FIELD INTERPRETATION OF ACTIVE VOLCANOES

A HANDBOOK FOR VIEWING LAVA

USGS Photo

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INTRODUCTION

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Aloha and welcome. This book is dedicated to assist the field interpreters working on the Hawaii County lava viewing program. These interpreters will enhance the visitor's experience by sharing knowledge about geological and cultural practices related to Hawai'i's volcanoes.

Providing a *SAFE* and authentic geological and cultural experience is primary to our objectives in which the perpetuation of the Hawaiian culture is vital .

Pele’s Farewell to Maui

Aloha o Maui, aloha, e!
Aloha o Moloka‘i, aloha, e!
Aloha o Lana‘i, aloha, e!
Aloha o Kaho‘olawe, aloha, e!
Ku makou e hele, e!
O Hawai‘i ka ‘aina
A makou e noho ai a mau loa aku.

Farewell to thee, Maui, farewell!
Farewell to thee, Moloka‘i, farewell!
Farewell to thee, Lana‘i, farewell!
Farewell to thee, Kaho‘olawe, farewell!
We stand all ready for travel:
Hawai‘i, it seams, is the land
On which we shall dwell evermore.

From “Pele and Hiiaka”
translated by N. B. Emerson, 1916.

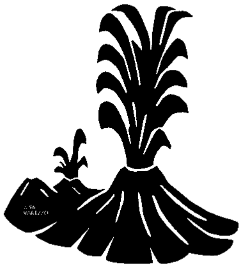
SECTION ONE

ERUPTION GEOLOGY

The landscape on active vocanoes is dynamic. You can never rely on conditions or events to be the same from one day to the next. You must learn to read the surface of the lava and surrounding environment to understand what is happening and what might happen next. A guide can never afford to be complacent, because the volcano's behavior can change in an instant. A tranquil scene of beauty can turn into chaos. Lava that was approachable the day before, may be unapproachable the next day. Landmarks come and go, just as safe routes shift or disappear.

Working on a volcano requires that you learn to assess and reassess the environment constantly. This requires developing a fundemental understanding about the range of processes that operate on the volcano and how and when they are likely to occur. The bottom line is, learn the hazards well.

CHAPTER 1
LAVA FLOWS



Lava flow is a term that is used for the liquid phase as well as for its solidified products. In this manual we are address chiefly Hawaiian lava flows, that is, basalt. The behavior, morphology, and textures of these flows depend on a wide variety of factors including composition (what it's made of), gas content, temperature, viscosity and many other complex interrelated factors. In general, Hawaiian lava flows are considered the most approachable in the world. While this is true, there are factors to be aware of.

What is Lava?

Lava is the primordial building block of the Earth's crust. Nearly three quarters of the crust is made of lava flows. The oceanic crust and the rift-zone volcanoes that produce it lie hidden deep beneath the Earth's vast oceans where they are effectively inaccessible. Only where extraordinary volumes of lava are erupted over an extended period of time do the volcanoes rise above sea level to form ocean islands like those found in Hawai‘i.

Lava can be defined in several ways. First, most of us immediately think of lava as red-hot flows of molten rock. Indeed, molten rock erupting at the surface of our (or any other) planet is called lava. Remember, however, that all molten rock deep beneath the surface is called magma, This is an often-confusing, but important distinction. Magma is kept under pressure beneath the ground; lava has reached the surface and pressure is released.

Second, the word lava is also used to refer to cooled, solidified products of lava flows. Unfortunately, this can lead to some confusion, especially when leading groups over lava flows. Mentioning that you have to walk for about a mile over lava to get to a particular viewing spot, can cause anxiety in inexperienced visitors who tend to conjure up images of red, flowing lava. For the sake of minimizing confusion, it is often best to distinguish between active molten lava and inactive solidified lava. Sometimes this distinction is not easy to make.

Active lava flows that have crusted over can have surface appearances similar to the surrounding inactive lava flows. Even the apparent surface temperatures can be much like the sun- and lava-heated older rock surfaces. The major difference is that molten lava lying beneath the solidified crust of active lavas can present a significant hazard depending on the type of crust. It is important to be able to distinguish these differences in the field.

Why Learn about Lava?

Active lava flows are amongst the most fascinating and inspiring geologic phenomena that occur on the surface of our planet. They are forces of both great beauty and destruction that draw people toward them. Unlike other forces of nature such as large earthquakes, explosive volcanic eruptions, tsunamis, hurricanes, tornadoes, and floods, many Hawaiian lava flows can be experienced by human beings in relative safety. Seeing lava flowing for the first time often has a profound effect on people's view of the natural world.

Pressurized magma beneath the ground force the lava to erupt vigorously. The lava quickly forms flows that carry the liquid down slope. USGS photo

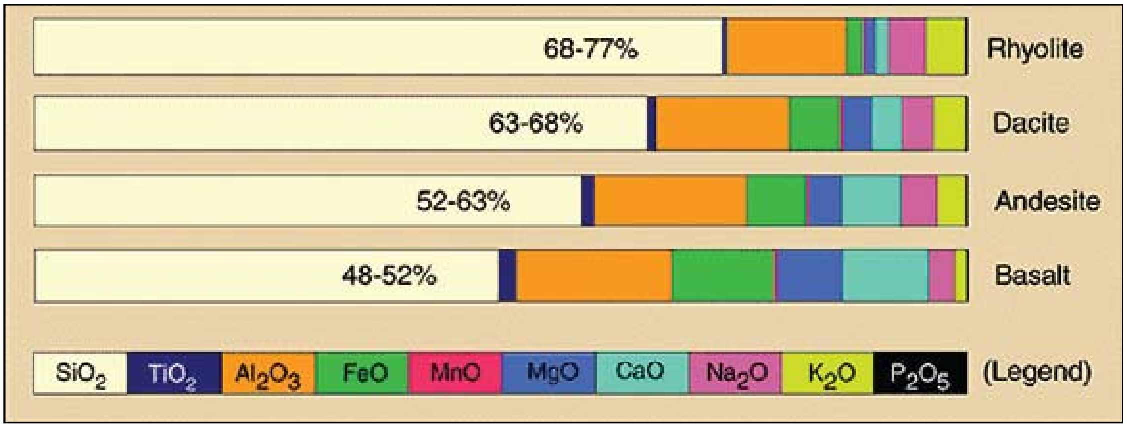
Learning about eruptions can influence people in several ways. From a scientific viewpoint, witnessing a volcanic eruption helps people understand their natural environment and inspires their curiosity about the geologic world. From a cultural perspective, the experience helps visitors understand the close association of native Hawaiians with the ‘aina (the land). Finally, and probably most importantly, having an understanding the hazards associated with how lava erupts and moves greatly improves viewing safety.

While it is true that Hawaiian eruptions are generally some of the most approachable eruptions on our planet, molten lava is extremely dangerous material. The value of having a scientific understanding of eruptions is that it can provide useful predictions about the behavior of lava during an eruption. However, volcanic eruptions are an uncontrollable force and even scientists with many years of experience are continuously learning new things about them. It is easy to get into trouble by overestimating your ability to anticipate all of the potential dangers. Volcanic eruptions are very dynamic and conditions change with time and also vary depending on the terrain or position on the flow field.

Composition of Lava

Aside from referring to lava as molten or solid, volcanologists make distinctions between lava flows based upon their composition or chemical makeup. The chemical composition defines a range of lava types, broadly from basalt to rhyolite. Composition

Chemical composition of the four main extrusive volcanic rocks. Silica is the dominant part of all of them. Other elements such as strontium, barium, rubidium, copper, etc. are measured in parts per million (ppm) or parts per billion (ppb) and are too insignificant to register on this diagram.



relates to the appearance, viscosity (stickiness), temperature, and mineral content, as well as to how explosive an eruption might be.

Although lava is composed of many chemicals, the most important are silica and oxygen, the two most abundant elements on Earth. In rocks they combine to make the compound silica dioxide (SiO_2). This sounds like a strange substance, but both window glass and the mineral quartz are made of nearly pure silica. Most volcanic rocks range from about 50% SiO_2 to 75% SiO_2.

Lava with low silica content, basalt, is generally almost black to medium gray in color. Rhyolite has high silica and is generally light gray to white. (The exception to this is black glassy obsidian flows.) There are many variations in between basalt and rhyolite and a lot of names that we don’t need to be concerned with in Hawai‘i.

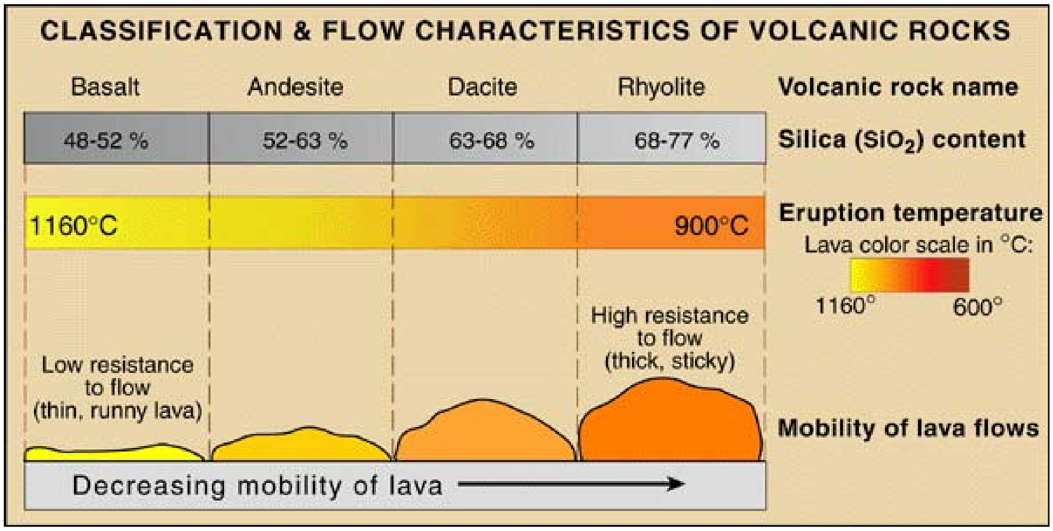
In general, the lower the silica content of molten lava the more fluid it is. Basaltic lava tends to be very fluid and forms thin flows ranging from a few feet to a few tens of feet thick. Rhyolitic lava tends to be very sticky and forms either thick flows up to several hundred feet thick or large near-vent piles called domes. The oceanic crust and most ocean islands are made up of basaltic lava, whereas most rhyolites are found on the continents.

In Hawai‘i, nearly all of our lavas are relatively thin basalt lava flows. An exception to this can be found on the west side of our island where “trachyte” (about 60% silica) lava flows more than 100 feet thick emerged from Pu‘u Wa‘aWa‘a cone around 100,000 years ago. This type lava is not found on Kīlauea or Mauna Loa volcanoes.

Differences in the overall shapes of volcanoes generally reflect these compositional differences as well. Hawaiian volcanoes tend to have a low sloping form called a shield in reference their broad curved profile. Shields are formed by repeated eruptions of fluid lava flows that can flow long distances from their vents. More silica rich volcanoes such as Mount Rainier or Mount Fuji, form steep–sided cones as their stickier lava flows do not move far from the vent.

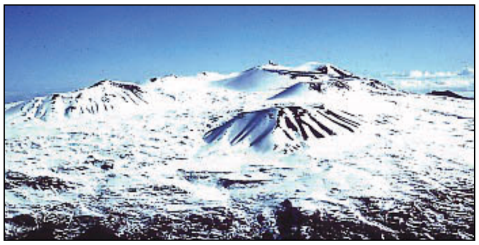
A similar, but more-subtle distinction can be made between the smooth, rounded shape of Mauna Loa volcano versus the more peak–like appearance of Mauna Kea. This difference reflects a difference in composition between Mauna Loa lavas and the last lavas erupted from Mauna Kea.

Samples of basalt (left) and rhyolite (right).

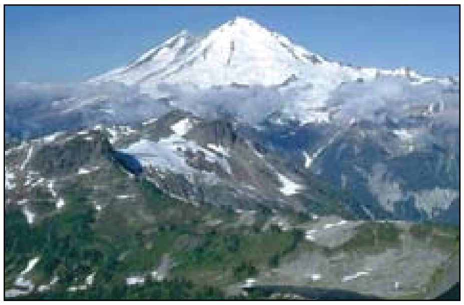


Comparitive characteristics of the four basic volcanic rock groups. Silica content affects temperature, which in turn affects the viscosity, or stickiness of a lava, which makes it more or less resistant to flow.

Mauna Loa. Example of a shield volcano. USGS Photo.



Mauna Kea blanketed with snow. USGS Photo.



Mt. Baker in Washington state is an example of a strato volcano. USGS Photo.

Lava Crust Types

Basaltic lavas generally form solidified crusts of two distinct types that are broadly used to identify lava flows: ‘ā‘ā and pāhoehoe. Anyone who spends even a little time hiking on recent lava flows quickly gets acquainted with the difference between the relatively smooth surface of pāhoehoe flows and the rough, clinkery surface of ‘a‘ā flows. These Hawaiian names are used around the world to distinguish between these two very different types of lava crust. The smooth lavas were given the name pāhoehoe in reference to the ropey and swirled textures that look similar to swirls produced in by canoe paddles in water. ‘A‘ā flows were named for their appearance similar to glowing embers or coals in a fire. Native Hawaiians, acutely aware of the differences between the two types of lava, commonly used slabs of pāhoehoe lava to pave trails through the much rougher ‘a‘ā lava flows.

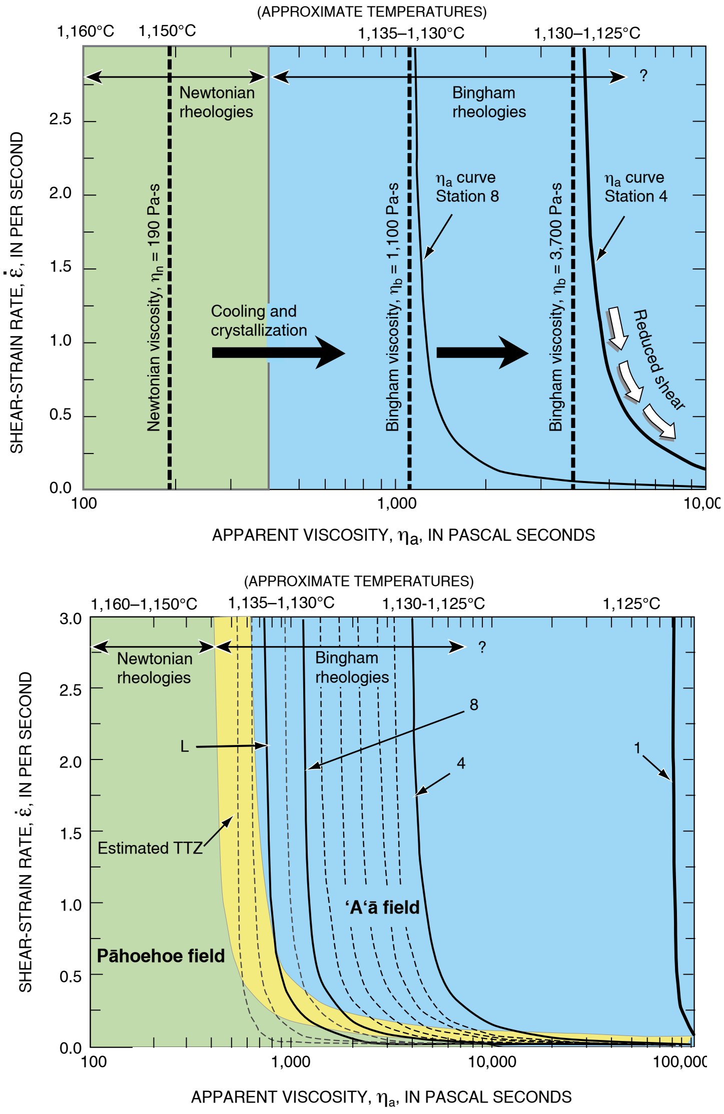
‘A‘ā and pāhoehoe flows can be found on all of the volcanoes of the Big Island. In general, there tends to be a higher percentage of pāhoehoe on the younger volcanoes, Kīlauea and Mauna Loa, and a greater percentage of ‘a‘ā on the older volcanoes, Hualālai, Mauna Kea, and Kohala. Much of the ‘a‘ā on the older volcanoes has been covered by soil and vegetation, making it much less obvious than on Kīlauea and Mauna Loa.

On Kīlauea and Mauna Loa, pāhoehoe lavas are much more common near their summits, while the amount of ‘a‘ā tends to increase with distance from the vent. The one exception to this is the flat coastal plain on the south side of Kīlauea volcano, which is almost entirely made up of pāhoehoe. ‘A‘ā flows are more prevalent on the steeper slopes of Mauna Loa than the more gentle slopes of Kīlauea. Types of Lava Crust Transitional Between Pāhoehoe and ‘a‘ā

The difference between pāhoehoe crust and ‘a‘ā crust is big, so it is probably not too surprising that there are several intermediate forms of crust. The most common transitional types in Hawai‘i are slabby pāhoehoe and spiny pāhoehoe.

Slabby pāhoehoe flows are easily distinguished by their upturned slabs of pāhoehoe crust. Whereas each of the individual crustal plates has a smooth pāhoehoe crust, the random jumbled orientation of these plates gives the flows a very rough and jagged appearance. This crustal texture requires relatively high strain rates in order to tear the crust into plates and to tilt and overturn the individual plates. Slabby pāhoehoe forms when

Top: ‘A‘ā lava flow
Middle: Pāhoehoe lava flow
Bottom: Slabby Pāhoehoe flow



Viscosity of lava flows.

relatively fast moving pāhoehoe flows become more viscous, allowing the molten lava to grab and rip the pāhoehoe crust into chunks.

Spiny pāhoehoe flows have toes and ropes that appear similar to normal pāhoehoe in general shape and continuity of the crust. Spiny pāhoehoe flows are covered by a rough spiny surface rather than the smooth shiny surface of normal pāhoehoe. The spiny texture is formed when the bubbles in the outer layer of molten lava are stretched and tear as the flow expands. The walls of the torn bubbles tend to form jagged edges that stand about __ of an inch or more above the surface. The amount of spininess depends on the number and size of bubbles present and how viscous the lava was when emplaced. In general, spiny pāhoehoe forms from slow moving, molten lava with relatively high viscosity and low strain rates. Spiny pāhoehoe flows commonly form as the last oozes outs of dying pāhoehoe flows or stagnating lobes of pāhoehoe flows. Spiny pāhoehoe also leaks from the edges and the fronts of some 'a'ā flows.

Why Is Lava Sticky?

Molten lava is a liquid, so many find it easy to compare its behavior to something familiar like water. Molten lava and water do share some important characteristics. For example, both flow downhill and both tend to follow low regions, such as valleys or gullies.

There are some important differences too. The most obvious is that lava is very hot! Water is fluid at temperatures above 32°F, while basaltic lava is fluid at temperatures of 2000°F and above. Additionally, lava is much stickier than lava. With respect to stickiness, lava is more like honey than like water. The "stickiness" of a fluid is called viscosity, which is simply the ability of a fluid to resist flow. Fluids with low viscosity, like water, flow easily. Fluids with high viscosities, like honey, (especially cold honey), resist flow and move more slowly.

Another way to look at this is to examine how quickly a fluid changes shape. Water poured from a glass to the floor nearly instantly takes the shape of the floor. Cold honey, fortunately, takes much longer to leave the glass and assume the shape of the floor. Therefore, water changes its shape much more rapidly when the same force (gravity and pressure) is applied. The force is called stress. The rate of shape change is called shear strain rate. Strain is simply a measure of how much an object's shape has changed. The amount of strain is simply the new length divided by the original length. Fluids with low viscosity change shape rapidly, while fluids with high viscosity change shape slowly when the same stress is applied over a given period of time.

Strain rates in Hawaiian lava flows are largely controlled by steepness of the slope the lava flows over (gravity) and by the size of the channel transporting the lava. The size of the channel is important because all lava is relatively viscous and will flow very slowly in a small channel. This is due to frictional drag on the channel walls. Cement would have a difficult time moving through a garden hose, but will travel rapidly through a large pipe due to reduced friction.

In lava flows, the most common reason for differences in viscosity is due to differences in chemical composition. Lava flows produced by melting of the mantle tend to be relatively fluid basalt (for example: ocean-floor and ocean island lavas), while lava produced by melting of the continental crust (which is much higher in silica) tends to produce very viscous rhyolite (for example: Ring of Fire volcanoes).

In Hawai'i, differences in composition may either be related to what was originally melted or to how long the magma was stored. Long periods of magma storage at shallow levels within the volcano results in cooling and formation of crystals, both of which greatly increase the viscosity of the lava. Using the honey example, crystallizing honey, of the less-desirable, stored-too-long crusty type, is less fluid than fresh warm honey.

On our most active volcanoes Kīlauea and Mauna Loa, however, the compositions are so close that they are generally not as important in determining viscosity as other factors such as temperature (hotter flows are much more fluid, colder flows more viscous like hot and cold honey), water content (adding water makes the lava more fluid just like adding water to honey makes it thinner), and amount of crystals (adding crystals makes the lava much more viscous like crystallized honey).

We can think of the fluids that compose lava flows as being of two types. The first type of fluid acts a lot like water and moves in response to very little stress. Every time it is pushed it moves. This type of fluid is called Newtonian, after the famous physics guy Sir Isaac Newton, (the guy who got hit on the head with an apple and invented physics to get even). Newtonian fluids are easy to deal with because low Newtonian viscosities appear runny to us and high Newtonian viscosities appear sticky. They are easy for humans to tell apart. To tell the truth, there are no lava flows that are truly Newtonian, but some are close enough that we can fudge the facts and call them Newtonian. In Hawai‘i, these “nearly” Newtonian flows are mostly pāhoehoe and are typically very thin and fluid when being emplaced. Heights of the fronts of active flows can be used as a rough measure of viscosity of the fluid (a puddle of honey is thicker than a puddle of water). The fronts of active pāhoehoe flows vary from a few inches to about a foot thick in Hawai‘i.

Another type of fluid is called Bingham, after a much less famous guy. Bingham fluids appear more or less solid until enough stress is applied to make it start moving. Toothpaste is a good example of this. A small amount applied by an adult to a toothbrush more or less stays in place. In contrast, the 25 tubes of toothpaste your toddler just squeezed onto the bathroom floor will begin to flow to the child’s great delight. Bread dough and silly putty are other less-fluid examples. These fluids have an internal strength (called a yield strength) to initially resist flow, but then as additional stress is applied they begin to have a Newtonian–like appearance. Bingham fluids create a number of problems for human observers as they appear to us like Newtonian fluids. Unfortunately, a fluid with a uniform Bingham viscosity will appear extremely sticky or even solid when stationary under low stress, but may appear very fluid when moving rapidly under high stress (cement is a good example of this). Bingham lava forms lava flows that typically are quite thick (5–50 feet) and are generally ‘a‘ā flows. And like all subjects, there are many more strange and wonderful types of fluids out there in the real world than we are prepared to talk about.

Types of Lava Crust Transitional Between Pāhoehoe and ‘A‘ā

The difference between pāhoehoe crust and ‘a‘ā crust is significant, so it is probably not too surprising that there are several intermediate forms of crust. The most common transitional types in Hawai‘i are slabby pāhoehoe and spiny pāhoehoe.

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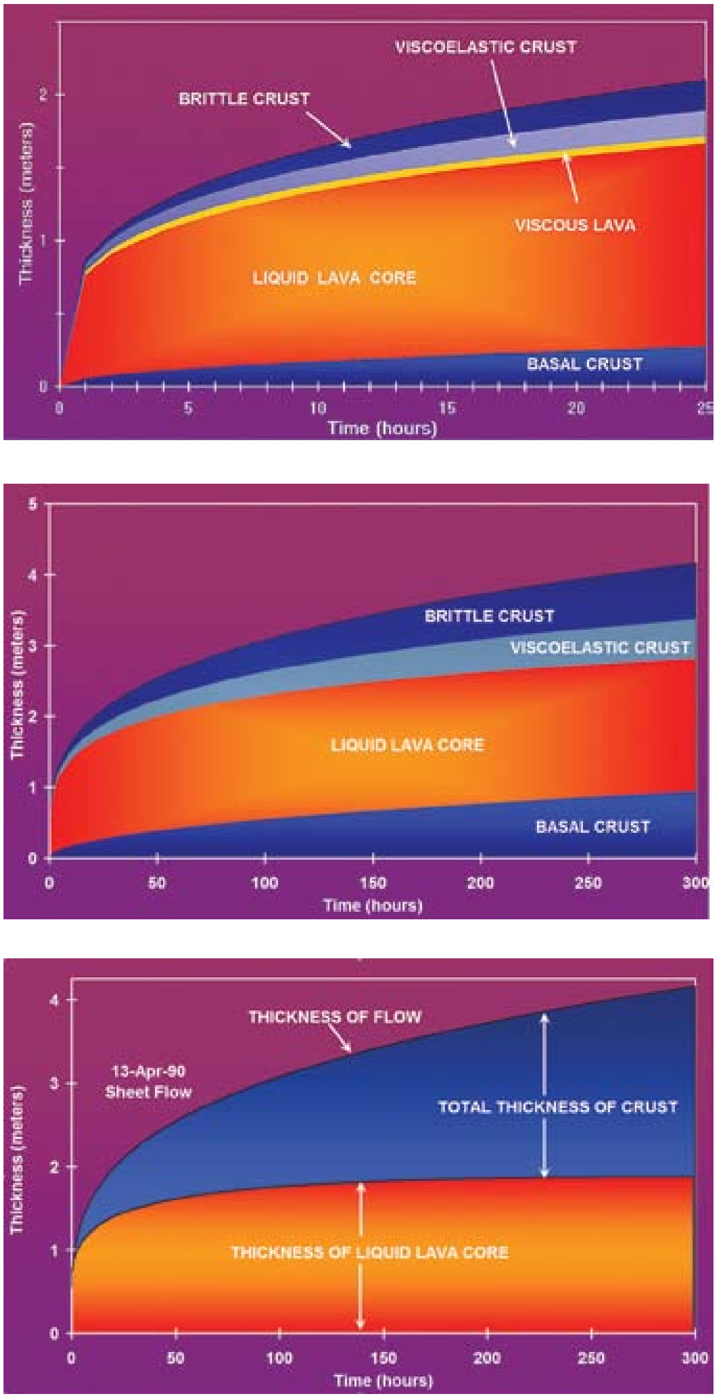


Graph depicts the change in the thickness and viscosity of the crust over time. The inner core is kept hot and liquid by the remarkable insulating properties of the rapidly developing crust.

What Causes ‘A‘ā and Pāhoehoe?

Lava flows behave really differently from fluids we are familiar with because they are a combination of a very hot fluid interior and an outer layer that is constantly cooling to form crust.This combination also greatly influences the thickness of a lava flow. The crust may vary from a very thin, plastic layer on fast moving channel to thick, hardened rock on the surface of slow moving pāhoehoe flows. ‘A‘ā and pāhoehoe crusts are related to the viscosity of the lava that produced them, the shear strain rate (rate of tearing), and how coupled the crust is to the underlying lava.

Pāhoehoe crust is generally smooth and unbroken. This suggests that the fluid was fairly low viscosity and was not exposed to high shear strain rates that would have torn and broken the crust. Pāhoehoe crust is similar to ice forming on a stream or river. Even though the stream may be moving rapidly beneath the ice, the water is sliding smoothly against the ice and not transmitting much force. The same thing happens in pāhoehoe flows, the molten lava is so fluid that it cannot grab and tear the crust.

In contrast, the torn, jagged crusts of ‘a‘ā flows indicate that the underlying molten lava is more viscous and able to effectively transfer force (high strain rates) into the overlying crust, tearing it to pieces. In order for ‘a‘ā crust to form, the molten lava must have a significant internal strength that allows it to remain attached to the crust and tear it. ‘A‘ā flows must form from Bingham or more complex fluids and much of their behavior has been attributed to the formation of submicroscopic plagioclase crystals as the lava cools.

Strangely enough in their final cooled forms, pāhoehoe has the more-solid surface crust, while ‘a‘ā flows are covered with a layer of loose clinker torn from the flow. A look at the interior of an ‘a‘ā flow confirms the presence of a very solid core of hard, dense rock that at one time was the molten flow interior.

In the simplest terms, it would be easy to just say that pāhoehoe forms from nearly Newtonian fluids and ‘a‘ā forms from Bingham fluids. Early studies on Mauna Loa volcano revealed that hotter near-vent lava tended to form pāhoehoe crust. As the flows traveled from the vent areas, they cooled, degassed and tended to form ‘a‘ā crusts. These observations fit neatly with the change from Newtonian viscosities to Bingham viscosities away from the vent. Ground slope remains more or less constant over the lengths of many of the observed flows and was largely overlooked.

Scientists observed that flows on Kīlauea Volcano commonly travel as pāhoehoe flows from flat areas near the vents southward to the steep hillsides known as palis where the increased strain rate of the lava traveling down the steeper slopes favor the formation of ‘a‘ā. In some cases, lava flows that reached the bottom of the steep slopes, slowed down and resumed production of pāhoehoe crust. The slope/crust type relationship does not always hold; pāhoehoe is found on slopes and ‘a‘a on the flats.

What we have learned is that while lava with Newtonian–like viscosities produce only pāhoehoe, lavas within a range of Bingham viscosities are capable of producing either ‘a‘ā or pāhoehoe crust, depending on the strain rate.

Emplacement of ‘A‘ā and Pāhoehoe Lava Flows

The most common image that people have of lava flows is of open “rivers” of lava flowing for miles down steep slopes. Large lava channels were common during high-volume Mauna Loa eruptions and some large eruptions of Kīlauea, but they don’t occur frequently and are generally are short–lived, lasting only a few days or weeks. During the past 20+ years of the Pu‘u ‘Ō‘ō –Kūpaianaha eruption, large open channels of lava are the exception rather than the rule. And most of these occurred during the initial 3 years of the eruption. It is more common to see short sections of small open channels or no active channel at all if a lava tube has formed. Many visitors are so conditioned by television, that when confronted with slow moving pāhoehoe toes, they often wonder where the “real” eruption is. The fact is that lava moves very effectively in several different ways.

Bob Decker of the USGS is getting ready to measure the advance rate of an ‘a‘ā lava flow that is advancing toward Kalapana.

Thin, runny pāhoehoe lava flows

ʻĀʻa flows

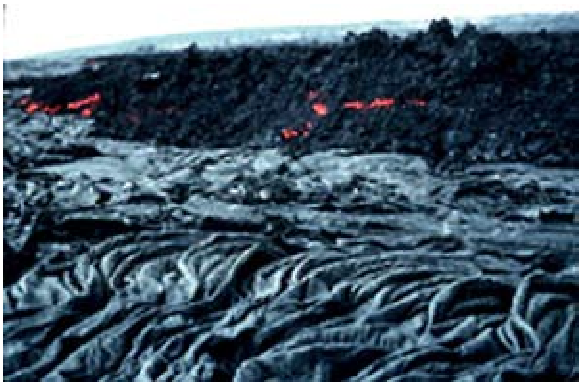
ʻAʻā flows are generally fed by large systems of open channels that may extend a few hundreds of yards up slope of the front on small flows, to several miles up slope on much larger lava flows. When a large amount of lava begins to flow most moves directly downhill, but a small amount will move sideways along the edge of the flow. The molten lava that moves sideways stagnates and cools quickly to from lateral ridges called levees (in water, levees are long linear dams used to keep rivers from flooding the surrounding area). The construction of levees constrains the lava in a channel where it can move rapidly downhill. As the lava reaches the flow front it spreads out over a broad area making a fan shape. The flow front is much wider than the channel so it moves much more slowly than lava in the channel itself. The edges of the fan slowly moves forward while it's edges form new levees allowing the channel to propagate down slope. ʻAʻā flows with open channels tend to lose a lot of heat as they move down slope (they become very viscous) and can become very sluggish, particularly when they encounter flatter ground. Closed channels, or lava tubes, are discussed in the next chapter.

The levee walls are inherently stable and can collapse into the channel. The pieces of levee walls can produce local overflows that increase the channel height or even permanently block the channel creating a branch in the lava flow. Changes in the amount of lava moving down the channel, called surges, can also cause channels to overflow unexpectedly. Both of these processes can create unpredictable changes in the path and velocity of ʻaʻā flows. The rapidity of change and potential for hazard is greatly enhanced around large channels flowing down steep slopes, the type of flows Mauna Loa is famous for producing.

Pāhoehoe flows

Large pāhoehoe flows may also form open channels very similar in cross section to the ʻaʻā channels. The only major difference is the levee's are construct of pāhoehoe lava rather than ʻaʻā lava. Smaller pāhoehoe channels and long-lived large channels eventually crust over and form lava tubes.. Lava tubes insulate the lava and allow it to travel long distances without losing much heat (see section on Lava Tubes). Even though it takes surface pāhoehoe flows much longer time to cover the same ground as ʻaʻā flows, when constrained in lava tubes they can travel much greater distances that the larger ʻaʻā flows. For example in the early stages of the Puʻu ʻŌʻō eruption, huge channelized ʻaʻā flows traveled 5–6 miles from the vent in less than a day. Generally ʻaʻā flows made it no further than this as the eruptions were typically only 10–20 hours long. Since 1987, pāhoehoe flows with lava tubes have consistently moved a distance of 8–10 miles before petering our or entering the ocean. Keep in mind, however, these flows generally take weeks or months to move the same distance as the large ʻaʻā flows moved in a day.

Pāhoehoe lava that reaches nearly flat ground tends to spread out and slow down allowing a crust to cover the entire flow front. Because there is no pronounced downhill direction of travel, the flow spreads fairly evenly in all directions and no levees form. Lava toes at the fronts of these flows tend to coalesce and form a "sheet–like" body of molten lava beneath the pāhoehoe crust. As more molten lava enters the flow front it pushes up the surface of the pāhoehoe flow in a process called inflation. The fronts of pāhoehoe sheet flows can inflate as much as 3 feet in an hour, producing a relatively thick lava flow. (Note: Lava Flows and Lava Tubes video has time-lapse sequences in the Inflation section that illustrate this process.) Sheet flows tend to follow low regions, fill them in with lava that inflates to produce a ridge. This process is called topographic reversal, where a low spot is turned into a high area. Hawaiian sheet flows may inflate up to 10–20 feet over a period of weeks. During this time, the lava in the molten flow interior cools slowly from the edges and eventually produces a lava tube in the central portion of the flow.



ʻAʻā and pāhoehoe lava flows juxtaposed.

Very low-volume pāhoehoe flows emplaced on slopes or flat areas with lots of micro topography tend to produce a third type of pāhoehoe flow called hummocky pāhoehoe. In these flows, the individual toes are either pulled down slope into long fingers or are separated by topographic barriers that prevent them from coalescing. Instead of a continuous molten core, the interior of these flows is made up of a myriad of interlaced, small capillary tubes. These tubes can easily become clogged due to cooling, causing pressure to build up within the flow. The localized blockages cause circular or elliptical uplifts called tumuli to form on the flow surface. Most tumuli range from about 10–50 feet in diameter and can be 5–20 feet high. Tumuli give hummocky flows an extremely lumpy appearance.

Definitions and Concepts

ʻAʻā—The rough, clinkery type of lava crust

Pāhoehoe—The smooth, ropey type of lava crust.

Slabby Pāhoehoe—Transitional lava with upturned slabs of pāhoehoe crust.

Spiny Pāhoehoe—Transitional lava with pāhoehoe form, but very rough, spiny surface.

Shelly Pāhoehoe—Billowy lava with large hollow folds or "shells" that forms near vents.

Viscosity—The ability of a fluid to resist flow

Shear Stress—The tearing force applied to a fluid

Strain Rate—How fast a fluid changes shape in response to an applied shear stress

*NOTE see **GLOSSARY** at end of this book*

Minerals

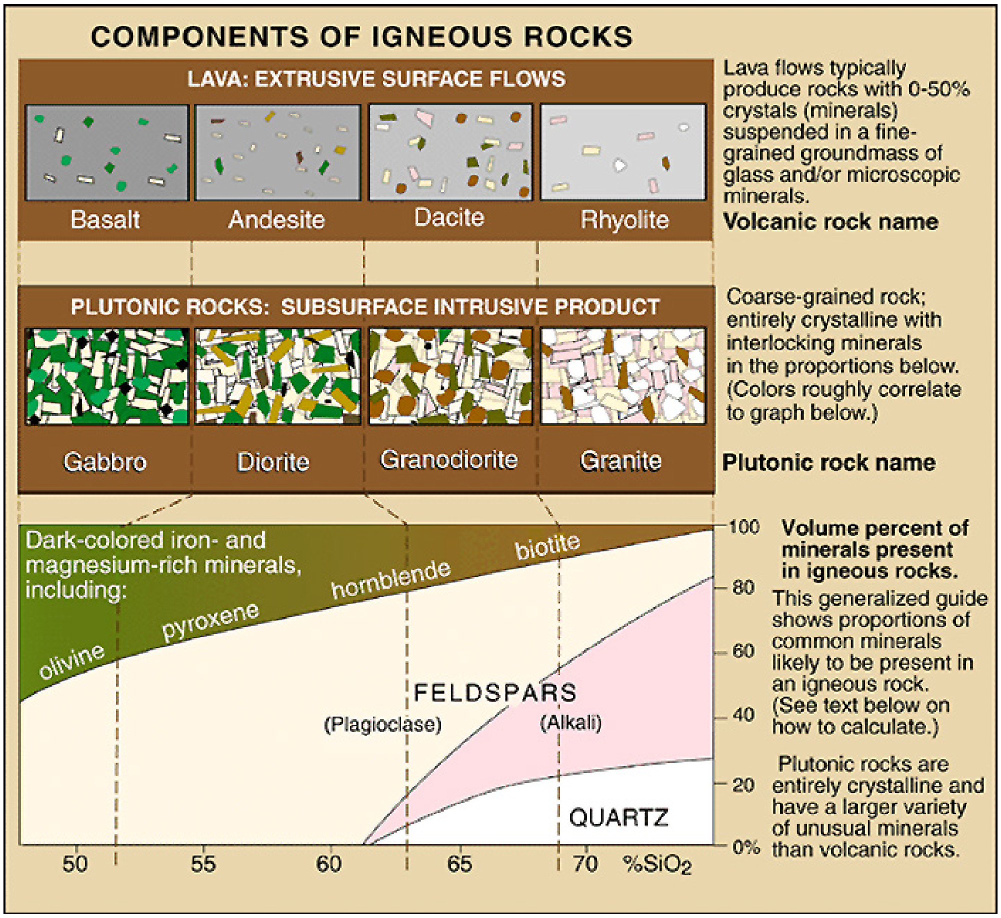
If you look closely at a piece of rock from a lava flow on the Big Island, you can generally see small minerals of different colors. Sometimes this requires a magnifying glass, but many can be seen without magnification. The major minerals that form Hawai‘i’s basaltic rocks are silicates, which means they are largely composed of Silicon (Si) and Oxygen (O), the two most abundant elements that make up our planet.

The best known of these minerals is the green mineral called olivine. Olivine is named for it’s olive green color. It has high concentrations of Magnesium (Mg) and Silica (SiO2) with some Iron (Fe). Basaltic lava flows are the only type of lava flow to contain easily visible olivine. In Hawai‘i, olivine generally is the first crystal to form. Many people know the gem form of olivine as peridot.

Pyroxene, a dark green to black mineral, is present in all of the lava flows but is only large enough to be visible in basalts lava flows on the Hualālai, Mauna Kea, and Kohala volcanoes. The name pyroxene means “fire stranger” in Greek, evidently because people originally thought they were accidental “victims” picked up by passing lava flows. Pyroxene is made up mostly of Iron (Fe), Magnesium (Mg) and Silica (SiO_2) with a little bit of Aluminum (Al). Pyroxene is the second crystal to form in Hawaiian magma.

A white or gray mineral, called plagioclase (a type of feldspar), is also found in almost all of the lava flows but is generally so small that it cannot be seen. Plagioclase is Greek for oblique fracture and is named for the way it breaks. Plagioclase is made up of Calcium (Ca), Sodium (Na), Aluminum (Al) and Silica (SiO_2). Rocks with visible plagioclase can be found on all of the Big Island’s volcanoes, but are relatively rare. On Kīlauea and Mauna Loa, rocks with plagioclase only form when lava is stored at shallow levels in the volcano for a long time. Really large plagioclases can be found in many stream boulders in Waipio Valley on Kohala volcano. Plagioclase is the last of the major minerals to form in Hawaiian magma chambers.

Minerals that are big enough to see in Hawai‘i invariably began to form when the lava was stored underground in a magma chamber (a large underground body of molten rock). So if the minerals are large enough to see with your eye, then they formed underground.



Olivine—Silicate mineral containing iron and magnesium. A green glassy mineral formed at high temperature. Gem-quality olivine is called peridote.

Plagioclase—A member of the feldspar mineral family. Plagioclase feldspars are silicates that contain considerable sodium and calcium.

Glass and the Color of Lava

The colors of lava flows in Hawai‘i can also be a bit misleading. Most recent lava flows have a black or very dark surface color due to a large amount of iron in the outer crust. The surface of ‘a‘ā flows is much duller than that of pāhoehoe flows. This is due to the spiny, rough surface texture (formed when the chunks were torn apart) that absorbs rather than reflects light. In addition, there is much less glass in the crust of ‘a‘ā flows due to the large amount very tiny plagioclase crystals that form in the molten lava as it cools..

The outermost crust of young pāhoehoe lava flows is made mostly of glass. Volcanic glass is simply molten lava that cooled so quickly that it froze without any new crystals forming. These glasses are similar to window glass except they contain large amounts of iron and magnesium. When the glass is very thin, such as in Pele’s hair or some pumices it is a beautiful shade of golden brown. The thicker glass layers on flow surfaces appear very dark and are often black due to the iron and magnesium in them.

There are a wide variety of textures on the outside of pāhoehoe flows. Bubble–rich lavas with produce an outer skin with a fibrous texture produced by stretching the bubbles into long tubes (on shelly pāhoehoe stretching of large bubbles can produce textures similar to Pele’s hair). Light entering these stretched bubble tubes gives the surface of many of these flows a golden brown sheen. On highly viscous flows, the bubbles in the outer layer cannot stretch, but instead pop and form coarse, spiny textures. The surface of these flows is usually dull black. On flows with very few bubbles, a very shiny surface of dense glass forms. This surface is highly reflective when new and varies from silver, to bluish silver, to black in color.

The surfaces of some lava flows, but especially the dense ones, can become iridescent. The glass may have an extremely thin layer of bright blue, gold, green, or purple. These iridescent colors are similar to those produced by small amounts of motor oil or gasoline floating on water. The thin boundary layers diffract light into different colors rather that either absorbing or reflecting light. The iridescent colors are common not only on pāhoehoe flows, but in glassy deposits of spatter and pumice near vents as well. The process that produces these colors is poorly understood. This virtually guarantees that is one of the questions most asked by visitors! We think that these colors may be produced by reaction of titanium in the glassy crust with the surrounding atmosphere. This reaction produces titanium compounds probably containing nitrogen. Similar reactions are responsible for the same types of colors seen in titanium jewelry.

Generally, the glassy crust of new lava flows is less than an inch thick. Road cuts through the same flow show that most of the interior is gray in color. The interiors of lava flows cool much slower than the outside skin and allow small microscopic crystals to form. These crystals are mostly made up light colored plagioclase and less black pyroxene giving an overall gray appearance to the rock. Sometimes the plagioclase has a bluish gray cast, which has led to many people referring to the hard, crystalline flow interiors as “blue rock”.

When lava flows are exposed on the surface for a long time, they may become more brownish or even orangish gray in color. This change in color occurs as iron in the surface crust of the lava reacts with oxygen in the air and rain, causing the iron to oxidize. We are all familiar with a similar process where iron in steel combines with oxygen to form rust.

Generalized Terms

Olivine—The green mineral in Hawaiian basalt
Pyroxene—The black mineral in Hawaiian basalt
Plagioclase—The white mineral in Hawaiian basalt
Glass—Lava on the flow surface that cooled too quickly to crystallize

Questions.

1. How do the large visible minerals form in Hawaiian lava?
2. What is the first mineral to crystallize from most Hawaiian lava?
3. What color is Hawaiian glass when it is very thin?
4. Why is the surface of lava a different color than the interior?
5. Which mineral is most common as visible crystals in Hawaiian lava?
6. Which mineral makes up most of the microscopic crystals in the interior of a lava flow?
7. Why does volcanic glass form?

CHAPTER 2
LAVA TUBES

Lava tubes are long sinuous cave systems that once carried lava from the erupting vent to downslope locations. Formation of lava tubes results in the most efficient method of transporting lava. Lava tubes occur near vents, on steep slopes, and on the flat ground near the ocean. In fact, they can be anywhere on a volcano. These subterranean tunnels can be found in lava flows throughout the world especially in basalt flows. There are thousands of lava tubes on the Big Island.

Lava tubes are both fascinating and dangerous. It is important to recognize the location of active lava tubes because they occur beneath the often-thin, solidified surface of the active flow field. Older inactive cooled lava tubes can also pose hazards. (See section on Hazards.)

Photograph of [name of tube here] lava tube in [location, state here]. Lava stalagtites appear to drip from the ceiling. Horizontal band on wall shows a high-lava level toward the waning stages of the tube.

Hawaiian Culture and Lava Tube Etiquette

Lava tubes were very important to native Hawaiians both for sustaining life and for maintaining ties to one's ancestors. They served as a source of water and shelter. In dry areas, the cool, damp environment of collapsed lava tubes could be used for farming. Many lava tubes were also sacred and served as burial sites. Iwi kupuna (bones of the old ones) were placed in lava tubes. The mana (divine power) of the iwi kupuna and the ʻaina (land) would flow together.

With the exception of Nahuku (Thurston) Lava Tube, it is illegal to enter any of the lava tubes in Hawaiʻi Volcanoes National Park without being accompanied by a ranger. Lava tubes outside of the National Park should be treated with great respect and should never be entered without direct permission of landowners or the appropriate government agency.

Never take food into a lava tube, and pick up any trash you may find and carry it out. Do not touch the walls, as the delicate formations found in lava tubes are easily destroyed and will not grow back. Lava tubes house a number of unique and unusual creatures and touching the walls can disrupt or destroy their ecosystems.

Please be respectful of Hawaiian cultural sites! If you come across any archeological materials, do not disturb them and leave the cave immediately. It is not only illegal to disturb any archeological sites, but it is particularly kapu (forbidden) to remove items from burial sites. Doing so disrupts the flow of the mana of the kupuna to the ʻaina. The sacred bond that connects the living and their ancestors is lost.

How do Lava Tubes Form?

The most common way for lava tubes to form is by the crusting over of an active lava channel. This is roughly similar to how a water stream channel might freeze in winter, while still allowing water to flow beneath the surface. Other lava tubes form within inflated sheet flows as the molten core moves forward in an enclosed system of multiply advancing flow fronts that solidify at the leading edge. Solidified lava is an excellent thermal insulator, The crust insulates the lava and allows it to travel great distances while losing less than 1° per mile traveled. When the eruption ceases, lava commonly drains out of the tube, leaving behind a cave system. If the lava doesn't drain out, the lava solidifies in the tube and it doesn't form a cave system that can be entered.

Crusting over of Lava Channels

Lava channels in both pāhoehoe and ʻaʻā flows can crust over to form lava tubes. A thin, plastic film of cooler lava forms on the surface of the stream where it is in contact with air. Flows with small channels tend to crust over very rapidly, while those with large, or quickly moving channels may take considerable time or may even fail to crust over before the eruption ends.

Crust begins forming immediately on the sides of active lava channels as it chills against cooler rock. At the edges of the channel, the lava is moving more slowly due to friction along the channel wall. This allows the plastic surface lava to roll up and adhere to the channel wall. The rolls form parallel to the channel edge and are generally less than an inch wide and several feet long. These small rolls are continuously added to the edge causing the crust to grow inward over the active lava stream.

Initially, the new crust at the channel edge is very thin and it makes approaching active channels extremely dangerous, as it is difficult to determine what is solid ground. During the Puʻu ʻŌʻō eruption, an HVO geologist accidentally stepped on new crust on a channel margin. The crust gave away and he slipped into the channel up to his knees. The geologist survived and recovered quite well, but had to spend half a year in the hospital. You can see his "fire proof" Nomex flight suit on display in Jaggar Museum.

As the crust on lava channels continues to grow inward, it also cools and thickens. Overflows from the channel may also coat and thicken the growing crust. The overall texture on the surface crust resembles irregularly braided cords. These differ from ropes in that the texture extends for long distances parallel to the direction of flow, which is generally more or less down hill. Ropes are folded crust that are aligned perpendicular to the direction of lava travel. Since ropes typically form on very small lobes, they tend to reflect the local topography and do not necessarily point in the regional down slope direction.

Formation of a complete "roof" of crust over the channel usually takes place either near the source first or at narrow spots along the channel. Crust growing directly from the source region produces a V–shape pattern of "corded" crust, with the apex of the V pointing upslope. This is because the crust grows from the upper edge as well as the sides. Crust forming right at the upper edge may have a fine zig–zag pattern due to growth of crust in a saw tooth–like pattern.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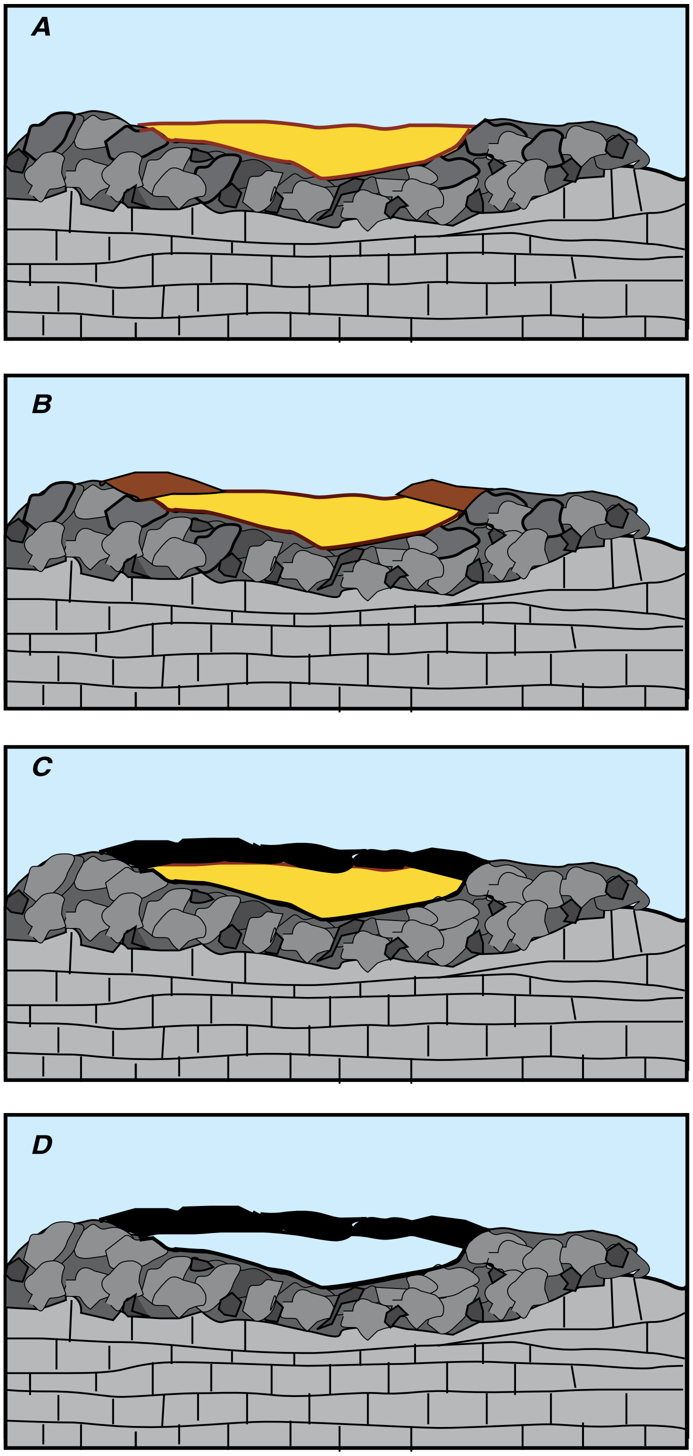
Top photo shows open channels atop an ʻaʻā lava flow spilling a thin mantle of pāhoehoe over its banks. Channel on the right is beginning to tube over in two locations. The thin "plastic" crust on the flow on the left shows as a gray snakeskin moving down the center of the flow.
The lower photo is a closeup of a channel entering a tube (away from the camera). The sides are forming cooled rolls that are building inward.

In narrow parts of the channel, the crust first grows inward until it either crusts completely over or begins to constrict the flow of lava. If left open, pieces of crust formed upstream on the channel are commonly rafted into the constricted section and finish sealing it up. On the uphill side of the roofed over section, more crust can pile up and cool together as a series of plates. Lava may spill over onto the edge of the new crust or pile up against it as ropes and cause the crust to grow upstream. Or it may simply continue to grow from the edges. Downstream, the crust continues to grow from the edges forming the distinct corded or braided texture indicative of a crusted channel.

Roofed over channels vary from about a foot wide to as much as 50–100 feet wide. Most commonly the channel roof is about 10–30 feet in width. The channel roof in long tubes can be traced intermittently over great distances. The surface of crusted channels stand out as smooth highways in otherwise jumbled volcanic terrains. They are particularly attractive for their easy walking, but should be avoided as it is difficult to tell how thick or sturdy the roof actually is. In places the crust may be extremely thin. Stay on the margin or levee of channels where the lava is thickest and strongest if you are walking along a lava tube. Avoid the center of the crust!



A. Graphic cross section of an ʻaʻā flow shows rubbley base and sides with lava channel down center. Layered bedrock below.
B. Lava begins solidifying in from the sides as a skin forms on the top.
C. Lava-tube formation is complete. If stream persists the floor will melt. (See section on Erosion and Deepening of Lava Tube.)
D. Inactive lava tube after lava input is shut off and tube empties.

Right Top: Skylight in etc etc [need full description]

Right Bottom: needs description of breakout

Small channels tend to form arched roofs as they crust over. This is because the growth of crust inhibits the flow of lava through the channel, causing the level to rise. As each successive piece of crust forms, it does so at a higher level. The center of the crust on small channels is commonly occupied by ropey textures. Another variant of smaller crusted channels is when lava forms “draperies” as it flows over steep slopes and cliffs. The tubes that form in these instances tend to be hollow and very fragile making walking across them dangerous.

Thickening of the Roof and Breakouts

Once the lava channel becomes roofed, the crust continues to grow downward. The thickening crust reduces the area inside the newly formed tube for lava to flow. The lava then must either flow faster or begin to back up in the tube system. This generally results in a build up of pressure within the constricting tube system. In places, lava breaks the surface of the new crust and creates small flows that cover the original channel roof.

This process serves to thicken the roof of the lava tube and also bury the lava tube more deeply within it’s own flow. While this is a great way to insulate the lava, it can make finding lava tubes much more difficult. The breakouts tend to be pāhoehoe flows with abundant toes and ropes that can coat much of the original channel. Large numbers of breakouts or leaks from the channel roof can completely coat the original lava flow. Lava tubes that begin in ʻaʻā flows can be hard to identify if they become thoroughly coated with pāhoehoe over time.

From Flow Lobes to Sheet Flow to Lava Tube

A

B

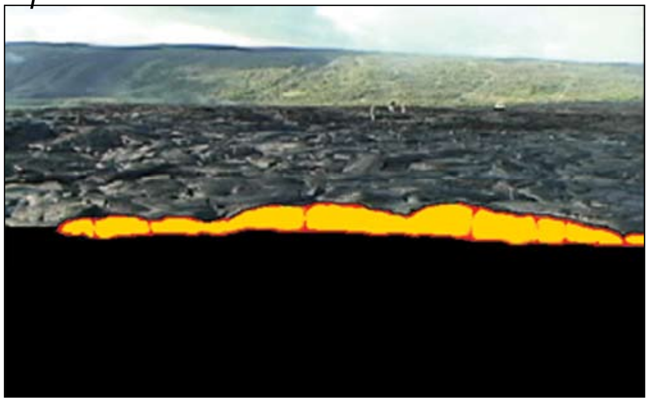
C

Figures ***A-C*** on left show a series of pāhoehoe flow lobes approaching the camera [poor quality due to video capture]. The individual lobes meet, coalesce, and begin rise as the influx of lava beneath the surface pushes the overlying rock upward. Figures A_1-C_1 show a graphic interpretation of cut-away view of the same lobes, if we could slice the ends off the lobes to expose the liquid interior. Figure A_1 shows individual liquid-filled “toes” only 4-8 inches high. These toes coalesce and continue to grow as a large “sheet” flow. C_1 shows the liquid interior thickening to more than 20 inches high as the roof is pushed up. Figure ***D*** is an interpretation of what might happen over the course of a day. With continued influx of lava the surface might push up as high as 50 inches or more, and concentrate all activity in one or two central conduits, or lava tubes. The weaker side breakouts would continue around the edges until the tube gets well established..

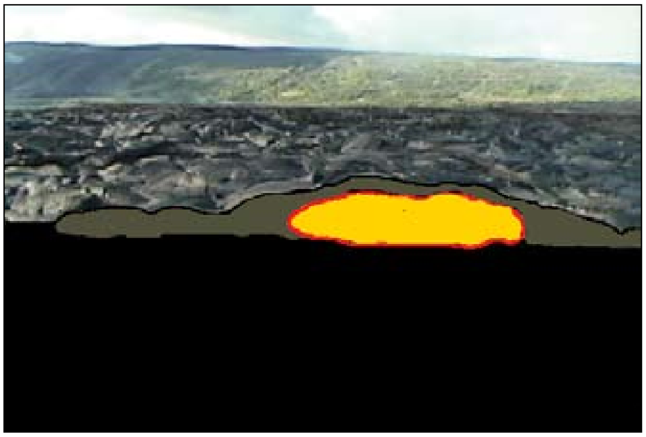
A_1

B_1

C_1

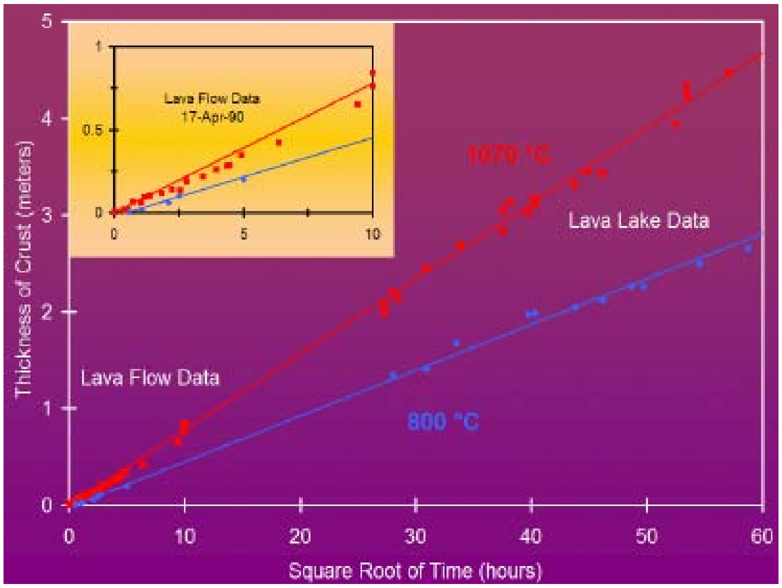


D



Tube Formation in Inflated Sheet Flows

For a description of inflated sheet flows, go to the subsection “Pāhoehoe Flows” in Chapter 1, section “Emplacement of ‘A‘ā and Pāhoehoe Flows”. Figures ***A-D*** on opposite page show progression of a lava flow over a period of hours. If the flow were to continue to have an input of lava over an extended period of days to weeks, lava in the molten flow interior cools from the edges and eventually produces a lava tube in the central portion of the flow.



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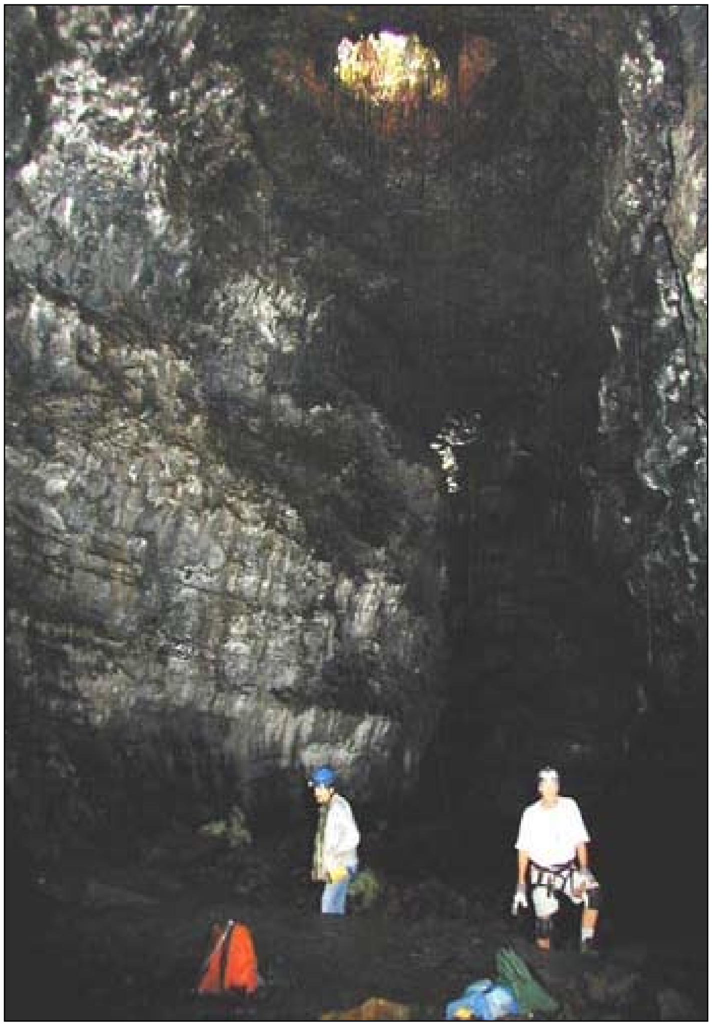


Cavers examine the walls of this unusually tall lava tube; light from skylight is directly overhead. This tube likely deepened from thermal erosion of the floor during long-lived lava stream.

Erosion and Deepening of the Lava Tube

Lava rock is an excellent insulator, such that the thick roof that forms over either a channel or an inflated flow prevents heat from escaping. In fact, the ground over a lava tube is generally only a few degrees warmer than the surrounding region and the excess heat can be difficult to detect on a sun-warmed lava field. This insulating property is confirmed by temperature measurements that show that the lava river flowing below ground will lose less than 1°C per kilometer (less than 1°F/mile).

Over a period of a few weeks to a month, the lava river and the heat trapped inside the lava tube begins to melt the floor, walls, and even the ceiling of the tube. As the wall rock and floor partially melt, they become mushy and the lava can begin to erode its base. The flowing lava, while it evokes thoughts of water, really has a density greater than concrete. That means that even if the stream looks fluid and easy, it begins to pluck away and erode the mushy rock at it’s base, causing the lava tube to deepen. As the tube deepens, it’s shape changes from the original wide and shallow cross–section of the stream to more circular or elliptical in shape. Original lava channels that were only 5–10 feet deep can erode and make tubes that are 10–30 feet or more high. If the lava stream flowing within the large tubes maintains a 5-foot depth, that leaves a lot of open space within the active tube.

The height of the ceiling may also increase if the roof begins to collapse into the lava tube. This generally happens due to thermal contraction and expansion weakening the roof. Pieces of the roof that fall into the lava tube are either swept away and form lava balls or they form large collapses that plug the tube system and ultimately force the backed-up lava to the surface. See description of changes in the ceiling during melting of the wall rock in the section on Lava Tube Formations.

Lava Tube Formations

Lava tubes often contain remarkable formations due to the combined effects of intense heat and oscillating lava levels within the tube. One of the first things that visitors notice when visiting cooled lava tubes is the very rough, almost ‘a‘ā like material on the floors of many lava tubes. The rough lava on the floors contrasts with the smooth pāhoehoe of the ceiling and walls. In the waning stages of an eruption, or when a lava tube becomes blocked, the amount of lava flowing through the tube begins to dwindle. The loss of lava causes an immediate loss of radiated heat and the tube begins to cool. The shallower lava stream also loses heat much more quickly and the lava can become very viscous allowing an ‘a‘ā –like crust to form. The tubes may also cool enough so that the entire lava stream may crust over and form a tube within a tube. Many of these tubes have very spiny lava textures on their surface crust.

Changes in the level of the lava stream within an active lava tube create interesting coatings on the inside of the tubes. If the tube develops a blockage downstream or experiences a surge in lava supply, the lava level rises and applies a new coating of lava to the tube interior. Repeated coating of the walls creates a concentric layering of the tube walls that can be seen where pieces have broken off. When the lava rises all the way to the roofthen recedes, it leaves drips that form triangular stalactites called shark’s teeth. If the lava only rises part way up the tube, it leaves a high lava mark or “bath tub ring”.

If the lava gets backed up filling the tube, it either pours through open skylights or bursts open the roof of the tube. These breakouts can form new lava flows and create stacked tube systems.

Intense radiated heat within lava tubes causes the tube walls and roof to partially melt. As this melt forms it reacts with the high levels of atmospheric oxygen in the tube. The outer portion of the melt forms a layer of iron oxide minerals in response to this reaction forming a shiny crust on the walls and ceiling. This shiny iron oxide crust is visible in the “wild”, unlit part of Nahuku (Thurston) Lava Tube and also easily seen in Kaumana Cave. This crust can fold and crinkle in response to gravity forming “elephant–skin” textures, as well as a wide variety of drips and even small lava flows.

Soda Straw Stalactites

Soda straw stalactites are thin-walled, hollow tubes that grow downward from ceilings and overhangs in still -hot lava tubes and drained tumuli. These can also form around a skylight in an active tube where air chills the melt. Unlike their limestone relatives which form when water percolates through cool rock and picks up minerals in the rock, these form where the roof or wall rock melts under high temperatures. The reaction of the drips with air in the lava tube forms a metallic crust (made up of a mineral called magnesioferrite) that constructs the wall of the soda straw. Subsequent drips of melt pass through the straw and lengthen it s downward into a long straw. This melt, incidentally, looks exactly like a drip of clear water, quivering on the end of the straw until it gets enough volume to let gravity pull it off. The walls and the roof of the lava tube are partially molten, containing 10-20% melt. This melt has a lot of water dissolved within it. (The water doesn’t escape as steam because its little H2Os are stuck to the other elements in the melt in a chemical reaction that is beyond the scope of this section.) Careful examination of true elongated soda straw stalactites shows that they form on the roof in areas where lava once filled the entire tube, or beneath ledges when the lava once rose to that depth or deeper. As long as there is pressure from lava when the tube is filled or active, the melt within the roof and walls cannot escape. As soon as the tube drains, however, the drop in pressure allows the water in

Long fragile soda straws hang from the roof of this unusually pristine shallow lava tube. Stalagmites, which formed from the drips of melts falling from the straws, rise like sentinals from the floor. Photo by Bill Halliday.

the melt to immediately expand into steam. This is similar to the pressure release that causes bubbles to form in soda when the top is opened. The steam bubbles within the melt cause a large volume increase and force the melt out of the roof and walls. This expansion of the melt produces not only soda straws, but spherical buds, and small "eruptions" of lava from the walls and even the floors of lava tubes. The features appear very smooth on the outside due to the formation of a coating of metallic minerals, but they are laced with foamy holes on the inside that were formed by steam bubbles. These steam bubbles also force individual drips of melt out of the soda straws, much like blowing a bubble on a straw.

In an active tube the drip falls into the lava stream and is carried away. In a hot, inactive tube the melt drops to the floor of the tube where it piles up as stalagmites. The stalagmites are made up of clusters of raisin-sized droplets that can build columns up to 2-3 feet high. They are wider at the base because of the spreading effect when they fall. The fact that the stalagmites are preserved on the floor of the tube demonstrates that they formed after the lava quit flowing within the tube. This has led to the popular idea that something causes the temperature inside of lava tubes to rise dramatically right after the lava ceases flowing, possibly due to burning of hydrogen or other gases, causing melting of the roof.

Skylights

Skylights are openings where the roof of the lava tube has collapsed. The name comes from the idea that the holes in the ceiling of inactive lava tubes act as a skylight for anyone inside the tube. On active flows, the skylights appear as holes in the ground that provide spectacular windows into the active lava tube.

When skylights first open up, the lava stream inside the tube is exposed providing great viewing. The open channel radiates enough heat to cause the entire interior of the lava tube to glow brightly. In fact, the roof and walls of the tube are usually less than 100 degrees F cooler than the lava itself. Over time, cool air entering the skylight causes the lava stream within the skylight to crust over. Eventually, many skylights will form an inner roof and seal themselves completely shut.

Skylights form on the steeper slopes where the lava tubes can be quite large. Approaching these skylights can be dangerous and should always be done with great caution as the ground around them is obviously weakened, otherwise there wouldn't be a skylight. Never walk close to a skylight without getting a good view of the area that you are going to walk onto; make sure the crust is thick and stable. The air coming out of the skylight is extremely hot and can cause burns or temporary blindness.Always approach skylights with the wind at your back and never get on the downwind half of the skylight. Always limit the number of people around a skylight to 2–3 at a time. Find a good viewing position well away from the edge of the skylight and in a place that is not over the underground lava stream. Only visit skylights that can be approached safely.

Left: Gravitational collapse of roof enlarges the skylight and litters the floor. Photo by Bill Halliday.

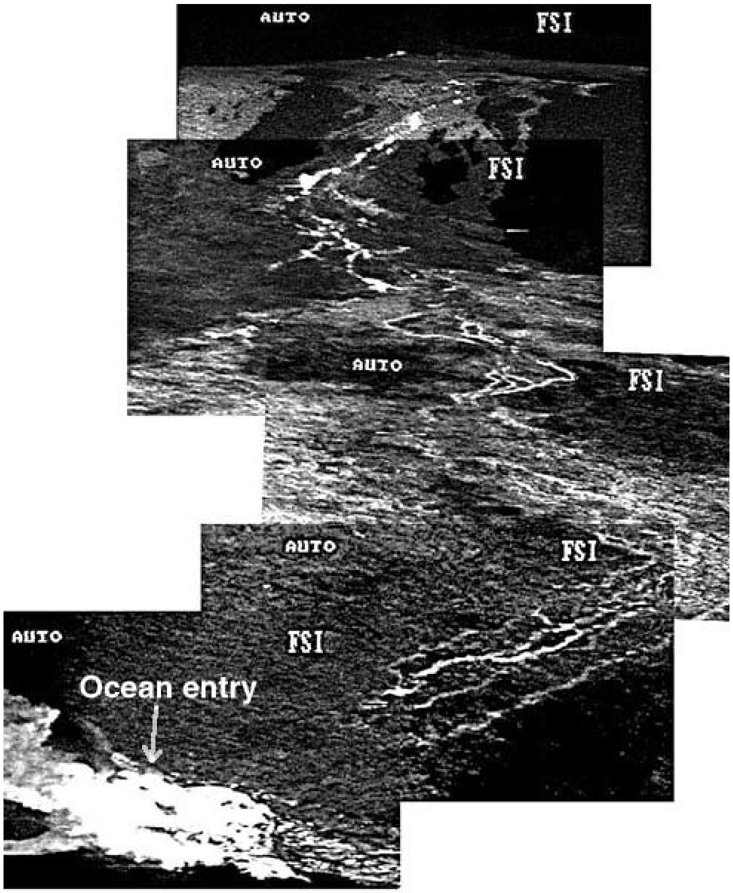
Below: Without knowledge of this flow field it would be difficult to figure out where the lava tube is located as it winds from the near skylight to the distant shoreline where lava is entering the ocean creating the steam plume. USGS photo,

How to Recognize an Active Lava Tube

Active lava tubes can be difficult to recognize in the field but there are some clues to their location. They often have no well-exposed skylight like in the photograph on the right, which gives an indication of just how thin the ceiling (your floor) is.

When a channel roofs over it leaves distinct corded or braided crustal textures. These are an important indications of the presence of a lava tube. Unfortunately, the original crusted channel is often covered by later pāhoehoe flows. In some cases, like inflated sheet flows, it never formed.

The best indication of an active lava tube is a more or less continuous series of cracks that emit gas rich in sulfur (SO_2, sulfur dioxide). Generally, scattered areas of strong sulfur fumes mark the trace of active lava tubes. Sulfur dioxide has a distinctive sharp smell and a bluish coloration that makes it easy to tell from regions that are producing white steam by heating groundwater. Native sulfur may actually form within these cracks making a coating of yellow crystals which rapidly oxidizes and forms powdery, white deposits of sulfate minerals.The dusting of white minerals often looks like a lousy spray paint job.



Infrared images of a lava tube system shows braided streams. Standard photographs of the flow field and ocean entry would not show the lava streams. In these infrared images, the white areas are hot areas which indicate that there is hot lava beneath the surface, and the dark areas are cool rock or water. The water at the ocean entry shows that it, too, is heated. Over time the many channels will consolodate into one or two larger tubes.

Skylights occur along some tubes and can be located by identifying their plumes of heat waves. The hot air causes wavy distortions that can be seen from several hundred yards away.

Not all lava tubes produce visible surface signs. Be aware that if you are near active lava and there is no visible feeder channel, then the source must be a lava tube.

Hazards Related to Lava Tubes

See Chapter 12: Understanding the Hazards on Lava Flow Fields for understanding how to approach a skylight.

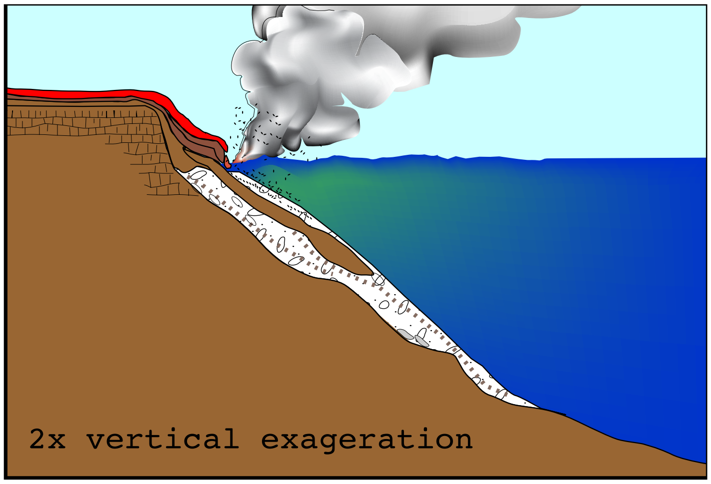
Geophysicist Jim Kauahikaua leans an ‘ōhia pole through skylight into a shallow lava stream to guage the depth. His location was determined after careful study of the location of the lava tube as well as by knowing the history of the tube.

USGS scientists in gas masks prepare to take a sample from an skylight in the Pu‘u “Ō‘ō flow field.. The bluish toxic gas cloud is typical around skylights and requires protection of a good SO_2 filter to protect your lungs. Note that it might be easy for a novice to ave walked past this skylight, but not easy to walk through the sulfur dioxide fumes.

CHAPTER 3
LAVA ENTERING THE OCEAN

There are few things more beautiful or more dangerous than lava entering the ocean, which provides the most spectacular viewing accessible on foot.. Unfortunately, the worst injuries and fatalities have occurred at or near there. Visitors approaching these areas are commonly completely unaware of the hazards. This is understandable. Unlike vent areas that have a more dramatic landscape and where visitors are much more aware of their safety, ocean entries can appear to be passive, and the streams of lava seem to beckon. Hidden dangers lurk both underfoot, where seemingly stable ground can fall away violently, or seaward where smaller rhythmic waves belie the occasional rogue waves. These events have caught many visitors unaware causing deaths and critical injuries. The interaction of hot lava with the salty ocean also produces laze, the hydrochloric acid-laced steam clouds ("plumes") that are often laden with tiny glassy particles. The acid irritates the skin and fine glass particulate can injure the eyes.

Lava entering the ocean at Kamoamoa. Acidic steam plume, "laze", is drifting off shore. Photograph by T. Jane Takahashi, USGS Hawaiian Volcano Observatory



Above: Illustration of fragmental pile of loose debris with intercalated lava flows building an unstable surface on the steep submarine slope.
Below: Within hours to days a black sand beach can form near the ocean entry. The fragile glassy fragments are rolled around in the surf and swept along by the waves and ocean currents.

The Construction of New Land

After a protracted march down slope from vents high on the east rift zone, lava flows finally reach the ocean. Surface flows are quickly quenched as they enter the water, shattering to particles of glassy sand and rubble. The sand and rubble particles form poorly consolidated layers that cling tenuously to the submarine slope. The topography of the ocean floor off the southeast coast of Kīlauea is very steep. Within 3,300 ft (1000 m) of shore, the bottom descends 1000 ft(300 m); this precipitous slope is maintained down to a depth of nearly 3,500 meters (11,500 ft).

When the fragmental pile is able to gain a foothold on the steep slope the resultant new land, built along the older eroded coastline is called a "bench". As the ocean entry matures, lava enters the sea via near-surface tubes encased within the bench, building outward at the ocean edge. Beneath the water, unseen from the shore, lava flows form long tongues of pillow basalt with occasional elongate channels that extend up to 70 m down the steep submarine slope.. In addition to the seaward growth of the bench, the bench is also mantled with capping lava flows, a particularly deceptive cover as described in the next section.

Because of easy access to ocean entries during the Pu‘u ‘Ō‘ō eruption, Hawai‘i Volcanoes National Park has been very active in trying to educate visitors about the dangers of ocean entries. Please heed all Park signs.

A newly formed lava bench can look peaceful as it beckons the uneducated to move closer for a look. Several people have been killed or severely injured during a bench collapse and when an unusual “rogue” wave washed over the new land creating a superheated environment.

Lava Bench— A lava delta, known as a bench, grows seaward as lava enters the sea and builds a foundation of loose lava fragments on the submarine slope. The platform of debris is subsequently capped by pāhoehoe lava flows. Lava tubes at the edge of the bench can reside below or at sea level, due to the continuous and sometimes abrupt subsidence of the new land.

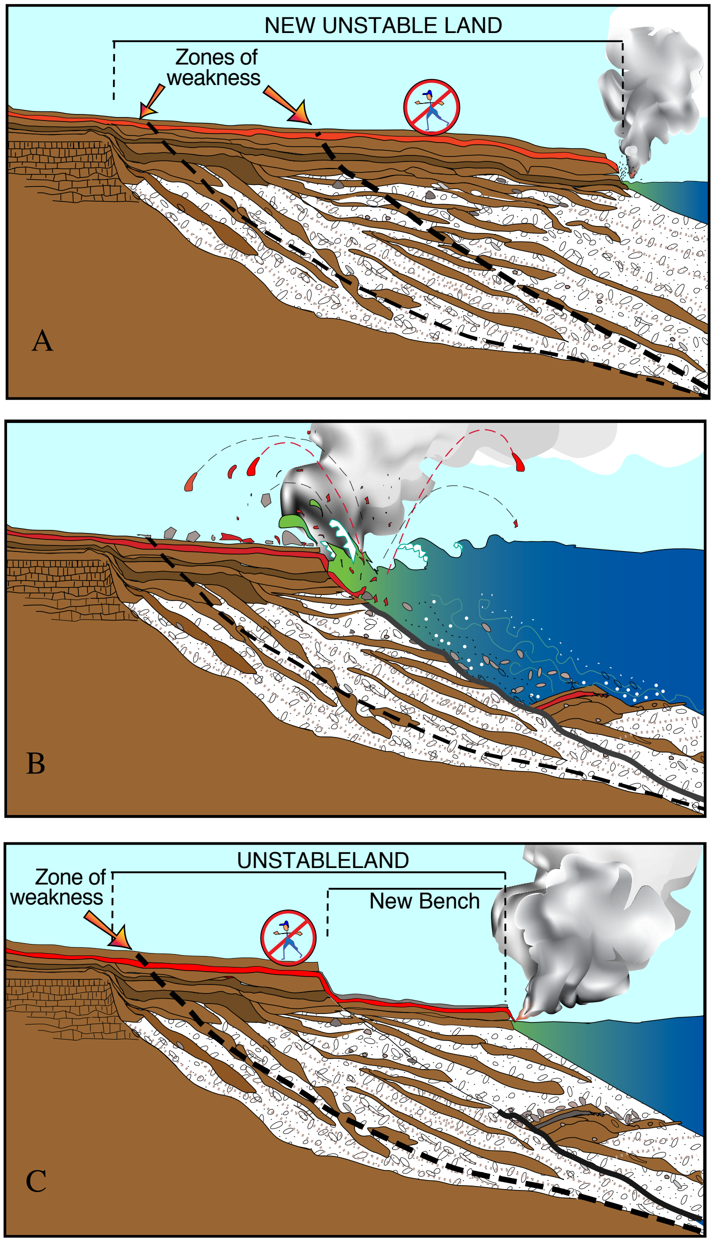
Collapse of New Land

The most violent and dangerous steam-driven explosions occur when the growing edge of a lava bench suddenly collapses into the sea. Capping lava flows that cover the fragmental pile create an illusion of rock-solid stability. The bench is essentially a lava-coated pile of sand and loose debris. Wave action can erode sand from beneath the bench, and without any basal support the leading edge of the new land constantly calves off.

We cannot emphasize enough that this over-steepened debris pile is a poor foundation for the new land. In fact, the entire bench often tumbles, as a submarine landslide, down into the deep basins offshore, carrying its load of new lava flows. This process is occurring wherever new land has formed.

Since a growing delta may collapse or subside at any time and the intensity of any one type of explosion may change suddenly, it is critical that it be viewed from behind the former sea cliffs. For people standing on the delta or its leading edge, these sudden steam-driven explosions can be fatal.

For long-lived benches the rate of erosion may be slow often taking decades to finally disappear On the Pu‘u ‘O’o flow field the rate of erosion, due to the steep offshore slope, seems to be keeping pace with the new land that is being created. For all the years that lava has been flowing into the sea, only 510 acres of new land has been added to the island, and most of this was created when the shallow bay of Kaimu was filled.



Collapse and rebuilding of new land where lava enters the ocean. Graphics by J. Johnson.

Left: Bench Collapse and Re-construction—The new land formed at the ocean edge is comprised of deceptive lava flows manteling an unstable pile of fragmental debris.

A. Broad bench with person near the leading edge.
B. Collapse of part of the bench
C. New bench being built adjacent to the still-unstable bench. Entire pile can collapse over night.

Bench collapses are dangerous. One fatality and numerous injuries are attributed to earlier bench collapses. Hawaii Volcanoes National Park has posted signs near the ocean entry area to warn visitors from going onto the unstable bench. It is difficult to recognize the boundary where the bench begins, so let the posted signs be your guide. Stay back of these signs and stay alive

Lava-Water Interaction

When lava pours into the ocean from a lava-tube entry, spectacular explosions commonly occur. With temperatures higher than 2,000°F (1,10°C), lava can instantly transform seawater to steam, causing explosions that blasts hot rocks, water, and molten lava fragments into the air.

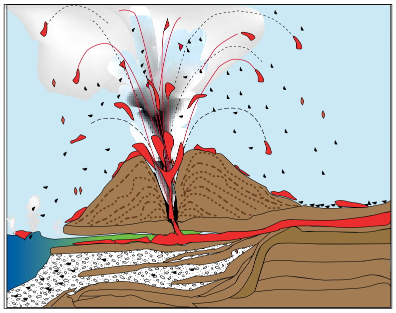
Unfortunately, the entry of lava into the ocean is difficult to observe from a distance because it's often obscured by an energetic and acidic steam plume or by an abrupt cliff above the entry point. This often invites visitors to jeopardize their safety by walking right up to and over the point where lava enters the ocean. Activity that may appear stable and non threatening can actually change without warning, leaving no time for escape. (See Hazards chapter for Hot Water At the Ocean Entry.)

Laze—The rapidly billowing plume of steam evolves into a gently wafting cloud that can drop acid rain (HCl, hydrochloric acid formed when lava enters the salty ocean) as well as very fine-grained glass particles onto hikers when it is blowing on shore. Wear hat as well as eye protection if you must walk beneath it.

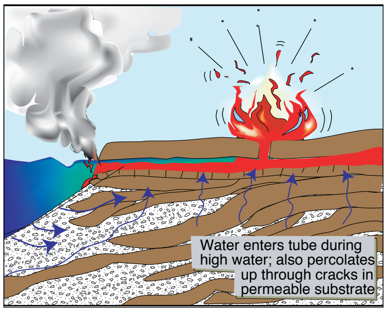
Tephra Jets (above)—The collapse of a bench's leading edge will sever lava tubes within the bench so that an open stream of lava pours into the sea and extremely hot rocks adjacent to the tube system are exposed to relatively cold seawater. When lava and seawater mix in such an "open" environment, two types of explosions may be generated: tephra jets (above) and rock blasts (right).

Rock Blast (right): This rock was lobbed 100 ft (30 m) inland during a partial bench collapse. Rock blasts can litter the landscape with fist- to boulder-sized rocks

Littoral lava fountains (below)—Littoral lava fountains build semicircular cinder cone build from the spatter and tephra during tephra jets. This molten and semi-molten lava falls onto the delta's leading edge constructing a heap of rubble as much as 50 feet high.



Bubble bursts may occur when the leading edge of a delta subsides allowing seawater to infiltrate the tube system. Bubbles can reach diameters of 30 ft (10 m) in less than 2 seconds. These bursts are frequently accompanied by a loud boom that shakes the entire delta.

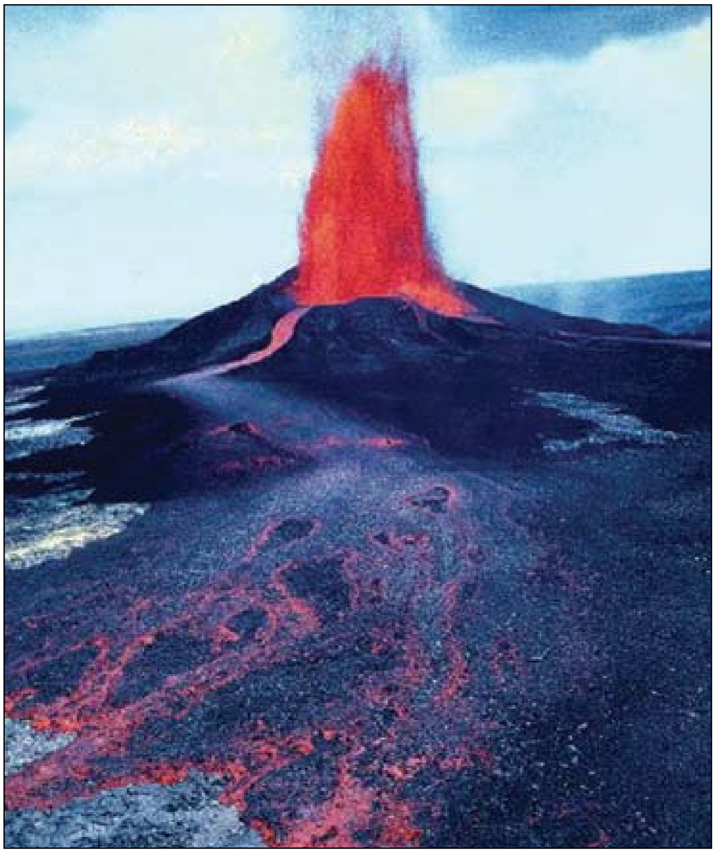


CHAPTER 4

Volcanic Vents: Habits, Hazards, and Brief Histories

Vents are outlets that allow material to flow from one place to another. Volcanic vents allow the magma and gases below the ground to escape the confinement and pressure of the earth and erupt as lava and related pyroclastic debris above ground. Common Hawaiian venting styles include fissures, fountains, and effusive eruptions. The longest-lived eruptions all go through each phase in that order. The size and shape of a vent has an effect on the style of an eruption, much like holding your thumb over the flow of a hose decreases the size of the hole, increasing the pressure thus the distance the water will travel.

The style of the eruption is driven by more than simple pressure on a liquid. With respect to volcanic vents world wide, chemistry of the magma, magma source, gas content, water content, temperature, volume of lava, substrate it is rising through, the pressure at depth all effect the eruption. The difference in eruption style for Hawaiian eruptions is chiefly affected by pressure, vent size, and gas and water content.



High fountaining events at Puʻu ʻŌʻō occurred episodically for 3 years building a high cinder cone and issueing forth broad lava flows.

Fissure eruption emits from long crack opens in the ground hurling lava 5-50 feet into the air.

Fissure Eruptions

Nearly all Hawaiian eruptions begin as fissure eruptions, whether at the summit or along the rift zone. This makes sense if you think of the fact that as the lava rises to the surface it is cracking the volcano, so it should be no surprise if the initial eruption comes from a crack in the ground. Fissure eruptions are the most common type of eruption to occur on Hawaiian volcanoes.

Fissure eruptions, erroneously called "curtains of fire", are among the more spectacular of eruptions, drawing people from all over the world hoping to revel in their grandeur. The eruption begins as a fine hairline crack in the lava rock that covers much of the rift zone. This happens as a magma-filled crack, called a dike, forces its way up to within a few tens or hundreds of yards of the surface. Gas and steam escape from the crack, as it grows longer, widening slowly until small clots of lava spit from the opening. Quickly lava emerges from the crack, forming a wall of erupting lava with individual fountains reaching 30 to 300 feet (10-30 m) high.

The fountains feed expanding lava flows that spread away from the crack or fissure. The flows adjacent to fissures are initially pāhoehoe but can change rapidly to ʻaʻā because of the loss of volatiles (gas) and heat as the lava is tossed into the air and ripped into smaller blobs. Lava often issues from the initial fissure for several hours, sometimes oscillating between vigorous effusion and more subdued flow. Frequently lava will pool near the fissure, drowning the fountains, while lava burbles out of the ground and flows continue unabated.

The surge of lava from a fissure during a rift zone eruption reveals some of the physics driving the eruption. As magma rises toward the surface, the pressure confining the fluid decreases. As this happens, water and other volatile compounds dissolved in the melt become saturated, which means there is too much in the melt and it wants to escape. Under high pressure, the water rests comfortably in the magma, much as gas ($CO2$) in soda pop rests in solution in a capped bottle. When magma rises to the surface, much of the water dissolved in it forms steam bubbles. These bubbles greatly increase the volume of the lava making it much less dense, but again by increasing the volume it increases

A fissure is a fracture or crack in rock along which there is a distinct separation. A fissure eruption ejects lava along the length of the crack. This Mauna Loa fissure eruption was short lived and did not evolve into a high-fountaining event.. Photograph by D.A. Clague in March 1984

Fumaroles are vents from which sulfur gas escapes into the atmosphere. Fumaroles may occur along tiny cracks or long fissures. They may persist for days to centuries depending upon the persistence of the heat source. Photograph by R.L. Christiansen on 27 July 1973

the pressure just before erupting, thus increasing the vigor of the eruptive process. The process is very similar to the bubbles that form in a soft drink when the cap is popped. Here as well, there is more of some volatile compound dissolved in the liquid than is possible at atmospheric pressure, so the excess gas forms bubbles that rise to the surface. In the case of soft drinks, the gas is carbon dioxide. For the young Hawaiian volcanoes, gas includes water (H_2O), sulfur dioxide (SO_2), and carbon dioxide (CO_2) in that order of importance. Carbon dioxide may play a larger role during eruptions of older volcanoes such as Hualālai and Haleakala.

The basalt that erupts from Kīlauea and Mauna Loa is 1% water by weight. As pressure on the lava decreases, it increases in volume by a factor one hundred to a thousand times, greatly expanding the melted rock into a foamy material. (To consider volume change, think of the density of soap when too much is added to a washing machine. What was 2 cups by volume suddenly increases to 100 cups of bubbles…more volume, less dense.) Most of the gas that is exsolved in this manner escapes at the surface and becomes part of Earth's atmosphere. Steam bubbles that are too small to escape the sticky lava become the small rounded vesicles that are so common on extrusive lava. Most lava flows, and indeed almost all spatter and bombs thrown out during an eruption have some degree of vesiculation. The most highly vesiculated ejecta, called "reticulite" has up to 99% air.

4-inch sample of reticulite

High Fountaining

High fountaining does not generally occur at the beginning of a fissure eruption, but tends to develop later in the eruption process, often after a hiatus when lava congeals and seals most of the fissure. As the eruption wanes, it leaves a glowing crack that reaches deep into the earth, belching sulfurous fumes. Sometimes this signals the end of an eruption, and these sulfur-rich cracks become fumeroles. But sometimes part of the crack remains open for some period of time while pressure in the summit magma reservoir continues to build. When this occurs, lava may again well up from the fissure, forming a new set of flows. With time the feeding conduit narrows and forms a localized cylindrical vent that acts like a nozzle. Lava, forced through a narrowed vent, travels rapidly upwards as the rapidly expanding gases provoke a dramatic show. This is the same thing that happens when agitated soda is propelled through the narrow opening of the bottle or when water shoots through a hose nozzle (though the water is not propelled by gas expansion).

The lava that feeds high fountains is generally stored for several days or weeks prior to each episodic outburst. As the pressure in the underlying magma chamber rebuilds, it forces dense, degassed lava out of the narrow vent. This heavier lava acts like the cork in a champagne bottle. Once it is removed, the newer, gas–rich lava rises quickly and expands rapidly as before. This removes even more weight from the underlying magma and soon all of the magma stored in the conduit begins to expand all at once, propelling melted rock into the air as if from a rocket engine pointed skyward. The vent itself is generally quite small, not more than 20–50 feet wide, but the jet of molten rock can reach up to 2000 feet high.

High fountaining tends to be periodic, lasting for several hours and then subsiding for days to weeks before repeating the cycle. The process is very similar to the cyclic behavior of a geyser, and the reasons for it are much the same, i.e., pressure buildup. Because of the regularity attending the periodic episodes of high fountaining, they can be predicted with some accuracy. The periods between fountains seem to increase with distance from the summit ranging from a few days at or near the summit, to more than 1 month down the rift zone.

Fountains can end with a fizzle or a flourish, and sometimes they just drown themselves with a rising lava pond. Volcanologists witnessing one eruption reported looking away briefly and when they looked back the fountains had vanished. On other occasions the termination of an eruption is followed by a tremendous release of gas roaring from the conduit so fast that clots of partially congealed lava are ripped from the inside of the conduit and thrown violently into the air. This degassing activity is very short lived, but impressive! Sometimes towards the end of a fountaining cycle the fountain pulsates, oscillating between fountaining and gas jetting, as if huge gas bubbles are being forced up the conduit. Eventually the nozzle–like vents collapse or breakdown, but if the pressure within the system is strong enough to push lava to the surface continuously a new effusive eruptive pattern takes place.

Lava flows generated by effusive eruptions erupting from the flanks of Pu‘u ‘Ō“ō have produced the highest volume of lava during the 20+ year eruption. Photograph by J.D. Griggs, January 31, 1984

Left: This lava fountain blasted pumice 1400 ft (425 m) above the vent during the Kīlauea Iki eruption. On the leeward side of the growing cone, the Crater Rim road was covered by 19 ft (6 m) of pumice in the late evening of November 28; 11 hours later, the pumice was 80 ft (25 m) deep! Photograph by J.P. Eaton, November 29, 1959

Effusive Eruption

An effusive eruption is vast the outpouring of lava onto the ground (as opposed to the violent fragmentation of magma in fissures and fountains). Lava flows generated by effusive eruptions vary in shape, thickness, length, and width depending on the volume of lava erupted (the discharge rate), slope of the ground over which the lava travels, temperature changes, lava tube production, and duration of eruption. Volumetrically they are the most important. When this effusive style of eruption occurs the lava piles up near the vent forming its own small shield volcano. Lava may then pond up in the center of the growing shields and can form football-field-sized lava lakes.The sustained effusive eruptions on the rift have the distinction of far greater coverage of land than the short-lived, but briefly high-volume fountain or fissure eruptions. Both the eruptions of Mauna Ulu (1969-1974) and Pu‘u ‘Ō‘ō (1983-present) evolved from fissures to impressive high fountaining, to relentless effusive flows.

Lava flows produced during this type of sustained eruption are fed by a lower rate of lava effusion and are more likely to form pāhoehoe flows. Pāhoehoe lavas build long tube systems capable of transporting large volumes of lava for great distances (up to tens of km).

Two Historic Fissure/Fountain Eruptions

Kīlauea Iki

The notable Kīlauea Iki eruption of November 14, 1959 began at 8:08 pm when several discontinuous fissures on the south wall of the crater began discharging lava. Within two hours the fissure grew to 1/2 mi (1 km) long with heights to 100 feet (30 m). By morning the activity waned greatly, and only one vent remained half way down to the base of the west end of the cliff (the crater was 800 ft deep). Over the next six days the rate of lava production and height of the fountain from that vent increased to 1200 ft. The peak discharge during this phase of the eruption was about 13,000,000 ft3/hr. That is 28,000 gallons per second! When the lava lake reached the level of the vent (by then the lava lake was 400 ft deep) the fountaining stopped. The phenomenon of a lava lake drowning an active vent was exquisitely displayed. Over the next 4 weeks there were 16 additional eruptive phases that ranged from 1 3/4 hours to 32 hours reaching as high as 1900 ft (980 m), the highest basalt fountain ever recorded. This eruption never made the transition to long-lived effusion.

Pu‘u ‘Ō‘ō

The Pu‘u ‘Ō‘ō eruption began on January 3, 1983 with a small fissure eruption in Nāpau Crater that migrated northeastward. The high fountaining came after a month-long hiatus. Episodic lava fountains as high as 1540 ft (468 m) were common during the first years of the Pu‘u ‘Ō‘ō eruption.

The increasing height of the vent on Pu‘u ‘Ō‘ō cone triggered a change in the eruption style. By the third year of the Pu‘u ‘Ō‘o eruption the cone was 1000 ft (~300 m) high and the vent was 600 ft higher than it was when the eruption began. It took greater and greater pressure to force the magma out and begin each new high fountain. Finally at the beginning of the 48th event (July 18,1986), part of the original fissure reopened at the base of the cone, now about 700 feet lower than the summit, and lava began to pour out all the time. Instead of having to wait a month for sufficient pressure to force magma from the vent, lava continuously welled up and overflowed the vent system. Two days later, the new fissures unfortunately migrated a 1 1/2 miles (3 km) down rift. The new fissure evolved into a single vent, later named “Kūpaianaha”. This was the vent site that fed the extensive flows that buried most of the town of Kalapana.

In 1992, after causing great destruction, the eruption moved back to Pu‘u ‘Ō‘ō, but found it a quite different landscape. The narrow conduit had collapsed leaving a large crater that began to fill with lava. Cracks in the base of the cone allowed lava to leak out continuously and begin to form shield structures around the original cinder cone. Today the crater keeps getting bigger due to collapse of the cinder cone and the shields surrounding the cone are getting close in elevation to the lava lake. Though numerous low spatter cones and dome fountains have formed at the base of the cone, it is very unlikely that we will ever see high fountains again because the narrow “gun-barrel” style of conduit necessary was destroyed long ago.

Pu‘u ‘Ō‘ō cone before (above, June 1992) and after (below, August 1997) the summit collapsed to form a crater. The small shield volcanoes that have grown on the flank of the cone continue to grow in 2004. Photographs by C.Heliker, USGS.

Hazards Associated with Vent Eruptions

High fountains and fissure events pose great danger to observers due to the voluminous amount of lava being thrown into the air. In addition, the amount of lava emerging from these vents is so high, it can produce enormous flows that can either over run observation points or encircle and trap you. A breakout of ponded lava cannot be outrun. Working safely around these vents generally requires direct communication with all other scientists on the ground as well as with the Hawaiian Volcano Observatory, and a helicopter standing by for emergency evacuation.

Large eruptions also release tremendous amounts of volcanic gases. These toxic plumes cause eyes and lungs to burn, impairing vision and breathing. In addition, they commonly contain minute particles of glassy material that can become permanently lodged in your lungs. It is imperative to have gas masks and eye protection when you are anywhere down wind of these eruptions. Fine glass and Pele’s hair can drift downwind for miles from the vents.

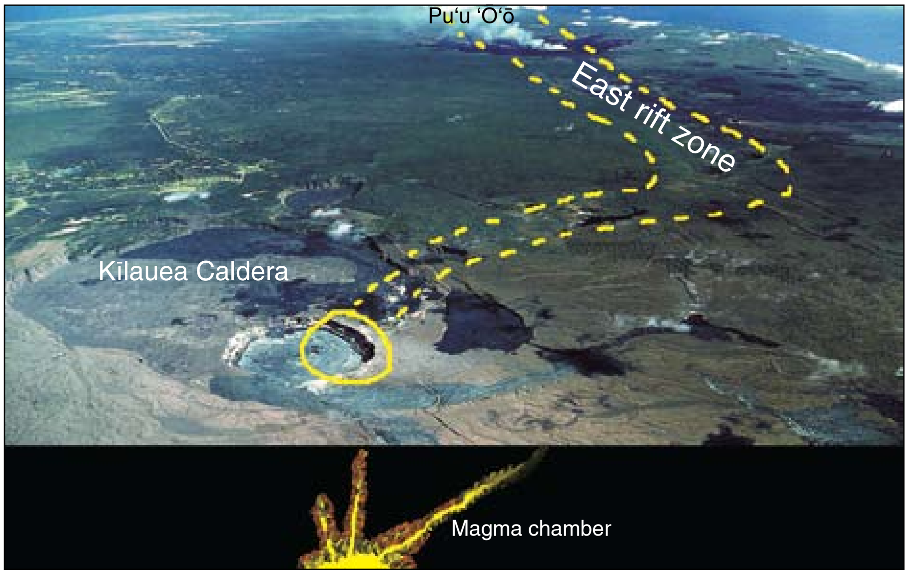
As underground pockets of lava reservoirs drain they leave large chambers with fragile roofs tops. Huge cracks open above these and collapse of these areas are nearly impossible to predict, but are part of the ongoing processes during an eruption. Currently, Pu‘u ‘Ō‘ō cone is collapsing into the underlying local magma chamber, and the area around the vents is extremely dangerous. The large shields forming on the sides and to the south of Pu‘u ‘Ō‘ō may house small covered lava lakes that can drain and leave gaping booby traps covered by a thin sheet of lava. In addition, overflows from the crater and these shields have produced large fields of treacherous shelly p_hoehoe that is impassible when hot. The shelly p_hoehoe can also cover deep cracks, as well as provide a fragile bridge over a still-molten interior.

Finally, the rift zones themselves are dangerous places simply because there are laced with deep crack systems. These are not so bad where you can see them, but on the heavily forested East Rift Zone of Kīlauea, a thin veneer of ash covers the cracks and 5–15 foot high stands of ferns and underbrush.

Collapse pits, such as this one on the southwest flank of Pu‘u ‘Ō‘ō, can appear overnight, giving pause for reflection for anyone who may have walked there the day before.

CHAPTER FIVE
Volcano Monitoring, Interpreting Precursors, and Forecasting Eruptions

The HVO Volcano Watch once mused? “Wouldn’t it be nice to have eruption forecasts as rich in detail as our current weather forecasts, watches, and warnings? “This is your Hawai’i County Civil Defense. There is an eruption warning in effect until 0800 Wednesday morning with a 10% chance of lava flows advancing faster than 1 km/hr.””



Aerial oblique view from Kīlauea summit caldera northeast to fuming Pu‘u ‘Ō‘ō cone in distance. Circle marks approximate birds-eye-view location above magma chamber ; dashed line showws approximate trace of Eeast rift zone.

That would be handy, and for surface flows it is essentially being done now. Unfortunately, the subsurface behavior of Earth is not as easily tracked as weather patterns that not only hover above the surface and are directly measurable, but are also visible by satellite cameras. Even with all that, there is no 100% accuracy on weather forecasting.

Volcano monitoring is a bit trickier. it involves recording and analyzing volcanic events not visible to the human eye, but measurable by precise and sophisticated instruments. These events include earthquakes (particularly those too small to be felt by people), ground movements (deformation), variations in gas compositions, and changes in local electrical and magnetic fields that respond to pressure and stresses caused by subterranean magma movement.

The Mission of the Volcano Hazards Program and the Hawaiian Volcano Observatory

The overall objectives of the Volcano Hazards Program are to advance the scientific understanding of volcanic processes and to lessen the harmful impacts of volcanic activity. The Volcano Hazards Program monitors active and potentially active volcanoes, assesses their hazards, responds to volcanic crises, and conducts research on how volcanoes work to fulfill a Congressional mandate (P.L. 93-288) that the USGS issue “timely warnings” of potential volcanic hazards to responsible emergency-management authorities and to the populace affected. Thus, in addition to obtaining the best possible

scientific information, the program works to effectively communicate its scientific findings to authorities and the public in an appropriate and understandable form.

The USGS VHP helps reduce the human and economic losses and disruptions associated with volcanic activity by 1) assessing and monitoring potential volcanic hazards, 2) providing warning information on volcanic activity and rapid monitoring response to volcanic crises, and 3) improving the scientific understanding of volcanic processes.

Background

There are many unknowns deep beneath the surface of the Earth. Much of what we have come accept as fact is often educated hypothesis based on surface evidence (rocks that formed at depth and have been thrust up to the surface) and subsurface geophysical evidence (seismic profiling). If weather forecasting is a hit and miss proposition because of the vagaries of pressure and temperature, you can imagine that predicting geologic phenomena must be even more so.

Accuracy in forecasting can only be accomplished by the collaboration of many scientists from many disciplines. Instrumentation must be spread evenly across a volcano to have a complete data set of comparative behaviors. Both data collection and interpretation are indispensable for interpreting volcanic processes, forecasting eruptions, and predicting the likely impacts of eruptions, thus make early detection of volcanic unrest possible.

Scientists continue to get better at it. Skills learned in Hawai‘i helped understand the precursors to the explosive Mt. St. Helen’s eruption; techniques used at Mt. St. Helen’s help avert great disaster from Mt. Pinatubo in the Philippines. Most of the scientists on the Volcano Hazards Team that respond to volcanic disasters worldwide have honed their skills at the Hawaiian Volcano Observatory.

Hawaiian Volcano Observatory

Kīlauea has been a fantastic laboratory for studying precursors to eruptions. Dr. Thomas Jaggar (see below), a scientist concerned with human safety around volcanoes, recognized this. In 1912 he set up the first volcano-monitoring observatory on the rim of Kīlauea Caldera with the belief that loss of life could be minimized by understanding how volcanoes work. The US Geological Survey took over direction of the facility in 1948 and in collaboration with scientists world wide, has continued to study all aspects of volcano's behavior. Their goal is not only to understand the behavior of volcanoes, but to provide the most accurate forecasts possible.

Volcano Monitoring

Monitoring volcanic activity, both visible and unseen, has evolved from dominantly hand-held-instruments and smoke drums, to chiefly computer and satellite operated equipment that collects real-time data far from the location of interest. This does not, of course, eliminate the need for the field component. Remote data loggers measure ground deformation, earthquakes, and gas. Cameras mounted on the rim of the active vent transmit to the world-wide web in near real time. Even with all the sophisticated equipment, highly trained scientists must interpret and reduce the data.

Dr. Thomas Jaggar--A Brief Biography

The ever-dapper Dr. Jaggar taking notes on crack measurements. From The Volcano Letters, No. 434, 1936

Jaggar was born in Pennsylvania in 1871, the son of an Episcopal Bishop. A childhood fascination with the natural world eventually translated into a Ph.D. in geology from Harvard University in 1897. His years as a graduate student and young professor were spent in the laboratory. He felt strongly that experimentation was the key to understanding earth science. Jaggar constructed water flumes bedded by sand and gravel in order to understand stream erosion and melted rocks in furnaces to study the behavior of magmas.

As he matured as a scientist, he began to feel the increasing need for field experimentation. Jaggar wrote at this time, `Whereas small scale experiments in the laboratory helped me to think about the details of nature...there remained the need to measure nature itself.' Thus Jaggar began a decade-long period of exploration to witness and analyze first-hand natural geologic processes.

His expedition to the West Indies in 1902 was a critical juncture in the scientist's career. On May 8 the news reached Jaggar that Mt. Soufriere (St. Vincent) had erupted, killing 1,500 people. A second eruption occurred a few hours later at neighboring Mt. Pelee (Martinique), resulting in a staggering 28,000 deaths. With the help of the U.S. Navy and the National Geographic Society, Jaggar landed on the steaming shores of Martinique some 13 days after the disaster.

In his autobiography published in 1956, Jaggar recounts, `It was hard to distinguish where the streets had been. Everything was buried under fallen walls of cobblestone and pink plaster and tiles, including 20,000 bodies....As I look back on the Martinique experience I know what a crucial point in my life it was....I realized that the killing of thousands of persons by subterranean machinery totally unknown to geologists...was worthy of a life work.'

The next 10 years of Jaggar's life brought expeditions to the scenes of great earthquakes and eruptions in Italy, the Aleutians, Central America, and Japan. With each trip, Jaggar became increasingly concerned that his field studies were but brief, inadequate snapshots of long-term, dynamic, earth processes. In 1908, an earthquake killed 125,000 people near Mt. Etna in Italy. With this disaster, Jaggar declared that `something must be done' to support systematic, ongoing studies of volcanic and seismic activity. He traveled to Hawaii in 1909 at his own expense, determined that Kīlauea was to be the home of the first `American volcano observatory.'

After a lecture on his Martinique expedition in Honolulu, Jaggar was approached by the Honorable L.A. Thurston of the Pacific Commercial Advertiser. Thurston, like Jaggar, believed that Kīlauea was a prime site for a permanent volcano observatory and inquired of Jaggar, `Is it then a question of money?' Within a year of this conversation, the Hawaii Volcano Research Association was formed, with financial backing from Honolulu businessmen. A small observing station was set up on the rim of Halema`uma`u. In 1912, support was forthcoming from the Massachusetts Institute of Technology, and construction of the new Hawaiian Volcano Observatory began.

During his early years as Director, Jaggar struggled after private endowments with the hope of eventually securing sponsorship by the Federal Government. In 1919, Jaggar convinced the National Weather Service to adopt HVO. The U.S. Geological Survey took over its operation in 1924, with the exception of a brief hiatus during the Depression, when HVO was run by the National Park Service.

Jaggar remained Director of HVO until 1940. Over the course of 28 years, Jaggar never lost sight of his original vision that `the main object of the work should be humanitarian...prediction and methods of protecting life and property on the basis of sound scientific achievement.'

From the USGS Hawaiian Observatory website

An important aspect of monitoring both during and between eruptions requires simple visual observations, such as noting the changes in steam from an area, unusual withering of plant life (a broad area of forest near Mammoth began to die following an earthquake swarm alerting scientists of an increase of poisonous CO_2 gas in the area), changes in color of mineral deposits on fumeroles, new cracks or widening of old cracks. Any features that might reflect a change in the state of the volcano are noted and monitored.

During an eruption scientists document, in words and photos, the course of the eruption in detail. They take temperature measurements of lava; collect the eruptive products and gases for subsequent laboratory analysis; measure the heights of lava fountains or ash plumes; gage the flow rate of ash ejection or lava flows; and carry out other necessary observations and measurements to fully document and characterize the eruption.

Geologists, geophysicists, and gas chemists provide the long-term basis for understanding how magma is transported to the shallow crust, stored, and erupted from the summit and rift zones of active volcanoes. Monitoring not only serves the moment, but contains an inherent research component by providing fundamental observations and measurements essential to develop and test models of volcanic processes and to improve monitoring methods.

Probing the Precursors

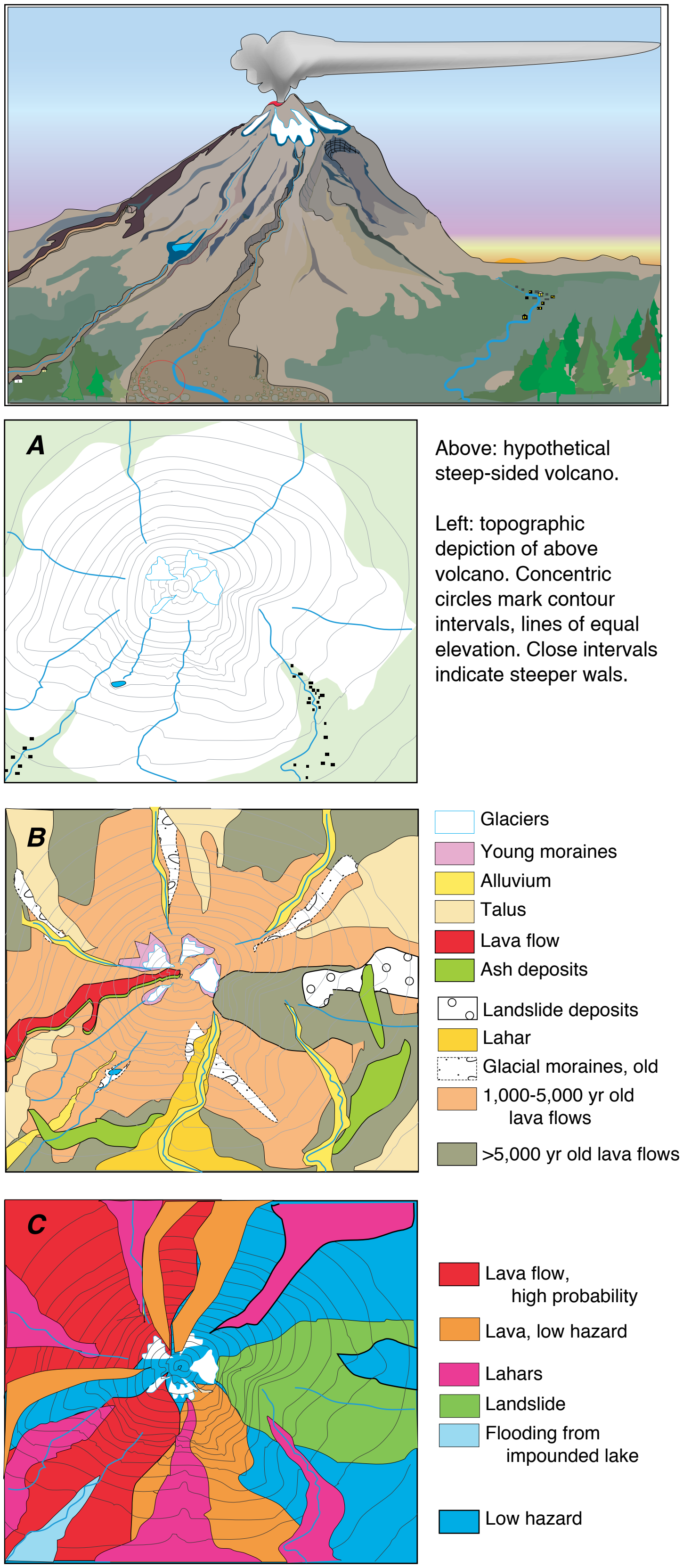
All volcanic eruptions are preceded by a variety of easily monitored events known as precursors. When a volcano is approaching an eruption several things are going on. First, magma is rising within the edifice, forcing itself through the weakest pathways in previous conduits and wall-rock cracks.With continued high-pressure intrusion it forces new cracks pushing the ground up and out. Like a cream puff having filling squeezed into it, the summit begins to rise. During this forceful intrusion, the rocks shift and broad areas are deformed during the sudden jerky movements known as earthquakes. At the same time gases contained in the magma are escaping into cracks and crannies, increasing the above-ground concentration.

By keeping finger on the pulse of the volcano through monitoring ground deformation, seismicity, gas composition, and changes in ground temperature you can make accurate forecasts about when, where and how a volcano is likely to erupt. The most effective monitoring is achieved by applying all of the above on a real-time basis.

What Techniques Contribute to Eruption Forecasting?

Geology and Geologic Mapping

In terms of monitoring the active volcano, geologists at HVO track the advance of active lava flows using topographic maps, hand-held GPS receivers, and aerial photographs. They also collect lava samples on a regular basis for study of their geochemical and mineralogic composition. Mapping and eruption information enable County, State, and Federal personnel to respond to imminent hazards that may affect individuals and communities.



Above: hypothetical steep-sided volcano.

Left: topographic depiction of above volcano. Concentric circles mark contour intervals, lines of equal elevation. Close intervals indicate steeper wals.

Steps in producing a vocanic hazards map. Hypothetical mountain (top) is depicted in A. topographic map showing glaciers, streams, and man-made structures; B. geologic map produced by studying all the geologic features and drawing them on the topographic map; and C. an interpretive volcanic hazards map produced by assessing the topography and geologic history and determining where the areas of greatest rish are. Although this represents a structure typical of Pacific Rim explosive volcanoes, it nonetheless shows the steps in map production.

Geodetic surveys allow scientists to precisely depict the growth of flow fields and vents. (Geodesy is the science of determining the size and shape of the earth and the precise location of points on its surface. Geodetic refers to the use of geodesy for measurements.)

Where lava enters the ocean geologists study the growth and destruction of new land and the hazards associated with these processes. All of these investigations provide the long-term basis for understanding how magma is transported to the shallow crust, stored, and erupted from the summit and rift zones of active volcanoes.

A good approximation of the probability of an eruption, as well as what a volcano is capable of doing, can be determined by knowing its geologic history. This is critical for volcanoes that have been dormant for a prolonged period. For example, geologic mapping around Mt. St. Helens in the mid1970’s led scientists to forecast an eruption there within 20 years. It erupted in 1980!

Systematic mapping of the rock type, volume, and distribution of the products of prehistoric eruptions, as well as the determining their ages by modern isotopic and other dating methods is key to understanding a volcano. Geologic mapping is a field skill that requires recognizing all types and forms of volcanic rocks and their relationship to each other and to the tectonic setting, and recording them on a topographic map. This detective work reveals the age of the eruptive deposits produced by a given volcano, which gives a key to the eruptive frequency (how often will it erupt?) as well as the style of eruption (will it erupt explosively?).

With this information, scientists can construct “volcanic hazards” maps that delineate the zones of greatest risk around a volcano and designate which zones are particularly susceptible to certain types of volcanic hazards (lava flow inundation, ash fall, toxic gases, mudflows and associated flooding, etc.). When Pinatubo showed signs of unrest rapid reconnaissance mapping indicated that the volcano might erupt violently. Methodical evacuation and rerouting of aircraft resulted in the saving of at least 5,000 lives and at least $250 million in property.

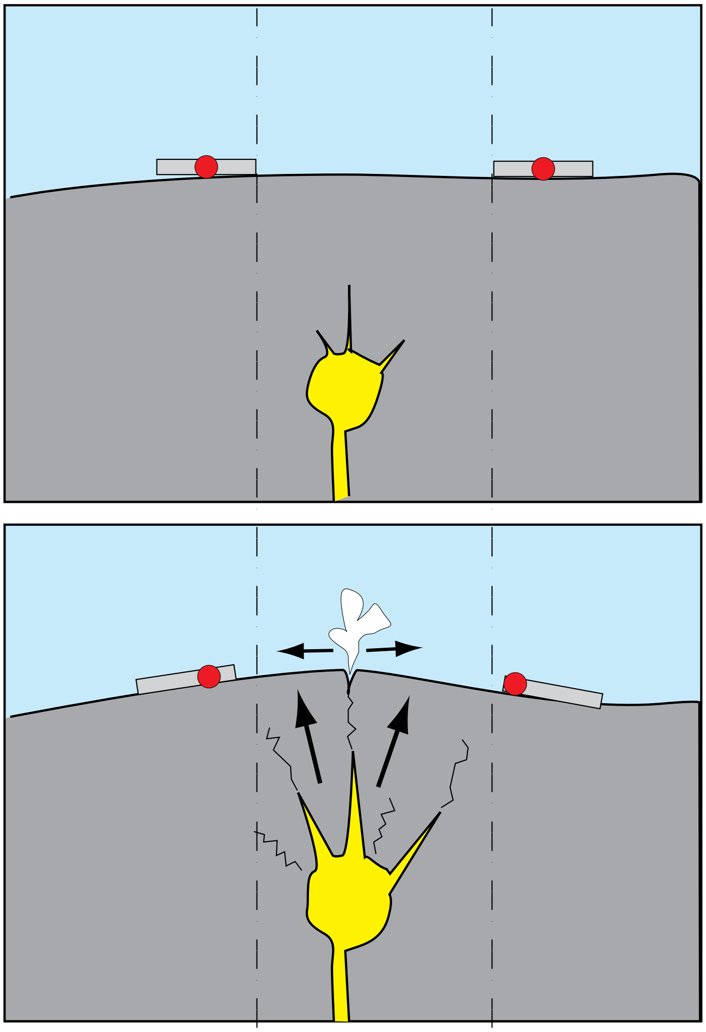
Ground Deformation

When magma is injected into shallower regions within the volcano the ground above it inflates, or swells causing both a vertical displacement upward and a tilting of the ground adjacent to it (figure this page). Large injections of magma into the magma reservoir or “plumbing system” beneath Kīlauea Caldera can cause the ground to rise as much as several feet. Inflation of the summit caldera of Kīlauea doesn’t necessarily mean that the eruption will take place there. The magma reservoir there is a veritable “Grand Central Station” where magma is stored then shunted to weak areas in the two rift zones. With a transport of magma away from the volcano’s reservoir and down a rift zone pressure is immediately relieved and the volcano rapidly shrinks or “deflates. The current preferred pathway for magma is to Pu‘u ‘Ō‘ō on the East Rift Zone.

The deformation is measured by 3 techniques: tiltmeters, GPS measurements, and EDM (electronic distance measuring) surveys with laser beams.

Tilt Meters

A tilt meter is an electronic displacement device that is used to measure of the slope angle of the flank of the volcano. As the volume of magma increases in the shallow reservoir beneath Kīlauea volcano, exerts pressure on the overlying rocks the pressure causes the summit of the volcano to move up and out to accommodate the greater volume of magma. When this happens, the slope (i.e., tilt) of the volcano around the inflation increases and the tiltmeters (electronic bubble levels) register the change. When magma leaves the summit reservoir and moves into a rift zone, the summit will deflate and the tilt decreases. By having many tiltmeters all over a volcano you can pinpoint where the greatest tilt is and where the eruption site will likely be. These “real time” devices can measure changes that are less than1 part per million (a microradian), like putting a penny under a mile-long board. Highly sensitive tiltmeters are sometimes installed deep in a bore hole with other monitoring devices, such as strain meters, where they are protected from the daily temperature fluctuations and interference with weather or from humans.



Two bubble levels, aka tiltmeters sit flat on the ground surface in top drawing. In lower drawing the magma chamber expands and injects magma into the ground, bulging the surface, cracking rocks and causing earthquakes. As the ground bulges upwards the bubbles float to the high end, indicating tilt. As the crack opens the two GPS units (*) move apart.

GPS Stations and Receivers

The Global Positioning System (GPS) is a worldwide radio-navigation system that uses 24 satellites "man-made stars" and their ground stations to locate the position, or track the movement of an object on the ground or in the air. Every square yard (meter) on the planet has a unique address with reference to latitude and longitude. Navigation, is the process of moving from one "address" to another, and tracking is the process of monitoring that movement. Using satellites as reference points GPS receivers track and calculate positions that are accurate to a matter of yards (meters). In fact, with advanced forms of GPS you can make measurements to better than a half inch (centimeter), and, in some cases, millimeters!

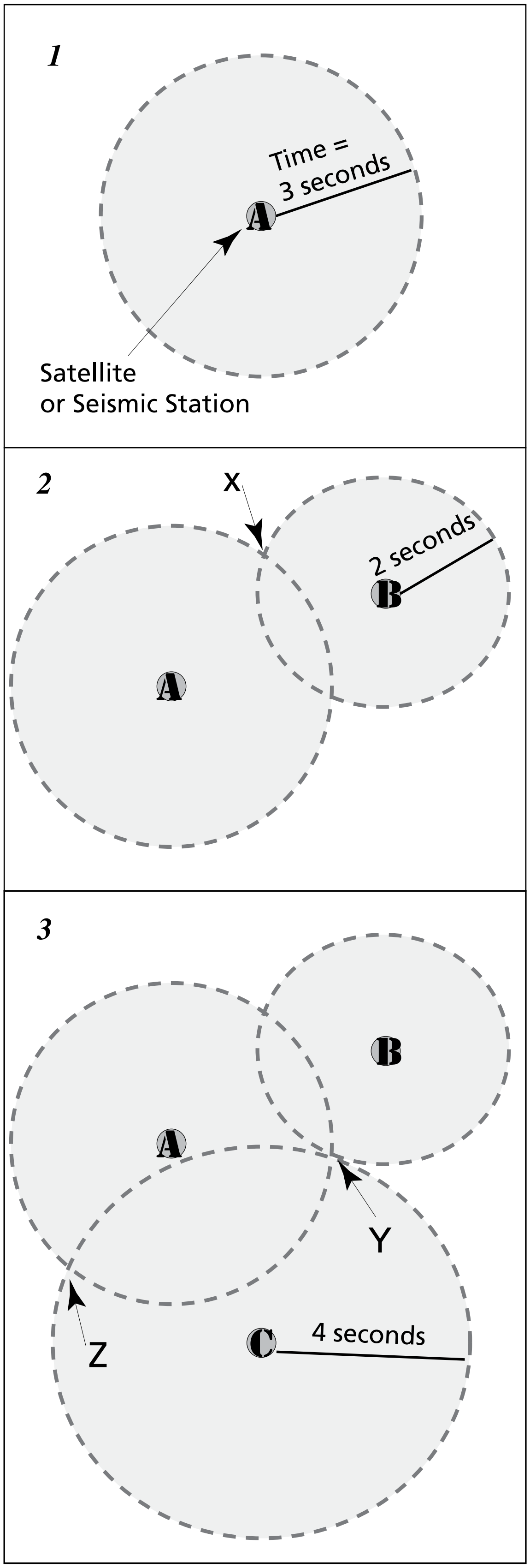
Although GPS seems like magic to most of us, it is a highly sophisticated method of using triangulation from satellites that requires some tricks. To triangulate, a GPS receiver measures distances using the travel time of radio signals to and from the satellites. This requires the timing of the GPS be very accurate. In addition to distance, it needs to know exactly where the satellites are. High satellite orbits and careful monitoring are the key. After that, the GPS has to correct for any delays the signal experiences as it travels through the atmosphere.

The fact that a series of satellites overhead can communicate with a GPS in your hand to not only tell you where you are, but where you are headed is really a remarkable technological achievement. Once, GPS receivers were the domain of military personnel who used clunky devices with moderately good precision, but low accuracy [see last page of this chapter for accuracy vs. precision], plus access to the satellites was prohibited. Not only is access now public, but GPS has become miniaturized to just a few integrated circuits thus becoming economical and accessible to virtually everyone. Aside from use by hikers not wanting to get lost, they are now built into cars, boats, planes, farm machinery, laptop computers and more.

In a strive for more accuracy, developers devised a way to make the GPS system have less error, thus a differential GPS (DGPS) was developed. This involves the cooperation of two receivers, one that's stationary and another that's roving around making position measurements. DGPS gives measurements good to a couple of yards in moving applications and even better in stationary situations. The stationary receiver ties all the satellite measurements into a solid local reference.

Here's how it works: GPS receivers use timing signals from at least four satellites to establish a position. Each of those timing signals has some error depending on atmospheric and stratospheric conditions. Since each of the timing signals has some inherent error, the calculations will compound the errors. If two receivers are fairly close to each other, say within a hundred miles, the signals that reach both of them will have traveled through virtually the same slice of atmosphere, and so will pretty much have the same errors. The reference receiver quickly taps all the visible satellites and computes each of their errors. Then it encodes the information into a standard format and transmits it to the roving receivers letting them know any delays in satellite transmission, so the roving receivers get the complete list of errors and apply the corrections for the particular satellites they're using. Voila.

A fixed differential GPS unit on top of Mauna Kea shows the movement of the islands relative to the satellites as they are rafted on the Pacific Plate towards Japan. By using that



One type of triangulation is used by radio (GPS) and seismic (earthquake) signals to determine the origin of the signal. For example Station A receives a signal in 3 seconds, therefore the location can be anywhere along the 3-second dashed line. If Station B receives the same signal after just two seconds, their overlapping circles narrows the possible source to two possible sources, X and Y. When Station 3 reports in with a 4-second delay, the intersection of all 3 marks the map location.

benchmark as a reference, many points on the same island can be tightly constrained. Several of these instruments monitor Kīlauea and Mauna Loa and are able to quickly see the change in distance between any two points on them measured in mere millimeters (100th's of inches). By recording the difference in position relative to the fixed Mauna Kea receiver, mathematical calculations on the computer resolve the true direction and rate of movement that happen as several points move apart during an impending eruption. It was this technique that detected swelling of the summit of Mauna Loa in 2002.

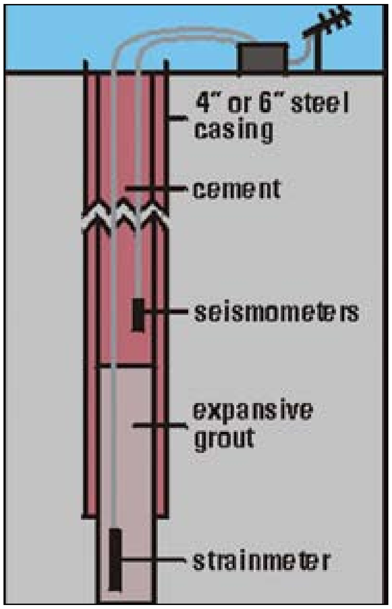
In addition to the 16 sites monitored with continuously recording GPS receivers, about 120 sites are surveyed using static GPS survey techniques every year.

An important member of the GPS family is hand-held receivers. The location of lava tubes and advancing perimeters of lava flows are mapped using both commercial-and military-grade receivers. The information is downloaded into the computer to generate flow-field maps.

Strainmeters

Strain is defined as a relative change in distance, divided by the distance over which the change occurs. For example, if you pulled a 1-km long rubber band 1 mm longer, that would correspond to a strain change of 1 part in 1,000,000 or 1 microstrain. A typical signal is 10 nanostrain = 0.000,000,001 mm across the instrument.

Three single-component, ultra-sensitive strainmeters (also called dilatometers) were cemented more than 300 ft (100 m) deep in the ground on Mauna Loa and one on Kīlauea. Each strainmeter is a stainless steel pipe about 3 m long and 10 cm in diameter filled with silicon fluid. As magma movement or earthquakes causes the ground to change shape, the dilatometer is squeezed like a balloon. The amount of strain is precisely determined by measuring the flow of the silicon fluid into or out of the dilatometer into a secondary reservoir. Dilatometers are so sensitive that they can easily detect the small deformation of the Earth's crust caused by gravitational attractions of the sun and moon and by the loads applied to the Earth's surface by passing weather fronts. In order to avoid noise introduced by wind, ambient temperatures, movement of people and vehicles, borehole strainmeters are usually installed in drill holes several hundred meters below the ground surface. Even at these depths, the instruments are subject to effects that cause the signal to drift. These types of changes are filtered out by analysis software, and what is left is a measure of the deformation of the ground. The strainmeters are sensitive to a few parts in 100,000,000! Mauna Loa dilatometers have clearly detected a small, 7 microradian tilting event that took place at Kīlauea's summit, as far as 60 km away!



Strainmeter, or dilatometer, in a deep borehole. Solar panels provide energy. Seismometers and tiltmeters are often installed in the same hole.

EDM (Electronic Distance Measuring)

An electronic distance meter is an instrument that both sends and receives an electromagnetic signal. With the advent of more accurate GPS real-time measurements, these time-consuming, hand-carried laser equipment are used less frequently. Nonetheless it is still one of the most accurate methods for determining the difference in vertical and horizontal displacement relative to data collected from the same points in the past. This is done annually on Kīlauea to monitor regional changes over time.

EDM leveling surveys use laser instruments (e.g.—as used by road engineers) for the purpose of precisely measuring horizontal distances, or angular relations, from point to point. This method requires that a team of real people go to the field to measure the distance between benchmarks that might be tens to thousands of yards (meters) apart. The data is collected by hand and later typed into a computer to compare with past measurements.

The changes in ground surface can be caused by rising magma that pushes overlying rocks upward or sideways. In either case, one part of the volcano may actually move horizontally relative to another part from as little as a few millimeters to as much as several tens of meters. The challenge in measuring such changes with an electronic distance meter is having benchmarks in the right places in the first place, and making frequent measurements between pairs of benchmarks.

Depending on the distance between the EDM and reflector, the wavelength of the returned signal will be out of phase with the transmitted signal. The instrument compares the phase of the transmitted and received signals and measures the phase difference electronically. There is a wide range of EDM capabilities in range and precision, but for volcano monitoring purposes,

Leveling survey to determine changes in the ground surface relative to earlier measurements of the same surface. Young Pu'u 'Ō'ō cone looms up in the background.

short-range (less than 10 km) EDM's are typically used. Short-range EDM's transmit and receive the near visible infrared part of the electromagnetic spectrum for measuring distances with an accuracy of about 5 mm.

Seismicity:

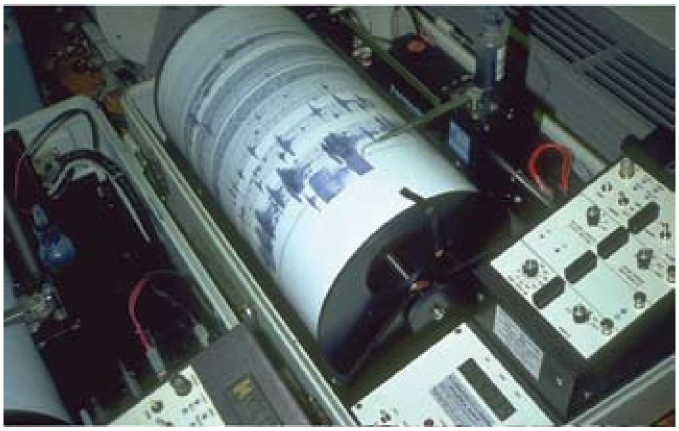
Eruptions are always preceded by an increase in earthquake activity due to injection of magma into cracks and fractures at depth. The study of seismology yields a precise determination of the location and magnitude of earthquakes by a well-designed seismic network. As the volcano inflates with rising magma, the overlying rocks are deformed to the breaking point to accommodate magma movement. When the rock can no longer hold the magma back it breaks and earthquakes result.

As the rock yields and breaks it produces small high-frequency, long-period earthquakes. As magma under increasing pressure squeezes into new underground conduits it causes thousands of small earthquakes to rattle the seismographs. If it is more-or-less continuous is called "volcanic tremor", and if the amplitude increases it will trigger a "tremor alarm". By carefully mapping out the variations with time in the locations and depths of earthquake foci, scientists in effect can track the subsurface movement of magma, horizontally and vertically.

Short-period earthquakes are not directly related to an eruptive event, but rather to settling of the volcanic island masses. Large earthquakes happen when there is an underground displacement caused by the shifting of the topographic load of the edifice. These big earthquakes have the potential for the most widespread destruction on the Big Island. The recurrence interval between large damaging earthquakes here is one every 8 years. They are an inevitable part of the active volcanic processes continue to shape our island.

Seismograph

A seismograph, or seismometer is an detector that receives the seismic waves as vibrations. It records and measures the movement in the earth caused by earthquakes. The traditional instrument is a drum that rotates while a pen continuously records the tremors on paper, known as the seismogram. Nowadays this information is recorded by computers and the information can be instantly reduced to usable information such as magnitude, depth, and location.

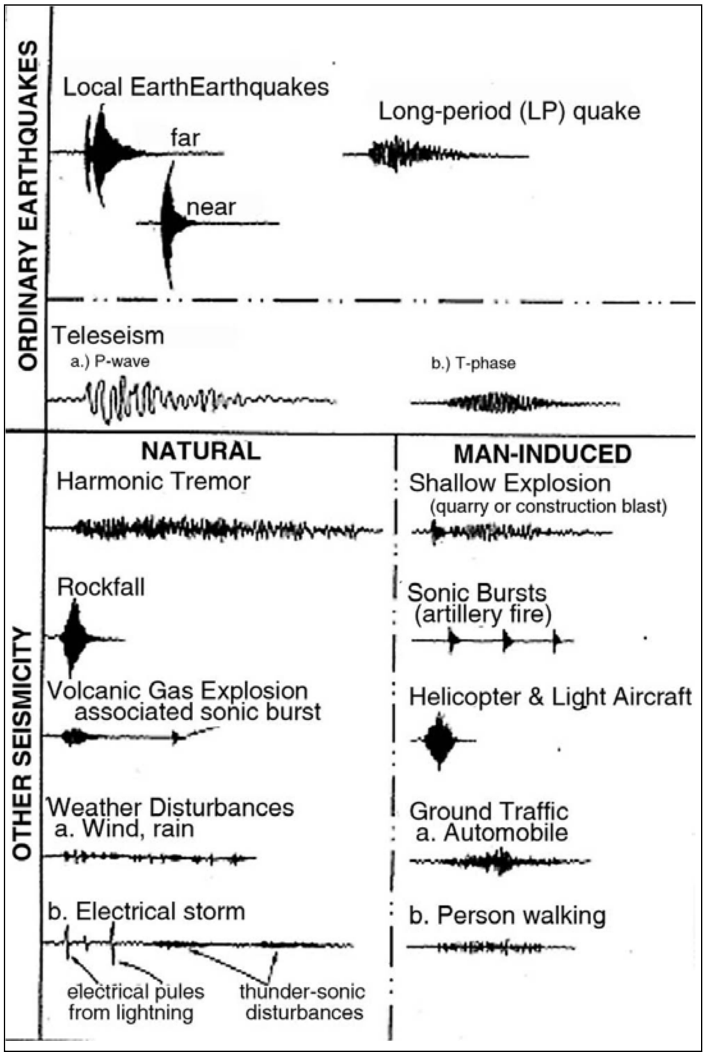


Seismograph recording large earthquakes prior to the eruption of Mt. Pinotubo.

Three-component broadband seismometer

The borehole strainmeter systems are complemented with packages of seismic sensors. Two sets of seismic instruments are placed in each hole. One set, referred to as a broadband system, features uniform, well-characterized sensitivity to a wide range of frequencies of ground motion. The other set is a strong-motion system that faithfully records the ground motions produced by nearby large earthquakes; standard seismometers go off scale during such earthquakes. Unlike typical seismic sensors placed at the ground surface, the systems must be somewhat miniaturized to fit in the drill holes, and a customized electronic package is required to provide appropriate sensitivity and response.

For a description of "How Big Was it? Magnitude and Intensity of an Earthquake" see last page of this chapter.



Various signals recorded by a seismograph.The different signatures show the intensity and duration of each event.

Geophysics and Lava Tubes

As mentioned in a previous chapter, lava tubes can be located by fumes, elongate tumuli, skylights, hornitos, and breakouts. They can be more precisely located by using very-low frequency (VLF) conductivity tools. Molten lava is electrically conductive, so by sending electrical signals through the ground VLF can be used to detect where the liquid is flowing in tubes below your feet. By repeated profiles at fixed locations along a lava tube you can estimate a cross-sectional area of the tube. To determine the flow rate, or how many cubic meters per second, you just need the speed of the flow, which can be obtained using a radar gun.

Jim Kauahikaua measures the electrical conductivity of the subsurface using a VLF (very low frequency) conductivity tool to determine the location of lava tube.

Gas

Gases dissolved in magma provide the driving force of volcanic eruptions. The release of gas into the atmosphere both between and during eruptions gives scientists a snapshot of what is going on compositionally with the volcano. As magma rises into the volcanic edifice it may allow some of gases to escape along fractures, thereby causing the volume and composition of the gases (measured at the surface) to differ from steady-state output when the volcano is quiescent and the magma is too deep to allow gas to escape. These toxic gases need to be monitored for public safety as well as for scientific investigation.

A primary objective in gas monitoring at Kīlauea is to determine changes in content and volume of gases released, chiefly carbon dioxide and sulfur dioxide. The changes are not only in how much of each gas, but the relative proportions of one to the other, the carbon/sulfur ratios.

The gas group at HVO samples volcanic gases by several methods. The most common method, and least affected by outside influence is to collect gas directly from fumaroles or adjacent to skylights by inserting a long metal tube into the fume-rich part and drawing the gas into a solution-filled bottle. The mixtures are then analyzed in the laboratory.

A small computerized gas monitoring site, located on Kīlauea's east rift zone, controls instruments which periodically sample the air near the Pu`u `O`o vent. Chemically selective sensors for SO_2 and CO_2 measure gas concentrations and a wind sensor measures

Right: Volcanic gases are collected by Jeff Sutton and Tamar Elias by inserting a chemically inert, durable tube into a hot fumarole. After allowing the tube to heat until condensation in the tube has reached equilibrium with the escaping gases, usually about 5 minutes, either a specially-designed evacuated-sample bottle or a flow-through sample bottle is attached to the collection tubing. Gas is taken to the lab for analysis. Photo for USGS by G. Brad Lewis.

Vehicle drives beneath plume as COSPEC instrument sticks out the window, facing upward measuring sulfur dioxide concentrations In the overhead volcanic plume. COSPEC measures light coming into the instrument after passing through the plume

A small computer at this gas monitoring site located near Pu‘u ‘Ō‘ō (in background). Chemically-selective sensors for SO_2 and CO_2 measure gas concentrations and a wind sensor measures wind speed and direction. Data are transmitted to HVO every 10 minutes, providing near real time data on degassing from Pu`u `O`o.

wind speed and direction. Data from this solar-powered station are transmitted to HVO every 10 minutes, providing near real time data on degassing from Pu`u `O`o.

Depending on wind and weather, HVO makes ground-based SO_2 measurements from a vehicle using a correlation spectrometer (COSPEC). The COSPEC measures the amount of ultraviolet light absorbed by sulfur dioxide molecules within a volcanic plume. Although originally designed for measuring industrial pollutants, the COSPEC is used worldwide to monitor volcanic “pollutants”. The instrument is calibrated by comparing all measurements to a known SO_2 standard mounted on the ground, in a vehicle, or on an aircraft. The highest quality measurements are obtained by mounting a COSPEC in an aircraft and flying traverses underneath the plume at right angles to the direction of plume

The ground-based SO_2 measurements from a vehicle are made by traversing directly beneath the volcanic plume in fixed and moving locations. Because roads around a volcano are fixed and the wind uncooperative, the best locations are not always possible. For the measurements to be successful, the plume must pass directly over a road. Wind speed and direction are critical for data interpretation.

The COSPEC can also be mounted on a tripod near a volcanic vent to scan horizontally or vertically so that the light coming into the instrument first passes through the plume. Wind speed is determined by using a hand-held anemometer or from a portable meteorological station.

An ambient air quality monitoring station (left) located at the summit of Kīlauea is operated cooperatively by the National Park Service and the USGS. The station measures concentrations of SO_2 gas down to the part per billion (ppb) level in order to provide information about the impact of volcanic emissions on air quality. Data from this site help confirm the importance of wind speed and direction on the geographic distribution and concentration of volcanic air pollution. This station is part of a nationwide network of air monitoring sites that operate within National Parks.

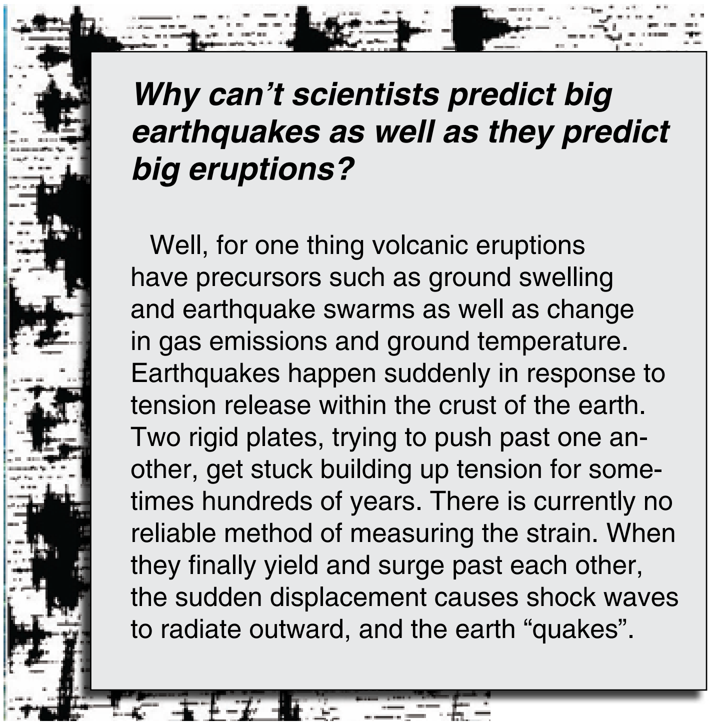
During specific wind regimes, emissions from the main degassing sources of Kīlauea impact the populated summit area. Data from this site show that federal health standards for SO_2 (145 ppb) have been exceeded on more than 80 occasions during the past 13 years. An alert system using the data from this station informs staff of the Hawai`i Volcanoes National Park of the presence of potentially unhealthy concentrations of SO_2 gas during episodes of very poor air quality.

Prediction

People often ask volcanologists to “predict” the next eruption of Mauna Loa, or to predict when Pu‘u ‘Ō‘ō will stop erupting. For many scientists, the word prediction implies being able to give date/time of when something will happen; a tough proposition at best. They prefer the term “forecast” which denotes making a judgment based on understanding both the history of a volcano and the geologic, geochemical, and geophysical signals collected during periods of unrest. For example, I can forecast that Mauna Loa will erupt but I can’t tell you when. When Mt. St. Helens began shaking they could forecast an explosive eruption was probable, but unfortunately they could not “predict” when or how it would erupt.

So, if we’ve studied volcanoes for so long how come we can’t predict when and where eruptions will take place anywhere in the world? Until we have monitoring devices on every tectonic coupling and every volcano we cannot know the subtle forces that sneak up on us at random places across the globe. Not to mention, the ultimate tool for detecting tension beneath Earth’s surface has yet to be discovered. Unfortunately, few of the world’s volcanoes erupt often enough to warrant peppering them with expensive monitoring devices.

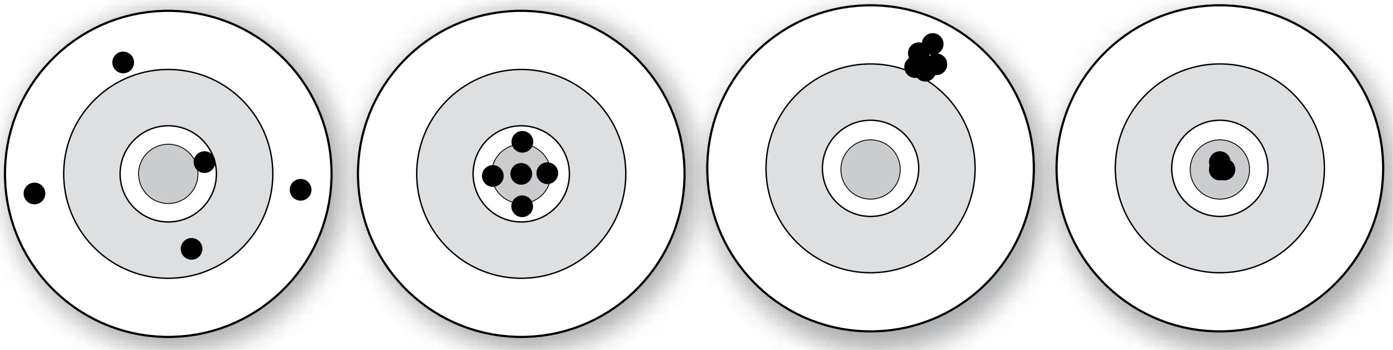
Keeping finger on the pulse of the volcano by applying all of the above traditional ground-based observations with remote-sensing technologies on a real-time basis enables accurate forecasts about when, where and how a volcano is likely to erupt. But then, all volcanoes have slightly different and unpredictable behaviors. As in all sciences, instrumentation is becoming more and more sophisticated, but we are still a long way from predicting accurately on a regular basis.



Why can’t scientists predict big earthquakes as well as they predict big eruptions?

Well, for one thing volcanic eruptions have precursors such as ground swelling and earthquake swarms as well as change in gas emissions and ground temperature. Earthquakes happen suddenly in response to tension release within the crust of the earth. Two rigid plates, trying to push past one another, get stuck building up tension for sometimes hundreds of years. There is currently no reliable method of measuring the strain. When they finally yield and surge past each other, the sudden displacement causes shock waves to radiate outward, and the earth “quakes”.

Precision vs. Accuracy.



Random pattern is neither accurate nor precise.

Accurate but lacks tight cluster in center of bulls eye.

Precise but not accurate.

Accurate and precise.

The definition of accuracy is to be "capable of providing a correct reading or measurement." In physical science it means 'correct'. A measurement is accurate if it correctly reflects the target being measured, in other words, a measure of how close to the mean of the results reaches the target or the correct answer.

The definition of precise is "exact, as in performance, execution, or amount." But in physical science it means "repeatable, reliable, getting the same measurement each time." Precision is a measure of how closely the data from replicated runs groups.

("*Accuracy is telling the truth... Precision is telling the same story over and over again*." Yiding Wang)

How Big Was it?

Magnitude and Intensity of an Earthquake

Magnitude is an instrumental measure of the size of an earthquake, based on maximum amplitudes of motions recorded on a seismographic network. It is a property of the earthquake, determined after effects related to a particular recording site like distance from the earthquake and local geology are accounted for. The Richter Scale was originally used by Professor Charles Richter to determine earthquake magnitudes in southern California by reading the maximum amplitude from a particular seismograph and correcting for the distance of that seismograph from the earthquake. Here's how it's done. The Richter Scale has been generalized to apply to other regions and other instruments besides the ones originally used by Richter to determine the local earthquake magnitude. Another commonly used method to determine magnitudes is by duration. Duration magnitude is calculated by relating the length, in seconds, of a recorded seismograph signal to local earthquake magnitude.

Intensity is the description of how strongly an earthquake was felt at a given site. It is a classification of changes in the earth's surface and/or damage to man-made structures caused by an earthquake. Intensity ratings for a given earthquake will vary from one site to another. The Modified Mercalli Intensity Scale is a common rating used to describe the results of an earthquake. The use of this description is a very important part of the reported information of an earthquake and its effects. It is critical at times when instrumental data are not available.

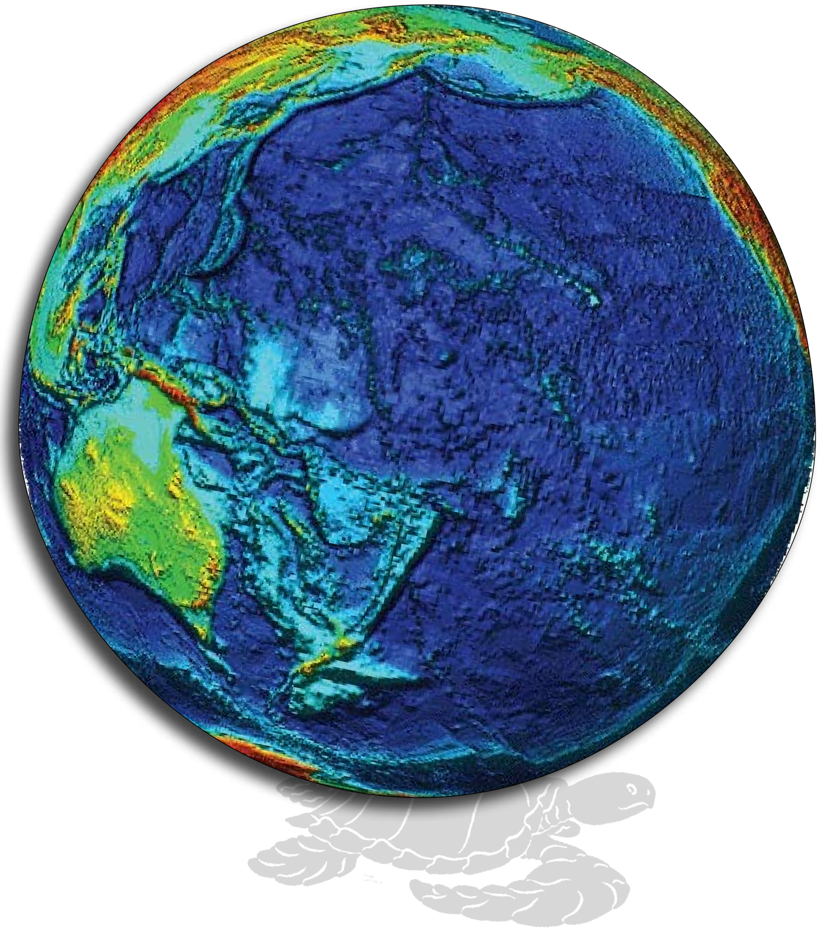
Excerpt from: July 11, l997 Volcano Watch

Fatalities From the Most Lethal Eruptions Since 1741

# Fatalities	Location	Year	Cause of Deaths
1,475	Oshima, Japan	1741	Tsunami
2,957	Papandayan, Indonesia	1772	Ash flows
1,377	Asama, Japan	1783	Ash flows, mudflows
14,300	Unzen, Japan	1792	Volcano collapse, tsunami
1,200	Mayon, Philippines	1814	Mudflows
92,000	Tambora, Indonesia	1815	Starvation
700	Ruiz, Colombia	1845	Mudflows
1,000	Cotopaxi, Ecuador	1877	Mudflows
4,011	Galunggung, Indonesia	1882	Mudflows
36,417	Krakatau, Indonesia	1883	Tsunami
1,335	Taal, Philippines	1911	Ash flows
5,110	Kelut, Indonesia	1919	Mudflows
2,942	Lamington, Papua N.G.	1951	Ash flows
500	Hibok-Hibok, Philippines	1951	Ash flows
1,184	Agung, Indonesia	1963	Ash flows
2,000	El Chichon, Mexico	1982	Ash flows
25,000	Ruiz, Colombia	1985	Mudflows
800	Pinatubo, Philippines	1991	Roof collapses, disease

Deaths greater than 500 due to volcanic eruptions since 1741. How many could have been prevented with volcanic prediction. Look at the 1985 Ruiz eruption vs. the 1991 Pinatubo. The vulnerable areas in valleys below the summit of Ruiz were not evacuated. Few believed the dire warnings. In 1991 tens of thousands of people were evacuated to safe areas. Without eruption forecasting most would have died.

SECTION TWO



THE HAWAIIAN ISLANDS: GEOLOGY AND HOTSPOT

The Pacific Ocean is the largest body of water on our planet and covers the Earth's largest tectonic plate, the Pacific Plate. Surrounding much of the Pacific Plate is the Ring of Fire, the most extensive and potentially most violent set of volcanoes on Earth. The Ring of Fire is not a single chain of volcanoes, but a highly irregular collection of curved and twisted volcanic island and mountain chains stitched together around the Pacific Rim. All of these volcanoes owe their origin to the slow, but unstoppable, subduction of the oceanic plates beneath the continental plates. As the massive continents grind towards each other, the Pacific crust is pulled down into the Earth. The immense friction generated creates huge earthquakes and also the heat necessary to melt rock and form volcanoes.

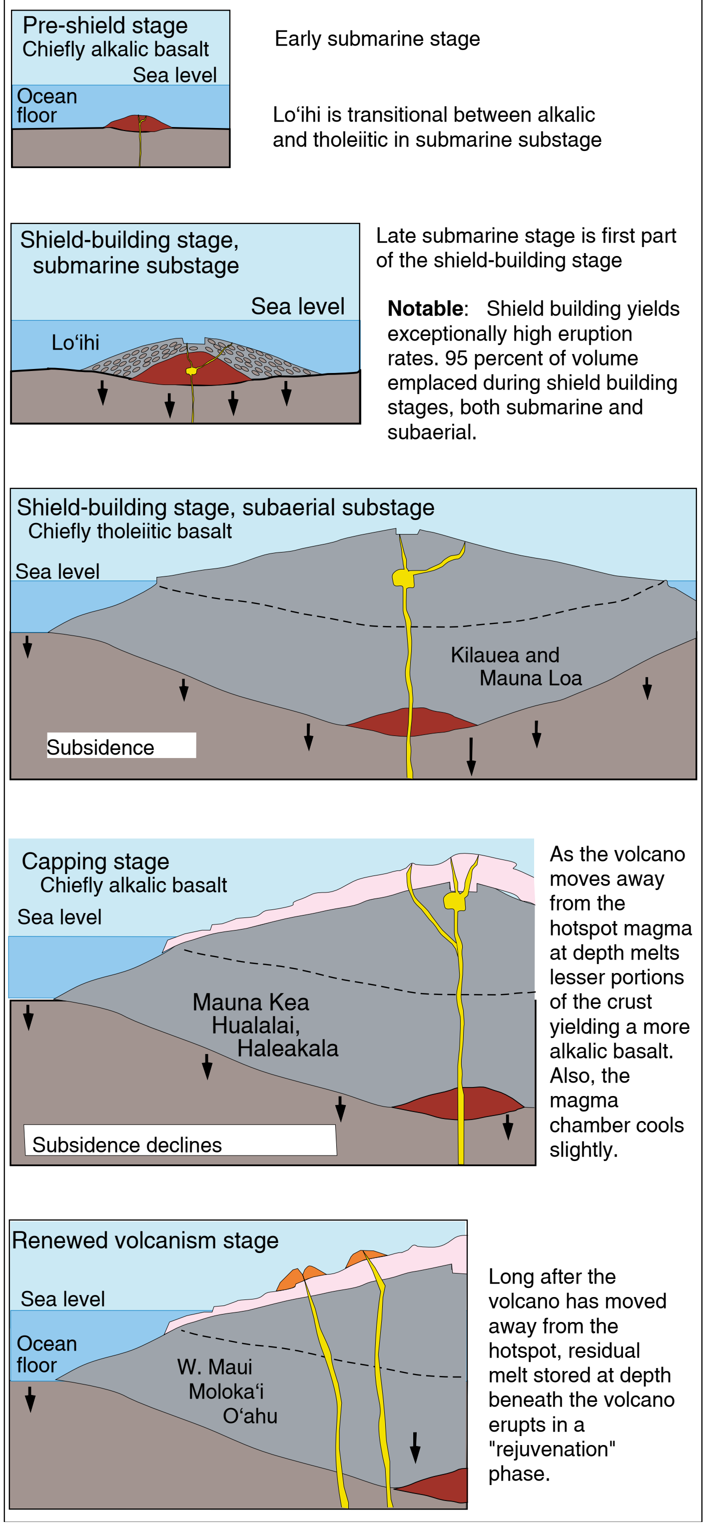
Most volcanoes on Earth occur at boundaries where the plates are moving apart (mid-ocean ridges, rift zones) or together (subduction zones.) In fact, more than 95% of the world's volcanoes are found in those locations. But the world's largest volcanoes sit quietly (well relatively quietly!) in the center of the Pacific Ocean and are related to neither of these processes. These giants rise 20,000 to 30,000 feet from the surrounding seafloor to form the Hawaiian Archipelago.

So, what the heck are the largest and most active volcanoes in the world doing in the middle of the Pacific Ocean far from any plate boundary?

CHAPTER SIX
GEOLOGIC HISTORY OF THE ISLANDS

Long before the first Polynesian ever dreamed of sailing the Pacific, in fact, well before the first human beings walked the Earth, ancestral Hawaiian Islands were propagating and growing on the migrating Pacific Plate [Chapter 9]. Eighty million years ago, when dinosaurs were roaming the continents, the volcanoes that are now being subducted beneath the Aleutian Trench once stood where Hawai‘i is today. As the lava flows piled up on the sea floor, they emerged to form the string of islands we know today as the Hawaiian Archipelago.

Volcanic Stages of "Hotspot" Oceanic Islands



Early submarine stage

Lo‘ihi is transitional between alkalic and tholeiitic in submarine substage

Late submarine stage is first part of the shield-building stage

Notable: Shield building yields exceptionally high eruption rates. 95 percent of volume emplaced during shield building stages, both submarine and subaerial.

As the volcano moves away from the hotspot magma at depth melts lesser portions of the crust yielding a more alkalic basalt. Also, the magma chamber cools slightly.

Long after the volcano has moved away from the hotspot, residual melt stored at depth beneath the volcano erupts in a "rejuvenation" phase.

As volcanoes form above and move away from the hotspot they go through four recognized stages of Hawaiian volcanism, an idea that has been widely accepted by geologists since the 1930s. The four volcanic stages include: submarine (known as pre-shield), shield (both submarine and subaerial), post-shield, and rejuvenated. From birth through the declining stage, the life of a Hawaiian volcano lasts somewhat less than 1 million years. Not all the volcanoes have gone through all the phases. As an island leaves the hotspot, erosion, subsidence, and reef building dominate the geologic processes.

Submarine Pre-shield Phase

During the submarine phase lava is chilled quickly by cold seawater, forming pillow basalts, bulbous structures each about the size and shape of watermelons. As the nascent volcano grows from the sea floor, these pillows are stacked one upon the other, eventually forming a pile high enough to reach the surface of the sea (about 5 km). It takes over 100,000 years of eruptions in one location to reach the surface. Since there is little chance for hot lava to cement the pile together, one might imagine a submarine volcano to be somewhat unstable. Indeed, during the growth of a submarine volcano, it appears that during its growth the flanks are prone to landslides, collapsing many times before finally reaching the surface.

The first lava erupted on the sea floor above this hotspot is compositionally different, i.e. more alkalic, than the subsequent lava that forms the vast bulk of the edifice. These alkalic basalts have slightly enhanced levels of the elements

Above: Fresh pillow basalt. Photo by Jim Griggs, USGS.
Right: Ancient pillow basalts still retain their rounded shape which formed as lava flowing under water was quickly quenched.

Na (sodium) and K (potassium). Many petrologists attribute the more alkalic nature of this material to a somewhat smaller amount of crustal melting, in the range of 5% to 10% around the edges of the "hot spot". Magma from the mantle tends to be low in these elements and higher in the heavier iron (Fe) and magnesium (Mg), but when it pushes its way through the overlying alkali-rich crust it melts a small amount of it and incorporates some of the new melt into the rising magma. Recently some very alkalic lava flows were found along the south edge of the Hawaiian Arch, helping to confirm this theory.

The only example we have of an actual volcano in this first alkalic phase is Lo'ihi, which is now undergoing a change to the tholeiitic, or less alkaline form of basalt. Unfortunately, fieldwork at 3,000-foot (980-m) depth is challenging, so extensive sampling has been limited. If other volcanoes in the Hawaiian chain had such a phase, the evidence lies buried deep below millions of tons of tholeiite.

In July of 1996 a swarm of over four thousand magnitude 1-5 earthquakes shook the summit of Lo'ihi for two weeks. Submersible dives to the summit area after the earthquake swarm abated, confirmed that a new collapse pit had formed near the summit. It is still unclear if a major eruption accompanied this event, but it seems likely to have happened.

It was once thought that calderas did not form until late in the life of Hawaiian volcanoes. With the discovery of small summit calderas on Lo'ihi, it is now known that summit calderas form, refill, and form anew throughout the life of the volcano as the summit magma chamber is pressurized and depressurized during eruptions, leaving the summit unsupported.

Incidentally, the submarine edifice is often overlooked by those who give little thought to the fact that the islands only *appear* to float atop the ocean, but represents, by far, the greatest volume portion of every island. In glacial terms, we see only the tip of the iceberg.

Submarine Shield Building Stage

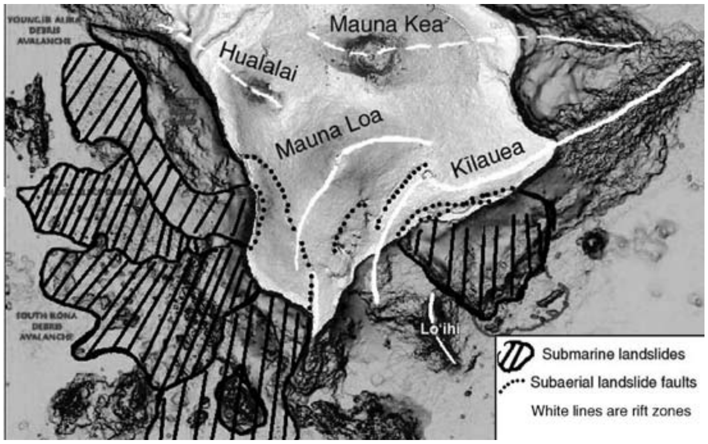
Before the summit of the volcano reaches the surface of the sea, it will have moved directly over the center of the hotspot. By then the chemistry of the lava will have shifted completely to tholeiite due to increased partial melting (~20%) of the crust. A mature volcano is composed of 90-95% tholeiitic basalt because the most voluminous phase of a volcano's history is when it is right above the "burner". When the volcano moves off of the hotspot (see below) and melt fractions drop and it might once again produce alkalic basalts.

As a volcano finally reaches the surface of the sea, eruptions become more explosive because of the reduced pressure. In the shallower ocean a new type of product, hyaloclastite ("broken glass", roughly defined) is formed. This black sandy material is composed of pyroclastic debris and lava that fragmented into glassy black sand when chilled in the shallow water. Hyaloclastite forms a coating over the preexisting mountain of pillow basalt that makes up the submarine edifice. The result is an unstable pile of watermelon–like pillows coated with an expanding shell of hyaloclastites. In spite of, or maybe because of that, the submarine and emergent parts of the volcano are much steeper (10-15 degrees) than the subaerial shield (5-8 degrees) that forms next.

There are no contemporaneous examples of this stage though ocean entries (Chapter 3) share many of the same features on a limited scale. Lo'ihi is about 40,000 years shy of that depth.

Main Subaerial Shield-building Stage

As the edifice grows subaerially, above the sea, lava cools slowing in contact with the air and forms a dense cap of pāhoehoe and 'a'ā flows. This is the main shield-building stage produced by the voluminous eruption of tholeiite. The pile is perched precariously on a pedestal of pillow basalts and hyaloclastites. The weakly supported cap of dense material is one factor in explaining why huge chunks of the island periodically break off in submarine landslides that can form tsunamis with wave heights exceeding 1000 feet (350 m).



Submarine landslide deposits off the south coast of the Big Island. Dashed areas indicate large-scale landslides. The size of these suggests that they likely generated large tsunamis.

The subaeral lower-silica tholeiite lavas form very fluid pāhoehoe flows and their slightly stickier 'a'ā cousins. These are very thin flows and thousands of them are stacked up to build the shield shapes (named after warriors shields, these could have just have easily been called "wok" volcanoes had the Chinese named them). Mauna Loa and Kīlauea are examples of this stage, although Mauna Loa may be reaching the end of shield building and beginning its entry into the declining stage discussed next. The shield volcanoes are fed lava continuously as they sit over the active hotspot and erupt very frequently. Large shallow magma chambers 1-4 km below their summits characterize them. The shields tend to be preferentially elongated and have narrower extensions of the summit magma chamber that feed eruptions along linear fracture zones called rift zones.

Post-Shield Alkalic Stage

During the declining stage, eruption volumes decrease and the summit magma chamber solidifies (apparently because the input of lava is too infrequent and insufficient to keep the chamber molten). Although the lower-silica content of the alkalic basalt should make it less viscous, long-term storage in the magma chamber allows it to cool, thus be less runny. One result of this is that the eruptions tend to be more explosive, blanketing the area with ash and cinders..

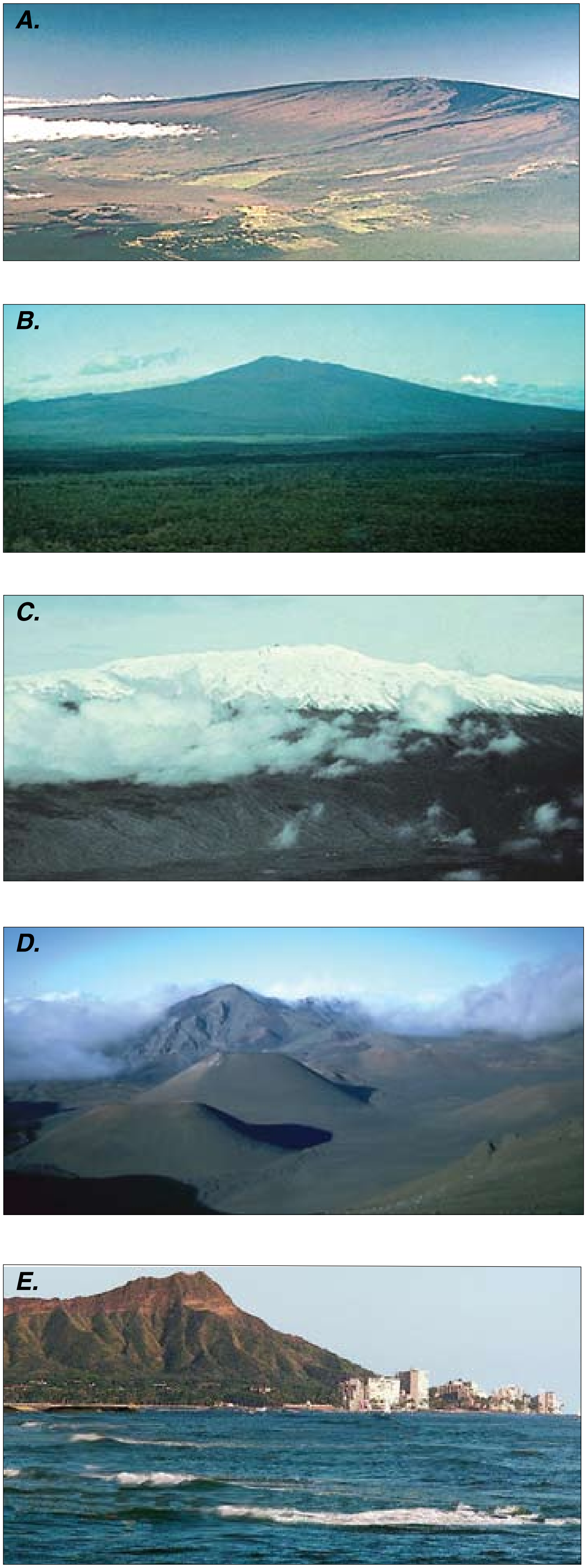
Eruptions of more viscous alkalic basalt produce the steep, hummocky cap on many of the shield volcanoes. Unlike the more fluid tholeiitic eruptions, alkali basalt eruptions are very short lived and build up clusters of steep sided cinder cones. Most of the lava flows are short and thick, but some can be very extensive. On Hualalai, eruptions of lava from the mostly crystalline chamber produced some very evolved sticky lavas called trachytes, a unique occurrence on the Hawaiian Islands.

Though these eruptions tend to exploit the pre-existing fractures of the rift zones, they are not confined to the rift zones. Alkalic cones are scattered all over declining-stage volcanoes. The highest concentrations of cones, however, occur near the summit and along old rift zones.

Not all Hawaiian volcanos go through this post-tholeiitic stage, although the reason for this is not known. The transition to the post-tholeiitic stage is gradual, lasting as long as 100 thousand years. The chemistry slowly changes (from petrological analysis of sections) with occasional interbedding of tholeiitic and alkalic flows depending upon vent location. Mauna Kea and Hualalai are presently in the declining stage. Hualalai erupts roughly every 200-500 years and the far less-vigorous Mauna Kea far has had no more than 8 eruptions in the last 40 thousand years.

Haleakalā (East Maui) also has an eruptive frequency of 200-500 years, though unlike Hualalai that is probably early in its post-shield growth, Haleakal is waning toward extinction. Until recently, it was thought that the alkalic rocks on Haleakalā represented a rejuvenation phase. A comprehensive set of 50 new ages shows that, although volcanism has fluctuated during the past million years, it has never stopped completely. The change in composition to more alkalic lavas resulted from less-frequent eruptions during the waning period of shield building caused by diminished heat supply. Thus it is likely in its post-shield alkalic phase.

Drill holes in submerged islands along the Emperor Seamounts reveal a coralline top, that is capped by late stage alkalic lavas underlain by massive tholeiite. There appears to be very little variation in this pattern going back to the oldest islands in the chain about 65 millions years ago. The fact that there is so little change in this pattern points to the rather incredible stability of the “hot spot”, and suggests that such phenomenon are extremely long-lived.



From shield to rejuvenation: examples of Hawaiian volcano stages.
A. The broad shield of Mauna Loa climbs gently to 13,700 feet.
B. Steeper sides on Hualalai reflect more-viscous alkalic lava flows.
C. Lumpy cinder cones on Mauna Kea are visible beneath snow cap.
D. Cinder cones in Haleakalā crater from late-stage alkalic eruptions.
E. Diamond Head, a rejuvenation-stage crater, dwarfs Honolulu.
Photographs courtesy of U.S. Geological Survey.

When Erosion Outpaces Eruption

As the declining stage wanes, erosion becomes the chief geological force shaping the surface of the edifice. Large gullies form as erosion outpaces lava production, e.g., stream-cut valleys on the north rain-pelted slopes of Mauna Kea, Along the coastal areas erosion by wave action is no longer held at bay by advancing lava, and steep coastal cliffs develop. Kohala volcano is currently thought to be in this resting stage as it has been about 60,000 years since its last eruption.

Waimea Canyon's deep-cut valleys reflect that erosion has dominated geologic processes since Kaua'i left the hotspot over 4 million years ago.

Rejuvenation

After the decline of some Hawaiian volcanos there is a long hiatus before a rejuvenated stage begins. Most Hawaiian volcanoes do not manifest this rejuvenated stage, and when they do the interval varies greatly and seems to depend upon whether or not a large shield volcano is being built several hundred kilometers down the chain.In some cases, the delay can be several million years and the late stage alkalic lavas are separated from the rejuvenatated flows by a thick soil layer. The cause of the rejuvenated stage is thought to be related to the remelting of still-hot rocks at depth in the volcano as a result of depressurization caused by the erosion of the edifice. These rocks result from even smaller amounts of partial melting than the alkalic basalts of the declining phase. The lavas erupted during this stage are strange, highly alkalic rocks called basanites, very depleted in silica, and forming tuff rings like Diamond Head and Coco Head on the island of O'ahu. Rejuvenation-stage vents are also found on West Maui and Moloka'i. Haleakalā volcano on East Maui is no longer thought to be in this phase (see previous section on Post-Shield Alkalic Stage.)

What's Next?

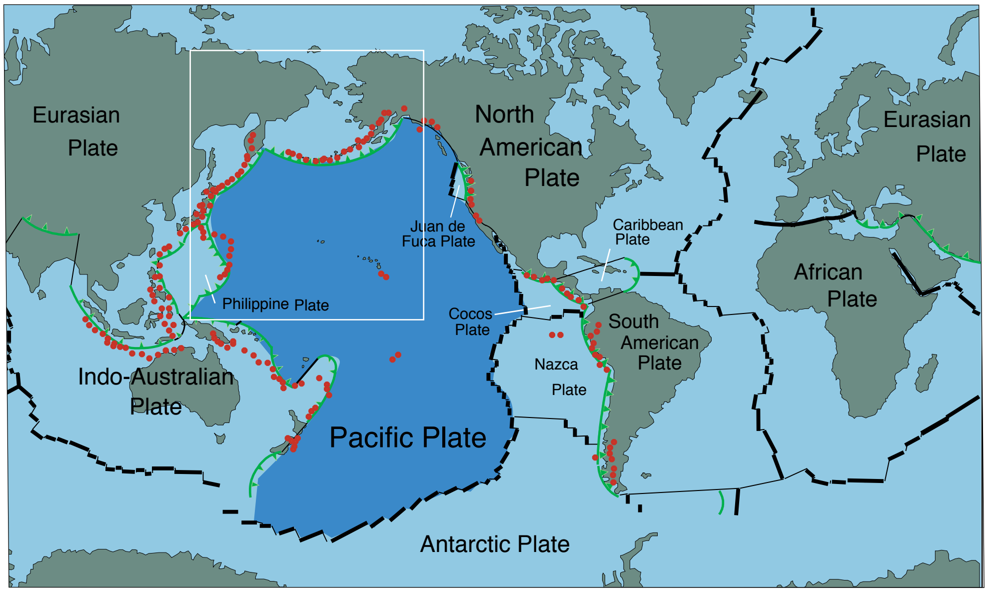
Given the long hot-spot history, volcanoes will continue to grow over the hotspot for many millions of years. And the Pacific plate will continue to raft them away. And if the current direction of plate motion towards Japan holds, in 70 million years or so the Big Island will be subducted beneath Japan, which itself will have grown to grander proportions.

In terms of sound economic investments, buying the potential island property of Lo'ihi and holding it for the next, say 50,000 years might see good return on your real estate dollar.

CHAPTER SEVEN

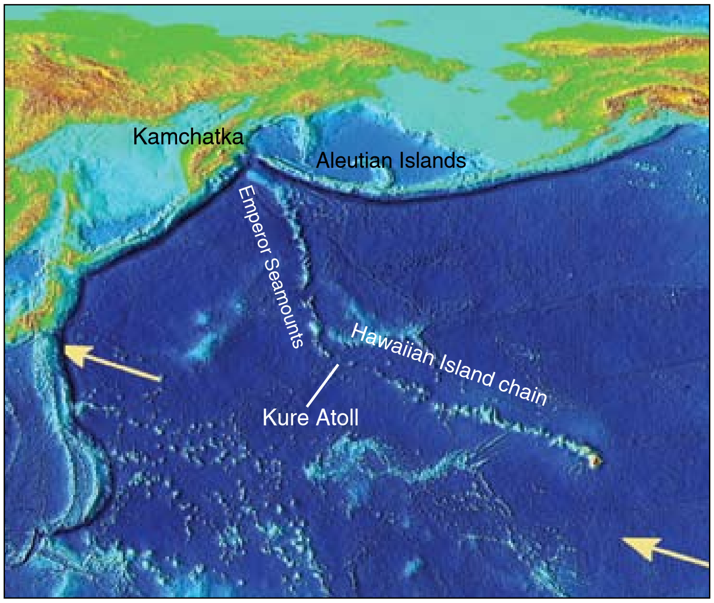
The Hawaiian Hotspot and the Origin of the Hawaiian Islands

Both the existence of and longevity of the Hawaiian hot spot are an enigma to scientists. There are over 1500 active volcanoes in the world, but less than 5% are in the middle of a tectonic plate, rather than on the edges where volcanism is understandable. What is is the hotspot, why is it here and why has it been here for so long? In a nutshell, what we think we know is this: The hotspot is a discrete heat source deep in the Earth that acts like a blow torch melting rock at the base of the crust, about 30 miles below the surface of the Earth. More than 80 million years ago a crack opened on the sea floor allowing this melt, or magma, to rise to the surface and erupt as lava flows. Eruptions here have persisted for long enough to build a long string of volcanoes on the slow moving conveyor belt of the Pacific Plate.



Map shows the major tectonic plates and plate boundaries of the Earth’s surface. The Pacific Plate is darker blue. Thick black lines are spreading ridges; thin black lines are transform boundaries. Green lines are subduction zones with the barb pointing in the direction of subduction. Red circles indicate many of the Ring of Fire volcanoes.

Below: Oblique relief image of area inclosed in white square above shows Hawaiian Island and Emperor seamount island/atoll/guyot chains marching toward Kamchatka/Aleutian subduction area. Sharp bend at Kure Atoll marks the change from the WNW-trending Hawaiian chain to the NNW-trending Emperor chain. Arrows indicate current plate motion.



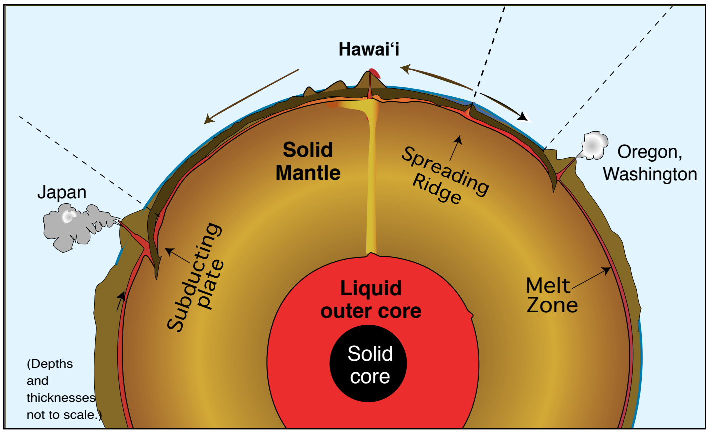
The Hawaiian Hotspot

The Hawaiian Islands, as well as all the islands and atolls in the Emperor Seamount chain, were each created in roughly the same location where the Big Island is now and transported northwest. At some time in the past they each had their moment on the hot spot. The current location of the hotspot is beneath the south end of the Big Island of Hawai‘i where the Mauna Loa, Kīlauea, and Loi‘hi are located. Frequent eruptions of these volcanoes are a good indicator that this is where the islands are born.

The puzzle is, what is this hotspot? Just what is causing melting to occur beneath Hawai‘i? Sources of unusual melting have been termed “hotspots” by geologists simply because they are hotter than the surrounding region and the appear to occur a fixed spots on the Earth. The Hawaiian hotspot is the largest and most persistent hotspot known on our planet.

There are several theories as to why hotspots exist, but they can be grouped into two basic ideas. One is that either unusual amounts of heat or other chemicals exist deep in the Earth beneath the hotspots and are the cause of melting. Many of the proponents of this theory think that plumes of heat transport materials from the boundary with the core (3000 km beneath the surface) up to the hotspot. The other idea is that fractures in the hard outer crust of the planet allows hot material to rise and melt beneath the hotspot. Most scientists currently favor the deep plume idea for the Hawaiian hotspot, though there are certainly hotspots like Iceland that may be the result of fracturing. Currently a definitive answer does not exist to the problem, and it remains to be seen if either are completely correct. Both the existence of and longevity of the Hawaiian hot spot are enigmas to scientists.

While it may seem like there are more puzzles than answers about the Hawaiian Islands, we do know that there is a discrete heat source deep beneath the crust that acts like a blow torch melting the crust directly above it, and that the islands were all formed by volcanoes much in the same way that the islands are forming today. Volcanoes have been erupting on or very near to the same spot near the south end of the Big Island for over 80 million years. How much older the island chain is we do not know as the remains of these seamounts have been consumed beneath Kamchatka and the Aleutian Islands and may even be responsible for the sharp kink between these volcanic arcs.



The Interior of the Earth

The outer shell of the Earth is a cold, rigid layer that we call the crust. There are two types of crust: oceanic and continental. Continental crust is generally old (> 1 billion years) and thick (30-40 km). Continental crust is formed mainly of lighter elements and is about 2.5 times denser than water. Oceanic crust is all young (<300 million years) and thin (5-10 km). However, oceanic crust contains large amounts of the denser, heavier elements iron, magnesium, and calcium. Oceanic crust is "basaltic" and is about 3 times denser than water. This means that oceanic crust can sink back into the interior of the Earth, whereas continental crust floats like a cork.

Beneath the crust is a 3000-km-thick layer called the mantle. The mantle is made up mostly of very dense magnesium-iron minerals called olivine and pyroxene (olivine is the bright green mineral found in Hawaiian basalt). This zone is about 3.3 times as dense as water. Most of this zone is hot, but solid. The convection currents cause the mantle to slowly flow in a plastic manner (like taffy, silly putty, or roofing tar).

Both the outer part of the crust and mantle are cool and fairly rigid beneath both oceans and continents. This cool outer zone, called the lithosphere, varies from about 30–40 km thick beneath oceans to 50-100 km thick beneath some continents.

The last 3000 km to the center of the Earth is made up by the iron-nickel core. The outer core is molten. Strong convection in the outer core is thought to be responsible for the Earth's magnetic field (the thing that makes your Boy Scout compass work!). Because of extreme pressure, the inner core is solid iron and nickel.

Left: highly generalized cross section of the Earth showing location and relationship of hotspot to select features above and below the surface of the Earth.

Below: generalized graphic depicting active volcanoes above, and moving away from the heat source as the plate migrates west. Depths and distances are not to scale.

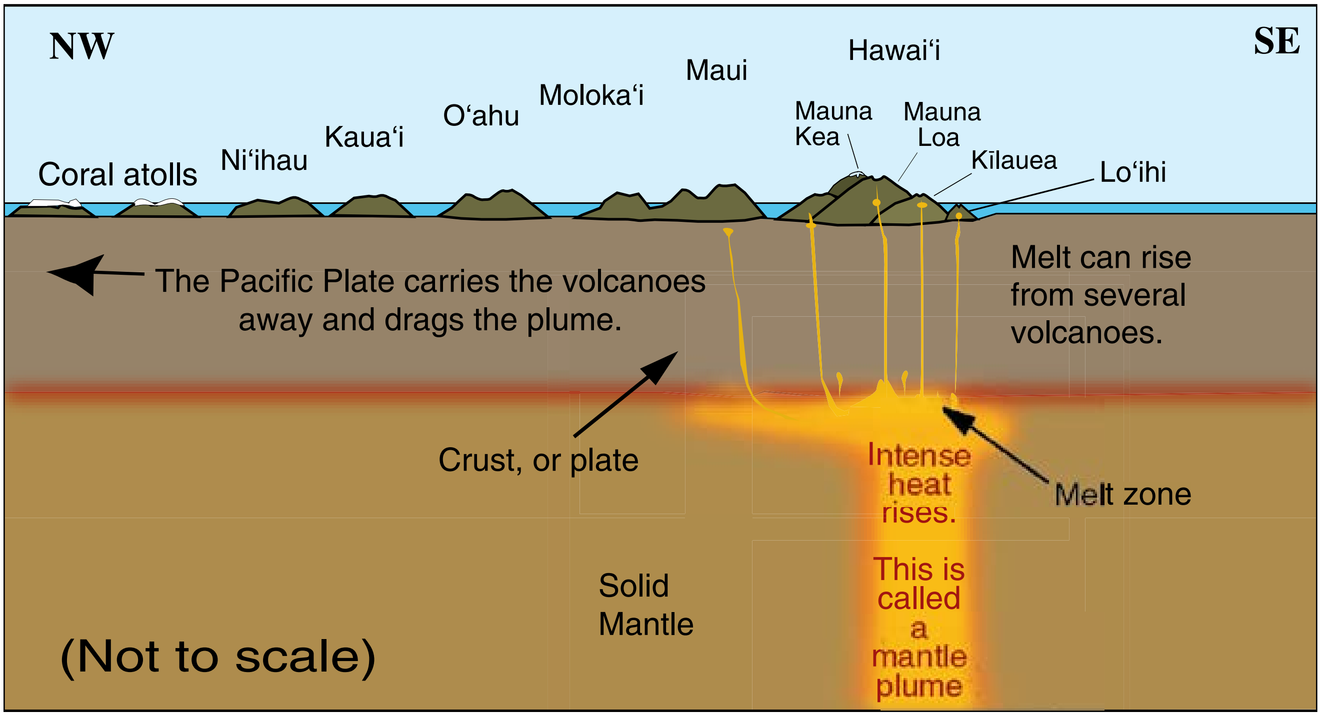


Plate Tectonics and the Formation of the Hawaiian Islands

The outer crust of the Earth is divided into many segments that are called plates that sit above a hot mushy substrate that allows them to slide relative to the others as the plates are driven by heat and gravity. (See Plate Tectonics on Page __.)

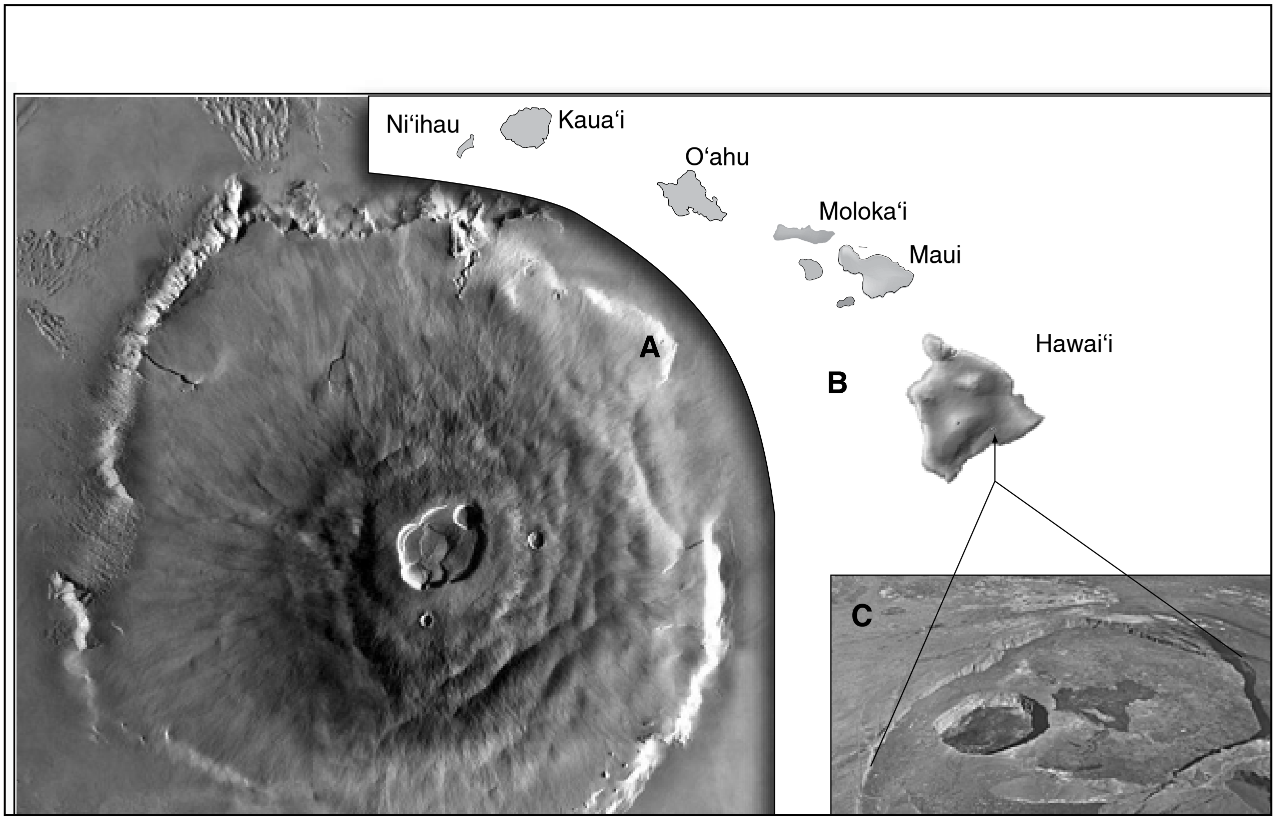
The Hawaiian Islands sit on the Pacific Plate, which is currently moving northwestward at a little over 3.3 inches per year (8.5 centimeters/year). Initially the rate of movement was calculated by dividing the distance along the chain by the age of the island or seamount. For example Midway Island is 1511 miles (or a hair over 95 million inches) away from Hawai‘i and it is roughly 28 million years old. Dividing 95 million inches by 28 million years give you a rate of about 3.4 inches per year. We can now precisely measure the yearly rate using either Global Positioning Satellites (GPS) and other very good measurement techniques that yield an identical number. Scientists just love when two independent techniques yield the same answer, it makes us pretty sure we are on to something. What we are less sure of is why the islands are here at all!

As the Pacific Plate slowly carries the volcanoes and their respective islands away from this location, the frequency of eruptions decreases rapidly. Kīlauea, at this time (2004) has been erupting for 21 years, but has a history of erupting every few years or decades. The eruptions of Mauna Loa occur every few decades. Hualālai, which has moved away from the most robust part of the hotspot, appears to erupt every few centuries. Even Haleakala Volcano on Maui has a 300-600 year eruption cycle. As volcanoes move away from the heat source, the amount of melting below them decreases, so to prevent the magma from solidifying between sporadic eruptions the lava must be stored deeper and deeper in the volcano or underlying crust.

The total volume of lava estimated to have erupted during the 80-million-year history of the hotspot is about 250,000 cubic miles. If all of this lava were to have poured out at a fixed location it would have created a huge volcano. Olympus Mons, the giant volcano on Mars (figure below), is made up from about that same volume of material. It is 80,000 feet tall (two and a half Mt. Everests) and it’s base would extend from the Big Island to Kaua‘i if it were superimposed on the Hawaiian Island Chain. The crater at the top of Olympus Mons is so large that most of the Big Island would fit into it.

Luckily volcanoes on Earth cannot reach this size for two reasons. First, the conveyor-belt-like crustal plates are moving the volcanoes away from the hotspot before they can grow this big. Second, because the Earth is much larger than Mars, it’s interior is much hotter and the outer skin or crust is much thinner and more flexible than the thick, cold crust of Mars. A volcano as large as Olympus Mons would sink back into our planet and could never grow as tall. And while Olympus Mons may be around the same age as the oldest Hawaiian Islands (around 100 million years or more), it has not had to suffer the indignities of erosion and weathering that quickly age volcanoes on Earth.

Our estimates of the amount of lava produced by the Hawaiian Islands may be too small as they are based on the present size of the volcanoes. With the exception of the Big Island, most Hawaiian volcanoes have undergone substantial erosion and have experienced huge landslides that have scattered large volumes of rock across the seafloor. If we based our estimates on the volumes of the main islands, the total volume would be 5–10 times larger.



Comparison of the largest known volcano, Olympus Mons on Mars, and Hawai‘i. A volcano this size on Earth is not physically possible as the shear weight would sink back into the planet. **A,** map view of Olympic Mons with 50-mile-wide summit caldera. **B**, the 8 main islands of Hawai‘i shown at the same scale as Olympic Mons. **C**, the 3-mile-wide summit caldera of Kīlauea Volcano, a dot on map B .

The Hawaiian Islands and the Emperor Seamount Chain

The Hawaiian Island/Emperor Seamount Chain is the longest island chains on the planet, extending over 3000 miles between the Big Island of Hawai‘i, past Kure Atoll just west of Midway, then north to the tip of the Aleutian Islands.

The main Hawaiian islands stretch about 350 miles from the Big Island to Niihau. Elevations of the islands range from over 13,700 feet on the Big Island to just over 1200 feet on Ni‘ihau. The remaining 1250 miles are marked by widely spaced small rocky islands and coral atolls referred to as the Northwest Hawaiian Islands. Most of the smaller, northwestern islands are near sealevel.

Past Kure Atoll a chain of submerged volcanic mountains, called the Emperor Seamounts, continues onward marking the progressive erosion and sinking of older islands that were once part of the Hawaiian Chain.

Each of the islands, atolls, and seamonts are made up of one or more volcanoes. Over 100 individual volcanoes have been identified along the Hawaiian–Emperor Seamount Chain and there are probably many more.

The Eight Main Hawaiian Islands

There are eight islands that make up the main Hawaiian Chain; they include Hawai‘i, Maui, Kaho‘olawe, Lana‘i, Moloka‘i, O‘ahu, Kaua‘i, and Ni‘ihau. These islands lie at least 2500 miles in every direction from the nearest continents, making them the most isolated island chain in the world. They are also roughly the same distance from the Tahaiti, Samoa, and the Marquesas, the most likely points of origins for the original Polynesian settlers of Hawai‘i.

The largest island, Hawai‘i, known as the Big Island has 5 volcanoes above sea level. They include Kīlauea, Mauna Loa, Hualālai, Mauna Kea, and Kohala. There are two additional volcanoes below sealevel that are also part of the edifice; the young Loihi about 20 miles to the south of Hawai‘i and the older Mahukona that is west of the island.

Maui is the next largest island and it consists of two volcanoes: Haleakalā, or East Maui, and the more subdued and eroded West Maui. Haleakaleā is the last of the large volcanoes east of the Big Island that is easily recognized as a volcano. The older islands are highly eroded and have often experienced large landslides that have greatly altered their appearance.

The island of Maui is part of a larger submarine edifice that includes the 3 smaller islands of Lana‘i, Moloka‘i, and Kohoolawe. These islands are each made up of 1 or 2 volcanoes. during the last great Ice Age, 15,000 years ago (recent in Earth’s history, but well before to the beginning of recorded human history) all of these islands formed a single great island now called Maui Nui. The channels between the islands did not disappear, but rather sea level was roughly 300 feet lower than today due to the large amount of water stored in glaciers that covered much of the northern hemisphere.

O‘ahu whose two main mountain ranges are the eroded remants of the Koolau and Waianae Volcanoes rises to only 3100 feet. These volcanoes yielded ages of 1.3 and 2.2 million years respectively.

The final two large islands of Kaua‘i and Ni‘ihau were also probably joined at one time and consisted of at least 3 major volcanoes. Kaua‘i is deeply eroded and boasts deep-cut steep-sided canyons that many liken to the Grand Canyon. It’s highest elevation is 5,243 feet, higher than O‘ahu. The furthest island Ni‘ihau, considerably smaller, is rarely visited as it is privately owned and inhabitated solely by Native Hawaiians.

The Northwestern Hawaiian Islands

The Northwestern Hawaiian Islands stretch from Nīhoa to Kure Atoll, 900 miles further. Submerged volcanic islands become atolls over relatively short geologic time. The volcanoes that formed these islands range in age from 7.2 milion years at Ni‘ihau to 27.7 million years at Midway, just east of Kure.

the small rocky island of Nihoa lies about 130 miles to the northwest of Ni‘ihau. It made up mostly of lava and there is little coral surrounding it. Nihoa is the last exposed remnant of a once great volcano that is disappearing beneath the sea. Coral reefs have begun to surround the Necker Island, the next in line. The rest of the islands out to Midway and Kure Atoll (roughly 28 million years old) are dominated by coral reefs and only have occasional pinnacles of lava rock that give away their origin as volcanoes. It is a truly remarkable testament to the tenacity of life that the huge volcanoes that were once up to 14,000 feet high can only remain above sealevel for 7–8 million years, whereas the coral reefs can build islands on top of these sunken giants for another 20 million years.

The Bend in the Emperor Seamount Chain

The age and depth of the ancient volcanoes of the Emperor Seamount chain increases toward the northern tip where it dives beneath the Kamchatka/Aleutian trench. Most of the older Emperors are flat topped seamounts(guyots).

The trend of the Hawaiian Islands and the Emperor Seamount Chain show a remarkable and abrupt bend about 44 million years before the present. There has been much speculation regarding the cause for this bend. One idea is that the bend originated with an abrupt change in plate motion. Prior to 44 million years ago the plates were moving in a much more northerly direction. There is considerable uncertainty, however, on just what caused this change in direction. Many scientists believe it was the collision of India with the Eurasian subcontinent, and event that has raised the Himalayan Mountains, that did the dirty deed. Other feel that it was the beginning of spreading on the Antartic Ridge south of Australia that was the culprit.

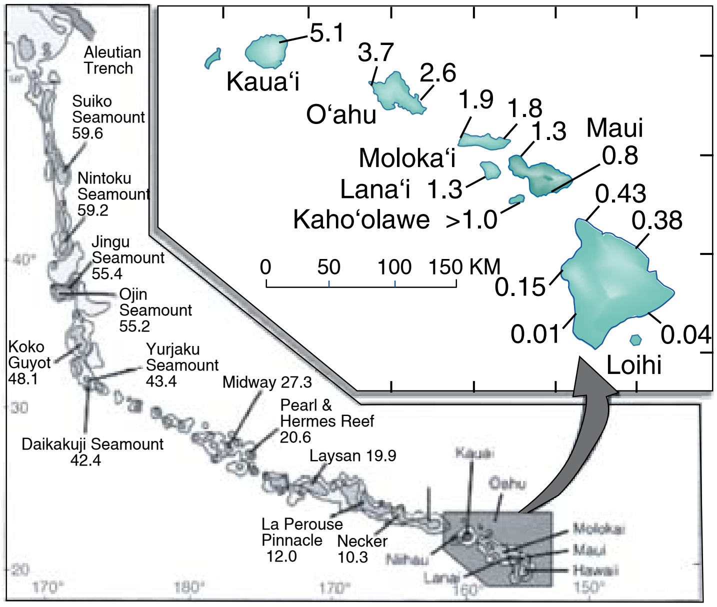
Recently, it has been suggested that the bend records the change from a non–fixed hotspot to a fixed hotspot location at about 40–45 million years ago. This theory suggests that prior to 45 million years ago the hotspot was actually located about 10 degrees north and drifted slowly to it’s present location. Both are intriguing ideas and it remains to be seen if either are completely correct.

Ages of the Hawaiian Islands

Modern analytical techniques allow very precise age determinations for individual lava flows and rock samples from all of the islands and seamounts. While this has helped immensely in understanding the history of individual volcanoes, it remains difficult to determine exact ages for each island. Why? Simply because the volcanoes are enormous and there are virtually no exposures of the oldest lavas deep inside the volcanoes. So, we can really only accurately date the most recent activity on each of the islands and the oldest rocks we can find in eroded valleys. Using the oldest ages of rocks exposed on the surface of each island, we get the following approximate ages:

Big Island—0.5 million years old
Maui, Kaho‘olawe, and Lana‘i—1.5 million years old
Moloka‘i—2 million years old
O‘ahu—2.5–4 million years old
Kaua‘i and Ni‘ihau—5 million years old
Necker Island—10 million years old
Midway Island—28 million years old
Yuryaku Seamount—43 million years old
Suiko Seamount—65 million years old

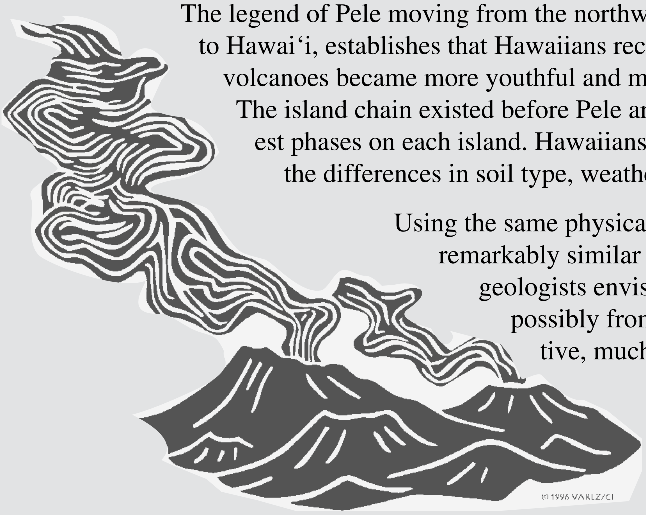
Most geologists estimate the time it takes to form each individual island to be somewhere between 1 and 2 million years, so the true ages of the inception of the islands are probably that much older than the values given in the table.



Approximate ages of the Emperor Seamount/Hawaiian Archipelago Chain. Inset is a blow up of the main Hawaiian Islands and Nihoa, the easternmost island of the Western Hawaiian Islands. Ages indicate about when each island was positioned above the hotspot.

The volcanic origins as well as the age progression of the Hawaiian Islands were well known to Native Hawaiians. The significance of frequent eruptions of lava played an important role in the Hawaiian attitude toward the ‘aina (land) and their respect for natural phenomena. The goddess Pele embodied the dual nature of creation and destruction that accompanies volcanic eruptions. Hawaiians incorporated various theories in their legends to explain the great phenomena of nature, especially meles about Pele [see Chapter 10, Hawaiian Legends and Volcanoes.]

The legend of Pele moving from the northwest to the southeast, from Kaua‘i to Hawai‘i, establishes that Hawaiians recognized that many features of the volcanoes became more youthful and more active to the southeast. The island chain existed before Pele arrived. What this recognizes is the youngest phases on each island. Hawaiians were excellent observers of their natural environment noting the differences in soil type, weathering, erosion, shape, and size.



Using the same physical criteria, early geologists noted an age progression that was remarkably similar to Hawaiian legend, i.e., younger to the southeast. Early geologists envisioned a chain of volcanoes that may have formed at one time, possibly from a great crack in the sea floor, but became sequentially inactive, much like snuffing out a row of candles.

What neither group could know is that the Hawaiian islands were not stationary and did not form at the same time. It has only been in the past 50 years that geologists have been able to demonstrate that the Earth’s crust is slowly moving.

Plate Tectonics

The Earth has active plate tectonics which produces obvious features that are readily visible on maps of the planet and even on satellite images. These include long chains of composite volcanoes marking subduction (such as the Ring of Fire circling the Pacific), ridges snaking around the planet where plates pull apart and fresh magma wells up to the surface, and great mountain ranges where continents have collided, and crumpled or are sliding against each other.

Plates may be entirely oceanic or a combination of ocean and continental crust. The lithospheric plates are able slide a bit over the underlying convecting mantle at this boundary. Spreading ridges vary in rate of opening from about 1 to 3 inches (2-8 cm) per year.

Principal Types of plate boundaries:

Spreading Ridges (divergent boundaries):

These are the regions of the world where plates are pulled apart and new crust is created. Convection in the earth's mantle pulls the thin ocean plates apart. The most extensive volcanic mountain ranges in the world are produced at these boundaries. However, with the exception of a few very high "peaks" like Iceland, the vast majority of these mountain ranges are beneath the oceans. The mantle melts beneath spreading ridges because it rises and depressurizes without losing heat. The diminishing forces allow minerals to melt. This process produces fluid magma that is very low in silica content and water. As it rises toward the surface, water bubbles escape easily and eruptions are typically thin, low viscosity lava flows.

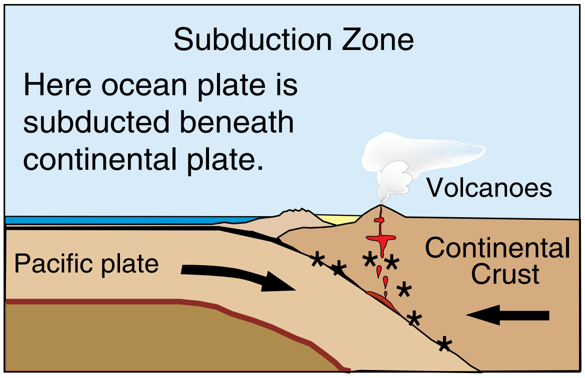
Collision Zones (convergent boundaries):

These are regions where plates are pushed together. When an ocean plate collides with either a continental plate or another ocean plate, one of the ocean plates will be forced back into the mantle. These zones are marked by chains of stratovolcanoes (like Mt. Ranier or Mt. St. Helens). Volcanism at subduction zones is produced by frictional heating as the cold crust is forced beneath the continent and by release of water from the ocean crust into the overlying mantle. The resulting magmas contain higher amounts of silica and water than mid-ocean ridge magmas. Because the magmas are very viscous, water cannot escape as the molten rock comes to the surface and instead the expanding steam bubbles cause highly explosive eruptions. Any magma that does erupt is very sticky and forms thick flows and domes that make up the steep sides of stratovolcanoes.

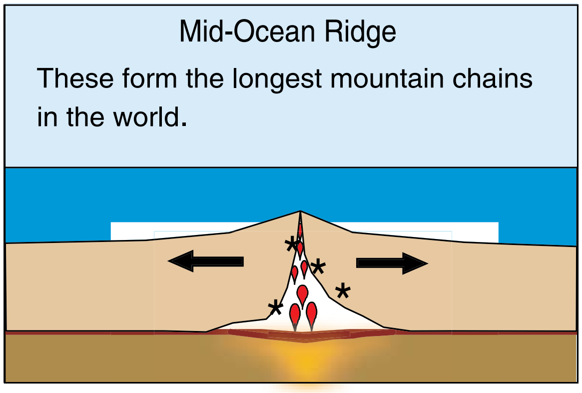
Large mountain ranges along the edge of continents commonly form where ocean crust is subducted beneath contineta1 crust. The Andes along the western edge of South America are an excellent example of this type of range. Where ocean crust is subducted beneath ocean crust volcanic island chains called island arcs form (originally named for the curved shape of these island chains). Classical examples of island arcs are the Aleutian Islands, the Marianas Islands, and Japan.

When two continents collide, neither is subducted. Instead large mountain ranges form in the interior of continental masses. The Himalayas, the highest mountains on Earth,

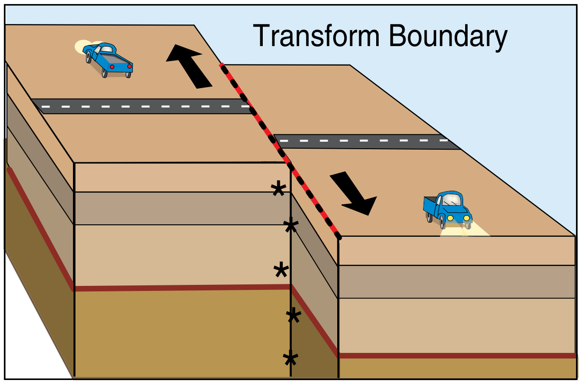
Convergent: Crust is destroyed as one plate dives beneath another plate. Explosive volcanoes are common here.



Divergent: New crust forms as magma rises, forcing the plates to move apart.



Sliding: Two plates slide against each other. E.g. San Andreas fault.



Three principal types of plate boundaries. Small box on upper left of each is keyed to map on first page of this chapter. Black arrows indicate plate direction. Asterisks show areas that generate formed this way when India began colliding with China about 40 million years ago. This collision is continuing today as India continues to push northward and the Himalayas continue to grow higher.

Transform Faults (sliding boundaries):

The final type of plate boundary is a type of fault where two plates slide past one another. These faults occur either where two pieces of continent slide past one another, like the San Andreas Fault, or where mid-ocean spreading ridges are separated by faults.

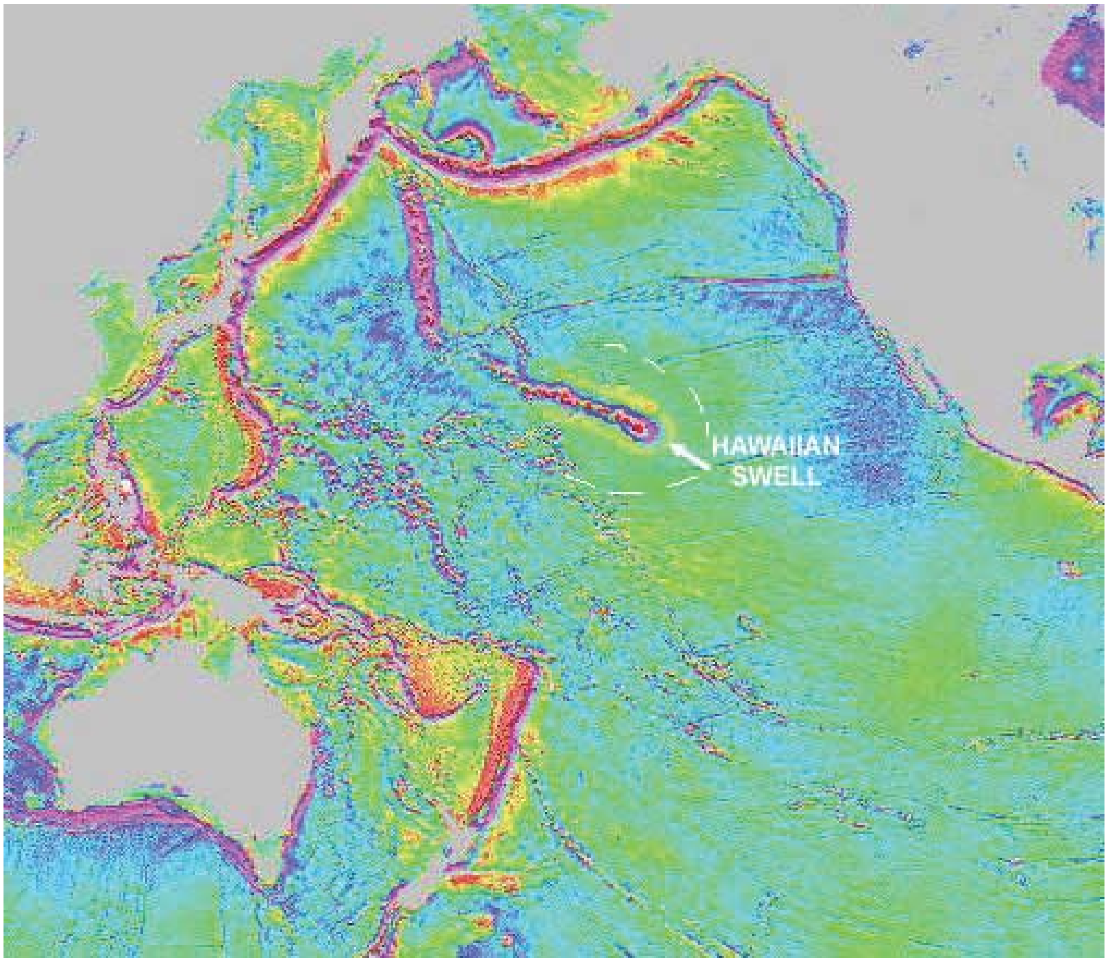
Though the San Andreas Fault is the most famous of these, transform faults on mid-ocean ridges far outnumber continental transform faults. Only the area between the two mid-ocean ridge segments is a transform fault (separating oceanic plates moving opposite directions). Outside of this zone, these become large fracture zones within oceanic plates. The best example of a mid-ocean transform fault can be seen on the figure just south of Iceland in the northern Atlantic ocean. The best fracture zones can be seen in the SE Pacific Ocean. This figure shows only submarine topography (the continents are gray) with high elevations in red grading to the lowest elevations in purple.

Ocean Basins and Island Chains

Interestingly, the highest (shallowest) portions of ocean basins seem to be in the center of the oceans, just opposite of what you might think. And the lowest (deepest) parts of many of the oceans are near the margins. This is due to plate tectonics. Subduction zones produce the deepest part of the ocean (off the Marianas the ocean is 37,000 ft deep!), while mid-ocean ridges make high mountains that can even emerge above sealevel (like at Iceland).

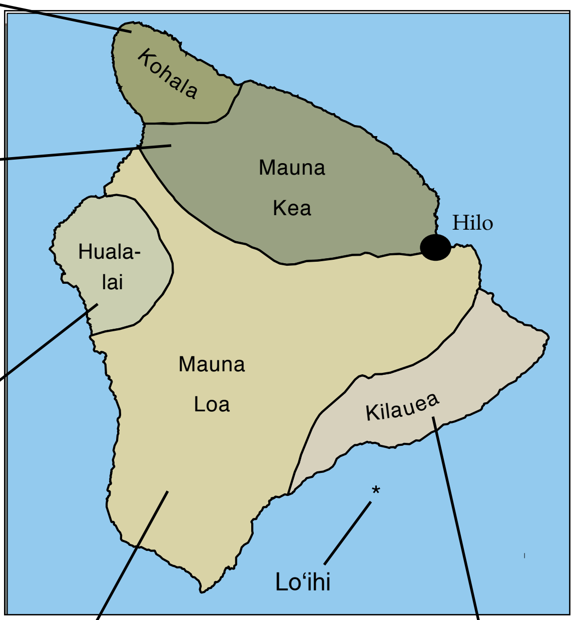
The Hawaiian Islands stand out as a pronounced anomaly on the ocean crust. They form a high ridge that cuts the NW Pacific Basin and appear unrelated to either spreading ridges or transform fracture zones.

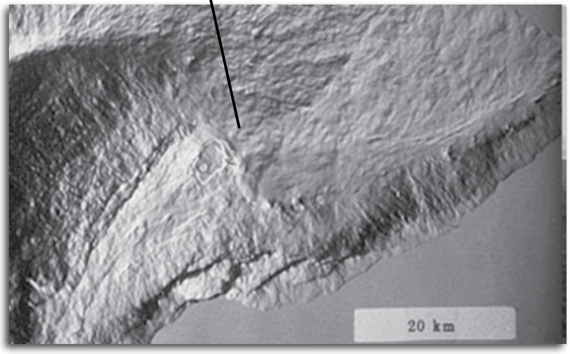
There are many other island chains scattered across the Pacific, but none that approaches the size and length of the Hawaiian Islands. Some island groups like Tonga, Samoa, and the Galapagos are related to plate boundaries. Many of the island chains that make up Polynesia including Tahiti and the Marquesas are hotspots, but are far less extensive and aligned with fractures on the ocean floor. The Hawaiian Islands are unique for their immense size, the striking linear progression of ages along the chain, and the longevity of the chain (> 80 million years).



NEED CAPTION ABOUT DEPTH OF OCEAN

SECTION THREE





Relief map of Kīlauea volcano shows how subdued the topography is relative to the looming Mauna Loa, the dark shadow in the left side of the image.

HAWAI'I'S ACTIVE VOLCANOES

The largest and most southeastern island of the chain, Hawai`i, consists of five volcanoes. Kīlauea, Mauna Loa, and Hualalai have erupted in the past 200 years. Kohala and Mauna Kea have not seen volcanic activity for over 5,000 years and have deeply eroded stream-cut valleys. Lo`ihi, the youngest volcano of the Hawaiian Volcanic Chain, and part of the greater Big Island edifice, is still about 1,000 meters beneath the ocean's surface. East Maui Volcano, commonly known as Haleakala, on the island of Maui, is the only other Hawaiian volcano to have erupted since the 1600's.

Information and photos for this section are taken directly from the USGS Hawaiian Volcano Observatory website. The title page for each volcano is copied directly with all links shown. Additional graphics were added.

Haleakalā crater, East Maui

USGS photos

Millenium of Eruptions

By anyone's reckoning, New Year's Day either starts a new millennium or ends its first year. What have Hawai`i's four active island volcanoes done during the past 1,000 years?

Let's start with the 20th century. An eruption was going on about 49.6 percent of the time, 48.3 percent at Kīlauea and 1.3 percent at Mauna Loa. The two erupted together about 0.3 percent of the time.

At Kīlauea, Halema`uma`u erupted for about 9,060 days, Pu`u `O`o and Kupaianaha about 6,575, Mauna Ulu about 1,775, and other sites about 486 days, 253 during ongoing Halema`uma`u activity. Mauna Loa erupted on 599 days, 122 of them in concert with Kīlauea. Kīlauea spilled out about 2.9 cubic kilometers (3.8 billion cubic yards) of lava and Mauna Loa, about 1.9 cubic kilometers (2.5 billion cubic yards). That's 380 million 10-yard dump-truck loads from Kīlauea and 250 million from Mauna Loa.

These figures clearly show that most eruptions of Mauna Loa are much larger than those of Kīlauea. Mauna Loa produced about 65 percent as much lava as did Kīlauea while erupting only about 3 percent as often.

Lava from several eruptions in the past century both covered land and destroyed buildings, roads, and other structures. Among them, the 1955 and 1960 eruptions in lower Puna, and the Pu`u `O`o-Kupaianaha eruption from 1986 to 1991, were the most damaging at Kīlauea. The 1926 and 1950 eruptions of Mauna Loa were also very destructive.

Two Kīlauea eruptions led directly to fatalities, one from an explosion at Halema`uma`u in 1924 and three at the coast during the ongoing eruption.

The picture gets fuzzier in the 19th century. Halema`uma`u was almost constantly active; its spill-outs built the caldera floor up more than 200 m (200 yards). At least eight other eruptions of Kīlauea are known; by far the largest, along the east rift zone in 1840, had a volume of 0.2 cubic kilometers (260 million cubic yards).

Mauna Loa had at least 24 eruptions in the 19th century, more than in the 20th. It produced more than 2.5 cubic kilometers (3.3 billion cubic yards) of lava, almost certainly more than did Kīlauea.

Hualalai, the third active volcano on the island, erupted in 1801. This flow underlies the north end of the runway at Keahole airport.

Precise dates of eruptions before 1823 are unknown, with one exception. At Kawaihae, John Young reportedly saw an eruption column issuing from Kīlauea during explosions in November 1790. Aside from this, we must depend on geologic evidence to recognize deposits of past eruptions and to provide approximate ages for them.

The geologic record shows that Kīlauea's summit area was very active during the first 500 years of the millennium, before the modern caldera formed. Many flows moved in all directions from the shield that capped the summit, some making it to the south coast.

The largest of these eruptions came from an off-center vent just east of Kīlauea Iki. It produced the remarkable `Aila`au flow, which started in about 1410, lasted for some 60 years, and covered the area north of the east rift zone from Volcano to Kaloli Point.

Mauna Loa erupted about 80 times between the start of the millennium and 1832. Its eruptions impressed residents less than did those at Kīlauea, probably because the activity was usually remote. Many of the eruptions must have been destructive, however, covering trails and destroying forests and cropland.

Two other volcanoes erupted in the last millennium before 1800. Hualalai had one or more eruptions in the late 1700s. East Maui volcano (Haleakala) erupted a flow into La Perouse Bay between about 1400 and 1600 by radiocarbon dating or shortly before 1790 by oral history.

Expect more of the same in the new millennium. Kīlauea and Mauna Loa will be the show-offs, but Hualalai and East Maui will strut their stuff too. Now, if we live long enough to check this forecast...

From January 2000 Volcano Watch

CHAPTER EIGHT
The Big Island

Kilauea

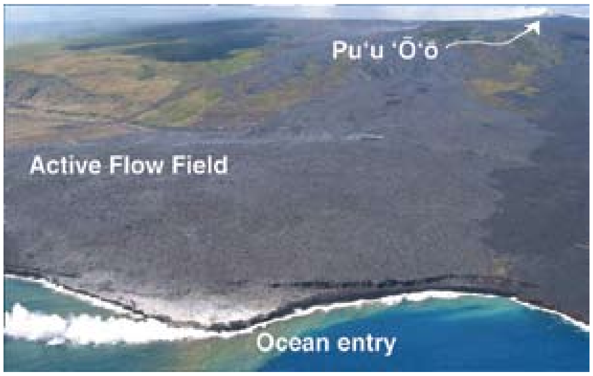
- **Kilauea**
  - Eruption Update
  - Eruption Summary
  - Hazards
  - History
- **Mauna Loa**
- **Earthquakes**
- **Other Volcanoes**
- **Volcanic Hazards**
- **About HVO**

Kilauea -- Perhaps the World's Most Active Volcano

View north-northeast across Kilauea's summit caldera and Halema`uma`u crater (left of center)

Kilauea is the youngest and southeastern most volcano on the Big Island of Hawai`i. Topographically Kilauea appears as only a bulge on the southeastern flank of Mauna Loa, and so for many years Kilauea was thought to be a mere satellite of its giant neighbor, not a separate volcano. However, research over the past few decades shows clearly that Kilauea has its own magma-plumbing system, extending to the surface from more than 60 km deep in the earth.

In fact, the summit of Kilauea lies on a curving line of volcanoes that includes Mauna Kea and Kohala and excludes Mauna Loa. In other words, Kilauea is to Mauna Kea as Lo`ihi is to Mauna Loa. Hawaiians used the word Kilauea only for the summit caldera, but earth scientists and, over time, popular usage have extended the name to include the entire volcano.



This view is northwest across coastal plain of Kīlauea from West Highcastle lava delta to Pu`u `O`o (upper right skyline). The delta extends 250 m seaward from old sea cliff and adds nearly 9 hectares of new land to Hawai`i. Lava flows through tubes between Pulama pali (steep fault scarp in top part of photo) and the sea. Frequent lava breakouts onto coastal plain since July widened active flow field eastward (right side of photo) and westward. White fume is acidic steam plume (laze) resulting from boiling of sea water by hot lava entering water.

The eruption of Kīlauea Volcano that began in 1983 continues at the cinder-and-spatter cone of Pu`u `O`o (high point on skyline). Lava erupting from the cone flows through a tube system down Pulama pali about 11 km to the sea (lower left).

Eruption History

When Kīlauea began to form is not known, but various estimates are 300,000-600,000 years ago. The volcano has been active ever since, with no prolonged periods of quiescence known. Geologic studies of surface exposures, and examination of drillhole samples, show that Kīlauea is made mostly of lava flows, locally interbedded with deposits of explosive eruptions. Probably what we have seen happen in the past 200 years is a good guide to what has happened ever since Kīlauea emerged from the sea as an island perhaps 50,000-100,000 years ago.

Throughout its history Kīlauea has erupted from three main areas, its summit and two rift zones. Geologists debate whether Kīlauea has always had a caldera at the summit or whether it is a relatively recent feature of the past few thousand years. It is likely that the caldera has come and gone through its lifetime.

The summit of the volcano is high because eruptions are more frequent there than at any other single location on the volcano. However, more eruptions actually occur on the long rift zones than in the summit area, but they are not localized, instead constructing ridges of lower elevation than the summit. Eruptions along the east and southwest rift zones have build ridges reaching outward from the summit some 125 km and 35 km, respectively.

Most eruptions are relatively gentle, sending lava flows downslope from fountains a few meters to a few hundred meters high. Over and over again these eruptions occur, gradually building up the volcano and giving it a gentle, shield-like form. Every few decades to centuries, however, powerful explosions spread ejecta across the landscape. Such explosions can be lethal, as the one in 1790 that killed scores of people in a war party near the summit of Kīlauea. Such explosions can take place from either the summit or the upper rift zones.

The Pu`u `O`o-Kupaianaha Eruption, 1983-Present

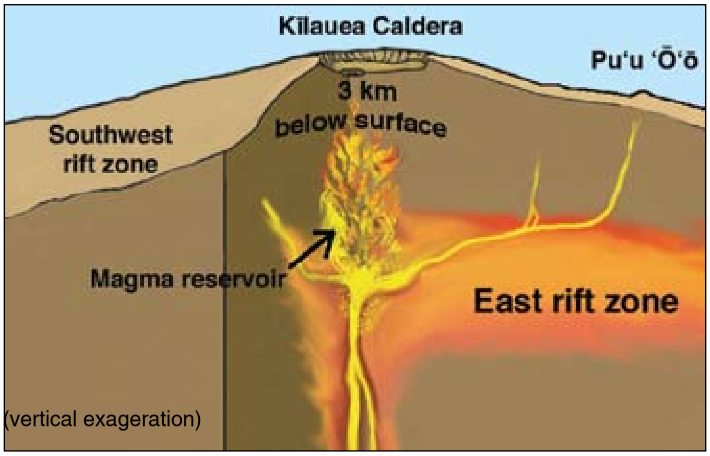
The Pu`u `O`o-Kupaianaha eruption of Kīlauea, now in its nineteenth year and 55th eruptive episode, ranks as the most voluminous outpouring of lava on the volcano's east rift zone in the past five centuries. By September 2002, 2.3 km3 of lava had covered 110 km2 and added 220 hectares to Kīlauea's southern shore. In the process, lava flows destroyed 189 structures and resurfaced 13 km of highway with as much as 25 m of lava.

Beginning in 1983, a series of short-lived lava fountains built the massive cinder-and-spatter cone of Pu`u` O`o. In 1986, the eruption migrated 3 km down the east rift zone to build a broad shield, Kupaianaha, which fed lava to the coast for the next 5.5 years. When the eruption shifted back to Pu`u `O`o in 1992, a series of flank-vent eruptions formed a shield banked against the uprift side of the cone. Continuous eruption from these vents undermined the west and south flanks of the cone, resulting in large collapses of the west flank.

In May 2002, a new vent opened on the west side of the shield and fed flows down the western margin of the flow field, sparking the largest forest fire in the park in 15 years. These flows reached the ocean near the end of Chain of Craters Road in July, and as many as 4,000 visitors per day flocked to view flowing lava up close for the rest of the summer.

Future of Kīlauea

As of 2004 the current eruption of Kīlauea continues its track record of being the longest lived eruption in historic time with no sign of stopping. The foreseeable future of Kīlauea looks much like the past. Continued effusive eruptions will fill the caldera, heighten the summit, and build the rift zones--over and over and over again. Sporadic explosions will cause destruction but hopefully not loss of life. We cannot tell how much larger Kīlauea will grow or when it will stop, but it will surely continue to erupt through the rest of human history.



Magma eters the "Grand Central Station" (reservoir) of Kīlauea and erupts at the summit or is shunted down one of the rift zones.

Lava fow seen here approaching an intersection, like the current eruption, shows no sign of stopping.

Year	Start	Days	Region of Kilauea	Area (km^2)	Volume (km^3)
1983	Jan-3	>7,500	East Rift – Pu‘u ‘Ō‘ō	102	>2.1
1982	Sep-25	<1	Caldera	0.8	0.003
1982	Apr-30	<1	Caldera	0.3	0.0005
1979	Nov-16	1	East Rift—Pauahi	0.3	0.00058
1977	Sep-13	18	East Rift—Pu‘u Kiai	7.8	0.0329
1975	Nov-29	<1	Caldera—M7.2 EQ	0.3	0.00022
1974	Dec-31	<1	Southwest Rift	7.5	>0.0143
1974	Sep-19	<1	Caldera—partially drained in Halema‘uma‘u	1.0	0.0102
1974	Jul-19	3	Caldera, Keanakako‘i, East Rift,	3.1	0.0066
1973	Nov-10	30	East Rift —Pauahi to Pu‘u Huluhulu	1.0	0.0027
1973	May-5	<1	East Rift—Hi‘iaka to Pauahi	0.3	0.0012
1972	Feb-3	900	East Rift —Mauna Ulu 2	46	0.162
1971	Sep-24	5	W. Caldera, Southwest Rift	3.9	>0.0077
1971	Aug-14	<1	S.E. Caldera	3.1	0.0091
1969	May-24	874 (s)	East Rift—Mauna Ulu 1	50	0.185
1969	Feb-22	6	East Rift—‘Alae to Napau	6.0	0.0161
1968	Oct-7	15	East Rift –Kane Nui o Hamo and 3 km E.	2.1	0.0066
1968	Aug-22	5	East Rift —Hi‘iaka	0.1	0.00013
1967	Nov-5	251	Halema‘uma‘u	0.7	0.0803
1965	Dec-24	<1	East Rift —Near ‘Alo‘i	0.6	0.00085
1965	Mar-5	10	East Rift—Makaopuhi to Kalalua	7.8	0.0168
1963	Oct-5	1	East Rift—Near Napau	3.4	0.0066
1963	Aug-21	2	East Rift—Near ‘Alae	0.2	0.0008
1962	Dec-7	2	East Rift—‘Alo‘i to Kane Nui o Hamo	0.1	0.00031
1961	Sep-22	3	East Rift–Napau and 21 km E	0.8	0.0022
1961	Jul-10	7	Halema‘uma‘u	1.0	0.0126
1961	Mar-3	2	Halema‘uma‘u	0.3	0.00026
1961	Feb-24	1	Halema‘uma‘u	0.1	0.00002
1960	Jan-13	36	East Rift—Kapoho	10.7	0.1132
1959	Nov-14	36	Kilauea Iki	0.6	0.0372
1955	Feb-28	88	East Rift—Lower Puna	15.9	0.0876
1954	May-31	3	Halema‘uma‘u, C. Caldera	1.1	0.0062
1952	Jun-27	136	Halema‘uma‘u	0.6	0.0467
1934	Sep-6	33	Halema‘uma‘u	0.4	0.0069
1931	Dec-23	14	Halema‘uma‘u	0.3	0.007
1930	Nov-19	19	Halema‘uma‘u	0.2	0.0062
1929	Jul-25	4	Halema‘uma‘u	0.2	0.0026
1929	Feb-20	2	Halema‘uma‘u	0.2	0.0014
1927	Jul-7	13	Halema‘uma‘u	0.1	0.0023
1924	Jul-19	11	Halema‘uma‘u	0.1	0.000234
1924	May-10	17	Caldera, Halema‘uma‘u	Ash	No lava
1923	Aug-25 ?	1	East Rift	0.5	0.000073
1922	May-28	2	MC, NC	0.1	?
1921	Mar-18	7	SW Caldera	2.0	0.0064
1919	Dec-21	221	Southwest Rift—Mauna Iki	13.0	0.0453
1919	Feb-7	294	NW Caldera	4.2	0.0252 ?
1918	Feb-23	14	Caldera	0.1	0.000183

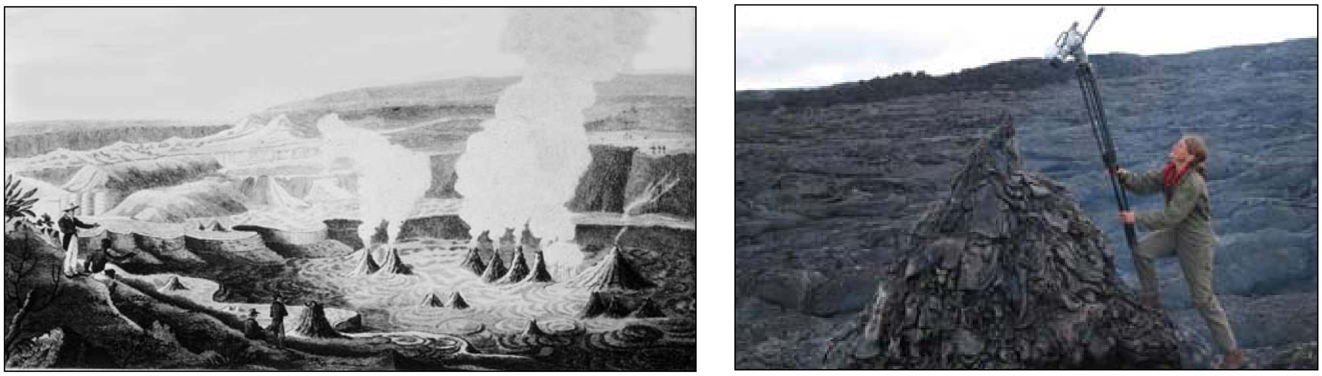
Chronological list, from 1868 to present, of eruptions of Kīlauea volcano recorded by Westerners. List from the 1800’s on next page.

continued from previous page.

Year	Start		Days	Region of Kilauea	Area (km^2)	Volume (km^3)
1894	Jul-7		4 ?	Caldera	?	?
1894	Mar-21		6+	Caldera	?	?
1889	?		?	Caldera	?	?
1885	Mar		80 ?	Caldera	?	?
1884	Jan-22		1	East Rift	0.1	?
1877	May-21 ?		-	Keanakakoʻi	0.1	?
1877	May-4		1 ?	Caldera Wall	?	?
1868	Apr-2 ?		Short	Southwest Rift—W side	0.1	0.000183
1868	Apr-2		Short	Kilauea Iki	0.2	?

Kīlauea volcano eruptive events from 1868 until 1894. Events from the 1900’s on previous page.

Yesterday and Today



Drawing by William Ellis in 1823 shows fuming fanciful hornitos on the floor of Kīlauea caldera in the approximate location of Halemaumau. Photo on the right shows a hornito on the Pu“u “Ō“ō flow field. A hornito is a small rootless spatter cone that forms on the surface of a basaltic lava flow (usually pahoehoe) is called a hornito. A hornito develops when lava is forced up through an opening in the cooled surface of a flow and then accumulates around the opening. Typically, hornitos are steep sided and form conspicuous pinnacles or stacks. They are “rootless” because they are fed by lava from the underlying flow instead of from a deeper magma conduit.

Painting by Titian Ramsey Peale, born 1799, who traveled from Philadelphia and were on the United States Exploring Expedition led by Lieutenant Charles Wilkes. Peale, a naturalist, is the first documented artist to paint the smoldering volcanic landscape.

Kilauea

Mauna Loa

Current
Activity
Hazards
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Earthquakes

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Volcanic Hazards

About HVO

Mauna Loa

Mauna Loa
Earth's Largest Volcano

Photograph by J.D. Griggs on January 10, 1985

Rising gradually to more than 4 km above sea level, Mauna Loa is the largest volcano on our planet. Its long submarine flanks descend to the sea floor an additional 5 km, and the sea floor in turn is depressed by Mauna Loa's great mass another 8 km. This makes the volcano's summit about 17 km (56,000 ft) above its base! The enormous volcano covers half of the Island of Hawai`i and by itself amounts to about 85 percent of all the other Hawaiian Islands combined.

Mauna Loa is among Earth's most active volcanoes, having erupted 33 times since its first well-documented historical eruption in 1843. Its most recent eruption was in 1984. Mauna Loa is certain to erupt again, and we carefully monitor the volcano for signs of unrest. See current activity for a summary of our monitoring efforts.

The Hawaiian name “Mauna Loa” means “Long Mountain.” This name is apt, for the subaerial part of Mauna Loa extends for about 120 km from the southern tip of the island to the summit caldera and then east-northeast to the coastline near Hilo.

Satellite imagery of the Big Island shows the recent lava flows from Mauna Loa and Kīlauea volcanoes.

FACTS ABOUT MAUNA LOA

Elev. Above Sea Level 4,170 m 13,680 ft

Area 5,271 km2 2,035 mi2 (50.5% of Hawai`i)

Volume 80,000 km3 19,000 mi3

Most Recent Eruption March 24-April 15, 1984

Number of Historical Eruptions 33

Summit Caldera Moku`aweoweo, "Moku" refers to a coastal land section or islet; "`aweoweo" is a type of red Hawaiian fish. Literal translation is fish section (the red of the fish suggests red lava).

* Dimension: 3 x 5 km, elongated northeast-southwest
* Depth: 183 m deep
* Age: estimated to have collapsed 600-750 years ago

Oldest Dated Rocks Between 100,000 and 200,000 years ago

Estimated Age of Earliest Subaerial Eruptions About 400,000 years ago

Estimated Age of First Eruption of Mauna Loa Between 1,000,000 and 700,000 years before present

Hawaiian Volcano Stage Shield-forming stage

Eruption History

Mauna Loa has grown rapidly during its relatively short (600,000 to 1,000,000 years) history to become the largest volcano on Earth. Although its rate of growth appears to have slowed in the past 100,000 years, our detailed geologic research on the volcano has nevertheless shown that about 98 percent of the volcano's surface is covered with lava flows less than 10,000 years old! Based on reliable ages of nearly 200 of these flows, we've found that Mauna Loa has erupted in time and place in fundamentally different ways -- as eruptions from the summit of Mauna Loa become larger and more frequent, eruptions from the rift zones decline.

A cyclic model was recently proposed for the volcano's summit-flank alternation of eruptive activity. Detailed geologic mapping suggests that the cycles may last about 2,000 years each. Since the most recent period of intense summit activity began about 2,000 years ago, perhaps Mauna Loa is "on the verge of shifting to a period of long-lived lava-lake activity, shield-building, increased summit overflow, and diminished rift zone eruptions."

Summary of Historical Eruptions, 1843 - Present

Polynesian settlers, who first reached Hawai`i about 1500 years ago, preserved almost no record of Mauna Loa's eruptive activity, and the earliest references are fragmentary accounts of activity in the late 18th and 19th centuries. The first extended written account of a Mauna Loa eruption was by a missionary who witnessed the June 1832 eruption from Maui, 190 km away; the lava flows erupted during this activity have not yet been positively identified, however, so this eruption is not included in the eruption-summary table on opposite page.

Eruption Precursors to the 1984 Eruption: Earthquakes & Deformation 1975-1984

The 1984 eruption of Mauna Loa ended a nine-year period of quiescence. The eruption began suddenly following a three-year period of slowly increasing earthquake activity beneath the volcano that included a swarm of earthquakes 5 to 13 km deep in mid-September 1983. The earthquakes reached a maximum frequency just after a 6.6-magnitude event beneath the southeast flank of Mauna Loa along the Ka`oiki fault system on November 16, 1983. Following the Ka`oiki earthquake, the number of earthquakes >M 1.5 increased gradually as the time of eruption approached.

During the entire period following the brief summit eruption on July 5-6, 1975, and before the beginning of the 1984 eruption, the summit region of Mauna Loa inflated. Although magma was clearly accumulating inside the volcano, there were no other clear signals or changes in the volcano's gas emissions, deformation, or seismicity before the eruption.

The immediate precursors to the eruption consisted of an abrupt increase in small earthquakes and volcanic tremor recorded on seismic stations located near Moku`aweoweo. At 10:55 p.m. on March 24, small earthquakes began at a rate of 2-3 per minute. By 11:30 p.m., the seismic background increased, marking the onset of tremor. Just before 1:00 a.m. on March 25, the tremor amplitude increased to the point that the astronomical telescopes on Mauna Kea, 42 km (26 mi) to the northwest, could not be stabilized because of the constant ground vibration.

1984 Eruption

The 1984 Mauna Loa eruption began at about 1:30 a.m., March 25 with lava fountaining in the southwest corner of the summit crater. Within 2 to 3 hours, 80% of the crater was covered by lava. The eruption activity soon shifted to the northeast rift zone. By about 5 p.m. on the 25th, the major activity had moved to the 9,200-ft level on the northeast rift, 2,000 ft below MLO.

Between March 26-29, lava flows approached the town of Hilo town. The lava stopped just at the outskirts as people were packing to evacuate. By April 14, no active `a`a lava flows extended more than 2 km from the vents, and on April 15, the eruption ended.

The natural breakdown of levees along the margins of the channelized `a`a flows diverted lava from the main channel into one or more new subparallel flows. Consequently the advance of the main flow was arrested. Many factors facilitated this diversion, including (1) relatively gentle slopes; (2) dense vegetation through which the flows moved; (3) the relatively low temperature of the erupted lava, which made it relatively viscous; and (4) the gradual decline of eruption rates. These factors and the short duration of the eruption helped to prevent lava from advancing into Hilo.

Year	Start (mo-day)	Summit	Flank	Eruptive	Area Covered	Volume	Error in Est.
	(mo-day)	(days)	(days)	Subdivision	km2	(Km3)	Volume (%)
1984	26-Mar	<1	22	S, NE	48	0.22	±20
1975	5-Jul	1	0	S	13	0.03	±20
1950	1-Jun	1	23	S, SW	112	0.376	±20-40
1949	6-Jan	145	0	S	22	0.116	±20
1942	26-Apr	2	13	S, NE	34	0.176	±20
1940	17-Apr	134	0	S	13	0.11	±20
1935	21-Nov	6	40	S, NE, MKN	33	0.087	±20-40
1933	2-Dec	17	0	S	6	0.1	±20-40
1926	10-Apr	<1	14	S, SW	35	0.121	±20-40
1919	26-Sep	<1	38	S, SW	28	0.183	±20-40
1916	19-May	0	12	SW	17	0.031	±20-40
1914	25-Nov	48	0	S	5	0.055	±20-40
1907	9-Jan	<1	15	S, SW	28	0.121	±20-40
1903	6-Oct	61	0	S	5	0.07	> ±40
1903	1-Sep	<1	0	S	1	0.003	no data
1899	1-Jul	4	21	S, NE	23	0.081	±20-40
1896	21-Apr	16	0	S	5	0.025	> ±40
1892	30-Nov	3	0	S	3	0.012	> ±40
1887	16-Jan	<1	7	S, SW	29	0.128	±20-40
1880	5-Nov	0	280	NE	51	0.13	±20-40
1880	1-May	6	0	S	5	0.01	no data
1879	9-Mar	S	0		1	0.001	no data
1877	14-Feb	<	<1	S, MKN	1	0.008	> ±40
1872	9-Aug	~1,200					
(nearly							
continuous)	0	S	5	0.63	±20-40		
1871	10-Aug	~20	0	S	3	0.02	no data
1868	27-Mar	<1	5	S, SW	24	0.123	±20-40
1865	30-Dec	~125	0	S	5	0.05	no data
1859	23-Jan	<1	~300	S, MKN	91	0.383	> ±40
1855	8-Aug	<1	~450	S, NE	66	0.28	> ±40
1852	17-Feb	1	20	S, NE	33	0.182	±20-40
1851	8-Aug	4	0	S	12	0.035	±20-40
1849	May-(?)	15	0	S	5	0.025	no data
1843	10-Jan	5	~90	S, NE, MKN	45	0.202	> ±40
				Total	**806 km2**	**4.124 km3**	

Summary of eruptions recorded by Westerners from 1843 to 1984.

Notes about the table: Other sources list as many as seven eruptions between 1872 and 1876; this table refers to the extended eruptive activity as one eruptive episode following the authors (below).
Eruptive subdivisions include the summit area (S) which consists of vent locations above 3,660 m; (SW) southwest rift zone; (NE) northeast rift zone; and (MKN) north of Moku`aweoweo Caldera. The number of historical eruptions and average rates of lava eruption for each subdivision are shown on this map.
Table Source: Lockwood, J. P., and Lipman, P. W., 1987, Holocene eruptive history of Mauna Loa Volcano, in Decker, R.W., Wright, T.L, and Stauffer, P.H., eds., Volcanism in Hawaii: U.S. Geological Survey Professional Paper 1350, v. 1, p. 518. Eyewitness Accounts of Early Eruptions

Descriptions of the earliest documented eruptions in table appear in Life in Hawai`i by Rev. Titus Coan, published in 1882 and presented online by The Hawai`i Center for Volcanology.

Lava fountains erupt from the principal vents of the 1984 eruption of Mauna Loa, high on the northeast rift zone. Referred to as the 2,900-m vents, they are 19 km east of the original outbreak point that began within Moku`aweoweo caldera about 36 hours earlier. Six separate structures eventually formed around the vents, including a cinder cone at the uprift end and a lava shield at the downrift end. The most productive vent along this fissure is in upper left. Note person in lower left.

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Hualalai
Hawai`i's Third Active Volcano

Photograph by J. Kauahikaua on December 30, 1996.

Hualalai is the third youngest and third-most historically active volcano on the Island of Hawai`i. Six different vents erupted lava between the late 1700s and 1801, two of which generated lava flows that poured into the sea on the west coast of the island. The Keahole Airport, located only 11 km north of Kailua-Kona, is built atop the larger flow.

Though Hualalai is not nearly as active as Mauna Loa or Kilauea, our recent geologic mapping of the volcano shows that 80 percent of Hualalai's surface has been covered by lava flows in the past 5,000 years. In the past few decades, when most of the resorts, homes, and commercial buildings were built on the flanks of Hualalai, earthquake activity beneath the volcano has been low. In 1929, however, an intense swarm of earthquakes lasting more than a month was most likely caused by magma rising to near the surface. For these reasons, Hualalai is considered a potentially dangerous volcano that is likely to erupt again in the next 100 years.

FACTS ABOUT HUALĀLAI:

Most Recent Eruption(s): 1800 and 1801 A.D.

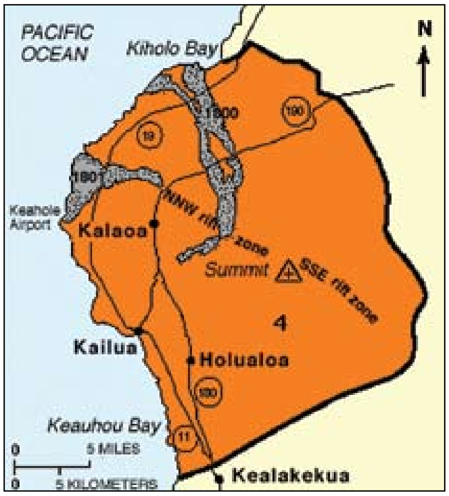
Number of Historical Eruptions (since 1790 A.D.): One, possibly two (six different vents active)

Oldest Dated Rocks: About 128,000 years before present

Estimated Age of Hualalai: Apparently grew above sea level before 300,000 years ago

Volcano Stage: Post-shield stage

Stippled area on map show the 1800 and 1801 lava flows. The location of Kailua makes it at risk for future eruptions.



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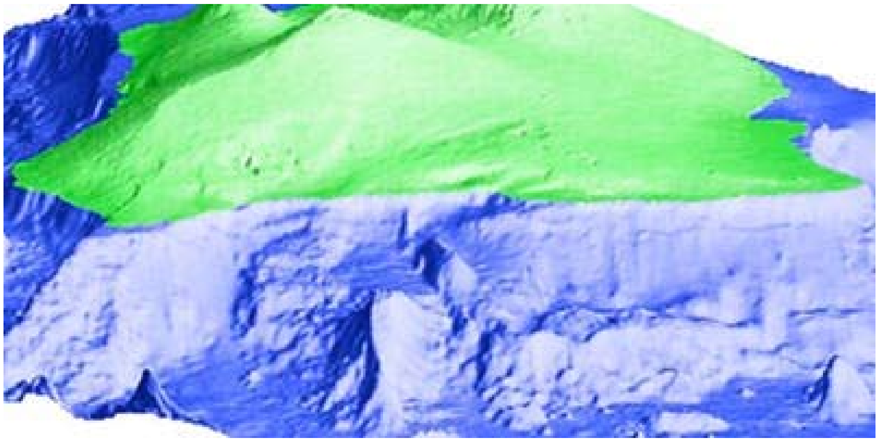
Lo`ihi Seamount
Hawai`i's Youngest Submarine Volcano



View of Lo`ihi Seamount northwest from a perspective high above and to the southeast of the Island of Hawai`i (green). Lo`ihi Seamount is in bottom center of image.

Lo`ihi Seamount is an active volcano built on the seafloor south of Kilauea about 30 km from shore. The seamount rises to 969 m below sea level and generates frequent earthquake swarms, the most intense of which occurred in 1996. An eruption at Lo`ihi has yet to be observed, but scientists from the University of Hawai`i have recently made many submersible dives to the volcano and deployed instruments on its summit to study Lo`ihi in much greater detail.

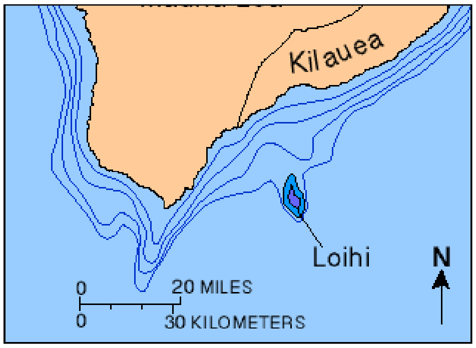
The summit of Lo`ihi is marked by a caldera-like depression 2.8 km wide and 3.7 km long. Three collapse pits or craters occupy the southern part of the caldera; the most recent pit formed during an intense earthquake swarm in July-August 1996. Named Pele's Pit, the new crater is about 600 m in diameter and its bottom is 300 m below the previous surface! Like the volcanoes on the Island of Hawaii, Lo`ihi has grown from eruptions along its 31-km-long rift zone that extends northwest and southeast of the caldera.

FACTS ABOUT LO‘IHI

Height Above Sea Floor: Lo`ihi is built on the seafloor that slopes about 5 degrees beneath the seamount.Lo`ihi’s northern base is 1,900 m below sea level, whereas its southern base is 4,755 m below sea level. Thus, the summit is about 931 m above the seafloor as measured from the base of its north flank and 3,786 m above the seafloor as measured from the base of its south flank.

Most Recent Activity: Earthquake Swarm (>4,000 events), July 16-August 9, 1996

Hawaiian Volcano Stage: In transition between pre-shield and shield stage



Lo`ihi Smaller and YoungerThan Kīlauea

Despite its notoriety as Hawai`i's youngest volcano, Lo`ihi remains a submarine mystery for most of us. This is because fieldwork there is limited to manned or remotely operated vehicles. At its shallowest depth, Lo`ihi is still 980 m (3,200 ft) below sea level.

Lo`ihi has had earthquake swarms almost every year since 1980. The most intense seismic activity ever recorded by HVO began in 1996, when 4,377 earthquakes shook the summit of Lo`ihi from mid-July to mid-August. Over 100 of these temblors were larger than magnitude 4. Subsequent submersible dives have discovered a newly formed small crater and active thermal springs.

Lo`ihi's summit is a plateau about 3 km (2 mi) wide and 5 km (3 km) long, lying 40 km (25 mi) due south of Halape. If going by kayak, put in at Punalu`u, a landfall only 34 km (21 mi) northwest of Lo`ihi's summit.

The volcano stands about 3.2 km (10,500 ft) above its base atop the sloping submarine flank of Mauna Loa and Kīlauea. Some subsidence of the sea floor has resulted from the mass imposed by Lo`ihi, so the volcano's total thickness is about 3.5 km (11,480 ft).

Lo`ihi, which means "long" in Hawaiian, is a narrow ridge 18 km at greatest breadth and 32 km in length. A useful Big Island comparison is to imagine the subaerial outline of Kohala volcano, which reaches from Waimea to Hawi. Height is another matter, however; Kohala's summit is only about 1,600 m (5,250 ft), half as high as submarine Lo`ihi if the volcanoes were placed side by side on a flat base. Another way to envision Lo`ihi's dimensions is to imagine a volcano stretching from Kīlauea's summit to Kea`au, but standing 3,350 m high (11,000 ft).

Landsliding is rampant at Lo`ihi, affecting more than three-quarters of the volcano's flanks. Indeed, the most startling aspect of Lo`ihi's shape is its knifelike form. Slopes of 35-40 degrees are common. To find slopes this steep, drive along the Chain of Craters road where it plunges over the Hilina Pali escarpments. The precipitous slopes of O`ahu's Ko`olau Range, viewed from Kaneohe, could also serve as a reminder about Lo`ihi's steep sides.

Where unaffected by landsliding, Lo`ihi's slopes are about 10-14 degrees. Such slopes are characteristic of the submarine parts of Hawaiian shield volcanoes. A similar average slope is found for Kīlauea and Mauna Loa at their 500-m water depth. In contrast, the subaerial parts of shield-stage volcanoes are commonly much gentler, about 4 degrees.

Volumetrically, Lo`ihi occupies about 715 cubic kilometers (172 cu mi), making it fourth-smallest of the volcanoes in the Hawaiian-Emperor seamount chain. (Smaller are three unnamed seamounts near the bend in the Hawaiian-Emperor chain.) For local comparison, Kīlauea has a volume ranging from 12,000 to 20,000 cubic kilometers (2,880-4,800 cu mi), or 15-30 times more voluminous. (Kīlauean estimates vary greatly because the volcano's base is poorly defined.) Of course, Lo`ihi is still growing.

Lo`ihi is undated, so its age remains a matter of speculation. Most commonly cited is an age of 100,000-150,000 years, an estimate based on rates of accumulation (meters of upbuilding per year) known from other volcanoes. Hawaiian volcanoes are thought to breach the sea surface about 300,000 years after their birth, give or take about 100,000 years. If these assumptions hold true, then Lo`ihi is about halfway to islandhood, which must await another 150,000 years, despite having grown nearly three-quarters of the way from ocean floor to sea surface.

Lo`ihi is sufficiently far from the centers of Mauna Loa and Kīlauea that it will emerge through sea level and become its own little island before those two volcanoes can spread their arid flanks southward. But continued Lo`ihi growth and the expansion of Kīlauea and Mauna Loa will create an isthmus between them at some later date, when Lo`ihi becomes part of the Big Island.

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Maui

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East Maui, or Haleakala-- A Potentially Hazardous Volcano

View east across Haleakala Crater, with young cinder cones in foreground.

When asked about Hawaiian volcanoes, most people imagine the Island of Hawai`i and its eruptions at Kilauea or Mauna Loa volcanoes. But East Maui volcano has witnessed at least ten eruptions in the past 1,000 years, and numerous eruptions have occurred there in the past 10,000 years. Thus, East Maui's long eruptive history and recent activity indicate that the volcano will erupt in the future.

Haleakala National Park is the most visited part of East Maui. The Hawaiian name Hale-a-ka-la (lit., house of the sun), is now nearly synonymous with the entire shield of East Maui volcano. Early Hawaiians, however, applied the name only to the summit area, the site where the demigod Maui snared the sun and forced it to slow its journey across the sky.

The oldest lava flow exposed on East Maui is about 1.1 million years in age. It is part of a sequence of flows emplaced near the end of shield building on East Maui. The time estimated to build a volcano from ocean floor to the end of its shield-building stage is thought by some scientists to be about 0.6 million years. East Maui volcano probably began its growth about 2.0 million years ago.

Volcanism of the past 30,000 years on East Maui has been focused along the southwest and east rift zones. These two volcanic axes together form one gently curving arc that passes from La Perouse Bay (southwest flank of East Maui) through Haleakala Crater to Hana on the east flank. The alignment continues east beneath the ocean as Haleakala Ridge, one of the longest rift zones along the Hawaiian Islands volcanic chain. The on-land segment of this lengthy volcanic line of vents is the zone of greatest hazard for future lava flows and cindery ash.

FACTS ABOUT HALEAKALĀ

Elev. Above Sea Level: 3,055 m (10,023 ft)

Area:1,470 km^2 (570 mi^2) (77% of Island of Maui)

Volume: about 30,000 km^3 (7,200 mi^3 (97% below sea level)

Most Recent Eruption: Perhaps about A.D. 1790, but newly obtained radiocarbon ages suggest the most recent eruption probably occurred earlier, sometime between A.D. 1480 and 1600.

Summit Crater: A large topographic depression, Haleakala Crater, occupies the summit region of East Maui volcano. The crater is breached at its northwest and southeast corners by large valleys that drain to the north and south coasts, respectively. The crater originated by erosion, not caldera collapse.

* Dimensions: 3.5 x 12 km, elongate east-west
* Depth: 860 m
* Estimated age: formed between 120,000 and 150,000 years ago

Oldest Dated Rocks: About 1.1 million years

Estimated Age of On-land Eruptions: Numerous small lava flows in past 30,000 years; slopes of volcano mantled by lava flows 700,000 to 150,000 years in age.

Estimated Age of Inception of East Maui Volcano: About 2.0 million years ago

Hawaiian Volcano Stage: Postshield stage (see Volcano Watch next column)

Regarding the "1790" Lava Flow

The 1790 inception date for the youngest lava flow on Maui was detremined when two maps were compared, wherein the earlier pre-1790 exploration lacked the prominent land mass seen on the post-1790 map. On the basis of current findings, it is possible that La Perouse's (ship 1) map makers didn't see it due to bad weather or passage in darkness.

Exerpt from Volcano Watch: "*In our efforts to refine the geologic map of Haleakala, we recently obtained radiocarbon ages from the youngest lava flows, those at La Perouse Bay. The ages indicate these flows were emplaced sometime between A.D. 1480 and 1600. This finding shakes the long-held assumption that the flows are vintage A.D. 1790. The charcoal that produced the ages was sought to test the 1790 hypothesis, and therein lies an unfinished story of scientific investigation.*

... the two charcoal ages are roughly coincident, within analytical error. They indicate an age substantially older than the previously assumed age of A.D. 1790. Our effort to resolve the discrepancy between different scientific findings, however, is unfinished. People questioned in 1841 about the age of the flow stated that their grandparents saw it. Their reports indicate a lava-flow age of about A.D. 1750.

The term for grandparents also means ancestors, thus early translators may have misconstrued the meaning. Seeing as how King Kamehameha I conquered Maui in the bloody Battle of Kepaniwai in 1790 in the Iao Valley, it seems highly likely that if there had been a rare lava flow on the island of Maui, that event would have been correlatd with it.

Post-shield Stage

Haleakala volcano, on Maui, is still in its postshield stage of volcanic evolution, as determined by 50 new isotopic ages. The volcano was long thought to have passed beyond that stage, with a lengthy eruptive lull lasting several hundred thousand years. The new ages show, however, that the lull does not exist and that lava flows have erupted persistently during the past one million years.

The idea that Hawaiian volcanoes progress through four stages has been widely accepted by geologists since the 1930s. Our understanding of why these stages occur increased when the plate tectonic theory was developed in the 1960s.

A volcano like Kīlauea or Mauna Loa grows fastest and erupts most frequently during the preshield and shield-building stages, when it is closest to the center of the Hawaiian hot spot. Hot spots, with their origin deep in the Earth's interior, are relatively stable compared to the moving plates that cover the Earth's surface. As the Pacific plate moves northwestward at 10 cm per year, it carries the shield-stage volcano away from its heat source. As a result, the volcano erupts less frequently. Also, the lava erupted will differ chemically from that produced during the shield stage because of the diminished heat supply. These changes define the character of the third stage, called postshield volcanism. Mauna Kea and Hualalai, located about 70 km from the hot spot, are examples of volcanoes that have entered their postshield stage.

Haleakala, nearly 200 km from the hot spot, has been active for two million years. It remains active, having erupted several times in the past 1,000 years. Until now, its recent lava flows were assigned to the fourth stage, the rejuvenation stage, for the following reason. Several large canyons cut into the volcano's flanks. Geologists assumed that a substantial time break and absence of eruptions were required for such erosion to gain the upper hand and carve deeply into Haleakala. Eruptions that followed such a lengthy episode of erosion, geologists reasoned, were the indicators of a rejuvenated volcanic system. Thus, an estimation of time has always been a critical part in assessing volcanic rejuvenation. But Haleakala's lava flows had never been sampled systematically to test the existence of a volcanic lull.

Our new ages, determined mostly by the potassium-argon method of dating, show that, although volcanism has fluctuated during the past one million years, it has never stopped completely. The large canyons on Haleakala's north, east, and south flanks were eroded in only a few tens of thousands of years, beginning after 150,000 years ago, based on the new ages. No lengthy period of erosion and eruptive quiet was required. Lava supply has diminished during the postshield stage, but it has never been curtailed completely. Chemically, lava flows of the past ten thousand years are similar to those erupted throughout the past 600,000 years. These flows are erupted from the same alignment of vents that has been building Haleakala's rift zones for eons.

Haleakala will erupt again, given the frequency of its past eruptions and long eruptive history. What's new in our understanding is that the recent, and coming, eruptions are the waning efforts of a postshield-stage volcano instead of a rejuvenated volcano. We have to look farther up the island chain, to West Maui, Moloka`i, and O`ahu, to find volcanoes that have erupted products of the rejuvenated stage.

Volcano Watch

SECTION FOUR

HAWAIIAN CULTURE

There was no written account of life in the Hawaiian Islands prior to the arrival of Captain James Cook in Waimea, Kaua'i on January 20th, 1778. There was no need for that as the oral histories passed down through the generations were sufficient in richness and detail for remembering ancestors, cultural and social history, noting celestial events in relation to births or other events of importance, exchanging stories of deities, and passing on ethical traditions. Though the accuracy of the original translations may have been colored by the transcriber, much is likely recorded as it was spoken. And there is a detailed geological record to be gleamed from the mele (chanted poetry) and mo'olelo (prose narative).

Alhough much of Hawaiian culture was suppressed by Western intruders during the 1800's and well past statehood in 1959, much had a unsupressible vitality in the hearts and souls of the Hawaiians. When a cultural renaissance began in the 1960's it produced a groundswell that is still developing momentum today. It is on the coat tails of this that we wish to promote the Hawaiian connection with the 'aina and to teach educate others to be sensitive to the land and to the Hawaiians who populate it.

Please note: The authors of this defer to other publications for stories of Pele and other deities of Hawaiian tradition rather than recreate what has already been done well. These include books by Herb Kane (Pele; Ancient Hawaii); Holo Mai Pele, created and choreographed by Pualani Kanaka'ole Kanahele and Nalani Kanaka'ole (http://www.pbs.org/holomaipele/index.html), Martha Beckwith (Hawaiian Mythology), Kalakaua (The Legends and Myths of Hawai'i). Brief discussions of stories are included as they correlate to geology as well as text from *W. D.* Westervelt which is permitted for use herein.

History of Hawaiian Culture and Society Prior to Western Contact, Hawaiian Mythology, and Holo Mai Pele: The Story

CHAPTER 10
Hawaiian Perceptions & Protocol

Terry Leianuenue Reveira was raised in the district of Ka'u. She has a Batchelor of Arts degree in natural sciences, and certificates in Hawaiian studies and elementary education. She spent many years at Hawaii Volcanoes National Park as an education specialist, designing curriculum and educational programs for visiting schools. She is now Chief of Interpretation for Pu'uhonua o Honaunau National Historical Park (City of Refuge). Here she shares her personal knowledge of Hawaiiana and awareness of all that surrounds you.

Guiding Through the Land of Pele

Written by Terry Leianuenue Reveira

Aloha, my name is Terry Leianuenue Reveira. My family comes from the land of Pele—the land from Ka'u to Puna and also the South Kona area. These are the lands of Pele the creator of land through volcanic eruptions. Her stories have been in my family for generations, some are shared with visitors and others are held for the family alone to hear. I have been visiting the Luapele (volcano) since I was very small with my grandparents. I have been listening to stories of this area for just as long. I am a grandparent and parent who now passes on these stories to my children in hopes they will continue this legacy of heritage. You will now have a legacy to share with others while helping to perpetuate the Hawaiian culture.

During the past 20 years I have been very lucky to have the opportunity to guide a diverse group of people through the Wahi Luapele (Volcano area) and Mokupuni o Hawai'i (Big Island). During these trips I have shared my stories and discussed the cultural interpretation of these wahi pana and wahi kapu (famous and sacred areas). I have also helped to enlighten others on becoming more comfortable in sharing the cultural interpretations and stories of these areas.

Introductions and Offerings

When first visiting the Luapele (Volcano) for the first time it is protocol and tradition to visit Halemaumau to give an offering. Traditionally this is the home of Pele where introductions are made. This is where you introduce your self (and group) and ask for safe guidance when visiting the realm of Pele. This is considered a sacred area and many who visit want to leave an offering. Some people bring traditional gifts to show their thanks for visiting the area or to ask for a safe visit. You may have read in a book the people use to bring offerings of "gin". This may link back to the traditional offering of the awa drink or the fact that many local businesses wanted to sell gin. If you decide to give a liquid offering please leave the offering and not the bottle (rubbish). Many people bring offerings that are not appropriate because when they are gone rubbish is left to blow across the lava fields. The offering should be something that does not hurt the environment. Some think they have to give something expensive or elaborate. I feel the best is what comes from the heart and is shared. The group could be introduced, read a short poem or sing a nice simple song. If the group creates a poem or song of the beauty of the volcano it could be read. This would be a traditional way of sharing and asking for guidance. As a guide you are in a position to create a unique experience for you group. Who knows what you will find during your visit to the Luapele. When you visit in a respectful manner nature will open its door and share with you its knowledge.

Expectations

Here are a few pointers that may helps to incorporate cultural interpretation into visitor program:

- Introduce yourself and share something about where you are from.
- Ask your group what they know about the history or culture of the area, you maybe surprised what they have to share. They may have a story too.
- You do not have to share long stories. Start with a few short stories about a few of the areas you visit. They should be about a specific site, a historic event, cultural deity associated with the area, or the cultural traditions practiced in the area (fishing, medicinal plants and uses, every day lifestyle)
- Share something that you like and enjoy, even something that happened to you.
- Never trivialize a local or native cultural practice, story or view by creating a new "cute" version or "joke" about a cultural story. This is an insult to the native people and their beliefs. Many times people will not say anything but word may get out on your approach or style.

Aia la o Pele i Hawai'i e—
There is Pele, she is Hawai'i

Pele Honuamea—
Pele, Sacred Land Creator

Story, Myth or Legend?

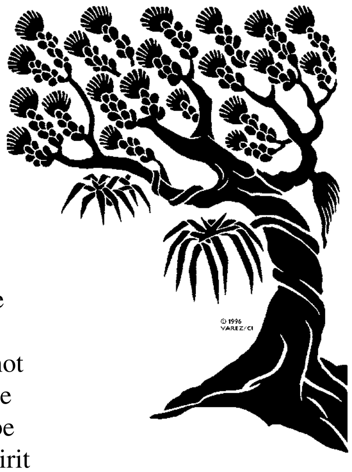
Real or not real? Many Native Hawaiian people do not like over-use of words like "myth" or even legends for their cultural stories. This is because it tends to give the story a make-believe or not-true connection. For many Hawaiians these stories are connected directly to their ancestors. They can trace theses stories back through generations to an original source. For many people Pele is a "legend" but to others she is a distant family relation. When you insult her, you insult generations of people. There are also many people who are not Hawaiian who enjoy and love the cultural stories and respect them. It is best to start off saying that the stories called "myths or legends" are oral traditions or family stories past on through generations. Many people have family stories and can relate to passing them along to document the past.

Cultural Interpretation – It's All Around You

I have met guides who have told me that they will not do cultural interpretation because they are geology major and that is what they teach. Well usually I invite them along on a few of my hikes to show them how culture is found all around them and can be easily shared without too much stress! The plants have native names and uses, the geology formations have Hawaiian names and stories of how they are formed by Pele and the sites have native place names linked to stories and events. Just choose a few to share and include into your program and the rest will fall into place when you are ready.

As you learn about the volcano and Pele you will learn she does not stand alone. Her family supports her. When you understand this you will begin to see the volcano through different eyes. Pele is the main deity who produces the eruptions and flows but she does it with the support of her whole family. Each in her family has a special role and function in the eruption. Her brothers take care of her fire sticks because that is a male role to start fires. Her sisters (the Hi'iakas) are the healers of the land and people. Where she goes they follow. As before, Pele can be seen as a destructive force or one that builds firm foundations in the land. When you learn some of the Pele stories you can then create intangible (stories, feelings) connections to tangible sources (land forms and places). You will also be able to link current science views on the volcano with past historic events and the people who witnessed and survived the events.

A Hawaiian View of Nature



Something to remember when beginning your quest into the unknown realm of Pele and her family is to understand the Hawaiian way of viewing nature. Many times nature is viewed through first-hand experience of seeing, hearing, smelling, tasting, touching and maybe even pain and fear. Nature can take away the blessings that it gives if it is not treated with respect. It should be not taken lightly. Also, things in nature are all very much alive and must be treated as such. They all have a spirit or mana and a place. Rocks have mana and sometimes do not want to be displaced or moved. When something was taken or used it was done by asking first then followed by prayer to give thanks. Pohaku or rock was used in every aspect of Hawaiian life but it was taken from places or quarries that had specific uses. Rules and protocol are set up around these experiences and shared in stories and chants to future generations as a way to keep others safe, tell an important story of nature and respect the elders and their knowledge.

Generations of Knowledge

The Hawaiian people have been living here for generations. They were the first to really study the volcano and its many modes. It was a way of life and survival. Pele is one story of creation of land while others include older stories of Maui and Papa and Wakea. Pele stories tell of her giving birth to the land. Products and formations of the volcano were named after her. There is Pele's hair, tears, steam is her breath, and earthquakes show her anger. Many old stories of Pele told by newcomers to Hawai'i did not understand her role. They gave her many negative attributes like as if she were continually angry, wanting to devour everything in the path of her flows. But the other side of the story was in destroying she created new land.

It is interesting to find that before Pele came the stories of the volcano were connected to a male deity called 'Ai la'au. When Pele came they had a battle and he gave in to her and her persuasive powers. Something in the eruptions had changed from a male source to a female source and Pele the creator became the volcano story. For many, her story is very much alive and going strong, because the volcano is alive. It is still erupting, continually adding to our land base. Pele is a female, a creative force that is her function and she does it well.

Pele finds a Home

The oral traditions tell us that Pele and her ohana come from a newer line of migrations to Hawai'i. They were navigation people who sailed the big wa'a (canoes) across the oceans. Her story tells of her unrest in her homeland and after gathering her supporting family members she went in search of her dream, a new homeland. Many people would understand the struggles she encountered in her search for a new home and even the family disputes that developed and became center stage. The Pele stories tell us of the struggles within the family - struggles for power between Pele and her older sister Namakaokaha'i and then with her younger favorite sister Hi'iakaokapoliopele as she comes of age. In nature Namakaokaha'i was the opposite of her sister Pelehonuamea. Namakaokaha'i held control over the ocean and used this in her fight with Pele. Pele held sway over fire. The two would clash often in a struggle of nature. Today, this struggle still continues and can been seen when hot lava enters the ocean and the explosions that follow.

Tangible and Intangible Links

The stories are an intangible link to all who have family. The tangible parts are the formations and features formed from these encounters between clashing forces. A good tangible link is to have your group members look for different types of lava formations and samples like the tears of Pele. Each island in Hawai'i has a Pele story and her eruptions or an event in her life are linked to the wahipana (special historic places) that she formed during her travels. So even if you do not have the energy to learn all the stories, you can find one or two places on your tour to connect to an historic event, feature or to Pele. Here is an example; when the people of Puna or Ka'u would see the flows on the mountainside and the glow of a lava tube they would say that Pele was hungry for fish. They knew within days her underground tube would reach the ocean and a steam plume would be seen in the sky. Another from Ka'u tells how the Ali'i (Chief) Keoua kuahu ula after defeating another area tried to pass through the Volcano area. He needed to reach his home to prepare for a fight with Kamehameha, a rival Ali'i. The volcano was erupting and he stopped to offer tribute to Pele and to ask for safe passage through. He waited a few days but the eruption continued so he divided his troops into three groups and sent them through. All of them did not make it through and many Hawaiians say that Pele had shown her choice between the two rival forces and of who should win the battle in the end.


Pele's tears and dime for scale.

Dangerous Flows

As you probably know, the volcano can be a dangerous place to visit and it takes its toll on many who do not give it the respect it deserves. Many of the Pele stories discuss respect and protocol when visiting the area as a way to keep safe. The stories tell us of Pele and her anger when people disrespect the area and her. Some stories give account of Pele as an old woman who travels through the land before an eruption to check if the people still respect her. The ones who do not will surely find a flow from her forthcoming eruption targeting their home area. These same stories give clues to how she should be approached and her movements. One describes when Pele, as an old woman will creep and crawl slowly across the land, slowly devouring all in her path. This would be an 'a'ā flow. The stories tell how the lava sounds when it moves or breaks, it has very sharp teeth that bite or can cut you. It is a "hungry" lava. These sound like some good rules to follow, in fact the park service has a list of rules to stay safe many are similar to these. So be very careful when approaching and walking across different types of lava especially if it is "hungry"

Wahi Kapu—Halemaumau, a Sacred Place

Many chants and stories give protocol when approaching or walking near the Halemaumau. It is because the area is considered sacred like a church. It is not good to make loud noises, pick up and throw rocks, kick rocks, spit or play around for this is the realm of Pele and it is considered sacred by many. Ask group members not to stack rocks even if they see others doing it. The rock mounds or cairns are called ahu in Hawaiian and are used to mark trails or large ones were used to show land divisions. It becomes very confusing and is disrespectful of have rock piles being made in a sacred area or throughout the park for the wrong reason. Another reminder is rubbish. Please have all group members pack out all rubbish and items they bring in. It is really bad to visit a site that has new land just born into the world and see cigarette butts, water bottles or toilet tissue. It really changes to whole experience of the hike besides being very disrespectful to the local culture.


Pele enters the ocean when she is "hungry for fish." Lava explodes in a violent show of steam and tephra as it enters the cool ocean water.


Halemaumau crater is partially framed in a natural 'ōhia-lehua lei. Photograph by Pauline Fukunaga, USGS-HVO, May 2000.

Family and Hawaiian Values

Stories of Pele and her family will help you learn about the volcano, how it functions and fits into the history of Hawai‘i. For many Hawaiians the family is the center most important thing in their lives and connects them to past generations that give them directions to the path to take in life. The story of what happens in nature is carefully watched by each generation and added to the family history and traditions. These stories take place over generations and change as nature changes. What better way to document these changes then through family stories, place names and songs?

Here are a few Hawaiian values and ideas that may help you understand the way people in Hawai‘i often think and feel.

E malama ka ‘aina—Take care of the land and it will take care of you

Kokua—Help others in need and someone will be there to help you

Kuleana—Respect each other and fulfill your responsibility, finish what you start

Ohana—Family connects us to our past and future, keep the bonds strong by continuing the stories and traditions

Aloha—share love and forgiveness from your heart with others and it will return to you.

Intuition: A Telling Force

Remember wherever you take your group to visit as a guide that you are a visitor and must be respectful to each place and the people even when you may not understand them.

If you visit a place and you do not feel comfortable, Hawaiians sometimes believe that something is telling you that you should not be there, heed the warning and find another place to visit. Please remember to tell your group members to be respectful of this area and other visitors. This place has a special feeling and “mana” or power that can be felt by many.

I hope this paper has helped you learn a little about the Luapele (volcano) area and the traditional way of viewing it. I also hope you will try to learn a few stories, some place names and native plants to share with your group. Remember to stop, look, listen and feel the areas that you visit. Share some moments of quiet and I am sure you to will feel the “mana” that is found at the home of Pele.

Thank you for allowing me share my thoughts and feelings with you on a place that is very special to my heart and family.

Terry Leianuenue Reveira

CHAPTER 11
Hawaiian Stories and Volcanoes

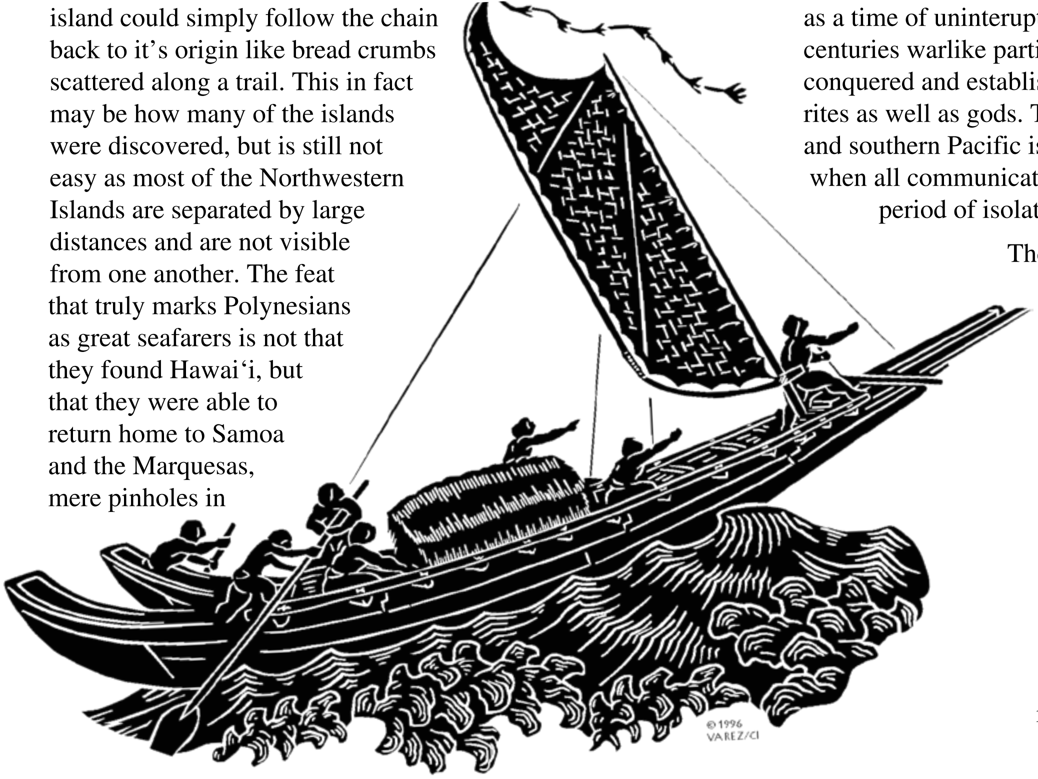
The recitation of geneologies, especially with respect to the lineage of the ancestors of chiefs served to maintain an elaborate social and political history of the Hawaiian islands from their discovery almost two millenia ago. Stories of deities also served to explain natural phenomena such as volcanic activity.

The Remarkable Feat of Polynesian Exploration

About 2000 years ago, Polynesians accomplished one of the most amazing feats of exploration in human history. Using the only natural resources available to them, rocks and wood (there are no significant metal deposits in Polynesia), Polynesians fashioned the first successful open–ocean catamaran. These double–hulled canoes would enable them to discover nearly all of the uninhabited islands in the Pacific Ocean.

To compliment this technology, they developed an extraordinary system of navigation and seamanship that had no equal in the world at the time. Even the grand Roman ships of that time rarely ventured far from the shores of the Mediterranean Sea. The Polynesian great were equivalent in scope to the space program today. However, unlike the moon program, Polynesians not only discovered these remote islands, but they colonized them and continued to travel between them for nearly a thousand years.

One might argue that a 1600-mile-long island chain would act like a huge fishnet that would collect any explorers that ventured near it. Polynesians finding one island could simply follow the chain back to it's origin like bread crumbs scattered along a trail. This in fact may be how many of the islands were discovered, but is still not easy as most of the Northwestern Islands are separated by large distances and are not visible from one another. The feat that truly marks Polynesians as great seafarers is not that they found Hawai‘i, but that they were able to return home to Samoa and the Marquesas, mere pinholes in the Pacific Ocean. The Hawaiian Islands were among the last major islands on Earth "discovered" by European sailors in the late 1700's.



Hawai‘i is thought to have originally been settled between 0 and 500 A.D. Hawaiians formed a thriving population on the main islands of Hawai‘i, Maui, Lana‘i, Kaho‘olawe, Moloka‘i, O‘ahu, Kaua‘i, and Ni‘ihau. Smaller fishing encampments and perhaps settlements have been found on Necker and Nihoa Islands, the first of the Northwest Hawaiian Islands.

Kalakaua, who wrote eloquently on Hawaiian oral tradition (The Legends and Myths of Hawaii), spoke of a paucity of oral tradition regarding the first 13 or 14 generations living on the islands, but that those centuries were regarded in chants as a time of uninterupted peace. In the late 10th or early 11th centuries warlike parties of visitors from the southern islands conquered and established a new dynasty introducing new rites as well as gods. There was much travel between Hawaii and southern Pacific islands until the close of the 12th century when all communication mysteriously ceased, beginning a period of isolation for Hawai‘i.

There were no permanent settlements past Ni‘ihau at the time of first European contact in the late 1700's and early 1800's. The native population is estimated to have been around 250,000-300,000 at that time. The following century saw a drastic decline in population due to epidemics of previously unencountered diseases brought by European voyagers.

While the sailing technology that led to the original exploration of Hawai‘i was lost around 1200–1300 A.D., Hawaiians continued to travel between islands in large outrigger canoes.

There has often been confusion about the role of Pele and the formation of the Hawaiian Islands. The islands were already here when Pele arrived. She did not form the islands. She may, however, have effected the landscape in an age progressive manner. The Hawaiians recognized that particular features on some of the islands were out of character with their surroundings. Rejuvenation-stage volcanism on the oldest islands witnessed a different style of eruption on Kaua'i O'ahu, Moloka'i, and West Maui long after they had left the hotspot (see Chapter 9: The Hawaiian Hotspot and the Origin of the Hawaiian Islands.) that could be correlated with the migration of Pele from west to east as she dug deep pits trying to make a home. The older islands saw her holes fill with water. Haleakala was too hot and Pele finally moved to the Big Island, first to Mauna Loa, finally to Kīlauea. .

How Pele Came to Hawai'i

The following was collected and translated by By W. D. Westervelt from Hawaiian oral histories, and published as Hawaiian Legends of Volcanoes, 1916 Boston, G.H. Ellis Press)

The simplest, most beautiful legend does not mention the land from which Pele started. In this her father was Moe-moea-au-lii, the chief who dreamed of trouble. Her mother was Haumea, or Papa, who personified mother earth. Moemoea apparently is not mentioned in any other of the legends. Haumea is frequently named as the mother of Pele, as well as the heroine of many legendary experiences.

Pele's story is that of wander-lust. She was living in a happy home in the presence of her parents, and yet for a long time she was "stirred by thoughts of far-away lands." At last she asked her father to send her away. This meant that he must provide a sea-going canoe with mat sails, sufficiently large to carry a number of persons and food for many days.

"What will you do with your little egg sister?" asked her father.

Pele caught the egg, wrapped it in her skirt to keep it warm near her body, and said that it should always be with her. Evidently in a very short time the egg was changed into a beautiful little girt who bore the name Hii-aka-i-ka-poli-o-Pele (Hiiaka-in-the-bosom-of-Pele), the youngest one of the Pele family.

After the care of the helpless one had been provided for, Pele was sent to her oldest brother, Ka-moho-alii, the king of dragons, or, as he was later known in Hawaiian mythology, "the god of sharks." He was a sea-god and would provide the great canoe for the journey. While he was getting all things ready, he asked Pele where she was going. She replied, "I am going to Bola-bola; to Kuai-he-lani; to Kane-huna-moku; then to Moku-mana-mana; then to see a queen, Kaoahi her name and Niihau her island." Apparently her journey would be first to Bola-bola in the Society Islands, then among the mysterious ancestral islands, and then to the northwest until she found Niihau, the most northerly of the Hawaiian group.

The god of sharks prepared his large canoe and put it in the care of some of their relatives, Kane-pu-a-hio-hio (Kane-the-whirlwind), Ke-au-miki (The-strong-current), and Ke-au-ka (Moving-seas).

Pele was carried from land to land by these wise boatmen until at last she landed on the island Niihau. Then she sent back the boat to her brother, the shark-god. It is said that after a time he brought all the brothers and sisters to Hawaii.

Pele was welcomed and entertained. Soon she went over to Kauai, the large, beautiful garden island of the Hawaiian group. There is a story of her appearance as a dream maiden before the king of Kauai, whose name was Lohiau, whom she married, but with whom she could not stay until she had found a place where she could build a permanent home for herself and all who belonged to her.

She had a magic digging tool, Pa-oa. When she struck this down into the earth it made a fire-pit. It was with this Pa-oa that she was to build a home for herself and Lohiau. She dug along the lowlands of Kauai, but water drowned the fires she kindled, so she went from island to island but could only dig along the beach near the sea. All her fire-pits were so near the water that they burst out in great explosions of steam and sand, and quickly died, until at last she found Kilauea on the large island of Hawaii. There she built a mighty enduring palace of fire, but her dream marriage was at an end. The little sister Hiiaka, after many adventures, married Lohiau and lived on Kauai.

SECTION FIVE

Safety is not always pretty. Be prepared; dress appropriately.
Stylish fashion is not a priority; comfort and safety are.

Hazards and Safety

Most injuries and fatal conditions on Kīlauea volcano are not volcano related, per se, but induced by heat or physical stress. These you can mostly circumvent if you and your group are prepared.

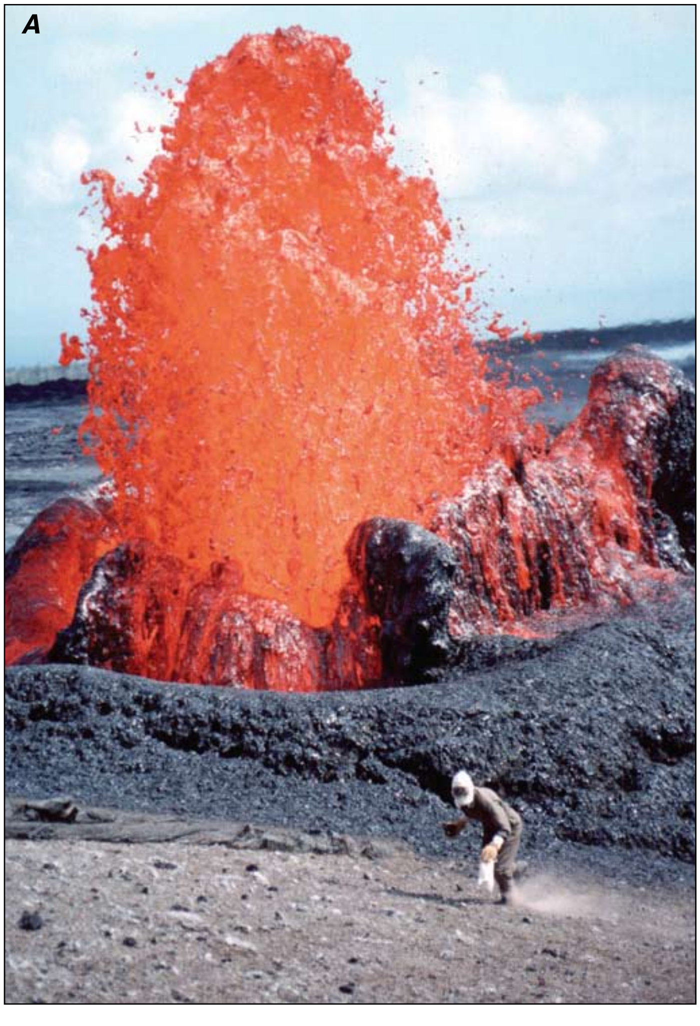
Most of the worst injuries and deaths attributed to volcanic activity on Kīlauea Volcano happened to people who were just doing what they had done before, in places they were not supposed to be, assuming that if it was safe before then it is still a worthwhile gamble. Many dangerous situations appear safe to the visitor (bench collapses, unexpected waves of hot water or steam, breaking through thin crust of solidified lava into molten lava).

CHAPTER 12
UNDERSTANDING THE HAZARDS ON LAVA FLOW FIELDS

Volcanoes are dangerous. Most people intuitively understand this. Yet, very few people have been injured or killed directly by the eruption. And those cases have been quite shocking and dramatic, and occurred in areas of restricted access. What most people don't understand is how many of the dangers are not conspicuous. If fact, the biggest problems don't arise volcanic events, but from pre–existing medical conditions, falling on the rough surfaces, and heat–related sickness.

Lava flow fields are extremely misleading for first time visitors for three primary reasons. Things appear much closer than they actually are, due to the vast expanses of barren landscape. Second, even without active lava, the black surface of the lava heats up considerably during the day. This creates an environment much more hostile than most deserts, as they generally aren't made up of black rock! In addition, the close proximity to the ocean diverts attention from the true desert–like character of Hawaiian lava fields. Third, the surface of the lava is rough, laced with deep cracks, and covered with pieces of glassy crust, not all that different from a splintered bottle. All of these add up to a terrain that is unfamiliar to most visitors, even those with a great deal of hiking experience. Visitors are often not convinced that hiking on lava flows is all that much different than walking city streets or park trails. It requires some special precautions. It is the guide's job to be prevent injuries and heat-related illness.

Visitors must be clearly informed of all the potential hazards both on the lava flow field and related to any strenuous hiking that they might be required to do. If you have advance communication with a group, you might even have them read the USGS Fact Sheet, *Viewing Lava Safely—Common Sense is Not Enough* available at http://geopubs.wr.usgs.gov/fact-sheet/fs152-00/



Which photo presents the most risk for your group, ***A*** or ***B***?

Safety issues are not always obvious. ***A)*** a scientist, wearing fire-resistant clothing, gloves, heat-protective headgear, heavy boots and gas mask, approaches cautiously and retreats quickly. Radiant heat is so intense that approaching too closely is not an option. In an eruption such as this the area will be closed to the public, thus your (group leader) vulnerability is limited. ***B)*** In this photo there are several points to be made to the novice. First, know the solidifying characteristics of the lava before stepping onto a lava-filled surface. If this were shelly pāhoehoe she could not walk on it due to collapse potential. Second, try to avoid taking a group through a fumey area in case breathing problems might be provoked. Third, avoid taking visitors to areas where lava is moving through or across a vegetated area as the potential for mathane blasts (later in this chapter) is high. Last, make sure everyone wears gloves when crossing a hot surface. (She has pulled hers off to use camera; gloves between legs.)

THE DANGERS OF DEHYDRATION, HEAT EXHAUSTION AND HEAT STROKE

Dehydration, heat exhaustion, and heat stroke are very common heat-related diseases that can be life-threatening if left untreated. They are amongst the most dangerous things you have to watch out for when taking groups to the lava. Heat sickness and dehydration can come on very fast and are difficult ot overcome on the lava. Make sure the group understands the dangers of dehydration and heatstroke. Be sure to provide plenty of water for the car trip and also for the group to carry. Freeze as many of the water bottles as possible prior to the trip so the group has cold water.

How to Prevent Heat Sickness

It is possible to avoid suffering the ill effects of heat related disorders by taking a few simple precautions.:

- Drink plenty of fluids, before as well as during the hike. Try to get everyone fully hydrated before starting out on the hike. It is strongly advised that you make each particpant drink 1 liter of water while travelling in vehicles to the trailhead.
- Make sure you are taking in more fluid than you are losing.
- Prolonged sun exposure makes people more susceptible to heat sickness. Reduce exposure to sun by using a strong sunblock on all exposed skin and wearing hats and lose, light colored clothes. If overheated remove hat and pour water on your head.
- Minimize exposure to hot lava. People can get overheated and not even notice it due to the high level of excitement.

DEHYDRATION

Dehydration can be a serious heat-related disease related to water loss. Overexposure to sun and heat can cause loss of water and essential salts faster than they can be replaced. High humidity aggravates dehydration because the moist air can mask thirst and sweating until it is too late. Dehydration should be treated as soon as possible.

Symptoms include: dry skin; thirst, dry mouth and mucous membranes; fatigue, light-headedness, dizziness, confusion; increased heart rate and breathing; less-frequent urination. (Each individual may experience symptoms differently)

Treatment: Force the person to drink as much water as possible. Stop the group and rest while getting people rehydrated.

HEAT EXHAUSTION

Excessive heat, high humidity, exposure to the sun, overexertion, and dehydration can cause the body to overheat, thus raising your body temperature to over 102-degrees. All of these factors combine as a “perfect storm” for heat illness during lava viewing. People that have high blood pressure, are overweight, elderly, or have heart problems are prone to heat stroke. Heat exhaustion is *very* serious and *needs to be dealt with immediately*.

Symptoms include: paleness and cool, clammy skin; nausea, vomiting; extreme fatigue; dizziness, lightheadedness, fainting.

Treatment: Get the person to as cool and shady spot as possible. Have others shade the person if necessary. Remove hat and pour water liberally over their head and soak their shirt with water as well (protecting the persons modesty as well). Let the person rest and keep drinking and cooling. Give sports drinks if available. A small amount of sugared drink or candy helps reduce the fatigue as well. If body temperature remains elevated even after treatment, evacuate them and consult a doctor.

HEAT STROKE

Heat stroke is the most severe form of heat illness and is a life-threatening emergency requiring immediate medical treatment. It is the result of long, extreme exposure to the sun, extreme heat, and dehydration in which a person does not sweat enough to lower body temperature. It is a condition that develops rapidly (in under an hour) and requires immediate medical treatment. High temperatures, lack of body fluids and overexposure to the elements can all bring about Heat Stroke. The very young and old are especially susceptible to the hazards of this heat related illness.

Symptoms include: Hot, dry, red, flushed skin (not sweaty); body temperature of 106-degrees or higher; Seizures, Unconsciousness; Headache, Dizziness; Rapid heart beat; Disorientation, Agitation or Confusion; sluggishness or fatigue.

Treatment: People who are suffering Heat Stroke, do not sweat, so it is critical that they receive emergency care immediately to relieve their body of heat.

- Get the person into the coolest, shadiest place possible.
- Remove clothing and gently apply cool water to the skin followed by fanning to stimulate sweating.
- Apply ice (if you have it) to the groin and armpits.
- Have the person lie down (if possible) in a cool area with their feet slightly elevated
- Call or send someone for medical help immediately.

It is critical the person to be treated immediately as heat stroke can cause permanent damage or death.

Effects of Heat from Lava Flows

Lava flows are hot. Thousands of years ago the long-lived volcano Mt. Etna in Italy was named Aitne from the Greek word "aitho", meaning "I burn." And it does. The extreme heat of molten lava is sure to get virtually everyone's attention. The danger of contact with molten lava is obvious and most people naturally keep a safe distance from it, in fact, few choose to approach closer than is comfortably possible.

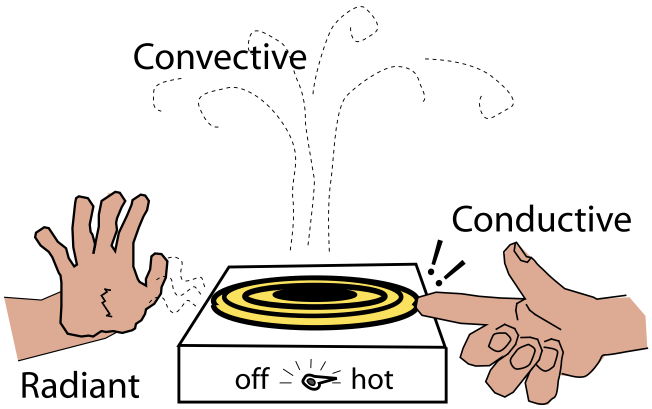
Lava Flows Produce 3 Types of Heat: Conductive, Radiant, and Convective

Conductive heat transfer refers to two surfaces, one hot/one cooler touching each other. Lava conducts heat by contact with either the molten lava or by touching very young and hot crust. Direct contact with either can result in serious burns. Most people will not intentionally contact hot lava flows, but accidental tripping or loss of balance can cause unintentional contact with the hot surface. Since we generally try to break a fall with our hands, wearing sturdy leather gloves is a good first line of protection from falls onto hot surfaces.

Radiant heat is produced when the energy wave from a glowing source radiates away from the source. The sun is a prime example of this. Radiated heat from lava flows can make you very hot and even cause first-degree burns or scorch clothing. Glowing lava radiates heat in exactly the same way that the sun does, but is much more intense as you are closer to the source. Radiated heat comes from lava flows, skylights, lava channels, and fountains. This heat is dangerous not because it burns, but because it can cause severe dehydration in a small amount of time. Encourage your group to limit time spent close to molten lava. Then have them move back. And drink water.

Convective heat happens when the lava heats the air (or water) in contact with it. The air rises (heat doesn't rise, hot air rises) and is swept downwind of the lava flow. While this air won't burn a person, it does cause dehydration and overheating. The air on the downwind side of lava channels and ʻaʻā flows is particularly hot. Avoid the downwind sides of lava flows. If possible stay on the upwind side of lava flows and reduce the heat the group is exposed to during the trip.

Similar convection heats the air coming out of skylights above lava tubes. This air, which often comes out in sudden forceful gusts, can burn you if you approach too closely to the down wind side of a skylight. Stay well back from the downwind side of skylights and only approach them from the upwind side.



Medical Problems

Medical problems and vulnerability are probably the most difficult things to find out about participants prior to leading a trip. Are there people with pre–existing medical problems like heart and circulatory problems, high blood pressure, diabetes, asthma, etc. that might cause complications during the trip. Several people have died from medical complications brought on by simply walking across inactive lava on a hot, summer day prepared only for their usual water-free strolls.

The overall fitness of participants needs to be considered, as well. Many people consider themselves in excellent condition if they walk two miles a day on city streets. What they cannot know is that walking two miles on inflated pāhoehoe surfaces is more like walking twice that distance on city streets with random stairways thrown in every block. Some people will not be able to make the entire trip if it is a long distance to view lava. You have to help them decide. And you can't always tell endurance levels by looking at someone's body type or apparent age. It is difficult to take people across the lava if they are not fit, and it can infringe on the satisfaction of others in the group

The only way to deal with this is to screen people before the trip and add a line to the waiver that requires them to state that they have no existing medical conditions that might cause complications hiking over the lava. Medical privacy laws make disclosure of problems difficult. However, encourage visitors with potential breathing problems, such as asthma, to identify themselves beforehand so you can bring additional equipment such as gas masks.

The most common cause of injury and death on the volcano is probably due to heat- and dehydration-related causes. See next page for detailed descriptions of these. Many visitors to Hawaiʻi are from dryer climates and are fooled into not drinking due to the high humidity. Make sure that everyone has enough water (2–4 liters is recommended depending on hike length) and is drinking constantly. Serious dehydration should be treated as a medical emergency with mmediate action taken. Hospitalization, along with intravenous fluids, may be necessary.

What You Can Do To Prevent Heat Illness

We cannot emphasize enough the importance of preventing overheating or dehydration are two of the most serious problems (see sidebar) that can be induced by hiking out to see active lava. The only way to avoid them is to make sure that people are fully hydrated, drinking continuously, plus limit their exposure to heat from the lava flows. As a guide, make sure that they drink before hiking, provide plenty of water for the trip, have adequate sun protection (clothing and sun block), make frequent stops and have everyone drink, watch all participants for signs of fatigue, dehydration, and heat exhaustion. Once these problems begin, it is very difficult to cure them in the field.

Again, try to limit participation to those who are fit enough to complete the journey safely. This is always difficult as people often have a strong desire to see lava. For the guide it is always a dilemma as reducing participants reduces the profit margin of a trip, which is generally pretty low under good circumstances.

Try to be at least aware of possible medical problems and monitor the person closely. Minimize exposure to hazardous elements such as volcanic fumes or heat, which might exacerbate existing medical conditions.

Watch the weakest person and make sure that people are drinking plenty of water. Dehydration and heat exhaustion can sneak up. If it happens, keep the person in a place where there is plenty of airspace to help allow the body to naturally cool itself.

Light colored, loose fitting clothing will aid the body in breathing and cooling itself down naturally. Wearing a light colored long sleeve shirt and long pants helps reduce the effects of radiated heat.Tight clothing restricts such a process and dark colors absorb the sun's light and heat. It's good to wear a hat to shield yourself from the sun, but if your head gets overheated it's best to remove any items that are covering your head and web your hat before replacing it on your head. Limit vigorous activity during hot days; don't overdue it. Heat Stroke can set in in less than an hour. If someone feels too warm or lightheaded, it's best to take a time out and rest in the shade, not an easy thing to find on the flow field.

Rough Terrain

The best way to minimize risk of falls is good preparation: make sure that all of the hikers have sturdy shoes (more on that later), long pants, and, most importantly, gloves. Proper clothing serves as the best protection from cuts and injuries due to small falls on the lava. Hands and shins are the most susceptible to cuts. In addition, falls on lava often embed small splinters of glass that can be very hard to remove. Protection is the best prevention.

The large cracks on the surface of the lava flows are dangerous as they can cause sprained and twisted angles or even break bones if a foot or leg becomes wedged during a fall. Encourage visitors to concentrate on the ground in front of them and avoid looking up or at other participants while walking. Take frequent stops to allow people to look around. These also provide opportunities for stragglers to catch up, people to drink water, and for explaining features in the lava flows.

Large ground cracks are present in many areas on the volcanoes due to earthquakes and frequent volcanic eruptions. Rift zones are dangerous places simply because there are laced with deep crack systems. These cracks can be huge and plunge 100–200 feet into the ground. These are not so bad where you can see them, but on the heavily forested east rift zone of Kīlauea, the cracks are covered by 5-15'-high walls of ferns and underbrush.

caption

Hot Lava Flows

Hawaiian lava flows, in general, are known for their accessibility. The heat limits how close most people are willing to approach. That doesn't mean that they don't pose hazards. Aside from heat, hazards to be aware of around the flows include being aware of ponded lava above you that could break out and inundate an area, walking across freshly crusted hot areas, and stumbling.

Sometimes it is necessary cross very hot crust on recently active lava flows, in particular when the reaches of the lava flows cut off an escape route before you realize it has happened. If you get cut off, or if a route includes walking over fresh hot newly crusted flows, it is important to make sure you know where any vulnerable areas are.

Make sure that you have walked across pāhoehoe flows many times before taking a group across. In terms of walking on fresh lava flows with cracks still aglow, chart a route and walk it alone first so that they can see you. Again, shoes with moderately thick soles are important. A group leader once very reluctantly let a participant in thin-soled tennis shoes let herself be talked into going. She ended up with heat blisters on her feet. Good long pants made of cotton or other nonflammable material (nylon pants are not good) are also essential when approaching or walking over young lava flows. And loose pants are better than tight, which many people who wore tight jeans across a hot flow field will attest to after being unable to shake the almost-unbearable heat from clinging pants.

Walk slowly and deliberately across these flows. Do not allow people to run or jump as the heat can make the rubber soles melt slightly and become extremely slippery. Walking flatfooted to increase surface contact on the flows is a good idea. Check and see if anyone is feeling emotionally uncomfortable with the route. People that panic may unexpectedly run, which is very dangerous. If anyone is uncomfortable, take him/her slowly back out to cool, inactive lava and give them assurances that it is natural to panic when you are unfamiliar with what is safe and what is not. Do not leave the other people unattended on the flows and keep them in sight at all times.

Behavior at the Lava Flows

Make sure the group behaves responsibly and calmly near active. Horseplay and panic can lead to unintentional falls on hot lava. Seasoned lava workers have all seen enthusiastic lava viewers stumble precariously close to a flow. Such an injury was incurred by a visitor on March 10, 2003. A tourist from France sustained first-, second- and third-degree burns when he fell onto a hot lava flow. Up to 8 percent of his body was burned, primarily his hands, right forearm, and right thigh.

Channelized Lava Rivers

Never approach a channelized lava flow without knowing absolutely that the solidified ground adjacent to it isn't just a deceptive thin overhanging ledge. At least two seasoned lava workers found themselves up to their knees in lava when the ledge broke. Chances are the radiant heat would be too great to approach, but it is essential to be aware of this extremely dangerous photo opportunity.

Collapses and Explosions

Lava flows and vents are subject to catastrophic collapses that may also be accompanied by explosions. Water entering the ocean flashing to steam is the most common cause of explosions. This can create a myriad of hazards from projectiles of lava and rock flying through the air. See descriptions of littoral lava fountains, tephra jets, rock blasts, and bubble bursts in Chapter 3, Lava Entering the Ocean.,

Fires and Methane Blasts

Secondary hazards caused by lava flows include forest or grass fires and methane blasts. In windy weather, make sure visitors are not down wind of the lava. In addition, ignition of organic gases such as methane underground may also cause explosions. The Volcano Watch below describes this process fully and is included because methane explosions are not discussed more fully elsewhere in this manual.

Left: 300-foot-high rock and tephra blasts shot boulders and spatter 100 feet inland. Photo from video capture.

Right: Aerial photograph shows white clouds of smoke from forest fires as tongues of lava flows move through a forest. The brown bomb-like cloud was produced by a methane blast. USGS photograph by J.P.Lockwood March 31, 1984.

Methane Explosions— A Volcanic Hazard Worth Understanding

Recent visitors to the coastal eruption site, especially those unwise enough to approach the flow margins where lava is encroaching on vegetation, are being greeted by a sometimes underrated volcanic hazard-the “methane” explosion.

Depending upon how close you are to the explosion site, your experience can range from hearing a far-off, deep-sounding boom, to being thrown several meters (yards) across the hard and abrasive lava as the ground beneath you explodes. Regardless of where you’re standing, the sound of these explosions is a call for your respect -- and besides, they’re cool to know about!

As a lava flow enters a vegetated area, grassland or forest, all the biomass in the flow’s path becomes available for one or both of two processes: combustion and/or pyrolysis. Molten lava at 1,130 degrees C (2,066 degrees F) is four times hotter than your cooking oven’s maximum temperature. Most natural materials on the surface of the flow field, such as grasses, trees, and shrubs are immediately burned up (combusted) as lava covers the area. The bases of very large trees often become encased in lava, charring the outside of the trunk but not completely burning up on the inside. This is the process that forms “lava trees” or lava-tree molds-a topic for another Volcano Watch.

The process of lava tree formation is instructive, however, for understanding what happens to root masses and tree trunks beneath the ground as the surfac e vegetation burns. Root material protruding downward through the thin soil and into the cracked pāhoehoe surface beneath flows does not burn completely. Instead, intense heat from surface flows radiates slowly downward (remember, rock can act as an effective insulator) and “cooks” the subsurface vegetation rather than burning it.

The lava cooking temperature is high enough to accelerate chemical breakdown of biomass as it chars the buried roots and stumps. A similar commercial process, pyrolysis, cooks wood in large, very hot ovens to make charcoal and another fuel byproduct called “producer” gas. Both producer gas and the gas generated by the lava flow consist of a mixture including methane, hydrogen, and carbon monoxide. Commercially, the flammable producer gas is extracted and burned to generate heat or electricity.

Beneath the lava flow, our fuel-gas mixture from the root mass penetrates subsurface passages, such as old empty lava tubes, tumuli, and cracks. The fuel-gas combines with air in these empty spaces to form combustible gas pockets. Recall that if you have the right proportions of a fuel (such as methane), a source of oxygen (such as air), and finally a source of heat (such as a match), you can make a fire.

When the underground air/fuel mixture is between 5 and 15 volume-percent fuel, a spark or the heat from a lava flow can ignite it. If ignition occurs in a constricted space, such as a lava tube, we observe Kīlauea’s answer to another technological innovation-the internal combustion engine. In your car’s engine, the energy released as the fuel/air mixture is ignited in the confined space of the engine’s cylinders is ultimately transmitted to the drive wheels and propels you down the road. Likewise, if you’re standing over a tube or tumulus when it explodes, which can happen if you ignore the National Park’s warnings, well, go figure.

From *October 17, 2002 Volcano Watch*

Ocean Entries

Natural hazards encountered near the flows are most severe where the lava enters the ocean. Here, dense, acidic fumes, scorching heat from the flows, sharp and rugged surfaces, steam explosions that can shower large areas along the coast with hot spatter, cinder, or incandescent blocks, and the swift killer, the bench collapse. See Chapter Three, Lava Entering the Ocean.

Gases and Steam

Large eruptions also release tremendous amounts of volcanic gases. These plumes can make it very hard to breath and see. In addition, they commonly contain minute particles of glassy material that can become permanently lodged in your lungs or eyes. It is imperative to have gas masks and eye protection when you are anywhere down wind of these eruptions. Fine glass and Pele's hair can drift downwind for miles from the vents.

Gas rising from cracks near lava tubes can be of high enough concentration as to be dangerous to anyone with circulatory and breathing problems. Gas masks are a must in this situation.

Sulfur dioxide gas, continuously emitted during Kīlauea's current long-lived eruption, has resulted in persistent volcanic air pollution (vog) in areas of the island downwind of the eruption. During Kona wind conditions, the concentration of vog in the Park compels them to close visitor centers and allow employees to go home. Expect to change plans to visit sites out of the vog.

Volcanic gases are described in the Fact sheet: Volcanic Air Pollution--A Hazard in Hawai`i , an overview of volcanic gases and their effects

Toxic fumes produced by the volcano come in several nasty varieties.
Above: The sulfur dioxide-rich plume that rises from both Pu“u “Ō‘ō and from all the nooks and crannies above lava tubes.
Below: The noxious smoke from burning asphalt as lava crosses a road.

Skylights & Lava Tubes

Skylights are very dangerous to approach because they occur in already weak sections of the lava tube roof. Approach skylights slowly and do not walk on anything without checking to make sure the crust is thick and stable. Identify the path of the lava tube and make sure that your viewing site is not over the lava tube.

Always approach skylights from the upwind direction. The toxic plume of heat exiting the skylight can be very close to the ground and shifts direction with air currents, so give yourself a large safety zone around the path of the plume. To be safe, stay upwind of the skylight. Fiery heat gusts sporadically out of skylights searing skin and sizzling hair and eyelashes of many who try to peek into a tube. The region around the skylight frequently produces sulfur gases that may irritate the lungs of people and trigger medical problems in people with asthma or other respiratory problems. The sulfur also can irritate people's eyes, making it difficult for them to see.

See: How to Recognize an Active Lava Tube

The initial roof that develops over a lava tube is a thin fragile bridge.

Vents

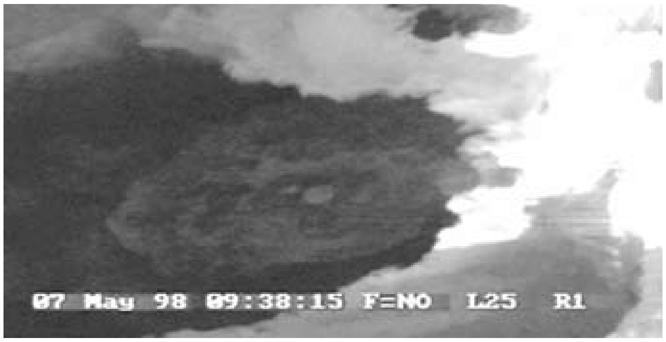
During periods of high fountains and fissure events pose the USGS, Civil Defence and/or the National Park will close an area of great danger to observers due to the voluminous amount of lava being thrown into the air. In addition, the volume of lava emerging from these vents is so high, it can produce enormous flows that can either over run observation points or encircle and trap you. Working safely around these vents generally requires direct communication with the Hawaiian Volcano Observatory and a helicopter standing by for evacuation.

Huge cracks open up all around the vents. The opening of these cracks and collapse of the vents are nearly impossible to predict, but are part of the ongoing processes during an eruption. Currently, Pu‘u ‘Ō‘ō cone is collapsing into the underlying local magma chamber, and the area around the vents is extremely dangerous. The large shields forming on the sides and to the south of Pu‘u ‘Ō‘ō enclose small covered lava lakes that can drain and leave gaping holes mantled by a thin solidified roof. In addition, overflows from the crater and these shields have produced large fields of treacherous shelly pāhoehoe that is impassible when hot. The shelly pāhoehoe can also cover deep cracks.

Hot Water Near the Ocean Entry

The unexpected large waves caused by normal ocean swells and sudden collapses of an active lava delta often send scalding hot water crashing onto shore.

Several people received second-degree burns from hot water that was swept onto shore where they were watching lava enter the sea. Several others may have died due to an unexpected wave washing over the still-hot bench causing the entire bench area to be enveloped in searing steam. A seasoned videographer described walking onto the bench to warn someone else to leave when a wave washed over. He said that if he had not had gas mask, long pants, long sleeved shirt and gloves that he would have been terribly burnt. Even with those the heat was almost unbearable and singed his neck.



Infrared image shows temperature contrasts at ocean entry. White areas represent temperatures above 150° C, which include the steam plume (upper right), the active lava bench, and hot rocks floating on the ocean surface near the entry point. See description of water temperatures in Volcano Watch article below.

Just how hot is the ocean at the lava entry?

Does the near-constant water-lava contact and presence of such a dense, rapidly evolving steam cloud indicate the water near the lava entry boils like a steam kettle? Surprisingly not. Water in contact with surface and near-surface flows flashes to steam and quickly rises; steam produced by submarine flows is quickly quenched by the sea water. Although the temperature immediately adjacent to the submarine lava reaches 190°F, it diminishes abruptly to 81°F, or 2-5° above the ambient ocean temperature, only a few centimeters from the contact.

This is not to say that the water isn't hot in some sites beyond the entry. Temperatures can be unpredictable. A thin layer of surface water near the entry ranges from 100-155°F. For perspective, a 108°F bathtub is uncomfortably hot for many people, scald-free faucets are calibrated to 115°F, and coffee between 140 and 150°F has been known to scald the skin.

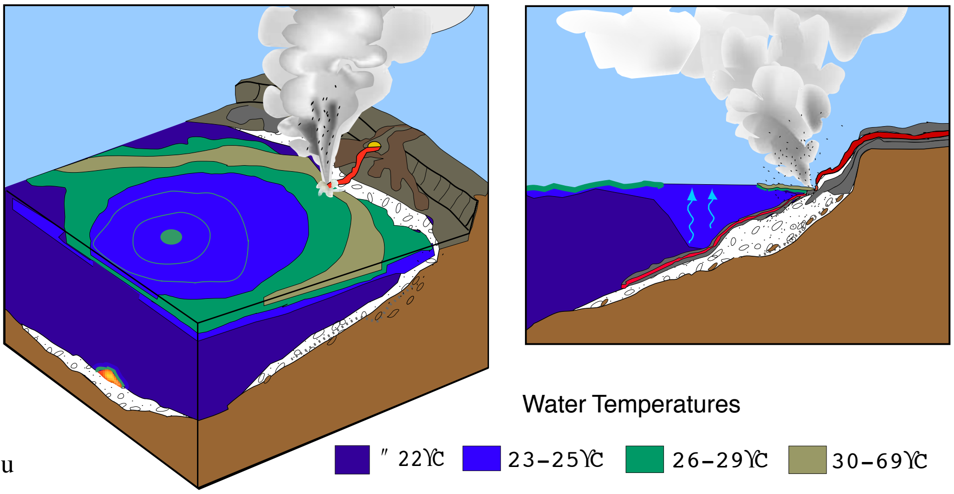
Now, you don't need a boat and a thermometer to get a general idea of thermal differences. The changes in water temperature can be interpreted from a distance by the variably tinted concentric circles that expand away from the entry. Several sharp color and temperature gradients exist between the hydrothermal plume and the surrounding ocean. The plume, which is generally less than 10 feet (3 m) thick and as much as 1.2 miles (2 km) from shore, increases in size when the volume of lava entering the sea increases.

The concentric patterns comprise several distinct temperature regimes. The hottest water is yellowish-brown. This water is heated at the entry point and travels offshore in a horseshoe pattern until it reaches the alongshore currents. Temperatures range from as high as 155°F near the lava contact to 95°F 200–300 feet (70-100 m) offshore. Where water is trapped in pockets along the bench, temperatures are as high as 190°F. The brown color results from high concentrations of suspended glass fragments and occasional gelatinous zoo plankton. Large temporarily buoyant steaming rocks are also seen in this zone. The temperature of the pale-green surface sea water surrounding the plume is elevated only 2-5° above that of ambient sea water.

Enclosed within the discolored plume is a patch of deep blue to black, curiously placid water. This upwelling is the coolest water near the entry and forms when heated submarine water quickly rises, mixing with cooler sea water on its way to the surface. Infrared video of the plume shows a cyclic pattern of upwelling, expansion, and quiescence; the video shows a centralized concentrated warm spot that rises and spreads away from the spot. The cycle takes 4–6 seconds. Exactly why this upwelling is so centralized is unclear.

Keep in mind, water temperatures at the bench are unpredictable. Any passing fancies about swimming near the entry could get you into a whole lot of hot water.

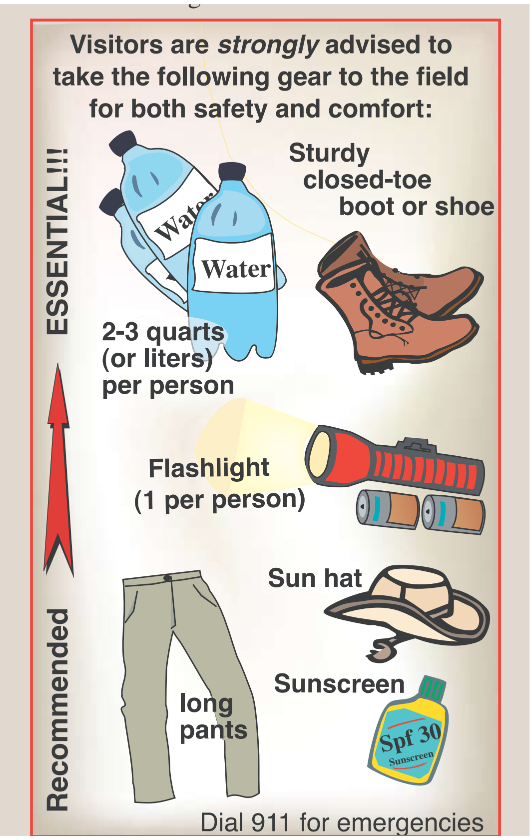
From Volcano Watch



EQUIPMENT AND CLOTHING LIST

WHAT TO BRING and WHY SHOULD I BRING ALL THESE THINGS?

Water	Carry 2-3 liters (quarts). There is almost always someone who needs more. Temperatures can be high at sea level and are very high near lava flows. Dehydration can occur quickly. Drink often and before you get thirsty. Watch hikers for flushed skin and encourage them to sip regularly.
Long Pants	You cannot get as close to hot lava with shorts as you can with long pants. To see molten lava, you may have to walk over fresh lava flows with their uneven, glassy surface. It is possible to walk on a crust with glowing cracks, but the rising heat will make it nearly impossible to cross if you have unprotected legs. If you fall on glass with bare legs, you will cut yourself. The first time your leg brushes against sharp lava, you'll appreciate this advice. (See p. __ about visitor receiving burns when falling on a still-hot solidified lava flow.)
Boots or shoes	Wear a sturdy pair of hiking boots or closed-toe shoes. Neither slippers nor sneakers help much on very hot lava, where the soft rubber or plastic can melt on your feet, plus they provide poor traction and allow sharp rocks to get under your foot. Hot or bleeding feet are common complaints.
Gloves	Preferably your ordinary, leather-palmed, gardening variety, but even cotton gloves are decent protection. Lacerations to the hands from simple stumbles, especially after dark, are common. Carry several extra pair of light cotton gloves for anyone who has forgotten or could not get a pair.
Flashlight	If there is any chance you will be out after sunset, make sure you have at least 2 flashlights plus batteries (in addition to those required by each participant). Make sure that they function properly. Even if there is no plan for staying into the evening, any afternoon hike is vulnerable to someone in the group changing your intended plan due to accident or physical ability. In fact, consider carrying a flashlight at all times, even for day trips.
Hat and Sunscreen	If you are out in the open between the hours of 9 and 3 p.m., it is important to be protected from the sun. Some fair-skinned visitors may not carry their own sunscreen; encourage them to use yours. The hat is also good protection for acid rain in the case of an ocean-entry steam plume blowing on shore.



Night Visits

At night the surface irregularities and cracks become considerably more dangerous and have even been lethal. On several occasions, hikers with inadequate or no flashlights have fallen and have sustained severe head injuries. Allowing people to share flashlights greatly increases the chance of injury.

SECTION SIX

Glossary and Commonly Asked Questions

GLOSSARY

Used with generous permission by Hazlett, R. W., 2001, Geological Field Guide Kilauea Volcano

‘A‘Ā—a type of lava flow having very jagged, clinkery surface and bottom layers, with a solid, dense core. Molten ‘a‘ā is more viscous than pāhoehoe at Kīlauea due primarily to loss of gas and temperature and increase in basal friction or shear strain as the lava is flowing.

ASH—very fine [less than about 1/12th of an inch (2 mm) in diameter] particle-size, gritty volcanic “dust,” produced by explosive eruptions.

BLOCK—a jagged, or rough-edged rock fragment, ejected from an erupting volcano.

BLOCK SAG—a structure formed by the sagging of layered material due to the impact of a large, jagged, or rough-edged rock fragment.

BOMB—a rounded, “streamlined” rock fragment, ejected from an erupting volcano while still partly molten.

CALDERA—a large volcanic crater, more than about a kilometer and a half (or a mile) across.

CARBON-14 AGES—absolute ages of materials dated by measuring their ratios of carbon isotopes. The moment a living organism dies, its ratio of carbon-14 (a scarce isotope in nature) to carbon-12 (the most common form of carbon) begins to change, as a function of time.

CINDER—a glassy, vesicular fragment of volcanic material that falls to the surface in essentially solid condition during an explosive eruption. Fragments of cinder are typically no more than a few cm (1-2 inches) across. Larger fragments are termed blocks. If the fragments are still partially molten upon impact, they are termed bombs.

COLUMNAR (COOLING) JOINTS—Vertically oriented seams or cracks in a lava flow that are regularly spaced, and that form polygonal patterns in cross section. They form as lava cools and contracts. The joints extend in the direction that heat flowed out of the lava.

CONTACT—the boundary between two layers or units of rock having different compositions and/or ages.

CRATER—A hole in the ground resulting either from explosions or collapse, or both. Collapse or pit craters have vertical walls. Explosion craters are roughly cup-shaped and surmount cones of tephra, in some cases interbedded with lava. A caldera is a special type of collapse crater exceeding 1.6 km (a mile) in diameter.

DEFLATION—surface subsidence on a volcano accompanying the withdrawal of magma from an underlying magma chamber.

DIKE—a sheet-like intrusive body that cuts across pre-existing layering inside the earth.

EFFUSIVE ERUPTION—eruption of molten lava, as opposed to explosive eruptions, which produce ash, cinder, and pumice.

EJECTA—a synonym of tephra that also includes lithic ejecta.

ENTRAIL PĀHOEHOE—a form of pāhoehoe resembling intestinal entrails.

EPICENTER—the position where the energy released from an earthquake first reaches the earth’s surface (i.e., the position where the surface effects of an earthquake are first felt.)

FALLOUT—adjective applied to ash or other tephra that falls directly out of the sky.

FUMAROLE—a vent on a volcano through which gases other than just water vapor escape.

GEOTHERMAL SYSTEMS—areas of hot water circulating convectively within the earth, often in proximity to cooling magma bodies.

GRABEN—a valley or trough bounded on both sides by normal faults.

HORST—a ridge, or elongate high area bounded on both sides by normal faults. (See diagram for graben.)

HYALOCLASTITE—A mixture of broken lava pillows and other blocky lava fragments immersed in a matrix of glassy volcanic sand, commonly yellowish brown or tan due to alteration of the glass to clay minerals, but in some places shows brick-red oxidation. Hyaloclastite forms from the explosive interaction of subaerial lava entering deep water.

HYDROEXPLOSIONS—a term related to phreatomagmatic explosions; explosions resulting from the interaction of molten rock with water.

HYPOCENTER (FOCUS)—the point of origin of an earthquake inside the earth. (Compare with epicenter; the hypocenter of any given earthquake usually directly underlies its epicenter.)

IGNEOUS—that group of rocks that forms from the cooling of magma.

INCRUSTATIONS—minerals that are deposited as crusts on pre-existing surfaces. Sublimates are minerals that often occur as incrustations around the mouths of fumaroles.

INFLATION—(a) the swelling and uplift of the surface of a volcano due to the filling of an underlying magma chamber with new magma or to a magmatic intrusion. (b) also refers to the swelling of a pāhoehoe flow by injection of fresh melt from upslope beneath the crust (cf. inflation pit, lava rise terrace, and tumulus).

INFLATION PIT—A feature that forms on inflating pāhoehoe. An inflation pit is a depression formed in the surface of the lava because that portion of the flow is not inflating as rapidly as its surroundings.

INTRUSIONS (INTRUSIVE BODIES)—“intrusion” is the process by which magma is injected into older rocks to form various intrusive bodies, such as dikes, sills, or laccoliths.

JOINT—a crack or seam in a rock.

KĪPUKA—a variation or change of form (such as an old surface surrounded by younger lava flows, which is a meaning often used by geologists in place of “steptoe,” a synonymous, classical term).

km—abbreviation for “kilometers.”

LAVA FANS—Similar to the alluvial fans formed where streams emerging at the base of a mountain range disgorge their sediment in a sloping fan-like deposit across adjacent flatlands. Alluvial fans are characteristic features of arid desert regions, such as the southwestern U.S.

LAVA SHIELD—a gently sloping dome-like hill composed of numerous thin, over-lapping lava flows piled up around an eruptive vent, typically on the side of a larger volcano.

LAVA TUBE—a cave in a lava flow formed from the drain-out of molten lava through a roofed over channel.

LAVA TREE—a hollow pillar of lava marking the site of a tree that was encased in a lava flow.

LEVEE(D)— rivers and streams carrying lots of sediment deposit the sediment along their banks in low country during floods to build up levees, which are naturally-occurring high-standing embankments. Likewise, the molten part of a lava flow on a slope tends to become restricted to a narrow channel after awhile, that may develop levees where surges flowing through the channel overtop and cool on the banks. Just as river levees can raise the level of a river above the surrounding floodplain, so too can levees eventually raise the level of a still active lava stream above that of the surrounding, initially emplaced flow surface.

LEVELING SURVEYS—surveys with diverse instruments (e.g.—as used by road engineers) for the purpose of precisely measuring horizontal distances, or angular relations, from point to point.

LITHIC EJECTA—Fragments of explosively ejected material from a volcano that are made up of rock unrelated to the molten magma that triggered the eruption.

LITTORAL—coastal.

m—abbreviation for “meters.”

MAGMA—molten rock beneath the earth’s surface.

MAGMA CHAMBER—a large body of magma, lying under the summit of a volcano. Typically, they are somewhat spheroidal or cylindrical in shape and are the source of repeated volcanic eruptions, if the magma chamber is replenished with new magma from time to time.

MELT—synonymous here with magma.

METAMORPHIC—a group of rocks which form in the solid-state from pre-existing rocks that have been subjected to extreme temperature and/or pressure conditions for a prolonged period of time.

M6.2, M7.5, etc.—”M” is the abbreviation for earthquake “magnitude,” in which M6.2 signifies an earthquake having a Richter scale magnitude of 6.2.

NORMAL FAULT—a fault in which the slips down a surface that is not overhanging. (Were the surface overhanging, the fault would by termed “reverse” rather than normal).

OBLIQUE-SLIP—a sense of motion along a fault that is acombination of dip-slip and strike-slip.

OLIVINE—a translucent green mineral (in Hawai‘i) made up of iron, magnesium, and silica. It is the most abundant phenocryst in the lavas of Kīlauea.

PĀHOEHOE— lumpy and, in places, ropy form of lava having smooth, glassy (when fresh) skin. When molten, pāhoehoe is less viscous then ‘a‘ā, the other principal form of lava found at Kīlauea. The low viscosity of molten pāhoehoe is due primarily to high temperature (typically exceeding 2000°F; 1100°C) and high dissolved gas content. Pāhoehoe is more common than ‘a‘ā at Kīlauea. Entrail pāhoehoe is a special type of pāhoehoe found on pali faces.

PALAGONITE—altered basaltic glass that typically has a brownish-yellow color. Palagonitization is the process by which the fresh, glassy surface of a basalt lava flow is converted to palagonite. The development of palagonite on a flow surface tends to be patchy and irregular.

PALI—Hawaiian word meaning “cliff,” or “steep slope.” Pali at Kīlauea are typically associated with normal faults.

PELE’S HAIR—Fragile thin threads of golden glass spun as the tails of lava droplets falling from high lava fountains. Pele’s hair may be carried away miles from an eruption site to accumulate in hollows and against leeward embankments downwind.

PELE’S TEARS—The solidified droplets of lava that fall from a lava fountain. Aerodynamic streamlining gives such droplets a tear shape.

PETROGRAPHY—a branch of geology that treats the description and systematic classification of rocks.

PHENOCRYST—a crystal in lava in most instances readily apparent to the unaided eye. Phenocrysts form in a magma chamber prior to eruption.

PHREATIC—refers to steam explosions caused by volcanic heat, but not involving material derived from the magma.

PHREATOMAGMATIC—refers to explosions triggered by a volatile mixture of water plus magma.

PHYRIC—crystal-bearing.

PICRITIC THOLEIITE BASALT—a tholeiitic basalt containing abundant olivine phenocrysts.

PILLOW LAVA—a type of lava flow comprised of numerous pillow-like lumps, some of which may detach and tumble downslope during formation. Pillow lava forms underwater. Ordinary pāhoehoe flows may become pillow lavas upon entering the sea.

PIT CRATERS—steep-sided craters, often with flat rims, that form by collapse of the ground.

PLAGIOCLASE—after olivine, plagioclase is typically the most common phenocryst in the lavas of Kīlauea and Mauna Loa. Plagioclase is an elongate white mineral, sometimes needle-like, containing calcium, sodium, alumina, and silica. It belongs to the feldspar group.

PLUG—a partially cooled and hardened mass of magma that occupies the conduit of an eruptive vent.

PORPHYRITIC—an igneous texture in which a rock is made up only partly of visible crystals, or consists of crystals of two very distinctive sizes.

POROSITY—the percentage of open or void spaces in a rock or soil, relative to solid material.

PUMICE—A form of pyroclastic ejecta consisting of highly vesicular, light-weight lumps of volcanic glass, ranging in size from as small as marbles to as large as basketballs. “Reticulite” is the common name given to basaltic pumice.

PYROXENE—the name for a large group of minerals, including augite. Two major categories of pyroxenes occur: those with monoclinic crystals (clinopyroxene), and those with orthorhombic crystals (orthopyroxene). Pyroxene tends to form dark green, brown, or black crystals, with chunky shapes.

PYROCLASTIC—refers to explosive volcanic eruptions which produce large quantities of fragmental ejecta (such as ash, or lapilli). The term also refers to the deposits formed by the accumulation of such ejecta.

PYROCLASTIC FLOW—a dense, hot hurricane of ash and (less abundantly) lapilli, which moves laterally (horizontally) across the earth's surface.

RELATIVE AGE—the determination of whether something is older, younger, or about the same age as something else.

RETICULITE—a very porous, highly permeable sponge-like mass of basaltic glass, usually gold-colored, that results from the gaseous frothing of molten lava around an active vent. Like Pele's hair, reticulite may become easily airborne during periods of high lava fountaining and travel for great distances.

RIFT ZONE—a zone of crustal weakness on the flank of a Hawaiian volcano, radiating outward from the summit, which is an area of frequent flank eruptions.

RING FAULT—synonymous with circumferential (or boundary) fault.

ROPY PĀHOEHOE—a form of pāhoehoe in which the lava surface resembles coils of rope.

SCORIA—cinder.

SEISMIC, SEISMOLOGICAL—pertaining to earthquakes.

SEISMIC SWARM—a group of earthquakes which occur in an area during a short interval of time.

SHELLY PĀHOEHOE—pāhoehoe that is extremely glassy, brittle, and fragile, with many cavities beneath thin crusts. It is easy for one to get cut or fall in walking across such lava.

SHIELD VOLCANO—a volcano such as Kīlauea, or Mauna Loa, made up almost entirely of thin lava flows piled one atop the other, generally having gentle slopes and a summit caldera. Large shield volcanoes also usually have rift zones.

SILICA—a compound made up of silicon plus oxygen (SiO2).

SKYLIGHTS—holes in the roof of a lava tube.

SOLFATARA—a fumarole, or group of fumaroles, from which sulphurous gases are the predominant emission, other than water vapor. Sulphur is the dominant mineral found around solfataras.

SPATTER—the droplets and clots of very fluid molten lava that fall around the base of a lava fountain.

SPATTER RAMPART—a ridge-like accumulation of spatter, usually enclosing a vent or eruptive fissure. Spatter ramparts range from a 1-2 m (few feet meters to over 15 m (50 feet) in height, and may extend for many miles (km).

STRAIN—any deformation resulting from stress.

STRATA—layers of rock, sediment, volcanic ash, or other geological materials, often piled one atop the other. The singular for strata is stratum.

STRATIGRAPHY—the study of how rocks are layered in the earth, or the actual layering of rocks.

STRESS—a concentration of force (force per unit area).

SUBAERIAL—pertaining to areas above sea level.

SUBLIMATES—minerals that form from the cooling of hot volcanic gases, especially around the mouths of fumaroles.

SUBSTRATE—material lying immediately underfoot.

TALUS—rock debris, as from landsliding, at the base of a slope.

TECTONIC—refers to the large-scale processes by which rocks become deformed, or to the large-scale structure of rocks in the earth's crust.

TEPHRA—particulate matter, such as ash, lapilli, or cinder, ejected from an erupting volcano.

THOLEIITIC BASALT—a class of basalts belonging to the tholeiitic series.

THOLEIITIC SERIES — a group of volcanic rocks in the basalt family rich in silica relative to potassium, or sodium, which may be very rich in iron. Middle-aged Hawaiian shield volcanoes, such as Kīlauea or Mauna Loa, typically erupt tholeiitic lava. Phenocrysts typically include olivine, pyroxene, and plagioclase.

TILT—the angular change in the slope of a volcano accompanying inflation or deflation.

TREE MOLD—A well-like depression, or shaft, in a lava flow, marking the site of a tree that was surrounded completely and burned away by the lava.

TUFF—ash that has become consolidated into rock.

TUMULUS—a small hill or knob on the surface of a lava flow, typically pāhoehoe. Tumuli

VARIATION TIME SCALE—a chart that illustrates how the magnetic field has changed through time in a certain region. (See also secular variation).

VESICLES—small rounded cavities in lava formed by the exsolution of gases from the lava as it flowed and cooled.

VESICULARITY—the amount of vesicles in a sample of lava.

VISCOSITY—the "stickiness" or resistance of a fluid to flow. A highly viscous substance does not readily flow (e.g.—taffy). Water and warm syrup are examples of low-viscosity fluids. Molten ʻaʻā is more viscous than molten pāhoehoe.

VITRIC ASH—glassy ash that originates directly from the explosive eruption of magma. (Contrast with lithic ejecta).

VITREOUS—glassy.

VOLATILES—the constituents present in a magma that can be released as gases through eruption or fumarolic activity. Primary, or juvenile, volatiles are those that come from the deep interior of the Earth (e.g.—the source region of the magma). Secondary, or meteoric, volatiles are those which are acquired as magma comes close to the surface (e.g.—due to assimilation of near-surface ground-water by the magma), or as magmatic gases mix and react with atmospheric gases while passing surfaceward through a fumarolic vent.

WELDED SPATTER—bits of spatter which are so hot that they stick together and fuse as they pile on top of one another.

ybp—abbreviation for "years before present."

yr—abbreviation for "year."

COMMON QUESTIONS ABOUT LAVA FLOWS AND HAWAIIAN VOLCANOES.

These questions are answered in the text of this book.

LAVA FLOWS

How hot is lava and how long does it take lava to cool? Molten lava is about 2000 degrees F (1150 C) The crust of the lava cools to about an inch thick in an hour and is about 150–200 degrees F on the surface.

Where does the lava come from? The lava erupts at the TEB vent and travels through about 9 miles of lava tubes to get to the ocean entry. The lava tube is about 10 feet in diameter, similar in size to Thurston lava tube.

How does a lava tube form? Lava tubes form when a lava channel crusts over. The crust grows down and is pushed back up by the lava in the stream. Small lava flows leak out of the crusted roof, burying the tube inside of the lava flow. These also insulate it and it starts to erode the lava underneath the stream causing it to get deeper. So the final shape of the tube is circular.

What is lava made of? Hawaiian lava is made up mostly of silica, which is what window glass and quartz are made of too. It is about 50% silica, and 20 % iron and magnesium, which are the elements that give it the dark color. There is also calcium, aluminum, and sodium in the rock.

Why is lava black? Lava is black because the iron and magnesium absorb much of the light entering the lava flow.

What are the blue colors on the surface of the lava from? The blue colors on the surface are from the oxidation of titanium in the outer glass. The titanium oxide diffracts light to make a blue color much in the same way the sky is blue.

What causes the colored layers in the cracks? Pahoehoe lava flows start out about a foot thick and swell or inflate to over 10 feet thick. As the crust cools it gets rigid so cracks form as the lava inflates. When the cold lava breaks, it tends to form a dark grey or rust red part of the crack. If the crack penetrates the hot flow interior, the sticky lava is pulled apart like taffy, leaving orange to gold spiny surfaces. The color bands represent different types of crack growth as the lava flow inflates.

OCEAN ENTRY

What is the steam plume made of? The steam plume is mostly water with some droplets of seawater. However, it also contains hydrochloric acid that is created when the saltwater touches the hot lava. This separates the hydrogen and oxygen in the water and the hydrogen recombines with chlorine from the salt to make hydrochloric acid. The steam plume has a pH of as low as 1.5, similar to battery acid.

How hot is the water? The water is boiling near the lava. The hot water has a brownish look and is steaming. The hot water floats on the cooler water and makes a layer about a foot thick.

What causes the colors in the ocean? Most of the ocean around Hawai`i is blue because it is very clean. Water around the ocean entry turns green due to the suspend fine fragments or “dirt” from the lava.

What happens when lava hits the water? The lava is very hot and most of it shatters to fine sand and “dirt” particles that slide down the side of the volcano. This is the stuff that the black sand beach is made up of.

BENCH

What is the bench and why is it so dangerous? The bench is the area of very new land that is built out in front of the cliffs. It includes the black sand beach. As lava goes into the water it shatters to form sand and debris. As the debris builds up, new beaches form and the lava can flow over them to add to the bench. The “solid” looking lava sits on a pile of debris at least 400-500 feet high that is very unstable. A small slide at the front of this debris can cause the entire bench to collapse.

U.S. GEOLOGICAL SURVEY and the NATIONAL PARK SERVICE—OUR VOLCANIC PUBLIC LANDS

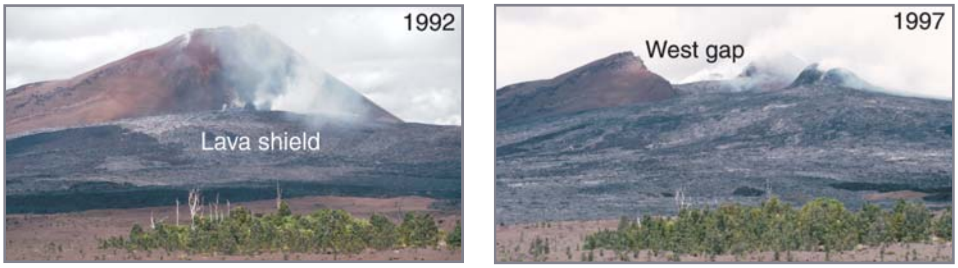
The Ongoing Puʻu ʻŌʻō-Kūpaianaha Eruption of Kīlauea Volcano, Hawaiʻi

The Puʻu ʻŌʻō-Kūpaianaha eruption of Kīlauea is the volcano's longest rift-zone eruption in more than 600 years. Since the eruption began in 1983, lava flows have buried 45 square miles (117 km²) of the volcano and added 560 acres (225 ha) of new land to the Island of Hawaiʻi. The eruption not only challenges local communities, which must adapt to an ever-changing and sometimes-destructive environment, but also has drawn millions of visitors to Hawaiʻi Volcanoes National Park. U.S. Geological Survey (USGS) scientists closely monitor and evaluate hazards at Hawaiʻi's volcanoes and also work with park rangers to help ensure safe lava viewing for visitors.

Glowing lava flows erupt from vents on the south flank of the Puʻu ʻŌʻō cone. Ongoing collapse of the southwest (left) side of the cone has formed a scallop-shaped scar, revealing red layers of welded spatter (deposited as clots of molten lava) that underlie loose tan-colored cinders (bubble-filled, glassy lava pieces that solidified while still airborne). (USGS photo by Richard Hoblitt, January 2004.)

On the evening of January 29, 1997, scientists at the USGS Hawaiian Volcano Observatory (HVO) hastily returned to work as a swarm of earthquakes struck Kīlauea's east rift zone. Deep within the rift zone, magma (molten rock) was escaping from the conduit leading to the Puʻu ʻŌʻō vent, cutting off the supply to the ongoing eruption. The lava pond at Puʻu ʻŌʻō drained, and residents 10 miles (16 km) away heard a low, rumbling roar as the crater floor dropped 500 feet (150 m) and the west wall of the Puʻu ʻŌʻō cone collapsed. A few hours later, magma found a new path to the surface in nearby Nāpau Crater, and lava fountains lit up the night sky. At dawn, HVO scientists were even more impressed when they saw the new gap in the west flank of Puʻu ʻŌʻō. Even after 15 years, monitoring the eruption was anything but routine.

Kīlauea is Hawaiʻi's youngest volcano and one of the world's most active. More than 90% of its surface has been covered by lava flows in the past 1,000 years. Kīlauea erupts either at its summit or along its east or southwest rift zone. From the early 1800s through 1954, the volcano erupted mainly in its summit caldera. Since 1955, however, most eruptions have occurred along the east rift zone. The Puʻu ʻŌʻō-Kūpaianaha eruption, which has produced more than half the volume of lava erupted by Kīlauea in the past 160 years, is by far the largest of these.



During the first 3½ years of the eruption, fallout from lava fountains at Puʻu ʻŌʻō built a cinder-and-spatter cone 835 feet (255 m) high, more than twice as high as any other cone on Kīlauea's east rift zone. Cone growth ceased after the activity shifted to Kūpaianaha in mid-1986. When the eruption returned to Puʻu ʻŌʻō in 1992, lava flows from flank vents built a "shield" against the west flank of the cone (left). In 1993, collapse pits appeared on the west flank of Puʻu ʻŌʻō as subsidence over the flank vents undermined the cone. When the crater floor dropped in January 1997, the weakened flank also failed, leaving the prominent "west gap." Note growth of the shield (right). (USGS photos by Tari Mattox and Christina Heliker.)

Eruption Chronology

The Puʻu ʻŌʻō-Kūpaianaha eruption began on January 3, 1983, on a remote stretch of the east rift zone, 12 miles (19 km) from the summit caldera. From mid-1983 through mid-1986, Puʻu ʻŌʻō erupted every 3 to 4 weeks, usually for less than 24 hours. Towering lava fountains, as high as 1,500 feet (460 m), were visible and audible for miles. The fountains fed thick, blocky flows of ʻaʻā, the less fluid of the two types of Hawaiian lava flows.

In July 1986, the eruption shifted 2 miles (3 km) downrift to a new vent, Kūpaianaha, initiating 5½ years of continuous, quiet effusion. A lava pond formed over the vent, and frequent overflows built a broad shield 185 feet (56 m) high in less than a year.

U.S. Department of the Interior
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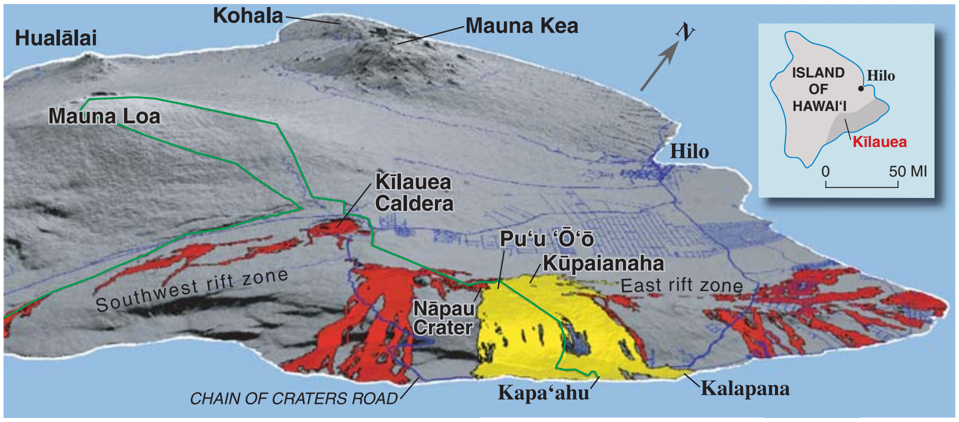

Lava flows erupted from Kīlauea since A.D. 1790 (shown in red) have originated from the summit caldera or the rift zones. Flows from the present eruption (shown in yellow) span more than 9 miles (15 km) along the coast and straddle the national park boundary (green line). The Island of Hawai‘i consists of five volcanoes: Kohala, Mauna Kea, Hualālai, Mauna Loa, and Kīlauea.

ERUPTION STATISTICS 1983 TO 2004

Lava flows

Area covered: 45.1 square miles (116.9 km^3)
New land: 560 acres (225 ha)
Volume: 0.6 cubic miles (2.6 km^3)
Thickness along coast: 33 to 115 feet (10-35 m)
Coastal highway covered: 8.9 miles (14.3 km)
Structures destroyed: 189

Pu‘u ‘Ō‘ō

Maximum height, 1987: 835 feet (255 m)
Height, February 2004: 595 feet (181 m)
Crater size: 820 x 1,312 feet (250 x 400 m)

On November 28, 1986, flows from Kūpaianaha reached the ocean, 7.5 miles (12 km) away, cutting a swath through the community of Kapa‘ahu and closing the coastal highway. Over the next 5 years, lava flows overran houses on either side of the ever-widening flow field.

By 1991, lava output from Kūpaianaha was in steady decline. Magma pressure increased uprift of Kūpaianaha, and new fissures erupted between Kūpaianaha and Pu‘u ‘Ō‘ō for 3 weeks in November 1991. Lava discharge from Kūpaianaha continued to wane and, on February 7, 1992, finally stopped.

Ten days later, the activity returned to Pu‘u ‘Ō‘ō. Low lava fountains erupted from a fissure on the west flank of the massive cone. This was the first in a series of flank vents that built a lava shield 260 feet (80 m) high, banked against the slope of Pu‘u ‘Ō‘ō. From 1992 through 2003, nearly continuous effusion from these vents sent lava flows to the ocean within the national park.

In May 2002, lava flows from a new vent on the west side of the shield advanced to the ocean along the western margin of the flow field. Flows entered the ocean near the end of Chain of Craters Road from July 2002 to June 2003, drawing as many as 4,000 visitors per day. In late 2003, the activity retreated upslope. Lava entered the ocean again from May to August 2004.

Volcanic gases escape from vents on the crater floor of Pu‘u ‘Ō‘ō. Since 1987, repeated collapses of the cone have formed a crater more than 1,300 feet (400 m) long. The crater has been as deep as 690 feet (210 m); infilling with lava has reduced the depth to 15 feet (5 m) below the lowest rim. (USGS photo by Christina Heliker, April 2004.)

Pāhoehoe Flows Dominate

The high lava fountains at Pu‘u ‘Ō‘ō from 1983 to 1986 produced mainly ‘a‘ā flows that were typically 10 to 15 feet (3-5 m) thick. Because of the short duration of each fountaining episode, none of these flows reached the ocean.

After the eruptive activity changed from episodic to continuous in 1986, pāhoehoe, a type of lava more fluid than ‘a‘ā, predominated. The main lava channels exiting the Kūpaianaha and Pu‘u ‘Ō‘ō vents crusted over and formed tubes that eventually extended to the ocean. Tubes insulate lava from heat loss, allowing it to remain fluid and travel far without cooling. Tube-fed pāhoehoe flows have formed a barren plain of lava as much as 115 feet (35 m) thick that spans 9.5 miles (15 km) at the coast.

Building New Land

Since late 1986, lava has poured into the ocean more than 70% of the time, by far the longest such interval in at least 600 years. New land is created as lava deltas build seaward over steep submarine slopes of lava rubble, black sand, and pillow lava (the submarine form of pāhoehoe). Such steep slopes are unstable and prone to slumping, which removes support for the active, leading edge of the lava delta, or "bench." When a bench suddenly collapses, several acres of land can slide into the sea in less than a minute. Large collapses are highly dangerous and frequently precipitate violent steam explosions and scalding waves. Four people have died near Kīlauea's active lava deltas (see USGS Fact Sheet 152-00, *Viewing Hawai‘i's Lava Safely—Common Sense is Not Enough*).

Impact on People

The current eruption ranks as Kīlauea's most destructive since A.D. 1790. Between 1983 and 1991, lava flows repeatedly invaded communities on Kīlauea's southern coast. In 1990, the flows from Kūpaianaha covered the village of Kalapana, leading to a Federal disaster declaration for coastal communities destroyed by the eruption. At the same time, the creation of new land and stunningly beautiful flows in the national park have drawn millions of people to experience and enjoy volcanic activity up close.

The continuous emission of more than 1,000 tons of sulfur dioxide (SO_2) gas each day from Kīlauea results in volcanic smog, or "vog," downwind of the volcano. SO_2 in the eruption plume reacts with oxygen, water, and particles in the air to form the sulfuric acid droplets and solid sulfate particles that produce vog and corrosive acid rain. Vog aggravates preexisting respiratory ailments and damages crops.

Since early 1992, lava flows have remained mostly within Hawai‘i Volcanoes National Park, reducing the immediate threat to residential areas. The geologic history of Kīlauea, however, indicates a high likelihood of continued activity on the east rift zone, even after the present eruption ends. To provide reliable and timely warnings of eruptions, USGS scientists at HVO continuously monitor Hawai‘i's volcanoes.

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