digital image taken 24 July 2007.)

If you look carefully at the ground around you here, you will see that it is composed of very small pieces of lava - ranging from ash to pieces as large as a quarter. This is the fallout from fountains of lava, and also part of the Keanakako'i Ash layer (Figure 32). Walk a bit to the right of the Keanakako'i Crater sign, right of the crater, and you will find this fallout of lava is a bit smaller. Crouch down and gently look through the pieces. You are looking for a type of lava known as Pele's Tears - bits of lava that are round or tear shaped. The more perfectly tear shaped or round, the better.

Pele's Tears (See Appendix 1) are formed when lava is ejected high into the air. The energy of the ejection causes the lava to break apart into smaller pieces which, as they tumble to earth cool. By the time they hit the ground they have cooled enough not to change shape and end up as round, oval or tear shaped pieces. Do remember though that you are only **looking** at Pele's Tears as it is against the law to take any lava from the park. You can find wonderful examples of Pele's Tears throughout the park, but especially on this side of the Kilauea Caldera as the wind brought the fallout to this area in most of the eruptions (Figure 33).

Figure 32 – Interlayered ash deposits and pyroclastic debris flows adcaent to Keanakako'i Crater showing cross beds and deformed bedding by volcanic bombs. (CM digital image taken 24 July 2007.)

Note the whitish crust on the edge of some of the ash layers. They have captured the interest of some planetary geologists, such as Schiffman and others (2004) of U.C. Davis in California. They suggest that on the summit of Kilauea volcano, sulfur dioxide, which is continuously emitted from Halema'uma'u crater and rapidly sequestered into sulfuric acid-rich aerosol entrained in the prevailing trade winds, is subsequently precipitated as acid-fog immediately downwind from the caldera in the Kau Desert. The characteristic pH of surface tephra deposits is <4.0 in Sand Wash, a region of continuous, acidic aerosol fall-out immediately SW of the caldera. The upper portion of the Keanakako'i Ash tephra in Sand Wash, deposited in the late 18th century, has a ubiquitous, 0.1-0.2 mm-thick coating of amorphous silica. Conversely, vertical walls of unconsolidated tephra, exposed within small, dry gullies eroded into the ca. 3-4 m-thick Keanakako'i section at Sand Wash, are coated with ca. 0.5-1.0 mm-thick, mixed amorphous silica and jarosite-bearing crusts.

Since these crusts are denuded from their outcrops during ephemeral, but probably annual flooding events in Sand Wash, they believe that they must accumulate rapidly. These crusts are apparently formed via an evaporative mechanism whereby acidic pore fluids, circulating in the upper few m's within the highly porous tephra, are wicked towards the walls of the gullies. Geochemical modeling of the crust-forming process implies that the sulfate formation via evaporation occurs subsequent to minimal interaction of acidic pore fluids with the basaltic tephra. This also suggests that the cycle from acid-fog fall-out to precipitation of the siliceous-sulfatic crusts must occur quite rapidly. Production of siliceous-sulfatic crusts via acid-fog alteration may also be occurring on Mars. The occurrence of evaporitic sulfate and silica at Sand Wash in Kilauea may serve as an example of how the jarosite-bearing outcrop at Meridiani on Mars may have formed.

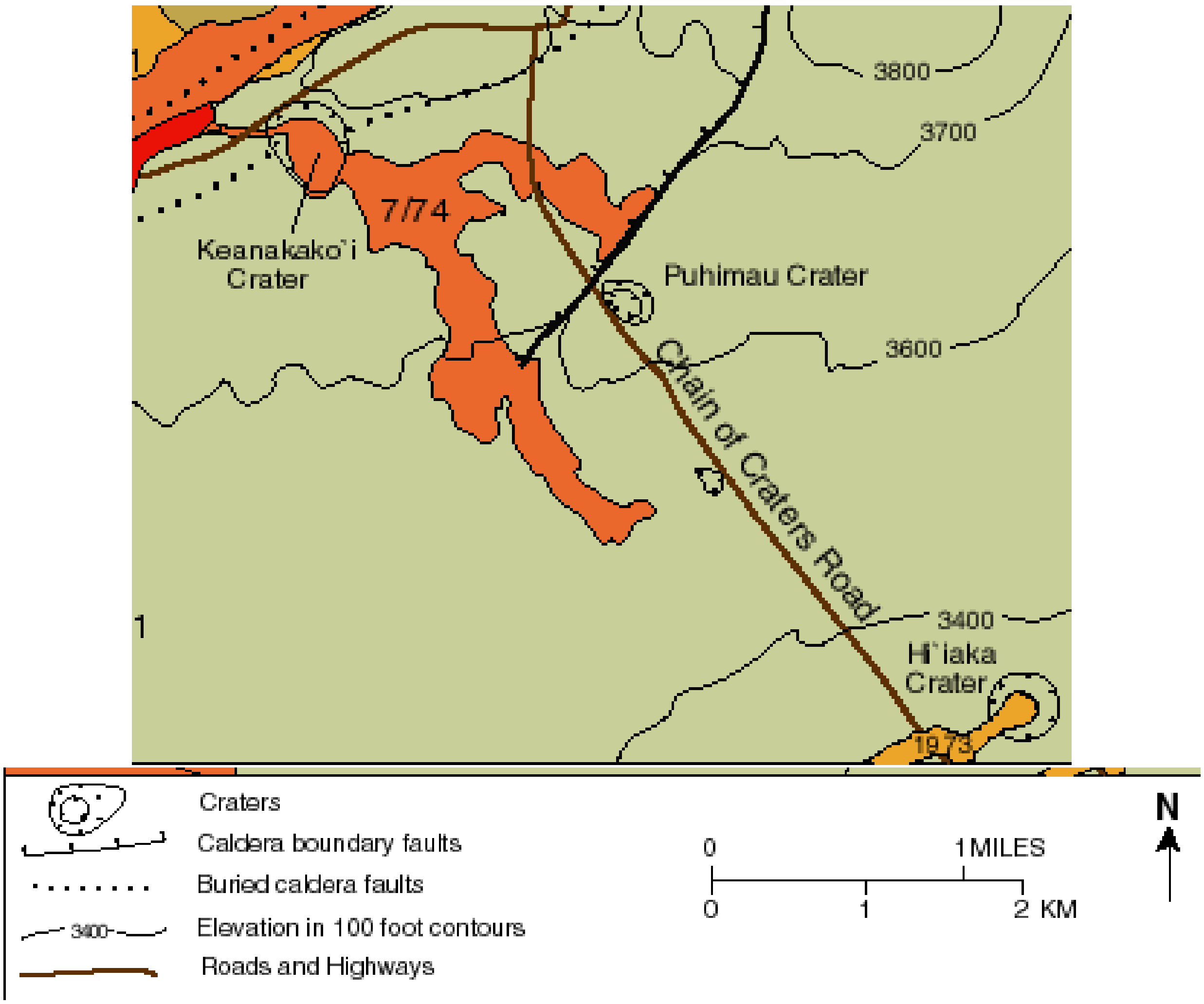


Figure 33 – Geologic map and explanation for features in the vicinity of Keanakako'i Crater.

Some questions to ponder for future generations:

1. From the overlook, what do you think is the origin of this crater? What is the evidence to support your conclusion?

2. In 1974, lava known as tholeiite basalt erupted from the fissure across the street. Tholeiite basalt is the most common type of basalt in Hawaii. How did this fissure originate?

3. At the bottom of this crater was a prehistoric source of basaltic glass called tachylite which was used to make spear points and adzes because of its sharp edges. What is the origin of the volcanic glass?

4. What are the numerous tubular structures beneath your feet?

5. Walk back towards the Keanakako'i Crater, then carefully walk down the road shoulder away from the crater, and look at the layers of the Keanakako'i ash exposed on the <u>left</u> side of the road. (See Figure 32). Watch your <u>ash</u> while crossing the traffic!!

6. What pyroclastic rock types do you see? Do the different layers contain the same size particles? Explain.

7. Go across the street and look closely at the ash layers. What is the origin of the inclined layers within the ash?

8. Now follow the edge of the ash until it enters a large open lava plain. Examine the ash layers on the far left wall. (See Figure 32.) Describe what you observe.

9. Which came first: the ash layers you just examined or the lava flows you are walking upon? Explain your answer.

10. Using the map above (Figure 33), what prevented the 1974 lava from burying a portion of the Chain of Craters Road?

Day 03 - Wednesday 25 July 2007 – Hawaii Volcano National Park (HVNP)

Waldron/Byron Ledge Earthquake Hike

Today's hike combines several of the interconnecting trails at the summit of Kilauea. Keeping left, follow the the Waldron Ledge trail for ~1 mile/1.6 km, which takes you along the north-east rim of Kilauea Caldera above a cliff called Waldron/Byron Ledge (Figure 34). Together, they make an interesting and varied trip through Kilauea's contrasting landscape - views into the barren caldera with its flows of smooth black lava, native rainforest, steaming vents, and banks of bright yellow and foul-smelling sulphur. Byron Ledge is a horst between Kilauea Iki pit crater and Kilauea caldera with gravity faults in between (Figure 36). It was named for Lord Byron in 1825.

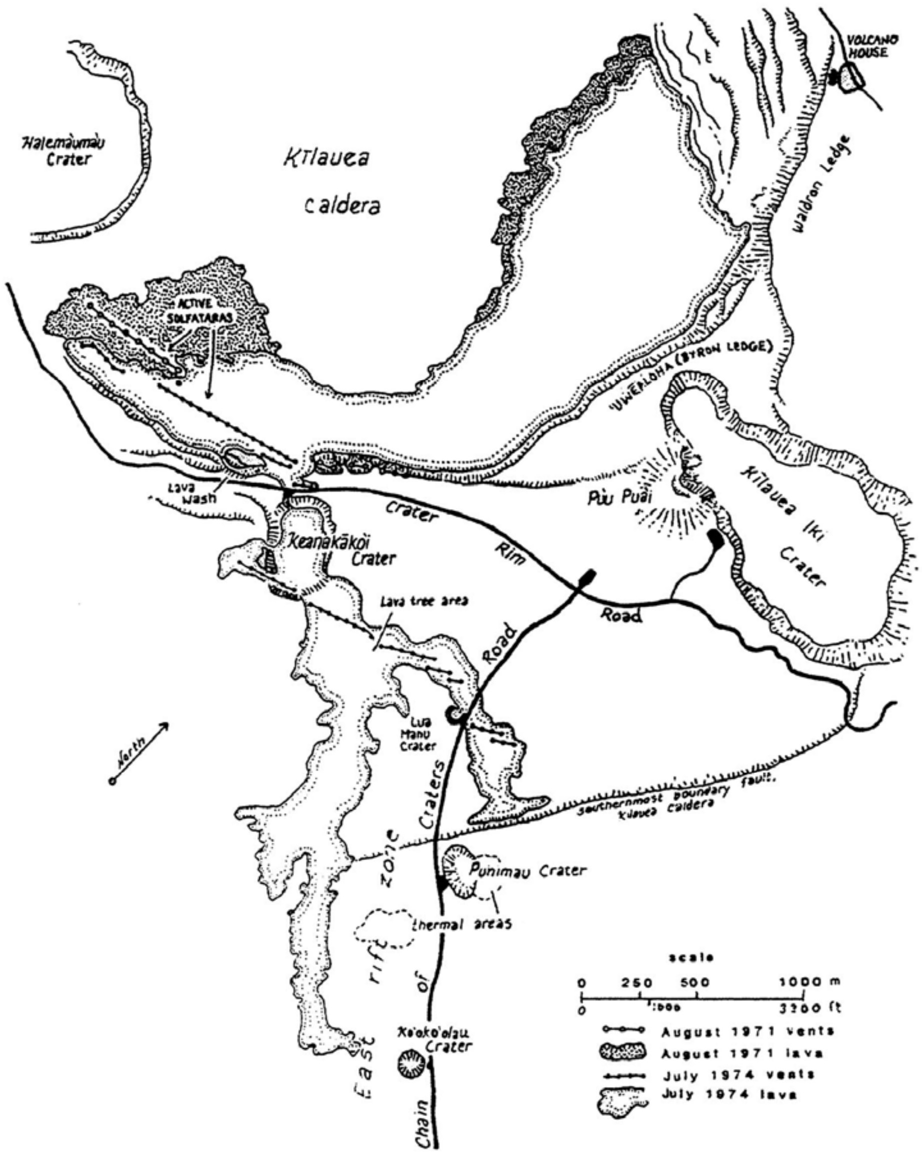


Figure 34 – Location map for the Waldron/Byron Ledge Earthquake Hike. (From Hazlett, 2002, Fig. 25, p. 86.)

Basics:

Walk a section of road cracked and destroyed in 1983 by the magnitude 6.6 Mauna Loa earthquake. Trail begins to the left of the Volcano House hotel.

Difficulty: Easy
Distance and hiking time: 1 mile roundtrip, 45 minutes
Length: 3.75 miles / 6 km
Trail Type: Loop
Elevation Change: 400 ft / 122 m
Duration: ~2 hours

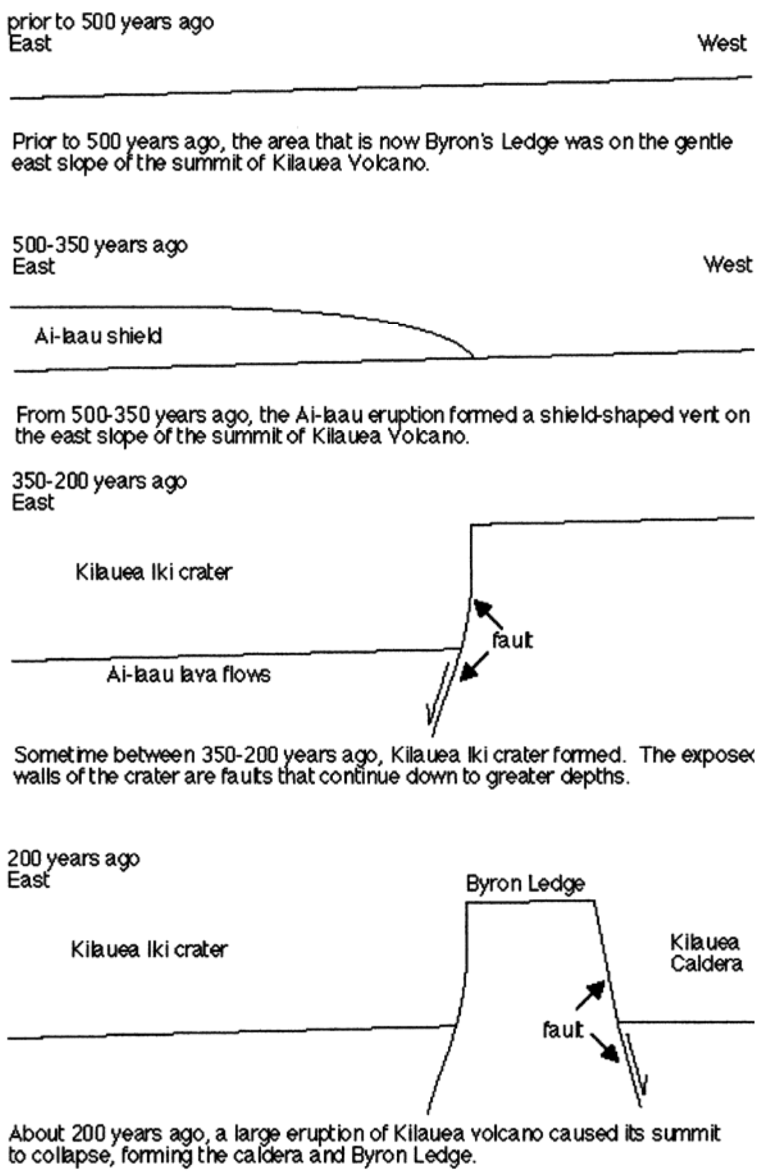


Figure 35 – Cross section and development of Byron Ledge. (From www.uhh.hawaii.edu/~kenhon/GEOL205/petrology/default.htm.)

Some questions to ponder about Waldron/Byron Ledge hike while we wait for Merguerian to catch his breath:

1. Locate yourself on the map. Why is this area known as “Earthquake Walk”?

2. What structural features can you observe that caused this road to be closed?

3. What type of force created these features?

4. What volcano does the walk border?

5. Briefly discuss the origin of earthquakes in Hawai’i.

6. Using the diagrams below what ultimately controlled the formation of Waldron and Byron’s Ledges and as well as the location of Kilauea Iki.

7. What kid of geologic structure does Byron Ledge have?

8. What types of forces were involved?

Kilauea Iki Trail Hike

From the visitor center, cross the road towards Volcano House Hotel and keep left at the fork for the short distance to Crater Rim Trail (Figure 36). This section of Crater Rim Trail, which makes an 11.6-mile circuit of the volcano's summit, offers excellent views into the caldera (Figure 37).

At the junction, Crater Rim Trail heads east to Kilauea Iki Overlook, but you turn sharp right towards the caldera. Ignore the trail branching off to the left after a few minutes, a short connector to the rim of Kilauea Iki Crater. Continue ahead to join forested Byron Ledge Trail after a few more minutes. Turn right, descend from the ledge, and bear north for the 0.5 mile/0.8 km to the junction with Halema'uma'u Trail. Keep right to continue north, and begin the climb out of the caldera.

After 0.4 miles/0.6 km, turn left to complete the climb on Iliahi (Sandalwood) Trail. On this 0.4-mile stretch to the north rim, there are more great views of the caldera through the green rainforest. You may even spot some sandalwood trees along the way, although only a few remain. At the top, you connect with Crater Rim Trail - consider extending the hike by a mile or so, as the Rim Trail to the west (left) of here is another interesting section, passing steam vents above aptly named Steaming Bluff.

It is all easy walking from now on, and no more than 1 mile/1.6 km to the visitor center. To return via Sulphur Banks, cross the Rim Trail and Crater Rim Drive a couple of minutes later. The final part of the hike is a real contrast to the dramatic caldera views and beautiful rainforest that has come before. You may well smell the banks before you see the steam or bright yellow mineral deposits - this is one of the few places on Kilauea where the vents give off the foul, rotten-egg smell of dihydrogen sulphide (H_2S).

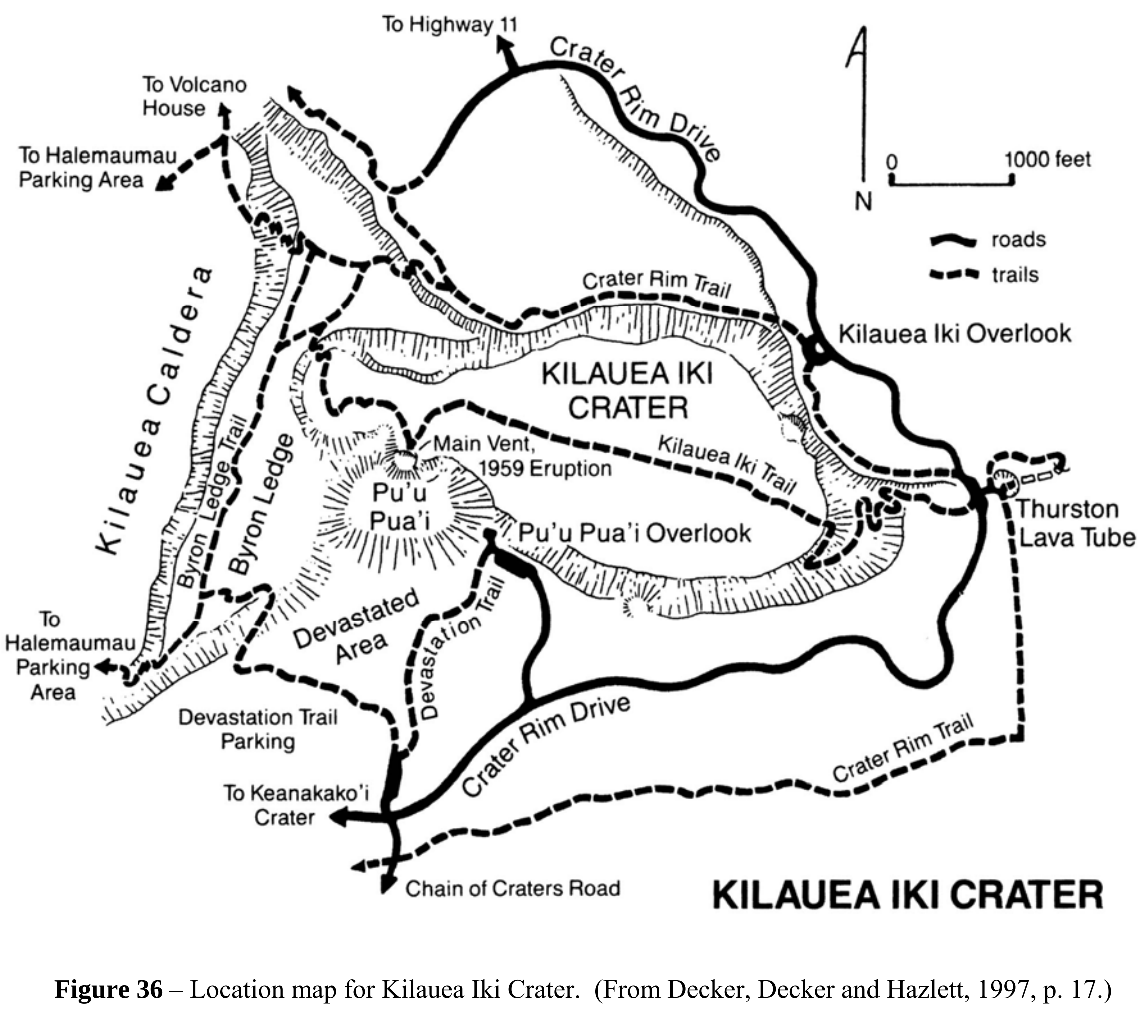


Figure 36 – Location map for Kilauea Iki Crater. (From Decker, Decker and Hazlett, 1997, p. 17.)

Figure 37 – View of Kilaeua Iki crater showing the prominent bathtub ring left by lavas from the 1959 event. Waldron/Byron ledge is in the upper center. (CM digital image taken 25 July 2007.)

Take the Kilauea Iki overlook trail backwards from the hoard of visitors and end at Thurston Lava Tube, a 4 mile loop trail that ends with a heart-throbbing sweaty climb up Waldron/Byron Ledge. The crater is 1 mile long, 3,000 feet across, and 380 feet deep. The Kilauea Iki pit crater (Figure 37) formed from the 15th century collapse near the top of the Aila'au shield *(**Aila'au** means one who eats the forest and was fire god prior to Pele)*, a vent for Kilauea volcano about 350-500 years ago. The crater formerly contained a whole forest prior to 1959 eruption when the crater developed in two stages forming figure-8 morphology. The Aila'au eruption was probably fed by a shallow magma chamber a few miles below the surface. Magma within this chamber either erupted on the surface or drained down into deeper levels within the volcano. After the eruption ceased, the chamber was no longer full and exerted less pressure on the surrounding rocks. The weight of the overlying rocks was greater that the upward pressure in the chamber. The rocks above the chamber collapsed, filling the open space within the chamber and causing the surface to collapse, making Kilauea Iki crater.

The Kilauea Iki eruption began 14 November 1959 and lasted 36 days. Following eruption at Kapoho in 1955, on 14 and 15 August 1959 swarms of earthquakes located 33 miles below Kilauea began and inflated it. Prior to the eruption the area had 3 months of rapid inflation and increasing number of harmonic earthquakes. The eruption in 1959 lasted for 36 days with 17 episodes of lava fountaining up to 1,900' high with lava thrown over 100' into the air. By contrast, the Empire State Building is 1,454 feet high. The volcanism formed a 390' deep lava lake. Most of lava drained back into the Pu'u Pua'i vent *(Gushing or Fountain Hill)* which is 100 feet in diameter (Figures 38 and 39). The peak vent discharge was 1.25×10^6 $feet^3$/hour. Later 208,000,000 $feet^3$ drained back in to chamber. Talus by the Pu'u Pua'i vent is from quakes in 1975 (7.2M Kalapana earthquake) and in 1983 (6.6M along Ka'oiki Fault).

The lavas in Kilaeua Iki are unusual in that they contain pheoncrystic olivine. The order of mineral crystallization is olivine followed by pyroxene and plagioclase at 2100°F (1149°C) but as temperatures decrease the olivine either sinks or becomes reabsorbed by reaction with the residual melt. The temperature of the lava was 1796°F (980°C) when it became solid. At that point it contained 40% olivine by volume and 20% by weight at the surface. This is rare for such mostly phenocryst free basalt.

Activity ceased on 20 December 1959 and the area inflated again on 13 January 1960 but the eruption began at Kapoho on 20 February 1960. Prior to the 1959 eruption, Kilauea Iki was nearly 600 feet deep and heavily forested. During that time there were 17 episodes of lava fountaining. The eruption filled the crater with 390 feet (120 m) of new lava and constructed the Pu'u Puai cinder cone (Figure 40). Many long-time lava watchers considered this the best eruption they have seen.

The overlook of Kilauea Iki pit crater is one of the most spectacular views in the park. Flows above the red ash are 1,000 years old; below are 1,500 years old; color from oxidation from steam activity.   A keen eye can find Halema'uma'u. Snow-capped Mauna Loa forms the skyline. Note the bath tub ring from the lava high stand in 1959. (See Figure 37.)

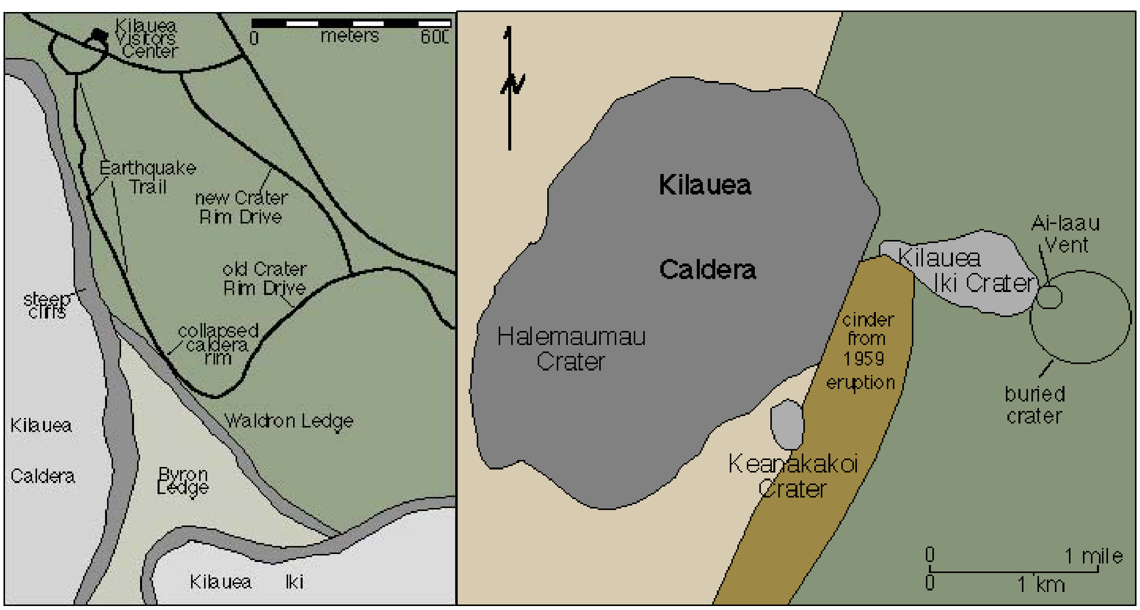


Figure 38 – Location and geological maps showing the pre-historic Ai-laau lava shield adjacent to Kilauea Iki. (From J.M. Buchanan-Banks, U.S. Geological Survey Professional Paper 1350, 1987.)

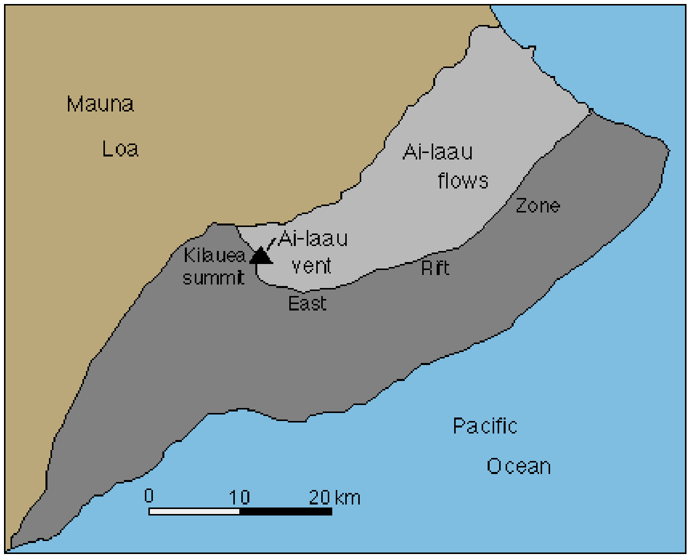


Figure 39 - Extent of lava flows from the Ai-laau vent. (From Buchanan-Banks, J.M., 1987 Geological Survey Professional Paper 1350, v. 1, p. 268.)

Figure 40 – View of 400' high Pu'u Pua'i cinder cone downwind of 1959 vent formed during the 1959 eruption of Kilauea Iki. (CM digital image taken 25 Jul 2007.)

Some Kilauea Iki questions to ponder:

1. What evidence suggests the formation of Kilauea Iki occurred in multiple stages?

2. What feature illustrates a higher position of the crater floor?

3. What type of basalt was erupted in 1959?

4. What features indicate the effects of the 1975 earthquake?

5. What mineral generally occurs as phenocrysts (visible crystals) on the floor of Kilauea Iki? Why is it so abundant?

6. What is the origin of the long, parallel, and vertical cracks observed in the crater walls?

7. What is the origin of the polygonal cracks on the crater floor?

8. What other nearby volcanic feature was created as a result of the 1959 eruption?

Thurston Lava Tube

Discovered in 1913 by **Lorrin Thurston**, a newspaper publisher of the Honolulu Advertiser who played an instrumental role in creating the park, the Thurston lava tube formed about 350-500 years ago. At that time a large vent, called the Ai-laau shield, was erupting pahoehoe lava on the east side of Kilauea's summit. Lava from this vent buried the entire north flank of Kilauea, all the way to the ocean. After the eruption ceased, the summit of the vent collapsed to produce the Kilauea Iki pit crater. Additional collapse adjacent to the Kilauea Iki pit crater produced two other small craters. Access to the lava tube is through one of these small pit craters. The trail descends along the wall of the crater then across its floor (Figure 41). The 20-minute walk at Thurston Lava Tube will give you a close-up look at a Hawaiian rainforest and the lava tube. Be careful, the trail can be slippery when wet, just like Steve Okulewicz, our veteran Hawaiian field trip co-leader and resident magician.

We will enter through a collapse crater and exit via a skylight. It is a relatively well-lit 400’ trail followed by 1,100 feet of dark passage near the entrance. **Bring flashlites and gloves.** We will take the 0.3 mile loop trail and try to get permission to enter the darker part of the tube. By contrast the Kazumura Cave system is 50 miles long and may actually be a part of the same structure. Look for lava marks on cave walls and the lack of lavacicles the result of detailed work by lava tube bandits.

When the eruption stopped the lava drained from the tube. The trail within the tube is 400 feet (120 m) long. The tube (Figure 42) extends beyond the main trail before pinching off (permission to visit this part of the tube must be granted at park headquarters prior to entry). The tube is named for **Lorrin Thurston**, a newspaper publisher that played an instrumental role in creating the park. Thurston lava tube is also called by its Hawaiian name, **Nahuku**, which refers to the small protuberances on the walls of the tube.

Similar to conditions in Nassau County, aggressive alien species are changing ecosystems in much of Hawaii. To protect native habitats within the park, rangers are removing alien species and building fences to keep out feral pigs. Pigs disturb the native plants, which helps to introduce alien plant species, and spread disease, such as avian malaria.

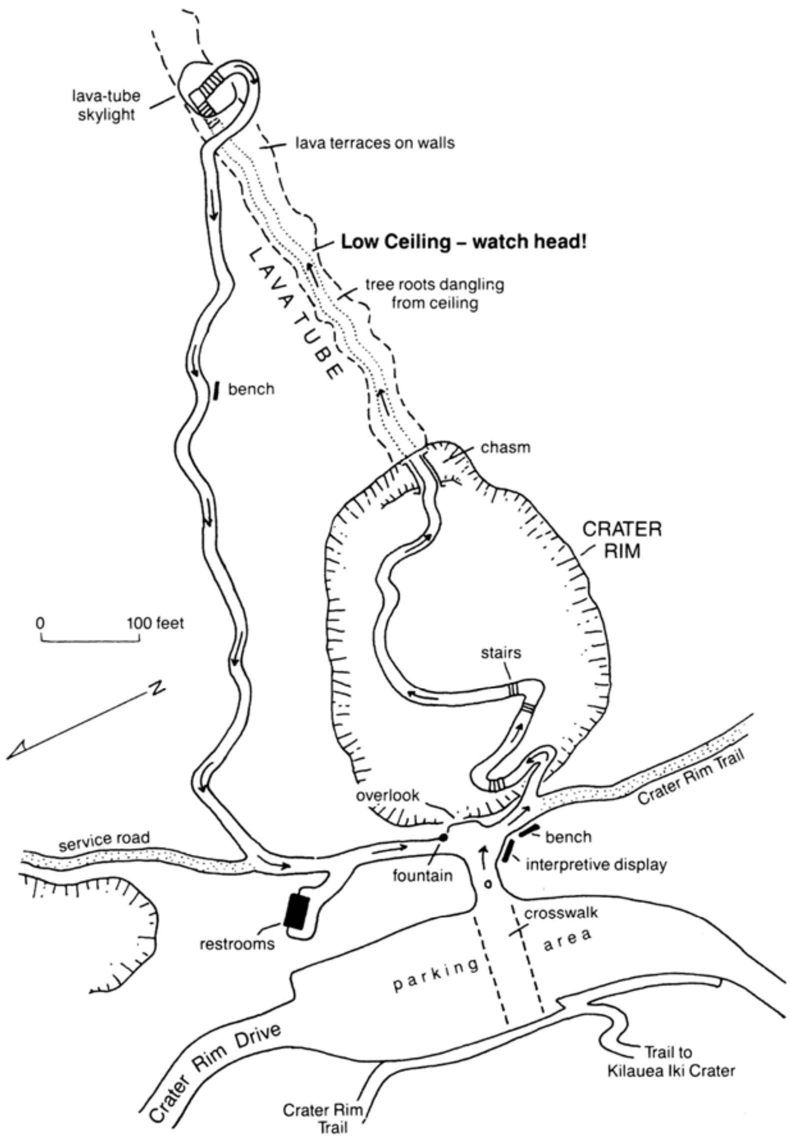


Figure 41 – Map of Thurston lava tube. (From Decker, Decker, and Hazlett, 1997, p. 19.)

Figure 42 - A view down the axis of the Thurston Lava tube. Lava tubes are created when molten lava evacuates a flow that has cooled on all sides. (Unknown Web Contributor.)

Devastation Trail (Time Permitting)

With a name suggestive of Merguerian's professional career, Devastation Trail (Figure 43) offers a great number of geological delights, particularly for those with some interest in geological controls on transportation issues. The devastation here resulted from the November 1959 eruption of Kilauea Iki which formed Pu'u Puai vent and related cinder cone which is 400 feet high. Vegetation was either burned or stripped from the area for 2 to 5 miles downwind. Look for tree molds, Pele's tears, cinder sink holes, cables left from earlier seismometers, and Ohia trees with aerial roots and red flowers.

Some questions:

1. Locate yourself on the trail map above (Figure 42). Pu'u Pua'i is about 400 feet high and formed during the 1959 eruption of Kilauea Iki (Figure 43). Identify the type of volcano.

2. What happened to all of the trees and vegetation in this area?

3. What factors influenced the explosive character of Pu’u Pua’i?

4. Using the terms coarse-, medium- or fine-grained, describe the grain size of the pyroclastics as related to their distance from the cone.

5. Why are there no lava flows found here?

6. What is the origin of volcanic fountaining?

7. What is the origin of small cinder sinkholes? What causes their alignment?

8. Where do you think the pyroclastics are thickest in this area? How would you know?

9. What is the origin of Pele’s Tears found within the pyroclastic debris?

10. Why is this cinder cone asymmetric in shape?

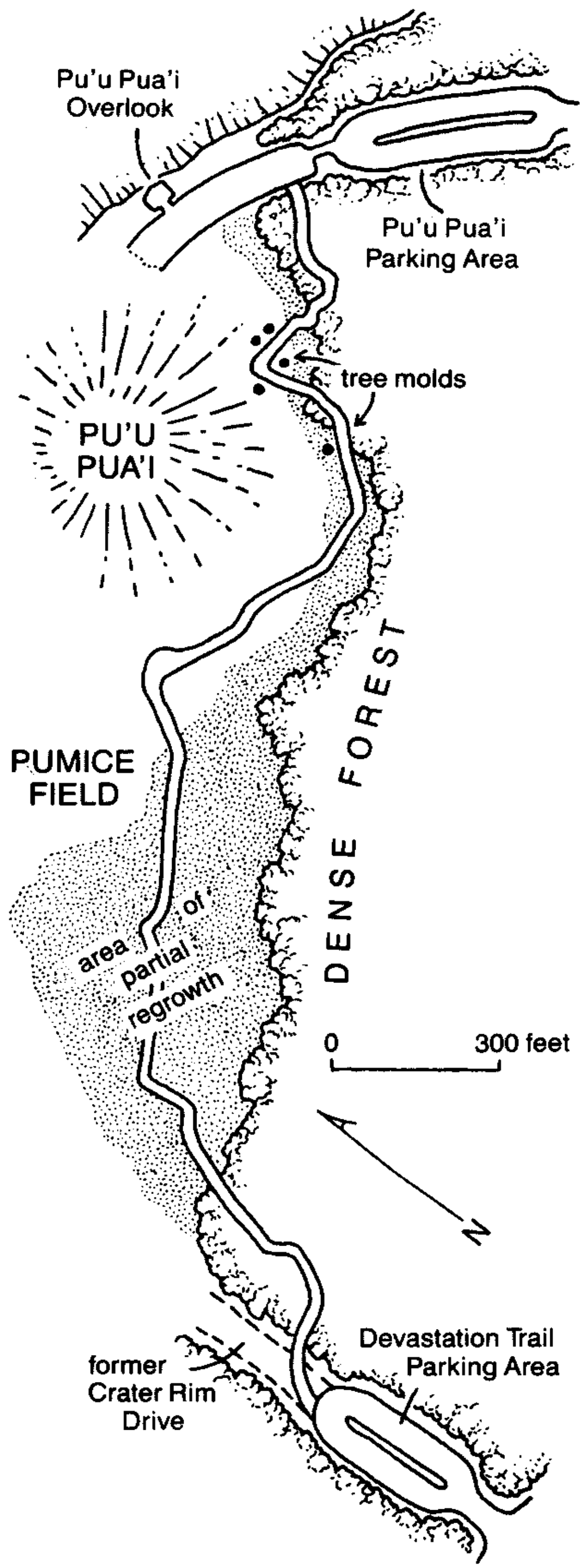


Figure 43 – Trail map of the Devastation Trail. (From Hazlett and Hyndeman, 1996.)

Day 04 - Thursday 26 July – Puna District

Pahoa Dump

Some interesting deposits of the youngest geological interval, younger than the Pleistocene and Holocene – the Obscene. Get your cameras and ratchet sets ready for pictures and spare parts (Figure 44). Oh yes, and there's some cool volcanics too! Here, in the midst of a solid waste dump found by traveling on Route 11 north to Route 130 then west toward Keaau to Pahoa on Route 132. The 1955 lava flows from the rift zone include thinly layered (0.3m – 0.5m) vesicular basalt in a modern dump cut (as opposed to road cut). Note the pipe vesicles, lava tubes, oxidation horizons, minor intercalated ash flows, and olivine-phyric basalt.

Figure 44 – Location map of Pahoa Dump. (From Unknown Internet Source.)

1. What type of volcanic material is present?

2. What is the texture of the rock and their origin?

3. What does the shape of the vesicles indicate about the lava?

4. Where did this material originate?

5. What is the origin of the red color?

6. Where did the pyroclastics come from?

Lava Tree State Park

The Lava Tree State Park is in the Nanawale Forest Reserve of the lower Puna district. The park is an excellent way to see both native Hawaiian plants as well as the fascinating lava trees themselves. To get to there take Highway 130 towards the town of Pāhoa. Drive past Pahoa lava from the 1290-1470 AD eruption from the Kilauea east rift zone. Pass the first intersection that takes you into Pāhoa and at the next intersection (the intersection with a traffic light) make a left onto Pāhoa-Kapoho Road (this is also Highway 132). Follow this road for about 3 miles until you see the park on your left (Figure 45). The park is open 24 hours a day, year round. There is no cost to visit the park, aside from the airfare to get to there.

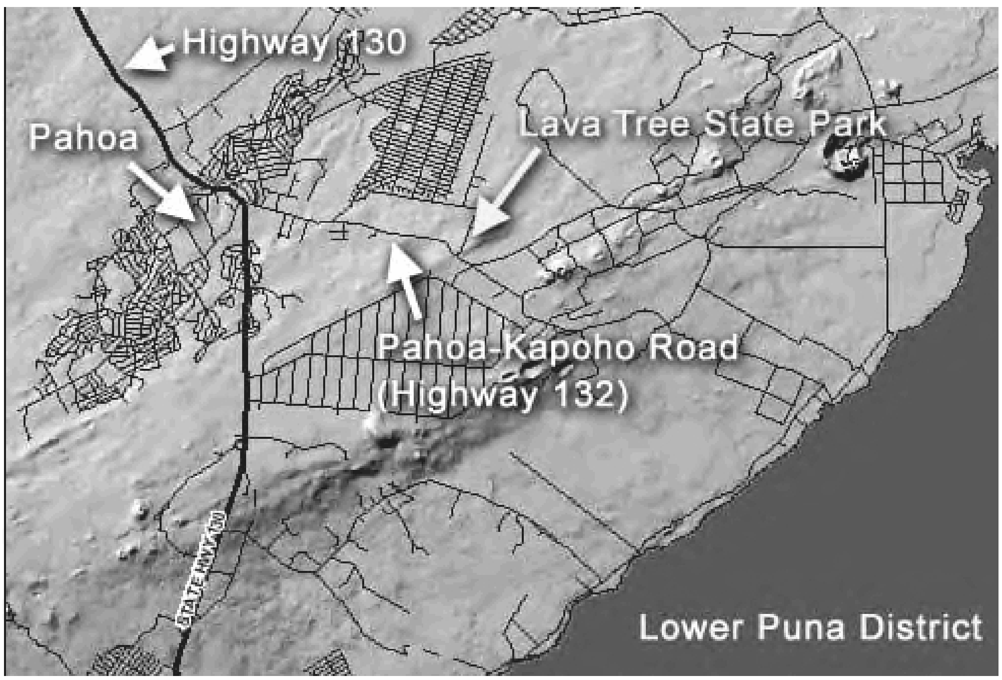


Figure 45 – Location map showing Lava Tree State Park. (From Unknown Internet Source.)

Lava Tree State Park consists of 17.1 acres of native plants, trees and many lava tree molds - most of which are still standing. A small paved trail takes the visitor around the park and is easy walking for adults and children. There are many dangerous, deep fissures, many hidden by vegetation. Another (even better but less accessible) example of lava trees can be found in the Hawaii Volcanoes National Park. The lava trees were formed during the 1790 pahoehoe flow from fissure flow of Kilauea but most of the lava drained back into fissures. Seams and lava-coated fractures, seams, and vents are drain back directional indicators. Later, Albizzea trees were planted in 1925. Here, lateritic soils are infertile but the plants thrive on leaf litter nutrients.

Lava trees are made when molten lava coats trees in one of two ways. First, a fissure can open that sprays fountains of lava into the air. The falling lava coats trees and burns the insides out leaving a lava mold around the tree. The second way for lava trees to form is molten lava flow filling an area and then draining - leaving the rock trees behind. The Lava Tree State Park is an example of this second method of formation.

In 1790 the East Rift of the Kilauea volcano opened up and issued a huge pahoehoe lava flow. This lava flow entered a wet 'Ōhi'a tree forest and filled it to a depth of over 11 feet in molten lava. When the liquid lava, at 2000° F, came in contact with the cool wet trees the lava touching the trees began to cool. At the same time, the tremendous heat consumed the tree leaving a perfect mold where the tree once grew. The mold is so perfect that you can still see the imprint of the bark in the lava rock itself (Figure 46).

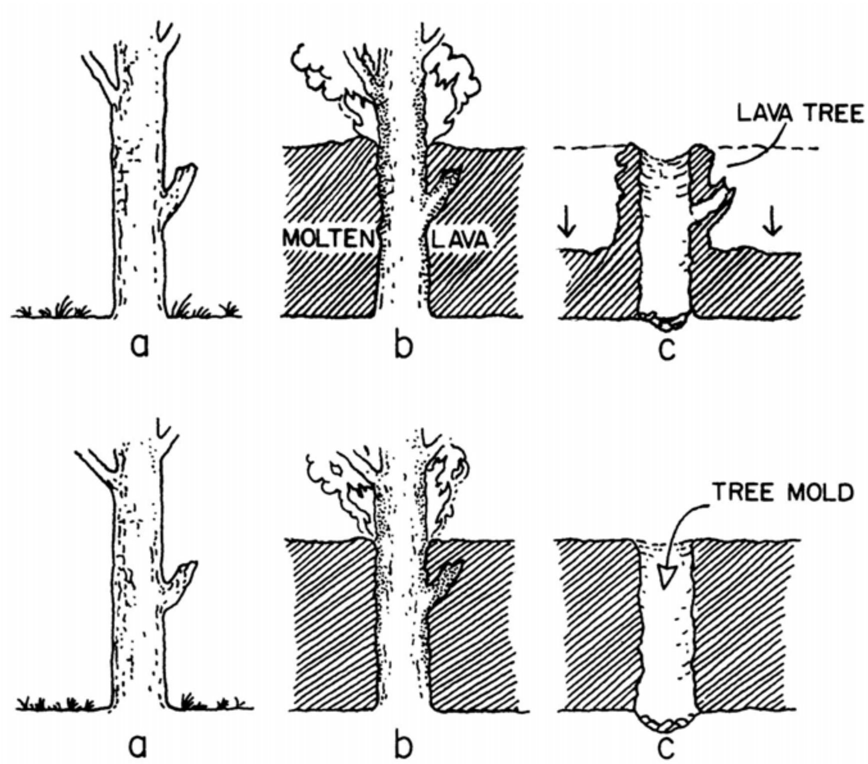


Figure 46 – Diagrams illustrating the method of formation of lava trees and lava tree molds. (From Hazlett and Hyndman, 1996, p. 31.)

Soon after filling the area with lava a nearby fissure opened in the ground allowing all the lava in the area to drain back into the earth. Because the lava surrounding the trees had already cooled due to the temperature of the trees, the lava molds did not drain but remained as monuments to the trees that once stood in the same spot.

Here are some stumpers for ya:

1. What is the age and type of lava found here?

2. What is the origin of the lava? Why are there no pyroclastics found here?
3. Look inside one of the hollow tree molds. What do you observe?

4. Where did all of the lava eventually go?
5. The fissures by the parking lot are approximately 30-feet deep. What is their origin and what kind of force is required to make such fissures?

6. Using the lava tree molds, how can the direction of the lava flow be determined?

7. Note the orientation of the fallen lava trees. Do you think they have any significance? How does this information compare with the flow direction of the lava trees still standing?

8. How can the thickness of this lava flow be determined? Approximately how thick was it?

9. Viscosity is defined as the resistance to flow. How does the viscosity of this lava compare to that seen in the lava from Rift Valley within Hawaii Volcano National Park?

10. Look closely at the native plants of wild orchids, ferns (pictured below: Hapu'u, Uluhe, Palalalai), and 'Ohi'a Trees. Note the density of the foliage. Examine the soil. In what type of soil are they growing?

11. What is the source of the nutrients for these trees, plants, and flowers?

Pu'u Laimana (Lyman's Hill) Volcanic Area

Take Route 132 to Route 137 and look for an iron gate on the left side of the road. If the gate is closed, it's OK to proceed. The Kapoho Cone initially formed 400 to 1,000 years ago when lava draining from Halema'uma'u moved down east rift zone into Kapoho area causing ground cracking, faulting and coastal subsidence. The town was partially destroyed. Earthquake activity resumed in 1954-1955, expanding the length of the lower east rift zone. The lava initially erupted in 1955 along a fissure that was 8.7 miles long. In 1960, 1,000 harmonic tremors occurred in the lower east rift valley from moving lava. Kilauea re-inflated along lower east rift zone and formed a graben by Kapoho village. By 13 January magma erupted along the graben axis and the eruption lasted 88 days producing 5.5 billion feet^3 of lava with a high percentage of olivine crystals. The resulting aa flow was 20 feet thick and 1,000 feet wide, flowing at 300 feet/hour. The village was destroyed in one week forming Pu'u Laimana scoria cinder cone (Figure 47) around the main vent. This resulted in a cone 360 feet high, ½ mile north of village; 6.2 miles2 of land covered with lava destroying 21 houses with 4,300 feet^3 of lava.

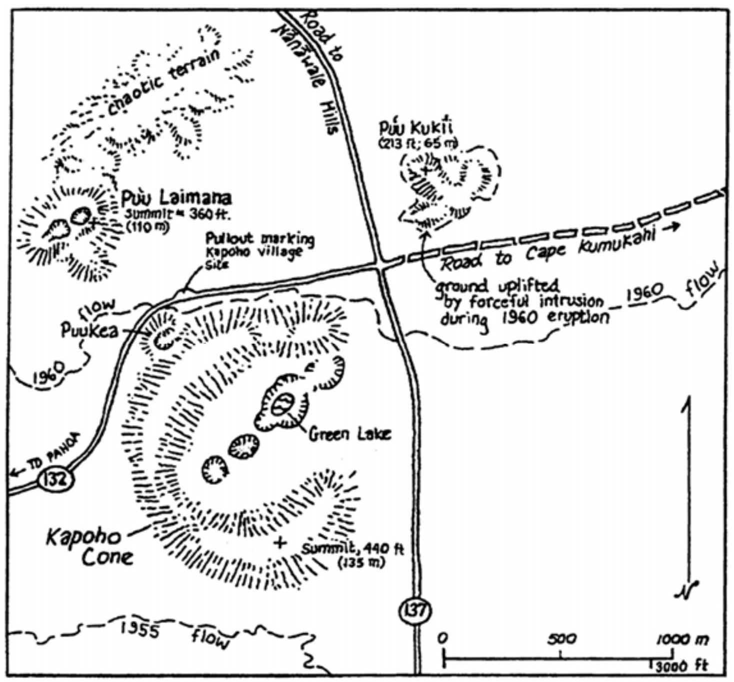


Figure 47 – Sketch map showing Pu'u Laimana and surrounding area. (From Hazlett, 2002, Fig. 49, p. 143.)

This 110-m tall spatter cone consisting of scoria that grew up around the most active vents of the 27 January 1960 Kapoho eruption in the lower east rift zone (Figure 48). Lava flows from this and other vents covered the village of Kapoho located only 800 m south and poured into the sea along the easternmost tip of the island. Lava fountains from Pu`u Laimana reached as high as about 500 m and were visible from the city of Hilo. Today, the spatter and cinder from Pu`u Laimana are mined for construction uses (Figure 49). On cloudless days, the summit of Pu`u Laimana provides a spectacular view of east rift zone all the way to Mauna Ulu.

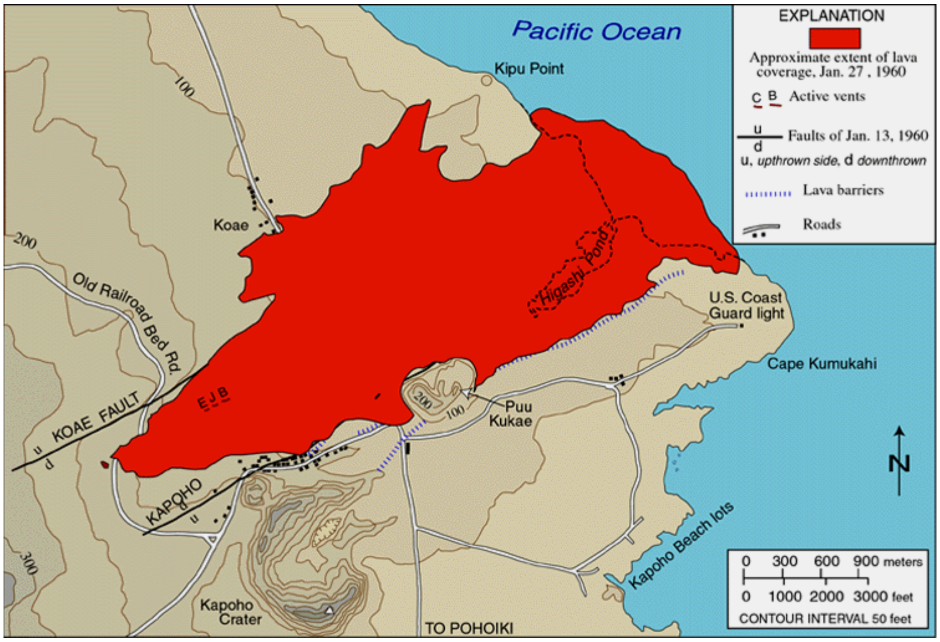


Figure 48 – Map showing the extent of lava coverage during the 27 January 1960 Kapoho eruption.

Figure 49 – View of 110-m tall spatter cone known as Pu`u Laimana or Lyman's Hill. Now an active quarry for colored cinder, note the conical internal structure and the steep fault cutting the cone near the center of the image. (CM digital image taken 26 July 2007.)

Some questions to ponder while we wait for students to stop collecting rocks:

1. What is the origin of this 1960 volcanic feature found at this location, named after the Lyman Family? Draw a quick sketch below.

2. Why is it located here?

3. Where did the lava originally come from?

4. What is the texture of this igneous rock? Explain how it formed. Collect some specimens (you are not in the national park!).

5. Look closely at some pieces of the rock. What is the green mineral?

6. Why is this mineral visible?

7. What is this geologic material being used for?

8. Explain why most of these rocks are red.

9. What is the red vesicular rock called?

10. What is the iridescent rock called? Why is it light in weight? Collect a specimen.

11. The town of Kapoho formerly existed ½ mile from here. Where is it now?

MacKenzie State Recreational Area (Lunch)

Take Route 130 south to Route 132 south to Route 137 southwest to the park for lunch (Figure 50). The park was built in 1860s by prison labor who, after lunch, planted imported iron wood trees. The irregular shoreline was created by differential erosion of pahoehoe, aa, and younger pahoehoe flows. This area is known for ghost waves – large tsunami that are not predicted or understood. Based on the number of monuments around us, they have claimed many unsuspecting sight seers. Keep watch!

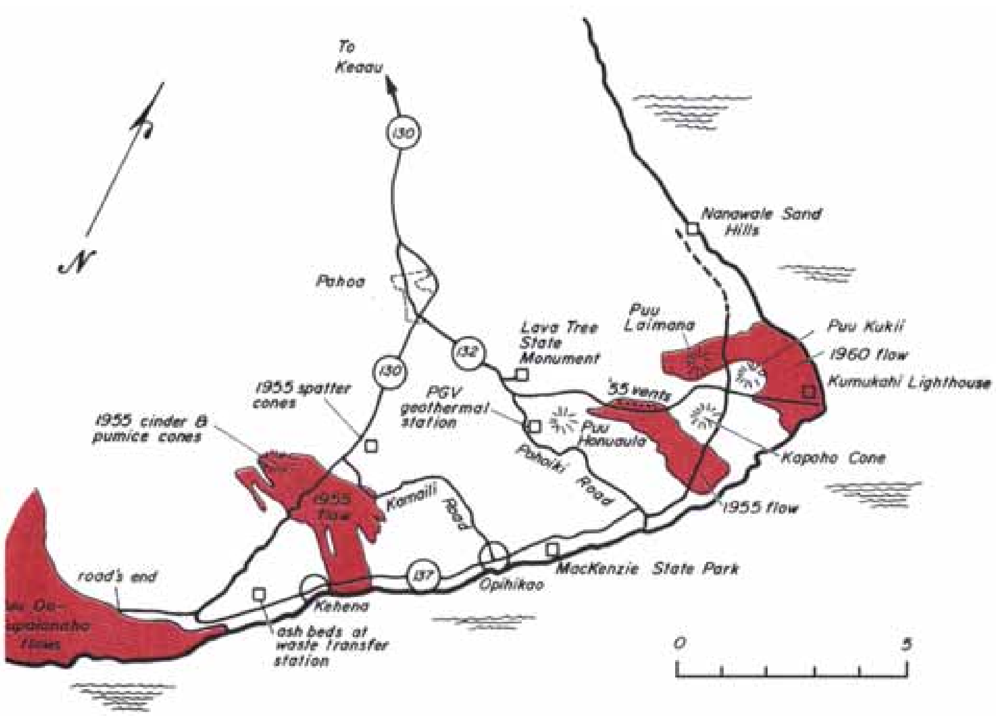


Figure 50 – Location map of the MacKenzie State Recreational area. (From Hazlett and Hyndman, 1996.)

Some post-lunch discussion questions:

1. What types of lava occur here (Figure 47) and how do you know?

2. As you walk around the park, what two geologic structural features are observed within the surface of the lava? Draw a quick sketch below.

3. What caused these structures to form?

4. What is the influence of these structures on the shape of the shoreline?

5. If you expected to see beach sand here, what kind of sand would it be? Where is the beach sand?

6. What is the origin of the high shoreline cliffs?

7. Explain the irregular morphology of these cliffs.

8. As you leave the park, you will observe some roadside memorials along Route 137. They were placed here to remember local fisherman and visitors to this area whose lives were claimed along the coast by Phantom Waves. What are they?

Kaimu Black Sand Beach

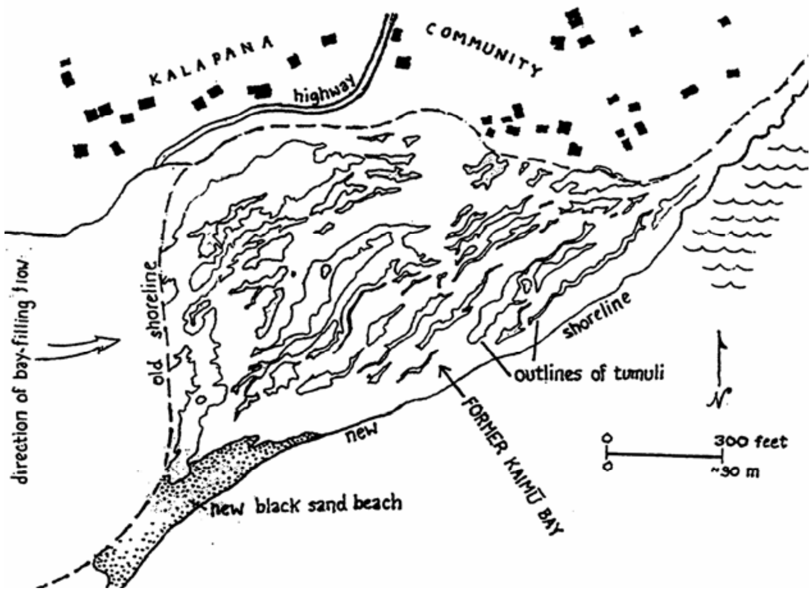


Figure 51 – Diagram showing the position of the black sand beach of Kaimu. (From Hazlett, 2002.)

The old Kaimu beach (Figure 51) was probably one of the most famous black sand beaches in the world, but was covered by about 20' of lava between 1990 and 1992. Local residents have started replanting new coconut trees in old tree molds (when lava cools around a tree). New ferns, palms and other plants are starting to pop out of lava cracks. Black sand beaches may form when basaltic lava hits cold ocean water. When this happens the lava explodes, forming sand-sized black shards. These shards are originally very sharp (like broken glass). There are several 'black sand' beaches on Hawaii's south side which have come from this type of event. They are very difficult places for sandy beach organisms to live because the sand is sharp and also because the black color tends to get extremely hot at low tide and kill marine organisms. Black sand beaches may disappear on Hawaii's southern shores as new lava flows cover them. Black sand beaches are temporary and associated with littoral cones. Once the littoral source erodes away the black sand beach is eroded away by wave action.

Not all black sand is from lava hitting the ocean. Black sand beaches may also form from erosion of black volcanic rock. In Hawaii there are a couple of black sand beaches on the north side of the island where raging rivers have cut through black volcanic rock and eroded it. As the eroded rock is carried toward the ocean it breaks up and may form small sediments by the time it gets to the ocean. These pieces of black sand are not sharp because they have been rounded by erosion and the grinding with other sediments on their way to the ocean. In September 1991 pahoehoe flows filled in the bay in 4 days from Kupaianaha.

Some questions:

1. Examine the map above (Figure 51). Note the location of the Kalapana Community and the earlier location of the shoreline of Kaimu Bay. This former tropical black sand beach and bay was destroyed by lava flows from a volcanic vent northwest of here called Kupaianaha, which means "mysterious" in Hawaiian. Refer to the cross-section below (Figure 52).

2. What type of volcanic rock exists here? What do you see preserved within the lava?

3. Identify two structural volcanic features seen along the trail and sketch them below.

4. What kind of material makes up this beach?

5. How did it form?

6. Where are no seashells or coral fragments found here?

7. What is growing on this beach? Describe how vegetation begins to form at this beach.

8. Would it be a good idea to build your house in this area?

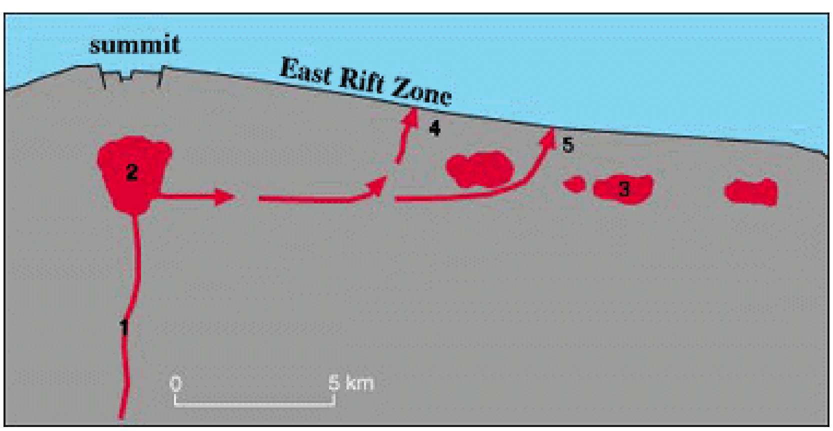


Figure 52 - Diagram of magma chamber and associated plumbing system beneath Kilauea volcano. (Modified from Wright and Fiske, 1971).

Destroyed Village of Kalapana (Possible lava viewing -Time Permitting)

Kalapana is a town on the island of Hawaii that was completely destroyed and partly buried by the eruptive flow of lava from Kilauea volcano in 1990 (Figure 53). A nearby housing subdivision, Royal Gardens, was also largely destroyed, though some of its structures remain untouched to the present day. The lava flow that destroyed Kalapana erupted from the southeast rift zone of Kilauea. Along with the destruction of Kalapana were those of the nearby town of Kaimu and Kaimu Bay, both of which now lie buried beneath more than 50 feet of lava. The lava flow also created a new coastline. Kalapana is now considered a ghost town. Although most access to the town has been cut off, there is currently a bed and breakfast running, and a few people still live there. These people mostly get in and out by 4-wheel drive vehicles.

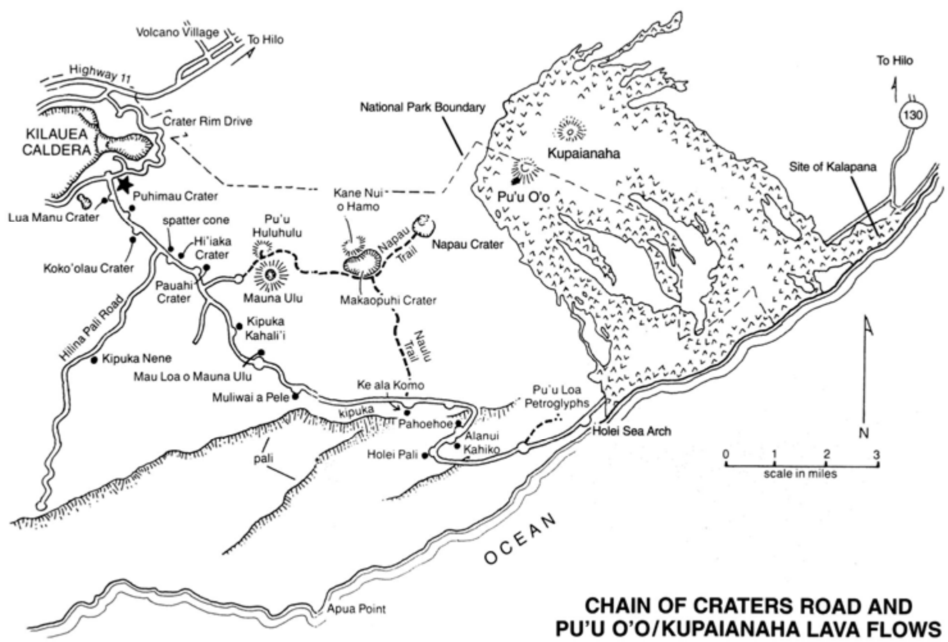


Figure 53 – Map showing the destroyed village of Kalapana. (From Decker, Decker and Hazlett, 1997, p. 30-31.)

1. Note the location of the Kupaianaha vent. What happened to all of the houses in the village of Kalapana?

2. What type of lava is present and what is its age?

3. Do you think anyone was killed during this eruption event? Explain your answer.

4. What geochemical feature controlled the movement of the lava?

5. How deep is the lava? How do you know?

6. How did the topography change after the lava ceased flowing?

7. List two or more items that can still be seen of the remains of the village.

8. Houses are being re-built and people are slowly starting to return to Kalapana. List several problems the new residents will face when trying to build and live upon these lava flows.

9. Examine the map below (Figure 54). Volcanic activity has currently shifted back to Pu'u O'o vent. Why do you think has this occurred?

10. Why are these volcanic vents and flows so unpredictable in their activity?

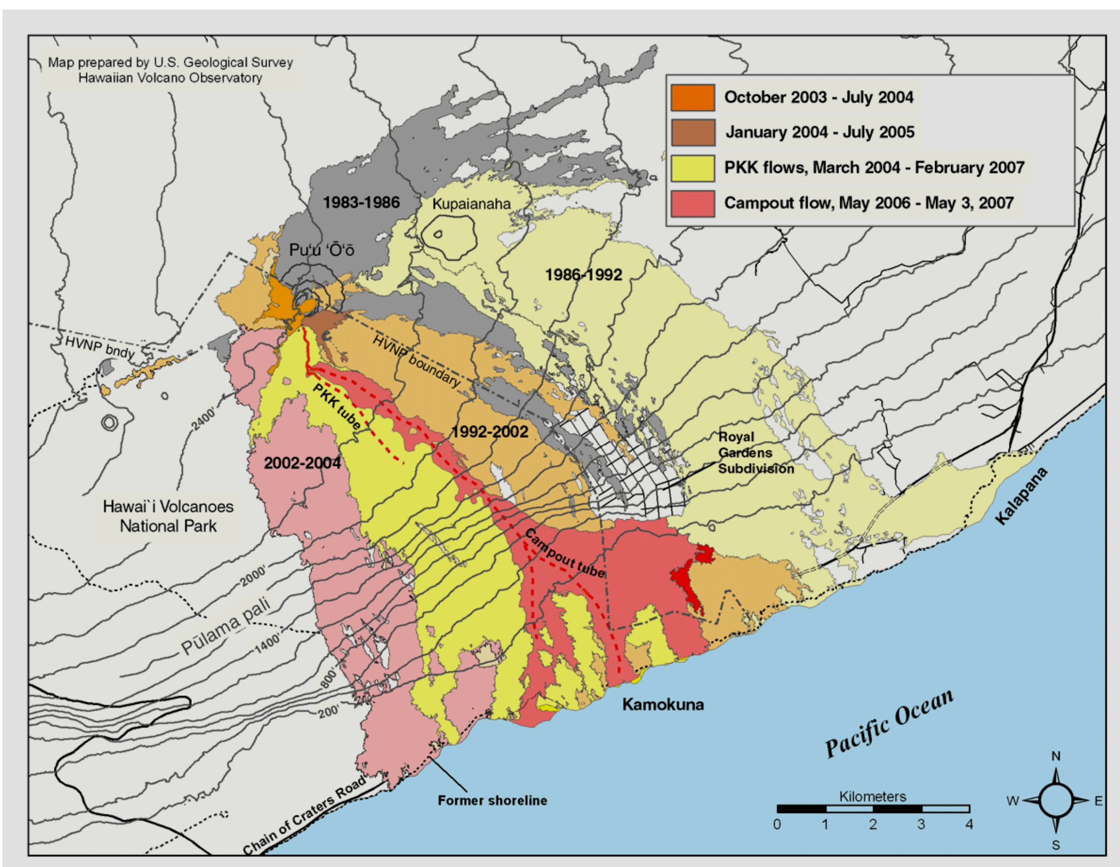


Figure 54 – Map showing the lava flows erupted from 1983 to present activity of Pu'u 'O'o and Kupaianaha. (U.S. Geological Survey.)

Ahalanui County Park Hot Tub and Active Steam Lava Tubes (Time Permitting)

Here get a chance for a hot foot by swimming in ground water heated to 165°C (329°F) from an intrusion into the east rift zone.

Figure 55 – Location map.

1. Locate yourself on the map above (Figure 55). Although partially modified by human endeavors, what volcanic feature created this area?

2. What kind of water fills the basin?

3. Where is all of the 90^{o} F hot water found in the basin? Why?

4. Where is all of the cold water found? Why?

5. What does this basin suggest about the location of the magma?

6. What does this area suggest about the potential for developing geothermal energy?

7. Would the Hawaiian people have any objection to this?

8. Would this be a good area to build housing tracts with an ocean view? Why or why not?

Nanawale Sand Hills (Time Permitting)

A sea cliff exposes the interior of two littoral cones (Figure 56) on the northeast shoreline of Kilauea volcano. These cones were built on the margins of aa flows that erupted in 1840 from fissures located near Pahoa; Nanawale Estates is built atop these flows. Cracks in the rubbly tops of aa flows allow water to penetrate to the hot core of the flows more readily than on the smooth surface of pahoehoe flows, thereby triggering larger littoral explosions (Figure 57). The littoral cones were about 75 m tall when the eruption stopped. By 1865, erosion by wave action had reduced them to a height of about 25 m. The sand hills of Nanwale are now eroded cinder cones that consist of small glassy lava fragments and blocks hurled into the air by the 1840 eruption of Kilauea (Figure 58).

Figure 56 – Aerial view of Nanwale littoral cones. (Adapted from U. S. Geological Survey image.)

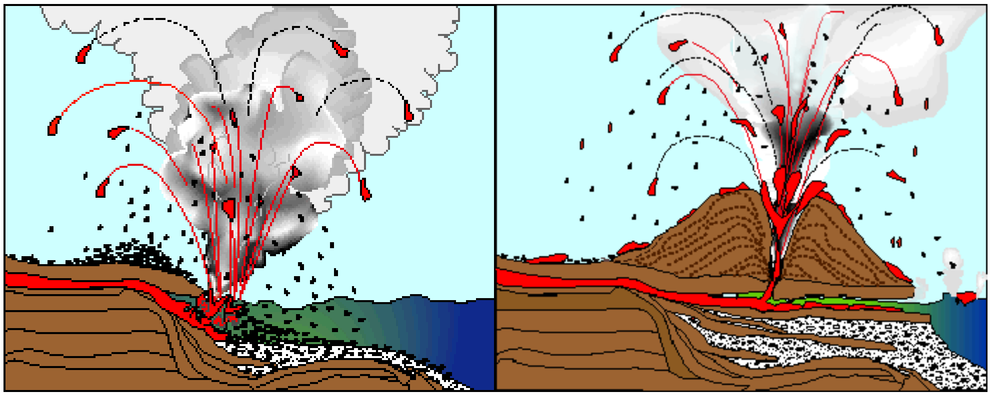


Figure 57 – Large littoral explosions caused by interaction of lava with coastal seawater. (Sketches by J. Johnson, modified from Mattox and Mangan, 1997.)

Figure 58 - This view of the larger, southern, littoral cone of the Nanawale Sand Hills shows the layered interior of the cone. The layers consist chiefly of small glassy lava fragments and blocks hurled into the air by explosions during the 1840 eruption of Kilauea. The seaward sides of both cones were removed by wave erosion, and less than half of each cone remains. Person on top of cone gives scale. (U.S. Geological Survey.)

1. How many volcanic cones exist at this beach?

2. Examine the cross-section cartoons above. What is their origin?

3. What role did seawater play in their development?

4. What type of material makes up these cones?

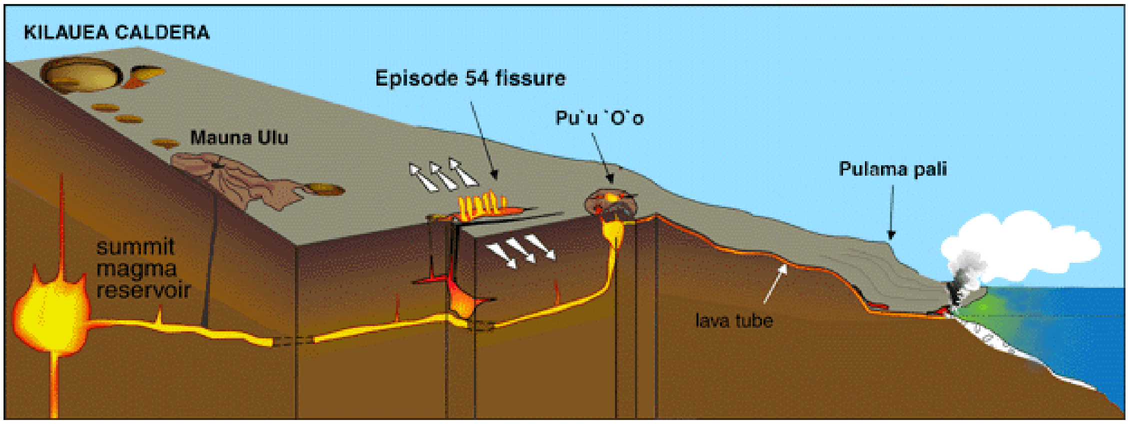
5. Describe the internal structure of these cones.

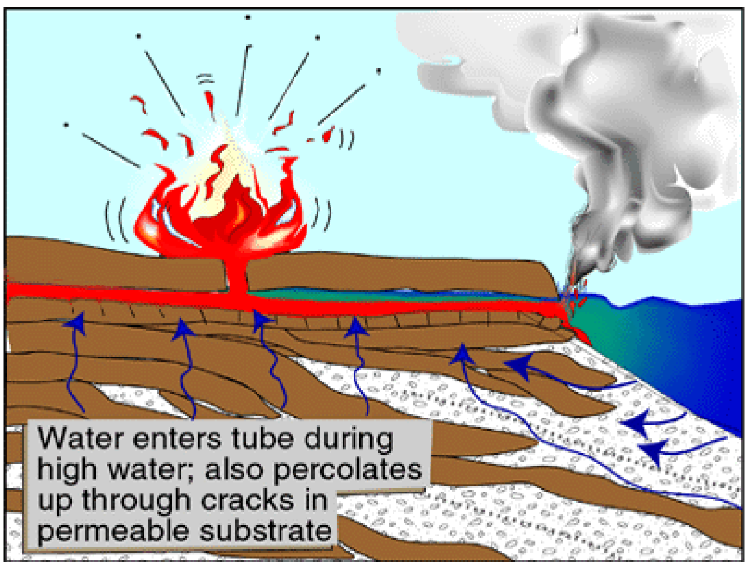
6. What are volcanic bombs and where did they come from?

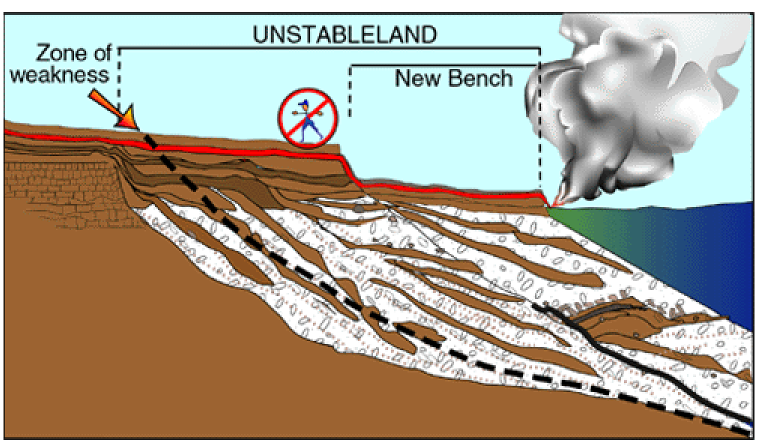
7. Why is the eastern side of one cone so steep?

8. With regard to the shoreline, how permanent are these cones?

9. Refer to the cross-sections below. Why are volcanic coastal regions so unstable?







Day 05 - Friday 27 July – Saddle Road Excursion to Kohala

Rainbow Falls and Boiling Pots

Rainbow Falls and Boiling Pots are both located on the Wailuku River just a short drive from Hilo along Waianuenue Avenue (Figure 59). Rainbow Falls (Figure 60) was aptly named for the frequent magnificent rainbows in the waterfall's mist. This is especially splendid in the early morning, which we will keep in mind in planning our day. In the same area, Boiling Pots are named for the effects of swirling waters of the Wailuku River which was a path for aa flows from Mauna Loa's NE rift zone roughly 10.5 Ka. We will backtrack later back toward Route 200 and turn right on Route 200 to see the Kaumana cave.

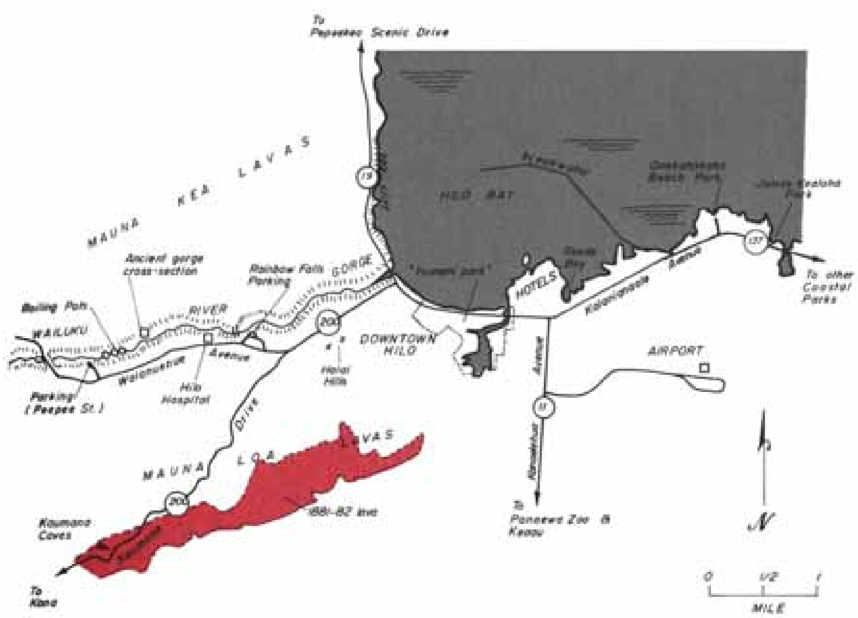


Figure 59 – Geological points of interest around Hilo, our base of operations. (From Hazlett and Hyndman, 1996.)

The 80-foot high Rainbow Falls tumble down through lavas of Mauna Loa into a large natural pool flanked by wild ginger. Here, the Wailuku River discharge is more than 300 million gallons daily. Legend has it that the cave underneath the waterfall was the home of Hina, mother of the powerful demigod Maui and creator of the Hawaiian Islands. Legend also has it that it's best to view the falls between 9:00 and 10:00 a.m., when the sun rises above the mango trees. Mangos! – You know what that means - Break into the cooler and get the blender!

Nearby the waterfalls you will find the Boiling Pots (Figure 61), a series of pools whose water roils and brews due to the geological processes that are still changing the face of Hawaii. During the rainy season the river churns through a succession of "pots," resembling a steaming Jacuzzi. Some of the river water flows beneath a level of old lava, then suddenly bubbles up as if it were boiling. The "pots" are visible from the parking area but hiking down the trail to the water's edge is much more exciting. Just don't enter the water – too much excitement is no good! To the left of the Boiling Pots note Pe'e Pe'e Falls, a beautiful, five-spouted waterfall.

Figure 60 – View of Rainbow Falls. (Unknown Web Contribution.)

Figure 61 – View of the Boiling Pots. (Unknown Web Contributor.)

Both the Rainbow Falls and Boiling Pots are controlled by past and present geologic forces. Boiling pots are steps of large, circular pools. Kind of like a series of potholes about 10 to 20 m in diameter (Figure 62). The first pool drops down into the second pool usually by a waterfall. All of the pools are in succession, flowing in route until they get to the ocean. They are developed between the shields of Mauna Loa and Mauna Kea at Humuula saddle, a natural channel for rain runoff from the southern and southeastern flanks of Mauna Kea. Because of the runoff, a shallow gorge developed along the edge of the Mauna Loa lava which was subsequently filled with a prehistoric lava flow. This flow, eroded by the present Wailuku River, formed the boiling pots. The cooling of the prehistoric flow made several distinct fracture zones including long skinny columnar joints with a hexagonal shape. The columnar joints are about 40 cm across with a height of 10 - 12 m.

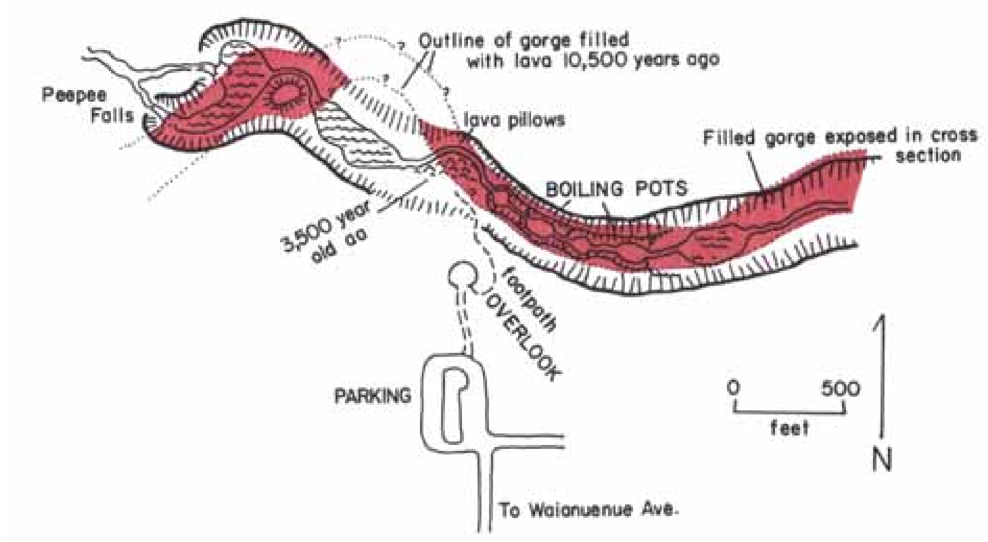


Figure 62 – Location map of the Boiling Pots area. (From Hazlett and Hyndman, 1996, p. 59.)

Time for some mental exercises (Where's Richard Simmons when you need him?)

1. Locate the Wailuku River Valley on the above map. What is its origin?

2. Locate Rainbow Falls on the map. Why does Rainbow Falls occur here?

3. What is the name of the feature that forms at the base of a waterfall? How does it form?

4. Examine the distant walls to the right of the falls. What has caused the vertical fractures?

5. Re-locate your skullcap to the Boiling Pots and Pe'e-pe'e Falls area. What causes the water to apparently boil?

6. What is the origin of the circular patterns within the surface of the 3,500-year-old lava from Mauna Loa?

7. What are the bulbous-shaped lava structures observed the wall across from the overlook and how did they form?

Kaumana Cave

Kaumana Caves (Figure 63) represent one of the Hawaii's neatest attractions. Formed from the lava flows in 1881 and 1882, the downtown area of Hilo held its breath as the flow approached. Because she sat in front of the lava flow praying to Pele to spare the town, many credit Princess Ruth from Honolulu with saving Hilo village. The cave extends for 3,000' and we enter through a skylight. Deeper inside the cave the lava changes to fine aa with lavacicles.

Figure 63 – View of the skylight entrance to Kaumana cave. (Web Contributor.)

The caves are located up the hill from the downtown area on Kaumana Drive (Saddle Road). Stretching for almost two miles, the main lava tube passes underneath the highway (Figure 64). When you get to the caves you can see a concrete stair case which leads through the old skylight down to the entrance to the caves. Once in the caves fabulous lava formations are preserved. Lavacicles were abundant on years past but very few exist today. Vines and roots are everywhere growing down from the ceiling and rain and runoff make the caves damp and muddy. Low ceilings and outcroppings make it very easy to get a bump on the head or worse.

You should come prepared for the caves with: a flashlight, long pants or jeans, gloves, and a long sleeve shirt or sweater. Make sure that you wear shoes (that will get dirty) because the tube is hardened lava making it more than likely to be slippery, especially when wet.

The "cave" is actually a large lava tube with the entrance through a collapsed skylight. The walls provide a cross-sectional view of a pahoehoe lava flow. The roof of the tube is 20 to 25 feet thick in most places and according to Hazlett and Hyndman (1996) most of the blocky rubble on the floor fell during or shortly after the eruption, when the skylight entrance fell.

The tube was initially filled with fast-moving lava then the level dropped and a long period of flow along the floor took place and from time to time slopped over to the side creating the bench-like features seen near the cave entrance. Roof blocks fell and became embedded and coated with basalt. The lava stream later emptied leaving the evacuated tube.

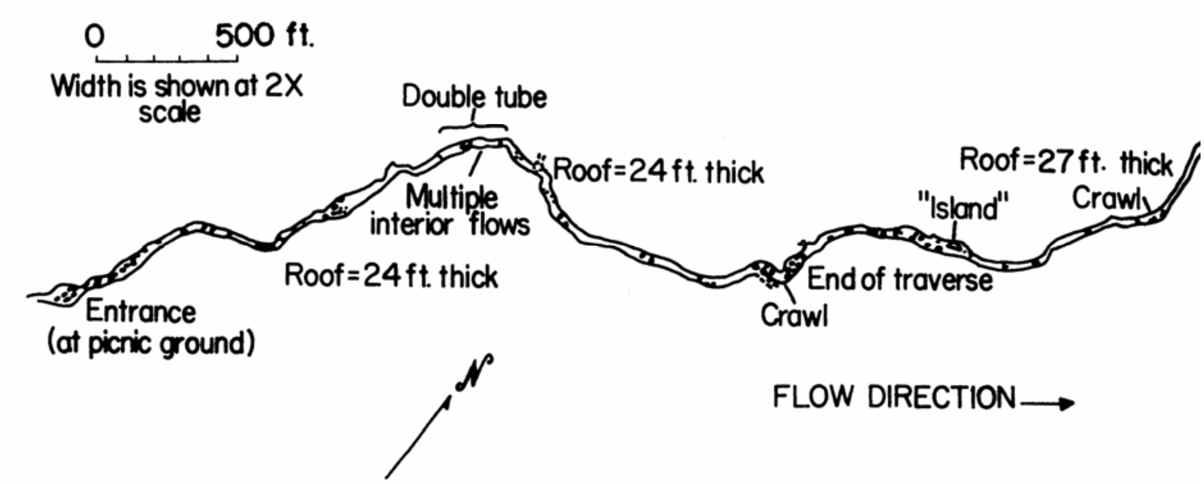


Figure 64 – Location map of the Kaumana Cave lava tube. (From Hazlett and Hyndman, 1996.)

Here are some more stumpers for ya:

1. What feature allows you access to this cave?

2. What is the age of this cave and to what volcano does it belong?

3. Carefully examine the brown walls and especially the floor of this cave. What type of lava is present?

Pu'u Huluhulu Preserve and Mauna Kea

Travel along Route 200 to Route 220 at the base of Saddle Road toward Mauna Kea. Pu'u Preserve offers a moderate difficulty level 3-mile (2-hour) roundtrip hike across lava flows from 1973 and 1974 (Bring your 8-track tapes)! The trail begins at the Mauna Ulu parking area on Chain of Craters Road (Figure 65). Bring water and prepare for hot and dry or wet and windy weather. Follow the ahu (rock piles) over the lava flows. Sulfur fumes may be strong on some days. We will walk across lava flows, through kipuka, past lava trees, and will climb 50 m to the summit of Pu'u Huluhulu. On a clear day view Mauna Loa, Mauna Kea, Pu'u 'O'o and the Pacific Ocean in a stupendous panoramic vista. Visible are pahoehoe lava, cinder cone, lava shield, kipuka, lava trees, and pioneer plants.

Source: http://www.alternative-hawaii.com/activity/biecotr.htm

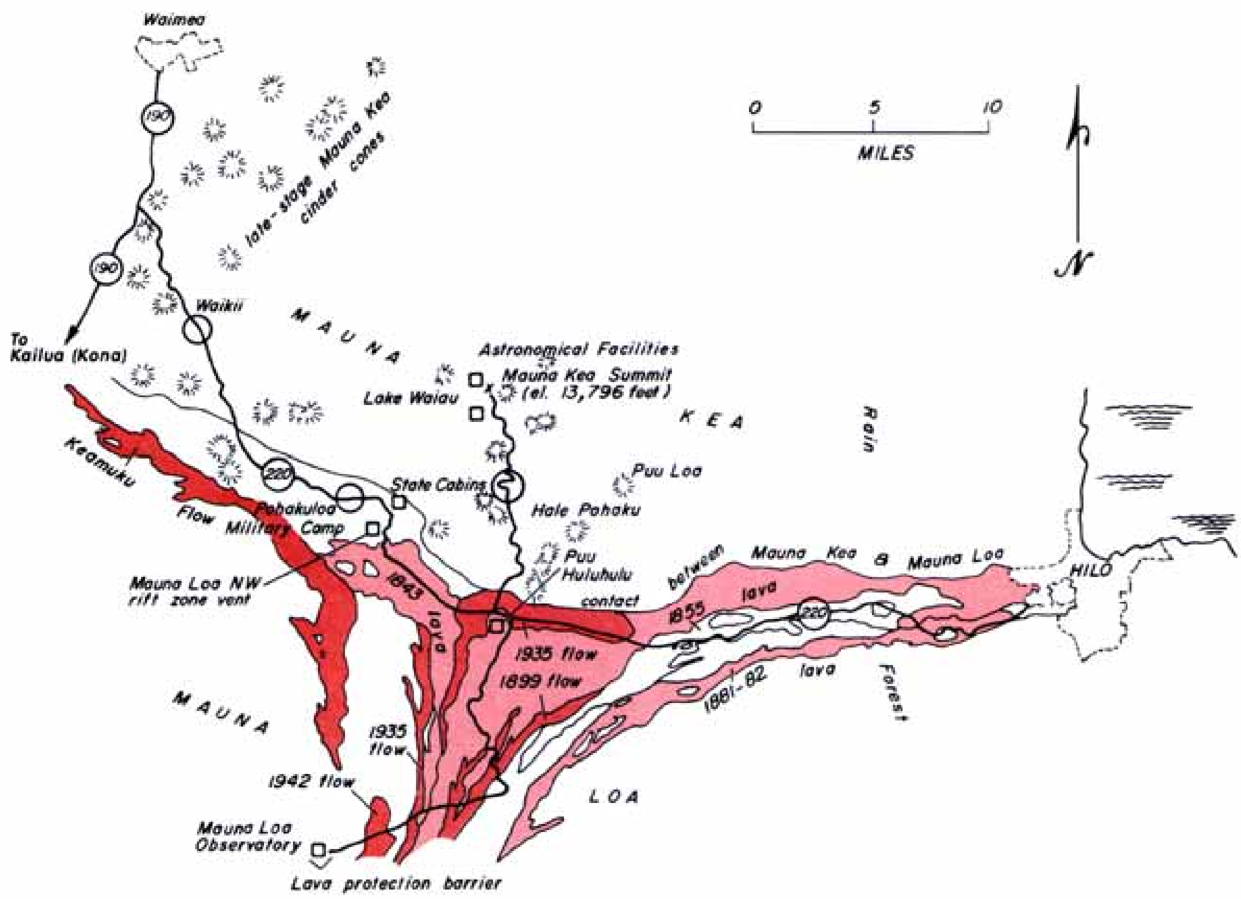


Figure 65 – Location map showing major features along Saddle Road between Mauna Kea and Mauna Loa volcanoes. (From Hazlett and Hyndman, 1996, p. 117.)

Mauna Kea

Mauna Kea is a dormant volcano in the Hawaiian Islands, one of five volcanic peaks that together form the island of Hawaii. It is the tallest mountain in the world when measured from base to peak, its base being some 19,678 feet (5998 m) under the surface of the Pacific Ocean, which would bring its total height to 33,474 feet (10,203 m). In Hawaiian, Mauna Kea means "white mountain", a reference to the fact that it is regularly snow- or frost-capped during the northern hemisphere winter. Its highest point, Pu'u Wekiu (one of numerous cinder cones on the summit), is the highest point in the state of Hawaii at 13,796 feet (4,205 m).

Tall cinder cones atop the summit of Mauna Kea and lava flows that underlie its steep upper flanks (Figure 66) have built the volcano a scant 35 m higher than nearby Mauna Loa (4,170 m). Mauna Kea, like Hawaii's other older volcanoes, Hualalai and Kohala, has evolved beyond the shield-building stage, as indicated by (1) the very low eruption rates compared to Mauna Loa and Kilauea; (2) the absence of a summit caldera and elongated fissure vents that radiate its summit; (3) steeper and more irregular topography (for example, the upper flanks of Mauna Kea are twice as steep as those of Mauna Loa – Figure 67); and (4) different chemical compositions of the lava.

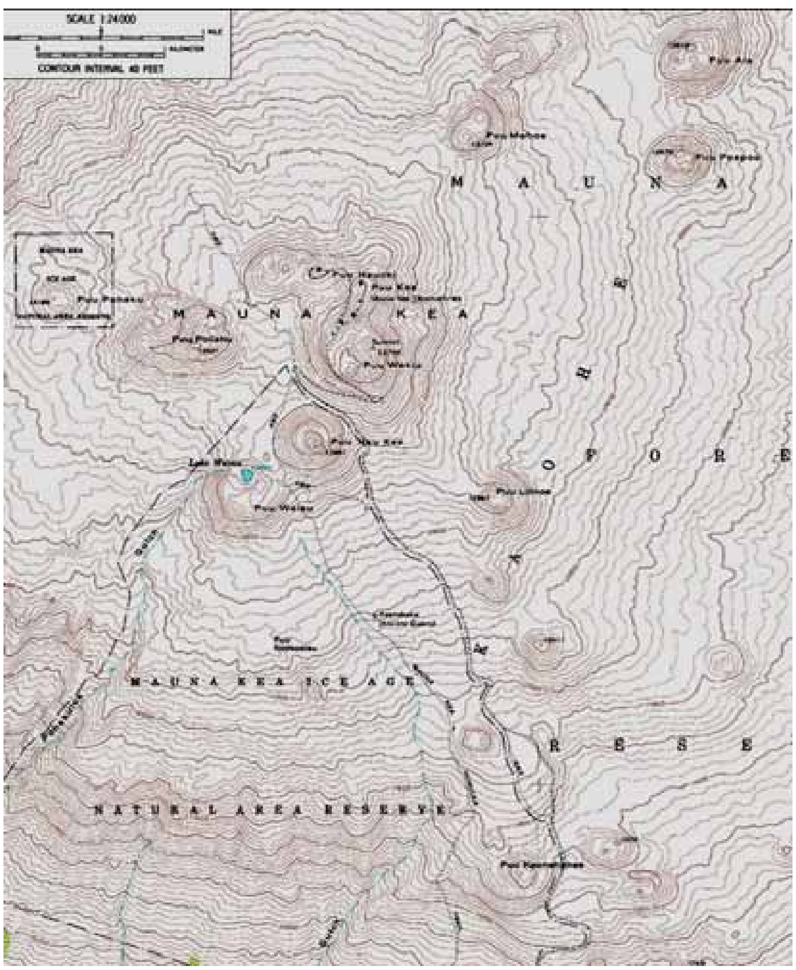


Figure 66 - USGS topographic map of Mauna Kea.

These changes in part reflect a low rate magma supply that causes the continuously active summit reservoir and rift zones of the shield stage to give way to small isolated batches of magma that rise episodically into the volcano, erupt briefly, and soon solidify. They also reflect greater viscosity and volatile content of the lava, which result in thick flows that steepen the edifice and explosive eruptions that build large cinder cones (Figure 68). After hundreds of thousands of years of building itself up by volcanic activity, the mountain's height is slowly decreasing as its massive weight depresses the Pacific seafloor.

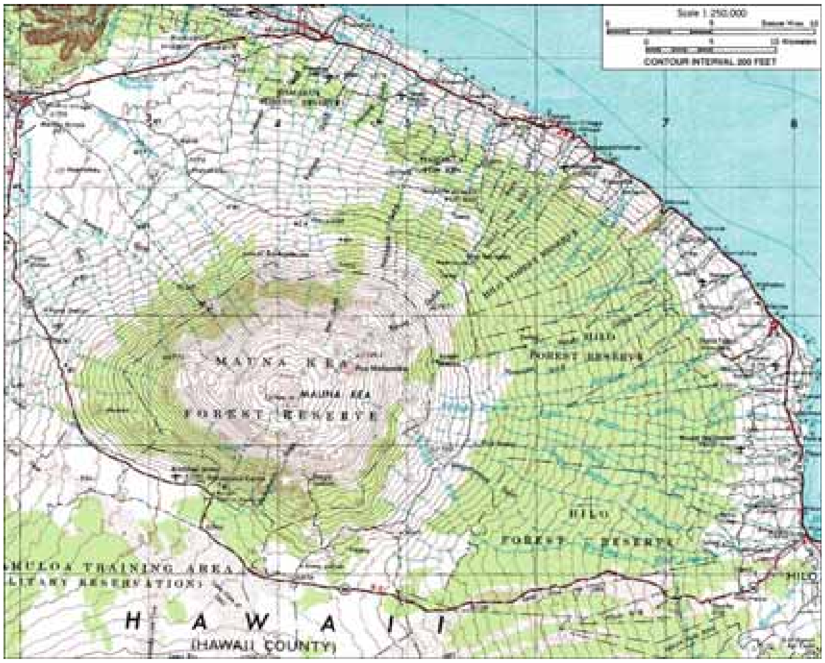


Figure 67 – Topographic map of entire Mauna Kea shield volcano showing the characteristic broad, sloping sides. (From U. S. Geological Survey.)

Figure 68 – Aerial view of the alkali cones on summit of Mauna Kea volcano. (Unknown Web Contributor.)

Glaciers on Mauna Kea

Although snow and ice occur now mostly in the period from November through March, Mauna Kea had permanent (year-round) ice caps during the Pleistocene ice ages (Woodcock et al., 1970). Most people don't think about snow or glaciers in Hawaii, but geologists have long recognized deposits formed by glaciers on Mauna Kea during recent ice ages (Figure 69). The latest work indicates that deposits of three glacial episodes since 150,000 to 200,000 years ago are preserved on the volcano. Glacial moraines on the volcano formed about 70,000 years ago and from approximately 40,000 to 13,000 years ago. If glacial deposits were formed on Mauna Loa, they have long since been buried by younger lava flows.

Even today, snow falls on both Mauna Kea and Mauna Loa. Both volcanoes are so high that snow falls during winter months, perhaps accumulating to a few meters depth. The seasonal snow cover on the steep slopes of Mauna Kea is easier to see from coastal areas than on the gentle, rounded slopes of Mauna Loa, whose summit cannot be seen from sea level.

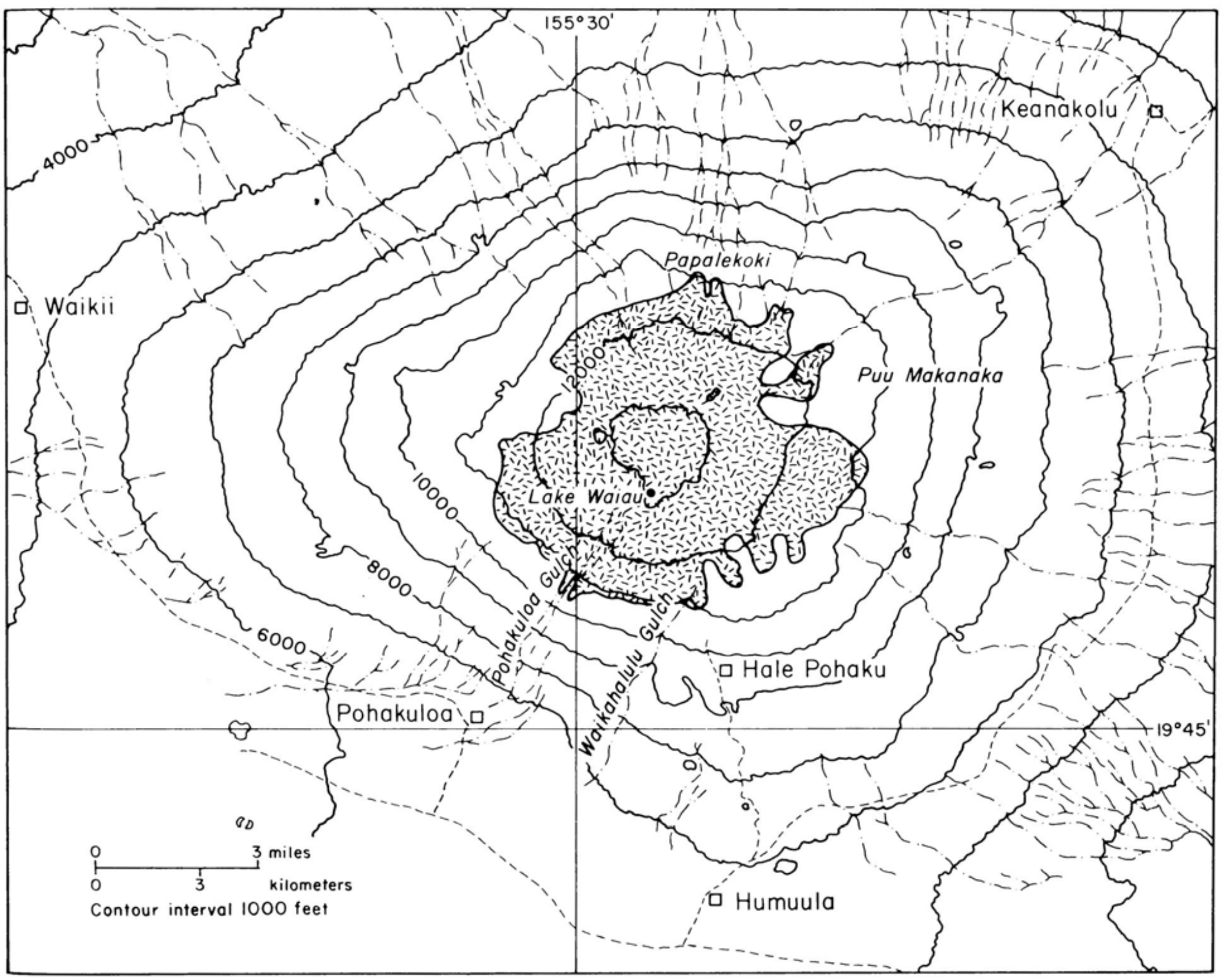


Figure 69 – Map of Mauna Kea showing extent of ice cap that occupied the summit during Pliestocene. (From Macdonald and others, 1983, Fig. 13.3, p. 257.)

Will Mauna Kea Ever Erupt Again?

Mauna Kea is presently a dormant volcano, having last erupted about 4,500 years ago. However, Mauna Kea is likely to erupt again. Its quiescent periods between eruptions are long compared to those of the active volcanoes Hualalai (which erupts every few hundred years), Mauna Loa (which erupts every few years to a few tens of years) and Kilauea (which erupts every few years). A swarm of earthquakes beneath Mauna Kea might signal that an eruption could occur within a short time, but such swarms do not always result in an eruption. Sensitive astronomical telescopes on top of Mauna Kea would, as a by product of their stargazing, detect minute ground tilts possibly foretelling a future eruption.

Most Recent Eruption(s)

At least 7 separate vents erupted between about 6,000 and 4,000 years ago. The oldest dated rocks are 237,000 ± 31,000 years before present but the estimated age of Mauna Kea is almost 1 Ma. The volcano is in the post-shield stage a transition that occurred before about 200,000 to 250,000 years ago.

Sources: http://en.wikipedia.org/wiki/Mauna_Kea; http://hvo.wr.usgs.gov/volcanoes/maunakea/

Here's some questions to comment on:

1. Locate yourself on the map. What controlled the location of Route 220 to this locality?

2. Enter the preserve and follow the trail to the right. What kind of structure do you observe?

3. What are the long and vertical intrusive rocks called? Here's an image to help out.

4. What is their age relative to Pu'u Huluhulu?

5. To the north is Mauna Kea. How high is it? Is it taller than Mauna Loa?

6. Why is Mauna Kea an ideal place to build an astronomical observatory?

7. What does the abundance of small cinder cones on its flanks indicate about the growth stage of Mauna Kea?

8. Is Mauna Kea older or younger than Mauna Loa? What evidence can you cite to support your answer?

9. Proceed up to the Visitor Center of Mauna Kea. Watch out for "invisible cows" along the way. Three or four periods of glaciation have affected the top of Mauna Kea. How can glaciers exist in the tropics?

10. Examine the attached geologic and topographic maps of Mauna Kea. What prominent glacial feature marks the last advance of these glaciers?

Kohala Mountain "Cherished land"

Kohala Volcano is the oldest of Hawaii's five subaerial volcanoes and probably emerged above sea level more than 500,000 years ago. Large portions of volcano slid into ocean 150,000 to 400,000 years ago. Toward the end of its shield-building stage 250,000 to 300,000 years ago, an enormous landslide removed the volcano's northeast flank, producing a steep scarp. Twenty kilometers wide at the shoreline, the landslide cut back to the summit of the volcano, which at the time was just over 1,000 m higher than today, and traveled 130 km across the ocean floor. The famous sea cliffs of windward Kohala shoreline mark the topmost part of the headwall of this ancient landslide (Figure 70).

When eruptions had built Kohala's broad shield to its greatest extent, the volcano was more than twice as wide as it is today. Based on an abrupt change in angle of the submarine slope at a depth of about 1,000 m, scientists estimate the subaerial part of the island at this time was more than 50 km wide. Then, when the rate of eruption decreased more than 300,000 years ago, the slow subsidence of the Island outstripped the rate of growth of the volcano, which slowly began to sink beneath sea level. But to the southeast, lava flows from Mauna Kea and Mauna Loa buried the southern flank of Kohala.

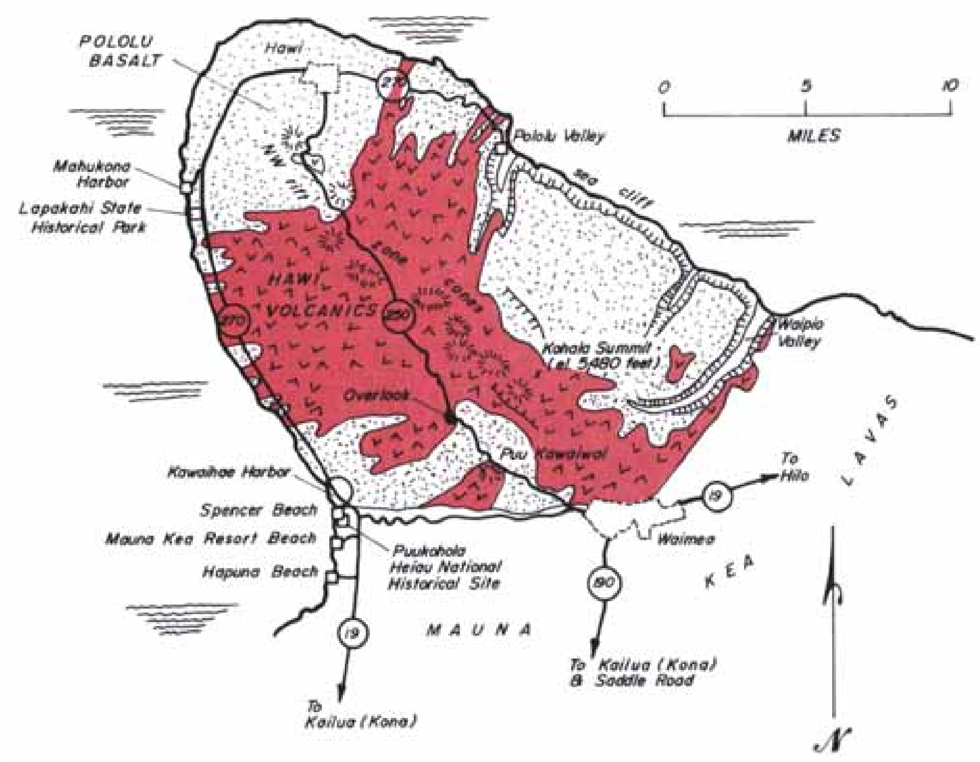


Figure 70 – Location map of Kohala volcano. (From Hazlett and Hyndman, 1996, p. 111.)

The volcano is 20 miles long and has 2 rift zones (NW and SE). Route 250 follows the NW rift zone. The elevation is 5,480 feet but was 5,280 feet higher in the past. The older Hawaiian lavas are part of Pololu Formation (730,000 Ka). Local alkalic cinder cones are from the Hawi Formation, dated by ^{40}K- ^{40}Ar techniques. On the way up to the **benmoreite** locality we will pass a quarry of **hawaiite** lava from Pu'u Kawaiwai cinder cone.

Near the top of the summit, note the dome of light-colored grayish benmoreite in the large road cut that locally contains phenocrysts of black hornblende and plagioclase. These rocks cap the 1,980' thick Pololu volcanic series which is tholeiitic in the lower part and alkali olivine basalt at the top. These rocks are also exposed on the cliff faces at the Waipi'o valley!

Hualalai Volcano (Time Permitting)

Hualalai volcano can be found by traveling on Route 270 west and south to 19 east and south where all lavas formed are alkali basalts. These mature alkalic rocks are indicative of passage away from the hot plume and suggest that the caldera is buried by late stage eruptions. The volcano is 8,300' high with steep sides produced by eruption of highly viscous trachytic lava containing abundant cognate xenoliths of gabbro and dunite from depths exceeding 10 km. The volcano exhibits two rift zones 20 miles in length. The SW rift zone erupts every 300 years; the NW rift last erupted in 1800-1801. In 1929, an earthquake swarm indicated dike intrusion but it did not break the surface. We are in Hazard Zone 4. Return via Route 19 south.

Some questions to spout off on:

1. Locate yourself on the map. Examine the roadcut at the top of the hill. Kohala had produced a lot of tholeiitic magma in the past, where is it now?

2. Refer to the attached diagram (Figure 71) for the life cycle of Hawaiian volcanoes. What is Kohala's stage of growth?

3. How does Kohala's stage of growth compare with that of Kilauea?

4. In the geologic past, Kohala was approximately 1,000 feet higher than today. Explain what is happening here.

5. At the Pu'u Kawaiwai quarry down the road from Kohala, what type of basalt occurs here?

6. What accounts for the steep cliff to the west of this outcrop?

7. Hualalai volcano occurs to the south of Kohala, beyond the tail end of Mauna Loa. Refer to the topographic map for this road stop below (Figure 72). Hualalai has not erupted for more than 200 years. In 1929, a series of harmonic tremors occurred for more than thirty days, but there was no volcanic eruption. Explain what was happening.

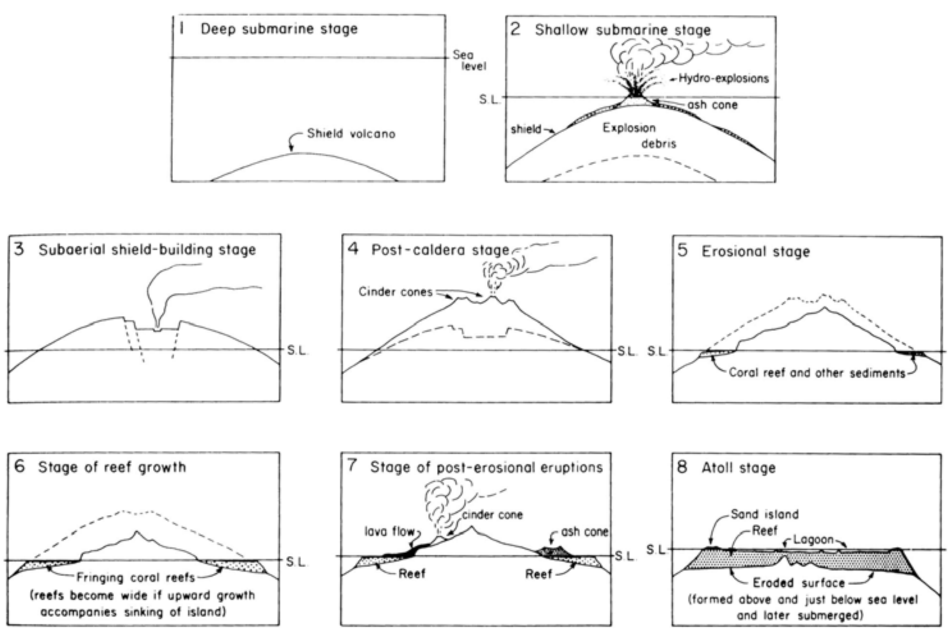


Figure 71 - Eight stages in the evolution of a shield volcano. (From Macdonald and others, 1983, Fig. 6.1, p. 147.)

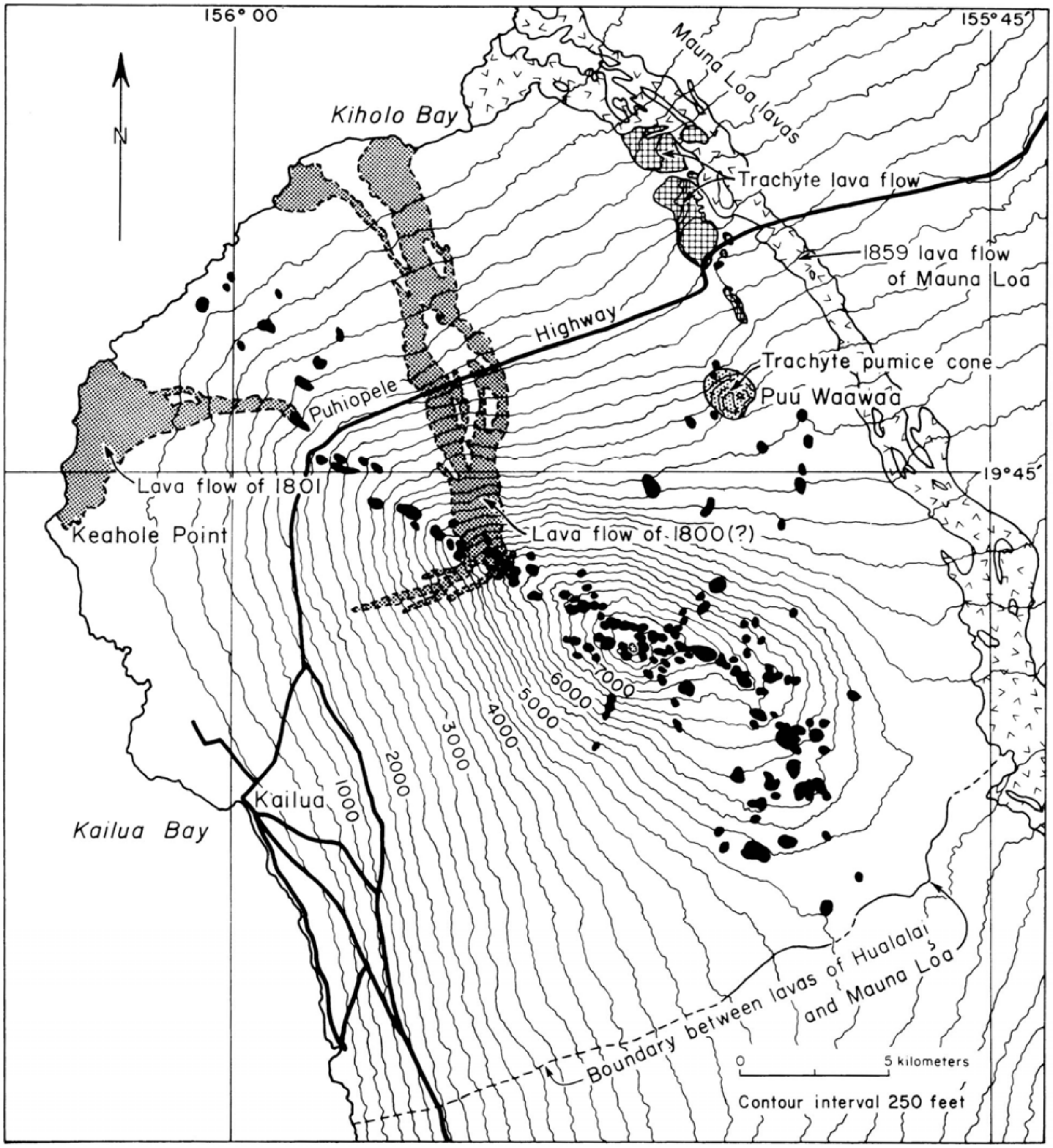


Figure 72 – Map of Hualalai volcano showing eruptive activity from 1800-1801, the trachyte pumice cone of Pu'u Waa-waa, and the trachyte flow from the cone. Black dots are spatter and cinder cones. (From Macdonald and others, 1983, Fig. 3.3, p. 61.)

Day 06 - Saturday 28 July – Hamakua Coast Excursion to Waipi'o Valley

Hawaii Tropical Botanical Garden

Traveling along Route 19 north to Scenic Drive to find the Hawaii Tropical Botanical Garden - a spectacular Garden in a Valley on the Ocean acclaimed as one of the most beautiful areas in all Hawaii. The Garden is located on the Big Island of Hawaii ~13 km (8.5 mi.) north of Hilo on the four-mile Scenic Route at Onomea Bay (Figure 73). In this garden valley, nature trails meander through a true tropical rainforest, crossing bubbling streams, passing several beautiful waterfalls and the exciting ocean vistas along the rugged Pacific coast. The cliffs along the Hamakua coast consist of ~100,000 years old aa lava from Mauna Kea. The 1946 tsunami created 35 foot high waves that destroyed a fishing village. Note the sea stacks of eroded basalt flows that collapsed in 1956 and the basalt flow breccia. Semi-diurnal tides occur here but vary by only 1.7 feet between high/low tides.

The Garden displays a vast variety of palms, heliconias, gingers, bromeliads, and hundreds of other rare and exotic plants from all parts of the tropical world - presently more than 2,000 species, and the collection is always growing! This non-profit nature preserve is dedicated to providing a plant sanctuary, a living seed bank, and a study center for trees and plants of the tropical world and to preserving the incredibly beautiful natural environment of Onomea Bay for generations to come. We include it as a stop on our field trip so that no one can say at the end, "Hey, you didn't stop once to smell the flowers – rocks, rocks, rocks, all day!"

Figure 73 – Location map for Kahuna and Akaka Falls.

Kahuna and Akaka Falls

Heading north out of Hilo on Highway 11 leads you onto the Hamakua Coast (Figure 74). Between the 14 and 15 mile markers is the junction with Highway 220, which takes you directly to Akaka Falls State Park. A sign is posted just prior to the junction, indicating this destination. The park is approximately 5 miles from your turn, at the end of the road. The drive will provide some of the most spectacular views of Mauna Kea to be found on the windward side of Hawaii. On a clear day, you will see 4 or 5 of the world-class astronomical observatories that sit at the top of Hawaii's tallest volcano, gleaming white and somehow otherworldly amidst the stark grey and brown of the peak's barren summit.

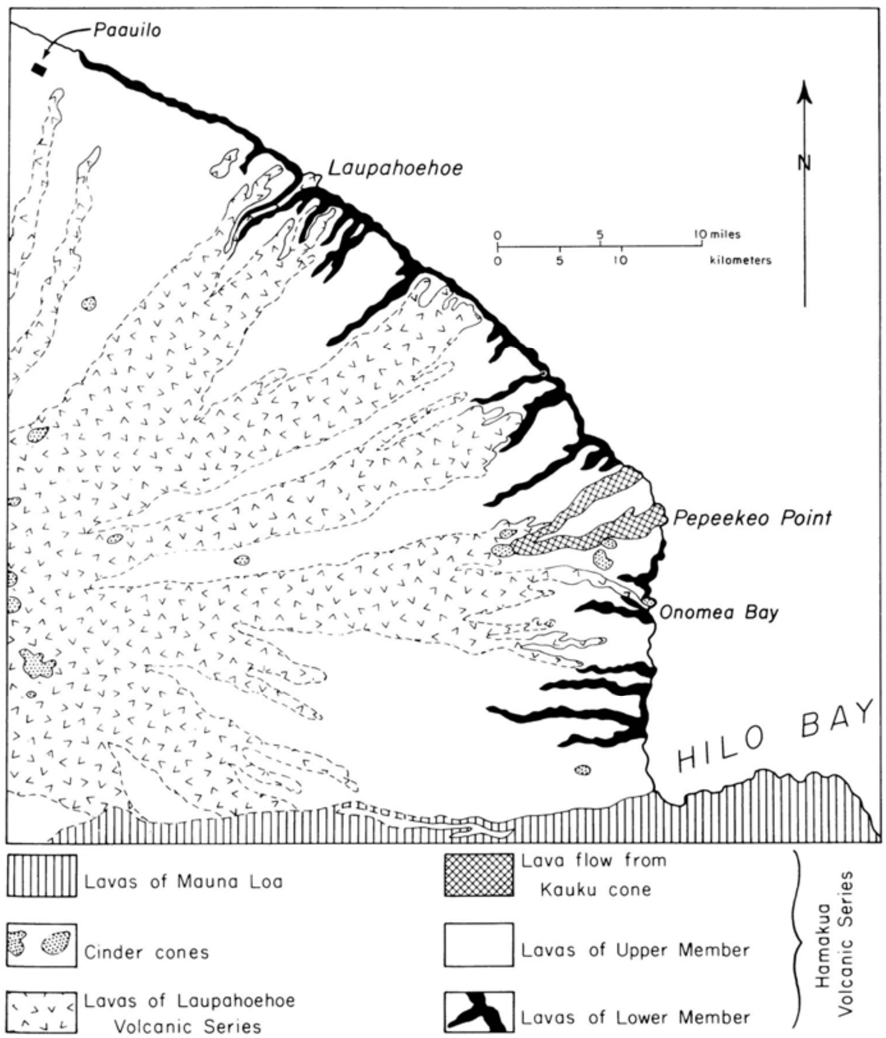


Figure 74 – Geology north of Hilo Bay. (From Macdonald and others, 1983.)

An easily navigated loop trail less than 1 mile begins at the small parking lot. A sign at the trail head provides the distance to Kahuna and Akaka Falls (Figure 75), as well as to a third water fall, which is an unexpected treat, since the park name gives no indication of additional water features. The trail is paved but has many steps, both up and down, along its length and a misstep will easily bring you to your knees on some rough lava rock. Your entire course is taken under towering bamboo, banyan trees, giant heleconia, banana, and ginger. Dizzying sights surround you in every direction.

Figure 75 – View of Akaka Falls showing stacked lavas and a plunge pool. (Unknown Web Contributor.)

By keeping to your right, you arrive first at Kahuna Falls, a 440 foot water fall that slides down the mountain across the ravine ahead of you, rather than tumbling down in a sheer drop. This fall is pretty but is partially hidden by the lush foliage and the deep channel it has carved for itself over the eons. Keep in mind this is not what you came to see. Continue the loop, which now climbs up the steepest section of the trail. This portion appears daunting, but lasts for no more than 100 feet before you reach the top. Once at the top of the incline, you will hear Akaka Falls before you see it and, with luck, you'll catch a cooling breeze from the ocean.

A few steps farther along and the trail begins to descend. Views of the fall appear through the trees and shortly you are at the viewing area. The fall is now directly in front of you, glorious in its sheer cliffs. It falls, straight and narrow for 420 feet from the lip of basalt, hitting bottom in a green, fern-filled grotto with a blaze of rainbows reflecting in the spray. The

Hawaiian word *akaka* means to split and the falls breach a steep normal fault and cascades downward through Mauna Kea aa flows with a capping of lateritic ash. A large circular plunge pool adorns the base of the falls.

While neither the highest nor most voluminous fall on the Big Island, Akaka Falls is certainly the easiest to access. The loop trail can be completed in no more than one half hour, though lingering at the viewing area to marvel at this virtually drive-up wonder of nature and cool off after the ups and downs of your walk can add as much time to the trip as you like. The drive back down to Honomu town provides some awesome ocean views. The Pacific is spread out before you in 3 directions and reminds you that you are indeed driving on an island. This fact, seemingly self-evident, is easy to forget since the island is so large. The view will bring you back to the reality of your location.

Source:
http://hawaii.kulshan.com/Hawaii/Hawaii_County/The_Big_Island/Honomu/Outdoors/Akaka_Falls_State_Park.htm

Some questions to enlighten us with:

1. The 440-foot high Akaka Falls is fed by the Kolekole Stream and two waterfalls exist on the 65- to 200,000-year-old Hamakua alkali basalt flows from Mauna Kea. What is the origin of these falls? **Hint:** Akaka in Hawaiian means “to crack or split”.

2. What happened in this area on April 1, 1946 at 7:00 am?

3. What is the similarity between here and Hilo Bay?

4. Examine the current shoreline. What is used to reduce wave energy?

5. If the warning sirens suddenly began, where would you go?

Laupahoehoe Point (Lunch)

To reach this scenic lunch stop, follow Route 19 north to the coast. An infamous location, here the 1946 earthquake in the Aleutian Trench caused a 30 foot high wave and killed 24 people, mostly school children.

Waipi’o Valley

Located along the Hamakua Coast on the northeast shore of the Big Island of Hawaii, the Waipi`o Valley is the largest and most southern of the seven valleys on the windward side of the Kohala Mountains (Figure 76). To reach it take Route 19 north to Route 240 north. The Waipi`o Valley is a mile wide at the coastline and almost six miles deep. Along the coast is a beautiful black sand beach often used by motion picture production companies and as a backdrop for hamster movies on the Dukelabs.com website.

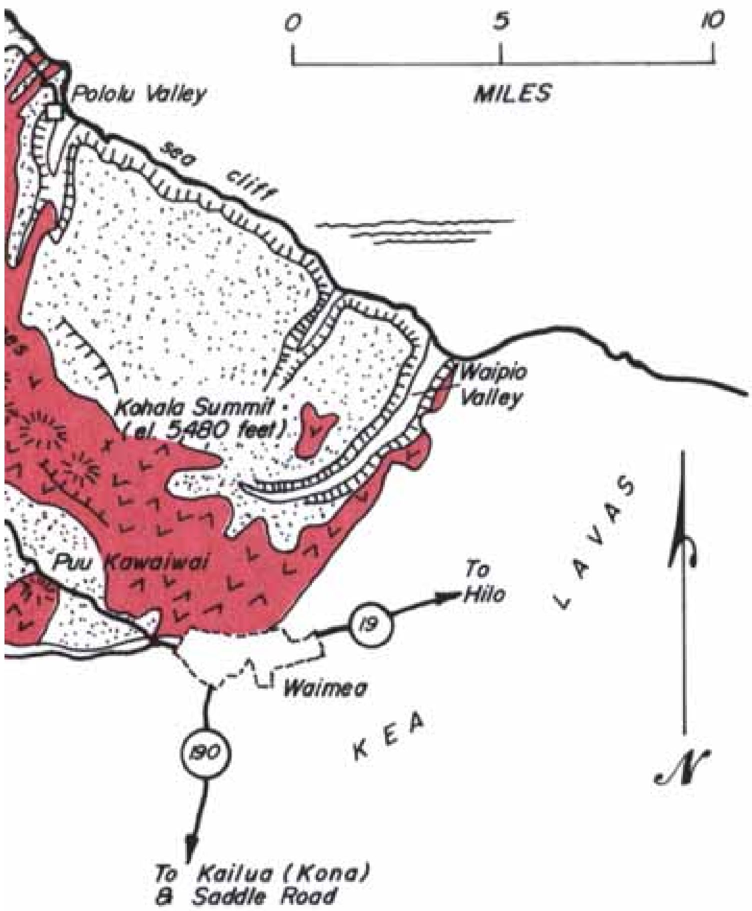


Figure 76 – Location map of the Waipi`o Valley. (From Hazlett and Hyndman, 1996, p. 111.)

On both sides of the valley there are cliffs reaching almost 2000 feet with hundreds of cascading waterfalls, including one of Hawaii's most celebrated waterfalls - Hi`ilawe. The road into the valley is very steep (a 25% grade). In order to travel into the valley, you must either ride down in a four wheel drive vehicle or hike down to the valley floor. Waipi`o means "curved water" in the Hawaiian language. The lovely Waipi`o River flows through the valley until it enters the ocean at the beach (Figure 77).

The Waipi`o Valley is often referred to as the "Valley of the Kings" because it was once the home to many of the rulers of Hawaii. The valley has both historical and cultural importance to the Hawaiian people. According to oral histories as few as 4000 or as many as 10,000 people lived in Waipi`o during the times before the arrival of Captain Cook in 1778. Waipi`o was the most fertile and productive valley on the Big Island of Hawaii. It was at Waipi`o in 1780 that Kamehameha the Great received his war god Kukailimoku who proclaimed him the future ruler of the islands.

Figure 77 – View of the black sand beach at the foot of the Waipio Valley. (CM digital image taken 28 July 2007.)

It was off the coast of Waimanu, near Waipi`o, that Kamehameha engaged Kahekili, the Lord of the leeward islands, and his half-brother, Kaeokulani of Kauai, in the first naval battle in Hawaiian history - Kepuwahaulaula, known as the Battle of the Red-Mouthed Guns. Kamehameha thus began his conquest of the islands.

In the late 1800s many Chinese immigrants settled in the valley. At one time the valley had churches, restaurants and schools as well as a hotel, post office and jail. But in 1946 the most devastating tsunami in Hawaii's history swept great waves far back into the valley. Afterwards most people left the valley, and it has been sparsely populated ever since.

A severe deluge in 1979 covered the valley from side to side in four feet of water. Today only about 50 people live in the Waipi`o Valley. These are taro farmers, fishermen and others who are reluctant to leave their simple lifestyle. Aside from its historical importance, the Waipi`o Valley is a sacred place for Hawaiians. It was the site of many important heiaus (temples). The most sacred, Pakaalana, was also the site of one of the island's two major pu`uhonua or places of refuge, the other being Pu`uhonua O Honaunau.

Ancient burial caves are located in the sides of the steep cliffs on either side of the valley. Many kings were buried there. It is felt that because of their mana (divine power), no harm will come to those who live in the valley. In fact, despite great devastation in the 1946 tsunami which entered a half mile up the valley with a 40' high wave and the 1979 flood, no one actually died in those events. Waipi`o is also a mystical place. Many of the ancient stories of the Hawaiian gods are set in Waipi`o. It is here that beside the falls of Hi`ilawe, the brothers of Lono found Kaikiani dwelling in a breadfruit grove. Lono descended on a rainbow and made her his wife only to later kill her when he discovered a chief of the earth making love to her. As she died she assured Lono of her innocence and her love for him. In her honor Lono instituted the Makahiki games - a designated period of time following the harvesting season when wars and battles were ceased, sporting competitions and contests between villages were organized, and festive events were commenced. Another story set in Waipi`o tells how the people of Waipi`o came to be safe from the attack of sharks. It is the story of Pauhi`u Paupo`o, better known as Nanaue, the shark-man.

The walk down the steep 4-wheel drive road is about 1 mile and the gradient is 1,066 ft/mile dropping down about 1,000 feet in elevation from the overlook to the valley floor. The valley was created by down dropping along a normal fault between Kohala and Mauna Kea and was later eroded by streams. Modification by a 300 foot sea level rise during melting of Pleistocene glaciers later deposited sediments onto the valley. Along the upthrown blocks waterfalls are > 1,500 feet high. Volcanics in the cliffs are alkali basalts from Kohala's Pololu Formation and represent a stagnant magma chamber with large sinking feldspar crystals. The black sand beach formed from erosion of alkali basalts from Kohala to north and Mauna Kea to southwest.

Let's get some snappy answers on these:

1. At this locality you are looking at the Pololu Formation. How did Waipi'o Valley form and where have you seen this type of valley formation before?

2. Why is this valley susceptible to a tsunami?

3. Walk a short distance down the road and examine the outcrops along the way. <u>WATCH OUT FOR TRAFFIC</u>!! Is this igneous rock intrusive or extrusive? What evidence can you cite to support your answer?

Day 07 - Sunday 29 July – HVNP

Halema'uma'u - Kilauea Crater Hike Across Kilauea

Since we have described the geology of this area previously (Day 02) we will keep it brief. The crater name means "House of a'mau ferns". OK, that's it. Look at the picture Figure 78) and hum along with us – "Halema'uma'u, Halema'uma'u, Halema'uma'u, Halema'uma'u, poppa ooh mau mau".

Figure 78 – View of Halema'uma'u pit crater from the back porch of the Volcano House. (CM digital image taken 24 July 2007.)

Questions to sputter over – time to look smart here:

1. The descent to the crater trail begins at Volcano House. Locate yourself on the map. Why is there no volcanic cone here?

2. What evidence can you cite of recent volcanic activity on the trail down to the crater?

3. Why are the crater walls along the trail so steep?

4. What kind of fault is present? Make a quick sketch below.

5. In which compass direction does this fault face?

6. What other evidence of faulting or earthquake activity can you observe?

7. What are the origins of horsts and grabens? Sketch and label each type below.

8. At the bottom of the trail, what type of lava flows do you observe?

9. What is the origin of the large polygonal plates on the crater floor?

10. How do you distinguish between older and younger lava flows? How are they different?

11. What is the origin of a lava rampart? Make a quick sketch below.

12. What are the dome shaped structures and how do they form?

13. Look for and sketch the ‘Uwekahuna Laccolith on the northwest wall of the crater. Is this an intrusive or extrusive feature?

14. Refer to the Kilauea geologic map and legend. (See Figure 22.) What is the year of formation of the oldest and youngest lava flows?

15. What is the name of the tan cinder cone observed to your left as you walk the trail?

16. With what volcano is it associated?

17. Using the geologic map, locate Kilauea Iki,Volcano House, and the Jaggar Museum. On what lava flow are you standing?

Hilina Pali Road Excursion

So structure fans, here's Merguerian's chance to qualify his existence on the trip with a few (probably very few) astute comments regarding the structural geology. Recognizing "what he doesn't know he makes up", pay close attention so that you can try to ask the tough questions he can't answer.

Hilina Pali Road in Hawaii Volcanoes National Park (HVNP) leads 8 miles southeast from Chain of Craters Road to the Hilina Pali Overlook perched atop Hilina Pali, a 1700' extensional fault scarp accommodating the seaward gravitational collapse of Kilauea's unstable south flank. By now, Okulewicz' blender has caused an unstable flank in many of our students. A pali, by the way, is a high cliff, a common sight throughout the Hawaiian Islands. Many palis are slump headwalls, just like Hilina. The things we will encounter here should include:

Koa'e Pali, a set of north-facing normal fault scarps
Kipukas, including the large, 1,100-year-old Kipuka Nene
Hilina Pali, a system of south-facing normal fault scarps
Lots of other **nenes**, and,
Nice views of the southeast coast from the top of the **pali**

Forgotten Faults

Most visitors to Hawaii Volcanoes National Park have driven down the Chain of Craters Road to the coast and observed the high south-facing pali that form the Hilina fault system of Kilauea Volcano (Figure 79). These active faults border huge blocks of the volcano that occasionally move downward and seaward in jumps of a meter (3') or more at a time, accompanied by large earthquakes. In west Hawaii, the pali on the north side of Kealakekua Bay is a good example of an active fault that strikingly resembles those in the Hilina system. Over time, the earthquakes and downslope movement have induced major submarine landslides that have displaced real estate and built broad aprons of debris in the surrounding ocean (Figure 80).

A lesser known and under-appreciated set of active faults and gaping ground cracks is the Koa`e fault system on Kilauea. From the Chain of Craters Road to the hair-pin bend near Kipuka Nene, the Hilina Pali Road winds its way around fault-formed pali and across open cracks. The zone of faults is more than 3 km (2 miles) wide and 15 km (9 miles) long, reaching from near Mauna Ulu to the southwest rift zone at the Kamakai`a Hills. Most of the pali face north, toward the summit of the volcano; the most prominent is 15 m high (50' high) Kulanaokuaiki Pali, which forms the southern boundary of the Koa`e fault system (Figure 81). The faults continue into the east and southwest rift zones, where they merge with eruptive fissures (not unlike those uncomfortable fissures experienced by CM in the week-long sitting and writing marathon that produced this guide).

Faults in the Koa`e are active. Parts of the fault system have cracked and been tossed up and down during big swarms of earthquakes several times during this century. The largest historical episode of cracking took place on Christmas Eve and Day 1965, when the Hilina Pali Road at its crossing of Kulanaokuaiki Pali was broken vertically more than 2.4 m (8'). The pali itself leaped up about 75 cm (2.5'), and the flat ground north of it sank about 1.8 m (6'). As USGS observers Dick Fiske and Bob Koyanagi wrote, "At 0840 [Christmas Day] the area was wrenched by an earthquake so violent that it nearly toppled a vehicle parked nearby, and the crack [at the foot of the pali] abruptly opened to about 1.5 m (5')." Cracks and faults continued to move for another two days.

Occasionally eruptions take place from vents near both ends of the Koa`e fault system. The most recent was in 1973 next to the east rift zone. For the most part, however, the Koa`e serves as a non-eruptive "bridge" connecting the two rift zones. The rarity of eruptions is probably why this remarkable fault zone, a key to understanding the growth of Kilauea, is so forgotten. Why go there when you can see liquid lava elsewhere?

From geologic studies we know that the Koa'e fault system has been active for at least the past 1,100 years and probably much longer. Numerous cracks totaling 18~34 m (60' to 110') in width cut 400-year-old lava flows in the Koa'e south of Kilauea's caldera (Figure 82). Other measurements suggest that similar cracking probably also took place repeatedly between 1,100 and 400 years ago. Strangely, the far western part of the fault system has not moved recently; here, unbroken beds of ash erupted in 1790 cover older cracks.

Figure 79 – Halina Pali fault scarp and tilted fractured lava in foreground. (CM digital image taken 29 July 2007.)

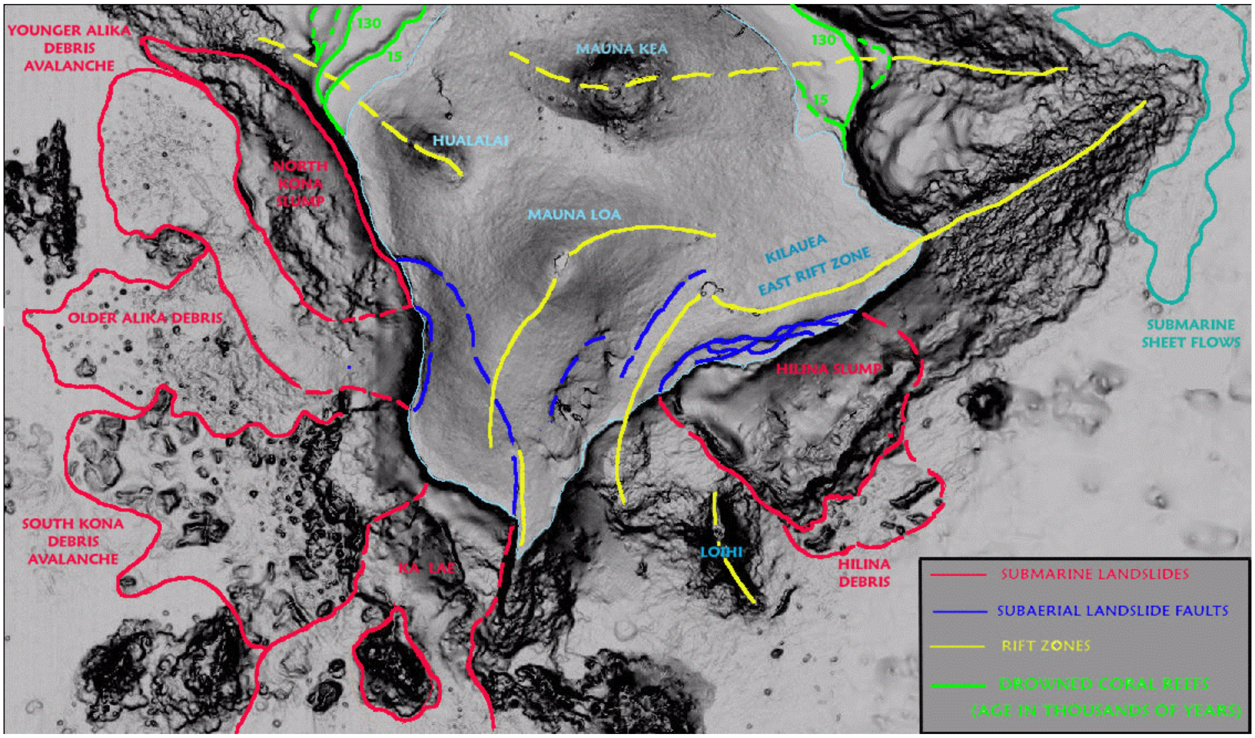


Figure 80 - Side scan sonar image of submarine landslides off of Hawaii. (From www.uhh.hawaii.edu/~kenhon/GEOL205/petrology/default.htm.)

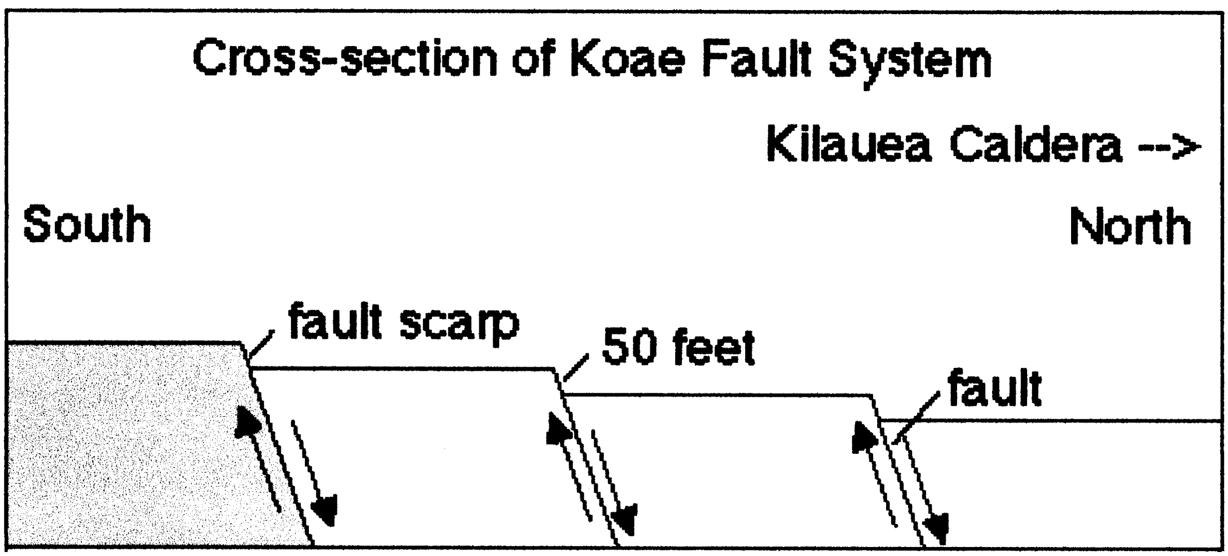


Figure 81 - Diagram of north-facing gravity faults of the Koa'e fault system of Kilauea Volcano. (From www.uhh.hawaii.edu/~kenhon/GEOL205/petrology/default.htm.)

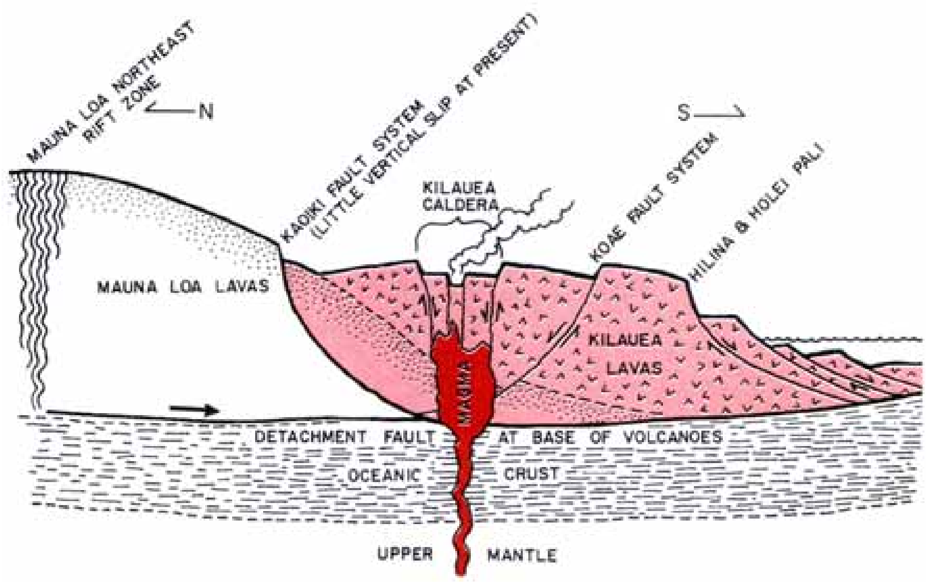


Figure 82 - Cross-section showing faults between Mauna Loa and Kilauea. (From Hazlett and Hyndman, 1996.)

The origin of the Koa`e fault system is controversial, but many geologists believe it to be related to the splitting of Kilauea along the east and southwest rift zones as the volcano is driven apart by a combination of gravitational collapse and magma wedging into the rift zones. That process is episodic, not continuous. At present, the Koa`e is simply sitting on the southern part of the volcano, which is rafting seaward. But eventually the rocks will break, the faults will move, and a new round of repairs will be due on the Hilina Pali Road. Certainly, landslides have had an important effect in building up submarine aprons on the islands as described in an earlier section.

One interesting thing to note about the Koa'e fault is that it appears to be a backwards or reverse fault. Most faults on Hawaii slip lower towards the ocean, as if the ground is sinking into the ocean. This fault, however, is lower on the side facing away from the ocean - completely the reverse of what one would expect. This indicates that either the higher ground rose, or the ground you are driving on sunk. While there is probably a combination of both factors - you will notice as you drive through here that you seem to be in a depression or slight bowl. This would lead one to suspect that the area you are driving through actually sank. How does that graben you?

Sources: http://www.cliffshade.com/hawaii/hilina/index.htm and http://hvo.wr.usgs.gov/volcanowatch/1997/97_02_07.html

Kindly answer these questions in the field and promise NOT to grandstand in front of CM:

1. What has caused the abundance of open fractures in the ground across from the campsite area?

2. Look carefully in the rock crevices. What is and what was the origin of the fine black glassy filaments?

3. What is the relationship between the Koa'e Fault Zone and the East Rift Zone?

4. Explain the possible origin of the Koa'e Fault System and the bend of the East Rift Zone.

5. Which way does the Koa'e fault face? How does this control the coastal topography?

6. What geologic structure accounts for these cliffs to be so steep and high?

7. What is the ultimate fate of this entire volcano?

Lua Manu Crater

Lua Manu crater (Figure 83) formed in 1790 and partially filled during the July 1974 fissure flow which is not visible but can be found 600 feet NW of the road. Follow the trail to lava trees and see if you can find charcoal in some. Look for drain back features and spatter ramparts across the road.

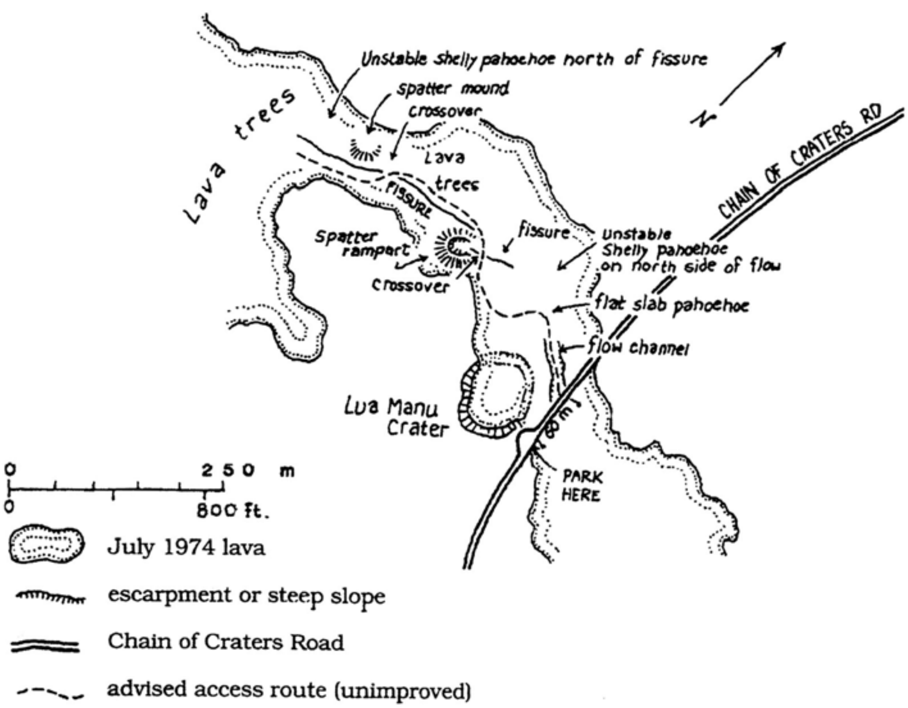


Figure 83 – Location map of Lua Manu crater and lava types. (From Hazlett, 2002, Fig. 32, p. 99.)

These questions are the pits:

1. Locate yourself on the above map (Figure 83). What is the origin of this volcanic rift zone?

2. What is the origin and age of these pit craters?

3. What is the age of the Lua Manu crater relative to the 1974 eruption?

4. From which direction did the lava flow during the 1974 eruption? How do you know?

5. Explain how lava trees and lava tree molds developed here.

6. What characteristic of the ‘Ohi’a tree enhances their preservation in the lava?

7. Across the road from the parking lot are several small spatter cones. Examine them and explain how they formed.

Pauahi Crater

Pauahi Crater (meaning “burning house”) is located approximately 3 miles along Chain of Craters Road and is one of its more impressive features (Figure 84). This depression is 2,000 feet long (610 m) and about 300 feet deep (90 m) with 2300 mm annual precipitation. Three eruptions have occurred near Pauahi Crater in historical time. The first was in May 1973, when a fissure erupted briefly on the floor of the crater. The November 1973 eruption lasted a total of 31 days (10 November to 09 December) but most of the activity was during the first 10 hours of the first day. Two fissures opened in Pauahi Crater within minutes of each other, and lava began to pool in both the east and west pits of the crater. The crater consists of three separate pit craters. Two make a figure-8 that is 1,650 feet long and 360 feet deep. Lava flowed from the bottom of the crater in 1973 and 1979 and in 1975 the 7.2 M (Kalapana) earthquake and 6.6M quake (Ka’oiki) of 1983 created landslide rubble at the bottom of the crater. The latest eruption from crater floor was during the 1979 eruption when lava whirlpools where observed here.

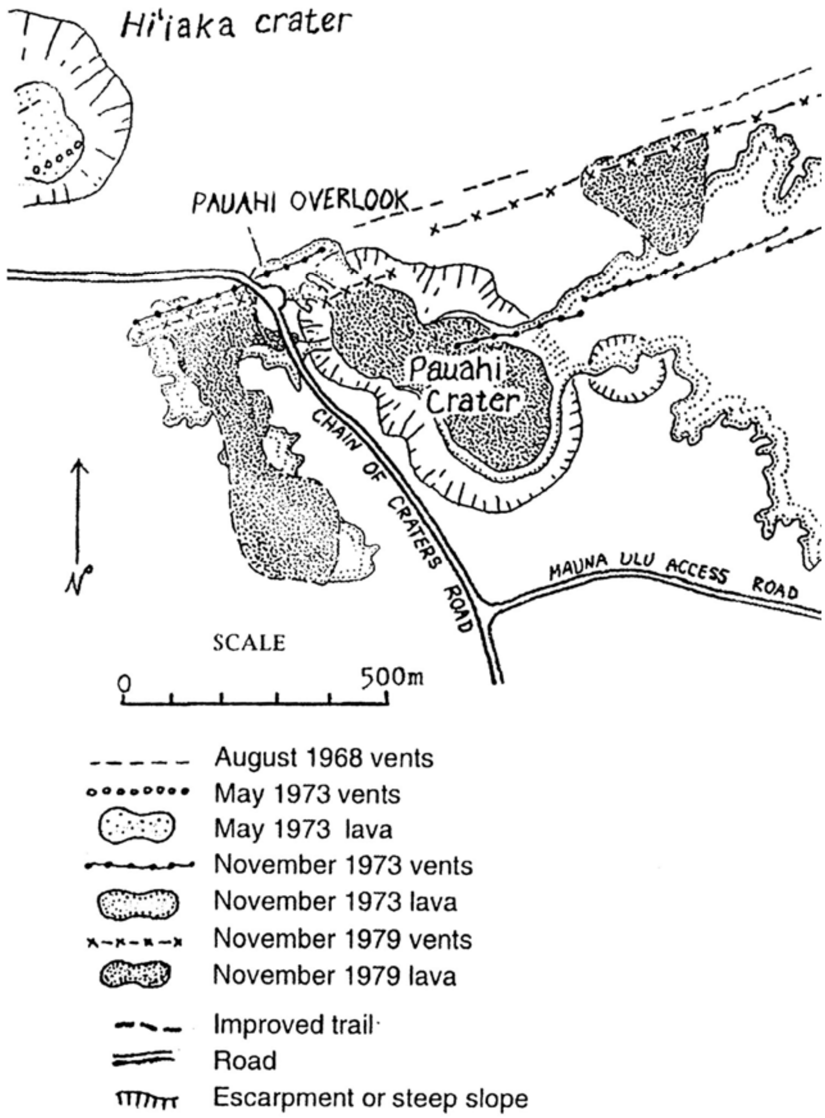


Figure 84 – Location map showing Pauahi Crater and vicinity. (From Hazlett, 2002, Fig. 35, p. 105.)

The lava not only flowed in from the fissures but also erupted from the crater itself and created a huge lava lake at the bottom of the crater. A set of en echelon fissures extended from just west of the crater, across the crater floor, and east of the crater almost to Pu'u Huluhulu, a total distance of about 2 miles (3 km). The November 1979 eruption lasted only 1 day and was preceded by swarm of small earthquakes started abruptly on 15 November. During the peak of the swarm, as many as 20 earthquakes per hour shook the ground beneath the Pauahi Crater area. As with many of the other craters, Pauahi Crater holds religious significance to the Hawaiians. Often you will see Ti leaf wrapped packages, fruit, leis or other gifts sitting near the edge of the crater. These are gifts to the crater and the gods and should not be disturbed.

Sources: http://www.brainygeography.com/features/HI.crater/pauahicrater.html and http://www.volcanolive.com/pauahi.html

Mauna Ulu hike (Time Permitting)

Before the current activity on Kilauea's east rift zone, the most long-lived rift eruption was that of Mauna Ulu (Figures 85 and 86), which began 25 years ago, on May 24, 1969. This eruption lasted until July 24, 1974. There were two main parts of the Mauna Ulu eruption, separated by a hiatus between October 1971 and February 1972. The first half of the eruption lasted roughly 2.5 years and produced an estimated 185 million cubic meters of lava (about 240 million cubic yards). The second half of the eruption lasted another 2.5 years and produced an additional 160 million cubic meters of lava. The lavas erupted between 1969 and 1974 from Mauna Ulu, and closely associated vents covered 17.6 square miles and added about 230 acres of new land to Hawaii.

The eruption at Mauna Ulu began on May 24, 1969, and, like the eruption of Pu'u 'O'o, the earliest part was characterized by episodes of high fountaining until December 1969, with fountains reaching heights of nearly 1,800 feet. The next stage of the eruption was passive effusion of lava from a new fissure just west of Mauna Ulu, then a new fissure just east of Mauna Ulu near Alae Crater. This quiet, effusive phase of the eruption was similar to that which took place at Kupaianaha from July 1986 to February 1992. The main differences are that Kupaianaha was located farther away from Pu'u 'O'o than the Alae fissure was from Mauna Ulu, and that this phase of the current eruption lasted much longer.

Starting in June 1971, the surface of the lava pond inside Mauna Ulu began to drop, and the summit area of Kilauea simultaneously began to inflate (uplift) as additional magma entered the summit magma reservoir. A brief eruption took place inside the summit caldera just east of Halema’uma’u during August 1971, and another took place inside the caldera and along the southwest rift zone in late September 1971. By October 15, lava could no longer be seen inside Mauna Ulu Crater, and the first part of the Mauna Ulu eruption was over. However, magma continued to enter the volcano, as seen by rapid inflation of the summit region. No eruptions took place for 3.5 months, but by February 3, 1972, lava quietly reentered the Mauna Ulu Crater and the second half of the eruption was under way.

During the 1972-1974 part of the eruption, activity was confined to Mauna Ulu and a satellitic shield at the former site of Alae Crater, except for two fissure eruptions along the upper east rift zone - - one near Pauahi Crater in May 1973 and the other near Pauahi and Hi’iaka Craters in November and December 1973. An eruption in the uppermost east rift zone near Keanakako’i Crater and within the summit caldera from July 19 to 22 marked the end of the Mauna Ulu eruption, but not the end of activity at Kilauea, since there followed a second summit eruption in September and a large southwest rift eruption that started on the last day of 1974. After each of these eruptions, the summit of Kilauea again inflated as magma continued to arrive and swell the magma reservoir beneath the summit. The summit deflated catastrophically during a magnitude-7.2 earthquake that occurred on November 29, 1975. This earthquake moved the south flank seaward and created a large underground volume in which additional magma arriving from below could be stored. Eruptive activity did not resume on Kilauea until 1977.

Figure 85 – View of Mauna Ulu crater. (Unknown Web Contributor.)

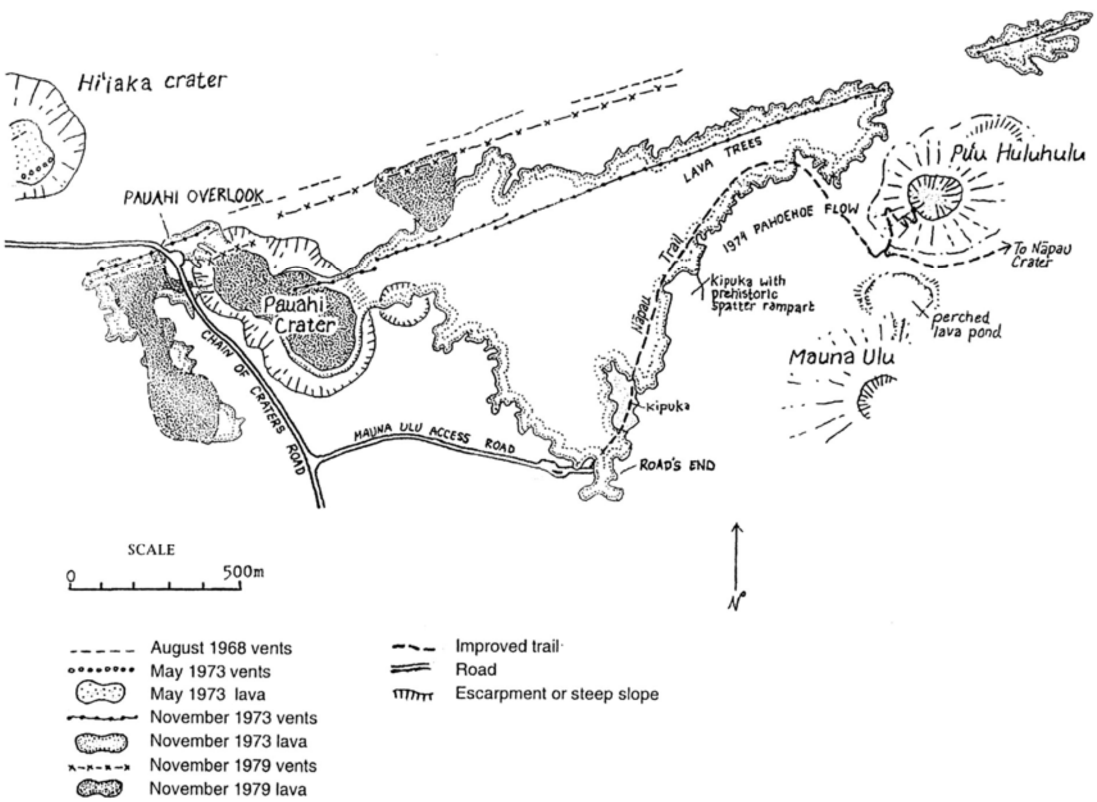


Figure 86 – Location map. (From Hazlett, 2002, Fig. 35, p. 105.)

The Mauna Ulu eruption is important because it is our best (and only!) previous example of a long-lived rift eruption. The sequence of events that occurred at Mauna Ulu provides us with some insight into how the current eruption may eventually end. The current eruption is the most long-lived rift eruption on Kilauea in historic time; it began on January 3, 1983 and is now in its twelfth year of nearly continuous activity. Several major phases of the eruptive activity, starting with an initial period lasting from the start of the eruption until July 1986, characterized by periodic high-fountaining events built the Pu'u 'O'o cinder and spatter cone.

This phase of activity was followed by development of a new vent, Kupaianaha, located several miles down drift from Pu'u 'O'o, which passively issued tube-fed pahoehoe flows from July 1986 until February 1992. These flows covered a large area, including the village of Kalapana, and entered the sea for several years. Since late 1991, five additional vents have formed, with the last four located on the south and west flanks of the Pu'u 'O'o cone. The first was a fissure eruption between Kupaianaha and Pu'u 'O'o. The currently active vents have erupted primarily tube-fed pahoehoe flows that have entered the ocean nearly continuously since November 1992. During the nearly 11.4 years of the current eruption, approximately 1 cubic kilometer of lava has erupted, about 34 square miles of land has been covered by lava, and about 500 acres of new land have been added to Hawaii.

There are similarities between events at Mauna Ulu and those at Pu'u 'O'o-Kupaianaha. Each eruption began with a period of high fountains, and each evolved into a passive, effusive eruption. The first half of the Mauna Ulu eruption ended following a decrease in eruptive output and a decrease in the level of the lava pond in Mauna Ulu, despite the continued addition of magma into the summit reservoir. When Kupaianaha shut down in 1992, the lava volume also decreased slowly over time, and the summit of Kupaianaha collapsed (indicating a withdrawal of magma and drop in the magma level under the crusted-over vent), despite the continued addition of magma into the summit reservoir. In addition to the inflation seen at the summit, the lava pond inside Pu'u 'O'o rose. The shutdown at Kupaianaha after slightly more than nine years of eruptive activity may be similar to the end of the first half of the Mauna Ulu eruption that lasted 2.5 years.

Based on the events at Mauna Ulu and at Kupaianaha, we suspect that the end of activity at Pu'u 'O'o will be heralded by a steady decline in lava output coupled with a lowering of the lava pond. However, we also expect the summit to reinflate with magma as the activity at Pu'u 'O'o wanes. Such pressurization of the summit region could result in eruptive outbreaks further up the east rift zone from Pu'u 'O'o, at Kilauea's summit, in the southwest rift zone, or in any combination of these locations. Eruptions occurred at all three places as Mauna Ulu activity waned in 1974. However, at the present time, we see no signs suggesting that the current eruption is slowing down.

Source: http://www.cr.nps.gov/history/online_books/hawaii-notes/vol4-2-7k.htm

About time we heard some hot answers, no?

1. Locate yourself on the map (Figure 86). Of the two existing lava flows here, which is older: the pahoehoe or the ‘a’a? How do you know?

2. Using the lava type table in Appendix 1, which lava type moves the slowest and the fastest?

3. What is the green mineral in the younger flow?

4. As the trail bends to the south east by Pu’u Huluhulu, go a short distance north of the trail and describe what feature occurs here.

5. What is the origin of the odd-shaped and isolated basalt mounds?

6. Which lava type forms the highest mounds? What causes this to occur?

7. What kind of cone is Pu’u Huluhulu?

8. The summit of Pu’u Huluhulu contains a crater. What is its origin? What is the evidence?

9. What is the classification of Mauna Ulu’s cone?

10. Briefly describe the formation of a perched lava pond.

11. Where was the final stop for the lava from Mauna Ulu?

12. To the east (left) of the Mauna Ulu lava shield is Pu’u ‘Oo. What causes the steam to erupt?

Day 08 – Monday 30 July – HVNP

Basalt Petroglyphs

Some of the most spectacular rock art in the United States is found throughout the Hawaiian Islands. This unique and well made rock art is very different than the rock art found on the continental U.S. and yet there are similarities in subject matter that indicates a common oneness between diverse ancient cultures. Hawaiian petroglyphs are carved into pahoehoe lava rock, basalt boulders, cliff faces and sandstones that usually occur in shades of brownish gray and are usually carved deep into the rock.

We will engage in a roughly 2-mile roundtrip hike here to see over 15,000 carvings into pahoehoe. Common subjects of Hawaiian petroglyphs are canoes, canoe paddles and sails; stick figure and solid body anthropomorphs, family groups- males, females and smaller images representing children; supernatural images of humans with horns, bird heads or wings; dogs, turtles and chickens are found, but fish petroglyphs are extremely rare; and cryptic symbols made from curving lines, dots, circles and shapes... all of which are often combined and superimposed on one another. Over 7,000 cuplike holes were made to hold the umbilical cords of newborns which translates into long life for babies. A cup surrounded by a circle means family. Amazingly, blender petroglyphs, with the initials SCO and friends, have been found in the last few years (Figure 87).

Figure 87 – Five views of Hawaiian petroglyphs including a recently discovered blender petroglyph.

Day 09 – Tuesday 31 July – Lava Tube Spelunking and Chain of Craters Road

Kazumura Cave Exploration

Kazumura Cave (Figure 88) is a very recent discovery. In the mid 1990s several known lava tubes and some new discoveries were connected to one big cave. So today Kazumura Cave is the longest lava tube in the world, more than 60 km long. It is the deepest cave of the USA and the eighth longest. The second deepest cave of the USA is still a lava tube of Hawaii, Huehue Cave. This cave is rather young, the lava flow and formation of the caves happened only about 350 to 700 years ago. The lavas formed from tholeiitic basalts of the Aila'au lava shield associated with Kilauea and Kilauea Iki.

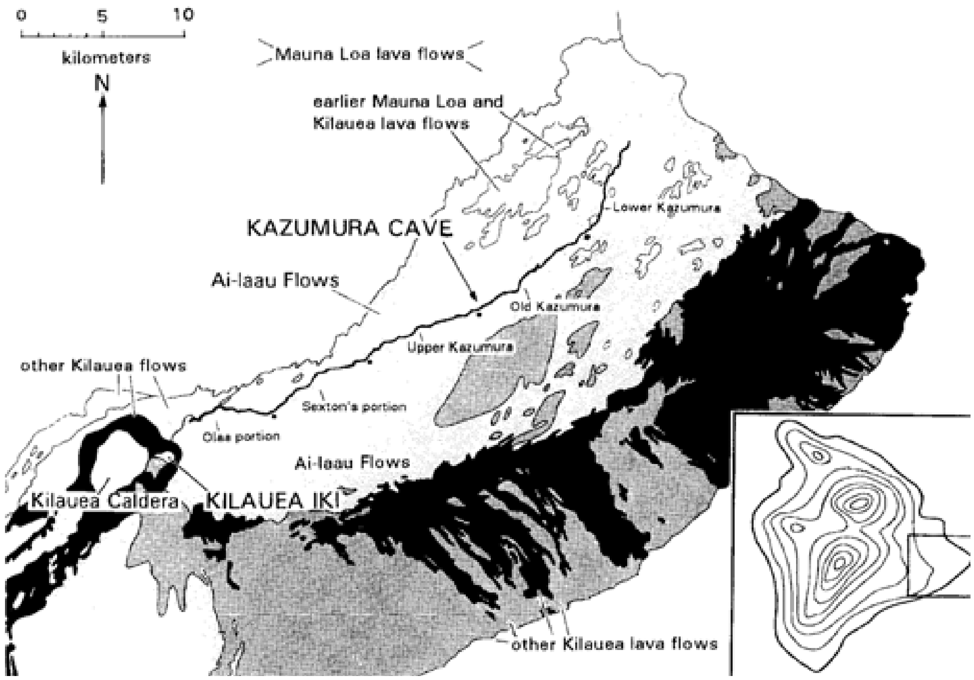


Figure 88 - Lava flow boundaries according to Holcomb (1987) showing Kazumura Cave and its five portions.

Kazumura Cave is, at 65,500 m (40 miles) the longest and at 1,101 m (3,614') the deepest lava tube in the world. It is located on the northeastern slope of Kilauea, the southeasternmost and most recently active volcano on Hawaii. Although this cave is still being explored, the most recent important discoveries were made during the 1990s - when several small caves were discovered to be connected to it. Despite Kazumura not being a commercial cave, limited tours are given by a local caver. The tube contains all kinds of lava formations, such as **lava falls**, **lava blades**, **tubular lava stalactites**, **stretched lava**, and **lava plunge pools**.

About 500 years ago, Kilauea Iki, a crater on the east side of Kilauea Volcano Caldera, started to erupt. Lava from the crater began to flow down the north east flank of the volcano toward the sea, 25 miles away. As the lava covered more and more of the surface, channels started to form in the flow. These channels allowed the bulk of the flow to be carried downstream more efficiently. Levees would then begin to build up on the sides of the channels followed by the crusting over of the top. When the crusting over was complete, the channels became a lava tube.

Lava traveling through a tube is insulated against the cooling effects of the air and can travel great distances with little heat loss. If you could see lava flowing through a lave tube, it would appear to be very fluid; but in reality it is a river of molten rock that has the consistency of wet concrete. Like wet concrete, lava is very abrasive. The walls and floor of the tube are heated to a putty-like consistency and then gouged out by the flow. In this way a lava tube can become deeper and wider. Given enough time and favorable conditions this down-cutting can create canyons and lava falls. Lava can also be forced into cracks or holes in the rock. This could possibly speed up the process of enlarging the tube.

Sometimes when lava has been injected into the walls or ceiling it will just remain there until the lava level in the tube begins to drop. At which time lava will ooze or gush from these holes and can create soda straws or soda straw like formations called **vermiform**, meaning worm-like. If during an eruption a hole develops in the ceiling of a lava tube (Figure 89), the hole is called a **skylight**. A skylight allows heat to escape from the tube and cold air to be introduced. This cold air can cause the lava in the tube to crust over creating a tube within a tube.

As lava levels in the tube drop; dripping from the ceiling can produce **lavacicles**. As lava levels drop further and the tube begins to drain, air from outside begins to rush in. At this point yet another tube in a tube is formed. Lava flowing over the falls is already cooling to a puttylike consistency and begins to pile up upon itself forming an irregular column called a **dribble spire**. Thick crusts form over the plunge pools at the base of lava falls and then begin to sag as lava drains away from beneath, unable to support it own weight. The last tubes to form also begin to collapse without lava to support the weight of their crusts. Cool air cracks the hot surfaces and in places, rocks fall from the walls and ceiling.

It can take years for a lava tube to cool. Plants and insects will have already begun recolonizing the surface. When the tube finally does cool enough to support life, insects will find their way into the newly formed cave.

Kazamura Cave Tour Visitor Information

Dress appropriately:

Hiking Boots or some other well made shoe is required. Hard-hats, gloves, and flashlights are provided. Lava is sharp and will slice up your feet if they are not covered. Long Pants can protect your legs in the event you trip and fall, or walk to close to a sharp rock. Jacket (optional). The cave temperature is 61°F and wet. Water drips all the time in places, more when it rains. All visitors must be able to climb/descend a ladder! Be on time or early. If you arrive late, you may find the group has left without you OR if your party fills the tour, you may not be able to see as much as you would like because your guide needs to get back for the next tour.

All visitors are asked to observe two rules while visiting the cave:

1. **Please Do Not Touch Anything!** All lava formations are irreplaceable. Many are quite fragile. When a lava formation is damaged or broken, it is damaged or broken forever. It will NEVER grow back! Crystals found in Lava Tubes are also quite fragile so please do not touch anything.

2. **Please Do Not Remove Anything** from the cave so the cave can be preserved for future generations.

Sources: http://en.wikipedia.org/wiki/Kazumura_Cave, and, http://www.fortunecity.com/oasis/angkor/176/

Figure 89 – View of Kazumura Cave. (Unknown Web Contributor.)

Chain of Craters Road Excursion

Tours are limited to six people and last about 3 hours. We'll take it in two shifts with alternate groups touring the pit craters, lavas, and sea arch along and at the terminus of Chain of Craters Road.

Day 10 - Wednesday 01 August – Kau Desert and Punaluu Harbor

Kau Desert Hike

Vast, rural dry, windblown, remote and friendly—that pretty well describes Hawaii Island’s southernmost region, which lies about an hour from the Hilo airport, and two hours from the Kona airport. Kau seems almost untouched by civilization except around the well-kept little communities of Naalehu and Pahala.

Don’t take the 12-mile drive off the highway to Ka Lae (also called South Point) just because it’s the southernmost point in the United States — do it because it’s a remarkable place brimming with beauty and history (Figure 90). Here, where the sea crashes against the rugged cliffs, ancient loops carved into the lava hundreds of years ago to tie off fishing canoes are evidence of the old ways’ survival—as are today’s fishermen reeling in ulua (crevalle) and other deep-water fish from cliff’s edge. The future is here at Ka Lae too in the form of a field of giant, graceful, white windmills generating electricity. Back up the road at Punaluu, the black sand beach offers a dramatic setting for sunbathing sea turtles.

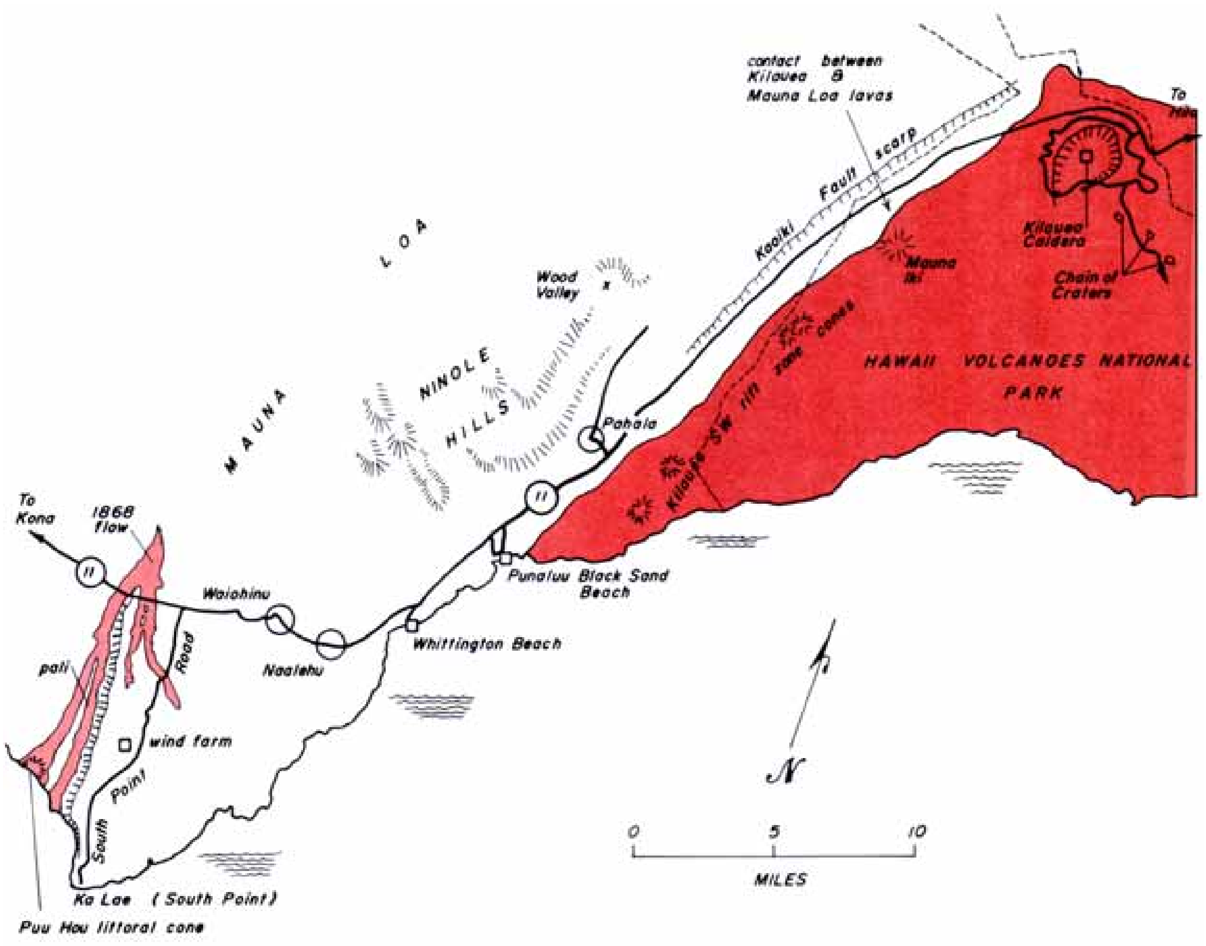


Figure 90 – Location map showing major features along the Mamalahoa Highway between Volcano and Ka Lae. (From Hazlett and Hyndman, 1996, p. 96.)

The district rises inland to the upcountry Kau Desert within the boundaries of Hawaii Volcanoes National Park. Here one of Kilauea's rare explosive eruptions has left the footprints of long-ago warriors trapped in volcanic ash. Taxing trails crisscross the land, from the mountains to the sea, daring backpackers to trek into wilder Hawaii. But all is not raw and dry in Kau. On the eastern slopes, there are macadamia nut orchards, cattle and a Buddhist retreat. Wood Valley, near Pahala, is a place for meditation and respite from the outside world. No wonder Kau is home to not only Hawaiian families who have been here for generations, but also writers, artists, philosophers and others seeking solitude. Original blender research was conducted here in antiquity.

The Kau desert is in the rain shadow of Kilauea volcano and receives very little rain (about 75 cm/yr or 30 inches/yr). Its barrenness also has very much to do with sulfur dioxide escaping the vents in the crater and blowing downwind. Sulfur dioxide combines with water to form sulfuric acid which falls as acid rain which creates a harsh, acidic environment.

The 1790 eruption

In 1790 occurred one of most devastating explosions in recorded Hawaiian history. The eruption produced accretionary lapilli tuff, which is fine volcanic ash that into forms tiny balls as a result of eruptions that involve water. At that time Chief Keoua was traveling around Kilauea to Kau to oppose the dominant chief, Kamehameha. At least 80 Hawaiian warriors suffocated from volcanic ash getting into their lungs. The footprints of these warriors are preserved in the ash.

The Kau Desert is dominated by aggradational processes. Periodic phreatic eruptions of Kilauea caldera have emplaced the Keanakako'i tephra, which is >5 m thick in places. Although the Kau Desert receives 130-30 cm of rainfall annually, the high permeability of the tephra and high evaporation rates support only occasional overland flows. Partially buried or exhumed lava flows are oxidized, but typically only the upper glassy layer has been removed. Other geologic processes that we observed include rocks deposited by Kilauea phreatic eruptions which may be analogous to impact cratering, rocks emplaced by overland flow, and rocks modified by wave action.

Source: http://www.bigisland.org/maps-regions/205/hawaii-map-kau

Questions on the last day? What's up with that!

1. Locate the Kau Desert in Figure 90 (above). Why is this area classified as a desert in Hawaii?

2. Compare the vegetation at this locality with that of Lava Tree State Park.

3. What type of fault is the Ka'oiki Fault? Make a sketch below.

4. What is a possible origin of the November 1983 earthquake?

5. Under what condition can pahoehoe lava can change into ‘a’a lava, but not the reverse.

6. What conditions allowed the preservation of the Hawaiian warrior footprints from the 1790 eruption?

7. In what type of material does footprint preservation occur?

8. What is the origin of the lava balls and where did they come from?

9. Make a quick sketch of the contact of the lava flows from Kilauea, Mauna Loa, and the 1790 flows.

10. Using relative geologic time, describe the sequence of events that created these flows.

11. What are pisolites and how do they form? Make a quick sketch.

Punaluu Harbor

Punaluu Beach is the most famous, most visited and easiest to access black sand beach on the Big Island. A trip to this stunning place requires about an hour drive from Hilo. Located in the far off Kau District, Punaluu Beach is located just of Highway 11, between the towns of Na’alehu and Pahala (approximately 4 .5 miles from either town). There are two access roads with well-marked signs for Punaluu Black Sand Beach/Sea Mountain Resort, so if you miss one turn, there will be another coming up in less than a mile.

Punaluu Beach is a popular site and you will not have it to yourself. With this said, you can be one of the few souls here if you come early in the day. This is the best time to avoid the crowds while getting to see the other main attraction at Punaluu...the Honu (sea turtles).

The sand here is truly black. Not gray or salt and pepper, but a deep, pure jet black. The blue Pacific Ocean breaking on the black sand is an amazing sight. The sand can get hot, since it is usually sunny in the Kau District. If so, there are plenty of beautiful, swaying coconut palms under which to spread your towel. Jumping into the ocean is a matter of taste. The water is typically pretty chilly, since the bottom of the bay has many fresh-water springs pumping cold water into it. Also, the water can be very rough. So, if you think a dip will be refreshing, you are probably correct, but beware of the surf. If there is no one else in the ocean, it is safest to refrain from going in yourself.

When the sea is calm, there is always the opportunity to swim or snorkel with the turtles. This is one of their favorite spots and early in the day there can be many of them paddling around, or sprinkled along the shore, resting after a seaweed breakfast. Photograph these beautiful and gentle creatures to your heart's content, but do not touch them. Turtles are an endangered species and it is illegal to touch or harass them in any way as they maintain legal representation.

South Point Olivine Sand Beach (Time Permitting)

One of South Point's most famous scenic spots is Mahana Beach, also called Green Sands Beach because it has a distinctive golden green color (Figure 91). "The grains of green sand are olivine (or call it peridot if you wish although not much of the sand is truly of gem quality), a common mineral in much of the Hawaiian basalt, and as the basalt undergoes weathering the olivine becomes concentrated on this beach due partly to its high specific gravity." (They are apparent as green flecks in the raw lava stones used to build the columns and walls of the Jagger Museum at Kilauea's Volcano National Park.) As lava reached the coast, erosional forces, and the specific gravity of the stones, perhaps are responsible for the accumulation of such a large quantity of the granules that produced the green sand beach.

Figure 91 – View of green sand beach at South Point. (Unknown Web Contributor.)

Acknowledgements

No endeavor of this scope is possible without the help of many individuals and agencies. CM would like to thank **Dr. Janice Koch** and **Eloise Gmur** of the IDEAS Institute and **Dean Steven Costenoble** of Hofstra University for their direct help in the logistical planning for air and ground travel and for our overnight accommodations and for their support of this field program. We are both indebted to **Professor Andy Ohan** of the College of Staten Island for sharing his knowledge of the geology of Hawaii. The assistance of the **National Park Service** in granting admittance into Hawaii Volcano National Park is gratefully acknowledged. In addition to these individuals and agencies, the staff at Duke Geological Laboratories and especially **H. Manne Vb** and **Mr. Jenkins** have been instrumental in completing the guidebook in a timely manner.

Since confession is good for the soul, existing textbook and web resources were used extensively in the preparation for this guide and some areas of text were cut and pasted in true plagiaristic style. In this connection, special thanks are due Hofstra Geology major and CM's special lab assistant, **Ms. Hallie Thaler** for her spectacular help in downloading and organizing pertinent web material over a two month period. None of these trips would have been possible without the assistance and spiritual fortitude of the late **Mr. John Gibbons** of Hofstra University who first implored CM to organize and conduct such undertakings. To his lasting memory and to the zeal that his self-education in Geology bore fruit, this field trip program and guidebook are respectfully dedicated.

Appendix 1 - Geologic Structure (a Primer)

Geologists use terminology to confuse the layman and to enable them to amass a huge library of terms that are undeniably useless in most social situations. Luckily, our Geology classes and field trips are an exception. We will not try to bury you in a mountain (how about a deeply eroded mountain range?) of terms to help you understand the major types of structures and geologic features that you will read and hear about on your field trip to Hawaii. But, if you are to understand what we are talking about, you need to know some important definitions. In the following section, we describe folds, faults, surfaces of unconformity, sedimentary structures and volcanic features. Be sure to consult Appendix 2 for a glossary of geological terms.

We begin with some concepts and definitions based on the engineering discipline known as **strength of materials**. Given today's sophisticated laboratory apparatus, it is possible to subject rocks to temperatures- and pressures comparable to those found deep inside the Earth.

Imagine taking a cylinder of rock out of the Earth and torturing it in a tri-axial compression machine to see what happens. Some geologists get a big charge out of this and tell us (the field geologists) that they really understand how rocks behave under stress. [CM thinks they need to perform these experiments over a longer time frame than a few generations of siblings will allow and thus relies more on field observation and inference than from rock-squeezing data to gain a feel for the complex nature of how rocks are deformed in nature.]

Despite the limitations of the experimental work, measurements in the laboratory on specimens being deformed provide some fundamental definitions. One key definition is the **elastic limit**, which is the point at which a test specimen no longer returns to its initial shape after the load has been released. Below the elastic limit, the change of shape and/or volume (which is known as **strain**) is proportional to the stress inside the specimen. Above the elastic limit, the specimen acquires some permanent strain. In other words, the specimen has "failed" internally. Irrecoverable strain manifests itself in the distortion of crystal lattices, grain-boundary adjustments between minerals composing the rock, and minute motions along cleavage- or twin planes.

When differential force is applied slowly (or, according to CM, over long periods of time), rocks fail by *flowing*. This condition is defined as behaving in a **ductile fashion** (toothpaste being squeezed out of a tube is an example of ductile behavior). Folds are the result of such behavior. If the force is applied under low confining pressure or is applied rapidly (high strain rates), rocks do not flow, but *fracture*. This kind of failure is referred to as rocks behaving in a **brittle fashion** (as in peanut brittle). The result is faults or joints. Once a brittle failure (fracture) has begun, it will propagate and may produce offset thus forming a fault surface. Joint surfaces commonly exhibit distinctive "feathers" which show the direction of joint propagation.

In some cases, during deformation, rocks not only undergo simple strain, but also recrystallize. New metamorphic minerals form and newly formed metamorphic minerals acquire a parallel arrangement. More on metamorphic textures later. From the laboratory studies of rock deformation, a few simple relationships are generally agreed upon regarding brittle- and ductile faulting and these are discussed below.

When subjected to differential forces, under high confining pressures and elevated temperatures, rocks (like humans) begin to behave foolishly, squirming in many directions and upsetting the original orientation of primary- or secondary **planar- and linear features** within them. Geologists try to sort out the effects of deformation by working out the order in which these surfaces or linear features formed using a relative nomenclature based on four letters of the alphabet: D, F, S, and M. Episodes of deformation are abbreviated by (D_n), of folding by (F_n), of the origin of surfaces (such as bedding or foliation) by (S_n), and of metamorphism by (M_n), where n is a whole number starting with 1 (or in some cases, with zero). Bedding is commonly designated as S_0 (or surface number zero) as it is commonly overprinted by S_1 (the first foliation). To use this relative nomenclature to describe the structural history of an area, for example, one might write: "During the second deformation (D_2), F_2 folds formed; under progressive M_1 metamorphic conditions, an axial-planar S_2 foliation developed."

In dealing with the geologic structures in sedimentary rocks, the first surface one tries to identify positively is **bedding** or **stratification**. The boundaries of strata mark original sub-horizontal surfaces imparted to sediments in the earliest stage of the formation of sedimentary rock. Imagine how such strata, buried by the weight of overlying strata and laterally compressed by the advance of lithospheric plates, are subjected to the differential force necessary for folds to form. Contrary to older ideas, we now realize that vertical burial cannot cause regional folds (although small-scale slumping, stratal disharmony, and clastic dikes are possible). Rather, resolved tangential force that creates differential stress must be applied to provide the driving force to bring about folds and faults.

It's now time to turn to some geometric aspects of the features formed as a result of deformation of rocks in the Earth. We start with folds.

Folds

If layers are folded into convex-upward forms we call them **anticlines**. Convex-downward fold forms are called **synclines**. In Figure A1-1, note the geometric relationship of anticlines and synclines. **Axial planes** (or **axial surfaces**) physically divide folds in half. Note that in Figure A1-1, the fold is deformed about a vertical axial surface and is cylindrical about a linear **fold axis** which lies within the axial surface. The locus of points connected through the domain of maximum curvature of the bedding (or any other folded surface of the fold) is known as the **hinge line** (which is parallel to the fold axis). This is geometry folks; we have to keep it simple so geologists can understand it.

In eroded anticlines, strata forming the limbs of the fold *dip away from* the central hinge area or core (axis) of the structure. In synclines, the layers forming the limbs *dip toward the hinge area*. Given these arrangements, we expect that in the arches of eroded anticlines, older stratigraphic layers will peek through whereas in the eroded troughs of synclines, younger strata will be preserved.

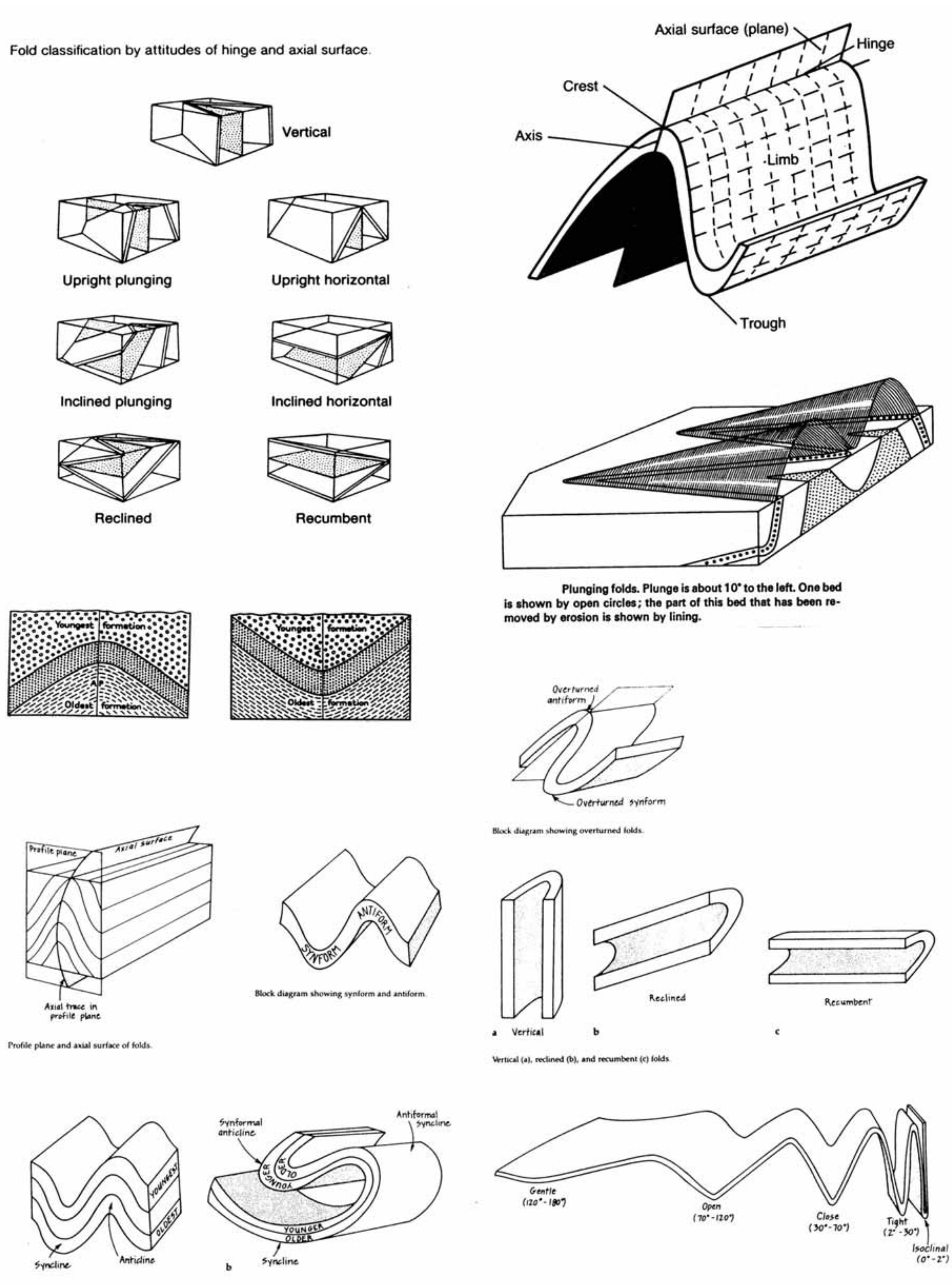


Figure A1-1 - Composite diagram from introductory texts showing various fold styles and nomenclature as discussed in the text.

In metamorphic terranes, field geologists are not always sure of the correct age relationships of the metamorphosed strata. Therefore, it is helpful to make use of the general terms **antiform** and **synform** which describe the folds by whether they are convex upward (antiform) or concave upward (synform) but do not imply anything about the relative ages of the strata within them.

Realize that in the upright folds shown in Figure A1-1, axial surfaces are vertical and fold axes, horizontal. Keep in mind that folding under metamorphic conditions commonly produces a penetrative mineral fabric with neocrystallized minerals (typically micas and amphiboles) aligned parallel to the axial surfaces of folds. Such penetrative metamorphic fabrics are called **foliation**, if primary, and **schistosity**, if secondary. Minerals can also become aligned in a linear fashion producing a **metamorphic lineation**. Such features can be useful in interpreting a unique direction of tectonic transport or flow direction. Because folds in metamorphic rocks are commonly **tight-** to **isoclinal** (high amplitude-to-wavelength aspect ratio) with limbs generally parallel to axial surfaces, a penetrative foliation produced during regional dynamothermal metamorphism will generally be parallel to the re-oriented remnants of stratification (except of course in the hinge areas of folds). Thus, in highly deformed terranes, a composite foliation + remnant compositional layering is commonly observed in the field. Departures from this common norm are important to identify as they tend to mark regional fold-hinge areas.

Folds could care less about the orientation of their axes or axial surfaces and you can certainly imagine that axial surfaces can be tilted, to form inclined or **overturned folds**. Or the axial surfaces may be sub-horizontal, in which case the term **recumbent folds** is used. In both overturned folds and recumbent folds, the fold axes may remain subhorizontal. (See Figure A1-1.) It is also possible for an axial surface to be vertical but for the orientation of the fold axis to range from horizontal to some angle other than 0° (thus to acquire a plunge and to produce a **plunging fold**). Possible configurations include plunging anticlines (or -antiforms) or plunging synclines (or -synforms). **Vertical folds** (plunging 90°) are also known; in them, the terms anticline and syncline are not meaningful. In **reclined folds**, quite common in ductile shear zones, the fold axes plunge directly down the dip of the axial surface.

In complexly deformed mountain ranges, most terranes show the superposed effects of more than one set of folds and faults. As a result of multiple episodes of deformation, the ultimate configuration of folds can be quite complex (i. e., plunging folds with inclined axial surfaces and overturned limbs).

We need to mention one additional point about the alphabet soup of structural geology. Seen in cross section, folds fall into one of three groups, the S's, the M's, and the Z's. Looking down plunge in the hinge area of a northward-plunging anticlinal fold, for example, dextral shearing generates asymmetric Z folds on the western limb and sinistral shearing forms S folds on the eastern limb. Usually only one variety of small, asymmetric folds will be found on a given limb of a larger fold. Therefore, if one notices a change in the pattern from S folds to Z folds (or vice versa), one should be on the lookout for a fold axis. The hinge area is dominated by M folds (no sense of asymmetry).

One final note on folding -- it is generally agreed, in geologically simple areas, that axial surfaces form perpendicular to the last forces that ultimately produced the fold. Therefore, the orientation of the folds give some hint as to the direction of application of the active forces (often a regional indicator of relative plate convergence). In complex regions, the final regional orientation of the structures is a composite result of many protracted pulses of deformation, each with its unique geometric attributes. In these instances, simple analysis is often not possible. Rather, a range of possible explanations for a given structural event is commonly presented.

Faults

A **fault** is defined as *a fracture along which the opposite sides have been displaced*. The surface of displacement is known as the fault plane (or fault surface). The enormous forces released during earthquakes produce elongate gouges within the fault surface (called **slickensides**) that may possess asymmetric linear ridges that enable one to determine the relative motion between the moving sides (Figure A1-2, inset). The block situated below the fault plane is called the **footwall block** and the block situated above the fault plane, the **hanging-wall block**. Extensional force causes the hanging-wall block to slide **down** the fault plane producing a **normal fault**. [See Figure A1-2 (a).] Compressive forces drive the hanging-wall block **up** the fault plane to make a **reverse fault**. A reverse fault with a low angle (<30°) is called a **thrust fault**. [See Figure A1-2 (b).] In all of these cases, the slickensides on the fault will be oriented more or less down the dip of the fault plane and the relationship between the tiny "risers" that are perpendicular to the striae make it possible to determine the relative sense of motion along the fault. Experimental- and field evidence indicate that the asymmetry of slickensides is not always an ironclad indicator of relative fault motion. As such, displaced geological marker beds or veins are necessary to verify relative offset. Fault motion up- or down the dip (as in normal faults, reverse faults, or thrusts faults) is named **dip-slip motion**.

Rather than simply extending or compressing a rock, imagine that the block of rock is sheared along its sides (*i. e*., that is, one attempts to rotate the block about a vertical axis but does not allow the block to rotate). This situation is referred to as a shearing couple and could generate a **strike-slip fault**. [See Figure A1-2 (c).] On a strike-slip-fault plane, slickensides are oriented subhorizontally and again may provide information as to which direction the blocks athwart the fault surface moved.

Two basic kinds of shearing couples and/or strike-slip motion are possible: **left lateral** and **right lateral**. These are defined as follows. Imagine yourself standing on one of the fault blocks and looking across the fault plane to the other block. If the block across the fault from you appears to have moved to the left, the fault is **left lateral** [illustrated in Figure A1-2 (c)]. If the block across the fault appears to have moved to the right, the motion is **right lateral**. Convince yourself that no matter which block you can choose to observe the fault from, you will get the same result! Naturally, complex faults show movements that can show components of dip-slip- and strike-slip motion, rotation about axes perpendicular to the fault plane, or reactivation in a number of contrasting directions or variety. This, however, is no fault of ours.

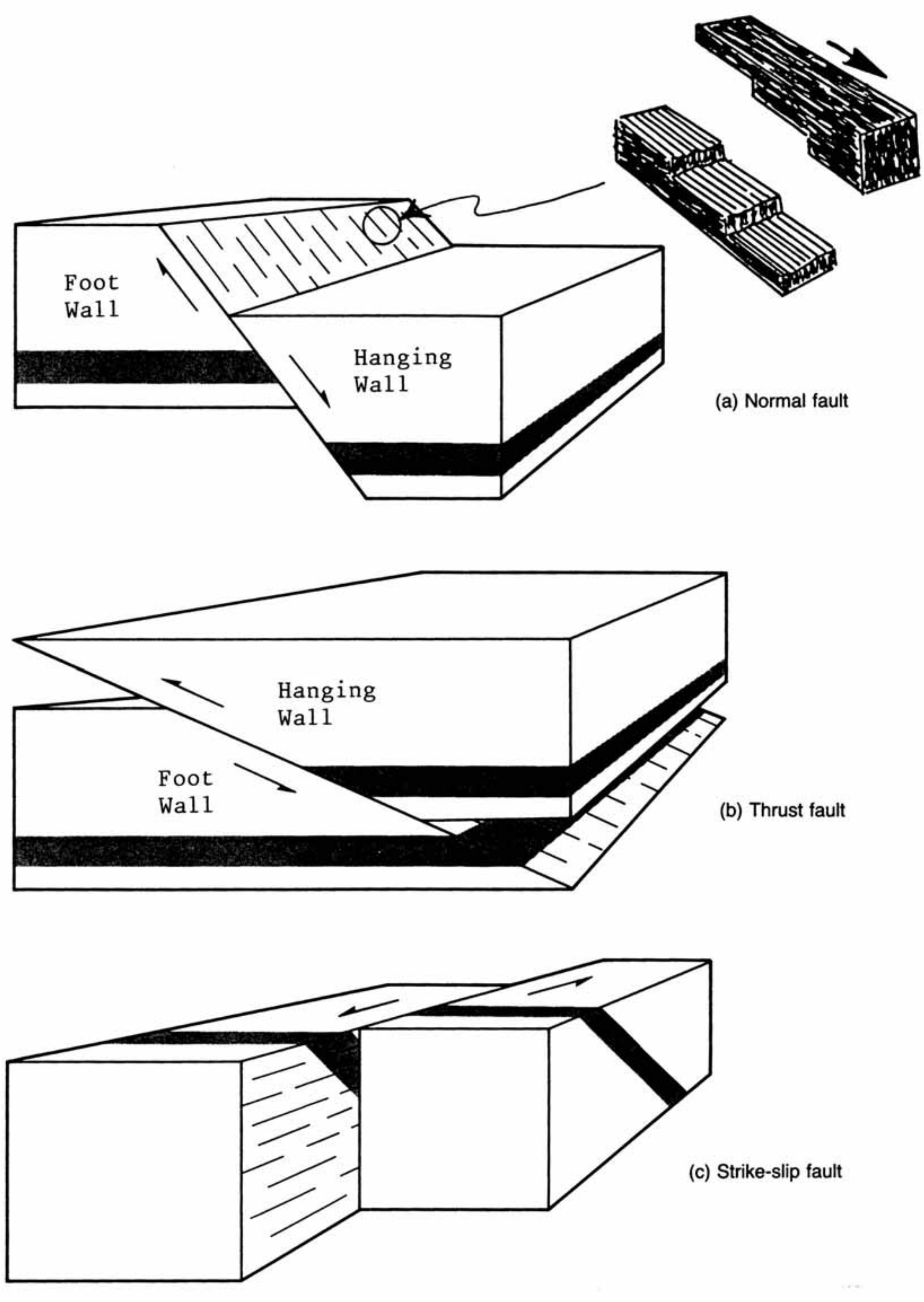


Figure A1-2 - The three main types of faults shown in schematic blocks. Along a normal fault (a) the hanging-wall block has moved relatively downward. On a thrust fault (or reverse fault) (b) the hanging-wall block has moved relatively upward. Along a strike-slip fault (c), the vertical reference layer (black) has been offset by horizontal movement (left-lateral offset shown here). Inset (d) shows segments of two blocks along a slickensided surface show how the jagged "risers" of the stairsteps (formed as pull-apart tension fractures) can be used to infer sense of relative motion. [(a), (b), (c), Composite diagram from introductory texts; (d), J. E. Sanders, 1981, fig. 16.11 (b), p. 397.]

Tensional- or compressional faulting resulting from brittle deformation, at crustal levels above 10 to 15 km, is accompanied by seismicicity and the development of highly crushed and granulated rocks called **fault breccias** and **cataclasites** (including fault gouge, fault breccia, and others). Figure A1-3 lists brittle- and ductile fault terminology as adapted from Sibson (1977) and Hull et al. (1986). Begining at roughly 10 to 15 km and continuing downward, rocks under stress behave aseismically and relieve strain by recrystallizing during flow. These unique metamorphic conditions prompt the development of highly strained (ribboned) quartz, feldspar porphyroclasts (augen), and frayed micas, among other changes, and results in highly laminated rocks called **mylonites** (Figure A1-3).

The identification of such ductile fault rocks in complexly deformed terranes can be accomplished only by detailed mapping of metamorphic lithologies and establishing their geometric relationship to suspected mylonite zones. Unfortunately, continued deformation under load often causes early formed mylonites to recrystallize and thus to produce annealed mylonitic textures (Merguerian, 1988), which can easily be "missed" in the field without careful microscopic analysis. Cameron's Line, a recrystallized ductile shear zone showing post-tectonic brittle reactivation, is an original ductile fault zone (mylonite) having a complex geologic history.

Over the years, field geologists have noted special geologic features associated with thrust faults. Because they propagate at low angles with respect to bedding, thrusts commonly duplicate strata. In addition, thrust faults can displace strata for great distances and wind up transporting rock deposited in one environment above rocks deposited in markedly disparate environments. In such cases, we call the displaced strata of the upper plate above a thrust fault an **allochthon** or describe an entire displaced sequence of strata as an **allochthonous terrane** (see Tectonostratigraphic Units below). In other words, *allochthonous rocks were not originally deposited where they are now found*. By contrast, regions consisting of rock sequences that were originally deposited where they are now found constitute an **autochthon** or **autochthonous terrane**.

Interesting geometric patterns result from the erosion of overthrust sheets of strata that have been folded after they were overthrust. When the upper plate (allochthon) has a "hole" eroded through it, we can peer downward through the allochthon and see the autochthon exposed in a **window**, **inlier**, or **fenster** surrounded by the trace of the thrust fault that was responsible for the dislocation (Figure A1-4). By contrast, if most of the upper plate has been eroded, only a remnant **outlier** or **klippe** may remain. (See Figure A1-4.) Both klippen and windows produce similar map-scale outcrop patterns. The difference is that the thrust surface typically dips *toward* the center of a klippe (a remnant of the allochthon) and *away from* the center of window (which shows a part of the underlying autochthon).

Bedding-plane thrusts are more-localized features but are geometrically the same as thrust faults in that they involve layer-parallel shortening of strata and produce low-angle imbrication of strata. They can easily be "missed" in the field but result in overthickening of strata and can produce anomalous stratigraphic thickness in sedimentary units. The field geologist can identify them by careful bed-by-bed examination of known sequences based on duplication of key- or marker beds and by identification of highly veined dislocation surfaces.

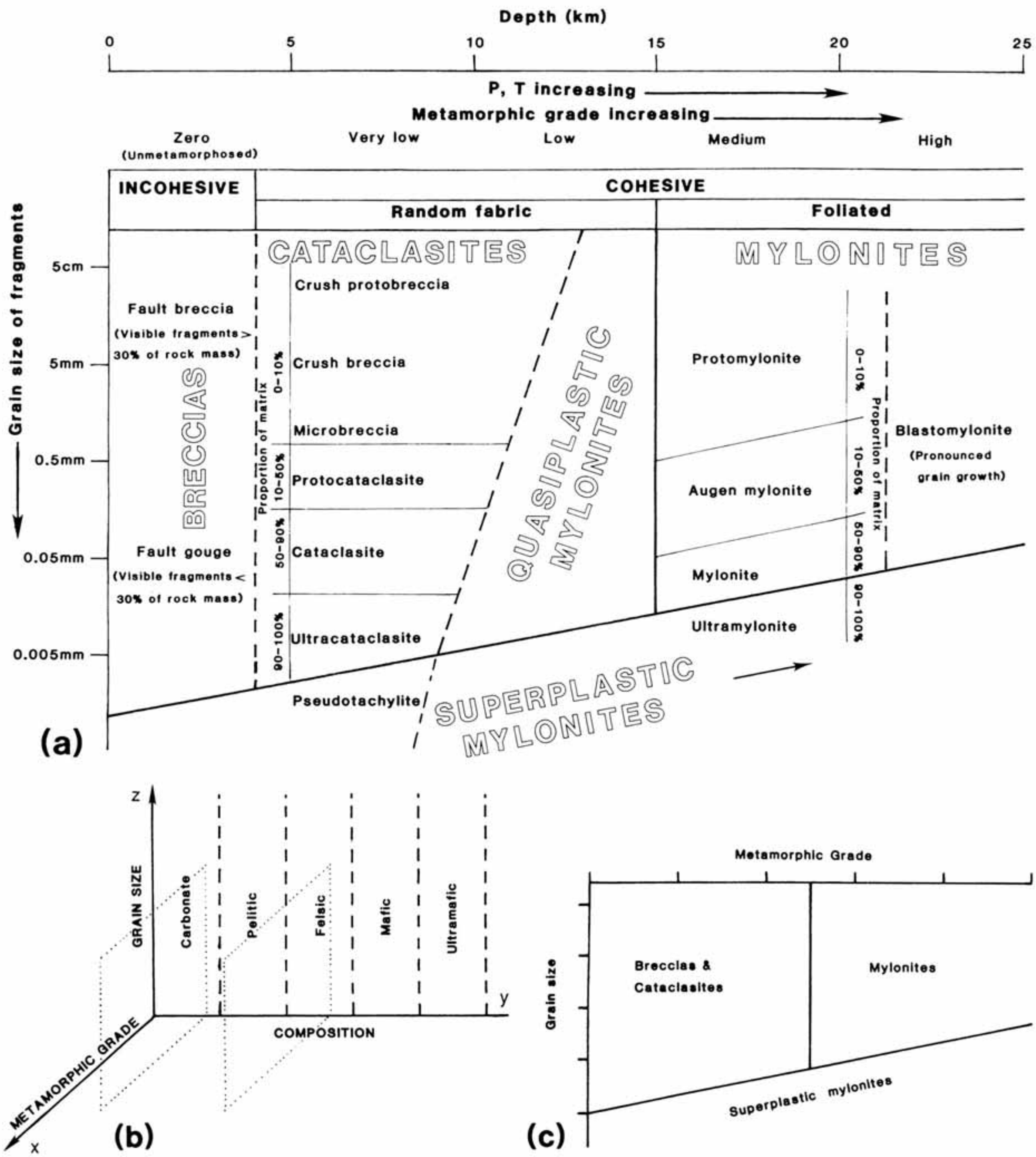


Figure A1-3 - Fault-rock terminology. (a) Classification of fault rocks that have been derived from quartzo-feldspathic lithologies (e. g. granite) (adapted from Sibson, 1977); (b) the grain size - metamorphic grade - lithologic composition grid used for classifying fault rocks (after Hull et al., 1986); (c) fault-rock diagram for marl showing expanded mylonite and superplastic mylonite fields as compared to those shown on the diagram for granite in (a) (from Marshak and Mitra [1988]).

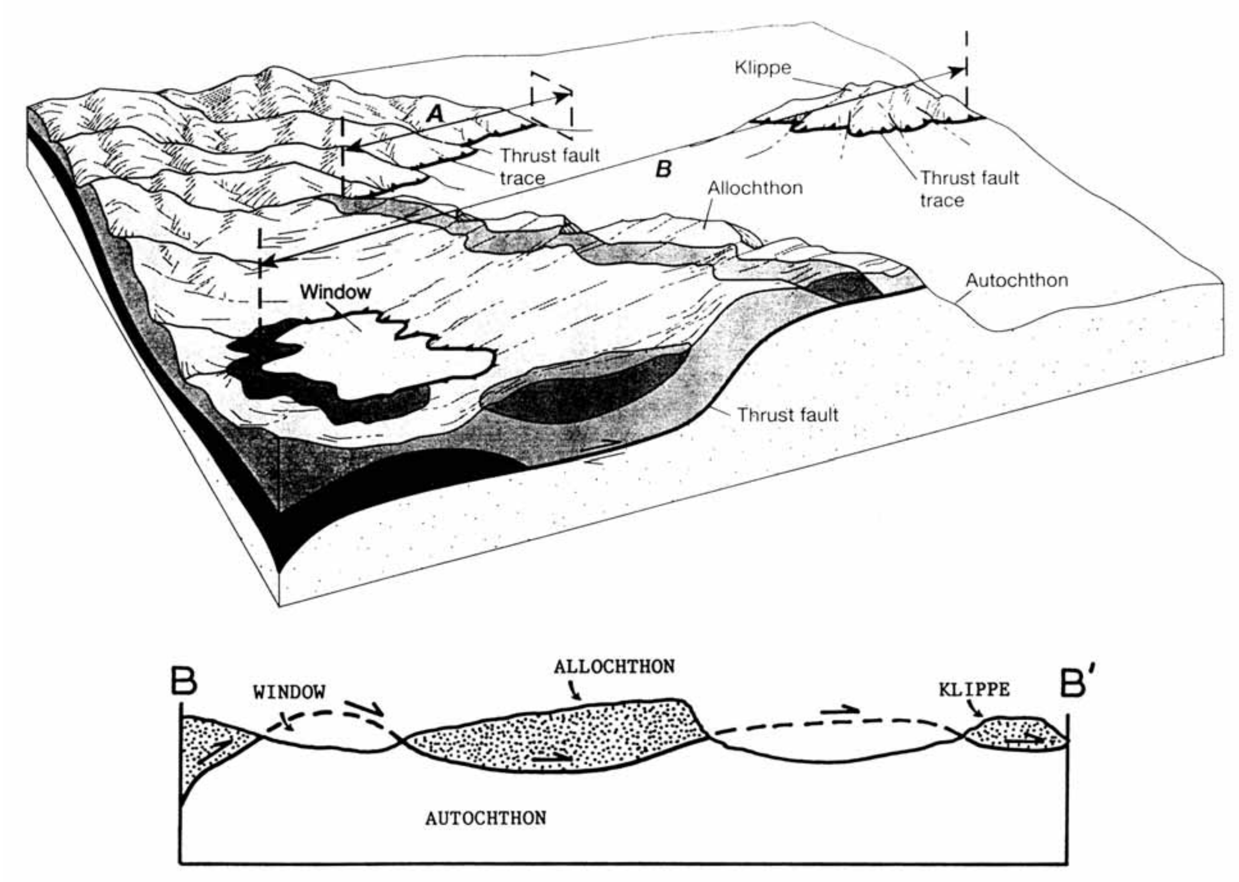


Figure A1-4 - Block diagram illustrating the relationships between allochthons, autochthons, klippen, and windows. (Twiss and Moores, 1992, p. 99) with section B-B' drawn by CM.

During episodes of mountain building associated with continuous subduction and/or collisions near continental margins, thrusting is typically directed from the ocean toward the continent. Accordingly, one of the large-scale effects of such periods of great overthrusting is to impose an anomalous load on the lithosphere that causes it to subside and form a **foreland basin**. These basins receive tremendous quantities of sediment that fill the basin with debris derived from erosion of uplifted areas within the active collision zone. In the late stages of convergence, forces transmitted from the collision zone into the developing foreland basin create a diachronous secondary stage of folding and continent-directed overthrusting of the strata filling the foreland basin. Thus, a thrust may override debris eroded from it.

Surfaces of Unconformity

Surfaces of unconformity mark temporal gaps in the geologic record and commonly result from periods of uplift and erosion. Such uplift and erosion is commonly caused during the terminal phase of regional mountain-building episodes. As correctly interpreted by James Hutton at the now-famous surface of unconformity exposed in the cliff face of the River Jed (Figure A1-5), such surfaces represent mysterious intervals of geologic time where the local evidence contains no clues as to what went on! By looking elsewhere, the effects of a surface of unconformity of regional extent can be recognized and piecemeal explanations of evidence for filling in the missing interval may be found.

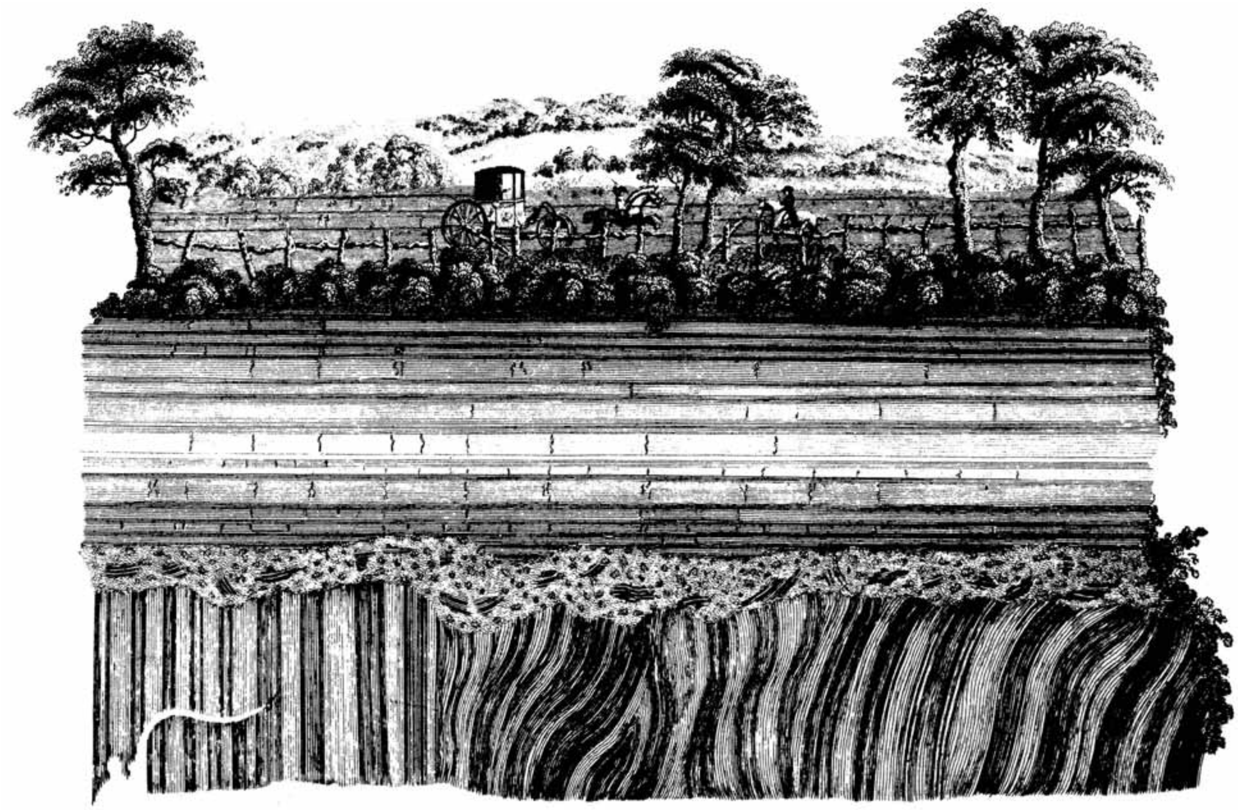


Figure A1-5 - Unconformity with basal conglomerate along the River Jed, south of Edinburgh, Scotland. From James Hutton's "Theory of the Earth", (1795).

Unconformities occur in three basic erosional varieties - angular unconformities, nonconformities, and disconformities (Figure A1-6). Angular unconformities (such as the River Jed) truncate dipping strata below the surface of unconformity and thus exhibit angular discordance at the erosion surface. Nonconformities separate sedimentary strata above the erosion surface from eroded igneous- or metamorphic rocks below. Disconformities are the most-subtle variety, separating subparallel sedimentary strata. They are commonly identified by paleontologic means, by the presence of channels cut into the underlying strata, or by clasts of the underlying strata in their basal part. The strata above a surface of unconformity may or may not include clasts of the underlying strata in the form of a coarse-grained, often bouldery basal facies.

Following the proposal made in 1963 by L. L. Sloss, surfaces of unconformity of regional extent within a craton are used as boundaries to define stratigraphic *Sequences*.

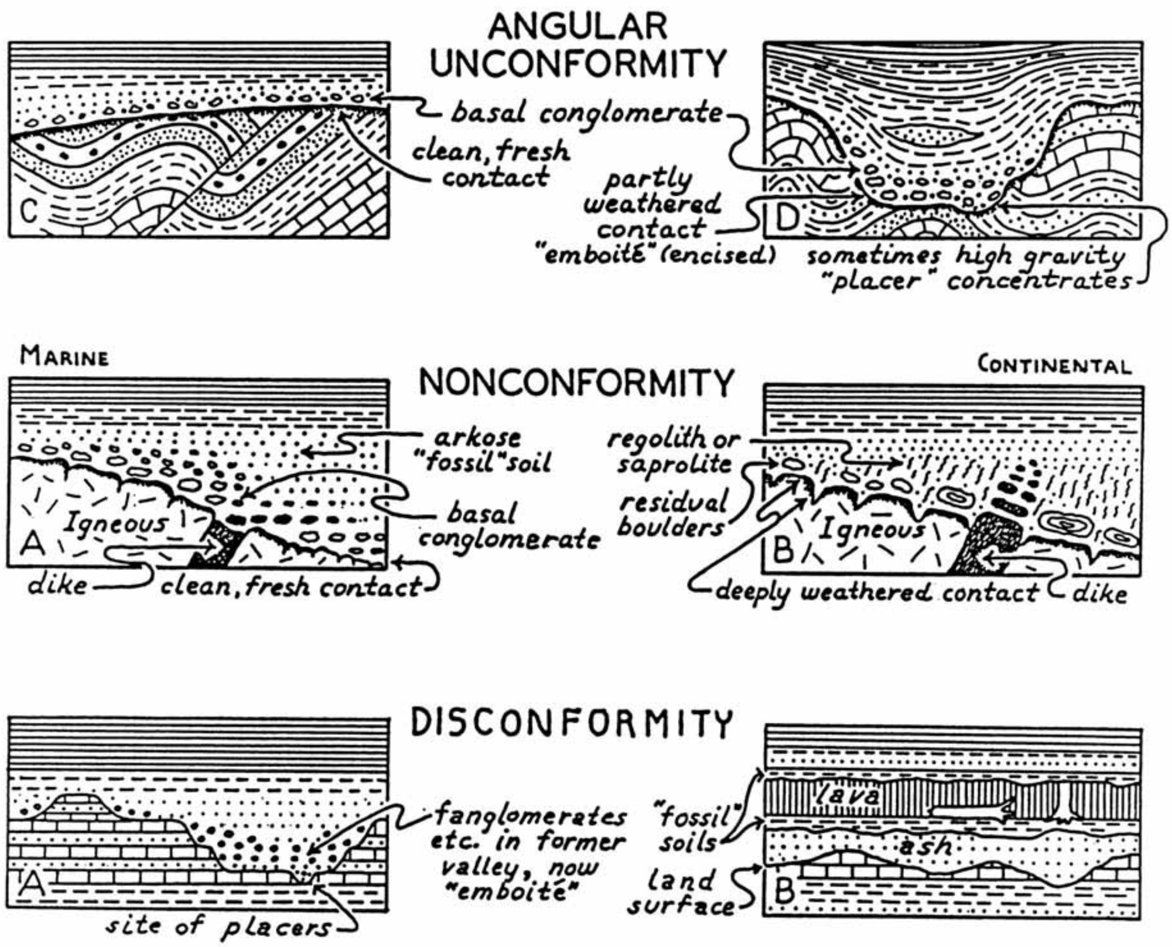


Figure A1-6 - Various types of unconformities, or gaps in the geologic record. Drawings by Rhodes W. Fairbridge.

Sedimentary Structures

During deposition in a variety of environments, primary- and secondary sedimentary structures can develop above-, below-, and within strata. During normal deposition, or settling from a fluid in a rainfall of particles, massive, essentially poorly stratified successions may result. The presence of **strata** implies a change in deposition and as a result most geologists appreciate the significance of layering in sedimentary rocks as marking **CHANGE** in big letters, be it a change in parent area of the sediment, particle size, or style of deposition. Thus, **bedding** can best be viewed as marking the presence of mini-surfaces of unconformity (diastems). During high-energy transport of particles, features such as **cross beds, hummocky strata, asymmetric current ripple marks,** or **graded beds** result. Cross- and hummocky bedding, and asymmetric current ripple marks are deposited by moving currents and help us unravel the paleocurrent directions during their formation. Graded beds result from a kind of a "lump-sum distribution" of a wide range of particles all at once (usually in a gravity-induced turbidity flow). Thus, graded beds show larger particle sizes at the base of a particular layer "grading" upward into finer particles.

Secondary sedimentary features are developed on already deposited strata and include **mud (or desiccation) cracks, rain- drop impressions, sole marks, load-flow structures, flame structures, and rip-up clasts**. The last three categorize effects produced by a moving body of sediment on strata already in place below. A composite diagram illustrating these common structures is reproduced in Figure A1-7.

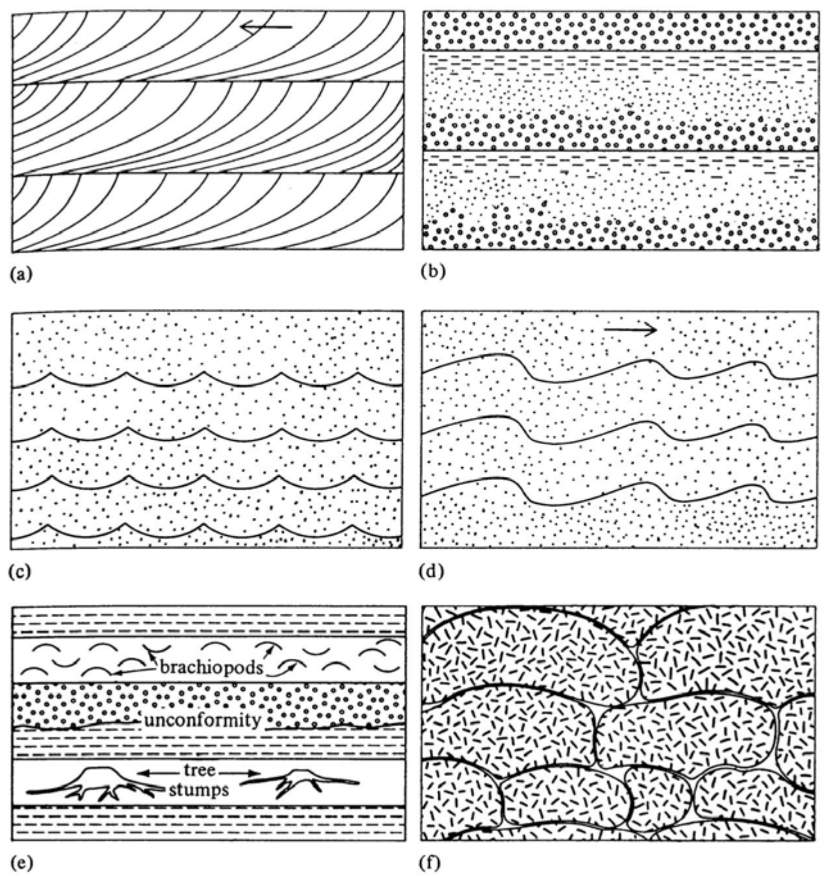


Figure A1-7 - Diagrammatic sketches of primary sedimentary structures (a through e) and cross sections of pillows (f) used in determining topping (younging) directions in rocks.

Together, these primary- and secondary sedimentary structures help the soft-rock structural geologist unravel the oft-asked field questions - namely.... **Which way is up?** and **Which way to the package store?** The direction of younging of the strata seems obvious in horizontal- or gently tilted strata using Steno's principle of superposition. But steeply tilted-, vertical-, or overturned beds can be confidently unraveled and interpreted structurally only after the true topping (stratigraphic younging) direction has been determined. As we may be able to demonstrate on this field trip, simple observations allow the card-carrying geologist to know "Which way is up" at all times.

Volcanic Features

As we will be investigating volcanic rocks almost entirely, it would be appropriate to discuss common volcanic features that we are likely to run across on our trip to Hawaii. The products of volcanism come in the three states of matter, **solid** (solidified lava flows, blocks, bombs, Pele's tears and hair, lapilli, cinder, ash, etc.), **liquid** (lava), and **gas** (volcanic gases such as CO_2, H_20, H_2S, SO_2, and others). Since the cooling rate of volcanic rocks ranges from instantaneous to weeks or months (rather than thousands or millions of years) little time is available for migrating ions to develop large lattice structures. The result of this is glassy (no crystals at all) to fine-grained textures (0.1 to 1.0 mm-scale crystals) that may or may not be visible to the naked eye. Geologists classify such rocks a **hyalohaline** (100% glass) to **aphanitic** (100% crystals) and define ratios of glass vs. crystals by performing careful petrographic examination.

Lava flows are typically viscous liquids that flow rather slowly. A function of composition (especially silica content), temperature, vapor content, flow rate, topography, slope, gravity, and air pressure, lava flows can cascade as ribbon-like flows for great distances, simply pool up into a small area, or fragment and flow as a semi-solid mass. The terms **Aa** (which means "rocky or stony" in Hawaiian) and **Pahoehoe** (which means "to paddle") refer to "blocky" (viscous) and "ropy" (fluidal) lava types ranging in thickness up to 10 m, each with characteristic surface and internal features. Variations (shelly, slabby) occur. A change in velocity down steep slopes or cooling causes changes in viscosity that results in a change from pahoehoe to aa types.

All basalt is thought to be derived from partial melting of lherzolite peridotite or melting of peridotite from a greater depth. Although the magma is derived from 40-55 km deep in the mantle the rising partial melt feeds a magma chamber roughly the size of Connecticut, 3-5 km below surface. Derived from large amounts of melting, no geochemical difference exists between aa and pahoehoe. The production of lava type depends upon temperature, topography, flow angle, amount of degassing, and internal shear.

LAVA TYPES AND THEIR CHARACTERISTICS	
'A'A	**PAHOEHOE**
Forms thick flow units, 6 to 33 feet thick	Forms thin flow units, 0.5 to 6 feet thick
Forms large channels	Forms lava tubes
Higher viscosity	Lower viscosity
Forms few large flow units	Forms many flow units
Is slightly cooler	Is slightly hotter
Has a high volume flow rate	Has a low volume flow rate

Pyroclastic (fire-broken) rocks are a classification given to volcanic materials that are launched from volcanic features and deposited near or far from the source area (usually a vent, cone, or volcano). Another term, **volcanic ejecta**, is also used to describe fragments thrown up (ejected) by volcanic explosion. Ejecta are classified according to size and also by their fluidity during ejection. Fragments larger than 4 cm are termed bombs or blocks depending upon their shape. **Bombs** exhibit aerodynamic forms indicating ejection in a fluidal form while bombs (angular) were ejected as solids (Figure A1-8). Bombs vary in shape from spherical to elongate and drawn out at their ends in a spindly form are termed **fusiform** or **spindle** bombs. **Cored** bombs commonly contain an angular core, the product of liquid lava enclosing a fragment of hardened material. Frozen lava squirts produce long thin bombs termed **ribbon** bombs. Flattish and circular **pancake** or **"cow-dung"** bombs occur when the ejected lava is still fluidal when the bomb hits the ground. So, be careful when the younger generation tells you, ***"You are the bomb"*** – they may mean something quite different than you might think! Also, keep in mind use of the term bomb should be avoided in the airport or on the airplane! Ask them to be more specific. Bombs have variable texture from aphanitic and dense to vesiculated and frothy. Some consist entirely of glass and some contain mixtures of glass and crystals. Some bombs contain remnants (xenoliths or inclusions) of mantle-derived materials rich in olivine and pyroxene.

Blocks are angular and can get quite large (car-sized) since they were launched in the solid state or were so viscous that they were unable to assume a rounded shape in transit. Follow the Wiley Coyote principle - Watch beneath you for unexpected dark angular shadows that get bigger as you view them. Blocks can consist of fragments of volcanic wallrock plucked (excuse the expression) from the throat of a volcanic construct or consist of entirely non-volcanic material. Much of what we know about the subsurface constitution of volcanic areas is learned from studying exotic non-volcanic blocks. Limestone blocks, ripped from subsurface layers of coral are well known in Oahu near Koko Head, for example. Collections of angular blocks are termed **volcanic breccia**, a general term used to describe any aggregate of angular fragments (cemented together or not). **Autobrecciation** is a common feature of the tops and fronts of aa lavas since they tend to crack, break, and become overrun by an advancing flow front. The product is a breccia, a common term used when people sneeze. Explosive and non-explosive breccias are recognized in the geological record. Termed **lahars**, other types of breccia are produced during mudflows.

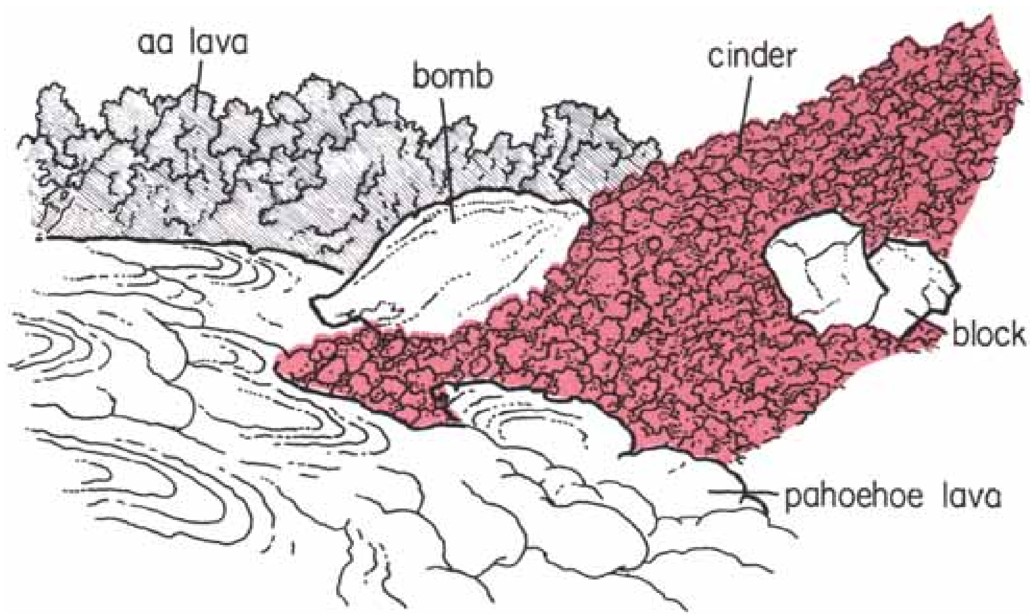


Figure A1-8 – Diagram showing major types of volcanic deposits. Pahoehoe and aa are types of surface flows. Conders, bombs, and blocks are lava fragments with an explosive origin. (From Hazlet and Hyndman, 1996, p. 210.)

Ejecta ranging in size from 0.5 cm to less than 4 cm in diameter are called **lapilli**, meaning “little stone” in Italian. Lapilli come in all shapes from rounded to angular in form. **Volcanic ash** refers to fragments varying from less than 0.5 cm in size and can consist of crystals, solid rock broken by explosion, or consist of particles erupted as a liquid spray that result in quenched glass. **Volcanic tuff** is produced by the quick cementation of volcanic ash. In some cases the ash is so hot that the tuff becomes solidified, as in **welded tuff**. Tuffs enriched in lapilli are termed **lapilli tuff**. When bits of liquid are catapulted into the air and solidify they can fall as rounded, typically jet black glassy globules (**Pele’s tears**) or as fine elongate strands or filaments of lighter-colored glass (**Pele’s hair**).

Cinder and **splatter cones** (or volcanic cones, in general) are produced when ejecta emanates from a vent and builds up a conical pattern on the ground. The difference lies in the nature of the materials. Cinder cones consist of spherical, ribbon, or spindle bombs and splatter cones typically contain more fluidal cow-dung bombs. Mixtures of cinder and splatter and quite common in Hawai’i. The effects of volcanic explosions near the ocean produce **hydromagmatic eruptions** which involve both magma and superheated water and produce ash cones and tuff cones. Heated groundwater explosions are termed phreatic and those explosions which involve magmatic gases are termed phreatomagmatic. Ash and tuff cones are typically broader in proportion to their height than are cinder or splatter cones with broad saucer-shaped craters. The best examples include Diamond Head and Punchbowl on Oahu (Macdonald et al., 1983).

Calderas are large semi-circular to oval features a few km in size and are produced when a shallow magma chamber is evacuated and a void develops below a volcanic summit. A series of circular inward dipping ring fractures develop and coalesce and eventually the tip of the volcano can subside into the voided chamber leaving a caldera in its wake. **Pit craters** and **craters** are smaller features that are secondary to calderas in size but are very similar in geology. They are sometimes found within caldera floors or found distributed along fractures emanating from the caldera area. Commonly found within caldera and crater floors, **ramparts** form as walls around eruptive fissure zones. **Tumuli** are cracked uplifts consisting of plates of basalt caused by accumulated gases or subsurface lava flow obstruction.

Appendix 2 – Glossary of Volcanic and Geologic Terms

Aa: Hawaiian word used to describe a lava flow whose surface is broken into rough angular fragments.

Accessory: A mineral whose presence in a rock is not essential to the proper classification of the rock.

Accidental: Pyroclastic rocks that are formed from fragments of non-volcanic rocks or from volcanic rocks not related to the erupting volcano.

Accretionary Lava Ball: A rounded mass, ranging in diameter from a few centimeters to several meters, [carried] on the surface of a lava flow (e.g., 'a'a) or on cinder-cone slopes [and formed] by the molding of viscous lava around a core of already solidified lava.

Acid: A descriptive term applied to igneous rocks with more than 60% silica (SiO_2).

Active Volcano: A volcano that is erupting. Also, a volcano that is not presently erupting, but that has erupted within historical time and is considered likely to do so in the future.

Agglutinate: A pyroclastic deposit consisting of an accumulation of originally plastic ejecta and formed by the coherence of the fragments upon solidification.

Alkalic: Rocks which contain above average amounts of sodium and/or potassium for the group of rocks for which it belongs. For example, the basalts of the capping stage of Hawaiian volcanoes are alkalic. They contain more sodium and/or potassium than the shield-building basalts that make the bulk of the volcano.

Andesite: Volcanic rock (or lava) characteristically medium dark in color and containing 54 to 62 percent silica and moderate amounts of iron and magnesium.

Ash: Fine particles of pulverized rock blown from an explosion vent. Measuring less than 1/10 inch in diameter, ash may be either solid or molten when first erupted. By far the most common variety is vitric ash (glassy particles formed by gas bubbles bursting through liquid magma).

Ashfall (Airfall): Volcanic ash that has fallen through the air from an eruption cloud. A deposit so formed is usually well sorted and layered.

Ash Flow: A turbulent mixture of gas and rock fragments, most of which are ash-sized particles, ejected violently from a crater or fissure. The mass of pyroclastics is normally of very high temperature and moves rapidly down the slopes or even along a level surface.

Asthenosphere: The shell within the earth, some tens of kilometers below the surface and of undefined thickness, which is a shell of weakness where plastic movements take place to permit pressure adjustments.

Aquifer: A body of rock that contains significant quantities of water that can be tapped by wells or springs.

Avalanche: A large mass of material or mixtures of material falling or sliding rapidly under the force of gravity. Avalanches often are classified by their content, such as snow, ice, soil, or rock avalanches. A mixture of these materials is a debris avalanche.

Basalt: Volcanic rock (or lava) that characteristically is dark in color, contains 45% to 54% silica, and generally is rich in iron and magnesium.

Basement: The undifferentiated rocks that underlie the rocks of interest in an area.

Basic: A descriptive term applied to igneous rocks (basalt and gabbro) with silica (SiO_2) between 44% and 52%.

Bench: The unstable, newly-formed front of a lava delta.

Blister: A swelling of the crust of a lava flow formed by the puffing-up of gas or vapor beneath the flow. Blisters are about 1 meter in diameter and hollow.

Block: Angular chunk of solid rock ejected during an eruption.

Bomb: Fragment of molten or semi-molten rock, 2 1/2 inches to many feet in diameter, which is blown out during an eruption. Because of their plastic condition, bombs are often modified in shape during their flight or upon impact.

Caldera: The Spanish word for cauldron, a basin-shaped volcanic depression; by definition, at least a mile in diameter. Such large depressions are typically formed by the subsidence of volcanoes. Crater Lake occupies the best-known caldera in the Cascades.

Capping Stage: Refers to a stage in the evolution of a typical Hawaiian volcano during which alkalic, basalt, and related rocks build a steeply, sloping cap on the main shield of the volcano. Eruptions are less frequent, but more explosive. The summit caldera may be buried.

Central Vent: A central vent is an opening at the Earth's surface of a volcanic conduit of cylindrical or pipe-like form.

Central Volcano: A volcano constructed by the ejection of debris and lava flows from a central point, forming a more or less symmetrical volcano.

Cinder Cone: A volcanic cone built entirely of loose fragmented material (pyroclastics.)

Cirque: A steep-walled horseshoe-shaped recess high on a mountain that is formed by glacial erosion.

Cleavage: The breaking of a mineral along crystallographic weak lattice planes that reflect weaknesses in a crystal structure.
Composite Volcano: A steep volcanic cone built by both lava flows and pyroclastic eruptions.

Compound Volcano: A volcano that consists of a complex of two or more vents, or a volcano that has an associated volcanic dome, either in its crater or on its flanks. Examples are Vesuvius and Mont Pelee.

Compression Waves: Earthquake waves that move like a slinky. As the wave moves to the left, for example, it expands and compresses in the same direction as it moves.

Conduit: A passage followed by magma in a volcano.

Continental Crust: Solid, outer layers of the earth, including the rocks of the continents.

Continental Drift: The theory that horizontal movement of the earth's surface causes slow, relative movements of the continents toward or away from one another.

Country Rocks: The rock intruded by and surrounding an igneous intrusion.

Crater: A steep-sided, usually circular depression formed by either explosion or collapse at a volcanic vent.

Craton: A part of the earth's crust that has attained stability and has been little deformed for a prolonged period.

Curtain of Fire: A row of coalescing lava fountains along a fissure; a typical feature of a Hawaiian-type eruption.

Dacite: Volcanic rock (or lava) that characteristically is light in color and contains 62% to 69% silica and moderate a mounts of sodium and potassium.

Debris Avalanche: A rapid and unusually sudden sliding or flowage of unsorted masses of rock and other material. As applied to the major avalanche involved in the eruption of Mount St. Helens, a rapid mass movement that included fragmented cold and hot volcanic rock, water, snow, glacier ice, trees, and some hot pyroclastic material. Most of the May 18, 1980 deposits in the upper valley of the North Fork Toutle River and in the vicinity of Spirit Lake are from the debris avalanche.

Debris Flow: A mixture of water-saturated rock debris that flows downslope under the force of gravity (also called lahar or mudflow).

Detachment Plane: The surface along which a landslide disconnects from its original position.

Diatreme: A breccia filled volcanic pipe that was formed by a gaseous explosion.

Dike: A sheetlike body of igneous rock that cuts across layering or contacts in the rock into which it intrudes.

Dome: A steep-sided mass of viscous (doughy) lava extruded from a volcanic vent (often circular in plane view) and spiny, rounded, or flat on top. Its surface is often rough and blocky as a result of fragmentation of the cooler, outer crust during growth of the dome.

Dormant Volcano: Literally, "sleeping." The term is used to describe a volcano which is presently inactive but which may erupt again. Most of the major Cascade volcanoes are believed to be dormant rather than extinct.

Drainage Basin: The area of land drained by a river system.

Ejecta: Material that is thrown out by a volcano, including pyroclastic material (tephra) and lava bombs.

En Echelon: Set of geologic features that are in an overlapping or a staggered arrangement (e.g., faults). Each is relatively short, but collectively they form a linear zone in which the strike of the individual features is oblique to that of the zone as a whole.

Episode: An episode is a volcanic event that is distinguished by its duration or style.

Eruption: The process by which solid, liquid, and gaseous materials are ejected into the earth's atmosphere and onto the earth's surface by volcanic activity. Eruptions range from the quiet overflow of liquid rock to the tremendously violent expulsion of pyroclastics.

Eruption Cloud: The column of gases, ash, and larger rock fragments rising from a crater or other vent. If it is of sufficient volume and velocity, this gaseous column may reach many miles into the stratosphere, where high winds will carry it long distances.

Eruptive Vent: The opening through which volcanic material is emitted.

Evacuate: Temporarily move people away from possible danger.

Extinct Volcano: A volcano that is not presently erupting and is not likely to do so for a very long time in the future.

Extrusion: The emission of magmatic material at the earth's surface. Also, the structure or form produced by the process (e.g., a lava flow, volcanic dome, or certain pyroclastic rocks).

Fault: A crack or fracture in the earth's surface. Movement along the fault can cause earthquakes or--in the process of mountain-building--can release underlying magma and permit it to rise to the surface.

Fault Scarp A steep slope or cliff formed directly by movement along a fault and representing the exposed surface of the fault before modification by erosion and weathering.

Felsic: An igneous rock having abundant light-colored minerals.

Fire fountain: See also: lava fountain.

Fissures: Elongated fractures or cracks on the slopes of a volcano. Fissure eruptions typically produce liquid flows, but pyroclastics may also be ejected.

Flank Eruption: An eruption from the side of a volcano (in contrast to a summit eruption.)

Fluvial: Produced by the action of flowing water.

Formation: A body of rock identified by lithic characteristics and stratigraphic position and is map able at the earth's surface or traceable in the subsurface.

Fracture: The manner of breaking due to intense folding or faulting.

Fumarole: A vent or opening through which issue steam, hydrogen sulfide, or other gases. The craters of many dormant volcanoes contain active fumaroles.

Geothermal Energy: Energy derived from the internal heat of the earth.

Geothermal Power: Power generated by using the heat energy of the earth.

Graben: An elongate crustal block that is relatively depressed (down dropped) between two fault systems.

Guyot: A type of seamount that has a platform top. Named for a nineteenth-century Swiss-American geologist.

Hardness: The resistance of a mineral to scratching.

Harmonic Tremor: A continuous release of seismic energy typically associated with the underground movement of magma. It contrasts distinctly with the sudden release and rapid decrease of seismic energy associated with the more common type of earthquake caused by slippage along a fault.

Heat transfer: Movement of heat from one place to another.

Heterolithologic: Material is made up of a heterogeneous mix of different rock types. Instead of being composed on one rock type, it is composed of fragments of many different rocks.

Holocene: The time period from 10,000 years ago to the present. Also, the rocks and deposits of that age.

Horizontal Blast: An explosive eruption in which the resultant cloud of hot ash and other material moves laterally rather than upward.

Horst: A block of the earth's crust, generally long compared to its width that has been uplifted along faults relative to the rocks on either side.

Hot Spot: A volcanic center, 60 to 120 miles (100 to 200 km) across and persistent for at least a few tens of million of years, that is thought to be the surface expression of a persistent rising plume of hot mantle material. Hot spots are not linked to arcs and may not be associated with ocean ridges.

Hot-spot Volcanoes: Volcanoes related to a persistent heat source in the mantle.

Hyaloclastite: A deposit formed by the flowing or intrusion of lava or magma into water, ice, or water-saturated sediment and its consequent granulation or shattering into small angular fragments.

Hydrothermal Reservoir: An underground zone of porous rock containing hot water.

Hypabyssal: A relatively shallow intrusive consisting of magma or the resulting solidified rock.

Hypocenter: The place on a buried fault where an earthquake occurs.

Ignimbrite: The rock formed by the widespread deposition and consolidation of ash flows and nuees ardentes. The term was originally applied only to densely welded deposits but now includes non-welded deposits.

Intensity: A measure of the effects of an earthquake at a particular place. Intensity depends not only on the magnitude of the earthquake, but also on the distance from the epicenter and the local geology.

Intermediate: A descriptive term applied to igneous rocks that are transitional between basic and acidic with silica (SiO_2) between 54% and 65%.

Intrusion: The process of emplacement of magma in pre-existing rock.

Intrusive: A term that refers to igneous rock mass formed at depth within surrounding rock.

Joint: A surface of fracture in a rock.

Juvenile: Pyroclastic material derived directly from magma reaching the surface. Also a term used to describe CM's approach to teaching Geology and life in general.

Kipuka: An area surrounded by a lava flow.

Laccolith: A body of igneous rocks with a flat bottom and domed top. It is parallel to the layers above and below it.

Lahar: A torrential flow of water-saturated volcanic debris down the slope of a volcano in response to gravity. A type of mudflow.

Landsat: A series of unmanned satellites orbiting at about 706 km (438 miles) above the surface of the earth. The satellites carry cameras similar to video cameras and take images or pictures showing features as small as 30 m or 80 m wide, depending on which camera is used.

Lapilli: Literally, "little stones." Round to angular rock fragments, measuring 1/10 inch to 2 1/2 inches in diameter, which may be ejected in either a solid or a molten state.

Lava: Magma which has reached the surface through a volcanic eruption. The term is most commonly applied to streams of liquid rock that flow from a crater or fissure. It also refers to cooled and solidified rock.

Lava Dome: Mass of lava, created by many individual flows, that has built a dome-shaped pile of lava.

Lava Flow: An outpouring of lava onto the land surface from a vent or fissure. Also, a solidified tongue like or sheet-like body formed by outpouring lava.

Lava Fountain: A rhythmic vertical fountain like eruption of lava.

Lava Lake (Pond): A lake of molten lava, usually basaltic, contained in a vent, crater, or broad depression of a shield volcano.

Lava Shields: A shield volcano made of basaltic lava.

Lava Tube: A tunnel formed when the surface of a lava flow cools and solidifies while the still-molten interior flows through and drains away.

Limu O Pele (Pele Seaweed): Delicate, translucent sheets of spatter filled with tiny glass bubbles.

Lithic: Of or pertaining to stone.

Lithosphere: The rigid crust and uppermost mantle of the earth. Thickness is on the order of 60 miles (100 km). Stronger than the underlying asthenosphere.

Luster: The reflection of light from the surface of a mineral.

Maar: A volcanic crater that is produced by an explosion in an area of low relief, is generally more or less circular, and often contains a lake, pond, or marsh.

Mafic: An igneous composed chiefly of one or more dark-colored minerals.

Magma: Molten rock beneath the surface of the earth.

Magma Chamber: The subterranean cavity containing the gas-rich liquid magma which feeds a volcano.

Magmatic: Pertaining to magma.

Magnitude: A numerical expression of the amount of energy released by an earthquake, determined by measuring earthquake waves on standardized recording instruments (seismographs.) The number scale for magnitudes is logarithmic rather than arithmetic. Therefore, deflections on a seismograph for a magnitude 5 earthquake, for example, are 10 times greater than those for a magnitude 4 earthquake, 100 times greater than for a magnitude 3 earthquake, and so on. Energy release is roughly 27 times greater for each successive Richter scale increase.

Mantle: The zone of the earth below the crust and above the core.

Matrix: The solid matter in which a fossil or crystal is embedded. Also, a binding substance (e.g., cement in concrete).

Miocene: An epoch in Earth's history from about 24 to 5 million years ago. Also refers to the rocks that formed in that epoch.

Moho: Also called the Mohorovicic discontinuity. The surface or discontinuity that separates the crust from the mantle. The Moho is at a depth of 5-10 km beneath the ocean floor and about 35 km below the continents (but down to 60 km below mountains). Named for Andrija Mohorovicic, a Croatian seismologist and wild blender aficionado.

Monogenetic: A volcano built by a single eruption.

Mudflow: A flowage of water-saturated earth material possessing a high degree of fluidity during movement. A less-saturated flowing mass is often called a debris flow. A mudflow originating on the flank of a volcano is properly called a lahar.

Myth: A fictional story to explain the origin of some person, place, or thing. Also a useful term to describe CM’s technical publications.

Nuees Ardentes: A French term applied to a highly heated mass of gas-charged ash which is expelled with explosive force and moves hurricane speed down the mountainside.

Obsidian: A black or dark-colored volcanic glass usually composed of rhyolite.

Oceanic Crust: The earth's crust where it underlies oceans.

Pahoehoe: A Hawaiian term for lava with a smooth, billowy, or ropy surface.

Pali: Hawaiian word for steep hills or cliffs.

Pele Hair: A natural spun glass formed by blowing-out during quiet fountaining of fluid lava, cascading lava falls, or turbulent flows, sometimes in association with Pele tears. A single strand, with a diameter of less than half a millimeter, may be as long as two meters.

Pele Tears: Small, solidified drops of volcanic glass behind which trail pendants of Pele hair. They may be tear-shaped, spherical, or nearly cylindrical.

Peralkaline: Igneous rocks in which the molecular proportion of aluminum oxide is less than that of sodium and potassium oxides combined.

Phenocryst: A conspicuous, usually large, crystal embedded in porphyritic igneous rock.

Phreatic Eruption (Explosion): An explosive volcanic eruption caused when water and heated volcanic rocks interact to produce a violent expulsion of steam and pulverized rocks. Magma is not involved.

Phreatomagmatic: An explosive volcanic eruption that results from the interaction of surface or subsurface water and magma.

Pillow lava: Interconnected, sack-like bodies of lava formed underwater.

Pipe: A vertical conduit through the Earth's crust below a volcano, through which magmatic materials have passed. Commonly filled with volcanic breccia and fragments of older rock.

Pit Crater: A crater formed by sinking in of the surface, not primarily a vent for lava.

Plastic: Capable of being molded into any form, which is retained.

Plate Tectonics: The theory that the earth's crust is broken into about 10 fragments (plates,) which move in relation to one another, shifting continents, forming new ocean crust, and stimulating volcanic eruptions.

Pleistocene: An epoch in Earth history from about 2-5 million years to 10,000 years ago. Also refers to the rocks and sediment deposited in that epoch.

Plinian Eruption: An explosive eruption in which a steady, turbulent stream of fragmented magma and magmatic gases is released at a high velocity from a vent. Large volumes of tephra and tall eruption columns are characteristic.

Plug: Solidified lava that fills the conduit of a volcano. It is usually more resistant to erosion than the material making up the surrounding cone, and may remain standing as a solitary pinnacle when the rest of the original structure has eroded away.

Plug Dome: The steep-sided, rounded mound formed when viscous lava wells up into a crater and is too stiff to flow away. It piles up as a dome-shaped mass, often completely filling the vent from which it emerged.

Pluton: A large igneous intrusion formed at great depth in the crust.

Polygenetic: Originating in various ways or from various sources.

Precambrian: All geologic time from the beginning of Earth history to 570 million years ago. Also refers to the rocks that formed in that epoch.

Pumice: Light-colored, frothy volcanic rock, usually of dacite or rhyolite composition, formed by the expansion of gas in erupting lava. Commonly seen as lumps or fragments of pea-size and larger, but can also occur abundantly as ash-sized particles.

Pyroclastic: Pertaining to fragmented (clastic) rock material formed by a volcanic explosion or ejection from a volcanic vent.

Pyroclastic Flow: Lateral flowage of a turbulent mixture of hot gases and unsorted pyroclastic material (volcanic fragments, crystals, ash, pumice, and glass shards) that can move at high speed (50 to 100 miles an hour.) The term also can refer to the deposit so formed.

Quaternary: The period of Earth's history from about 2 million years ago to the present; also, the rocks and deposits of that age.

Relief: The vertical difference between the summit of a mountain and the adjacent valley or plain.

Renewed Volcanism State: Refers to a state in the evolution of a typical Hawaiian volcano during which --after a long period of quiescence--lava and tephra erupt intermittently. Erosion and reef building continue.

Repose: The interval of time between volcanic eruptions.

Rhyodacite: An extrusive rock intermediate in composition between dacite and rhyolite.

Rhyolite: Volcanic rock (or lava) that characteristically is light in color, contains 69% silica or more, and is rich in potassium and sodium.

Ridge, Oceanic: A major submarine mountain range.

Rift System: The oceanic ridges formed where tectonic plates are separating and a new crust is being created; also, their on-land counterparts such as the East African Rift of Africa or Southwest Rift of Hawaii.

Rift Zone: A zone of volcanic features associated with underlying dikes. The location of the rift is marked by cracks, faults, and vents.

Ring of Fire: The regions of mountain-building earthquakes and volcanoes which surround the Pacific Ocean.
Scoria: A bomb-size (> 64 mm) pyroclast that is irregular in form and generally very vesicular. It is usually heavier, darker, and more crystalline than pumice.

Seafloor Spreading: The mechanism by which new seafloor crust is created at oceanic ridges and slowly spreads away as plates are separating.

Seamount: A submarine volcano.

Seismograph: An instrument that records seismic waves; that is, vibrations of the earth.

Seismologist: Scientists who study earthquake waves and what they tell us about the inside of the Earth.

Seismometer: An instrument that measures motion of the ground caused by earthquake waves.

Shearing: The motion of surfaces sliding past one another.

Shear Waves: Earthquake waves that move up and down as the wave itself moves. For example, to the left.

Shield Volcano: A gently sloping volcano in the shape of a flattened dome and built almost exclusively of lava flows.

Shoshonite: A trachyandesite composed of olivine and augite phenocrysts in a groundmass of labradorite with alkali feldspar rims, olivine, augite, a small amount of leucite, and some dark-colored glass. Its name is derived from the Shoshone River, Wyoming and given by Iddings in 1895.

Silica: A chemical combination of silicon and oxygen.

Sill: A tabular body of intrusive igneous rock, parallel to the layering of the rocks into which it intrudes.

Skylight: An opening formed by a collapse in the roof of a lava tube.

Solfatara: A type of fumarole, the gases of which are characteristically sulfurous.

Spatter Cone: A low, steep-sided cone of spatter built up on a fissure or vent. It is usually of basaltic material.

Spatter Rampart: A ridge of congealed pyroclastic material (usually basaltic) built up on a fissure or vent.

Specific Gravity: The density of a mineral divided by the density of water.

Spines: Horn-like projections formed upon a lava dome.

Stalactite: A cone shaped deposit of minerals hanging from the roof of a cavern.

Stratigraphic: The study of rock strata, especially of their distribution, deposition, and age.

Stratovolcano: A volcano composed of both lava flows and pyroclastic material.

Streak: The color of a mineral in the powdered form.

Strike-Slip Fault: A nearly vertical fault with side-slipping displacement.

Strombolian Eruption: A type of volcanic eruption characterized by jetting of clots or fountains of fluid basaltic lava from a central crater.

Subduction Zone: The zone of convergence of two tectonic plates, one of which usually overrides the other.

Surge: A ring-shaped cloud of gas and suspended solid debris that moves radially outward at high velocity as a density flow from the base of a vertical eruption column accompanying a volcanic eruption or crater formation.

Talus: A slope formed at the base of a steeper slope, made of fallen and disintegrated materials.

Tephra: Materials of all types and sizes that are erupted from a crater or volcanic vent and deposited from the air.

Tephrochronology: The collection, preparation, petrographic description, and approximate dating of tephra.

Tilt: The angle between the slope of a part of a volcano and some reference. The reference may be the slope of the volcano at some previous time.

Trachyandesite: An extrusive rock intermediate in composition between trachyte and andesite.

Trachybasalt: An extrusive rock intermediate in composition between trachyte and basalt.

Trachyte: A group of fine-grained, generally porphyritic, extrusive igneous rocks having alkali feldspar and minor mafic minerals as the main components, and possibly a small amount of sodic plagioclase.

Tremor: Low amplitude, continuous earthquake activity often associated with magma movement.

Tsunami: A great sea wave produced by a submarine earthquake, volcanic eruption, or large landslide.

Tuff: Rock formed of pyroclastic material.

Tuff Cone: A type of volcanic cone formed by the interaction of basaltic magma and water. Smaller and steeper than a tuff ring.

Tuff Ring: A wide, low-rimmed, well-bedded accumulation of hyaloclastic debris built around a volcanic vent located in a lake, coastal zone, marsh, or area of abundant ground water.

Tumulus: A doming or small mound on the crest of a lava flow caused by pressure due to the difference in the rate of flow between the cooler crust and the more fluid lava below.

Ultramafic: Igneous rocks made mostly of the mafic minerals hypersthene, augite, and/or olivine.

Unconformity: A substantial break or gap in the geologic record where a rock unit is overlain by another that is not next in stratigraphic succession, such as an interruption in continuity of a depositional sequence of sedimentary rocks or a break between eroded igneous rocks and younger sedimentary strata. It results from a change that caused deposition to cease for a considerable time, and it normally implies uplift and erosion with loss of the previous formed record.

Vent: The opening at the earth's surface through which volcanic materials issue forth.

Vesicle: A small air pocket or cavity formed in volcanic rock during solidification.

Viscosity: A measure of resistance to flow in a liquid (water has low viscosity while honey has a higher viscosity.)

Volcano: A vent in the surface of the Earth through which magma and associated gases and ash erupt; also, the form or structure (usually conical) that is produced by the ejected material.

Volcanic Arc: A generally curved linear belt of volcanoes above a subduction zone, and the volcanic and plutonic rocks formed there.

Volcanic Complex: A persistent volcanic vent area that has built a complex combination of volcanic landforms.

Volcanic Cone: A mound of loose material that was ejected ballistically.

Volcanic Neck: A massive pillar of rock more resistant to erosion than the lavas and pyroclastic rocks of a volcanic cone.

Vulcan: Roman god of fire and the forge after whom volcanoes are named.

Vulcanian: A type of eruption consisting of the explosive ejection of incandescent fragments of new viscous lava, usually on the form of blocks.

Water Table: The surface between where the pore space in rock is filled with water and where the pore space in rock is filled with air.

Xenocrysts: A crystal that resembles a phenocryst in igneous rock, but is a foreign to the body of rock in which it occurs.

Xenoliths: A foreign inclusion in an igneous rock.

Mr. Jenkins from Duke Laboratories asking the all important field question.

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Geology Field Trip Rules

The following rules, first organized by Kevin Higgins and Brendan Jordan and then modified by the words and deeds of other Hofstra students, apply to all departmental field trips in which you will participate. As many of these rules apply to life in general, you should heed all rules.

1. Never ever ask "what's next?", "where are we going?", "when will we get there?", or "when are we getting back?"
Rule 1a. *(The Regan Corollary)* – Never break Rule #1 while backing away from the Gittleson Hall loading dock on the initial day of any field trip.
2. Don't bother anyone before breakfast unless you are a morning person and have acquired special permission.
3. Never speak at breakfast unless spoken to.
4. Never approach a surface outcrop before the professor. Students may enter any subsurface adit, pit, cavern, or mine shaft, first, however.
5. Do not stand so that you will be at a greater elevation than the professor while he or she is lecturing.
6. Avoid standing in front of the professor at any time.
7. While in the van or bus do not sit in Dr. Merguerian's seat.
8. Never attempt to borrow money from a professor.
9. Never end the semester owing a professor money. The converse is, however, acceptable.
10. Leave the jokes to the professor.
11. No back seat driving. Unless you are the navigator or have been specifically asked, do not give the driver **any** instructions.
12. Never read the comics out loud at breakfast or while driving in the van.
13. The President and Vice-President/Chief Decision Maker sit in the primary van seats. At a certain point on all field trips, certain seats become most desirable. Avoid being in the way at these times.
14. Loud music and smoking are strictly forbidden during the vehicular phase of all field trips unless you provide a personal walkman and portable iron lung or decompression chamber.
15. All club officers, past and present, are exempt from all fire duties. These include such things as finding wood, starting the fire, and maintenance.
16. Always get receipts for all expenses for subsequent donation to the professor.
17. When in natural surroundings, pack out what you pack in.
18. Read the rules carefully. Never ask, "What are the rules?".
19. Never be the last person to board the van more than once in a row.
20. Special rules are invoked during long-duration return trips in the driving rain or in heavy traffic. These include the following:
   A) Absolutely no singing of grunge-rock, hip-hop, rap, or heavy metal while seated near Dr. Merguerian.
   B) Use of the radio is limited to the driver's discretion and the front speakers.
   C) Discussion of social issues is limited to one fifteen-minute period per field day.
   D) The Hess Rule – Never talk for more than 30 minutes straight without eliciting some form of feedback from the person you are speaking to.
21. Never complain and always remember the famous saying, "If you don't like it, too bad".
22. Never be the one to ask, "Is this the last stop?"on the last day of any weekend field trip.
23. When you are 15 minutes late, never walk towards the van at a leisurely pace.
24. Never complain to the Professor that he or she is late when the van is pre-parked in the lot.
25. Cell phone calls from family members inquiring as the timing of trips are strictly forbidden.
26. Never buy two cups of coffee within 2-3 minutes of one another.
27. Most importantly, what happens in the field stays in the field. There is no need for the circulation of tall tales here on campus. If, however, these tales enhance greater student participation or professional neck rubs, talk as much as you like, and lastly,
28. Refrain from applying scented creams, oils, or tinctures while riding in the van unless you are over age 80 and have a note from your parents.
29. Obey all rules!