Alpine/Aeolian Unit 1

Learning From the Mountain

Overview

The geological features of the summit area of Haleakalā strongly influence the conditions under which plants, animals, and insects live in the alpine/aeolian zone. The history and influence of these features is not always easy to decipher. This unit helps students explore the geology of the summit area, focusing on what we can find out about the alpine/aeolian ecosystem and the geologic processes that shape it by observing and studying Haleakalā.

Length of Entire Unit

Three class periods

Unit Focus Questions

1) What can we learn about Haleakalā by studying its geological features?

2) What can we learn about the conditions for life in the alpine/aeolian ecosystem from studying the geological formations of Haleakalā?

3) How do geologists use science skills such as observation, hypothesizing, collecting data, and analysis to answer questions about Haleakalā?

Unit at a Glance

Activity #1
Haleakalā Past and Present

Students study the origin of Hawaiian volcanoes, including Haleakalā, and relate the history of these volcanoes to present conditions in the alpine/aeolian ecosystem.

Length
One class period, followed by a homework assignment

Prerequisite Activity
None

Objectives
- Make connections between environmental conditions in the alpine/aeolian ecosystem and the formation of Haleakalā.
- Describe basic characteristics and the process of formation of Hawaiian volcanoes, including plate tectonics.
- Compare a modern scientific explanation of the origin of the Hawaiian Islands with a traditional Hawaiian explanation.

DOE Grades 9-12 Science Standards and Benchmarks
FORCES THAT SHAPE THE EARTH: Students analyze the scientific view of how the Earth's surface is formed.
- Analyze how any of the Earth's Systems shapes the Earth.
- Relate the Theory of Plate Tectonics to our island formation, volcanic activity, and/or earthquakes.

Activity #2
Haleakalā Detective Work

Students learn how geologists apply the scientific method to posing and answering questions about the past and future of Haleakalā and describe examples of hypothesis creation and testing.

Length
One class period, preceded and followed by a homework assignment
[Note: More time may be required for this activity if students have not met the Grades 4-5 Science Standard and Benchmark:
FORCES THAT SHAPE THE EARTH: Students analyze the scientific view of how the Earth's surface is formed.
- Explain the causes and effects of earthquakes and volcanoes.]

Prerequisite Activity
None

Objectives
- Describe how the ability to determine the age of lava flows using different methods is used to answer specific questions about Haleakalā.
- Explain the difference between a dating method that yields an absolute age and a comparative method.
- Explain and illustrate the process of radioactive decay and how it is used in determining the age of rocks.
- Hypothesize about the potential effects of a future eruption on the alpine/aeolian ecosystem of Haleakalā.

DOE Grades 9-12 Science Standards and Benchmarks
USING UNIFYING CONCEPTS AND THEMES: Students use concepts and themes such as system, change, scale, and model to help them understand and explain the natural world.
- CHANGE: Explain the effect of large and small disturbances on systems in the natural world.

NATURE OF MATTER: Students examine the nature of matter.

- Analyze the interactions of molecules and their relationship to the physical properties of compounds in the context of biological, chemical, and/or physical systems.

FORCES THAT SHAPE THE EARTH: Students analyze the scientific view of how the Earth's surface is formed.

- Analyze how any of the Earth's Systems shapes the Earth.

Activity #3

The Dating Game

Students play a game in which they demonstrate their knowledge of the geology of Haleakalā and proper visitor behavior in the alpine/aeolian ecosystem.

Length
One class period

Prerequisite Activity
Activity #2 "Haleakalā Detective Work"

Objectives

- Demonstrate an understanding of:
    - Different techniques for determining the age of lava flows,
    - Basic geological facts about Haleakalā,
    - Characteristics of different volcanic products,
    - Cultural connections with the alpine/aeolian zone, and
    - Proper visitor behavior in the summit basin.

DOE Grades 9-12 Science Standards and Benchmarks
See Activity #2 standards and benchmarks.

Enrichment Ideas

- Simulate the process of predicting volcanic eruptions by placing Alka Seltzer in water in a film canister and closing the lid. Before you do this, ask for predictions about what will happen after you cap the canister. Have students predict how much time it will take for the canister to "blow its top," then compare predictions to the actual elapsed time.

  Link this activity to the general theme of the unit by explaining that geologists studying Haleakalā and other Hawaiian volcanoes are interested in when the volcanoes will erupt again. They gather clues from the layers of rock produced by past eruptions and use that evidence to help them predict when and where future volcanic activity is likely to occur. In making their predictions, scientists rely on basic science skills such as observation, discerning patterns, and sorting out likely effects of different variables.

  Expand on this demonstration:

  - Repeat the process several times using the same proportion of Alka Seltzer and water. Calculate the mean eruption time, and the range. Make the point that scientists can predict future eruptions based on past patterns, but there is still variation.
  - Have students calculate the average error in their predictions using all of the data they collected. Then have them re-calculate the average error, throwing out the data from the first round. Teaching point: The first round helped them "calibrate" their predictions, probably leading to more accurate predictions in the second and subsequent rounds.
  - Mark film canisters with different colored labels and vary the amount of Alka Seltzer in each. Ask students to predict how long each will take to erupt. Then time and record each "eruption." Then do one final "eruption" without telling students how much Alka Seltzer you used. Have them estimate the quantity of Alka

Seltzer based on past observations. Teaching points: Different types of volcanoes and individual volcanoes at different stages of development have different eruptive patterns. Scientists compare current eruptions with past eruptions to learn about the volcano's stage of development.

- Brainstorm other variables that could affect the timing of the film canister "eruptions." These could include the fit of the lid, small variations in the amount of water or Alka Seltzer used, outside air pressure and temperature, and so forth. Then brainstorm a list of factors that might influence the timing and/or character of a volcanic eruption. Students may not know a lot about volcanoes, so this list may be quite general. You may need to give students clues. Use this brainstorm to set up the rest of the unit.

- Following the Activity #1 comparison of cinders to soil, have students design an experiment to compare the two as growing media for plants under different climatic conditions.

- Enlarge and photocopy the stages in the life of a Hawaiian volcano (p. 18), whiting out the numbers that indicate their sequence. Cut them apart and have students assemble these stages into the correct order as a thought experiment leading into the student reading "Haleakalā Detective Work."

- Have students select a topic about Hawaiian volcanoes and research it using Internet and print resources.

- Have students make an educational display and presentation about the formation of Hawaiian volcanoes and the geological history of Haleakalā for a younger class.

- While students are playing Activity #3 "The Dating Game," have them keep track of questions they miss. As homework, have students explain the correct answer to each question.

Resources for Further Reading and Research

Hazlett, Richard W. and Donald W. Hyndman, *Roadside Geology of Hawai'i*, Mountain Press Publishing Company, Missoula, Montana, 1996.

Macdonald, Gordon A., Agatin T. Abbott, and Frank L. Peterson, *Volcanoes in the Sea: The Geology of Hawaii*, 2nd edition. University of Hawai'i Press, Honolulu, 1983.

Hawai'i: Born of Fire, NOVA video production, 1995. One hour in length. Order from 1-800-949-8670.

Information About Hawaiian Volcanoes Available on the Following Websites:

Hawaiian Center for Volcanology at <www.soest.hawaii.edu/GG/hcv.html>.

U.S. Geological Survey Hawai'i Volcanoes Observatory at <hvo.wr.usgs.gov>.

Activity #1

Haleakalā Past and Present

• • • Class Period One *The Influence of the Past on the Present*

Materials & Setup

- *ʻO Wākea iā Papa Hānau Moku* acetate (master, p. 9)
- Overhead projector and screen
- *Inside Hawaiian Volcanoes* video, Smithsonian Institution (provided with this curriculum)
- VCR

For each group of four to six students

- Small plastic bag of cinder (from a garden supply store)
- Small plastic bag of soil

For each student (optional)

- Student Page "*Inside Hawaiian Volcanoes* Quiz" (pp.10-11)

Instructions

1) Divide students into groups of four to six students. Give each group a bag of cinders and a bag of soil. Have them observe the contents of the two bags, write down a description of each, then write a comparison of the two.

2) Ask groups to share some of their responses.

3) Ask groups to write down an hypothesis about which would be easier for a plant to grow in and why. Again have groups share some of their responses. Help students consider the effects of the cinders' porosity (inability to store water) and sharpness (danger of cutting fragile roots) on the ability of plants to grow.

4) Ask students whether an earthworm would do best in the soil or cinders. What about a spider? Have students explain their reasoning.

5) Ask whether anyone has been to the summit area of Haleakalā. Did they see cinders up there? How about soil? The substrate of the summit area largely consists of cinders and other volcanic products such as lava bombs. These rocks can tell us a lot about the past, present, and future of Haleakalā. They tell a story about the challenges of life in the summit area. They tell us something about the age of Haleakalā. As Hawaiian volcanoes reach a certain stage, their eruptions tend to become more explosive and they tend to eject more cinders than lava flows. And they may help scientists predict the general location and timing of future eruptions. Deciphering the secrets of Haleakalā and learning from the mountain are the themes of this unit. In order to learn about the present, we need to understand the past.

6) Show the *‘O Wākea iā Papa Hānau Moku* acetate. Read the chant aloud with students. Take the “one” role yourself or ask a student who is proficient in Hawaiian pronunciation to take that role. This chant illustrates one view of the origin of the Hawaiian Islands. Ask students to share ideas about how this chant compares with their understanding of the origin of the islands.

7) For another perspective, show the *Inside Hawaiian Volcanoes* video (25 minutes).

8) As homework, assign students the task of writing and/or illustrating how plate tectonics theory explains the formation of the Hawaiian Islands.

Teaching Option

- Instead of, or in addition to, the homework assignment, have students complete the Student Page “*Inside Hawaiian Volcanoes* Quiz.”

Journal Ideas

- How is the formation of the Hawaiian Islands explained in Hawaiian tradition? Write and/or illustrate your response, and keep in mind that there is more than one traditional explanation of the Islands’ origin. You may wish to find another version than the one presented in the chant you read during class.
- Compare the plate tectonics explanation of the formation of the Hawaiian Islands with a traditional Hawaiian explanation.

Assessment Tools

- Student writing and illustrations of the plate tectonics theory explanation of Hawaiian Islands formation
- Optional: Student Page “*Inside Hawaiian Volcanoes* Quiz” (teacher version, pp. 7-8)
- Journal entries

Teacher Version

Inside Hawaiian Volcanoes Quiz

1) What is the name of the rock that Hawaiian volcanoes are made of?

   Hawaiian volcanoes consist almost entirely of a rock called basalt.

2) If the active volcano Lo‘ihi, now 914.6 meters (3000 feet) beneath sea level southwest of Kīlauea Volcano, has .3 meters (1 foot) of lava added to its summit each year, when will the volcano become an island?

   A little over 3000 years from now

3) Geologists know that the increasing weight of a growing volcano progressively depresses or pushes down the underlying sea floor. How will this process affect the time needed for Lo‘ihi to become an island?

   Lo‘ihi will require more time to become an island because of that process.

4) What is the geographic relationship between most active volcanoes and the boundaries of tectonic plates? Do the Hawaiian volcanoes conform to this general relationship? Why or why not?

   Most active volcanoes are located along the boundaries between the crustal plates. These are locations where the processes of global plate tectonics favor the emergence of magma at the boundaries.

   The Hawaiian volcanoes do not conform to this general situation and instead are near the center of the largest of all the crustal plates, the Pacific Plate. The Hawaiian volcanoes receive magma from a “melting spot” or “hot spot” in the mantle, 25 miles or more beneath the ocean floor. The reason for the existence of the hot spot is not known.

5) Hawaiian volcanoes swell or inflate before eruptions. How can the resulting change in shape of the ground surface be measured?

Inflation-caused change in shape (ground deformation) of Hawaiian volcanoes can be measured a) by leveling surveying stations to determine their change in elevation, b) by using an electronic distance-measuring instrument to determine changes in horizontal distance and, c) by leveling the corners of a triangle to determine changes in the slope or tilt of the ground surface.

6) Most Hawaiian volcanoes are called shield volcanoes because of their broad, gentle profiles. Why do you suppose this shape is so common for Hawaiian volcanoes, in contrast to shapes of such steep-sided cones as Mount St. Helens and other high volcanic peaks in the Cascade mountain range of the Pacific Northwest?

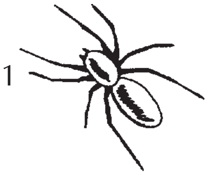
Hawaiian lavas (basalt) flow far more easily (lower viscosity) than the lavas (andesite and dacite) of a volcano like Mount St. Helens. Flows of high fluidity tend to spread farther and thinner than the stickier (higher viscosity) Mount St. Helens lavas. In addition, a Hawaiian volcano erupts lava flows at many vent areas on its flanks (rift zones) as well as at the summit. This wide vent distribution helps to build a similarly wide volcano with a broad, gentle profile.

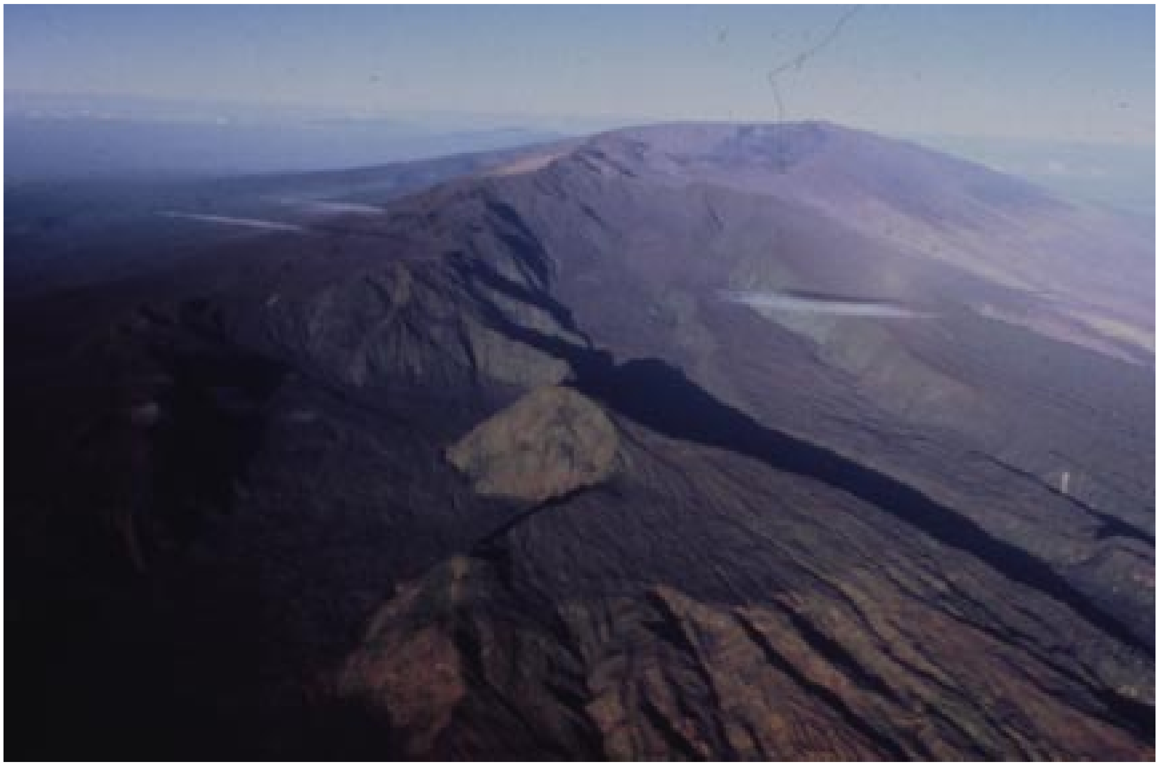
7) Which is older, the West Maui volcano or Haleakalā? Explain your reasoning.

The West Maui volcano is older. Reasoning may include:

• West Maui is more weathered and eroded than Halekalalā.

• Haleakalā is located southeast of the West Maui volcano. The Hawaiian Islands are progressively older to the northwest.





Haleakalā from the air (Photo: The Nature Conservancy)

‘O Wākea iā Papa Hānau Moku

(Malo/Traditional)

One: *‘O Wākea noho iā Papa-hānau-moku*
All: *Hānau ‘o Hawai‘i, he moku*
Hānau ‘o Maui, he moku
One: *Ho'i hou ‘o Wākea noho iā Ho'ohōkūkalani*
All: *Hānau ‘o Moloka‘i, he moku*
Hānau ‘o Lāna‘i ka ula, he moku
One: *Lili-ōpū-punalua ‘o Papa iā Ho'ohōkūkalani*
Ho'i hou ‘o Papa noho iā Wākea
All: *Hānau ‘o O‘ahu, he moku*
Hānau ‘o Kaua‘i , he moku
Hānau ‘o Ni‘ihau, he moku
He ‘ula a o Kaho‘olawe

This chant talks about the birth of the Hawaiian Islands.

First is Hawai‘i and Maui born of the union between Wākea (Sky Father) and Papa (Earth Mother).

Then Wākea is with Ho'ohōkūkalani (his daughter) and Moloka‘i and Lāna‘i are born.

Then Papa and Wakea have O‘ahu, Kaua‘i, Ni‘ihau and Kaho‘olawe.

Inside Hawaiian Volcanoes Quiz

1) What is the name of the rock that Hawaiian volcanoes are made of?

2) If the active volcano Lo‘ihi, now 914.6 meters (3000 feet) beneath sea level southwest of Kīlauea Volcano, has .3 meters (1 foot) of lava added to its summit each year, when will the volcano become an island?

3) Geologists know that the increasing weight of a growing volcano progressively depresses or pushes down the underlying sea floor. How will this process affect the time needed for Lo‘ihi to become an island?

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5) Hawaiian volcanoes swell or inflate between eruptions. How can the resulting change in shape of the ground surface be measured?

6) Most Hawaiian volcanoes are called shield volcanoes because of their broad, gentle profiles. Why do you suppose this shape is so common for Hawaiian volcanoes, in contrast to shapes of such steep-sided cones as Mount St. Helens and other high volcanic peaks in the Cascade mountain range of the Pacific Northwest?

7) Which is older, the West Maui volcano or Haleakalā? Explain your reasoning.

Activity #2

Haleakalā Detective Work

● ● ● In Advance *Student Reading and Questions*

- Assign the Student Page "Haleakalā Detective Work" (pp. 17-24) and "Haleakalā Detective Work: Questions About the Reading" (pp. 25-26).

● ● ● Class Period One *Detective Work Discussion*

Materials & Setup

- A piece of light-colored string about a foot long
- Several colored markers

For each student

- Student Page "Haleakalā Detective Work" (pp. 17-24)
- Student Page "Haleakalā Detective Work: Questions About the Reading" (pp. 25-26)
- Student Page "The Dating Game: How Geologists Study the Age of Haleakalā Lava Flows" (pp. 27-31)

Instructions

1) To begin a discussion about the reading, ask students to share their responses to each of the four questions from the Student Page "Haleakalā Detective Work: Questions About the Reading."

2) Ask for student questions about the reading. Be sure to review how radiocarbon (carbon-14) dating works to be sure that students understand the process and how it is applied to dating lava flows. This is important background for the next part of this activity.

3) Hand out the Student Page "The Dating Game: How Geologists Study the Age of Haleakalā Lava Flows." Have students read the student page, skimming through the table that compares dating techniques (p. 31) for now. (Students will also take this student page home to read more carefully as homework.)

4) Use the information in the reading as background for a discussion of the difference between absolute dating methods, such as radiometric techniques, which yield a numeric age for rocks, and comparative methods such as paleomagnetic dating.

5) To illustrate the results of using a comparative technique, follow the instructions on pp. 29-30 of the reading to perform a demonstration using string and colored markers. Ask students to discuss what additional information would be needed to assign a correct date to a lava flow using a comparative method (e.g., cross checking against dates established through absolute methods, using the rule of superposition).

6) As homework, have students read the Student Page "The Dating Game" more carefully. Assign one or more of the journal entries as written homework as well.

Journal Ideas

- Describe the difference between a dating method that yields an absolute age and one that is comparative. Illustrate the difference using examples of things that you know for certain (and how you know or learned them) and knowledge that you've needed to cross-check before feeling confident about it. These examples could be from everyday life.

- Using drawings and/or writing, illustrate the process of radioactive decay. Explain why it is important in determining the age of rocks.

- Describe the environmental conditions created by the geology of the summit area of Haleakalā. How do you think plants and animals would be adapted to live in this environment?

Assessment Tools

- Student Page "Haleakalā Detective Work: Questions About the Reading" (teacher version, pp. 15-16)
- Participation in class discussions
- Journal entries

Teacher Version

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?

   These are the lava flows produced during the most recent period of volcanic activity, in the volcanic life of Haleakalā. The patterns of these more recent flows should tell scientists more about what is likely to happen in the future than the patterns of volcanic activity in earlier stages (such as the alkalic capping stage, which corresponds to the Kula Volcanics, or the shield-building stage, which corresponds to the Honomanū Basalt).

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?

   Lava is not an organic (carbon-containing) substance, so the flows cannot be dated directly. In order to use radiocarbon dating, Dave finds charcoal under the lava flow and tries to figure out whether the charcoal was formed by that flow. Once he is confident of that, he performs the radiocarbon analysis on the charcoal and assigns that age to the associated lava flow.

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

Possible answers include:

- There were never glaciers on Haleakalā. To test it, Dave has made calculations of the volcano's height over time by considering erosion, mountain building by eruptions, and subsidence. He correlated his calculations with the dates of the last ice age.
- The scarcity of rocks between 200,000 and 50,000 years old is linked to the erosion that formed the summit basin of Haleakalā. To test it, Dave is looking for rocks that might help fill this time gap, in places where they may have been deposited by erosion such as the southwest rift zone and stream canyons near Haʻikū, near Hāna, and in Kīpahulu Valley.
- The Hāna formation lava flows were produced during the waning stages of the alkalic capping stage of volcanic activity. Based on chemical analyses, the rocks of the Hāna and Kula formations are indistinguishable. Dave and a Japanese graduate student are dating flows from the Kula Volcanics looking for long quiet periods within the Kula sequence that could set a precedent for the long lull that took place between production of the Kula and Hāna Volcanics.
- Where and how will Haleakalā erupt again? Dave's just going to have to wait and see on this one!

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.

Well-reasoned responses are acceptable. Dave predicts that the eruption will begin with an eruption of jagged cinder or spatter, along with ash, followed by lava flows. Large volumes of ash may blanket parts of the alpine/aeolian ecosystem, killing or displacing plant and animal life. Smaller parts of the ecosystem would be covered by the new cinder cone or the ensuing lava flows. Parts of the ecosystem will probably remain intact, especially if they are upwind from the ash plume and out of the path of the lava flow. Once the eruption has stopped, it will probably be a long time before significant plant growth is established on the new lava.

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?

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."

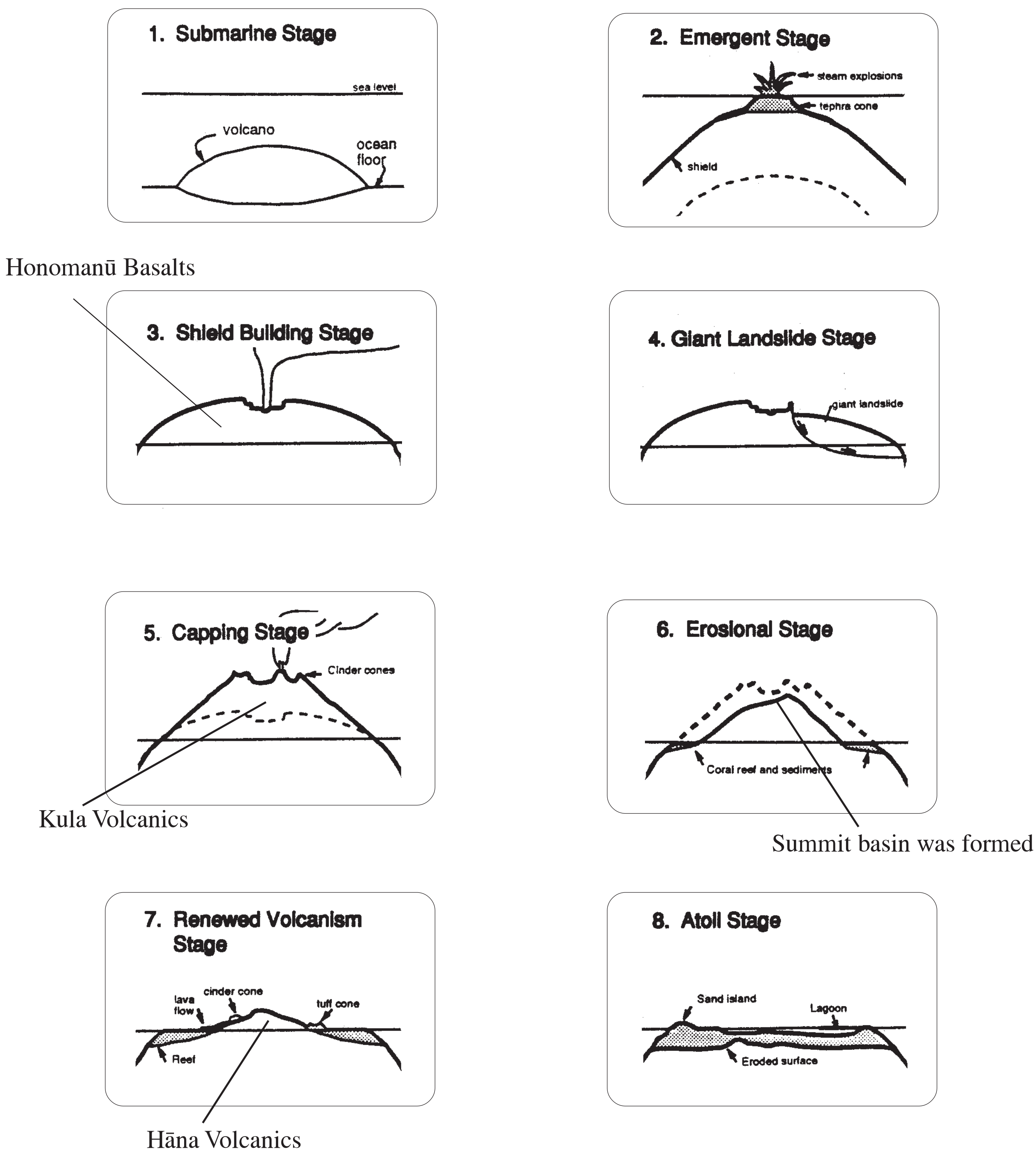
Dave Sherrod, middle, with a geology field crew (Photo: Sharon Ringsven)

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 *'a'ā* 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.

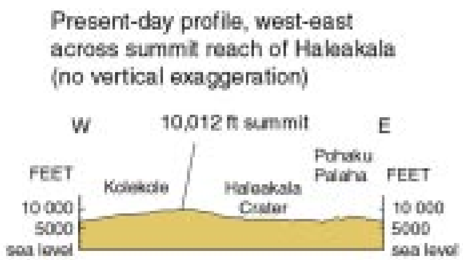
Because Haleakalā once rose much higher above sea level than it does now, some people have hypothesized that its summit, too, was covered by glaciers during the last ice age. Dave's calculations suggest that, during the time of the last ice age, the Haleakalā summit was already too low in elevation to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

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

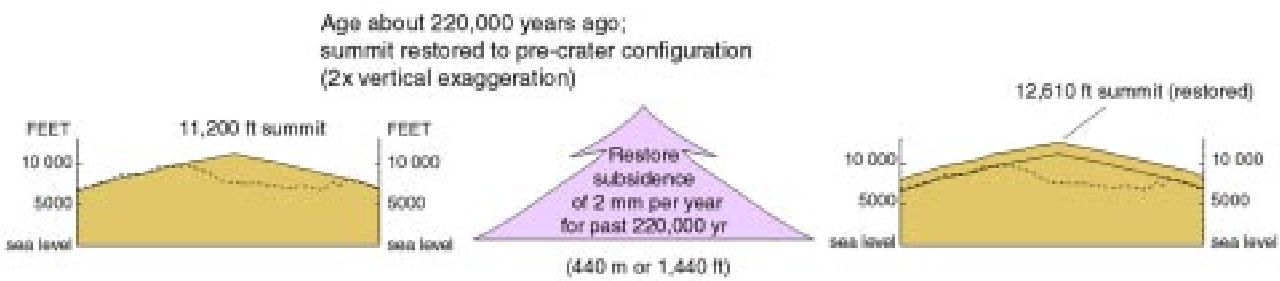
Geologists began studying the volcanic history of Haleakalā in the 1930s. Based on that early research, geologists identified three main age

Figure 2: Reconstructing the height of Haleakalā through time

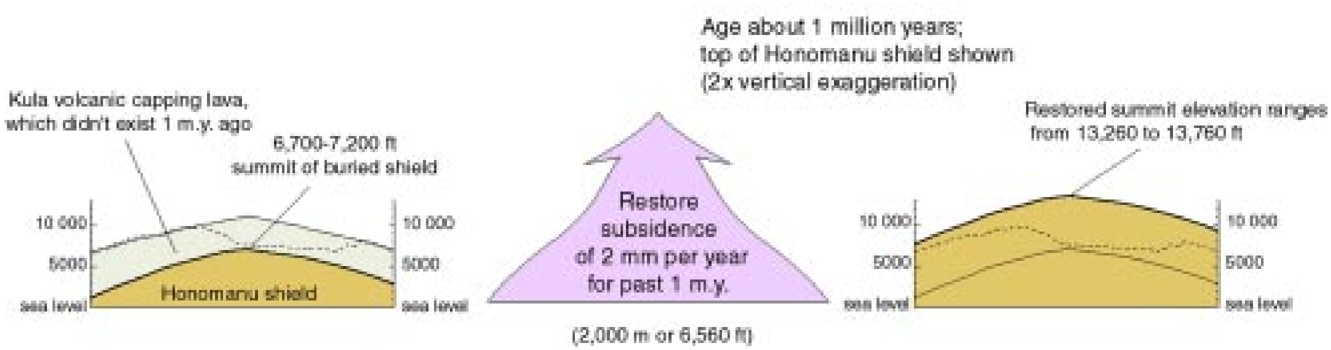
1. Present-day profile



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 Ha'ikū, 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 *"ʻaʻā."* *Pāhoehoe* has smooth, billowy, or ropy surfaces. *ʻAʻā* 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 *ʻaʻā* as they move downslope. *The reverse change, from* ʻaʻā *to* pāhoehoe*, does not happen.* The more viscous the lava, the greater its tendency to change to *ʻaʻā.*

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 *ʻaʻā* 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 *ʻaʻā* 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.

Photo: John Flynn

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.

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.

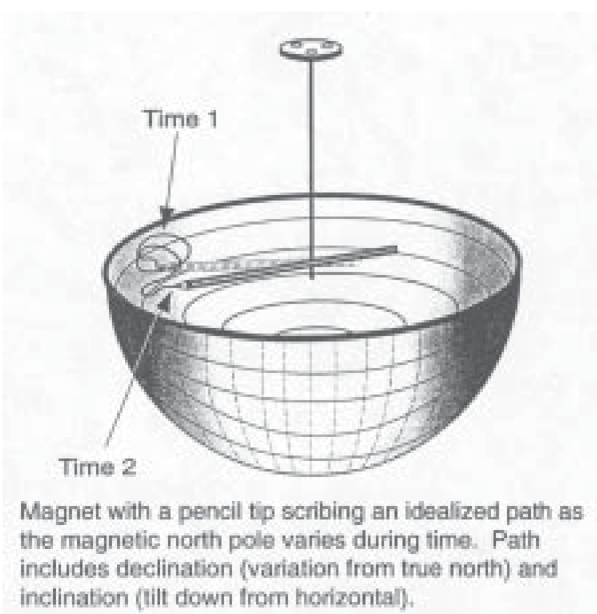
Properly speaking, the paleomagnetic technique will not provide a date for the lava flow. By relating the sample’s alignment to the record of past changes in the magnetic field, scientists can narrow down the possible age of the rock so they can use other clues to decide which of the possible ages is 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.

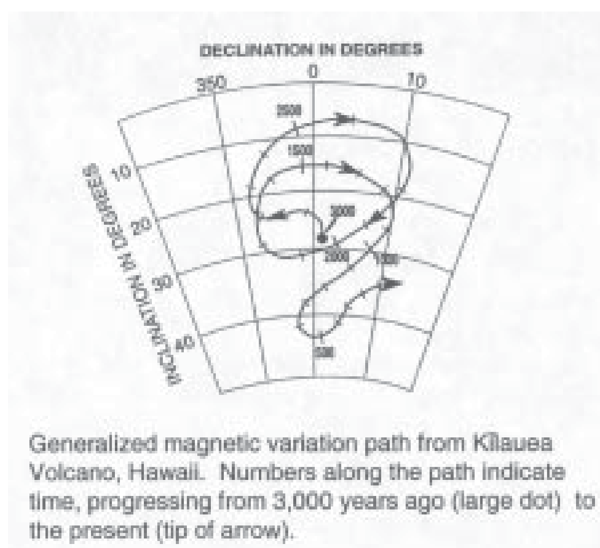
Imagine that you are trying to date a lava flow, so you take a sample. When the paleomagnetic analysis is complete you learn that the magnetic orientation in the lava corresponds with one of the places on your magnetic variation curve where the string overlaps itself. Let’s say that the color you’ve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

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

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.

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

Activity #3

The Dating Game

● ● ● **In Advance** *Game Preparation*

- Prepare game cards (master, pp. 35-48) by copying, cutting apart, and folding each in half along the dotted line. In this way, you will create a “front” and “back” of the card. The front will have only the card type and corresponding shape on the game board. The back will contain the question, answer, and/or playing instructions. You may wish to laminate these cards, as well as an instruction card for each group.

● ● ● **Class Period One** *The Dating Game*

Materials & Setup

For each group of up to six students

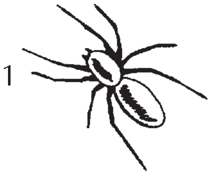
- Game board (provided with this curriculum)
- 1 die
- Game instructions card (master, p. 34)
- Game cards (master, pp. 35-48)
- Six player pieces (small objects such as buttons, stones, or shells that can be easily distinguished)

Instructions

1) Conduct the game with groups of up to six students each. Use the game materials provided with the curriculum and “The Dating Game Instruction Card.”

Assessment Tools

- Participation in the game
- Optional: During the class period following the game, use some of the game cards to conduct an in-class written quiz. Draw cards randomly or select them in advance.



The Dating Game
Instruction Card

The game begins at Sliding Sands Trailhead, follows the trail to Palikū, and ends at Halemauʻu Trailhead. Move your player pieces by the roll of the die, answering questions, and/or following instructions given on the game cards. The first player to Halemauʻu Trailhead wins!

Once you have used a game card, put it on the bottom of the pile it was drawn from.

Each player rolls the die **once** per turn and draws **one card**. Play advances **clockwise**.

When you land on a space, follow the symbol.
Here's what happens:

A, B, C, D = Special Interest!

Draw the corresponding card. Use clues provided to locate the site on the game board/map and read the card to the other players.

Locate the site on the map = **Move forward 3 spaces**

1-7 = Dating Sites

Follow the arrow to the corresponding dating site. Read aloud the card with the matching number.

After reading the card, **follow the arrows back to the trail.**

TM = Dating Questions

Another player draws a card and reads you the question on it. You try to answer the question.
Movement

Correct answer = **Move forward 2 spaces.**
Incorrect answer = **Move back 1 space.**

n = Landforms & Volcanic Products

Another player draws a card and reads you the question on it. You try to answer the question.

Correct answer = **Move forward 2 spaces.**
Incorrect answer = **Move back 1 space.**

H = Risks & Challenges

Another player draws a card and reads you the instructions on it. There are two kinds of cards:

- Situational cards: You choose the correct answer from 3-4 choices.
  Incorrect answer = **Move back 1 space.**
- Potluck cards: You have no control here!
  Follow the directions on the card.

U = Double Jeopardy

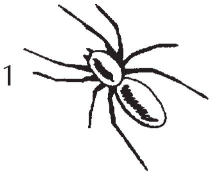
Choose to risk 2, 4, or 6 spaces before you hear the question. Then listen to the question and answer it.

Correct answer = **Move forward number of spaces risked.**
Incorrect answer = **Move backward number of spaces risked.**

l = Connector Trails

You may choose to take a "connector" trail. Another player draws a card and reads you the question. You try to answer it. To cross the connector trail, answer a question correctly for each space on the trail.

Correct answer = **Move forward one dot on the connector trail.**
Incorrect answer = **Go back to where you started on the main trail and continue down the normal trail.**



The Dating Game Cards (cut on solid lines, fold on dashed lines)

Special Interest
A

High atop the *pali* at Haleakalā, the Kilohana area is an archeological site. This site has basalt lava flows and was used for an adze quarry.

Special Interest
B

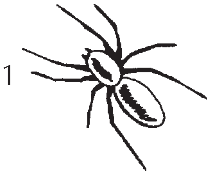
Up on the rim of the summit basin or valley sit the remnants of a *heiau*. This *heiau* is located due south of Puʻu o Pele.

Special Interest
C

Pōhaku Pālaha is a point on Haleakalā where the *ahupuaʻa* boundaries are determined for the east side of Haleakalā.

Special Interest
D

Lava tubes, rock crevices, and other sites were areas commonly used as burial sites for *piko* (umbilical cords) and for burials.



The Dating Game Cards (cut on solid lines, fold on dashed lines)

Dating Site 1

A paleomagnetic dating technique was used to date the youngest flow from Ka Luʻu o ka ʻŌʻō. The results came back inconclusive. However, based on relative ages of surrounding flows, we know this flow is younger than 970 years and probably younger than 900 years.

Dating Site 2

This flow on the south rim of the "crater" was dated using a radiocarbon method. It is estimated to be 3750 (+/- 50) years old.

Dating Site 3

A carbon-14 dating technique was used here on this flow from Puʻu Maile. A date of 4070 (+/- 50) years ago was determined. This flow was dated using the paleomagnetic method as well. That method came up with an age of around 4000 years.

Dating Site 4

Kālua ʻAwa is one of the few *pāhoehoe* flows within the "crater." This flow was dated by both the radiocarbon and the paleomagnetic techniques. An age of 1040 (+/- 40) years was determined.

The Dating Game Cards (cut on solid lines, fold on dashed lines)

Dating Site 5	**Dating Site 6**
The Hanakauhi fissure produced the youngest flow dated on the east side of the summit basin. This flow has an age of 870 (+/- 40) years, based on both a radiocarbon and a paleo-magnetic analysis.	A paleomagnetic dating technique was used for Pu‘u o Māui. The approximate age of this flow is 3000 years.
Dating Site 7	**Dating Card**
An older flow from Ka Lu‘u o ka ‘Ō‘ō was dated both by carbon-14 and paleomagnetic analyses. The flow is estimated to be 970 (+/- 50) years old.	**Question** Paleomagnetic drilling works because which components of rocks align to the magnetic orientation of the poles when heated to high temperatures? **Answer** Minerals

The Dating Game Cards (cut on solid lines, fold on dashed lines)

Dating Card

Question
Why might lava flows at high elevations not be able to be dated by radiocarbon methods?

Answer
These lava flows have very little organic matter associated with them, which is what the carbon-14 method dates.

Dating Card

Question
What type of material is used to date flows using the radiocarbon method?

Answer
Organic material (such as plants, stems, roots, trunks)

Dating Card

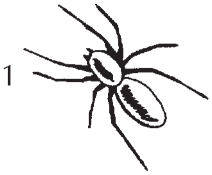
Question
Radiocarbon dating is most accurate on flows with organic materials less than how old?

Answer
50,000 years old

Dating Card

Question
Name the three types of dating processes used on Haleakalā.

Answer
Radiocarbon (or carbon-14), Paleomagnetic, Potassium-Argon



The Dating Game Cards (cut on solid lines, fold on dashed lines)

n

Landforms & Volcanic Products

Question
What is the most probable hypothesis about how the summit basin or valley formed?

Answer
Erosional processes

n

Landforms & Volcanic Products

Question
What are two of the three kinds of volcanic ejecta that Dave Sherrod expects to see from the next eruption of Haleakalā?

Answer
Two of these: cinder, spatter, ash

n

Landforms & Volcanic Products

Question
Can an *ʻaʻā* flow turn into *pāhoehoe*?

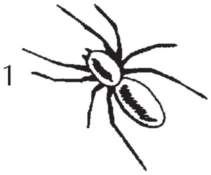
Answer
No

n

Landforms & Volcanic Products

Question
What chemical element determines higher or lower viscosity?

Answer
Silica



The Dating Game Cards (cut on solid lines, fold on dashed lines)

u

Landforms & Volcanic Products

Question
What is the **youngest** volcanic formation on Haleakalā?

Answer
Hāna Volcanic formation

u

Landforms & Volcanic Products

Question
Name the three volcanic formations of Haleakalā.

Answer
Honomanū Basalt, Kula Volcanic, Hāna Volcanic

u

Landforms & Volcanic Products

Question
What is the oldest volcanic formation of Haleakalā?

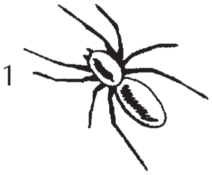
Answer
Honomanū Basalt

u

Landforms & Volcanic Products

Question
What **two** factors will determine whether or not an eruption will be explosive or more gentle?

Answer
•Viscosity or fluidity of lava
• Gas content of lava



The Dating Game Cards (cut on solid lines, fold on dashed lines)

U

Landforms & Volcanic Products

Question
Define volcanic ejecta.

Answer
Any solidified lava fragment thrown into the air by a volcanic explosion

U

Landforms & Volcanic Products

Question
Define cinders.

Answer
Volcanic ejecta less than 4 cm in diameter (Other answers may include "frothy" volcanic ejecta with irregular shapes.)

U

Landforms & Volcanic Products

Question
This lava is ejected in irregularly shaped globs that fall in heaps around the vent. They flatten out or splash when they hit. What is this type of ejecta called?

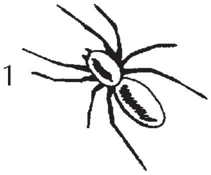
Answer
Spatter

H

Risks & Challenges

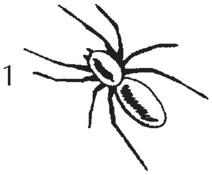
You go off the trail, fall into a lava tube, and break your leg.

Go back to Start.



The Dating Game Cards (cut on solid lines, fold on dashed lines)

H Risks & Challenges	H Risks & Challenges
You fed a *nēnē*, encouraging it to bother other humans for food that's not in its natural diet. **Go back 5 spaces.**	You climb over the railing at Kawilinau (the Bottomless Pit). You fall in and have to be rescued. **Go back to Start.**
H Risks & Challenges	H Risks & Challenges
You didn't bring your rain gear and got caught in the early-morning fog and rain. **Lose a turn** while you wait for your clothes to dry out.	What do you need to bring with you when you hike in Haleakalā National Park? a) rain gear and warm clothes b) Gameboy and extra batteries c) food & water d) a and c **Answer:** D



The Dating Game Cards (cut on solid lines, fold on dashed lines)

H

Risks & Challenges

H

Risks & Challenges

You didn't bring enough water with you.

Lose a turn while you wait for your hiking companions to share their water with you.

You wore slippers instead of hiking boots and sprained your ankle.

Lose a turn while you wrap your ankle.

H

Risks & Challenges

H

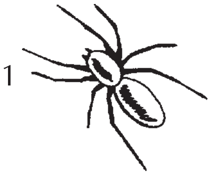
Risks & Challenges

You are drinking plenty of water, which helps keep your body hydrated in the dry, sunny environment.

Move ahead one space since you're feeling so strong.

You picked up *ʻōpala* (garbage) on the trail.

Move ahead two spaces for cleaning up after thoughtless visitors.



The Dating Game Cards (cut on solid lines, fold on dashed lines)

H

Risks & Challenges

H

Risks & Challenges

You saw another visitor going off the trail and politely asked that person to stay on established and marked trails.

Move ahead one space for helping to protect the plants and insects that live among the cinders.

You see a *nēnē* begging. What do you do?
a) feed it Oreos
b) feed it your granola bar
c) chase it away
d) ignore it

Answer
D (You shouldn’t chase a *nēnē* since it is an endangered species and it may feel threatened and try to attack you.)

H

Risks & Challenges

H

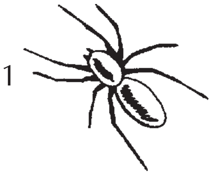
Risks & Challenges

You see another visitor feeding a *nēnē*. What do you do?
a) join in
b) push the other person out of the way so you can feed the *nēnē*
c) ask the other visitor not to feed the *nēnē*
d) tell the person to feed the chukars instead

Answer: C

You see two other students going off trail and making designs in the cinder. What do you do?
a) help them because you are a better artist than they are
b) ask them to come on trail as the design won’t go away for many years
c) ignore them
d) make your own design somewhere else

Answer: B



The Dating Game Cards (cut on solid lines, fold on dashed lines)

H

Risks & Challenges

Why do you need to stay on trails in Haleakalā National Park?
a) there are endangered species that you could accidentally crush
b) just because
c) because the park ranger told you to
d) so you don't get lost

Answer: A

U

Double Jeopardy

How many spaces are you willing to risk? 2? 4? 6?

Which two stages of volcanic activity are the most likely for Haleakalā to be in currently?

Answer: Alkalic capping and renewed volcanism (or rejuvenation) stages

U

Double Jeopardy

How many spaces are you willing to risk? 2? 4? 6?

How tall does Haleakalā stand above sea level today?

Answer: 3056 meters (10,023 feet)

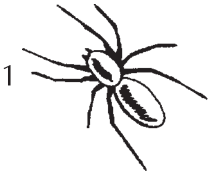
U

Double Jeopardy

How many spaces are you willing to risk? 2? 4? 6?

How old is Haleakalā Volcano?
a) 1.7 million years
b) 0.7 million years
c) 1 million years
d) none of the above

Answer: 1.7 million years



The Dating Game Cards (cut on solid lines, fold on dashed lines)

u

Double Jeopardy

How many spaces are you willing to risk?
2? 4? 6?

On average, how frequently has Haleakalā erupted?

Answer: Every 200-500 years

u

Double Jeopardy

How many spaces are you willing to risk?
2? 4? 6?

What are vesicles?

Answer: Holes in the lava from when the lava cooled quickly and trapped gases

u

Double Jeopardy

How many spaces are you willing to risk?
2? 4? 6?

What does pyroclastic mean?

Answer: Fire-broken

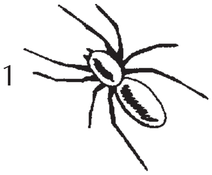
u

Double Jeopardy

How many spaces are you willing to risk?
2? 4? 6?

What are the two types of lava flows?

Answer: *ʻAʻā* and *pāhoehoe*



The Dating Game Cards (cut on solid lines, fold on dashed lines)

Connector Trails
1

Question
True or False? Based on past patterns of eruption, Haleakalā is not expected to erupt again for another 50,000 years.

Answer
False

Connector Trails
1

Question
True or False? The basin at the summit of Haleakalā was caused by a huge explosion which blew the top of Haleakalā off.

Answer
False

Connector Trails
1

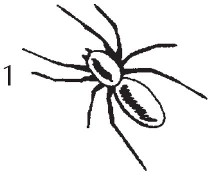
Question
True or False? Hawaiian volcanoes tend to have very explosive eruptions compared to other types of volcanoes around the world.

Answer
False

Connector Trails
1

Question
What is an isotope?

Answer
An atom of an element that has a different number of neutrons than other atoms of the same element.



The Dating Game Cards (cut on solid lines, fold on dashed lines)

Connector Trails

1

Question
True or false? Chemical analyses have found many differences between rocks from the Kula Volcanics series and the Hāna formation.

Answer
False

Connector Trails

1

Question
What percentage of the total volume of Haleakalā stands above sea level?

Answer
5 percent

Connector Trails

1

Question
True or false? Dave Sherrod believes there were glaciers on the summit of Haleakalā during the last ice age.

Answer
False

Connector Trails

1

Question
When did Haleakalā last erupt?

Answer
About 1790 (although this answer is debatable since recent evidence suggests these flows may be about 400 years old)