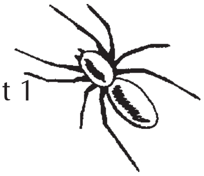


Haleakalā Detective Work

Would you be interested in getting paid to pose questions, find ways to answer them, and then map out what you learned? How about working outdoors three to six months of the year? In a job that challenges you to be your own cartographer (map maker), photographer, and camp cook rolled into one?

If this sounds inviting, you might consider a career as a field geologist. As a field geologist, one of the jobs you might have is to make geological maps based on information collected outdoors, or “in the field.” Sound simple? It usually isn’t, says Dave Sherrod, a reconnaissance geologist who has studied Haleakalā since 1997. “But it *is* fun,” he adds.

A Detective at Work

Dave’s describes his job as a detective game. “There’s a story here,” he explains. “But some of the pieces are missing. They’re buried or eroded away or we just don’t know where to look. Haleakalā doesn’t show its full hand to me. But the questions I’m asking can be answered if I’m careful enough in gathering clues and if I apply a variety of methods to understand the volcano.”

What kinds of mysteries has Dave Sherrod been trying to solve?

Dave Sherrod, middle, with a geology field crew
(Photo: Sharon Ringsven)

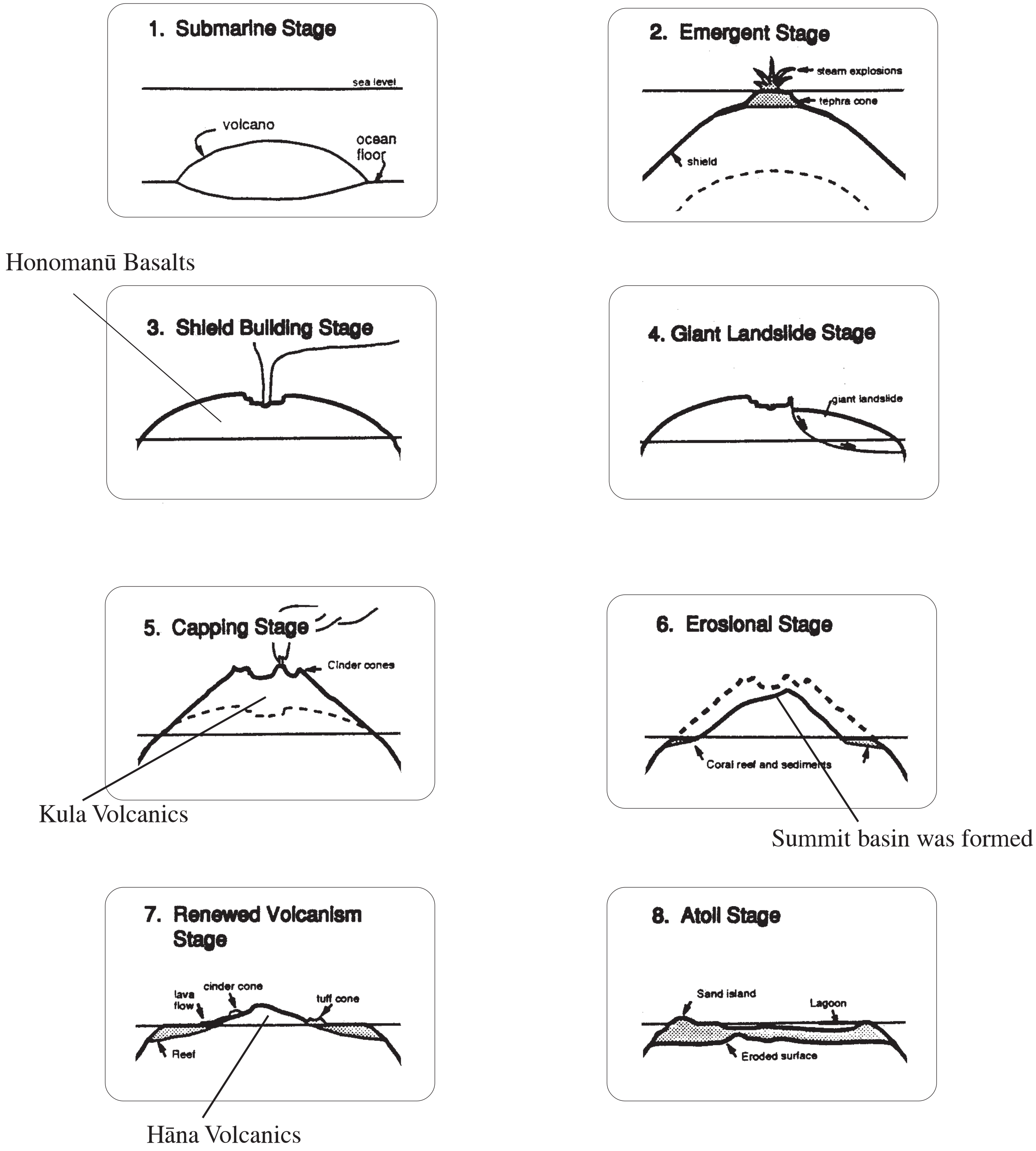
His main task is to map lava flows on Haleakalā to provide information about when the volcano might erupt again. His goal is to create a sort of personality profile of Haleakalā by looking at prehistoric and historic eruption patterns. According to Dave, this profile will help scientists forecast future activity. “Haleakalā seems to erupt every 200-500 years, but we need to verify that. We also need to know whether Haleakalā has a history of erupting at regular intervals or whether it erupts frequently for a while and then goes into long quiet periods.”

Dave will produce a series of maps of the youngest lava flows on Haleakalā, the ones laid down in the past 50,000 years or so. Several of these flows are younger than 1,000 years. Together, all of these flows younger than 50,000 years are known as the Hāna formation. It is commonly accepted that these flows were produced during the renewed volcanism or rejuvenation phase when Haleakalā returned to activity after a long lull. As you’ll find out later, this explanation is under scrutiny. [Figure 1 on page 18 contains more information about the life stages of Hawaiian volcanoes and the volcanic rock formations on Haleakalā.]

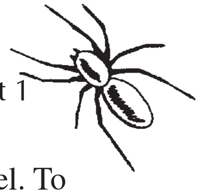
In order to produce these maps, Dave works with aerial photos and observations he makes on the ground to outline the edges of different flows, note the position of flows in relation to each other, and determine the source of each flow. In order to make sense of that information, he needs to know the ages of the different flows.

Most often, Dave uses the “radiocarbon dating” technique to determine the age of rock samples he has collected in the field. This process uses the rate of radioactive decay of carbon-14 as a clock for determining the age of “organic” (carbon-containing) materials. But wait, you might be thinking, lava is *not* an organic substance! That’s one reason why Dave

Figure 1: Stages in the life of Hawaiian volcanoes



Images: Haleakalā National Park



Sherrod calls radiocarbon dating "one of the worst ways to determine the age of a lava flow."

Radiocarbon dating (or carbon-14 dating) works only if the geologist can find charcoal—the remains of tree trunks, plant roots or stems, and other plant parts that were burned by the lava as it flowed across the landscape. "First," Dave says, "I have to get *under* the lava flow and find charcoal. Then I have to convince myself the charcoal was formed by the lava flow." The radiocarbon analysis is done on the charcoal, and the age of the associated lava flow is based on the results of that analysis.

Even though carbon-14 dating can be a difficult technique to apply to dating lava flows, for Dave's project, it is a good option. The lava flows he is mapping are younger than 50,000 years old, and radiocarbon dating is most accurate when used on organic materials younger than about 40,000 years. Because carbon-14 decays at a predictable rate, the radiocarbon technique usually provides reliable estimates of age and can be used by itself without using other techniques to cross-check results. Plus, through trial and error, Dave's become a pro at finding charcoal even in rubbly *ʻaʻā* flows—a task that many geologists deem next to impossible.

Unsolved Mysteries

Dave Sherrod professes to enjoy few activities more than "walking around on lava flows all day, scratching my head and coming up with more questions and ways to address them." One can think of Dave's job as "interrogating" the rocks, using observation, careful data collection, and clear reasoning to hear and decipher the stories the rocks can tell. Here are some of the questions that Dave has been exploring in the course of gathering information for his "personality profile" of Haleakalā:

At its peak height, how tall did Haleakalā stand?

Today, Haleakalā stands 3056 meters (10,023 feet) above sea level, with only about five percent of the volcano's volume above sea level. To estimate the former height of Haleakalā, Dave needed to consider three main factors:

1) Erosion that happens over time,
2) Mountain building by eruptions, and
3) Subsidence—the sinking of the mountain's mass into the earth's crust. [Figure 2 on page 20 shows Dave's estimates.]

For Dave Sherrod, part of the fun of being a field geologist is that he gets to learn new technology, like the graphics software he uses to create images such as Figure 2 and the Geographic Information System (GIS) software he uses to compile his maps and more effectively share data with colleagues in other professions. "The technology helps me get information to people so they can understand it," he says. "And I acquire a lot of new skills along the way!"

Were there ever glaciers on Haleakalā?

One reason scientists are interested in estimating the former height of the volcano is to determine whether glaciers may have helped shape the 915-meter-deep (3000-foot-deep) summit basin or "crater." There is plenty of evidence for glaciation on Mauna Kea, but Haleakalā shows no evidence of the glacial till, moraines, or ice scouring that show up on Mauna Kea.

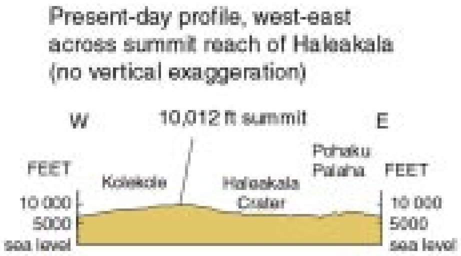
Because Haleakalā once rose much higher above sea level than it does now, some people have hypothesized that its summit, too, was covered by glaciers during the last ice age. Dave's calculations suggest that, during the time of the last ice age, the Haleakalā summit was already too low in elevation to support glaciers.

What happened to the lava that Haleakalā produced between 200,000 and 50,000 years ago?

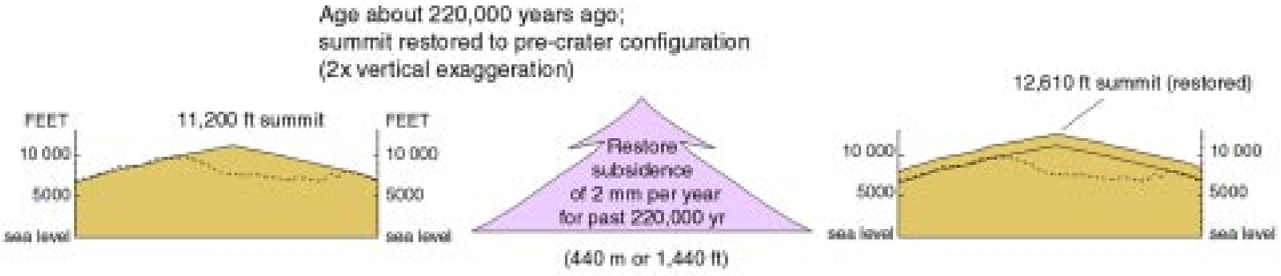
Geologists began studying the volcanic history of Haleakalā in the 1930s. Based on that early research, geologists identified three main age

Figure 2: Reconstructing the height of Haleakalā through time

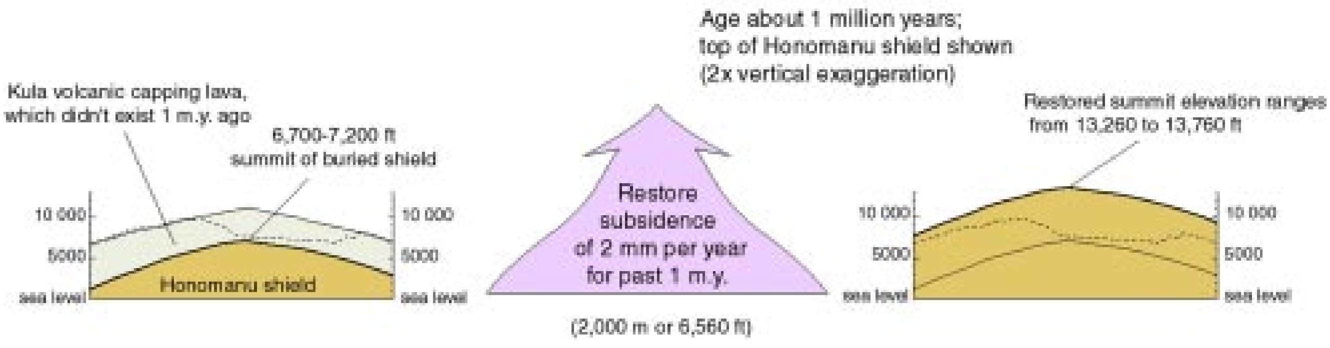
1. Present-day profile



2. Height 220,000 years ago estimated by 1) extending existing ridgelines to approximate pre-erosion summit, and 2) increasing height by 2mm per year to compensate for subsidence into the earth's crust.



3. Height one million years ago estimated by 1) "removing" approximately 2134 meters (7000 feet) of capping lava, and 2) increasing height by 2mm per year to compensate for subsidence.



Graphics: Dave Sherrod

classes of rocks on the volcano. These rocks seemed to differ from each other enough to suggest the volcano was in a different stage of its life cycle as each of these age classes was formed (see Figure 1).

Between the youngest rocks of the Kula Volcanics and the oldest rocks of the Hāna Volcanics, there is a perceived time gap. Few rocks have been dated that fit in this gap between 200,000 and 50,000 years ago. Dave Sherrod asked, "What happened during that time? Was the volcano completely quiet? Were the flows much smaller than the ones that came before and after, making it less likely to find rocks from that time? What else could explain this gap?"

Dave Sherrod and Sharon Ringsven doing field work (Photo: Sharon Ringsven)

One hypothesis Dave is testing is that the time gap is linked to the formation of the "crater" at the top of the mountain. The "crater" is actually a valley carved by streams during the erosional stage of the volcano. Collecting rock samples from the steep cliffs that surround the summit basin, Dave has found that they range in age from about 200,000 to 800,000 years old. That means that the "crater" was eroded away more recently than 200,000 years ago, then mantled by the younger flows (<50,000 years old) found on the floor of the basin.

During the interim period, Dave hypothesizes, the rate of erosion could have surpassed the rate at which lava was built up, especially if the flows were small and infrequent. Erosion could have stripped all of these intermediate flows from the summit basin. Dave has been looking for rocks that might help fill the lengthy time gap, in places such as the southwest rift zone, some stream canyons near Haʻikū, near Hāna, and in Kīpahulu Valley.

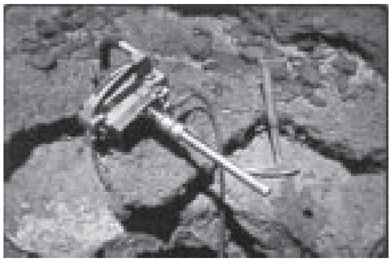
What stage of volcanic activity is Haleakalā in?

One of Dave's working hypothesis is that the Hāna formation was *not* produced during the rejuvenation stage of activity but actually represents the waning phases of the alkalic capping stage. The Kula volcanics are associated with this stage of activity. Chemical analyses performed since the 1980s have not been able to distinguish Hāna rocks from Kula rocks. So Dave hypothesizes that they were actually both produced during the same stage of activity, when the chemical makeup of the rocks would have been similar.

Dave and a graduate student from Japan are looking for evidence to support this hypothesis. They are dating flows from the Kula Volcanics for evidence of long periods without eruptions *within* the Kula sequence. If they find this evidence, what now seems to be a long quiet period between two stages of activity could be explained as a long lull during the alkalic capping stage.

When will Haleakalā erupt again?

"When it's ready," says Dave Sherrod. Even with all the work Dave's been doing to profile the "personality" of Haleakalā, this is still a tricky question. Looking at the patterns of activity over the last 1,000 years, it could be that Haleakalā is overdue for an eruption. In the last 1,000 years, it has erupted 12-14 times, with an



Tools of the trade: A core sample drill and rock hammer (Photo: Sharon Ringsven) average of 50-100 years between eruptions. Sometimes, these eruptions were as many as 400 years apart. Other eruptions happened just a few years apart.

Haleakalā is believed to have last erupted in 1790, but new information from dating the most recent lava flows suggests they may be about 400 years old. There is a good chance that Haleakalā will erupt again during the next 200 years. But, as Dave notes, "It's unlikely the volcano follows a strict calendar. We're certainly living in a time when none of us should be surprised if Haleakalā becomes restless and new eruptions ensue."

Dave is more comfortable forecasting *where* Haleakalā will erupt next than *when*. "Almost certainly," he notes, "the next eruption will begin somewhere along the rift zone, which is the axis of the volcano from Mākena to the summit and east to Hāna. It is less likely that a cinder cone will sprout as far as six kilometers on either side of the axis."

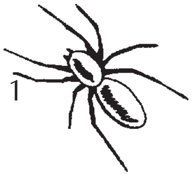
When Haleakalā erupts again, Dave says, it will begin with an eruption of cinder or spatter. Ash will be borne on the wind into parts of the Central Valley and Upcountry. The lava flows that accompany this cone-building activity will probably be *ʻaʻā* or *pāhoehoe* that changes to *ʻaʻā*. The flows will move slowly enough to allow people to escape their path. There's a good chance that the lava flows will reach the ocean, as they do from Kīlauea. This eruption may be as short as a few days, or as long as a couple years.

Learning from the Mountain

Dave Sherrod and other geologists who study Haleakalā learn from the volcano's past in part to understand what might happen in the future. But the past also offers windows on the present, and a way of understanding the alpine/aeolian ecosystem. The summit basin of Haleakalā is partially filled with lava and cinder ejected from cinder cones that span the floor of the "crater." According to Dave, the next eruption is likely to produce more cinder, spatter, and rubbly *ʻaʻā*—over time, perpetuating the conditions under which life exists in this ecosystem. The rubbly and coarse substrates hold little water and offer minimal organic nutrients for plants. In the dry and relatively cool climate of the summit area, organisms decompose slowly, making the process of soil formation in this relatively young landscape a long one.

Resource managers learn from the mountain, too. They discovered that plants, such as the *ʻāhinahina*, growing on loose cinder slopes are susceptible to having their shallow, spreading roots cut by sharp and shifting cinders. Trampling by human visitors is a signficant threat to these plants. Now Haleakalā National Park advises visitors to stay on trails to protect the native plants in this harsh, but fragile, environment.

This lava flowed down an eroded channel. (Photo: John Flynn)



Coming to Terms With Volcanoes

Dave Sherrod and other field geologists work like detectives, piecing together stories and following hunches. Like detectives, they also study to learn more about what they are investigating. Here is some information that will help you understand the dynamics of Hawaiian volcanoes and the terminology Dave uses to describe what he expects from future eruptions of Haleakalā.

What is a volcano?

A "volcano" is a place where magma (molten rock) and/or gas comes to the surface from within the earth's core. Some volcanoes erupt only once. Others erupt many times over the course of millions of years. Most volcanic mountains are made up of the accumulated products of dozens or even hundreds of eruptions. All eruptions are not the same. Hawaiian volcanoes tend to have gentle eruptions, while other volcanoes erupt explosively. As volcanoes near the end of their life spans, their eruptions usually become more explosive.

To explode or not to explode?

How explosive an eruption is depends largely on two main factors: gas content of the lava and its "viscosity" (or fluidity). Highly viscous lava is thick and sticky, making it difficult for gas to work its way to the surface. Gas tends to get trapped in the lava until the pressure is high enough to allow it to burst free (like shaking up a soda can and then opening it). In contrast, gas escapes more easily and gradually from low viscosity, fluid lava, creating eruptions with minimal spattering and explosion.

Viscosity is related to three main factors:

Chemical composition: silica content

In general, the higher the silica content, the higher the viscosity. Mount St. Helens, for example, erupted highly viscous lava with high silica content.

Temperature

Cooler lava is more viscous than hotter lava.

Gas content

Lava with lower gas content is more viscous than lava that contains more gas.

You're outta here

Any fragments of lava or already-solidified rock that are thrown into the air (or ejected) by a volcanic explosion are called "volcanic ejecta." As volcanic gas escapes at the earth's surface, it carries fragments of magma with it, and sometimes older, solidified rocks, too. Violent explosions may carry large amounts of material high into the air scattering fragments close to the vent or far away, depending on their size and the explosiveness of the eruption. These fragments are of "pyroclastic" (fire-broken) origin. They are also called "tephra."

Ejecta are classified according to size, and the larger fragments are also classified according to how fluid they were when they were ejected. Here are three types Dave expects to see if he's around when Haleakalā next erupts:

"Cinder"

Smaller than four centimeters (1.6 inches) in diameter; frothy fragments with highly irregular shapes

"Volcanic ash"

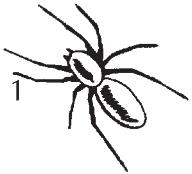
Less than .5 centimeters (.2 inch) in diameter; ash may be bits of already-solid rock, crystals from solid rock, or particles of lava that were thrown up as liquid spray.

"Spatter"

Expanding gasses in lava fountains of Hawaiian-type eruptions tend to tear the liquid into irregularly shaped globs that fall in heaps around the vent. Many of the fragments are still partly liquid when they strike the ground. They flatten out or splash when they hit, forming spatter.

Cinder and spatter cones

The hill built by fragments falling around the vent will often take the shape of a cone with a crater at the summit. Spatter cones are made up



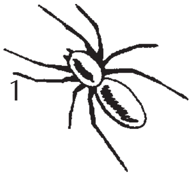
of, you guessed it . . . spatter. Cinder cones are made up of cinders and some spherical, ribbon, or spindle bombs.

Lava flows

When liquid magma pours out of the ground, it can form lava flows. There are two types of Hawaiian lava flows — *“pāhoehoe”* and *“‘a‘ā.” Pāhoehoe* has smooth, billowy, or ropy surfaces. *‘A‘ā* has a very rough, spiny, or rubbly surface. *Pāhoehoe* is the more “primitive” of the two types. In other words, most flows emerge from the vent as *pāhoehoe*, often changing to *‘a‘ā* as they move downslope. *The reverse change, from* ‘a‘ā *to* pāhoehoe*, does not happen.* The more viscous the lava, the greater its tendency to change to *‘a‘ā.*

Both types of lava contain “vesicles”—holes left behind when the lava cooled quickly and trapped gases. Vesicles in *pāhoehoe* generally have a regular, round shape. Vesicles in *‘a‘ā* tend to have twisted, irregular shapes. This occurs because the high fluidity of *pāhoehoe* lava allows the gas bubbles to keep their spherical shapes while gas bubbles in the more viscous *‘a‘ā* are easily deformed.

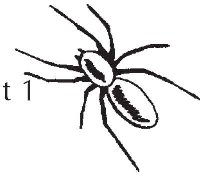
Hawaiian lava tends to be highly fluid, resulting in rapid movement of the flows.



Haleakalā Detective Work: Questions About the Reading

1) Why would Dave Sherrod be focusing on the lava laid down in the last 50,000 years to develop his "personality profile" of Haleakalā? Why isn't he mapping the Kula Volcanic and Honomanū Basalt formations?

2) Why does Dave Sherrod call radiocarbon dating "one of the worst ways to determine the age of a lava flow"? How does he make it work anyway?



3) Identify one hypothesis that Dave Sherrod is testing in his research and describe how he is testing it.

4) A future eruption could take place in the Haleakalā summit basin. Describe the likely effects that an eruption of the type that Dave Sherrod anticipates would have on the plants and animals in the alpine/aeolian ecosystem.

The Dating Game: How Geologists Study the Age of Haleakalā Lava Flows

A question that has fascinated geologists since the field of study began is, How old is the earth? As scientists used fossil evidence to piece together a record of the evolution of life on this planet, they created a standard "geologic time scale." On this time scale, groups of similar fossils ("fossil assemblages") are used as a basis for dividing time into four broad eras, each of which is subdivided into periods and shorter epochs. The geologic time scale is "relative." That means that it tells the relationship of these epochs, periods, and eras to each other—not how long each lasted or how long ago they began.

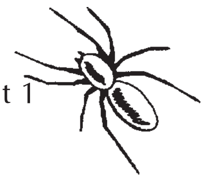
Many geologists were not content to know only that the Paleozoic era came before the Mesozoic, or that the Jurassic period followed the Triassic. They were interested in "absolute age," in determining a numeric age for the rocks in which fossils are contained. The ability to make these determinations has come only in the handful of decades since the discovery of "radioactivity" (a property possessed by some elements in which streams of charged nuclear particles are emitted due to the disintegration of the nuclei of atoms). The development of reliable techniques for "radiometric dating" (establishing an age based on changes in atomic structure) has given geologists the ability to calculate the age of rocks and minerals that range from very young to billions of years old.

Some of the same techniques that scientists used to put dates on the divisions of geologic time have also helped geologists determine the age of the lava flows that make up Haleakalā. Determining the age of the lava flows helps them understand more about the life cycle of Hawaiian volcanoes and be able to determine the risks of future eruptions.

Photo: John Flynn

Radiometric Dating Techniques

All radiometric dating techniques use the same general principles. When minerals are newly crystallized, as they are when magma erupts at the surface and lava flows, they seal in radioactive isotopes. Then the process of "radioactive decay" begins (see page 29 for an explanation of isotopes and radioactive decay). The rate of decay for many elements has been precisely measured and is constant for each element, so radioactivity works like a clock. Scientists determine the ratio of a radioactive element to its decay products to calculate how long ago the mineral crystallized.



What makes radiometric dating work?

An atom is classified as a particular element based on the number of protons in its nucleus. Uranium atoms, for example, contain 92 protons. Carbon atoms contain 6. The number of neutrons may vary, however. The "isotopes" of an element have the same number of protons, but different numbers of neutrons. Potassium, for example, has three naturally occurring isotopes, each named for its mass number (the total number of protons and neutrons in the nucleus): K-39, K-40, and K-41.

Of the three potassium isotopes, only one is radioactive. K-40 atoms have unstable nuclei, which spontaneously break apart in a process known as "radioactive decay." This process involves the formation of "daughter products" (atoms that result from radioactive decay) from the original parent isotope. K-40 disintegrates at a constant rate that scientists measure in terms of half-life. A half-life is the time required for one-half of the nuclei in a sample to decay. There are radioactive isotopes of many elements. Each has its own rate of decay and therefore its own half-life. If the half-life of an isotope is known, the age of a material containing that isotope can be calculated by measuring the proportion of the parent isotope to the daughter isotope.

The basic principle behind radiometric dating is simple and based on straightforward calculations. In practice, however, radiometric dating is a complicated procedure requiring careful sampling, precise chemical analysis, and an exact knowledge of how radioactive isotopes break down into stable daughter products. For some isotopes, the process of radioactive decay produces several unstable daughter products before the stable daughter product—which will not decay immediately into another isotope—is formed. Each of these unstable intermediate products has its own half-life.

The radiometric dating done directly on rock samples from Haleakalā has been "potassium-argon dating." The radioactive isotope used in this technique is potassium-40, which has a half-life of 1.3 billion years. Its stable daughter product (the final result of radioactive decay, which does not break down further) is argon-40. Because potassium-40 has such a long half-life, this dating technique can be used to determine the age of very old rocks. It has been used to date samples collected from the face of lava flows revealed by erosion in the walls of the Haleakalā "crater." These rocks ranged in age from about 200,000 years to about 800,000 years old!

For the younger lava flows on Haleakalā, another type of radiometric dating is important. "Radiocarbon" dating is not done on rocks themselves, but on the remains of plants or animals associated with the rock formations a geologist wants to date. On Haleakalā, geologists look for charcoal—roots or stems from plants that were incompletely burned when the lava flow passed over or around them. These remains contain carbon-14, an unstable carbon isotope that can be used reliably to determine ages up to about 50,000 years.

Paleomagnetic Dating

Similar to potassium-argon dating, "paleomagnetic dating" works with a sort of clock that is set when lava cools and solidifies. Lava flows contain minerals that record the orientation of the earth's magnetic field at the time they form. The earth's magnetic field changes over time, with the magnetic north pole shifting around and sometimes completely reversing. A compass reading would indicate north as a different direction today than it would have ten or 1000 or 10,000 years ago. This change is known as "magnetic secular variation."

Paleomagnetic dating is a "comparative technique." This means that a magnetic history of the area needs to be established before the ages of undated flows can be determined. This is done by taking samples from lava flows that have been dated using other methods such as radiocarbon dating. The magnetic orientation of these samples is used to develop a history of how the earth's magnetic orientation has changed over time. Many samples from Kīlauea, Mauna Loa, and Haleakalā have been used to create a magnetic variation curve for the Hawaiian Islands. New samples from undated flows can be compared to this curve and their ages estimated.

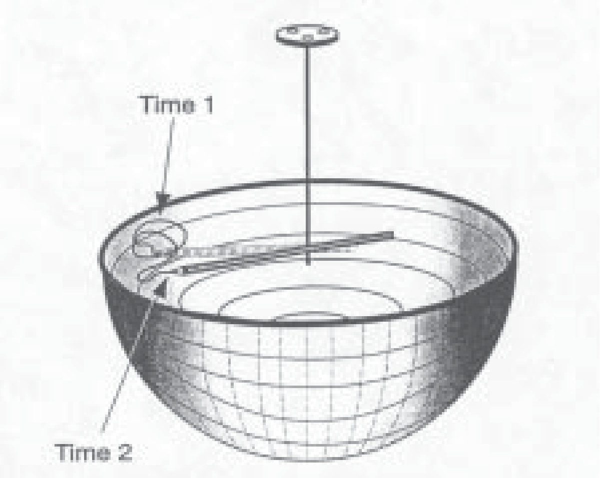
Properly speaking, the paleomagnetic technique will not provide a date for the lava flow. By relating the sample's alignment to the record of past changes in the magnetic field, scientists can narrow down the possible age of the rock so they can use other clues to decide which of the possible ages is most reasonable. The reason for this lack of certainty is that, as the earth's magnetic pole wanders, it often crosses paths with itself, showing the same orientation as it did thousands or even hundreds of thousands or more years previous.

Show Yourself

Take a piece of string about a foot long. Lay it down on a table, looping it around so it crosses over itself a few times. This represents the established magnetic variation for an area over time, say 30,000 years. (See the generalized magnetic variation path in Figure 2 for an idea of the kind of looping and crossing you are trying to make.) Mark each point where the string crosses itself with a different color pen or marker—one with red, one with blue, one with black, or whatever colors you have on hand. At each intersection, make sure you mark both the upper and lower strings with the same color.

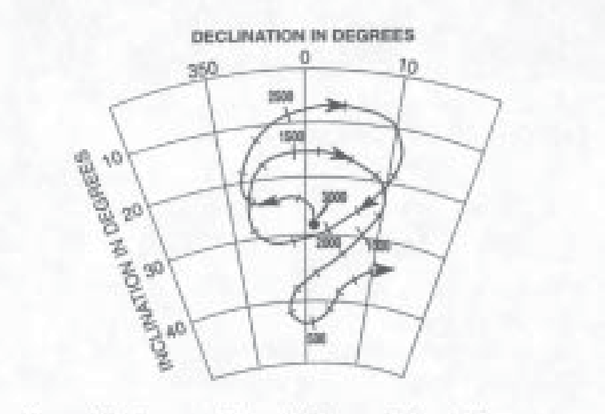
Imagine that you are trying to date a lava flow, so you take a sample. When the paleomagnetic analysis is complete you learn that the magnetic orientation in the lava corresponds with one of the places on your magnetic variation curve where the string overlaps itself. Let's say that the color you've used to mark this overlap is red.

Figure 1: Illustrations of how the magnetic north pole "wanders" over time



Magnet with a pencil tip scribing an idealized path as the magnetic north pole varies during time. Path includes declination (variation from true north) and inclination (tilt down from horizontal).

Figure 2: Magnetic variation path



Generalized magnetic variation path from Kīlauea Volcano, Hawaii. Numbers along the path indicate time, progressing from 3,000 years ago (large dot) to the present (tip of arrow).

Images: Haleakalā National Park

word, “present.” At the other end of the string, write “30,000.” Now you’ve made your string into a timeline that represents the last 30,000 years. Estimate the age represented by the two red marks on this timeline and write them down on the piece of paper, near each red mark.

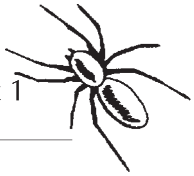
How would you know which of the red marks represents the age of your lava sample? You would not know, based only on the paleomagnetic analysis. The paleomagnetic analysis would tell you only that your rock sample is one of two ages, perhaps 5000 or 15,000 years old. At that point, you would need to use other means for figuring out which is the correct age.

Cross Checking

One way you could tell whether your rock sample is 5000 years old or 15,000 years old is to look at the lava flow in relationship to other lava flows. If a flow above or below it has been dated, you can use the rule of superposition to help you narrow down the correct age. The rule of superposition states that unless the rock layers have been disturbed, the older layers will lie underneath the younger layers. So if the lava flow you are trying to date lies *underneath* a flow that has been radiocarbon dated at 8000 years old, you can be confident that your sample is 15,000 years old rather than 5000.

Cross checks such as these are important for all dating techniques. Since the analyses required for all of the dating techniques are so complicated, it is important to check results against other ways of determining the ages of rocks to assure accuracy.

Geologist removes a core sample for paleomagnetic dating. (Photo: Sharon Ringsven)



Dating Technique	How It Works	Strengths & Weaknesses
Potassium-argon	Scientists measure the proportion of K-40 (an unstable isotope of potassium) to Ar-40 (a daughter product, a stable isotope of the inert gas, argon). K-40 converts to Ar-40 when the K-40 nucleus captures one of its orbiting electrons. The electron's negative charge neutralizes one proton, which becomes a neutron. With one less proton in its nucleus, what was once a potassium atom (atomic number 19) is now an argon atom (atomic number 18). The half life of K-40 is 1.3 billion years.	•Is useful for dating rocks because potassium is abundant in many common minerals •Can be used to date old rocks, over 100,000 years old •Is accurate only when the potassium-bearing mineral remained in a closed system since its formation (Since argon is a gas, it may leak out of the minerals in which it forms. Significant losses can occur when the rock is subjected to high temperatures. Scientists must look for fresh, unweathered samples.)
Radiocarbon Carbon-14	• Carbon-14 is produced when high-energy nuclear particles known as cosmic rays bombard the upper atmosphere. In this bombardment, the nuclei of gases are shattered, releasing neutrons. The neutrons are absorbed by nitrogen atoms (atomic number 7), causing the nucleus to emit a proton. A new element, carbon-14 is formed (atomic number 6). • Carbon-14 is an unstable isotope which circulates in the atmosphere and is absorbed by all life forms. As long as the organism lives, the decaying C-14 is continually replaced, maintaining consistent proportions of C-14 to C-12, the more common, stable carbon isotope. • When the organism dies, C-14 is no longer replaced, and C-14 atoms decay to N-14 by emitting a single electron, after which one of the neutrons takes on a positive charge (i.e., becomes a proton). • The ratio of C-14 to C-12 decreases at a constant rate (the half-life of C-14). Radiocarbon dating measures that ratio to determine the age of the material. The half-life of C-14 is 5730 years.	•Carbon-14 is common. It is found in the remains of all living things. •Can be used reliably on organic matter less than 50,000 years old •Is tricky to use on rocks, since C-14 does not occur in rocks (The scientist must be careful to establish with great certainty that the charcoal or other organic remains being dated are from the same time period as the lava flow in question.) •Is difficult to use on lava flows because finding charcoal is difficult, if not impossible, at many lava flows (In some places, the base of the flow is not exposed. In others, there was no vegetation prior to the lava flow. And in others, there is not enough charcoal remaining to use for dating.)
Paleomagnetic	When minerals are heated above 650° C, they lose their magnetic orientation. When magma cools to form solid volcanic rock, the alignment of these minerals is "locked in" to the earth's magnetic orientation at the time of cooling. By matching the magnetic orientation of a carefully taken rock core with the magnetic history of an area, scientists can narrow down the possible age of the sample.	•Can be used on rocks that scientists have been unable to date with other techniques such as radiocarbon • Is useful for lava rock, which is rich in magnetic minerals •Is a comparative technique that must be calibrated to rocks with known ages (The magnetic history of an area is produced by analyzing rocks that have been dated using other techniques.) •Does not always produce a definite age, but does help narrow down the possibilities