Learning Experience
2

Teacher Guide

A Glimpse Beneath Earth's Surface: Studying Volcanoes

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Overview

What we see on the surface of Earth is a reflection of what is happening at depth. Volcanoes provide us with an opportunity to investigate what is happening beneath the surface and gain an understanding of the processes that occur at plate tectonic boundaries—in this case along subduction zones.

Most geological processes occur very slowly, over long periods of time. They are difficult to comprehend on a human time scale. Scientists who study volcanoes, however, are able to collect observations reflecting changes beneath the surface that occur within a matter of days or hours. These changes sometimes predict dramatic events.

Using a story about a plan to develop a new town on the flanks of Mount Rainier in the Cascade Range of the Pacific Northwest, students assess the potential dangers associated with living near volcanoes. Although most will have heard of the eruptions of Mount St. Helens, they may not be aware that this famous mountain is part of a chain of volcanoes that extends from Canada through Washington, Oregon, and northern California. Located in one of the most rapidly developing parts of the country, tens of thousands of people live in the shadow of these volcanoes.

The Cascades volcanoes are related to one another by their location along an active subduction zone, and lessons learned from one volcano can be used to better understand the others. Students learn about the 1980 eruption of Mount St. Helens and study the monitoring techniques used by scientists to predict eruptions. Ultimately, they use information about the eruptive history of Mount Rainier combined with current monitoring data to assess the risk associated with living close to a volcano such as Rainier.

Predicting the exact timing and nature of volcanic eruptions is not currently possible, and this study of volcanoes challenges students to confront scientific problems that do not have a clear, straightforward answer. However, it is the quest to resolve what is unknown that drives scientific investigation.

This learning experience makes use of the extensive information available on the Internet regarding hazard monitoring of the Cascades volcanoes. The curriculum does not require classroom access to the Internet. However, if your students have access to the Web, their experience will be enhanced through the exploration of the most current data available.

Goals for Student Understanding

- Students understand that Earth is dynamic and constantly changing.
- Students understand that volcanoes occur where magma from Earth's mantle moves to the surface. In some areas of the world, this magma originates from mantle rock near slabs of Earth's lithosphere descending into subduction zones along plate boundaries.
- Students understand that igneous rocks form from magma that cools either on the surface (extrusive igneous rocks) or at depth (intrusive igneous rocks).
- Students understand that scientific measurements can be used to monitor the movement of magma beneath the surface and predict when a volcano is likely to erupt.
- Students understand that complex dynamic systems have multiple interacting factors that cause a volcanic eruption and make it difficult to predict exactly when an eruption will occur.
- Students understand that study of volcanic deposits in the vicinity of a volcano can give evidence of its eruptive history.
- Students understand that improvements in technology allow scientists to make more sophisticated observations, in turn, allowing a more complete understanding of Earth's processes.
- Students understand that scientific data can and should be used to inform public policy decisions.
- Students practice visualizing Earth's processes in four dimensions (three physical dimensions changing through time).

Student Assessment Outcomes

Students should be able to:

- Describe the processes that occur along subduction zones that lead to the formation of volcanoes.
- Describe how extrusive igneous and intrusive igneous rocks form.
- Identify the changes that typically occur within a volcano prior to an eruption.
- Describe how scientists collect observations and measurements of active volcanoes and use these data to predict eruptions.
- Describe how scientists learn about a volcano's eruptive history, and how they use these data to make predictions about future eruptions.
- Relate their understanding of the Cascades volcanoes to other volcanoes around the world.
- Incorporate their new scientific understanding of volcanoes into a personal or public policy decision.

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Assumptions of Prior Knowledge and Skills

Students should already know:

- Density is a measure of the amount of mass in a given volume. Materials with a lower density tend to rise above those with a higher density. Generally, when the temperature of a material increases, its density decreases.
- The basic internal structure of Earth (based on the chemical composition) consists of a crust, mantle, and core.

Possible Misconceptions and Possible Barriers to Learning

- Research has shown that high school students have difficulty understanding 3-dimensional block diagrams, such as those typically used to show what is happening beneath Earth's surface. They may not be able to project what they see on the surface of the diagram to the parts that are not shown. They may also have difficulty mentally viewing these diagrams from different perspectives. Work carefully with students to make sure they understand these diagrams when they are included in the learning experiences.
- Students may have difficulty reading maps and relating them to physical reality. Make sure they understand the symbols and can relate them to real features.
- Students have varying amounts of prior knowledge about plate tectonics. Their understanding of what constitutes a tectonic plate may be vague or incorporate misconceptions. For example, some students may visualize that the plates are deep below the surface and not understand that they are standing on them. They will have difficulty understanding what a plate is unless they understand the concept of bedrock. Many do not realize that solid rock is present everywhere beneath the soil, and that this solid rock constitutes the Earth's crust.
- It is challenging for students to conceptualize dynamic systems. They tend to try to identify a single causal force or a linear chain of causal forces to explain complex natural phenomena. You will need to help students mentally process the multiple factors that interact with one another to cause a volcanic eruption and make it difficult to predict exactly when an eruption will occur.

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Assessment Strategies

Students have a number of opportunities in this learning experience to demonstrate their understanding of the material. These formative and summative assessment opportunities include:

Opportunities	Page	Information Gathered About
Brainstorming	1	Students' prior knowledge of volcanoes and what causes them to erupt.
Story: A Hazardous Development?; Thinking About What You Read	2; 5	Students' understanding of the processes that occur at subduction zones, including their ability to visualize these processes in three dimensions.
Reading: What Happens Before and During an Eruption?; Thinking About What You Read	7; 11	Students' developing understanding of what is happening beneath the surface of a volcano prior to an eruption and how these changes are useful for predicting eruptive events. Students' understanding of how the 1980 eruption of Mount

		St. Helens might help anticipate future events at Mount Rainier.
Activity 1: How Do Scientists Monitor Volcanoes?; Group presentations	11; 12	Students' understanding of the changes that occur within a volcano prior to an eruption and how they are monitored by scientists within their assigned area of specialty. Students' ability to effectively teach this information to the rest of the class.
Activity 1: Questions for Discussion	13	Students' understanding of the range of instruments/ technologies used by scientists to monitor volcanoes—what they are measuring and how this helps them predict eruptions.
Reading: Has Rainier Erupted in the Past? Thinking About What You Read	13; 16	Students' ability to recognize patterns in records of past eruptive events and use this information to predict the timing and nature of future eruptions.
Activity 2: Monitoring Mount Rainier; Analysis; Draft Position Paper	17; 23	Students' ability to read and understand graphic plots of earthquake data for Mount Rainier, and use them to assess the degree of hazard associated with living on the flanks of this volcano.
Activity: Take a Stand; Final Position Paper	24	Students' ability to incorporate their new scientific understanding of volcanoes into a personal or public policy decision about whether it is safe to live near a volcano such as Mount Rainier.
Application: Volcanoes Around the World	26	Students' ability to apply their understanding of volcanoes and their relationship to subduction zones to other volcanoes around the world.
Checks for Understanding	Appendix B	Students' grasp of the assessment outcomes of this learning experience. These questions can be used in class, for homework, or as a quiz at the end of the learning experience.

You should determine ahead of time which of these assessment opportunities you will evaluate formally (assign a grade) and which you will evaluate more informally.

Suggested Class Sessions

11–14 class sessions (45 minutes each)

Advance Preparation

- Make sure you have enough Activity 1 Information Sheets for groups to use during Activity 1 of Experimenting and Investigating.
- Schedule the use of computers, if available, to access current Cascades monitoring data during Experimenting and Investigating.

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- Obtain/schedule access to computers and/or the library for research about volcanoes around the world during Applying.
- Gather materials (such as poster paper, markers, cardboard, and other construction materials, soda bottles, etc.) for students to use to create posters as well as demonstrations and/or 3D models during Activity 1 of Experimenting and Investigating. They will also need poster materials for Applying.
- Obtain a video about the 1980 eruption of Mount St. Helens, such as *The Fire Below Us* by Global Net productions, which has dramatic eyewitness accounts of the 1980 eruption.

Teaching Sequence Preview

Setting the Context

- Students brainstorm about their current knowledge of volcanoes—where they are found and why, what makes them erupt, why some are active and others extinct, and their own willingness to live near a volcano. They draw a diagram of what they think it looks like under volcanoes and what happens when they erupt.
- Students read the story "A Hazardous Development?" about a planning board meeting in which a developer presents a plan to build a new town near Mount Rainier. They study a map and diagram presented by a scientist at this meeting and think about the relationship of volcanoes to subduction zones.

Experimenting and Investigating

- Students read some basics about volcanoes and about the 1980 eruption of Rainier's neighbor, Mount St. Helens. They think about the signals sent by the mountain that indicated an eruption was imminent. They also think about what the St. Helens eruption tells them about possible future events at Mount Rainier.
- In Activity 1, students work as groups of specialists to research the instruments/technologies used by scientists to 1) monitor for earthquakes that signal magma movement beneath the surface of volcanoes; 2) measure ground deformation on the surface of a volcano, also due to magma movement; or 3) measure temperature changes and gas emissions from accumulating magma. They develop presentations including demonstrations and/or 3D models to teach others in the class about the monitoring techniques within their assigned specialty area.
- Students study maps and tables that contain information about past eruptions of Rainier and think about the patterns in these data that might help them predict the timing and nature of future eruptions.
- In Activity 2, students study graphic diagrams showing data from seismographs located on Mount Rainier that detect earthquake activity beneath the mountain. They look at data from the past 10 years, and (if possible) current monitoring data available for Mount Rainier on the Cascades Volcano Observatory (CVO) Web site. They answer questions that encourage them to think about the likelihood that this volcano will reawaken. They use these data and other information from this learning experience to draft a position paper stating whether or not development should be allowed on the flanks of Mount Rainier.

Processing for Meaning

- Students participate in a Take-a-Stand activity in which they physically arrange themselves along a continuum in the classroom according to how they feel about approving the development near Rainier and about living near the volcano themselves.
- Students discuss the challenges of predicting a volcanic eruption and explain their thinking about whether or not the volcanoes of the Cascade Range could erupt. They revise and finalize their

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position papers with recommendations about the development, based on what they have learned about volcanoes in this learning experience.
Applying

- Students research other volcanoes around the world that are in similar tectonic settings to that of the Cascades volcanoes. They create posters that show their assigned volcano's relationship to adjacent plate boundaries, their eruptive history, the types of monitoring currently being performed by scientists, and whether these volcanoes pose a hazard to nearby populations. They share their posters with classmates in a poster session.

Setting the Context

[Student Book page 1]

Purpose

The Brainstorming discussion allows you to assess students' prior knowledge of volcanoes, plate tectonics, and plate boundary processes. It helps students begin to think about what they already know and don't know, and develop questions that can be addressed during this learning experience.

It is recommended that you have students work in small groups (2–3 students) in class on the written answers and drawing in the Brainstorming section. Then discuss the questions and their drawings as a class.

Materials and Preparation for Brainstorming

1. Have paper and colored pencils available for students to use when completing their drawings.
2. If possible, have a U.S. map and world maps displayed in the classroom to refer to during the Brainstorming discussion.

Teaching Strategies

The answers to the Brainstorming questions will give you an indication of your students' prior knowledge of volcanoes, plate tectonics, and plate boundary processes. It is not necessary for you to ensure that they know the correct answers to all of these questions at this point. Be aware that there is undoubtedly a range of prior knowledge in the class, and those who know less are not as likely to speak up. However, use the students' answers to drive the level and focus of discussion during this initial brainstorming and in subsequent discussions during this learning experience.

Possible Responses to Brainstorming Questions

1. What volcanoes have you heard about and where are they located? Do you know why they are located there? *Use this question as an opportunity for students to talk about what they know. If they seem to be able to name a number of volcanoes around the world, plot their locations on a map (if you don't have one, have them draw one on the board). Some students may have already learned in previous science classes that volcanoes are found primarily on plate boundaries. If*

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you are able to plot enough volcanoes on the map, ask them to describe any patterns they observe. Volcanoes occur in a variety of conditions—along rift zones (e.g., Iceland), where plates are pulling apart and magma is moving to the surface; along subduction zones (e.g., Alaska, Japan, and the Pacific Cascades),where tectonic plates are converging and one plate is diving under the other; and above hot spots in the middle of plates (e.g., Hawaii), where heat from Earth's interior is rising toward the surface. Students will focus on volcanoes along subduction zones in this learning experience.

2. Explain what you think makes a volcano erupt. *Try to get students to think about why magma tends to move to the surface (density differences between the hot magma and surrounding rock). Ask them to think about how it "finds" its way to the surface. It will follow the easiest route—through weak and fractured rock. More advanced students may also be able to talk about the pressure due to the weight of overlying rock decreasing as the magma rises. Ask them to think about what happens when a liquid or gas is under pressure and that pressure is released (champagne cork flying, balloon popping).*
3. Not all volcanoes are active—some are extinct, which means they are never expected to erupt again. How would you know if a volcano is active or extinct? *The purpose of this question is to get students to think about what is happening below an active volcano that is not happening below an extinct one. Try to get them to think about why magma would rise to the surface, forming a volcano for a period of time, and then stop permanently. What would have changed?*
4. Draw a cross section of a volcano that extends at least 100 kilometers into Earth. Your diagram should show what Earth looks like down to this depth and should be labeled to show the following aspects of a volcanic system:

   a. Where does the magma come from that erupts out of a volcano? *Try to push students beyond just showing a blob of magma under the ground. Where does the melted rock come from? How does it reach the surface? Why is magma rising beneath the volcano and not somewhere else? Again, your goal shouldn't be to get them to the "right" answer at this point—just push them to think about what they know and don't know.*

   b. What causes a volcano to erupt? (Show on your diagram your answer to question 2 above.) *This is a chance for you to see the "picture" that was in students' heads when they wrote their answer to question 2. Make sure students label their diagrams to show their thinking.*
5. Would you choose to live near an active volcano? Why or why not? *This question is a lead-in to the story, which focuses on the development of a residential community near Mount Rainier. Students' answers should further illuminate what they know about volcanoes, scientists' ability to predict the eruptions, and their own level of comfort with risk taking. You might mention that while volcanic eruptions are destructive, volcanic ash produces rich soils and that entire countries (such as Japan, the Philippines, and much of Italy) lie on the flanks of major volcanoes.*

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Suggested Homework

Have students read the story "A Hazardous Development?" and answer the Thinking About What You Read questions as homework in preparation for the class discussions. Make it clear to students that they should try to answer the questions based on their prior knowledge. (They do not need to do Internet research at this point to make sure they have the correct answers!)

STORY: A Hazardous Development?

The story describes a planning board meeting in which a developer proposes a new town on the flanks of Mount Rainier.

Science Background
Mount Rainier has been called "America's most dangerous volcano" because of the potential for catastrophic eruptions and lahars (mudflows), and the large number of people living close to the volcano. Although the story is fiction, the situation is real—over 150,000 people live, work, and go to school on geologically recent lahar deposits on the flanks of Rainier.

Have students discuss their responses to the Thinking About What You Read questions.

The Thinking About What You Read questions set the context for this learning experience by helping you better understand your students' prior knowledge about volcanoes and plate tectonics. You will also be able to assess their knowledge of world geography and their ability to read maps and subsurface diagrams. For students who are not familiar with the Pacific Northwest, this is an opportunity to introduce them to this area of the United States.

Responses to Thinking About What You Read Questions for A Hazardous Development?

1. Several vocabulary words were introduced in this story—plate tectonics, lithosphere, subduction zone, magma, intrusive igneous rocks, extrusive igneous rocks, and dormant. Write the meaning of these words in your notebook based on your understanding from the reading. Leave space to revise or add to these definitions as you come to understand them better. *To help them learn the language of Earth Science, students will build a vocabulary list throughout this course.*

Science Background
Students may become confused about the difference between "lithosphere" and "crust." Scientists describe Earth's structure both in terms of compositional layers (crust and mantle) and based on their mechanical properties (lithosphere and asthenosphere).The lithosphere is defined as the rigid material that makes up the tectonic plates. The lithosphere consists of all or part of two compositional layers: the crust (composed mainly of alumino-silicates) and the upper part of the mantle (composed mainly of ferr-magnesium silicates).

2. Throughout this course, you will be developing your understanding of the rock cycle, which explains how different types of rock form. Begin by drawing a labeled diagram in your notebook that shows and explains how extrusive igneous rocks and intrusive igneous rocks form, based on your understanding from the reading. *Students' drawings may be a series of cartoons illustrating the steps or the beginnings of a more integrated drawing showing the relationships between the rock types.*
3. The story explains that magma rises toward the surface because it is less dense than surrounding rock. Can you think of other examples of less dense materials rising above more dense materials? *You may have discussed this at some length during the Brainstorming, so you can decide how much discussion to have here. Convective processes will be referred to throughout this course, so it's a good idea to make sure students understand the physics. A lava lamp is a good way to demonstrate how density differences caused by changes in temperature cause materials to rise or sink. You may draw a parallel to hot air masses rising above cooler air masses in the atmosphere, driving weather events.*
4. Figure 2.1 shows a map view of the Cascades volcanoes, and Figure 2.2 shows a three-dimensional block diagram. Using two sheets of paper, or any other materials you think are

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appropriate, demonstrate how you think these two views relate to each other. *Students should show how the oceanic plate dives beneath the continental plate.*

Teaching Strategies

Students may have difficulty understanding the diagram of the subduction zone in Figure 2.2, particularly if their prior knowledge of plate tectonics and the structure of Earth is limited. When reviewing question 4 in class, have students demonstrate for you what they think is happening using two sheets of paper. Make sure you ask them to relate the volcanoes to this physical model.

5. Figure 2.2 shows a "subduction zone." Describe in your own words how you think the subduction zone is responsible for the presence of volcanoes in the Pacific Northwest. If the downwardly moving slab was dipping more steeply into the mantle, how would that affect the location of the volcanoes on the surface? *This question will help you assess whether the exercise in question 4 has helped students visualize what happens in a subduction zone and the relationship of the chain of volcanoes to plate boundary processes. Using the two sheets of paper from question 4, ask students to show you where the volcanoes are located on the continental plate and where the magma comes from that feeds them. If the descending slab was dipping more steeply, the line of volcanoes would be closer to the subduction zone (west of their current location in the Pacific Northwest).*
6. Do you think the questions posed by the planning board members make sense? Are these the questions you would want answers to if you were in their position? *Use this as an opportunity to focus students on these questions, which they will be exploring during this learning experience. Listen to their ideas about why it might be important to find the answers to make a good decision about the development. The questions posed by the planning board are scientific questions; point out that good public policy decisions are supported by science, but that science doesn't provide all of the answers. For example, it may be important to understand the alternatives to developing in this area—are there other places to build? How would it affect the property values of existing residents near Mount Rainier if further building were prohibited due to the hazard? If it causes their property values to decline, is this an unfair burden if the likelihood of an eruption is small?*

Science Background: Subduction Zones

Subduction zones occur around the world at locations where tectonic plates are converging. As these rigid lithospheric plates push together, the denser of the two plates descends beneath the other into Earth's mantle. Oceanic crust (made of basalt of volcanic origin at mid-ocean ridges) is denser than the rock that makes up continental crust, so the oceanic plate will typically dive beneath the continental plate. Where two oceanic plates converge, the older plate is generally denser, so it will be subducted beneath the younger plate. The angle of descent depends on their relative densities and varies from 10 to 45 degrees.

Once the oceanic plate begins to descend, the force of gravity continues to pull the plate down into the mantle because of density differences between the cool oceanic plate and the warmer mantle, much like a heavy blanket falling off of a bed. As the water-rich slab of seafloor experiences increasing temperatures and pressures, it releases water from hydrous minerals such as clays. This water lowers the melting temperature of surrounding rock, and magma forms. The magma rises to the surface because it is less dense than the overlying solid rock. When water is released from the descending slab, this rock becomes denser, and the slab continues to sink downward into the mantle.

In western Washington and Oregon, the Juan de Fuca oceanic plate (see Figure T2.1) is moving eastward and is being subducted beneath the North American continental plate. The Juan de Fuca plate

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is small, since most of it has already been subducted and consumed beneath the continent. Magma from the mantle near the sinking slab rises, and where it reaches the surface, forms a chain of volcanic mountains called the Cascades.

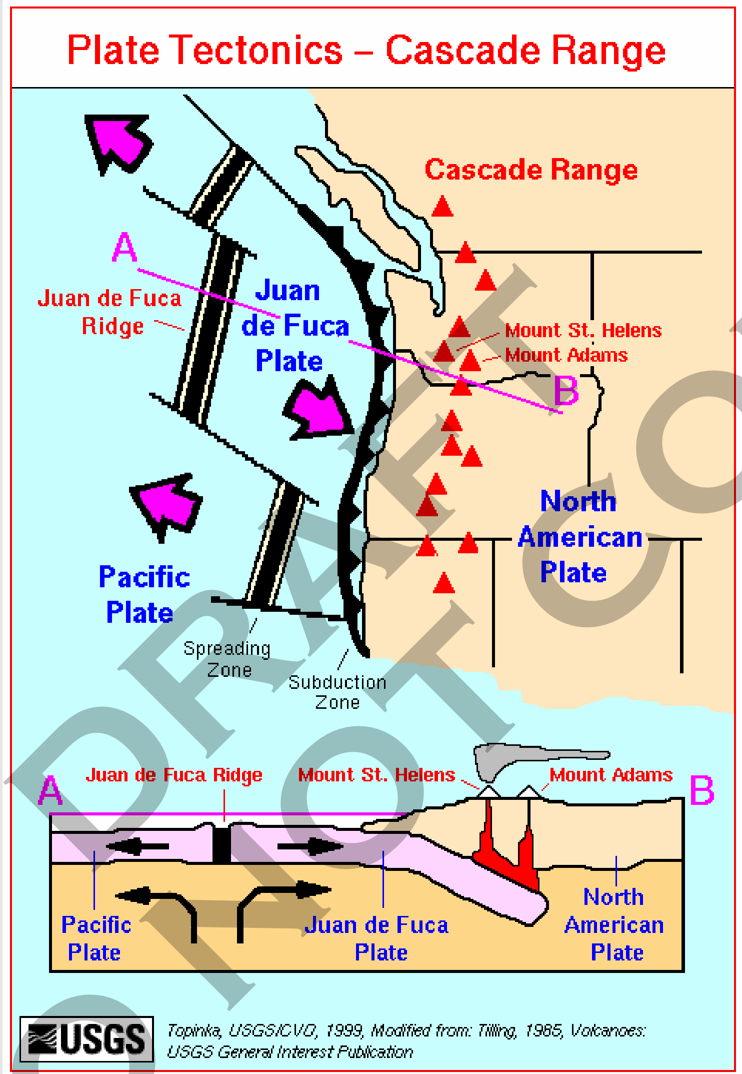

Figure T2.1: *Juan de Fuca tectonic plate.*
Source: http://vulcan.wr.usgs.gov/Glossary/PlateTectonics/Maps/map_plate_tectonics_cascades.html

Suggested Homework
Have students read "What Happens Before and During an Eruption?" and answer the Thinking About What You Read questions as homework.

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Experimenting and Investigating

[Student Book page 6]

Purpose

Students gather background information that will ultimately help them make recommendations to the planning board about whether development should be allowed on the flanks of Mount Rainier. Students will:

- Read about the 1980 eruption of Mount St. Helens. They may also watch a video about the eruption (optional).
- Research and teach each other classmates about the instruments and technologies used by scientists to monitor Mount St. Helens.
- Review recent monitoring data for Mount Rainier, as well as information about the eruptive history of this volcano, to support an informed personal decision about whether development should be allowed.

Materials and Preparation

Obtain a video about the 1980 eruption of Mount St. Helens (see Advance Preparation for recommendations) to show to students prior to Activity 1.

For Activity 1: How Do Scientists Monitor Volcanoes?

Each group of students will need:

- Activity 1 Information Sheets for one of the specialist groups. If you would like students to do research beyond what is provided in the packets, you will need computers and Internet access.
- Materials for the students to choose from to construct their 3D models or demonstrations (or you may ask them to bring these from home). See Advance Preparation for recommendations.
- Poster board and markers or other technology for presenting visuals.

Each student will need:

- Several copies of Think Sheet 2.1, the Volcano Monitoring Technology Note Sheet.

CHALLENGE: Should the new development on the flanks of Mount Rainier be approved?
Students gather information to find the answers to the questions posed by the planning board. They read about the 1980 eruption of Mount St. Helens and complete two activities.

Video and Reading: What Happens Before and During an Eruption?

Several excellent videos are available that dramatically depict the 1980 eruption of Mount St. Helens. It is strongly recommended that you show one of them to students either before or after they complete the reading.

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The reading addresses the events that occurred before and during the eruption of Mount St. Helens in 1980. After students have completed the reading and answered the questions on their own, conduct a whole class discussion.

Responses to Thinking About What You Read Questions for What Happens Before and During an Eruption?

1. More vocabulary words were introduced in this reading—lava flows, shield volcano, stratovolcanoes, pyroclastic flows, tephra, lahars, and magnitude. Add the meaning of these words to the vocabulary list in your notebook. Leave space to revise or add to these definitions as you come to understand them better. *To help them learn the language of Earth Science, students will build a vocabulary list throughout this course.*
2. Why do scientists think an eruption of Mount Rainier could be like those of Mount St. Helens? *Rainier is also a stratovolcano whose magma comes from the same source (the subducting plate). The magma is likely to be of similar composition (thick and gas-rich) that can cause explosive eruptions.*
3. What evidence did scientists have before the 1980 eruption that indicated to them that this was a dangerous volcano? *When scientists studied the rocks around Mount St. Helens, they recognized the deposits of violent eruptions in the past. Although not mentioned in the reading, Native Americans, explorers, missionaries, and early settlers in Oregon Territory experienced more than a dozen eruptions in the 1800s.*
4. What were the danger signs observed on the surface in the days leading up to the eruption? *Several months before the 1980 eruption, small earthquakes and explosions of ash, rock, and ice chunks occurred. Then a bulge formed on the north face of the mountain that grew rapidly.*
5. Describe what you think was happening below the surface of the volcano before the eruption that caused these danger signs. Can you think of ways that a scientist could monitor this? *The earthquakes, steam-venting eruptions, and explosions may have been caused by magma and released gases shifting below the surface of the volcano. Students might be aware of surveying techniques that could be used to measure changes in the shape of the land and how fast they are happening (students may or may not know at this point that earthquakes can be detected using seismographs). The explosions of ash, rock, and ice chunks may have been due to the sudden release of gases from magma as it neared the surface. The bulge growing on the north face of the mountain was a key precursor to the massive landslide and lateral blast. Scientists were able to monitor the growth of this bulge visually.*
6. Why do you think some people were reluctant to leave the danger zone around the volcano? *Try to get students to put themselves in the place of the residents, who had been asked to abandon their homes and belongings, and then wait an indefinite period of time, not knowing for sure if and when the volcano would erupt.*
7. Scientists didn't seem to know exactly when the eruption was going to happen, because they were planning to let some residents back into the danger zone to retrieve belongings the day the mountain exploded. Why do you think it was difficult to make an exact prediction? *The bulge growing in the side of the mountain was an indication that pressure was building. This pressure was held in by the weight of the rock on top of it. Because it is impossible to measure exactly how much pressure is building and how much weight is containing it, it is difficult to predict exactly when a critical point will be reached and the pressure will overcome the containing forces. Have students try to come up with analogies they've experienced in everyday life—predicting exactly when a pot of water on the stove will begin to boil, etc.*

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8. What did you figure out about the questions posed at the beginning of the reading? What do events that happened before and during the eruption of Mount St. Helens tell you about the possible future of Mount Rainier? Were scientists able to give ample warning to residents? What kind of damage could happen to the area around Rainier? Could it affect people as far as 20 miles away from the mountain? *This question is intended to bring students' thinking back to the questions they are trying to answer in the challenge, so that they can make a decision about the housing development. The 1980 eruption of Mount St. Helens was particularly dramatic. Not all eruptions cause so much damage. (St. Helens reawakened in 2004, and this eruption affected a much smaller area. You may want to have students research this eruption as well.)*

Suggested Homework

During Activity 1, students can research their group's instruments and technologies at home and work on components of their presentations.

ACTIVITY 1: How Do Scientists Monitor Volcanoes?

In this activity, students work in three specialty groups: seismologists, gas monitoring temperature specialists, and ground deformation specialists. They research the tools and techniques used by their specialists to monitor changes in a volcano that might signal an imminent eruption, and teach what they've learned to the rest of the class.

Facilitating Activity 1: How Do Scientists Monitor Volcanoes?

Have students work in groups of not more than 3 or 4. Since there are only three scientific specialist groups, you will probably need to have more than one group of each type. Give each group a set of Activity 1 Information Sheets: Seismology Specialists, Ground Deformation Specialists, or Gas/Temperature Specialists. You can also ask groups to research the tools and technologies on their own. The USGS has excellent Web resources for students to use (see http://volcanoes.usgs.gov/About/What/Monitor/monitor.html). The technologies featured in the packets include instruments and equipment that will be referred to in future learning experiences, so make sure these are adequately represented in the students' presentations.

Explain to students that the goal is for them to teach the rest of the class about the changes that are occurring within the volcano that are being monitored by specialists in their group, and the instruments and technologies used to monitor these changes. Have them think about what teachers do that helps students learn and incorporate these strategies into their presentation. Point out that they need to understand their monitoring techniques well enough to be able to teach them to others.

The Activity 1 Information Sheets have two parts: Part A focuses on the processes occurring within the volcano that are being monitored, and Part B describes the technologies used to monitor these processes. It is important to make sure students pay adequate attention to the Earth's processes, so have them complete Part A first and develop a demonstration to teach others about the process. These demonstrations do not need to be elaborate; for example, students can use a shaken soda can to demonstrate how gases come out of solution when pressure is released. For Part B, which focuses on the monitoring instruments and technologies, students are asked to produce visuals that help to teach the material. They should also show and explain examples of the data produced. The visuals need to be clearly seen from all parts of the

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classroom, so you should encourage them to create large, simplified drawings with the essential information, or you may want them to use overhead transparencies.

Explain that all group members should participate in the preparations and presentation, and suggest ways that they can accomplish this. For example, there may be more than one technology within a given specialty area, and these can be assigned to different students. Some students may concentrate on preparing the visuals while others focus on the 3D model or demonstration.

During the presentations, students in the class should take notes about the monitoring technologies and instruments on Think Sheet 2.1 (shown in Table T2.1). Tell students they are ultimately responsible for learning the information presented by all of the specialty groups and for answering a set of related questions.

Table T2.1: *Volcano Monitoring Technology Note Sheet (Think Sheet 2.1)*

Name of Specialty Group	Changes Happening Within Volcano	Monitoring Technique	How Does This Technique Work?	How Could This Be Used to Predict an Eruption?

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Responses to Questions for Discussion

1. Using the notes you took during the presentations, summarize the changes that occur within a volcano prior to an eruption. *Help students synthesize the list of changes they generated on Think Sheet 2.1 during the presentations into a more connected view of the multiple interacting processes occurring within the volcano that lead up to an eruption. You can refer back to the 1980 eruption of Mount St. Helens.*
2. Does your knowledge of the monitoring techniques give you confidence that scientists would be able to warn nearby residents of an imminent eruption in time for them to evacuate? *Scientists are able to use these monitoring techniques to recognize changes in activity that*

mean an eruption could happen, and then issue warnings to nearby residents. They cannot, with current technologies, predict exactly when they will occur, and students will have varying levels of comfort with this. This might be an opportunity to talk about the importance of having an emergency plan in place to make sure the residents of neighboring communities receive warnings and know how to act on them.

3. What are the possible limitations of the techniques? Are there any hazards associated with using these technologies to monitor an active volcano? Could you be sure you weren't missing any important signs of an imminent eruption? *Some techniques can only be effectively used under certain conditions, and their results may be biased by conditions on the mountain. Some techniques, which require scientists to work directly on or very near the volcano, may be too dangerous to use at times. Remind students that monitoring technologies can be costly to deploy and operate as well, and decisions have to be made about where to focus monitoring efforts.*
4. What do you feel unsure about at this point? What more would you need to know to make a decision about the development? *This question is intended to bring students back to the purpose of the challenge and have them think about the progress they've made toward answering the planning board's questions.*

At this point, students have gained background knowledge about volcanic eruptions and monitoring techniques, but they still need to learn more about Mount Rainier.

READING: Has Rainier Erupted in the Past?

Have students do the reading and write answers to the Thinking About What You Read questions in their notebooks. Then discuss them as a class.

Responses to Thinking About What You Read Questions for Has Rainier Erupted in the Past?

1. What patterns do you see in the diagram of past Cascades eruptions in Figure 2.8? For example, which volcanoes seem to have been most active during the last 4,000 years?
   a. Looking at individual volcanoes, are the eruptions evenly spaced in time, or do they occur in clusters?
   b. Have there been any times when several of the volcanoes have been active? dormant?
   c. What is the longest time period a volcano has been dormant, based on the data in the diagram, before erupting?
   d. How would you compare the overall level of activity of the Cascades volcanoes to that of 4000 years ago?

   It should be clear from the diagram that all but one of the volcanoes have been active during this time period, and that eruptions can happen after several thousand years of dormancy.
2. According to Table 2.1, how many active periods has Rainier had in the last 10,000 years? How long have these active periods lasted? What is the longest period it has been dormant before erupting again? *Make it clear to students that the age ranges in the table represent periods of time in which Rainier was active. In most cases, there were multiple eruptions during each of these active periods. The recent data are likely to be more accurate (especially those that occurred in recorded time), since the deposits of older eruptions might be obscured by more recent ones. According to the information in the table, there have been*

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nine active periods within the past 10,000 years. Some of these active periods have lasted over a thousand years. There have been two dormant periods, 1800 years and 800 years in length. It is worth noting that volcanoes with less frequent eruption histories may actually be the really dangerous ones. A volcano like Mount St. Helens, which seems to "clear its throat" fairly frequently will have smaller eruption events.

3. What have Rainier's eruptions been like? Were these eruptions explosive like the ones at Mount St. Helens? What is your evidence? *The table describes pyroclastic flows and tephra, which result from explosive eruptions similar to those at Mount St. Helens. There have also been multiple large lahars.*
4. How far from the volcano's summit do these volcanic deposits extend? What kinds of damage would you expect from lahar flows if they were to happen today? *According to Figure 2.9, the lahar deposits from previous eruptions extend 70 km or more from the summit of the volcano. These lahars flowed down river valleys, and you might want to point out that the story indicates that the proposed development would be located in a river valley.*

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ACTIVITY 2: Monitoring Mount Rainier

During this challenge activity, students study recent monitoring data for Mount Rainier, which consists of earthquake records from the Pacific Northwest Seismographic Network (PNSN). They use these data to assess the level of activity beneath the mountain and think about the likelihood that an eruption could happen, putting nearby communities in danger. Based on what they have learned, students write a draft position paper stating whether or not they think the development near Rainier should be approved and include the basis for their thinking.

Facilitating Activity 2: Monitoring Mount Rainier

It is important to make sure students understand how to read the diagrams in this activity. One of the specialty groups taught the class that earthquakes occur as magma moves beneath the volcano, and the group may have shown the class seismograms. In order to ensure that all students understand this information, explanations are provided in the text of Activity 2 in the student book. You may also want to review this information before students study the earthquake data.

You may have students work individually or with a partner on this activity. As they review each diagram, they should record in their notebooks their answers to the Stop and Think questions. Then they should write in their notebooks their answers to the Analysis questions that follow.

If students have Internet access, a wealth of additional information is available about Mount Rainier and the communities surrounding it. For example:

- The CVO issues daily updates regarding the level of activity at the Cascades volcanoes, including Mount Rainier (see http://vulcan.wr.usgs.gov/).
- Students can obtain current earthquake monitoring information on the PNSN Web site at http://www.pnsn.org/INFO_GENERAL/volcanoes.html.

- The USGS Web site includes a number of reports about hazards associated with Mount Rainier; for example, see: http://vulcan.wr.usgs.gov/Volcanoes/Rainier/Hazards/OFR98-428/framework.html.
- Individual towns in the vicinity of Rainier may have emergency management plans posted or discussed on their town Web sites.

Suggested Homework

Have students study the Activity 2 earthquake data and prepare answers to the Stop and Think and Analysis questions as homework.

Conduct classroom discussions of the Stop and Think questions and then the Analysis questions.

Students are asked to prepare a draft position paper at the end of this challenge and to finalize this paper after the Take-a-Stand discussion in the Processing for Meaning. Remind students that although they may have an emotional feeling about whether the development should be approved, they need to support their position with scientific evidence, focusing on the guiding questions provided.

Teaching Strategies

During the class discussion that follows this activity, take plenty of time to review each figure and the Stop and Think questions that relate to them. Make sure students understand what the figures are showing.

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Responses to the Stop and Think Questions for Monitoring Mount Rainier

1. Approximately how many earthquakes occurred during this 12-hour period beneath Mount Rainier (you don't have to count the really small ones)? What do you think may be happening beneath Rainier that is causing these earthquakes? *Students may count approximately 12–15 earthquakes during this 12-hour period. These may be due to magma movement breaking rock beneath the volcano. You should point out, however, that the seismograph will detect any ground movement, and sometimes this movement is caused by events on the surface. The Mount Rainier seismographs will also record large earthquakes that are located some distance from the mountain, such as under other Cascades volcanoes. This is why it is important to correlate this seismogram with those from others in the seismographic network to determine the location of the earthquake's source.*
2. What patterns do you see in these data? For example, where do most of the earthquakes occur? What do you think is happening beneath the volcano that is causing this? *Students should notice that most of the earthquakes occurred directly beneath the center of the mountain. This may be due to movement of magma within the conduit that has built this summit.*
3. Describe the patterns you see in these data. What you think happened beneath the volcano during this ten-year time period that caused the patterns you observe? *Most of the earthquakes occurred directly below the summit to depths of approximately 6 kilometers below sea level. Below this depth, there are not many earthquakes, indicating that not much magma movement is occurring.*
4. List the differences you see between the two cross sections, focusing on the number and locations of earthquakes. Explain what you think has caused these differences. *Remind*

students that Mount St. Helens was actively erupting during some of this time period. There were clearly more earthquakes beneath St. Helens than Rainier during this time, indicating more magma movement, and at a greater depth, at the former.

5. Were there any changes in the frequency and/or depth of earthquakes beneath Rainier during the one-year time period shown in Figure 2.14? During the ten-year time period shown in Figure 2.15? Relate any patterns you see to possible magma movement beneath the volcano. *There was more activity during October 2004 than at other times during the one-year period beneath Rainier, according to Figure 2.14. Although there is some variation in earthquake activity, there does not seem to be an overall increase in activity beneath Rainier during the ten-year time period.*

> **Teaching Strategies**
>
> When you discuss the Analysis questions, encourage students to relate their answers to the questions to evidence from the Activity 2 earthquake data, the reading, and their own Internet research.

Responses to Analysis Questions for Monitoring Mount Rainier

1. Using the data you reviewed from Mount Rainier, do you think this volcano may be reawakening? Cite specific evidence. *Students are likely to focus on the earthquakes occurring beneath Mount Rainier as evidence that the volcano is currently active. Have them think about whether movement of magma beneath the mountain necessarily means an eruption will happen soon. What would they look for as an indication that pressure within the volcano may be building to the point where it could erupt?*
2. Do you see any evidence of changes in the level of activity beneath Mount Rainier in the last ten years? *Ask students which figures are most useful for answering this question. Based on Figure 2.15, which is a time versus depth plot of earthquakes beneath Mount Rainier over the past ten years, there hasn't been much change in the level of activity during this time period.*
3. What are some of the potential hazards associated with living near Mount Rainier? *Most of the deposits of previous eruptions are those of explosive eruptions (tephra, pyroclastic flows, etc.). These are dangerous because they are powerful and move very fast. It is also difficult to predict exactly when and where they will occur. Pyroclastic flows could move quickly along the ground and threaten those who are in low-lying areas near the volcano. The ash associated with airborne tephra deposits can travel longer distances and threaten air traffic. There have also been a number of lahars in the past. These have traveled long distances down the river valleys near the volcano and could threaten the many people living and working in these areas.*
4. How likely is it that these hazards will actually occur in the near future? ever? Explain your thinking. *Students may look at the statistical data—how often has Mount Rainier erupted in the past? How long has it been since the last eruption?*
5. Do you think the monitoring techniques used by scientists will be adequate to warn nearby residents and allow them to get out of harm's way if a volcanic eruption or lahar is about to happen? *Scientists were able to predict within a period of days or weeks that an eruption of Mount St. Helens might occur. It is more difficult to predict when lahars will occur, and residents in the path of a lahar may need to evacuate very quickly. Make sure students think about the logistics involved in communicating a warning to residents and evacuating them*

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from homes, schools, and businesses, and the importance of having emergency plans in place and rehearsed.

6. What further information would help you decide whether or not to approve the new development on the flanks of Mount Rainier? *It would be useful to know what types of emergency plans would be developed and implemented to protect residents of the new city.*

Suggested Homework

You may want to assign the draft position paper as homework in preparation for the Processing for Meaning.

Processing for Meaning

[Student Book page 24]

Purpose

Students incorporate their new scientific understanding of volcanoes into a personal and public policy decision about whether it is safe to live near a volcano such as Mount Rainier. This involves participating in a class Take-a-Stand activity and a class discussion. Following the activity and discussion, students prepare a final position paper.

Materials and Preparation

Set up the room so that students can physically arrange themselves along a continuum during the Take-a-Stand activity without standing in front of each other. All students should be able to see and hear each other—a horseshoe-shaped line, wrapping three quarters of the way around the classroom works best. You may want to make up signs that read “Definitely!” and “Absolutely not!” to represent the positions of the two extremes of the continuum.

Facilitating the Take-A-Stand Activity

It is important to point out to students that there are no wrong answers to the Take-a-Stand questions, only answers that aren’t adequately explained and supported by evidence.

Before beginning the Take-a-Stand activity, explain the ground rules to students. Explain what the two ends of the continuum represent in general terms—students will define this more clearly as they explain their positions. It is critical that students speak one at a time and listen to each other. Make it clear to students that they must all take an initial position, but that they can change their physical position at any time in response to what their classmates are saying. They should all be prepared to explain why they are standing where they are. Emphasize to them that this is not a competition to find the “winning” or “right” answer. The goal is to explore different perspectives as well as clarify their own thoughts.

When students have taken their positions, ask students at the two extremes to explain their position, and then ask a student or two in the middle. This will help establish the range of opinions in the group. At some point, students should begin wanting to respond to each other’s comments; make sure when this is happening that they continue to speak one at a time and listen to each other. Watch the body language for those who may want to say something but are hesitant, and encourage them to explain their position.

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As facilitator, make sure students stay focused on the question posed. At times, you may want to ask them clarifying questions, or remind them to relate their statements to the scientific information they've learned about volcanoes as well as socioeconomic factors. Students may tend to cluster toward the "don't build" end of the spectrum. If so, you may want to prompt the class by asking questions to push their thinking. For example, as long as population keeps increasing can we always choose to avoid living in places that have hazards? Other questions to keep the discussion going might include asking if it is okay to have false alarms—where people have to evacuate but then no eruption occurs. Should realtors or the local government be required to provide warnings to would-be home buyers in this town? Should the federal government provide insurance?

Listening for Understanding

Take-a-Stand Activity

1. If you were on the planning board, would you approve the plan to build a new town on the flanks of Mount Rainier? *You may want to have students imagine that they are on the planning board and have to defend their position to the developers as well as concerned present and future residents. Encourage them to think of the potential consequences of their decision for people in the community whom they represent. Listen to make sure students relate their explanations to the scientific information presented in this learning experience as well as other socioeconomic factors.*
2. Would you personally be willing to take the risk of living near Mount Rainier? *Students should recognize that they may vary from their classmates in their willingness to take risks. This may be related to their life experiences.*

Responses to Questions for Discussion

1. Generally, how far in advance can volcanologists predict that an eruption is about to occur? Base your answer on what you have learned about the Mount St. Helens eruptions. *Scientists can tell when a volcano is "waking up" and say whether an eruption is likely in the coming weeks. They can't predict the exact week, day, or time that the eruption will occur, however.*
2. The volcanologists monitoring Mount St. Helens were not able to predict the exact date and size of the volcanic eruption. Explain why you think they were unable to do this. *Students should focus on the complex nature of predicting volcanic eruptions. Have them list some of the factors that may cause a volcano to erupt (the amount of magma accumulated, the strength of rocks above the magma body, the composition of the magma [how gas- and silica-rich it is]). You might review the events that preceded the 1980 eruption of Mount St. Helens and the difficulties associated with predicting the specific events that occurred. Also emphasize that despite the difficulty of predicting events with complex causes, scientists' understanding of the processes occurring beneath volcanoes allowed them to evacuate most people from the area and save many lives. The lessons learned at Mount St. Helens in 1980 were successfully applied in the eruption of Mt Pinatubo in 1991, and thousands of lives were saved by evacuating people before the main eruption there occurred.*
3. Do you think the Cascades volcanoes will always be active, or will there be a time in the future when they will become extinct? Explain your thinking. *At this point, you may want to show students a map that shows the entire Juan de Fuca plate. As long as this plate is*

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subducting and magma is being generated, there is the potential for volcanoes in the Cascade Range to continue to erupt. However, at some point in the future, perhaps when the Juan de Fuca plate is entirely consumed into the mantle, subduction will stop. At this point, magma would no longer be actively generated beneath the Cascades, and the volcanoes would no longer be active.

4. During the brainstorming at the beginning of this learning experience, you described your initial ideas about volcanoes—what causes them to erupt, and what happens when they erupt. How have your ideas changed at this point? *This is an opportunity for students to summarize what they've learned about volcanoes in this learning experience. They should be able to demonstrate growth relative to the Goals for Student Understanding at the beginning of this Teacher Guide. You might have them redo their drawings: They should show magma being generated just above a descending slab of oceanic lithosphere in a subduction zone. The magma should trickle upward and collect in a magma chamber a few kilometers below the surface. The drawing should show magma following fractures upward from the magma chamber and erupting on the surface.*

Final Position Paper

Have students finalize their position papers, incorporating any new thinking or ideas they have derived from the Processing for Meaning discussions.

Applying

[Student Book page 26]

Purpose

Students apply what they have learned about volcanic processes at subduction zones to other volcanoes around the world.

APPLICATION: Volcanoes Around the World
Students should either select or be assigned one of the volcanoes from the following list:

Vesuvius, Italy
Etna, Italy
Krakatau, Indonesia
Pinatubo, Philippines
Fuji, Japan
Augustine, Alaska
Paracutin, Mexico
Montserrat, West Indies
Pelee, West Indies

All these volcanoes are in a similar tectonic setting as the Cascades volcanoes.

Students prepare a poster presentation, which they will share with the rest of the class in a poster session.

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Facilitating the Application: Volcanoes Around the World

Tell students that scientists share the results of their research in poster sessions at scientific conferences. At these conferences, scientists place their posters on a wall with others researching topics within their area of specialty (for example, there might be a poster session featuring research on past volcanic activity on Mars). They stand next to the poster as other scientists wander through the session, stopping to talk with the scientists about their work.

During the class poster session, since multiple "scientists" worked on each poster, they will be able to take turns standing next to the poster and circulating around the room asking questions of the other presenters.

Plan the time so that all group members have an opportunity to answer questions and to circulate around the room. They may do this in pairs. As they circulate and study the other posters, have them complete Think Sheet 2.x with information about the other volcanoes.

Checking for Understanding

It is suggested that you end this learning experience by having students answer the Checks for Understanding questions on their own and then discuss their answers as a whole class. By doing so, both you and your students will be able to assess and clarify understanding of the learning experience content. A soft copy of the Checks for Understanding questions—without answers—is on the Earth Science Field Test Resources Web page (in PDF and in Word). The Checks for Understanding Questions and Answers for this learning experience are located in Appendix B.

Appendix B also contains an Assessment Item Bank of short-answer and multiple-choice items with answers. You may decide which items to use, when to use them (e.g., at the end of this learning experience or after a group of learning experiences), and how to use them (e.g., as homework, quizzes, or tests). A soft copy of the Item Bank items—without answers—is on the Earth Science Field Test Resources Web page (in PDF and in Word) so that you can customize your use of items.

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