

Exploring Earth: Plate Tectonics



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6th Grade Earth Science Immersion Unit



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SYSTEM-WIDE CHANGE FOR ALL LEARNERS AND EDUCATORS

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Exploring Earth: Plate Tectonics

This Grade 6 Immersion Unit is being developed in partnership with the Los Angeles Unified School District and is being tested and revised by teachers, scientists, and curriculum developers associated with the NSF-funded Math/Science Partnership, System-wide Change for All Learners and Educators (SCALE) and the DOE-funded Quality Educator Development (QED) project at the California State University – Dominguez Hills.

Immersion Units provide a coherent series of lessons designed to guide students in developing deep conceptual understanding that is aligned with the standards and key concepts in science. In Immersion Units, students learn academic content by working like scientists: making observations, asking questions, doing further investigations to explore and explain natural phenomena, and communicating their results based on evidence.

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Navigating the Unit

This Immersion Unit provides a coherent series of lessons designed to guide students in developing deep conceptual understanding that is aligned with the standards, key science concepts, and essential features of classroom inquiry (as defined by the National Science Education Standards). In Immersion Units, students learn academic content by working like scientists: making observations, asking questions, doing further investigations to explore and explain natural phenomena, and communicating results based on evidence. Immersion Units are intended to support teachers in building a learning culture in their classrooms to sustain students' enthusiasm for engaging in scientific habits of thinking while learning rigorous science content.

This Immersion Unit is comprised of several steps; each step contains between one and four lessons. The unit begins with the Unit Overview, which includes a description of the key concepts, evidence for student understanding, assessment strategies and other relevant implementation information. The Unit Overview outlines the conceptual flow and rationale for the structure of the unit.

Each step in the unit begins with an overview, which describes the individual goals and activities of the specific step, and its relationship to the previous and following steps. The title and approximate length of time needed for each lesson is also shown. Within the step, each lesson contains:

- Snapshot
- Background Information
- Implementation Guide
- Student Pages
- Teacher Pages

Snapshots are printed on a single page and provide key information for implementing the lesson. Each snapshot includes the key concept(s), evidence of student understanding, list of materials, procedures for lesson implementation, key words and REAPS—a strategy for assessing student learning. This page is designed to have on hand while you implement the lesson.

The Background Information and Implementation Guide sections provide learning experiences such as investigations, reading research, or other engaging supporting strategies designed to teach a specific concept(s). They include instructions for any advance preparation required, explain the design of the lesson, include strategies for assessing student learning, and provide teacher background information on relevant science content. The Implementation Guide for each lesson addresses teaching methodology, including specific examples and information related to effective teacher implementation. If research identifies common misconceptions related to the content, a detailed explanation of common misconceptions is provided with suggestions for addressing them.

Student pages may include readings, guides, handouts, maps or instructions to engage students during the lesson. These pages assist you as you guide students through the lesson, and are intended to be readily adapted to suit a variety of classrooms with diverse student populations.

Teacher pages may include overheads, maps, data charts and other materials that can help you implement the lesson.

(continued on following page)

Snapshot Page

The information on the Snapshot page includes the following:

- | | |
|----------------|-------------------|
| • Lesson Title | • Materials |
| • Key Concept | • Key Words |
| • Time Needed | • REAPS Questions |

This Immersion Unit contains a variety of opportunities for modifying content and methodology based on your students' needs and your classroom situation. The basic structure of the unit is designed to support you in anticipating

the particular needs of your students to foster understanding of inquiry, nurture classroom communities of science learners, and engage students in learning key science concepts.

Unit Overarching Concepts

- Plate tectonics explains the landforms, changing features, and catastrophic events of Earth’s surface.
- Science knowledge advances through inquiry.

Unit Supporting Concepts

- Plate tectonics explains how major geological features of California formed, including mountains and locations of earthquakes and volcanoes
- Scientists differ greatly in what phenomena they study and how they go about their work. Although there is no fixed set of steps that all scientists follow, scientific investigations usually involve the collection of relevant evidence, the use of logical reasoning, and the application of imagination in devising hypotheses and explanations to make sense of the collected evidence (Benchmarks quote).
- Important contributions to the advancement of science, mathematics, and technology have been made by different kinds of people, in different cultures, at different times (Benchmarks).
- Tracing the history of science can show how difficult it was for scientific innovators to break through the accepted ideas of their time to reach the conclusions that we currently take for granted. (NSES quote).
- Developing and using a model is one instance in science where intuition and creativity are needed to make a model with explanatory power that will help others understand how things work. (reference NSES content Standards A—all levels, pg 117).

Evidence of Student Understanding

By the end of this unit, the student will be able to:

- *Describe how the theory of plate tectonics explains how most landforms developed and how most catastrophic events occurred (including mountains, volcanoes, deep ocean trenches, earthquakes, and volcanic eruptions).*
- *Identify and engage in all aspects of scientific inquiry.*
- *Explain how studying natural phenomena through scientific inquiry advances knowledge.*
- *Apply their knowledge of plate tectonics to explain specific features of California geology including the Sierra Nevada mountain range.*
- *Recognize how science knowledge progresses over time.*
- *Design and use a physical scientific model to explain the landforms and catastrophic events in a particular region of the world.*

Unit Preview

A view of Earth from space is a familiar sight now, thanks to photographs taken by satellites. As familiar as it is, this view is just a snapshot in Earth’s long history. Earth is an active planet, changing visibly in the course of a human lifespan and enormously in the course of geologic time.

This Immersion Unit engages students in an in-depth, student-directed investigation and several guided inquiries to discover, test, and use the theory of plate tectonics. Plate tectonics is a relatively new, well-supported scientific theory that helps explain Earth’s landforms, catastrophic events like earthquakes and volcanic eruptions, and other dynamic phenomena on and beneath Earth’s surface.

Exploring Earth: Plate Tectonics focuses on the overarching question: How does the theory of plate tectonics explain the movement and structure of Earth's surface? The evidence for the answer lies in Earth's landforms that surround us today.

Eight geographic regions are featured in this unit's student-directed investigation, which provide a global view of plate tectonics. Student groups use knowledge and evidence they gain through guided inquiry lessons to design, build, evaluate, and revise a physical scientific model that accurately represents the tectonic processes responsible for the landforms in their particular region.

Throughout the guided inquiries in this unit, students uncover many lines of evidence that support their understanding of present-day landforms. This evidence includes dramatic images of changes to Earth's surface resulting from earthquakes and volcanic eruptions; seismic data; GPS data, the fit of continents and distribution of fossils; information about Earth's crust and convection currents to understand Earth's inner structure; the age of rocks relative to seafloor spreading centers; and more. All of these data are pieces of the puzzle that students put together as they work like scientists to understand landforms in regions around the world and in California.

Unit Standards

Plate Tectonics and Earth's Structure

1. Plate tectonics accounts for important features of Earth's surface and major geologic events. As a basis for understanding this concept:

- a. Students know evidence of plate tectonics is derived from the fit of the continents; the location of earthquakes, volcanoes, and midocean ridges; and the distribution of fossils, rock types, and ancient climatic zones.
- b. Students know Earth is composed of several layers: a cold, brittle lithosphere; a hot, convecting mantle; and a dense, metallic core.
- c. Students know lithospheric plates the size of continents and oceans move at rates of centimeters per year in response to movements in the mantle.
- d. Students know that earthquakes are sudden motions along breaks in the crust called faults and that volcanoes and fissures are locations where magma reaches the surface.

- e. Students know major geologic events, such as earthquakes, volcanic eruptions, and mountain building, result from plate motions.
- f. Students know how to explain major features of California geology (including mountains, faults, volcanoes) in terms of plate tectonics.
- g. Students know how to determine the epicenter of an earthquake and know that the effects of an earthquake on any region vary, depending on the size of the earthquake, the distance of the region from the epicenter, the local geology, and the type of construction in the region.

Shaping Earth's Surface

- 2d. Students know earthquakes, volcanic eruptions, landslides, and floods change human and wildlife habitats.

Heat (Thermal Energy) (Physical Science)

- 3c. Students know heat flows in solids by conduction (which involves no flow of

Unit Standards *(continued)*

matter) and in fluids by conduction and by convection (which involves flow of matter).

Energy in the Earth System

- 4c. Students know heat from Earth's interior reaches the surface primarily through convection.

Investigation and Experimentation

- 7. Scientific progress is made by asking meaningful questions and conducting careful investigations. As a basis for understanding this concept and addressing the content in the other three strands, students should develop their own questions and perform investigations. Students will:
 - a. Develop a hypothesis.
 - b. Select and use appropriate tools and technology (including calculators, computers, balances, spring scales, microscopes, and binoculars) to perform tests, collect data, and display data.
 - c. Construct appropriate graphs from data and develop qualitative statements about the relationships between variables.
 - d. Communicate the steps and results from an investigation in written reports and oral presentations.
 - e. Recognize whether evidence is consistent with a proposed explanation.
 - f. Read a topographic map and a geologic map for evidence provided on the maps and construct and interpret a simple scale map.
 - g. Interpret events by sequence and time from natural phenomena (e.g., the relative ages of rocks and intrusions).
 - h. Identify changes in natural phenomena over time without manipulating the phenomena (e.g., a tree limb, a grove of trees, a stream, a hill slope).

Unit Timeline

Step	Lesson	Class Time	Key Concepts
Step 1	Exploring Earth's Surface	50 minutes (with suggested breakpoint)	Regions of the world have diverse landforms that we can learn about by studying maps and photographs and by making observations.
	Modeling Earth's Surface	35 minutes	Scientists support their ideas with evidence such as facts found in books or articles, observations, and results of investigations.
Step 2	Earth-shattering Events	20 minutes	Earthquakes and volcanic eruptions provide evidence that Earth's surface changes. Earthquakes and volcanic eruptions are sudden, local events but may affect large areas.
	Exploring Seismic Waves	50 minutes	Earthquakes cause vibrations called seismic waves that spread outward from a focus. Earthquakes are sudden motions along breaks in Earth's crust called faults.
	Analyzing Seismic Data	80 minutes (with suggested breakpoint)	Earthquakes and volcanic eruptions occur in a pattern around the world. Volcanic eruptions often occur in regions that also have earthquakes.
	Scientific Modeling	45 minutes	Scientific models are based on evidence.
Step 3	Tracking Slow Movements	45 minutes	Earth's surface moves slowly and continuously, not just during catastrophic events. GPS is a tool used for direct measurement of slow surface movement. Different areas of Earth's surface move in different directions and at different speeds.
	Discovering Plates	30 minutes	Areas of Earth's surface moving as a unit are outlined in a pattern similar to the locations of earthquakes and volcanoes. Scientists have discovered that Earth's surface is broken into large segments, called plates, which move slowly and continuously.
	Revising Region Models	20 minutes	Scientists revise models and explanations based on new information.

Step	Lesson	Class Time	Key Concepts
Step 4	Geologic Time	50 minutes	Continents have been in different positions during Earth's history. There are many important pieces of evidence for the arrangement of continents being different in the past.
	The Case for Continental Drift	50 minutes	Scientists are more likely to agree with claims if they are supported with evidence and a logical argument.
Step 5	Earth's Crust	35 minutes	Plates are sections of Earth's outer layer, the crust. Developing and using a model is one instance in science where intuition and creativity are needed to make a model with explanatory power that will help others understand how things work.
	Inside Earth	35 minutes	The inside of Earth is made of layers with different properties. Convection currents inside Earth cause plates to move.
	Revising Region Models	20 minutes	Scientists often gather more than one type of evidence to support an idea. Scientists revise their models based on new evidence. Developing and using a model is one instance in science where intuition and creativity are needed to make a model with explanatory power that will help others understand how things work.

Step	Lesson	Class Time	Key Concepts
Step 6	Divergent Plate Boundaries	40 minutes	Plate boundaries are categorized as divergent, convergent, or transform. As plates diverge, new rock fills the gap and older rock moves away from the plate boundary. Scientists usually gather more than one type of evidence to support an idea.
	Convergent and Transform	45 minutes	Deep trenches, volcanic action, and mountain ranges can occur near convergent plate boundaries. Subduction is the process of one plate sliding under another, recycling old crust back into the mantle.
	Explain That Feature	45 minutes	Plate tectonics explains the landforms, changing features, and catastrophic events of Earth's surface. Science knowledge advances through inquiry.
	Revising Region Models	35 minutes	Scientists revise models based on new evidence
Step 7	Model Showcase	50 minutes	Plate tectonics explains the landforms, changing features, and catastrophic events of Earth's surface.
	Explaining Mountains	50 minutes	Plate tectonics explains major geological features of California, including mountains and locations of earthquakes and volcanoes.
	California on the Move	50 minutes	Plate tectonics explains major geological features of California, including mountains and locations of earthquakes and volcanoes.

Unit Content Background

Plate tectonics is a scientific theory describing many of the features and events that happen on Earth's surface. Note that in science a "theory" is not "just an idea." In science, a "theory" is a well-proven set of ideas that accurately explains one or more natural phenomena. A scientific theory has been tested many times over and, while it may have limitations in some cases, it explains natural phenomena well enough to be entrenched in scientific thought. Plate tectonics is a relatively young theory, born in the mid-20th century, but accurately describes such phenomena

as mountain-building, earthquakes and volcanic activity, and other aspects of the dynamic Earth.

Unit Investigation and Scientific Modeling

The Unit Investigation is a student-directed inquiry to meet this challenge: How can you explain land formations and processes that formed them in a region of the world using a physical scientific model? Students develop a model for the

surface structures, plates, plate interactions, and Earth's layers in a particular region of the world. They develop the model in cycles, changing it as they engage in the unit's lessons, collect, and understand new evidence. For each version of the model, students report their rationale, the ideas they want to convey, and their evidence. In the end, the class shares the models and students look for global patterns. What students build in this investigation is more than a display or art project. A physical scientific model is a tool used in the scientific process of asking questions, using evidence to test ideas, and modifying explanations. Students go through several cycles of collecting evidence, forming ideas, and revising their models in an effort to communicate their ideas accurately and effectively.

- ***What is a scientific model and how can it help students understand Plate Tectonics?***

Understanding the concepts involved in knowing that “The solid crust of the earth—including both the continents and the ocean basins—consists of separate plates that ride on a denser, hot, gradually deformable layer of the earth. (AAAS, 1993)” requires students to grasp a number of abstract ideas. The sequence in this unit in which students build and revise a model makes these abstract ideas more concretely tied to Earth's surface features and processes.

Throughout the unit, students use evidence to evaluate and modify their models, and they interact with newly developed concepts by applying them to a real region of the world. The model provides a concrete example for students to interact with and apply their understanding of new evidence to as it is introduced throughout the unit.

In addition to supporting their understanding of Plate Tectonics, engaging in modeling provides students with an opportunity to practice what scientists do: use models to build scientific explanations. Models help scientists understand natural phenomena that may not be easy to observe or manipulate directly.

- ***How will you help students achieve success with the model-based investigation?***

Allow the model to begin as a simple representation and change over time to become a more complex scientific model. The first model will likely show only surface features like mountain ranges and valleys. Then, as students learn about areas of seismic and volcanic activity and plate boundaries, they are guided to inquire of their model, “Does this model explain all the scientific evidence I know about land formation in the region being modeled?” Based on that question, students revise their models to include explanations for newly learned evidence, such as where seismic and volcanic activity are located in their region. Similarly, when they learn about Earth's interior structure, they could, for example, revise the model so it describes how convection currents cause the plates in their region to move.

- ***How will you help students organize and reflect on their progress with modeling***

As students gain knowledge about plate tectonics, they re-evaluate their model, add to and modify it to reflect how their region's landforms have been influenced over time. To help them organize and understand this process, students create a collection of student pages titled *Developing My Scientific Model*, which they complete with each new version of the model. These pages provide space for the students' thoughts about the following four questions:

1. What new evidence did I learn that called for me to change my model to improve its scientific accuracy?
2. How does my model explain what we observe about Earth's surface in my region?
3. What are the limitations of my model for explaining what we observe about Earth's surface?
4. What things does my model do a good job of explaining? What ideas do the different pieces of my model represent?

The pages provide a tool to guide students to revise and then self-reflect on the models. They also provide teachers with an opportunity to check for developing conceptual understanding around the processes of plate tectonics and the importance of models in the nature of science. The student's ability to state the strengths and limitations of a model are as important as the model itself.

The progression of model development through the unit is designed so that students will likely make choices in model construction that may require them to significantly revise the model when they learn additional evidence. It is important during instruction to explain to students that real scientific models, like the ones they are building, *change* as new evidence is brought to bear on a problem or question. It is important to help students resist becoming too attached to a “pretty” model and for them not to view a revision as a penalty for having done something wrong. It is equally important to guide the revisions as a scientific inquiry by prompting students to ask questions of their model, like:

- Does the model accurately explain the evidence for Earth's surface features and processes in that region? If so, how? If not, what are some limitations to the model?

The cycle of learning about new evidence for landform development and then inquiring if the model accounts for the new evidence is repeated as students develop a rich understanding of plate

tectonics throughout this unit. The modeling inquiry continues in parallel with the guided inquiry found in each lesson. In a culminating presentation of all the class' models, students develop scientifically-oriented explanations for the landforms in the unit's world regions. Finally, students use what they learn from each of these representational regions to explain landform formation in an entirely new (but familiar) region—California.

***Exploring Earth's Surface* Unit Level Graphic Organizer**

Many lines of evidence work together to explain the formation of Earth's surface features. This unit uses a graphic organizer to help students visualize how all this evidence fits together. Students also use the organizer as a starting place for revising their models. In the final step, students use this graphic organizer to gather their learning to explain two California landforms not previously discussed. The *Exploring Earth's Surface* graphic organizer is used throughout the unit, and evolves as students gather more evidence that support understanding tectonic processes.

The example below shows how the Unit Level Graphic Organizer may look at the end of this unit. (Note: In the Implementation Guide for each lesson that references the chart, there is an example chart that illustrates how the chart may look at that specific point in the unit.)

Exploring Earth's Surface

What did we observe about Earth's surface today?	How were those observations made by scientists?	What can we learn from those observations?
We saw mountains, valleys, and oceans.	First-hand observations, still and video cameras.	Earth's landforms are different in different places.
Sometimes the ground shakes.	First-hand observations, seismometer recordings.	Earth's surface can move suddenly.
We saw damaged buildings and roads.	First-hand observations, photos of damage.	
Locations of earthquakes and volcanic eruptions.	Seismometers (and computers for display).	Earthquakes and volcanic eruptions happen in similar locations.
		Earthquakes and volcanic eruptions happen mostly in particular regions around the world.
Land moves slowly.	GPS stations and satellites.	Parts of Earth's surface move slowly all the time.
		Earth's surface is broken into large pieces called plates.
Locations of fossils on several continents.	Geologists collect fossils from the field.	Continents used to be closer to each other and connected.
		Continents now in one climate have been in extremely different climates in the past.
Locations of types of rock on several continents.	Geologists collect rocks from the field and analyze them.	Continents used to be closer to each other and connected.
Earth gets hot as you go into the crust.	Core samples, deep mine shafts.	Inside of Earth is hot, unlike the surface.
There are no S waves in some places on the opposite side of the world from an earthquake focus.	Seismograph readings.	Part of Earth's interior is liquid.
		Earth has layers with different physical and chemical properties.
Some plates slowly move away from each other; There are fissures, volcanoes, and earthquakes where this happens.	GPS data, photographs, seismic data.	At divergent plate boundaries new rock "fills the gap" and pushes older rock away.
Some plates slowly move towards each other; There are mountains and earthquakes where this happens if both plates are continental crust	GPS data, photographs, seismic data.	At convergent plate boundaries (continental-continental), old rock is pushed up (and down) and makes mountains and high plateaus.

Some plates slowly move towards each other; There are mountains, volcanoes, deep trenches, and earthquakes where this happens if the plates are both oceanic or if one is oceanic and one is continental	GPS data, photographs, seismic data	At convergent plate boundaries (oceanic-oceanic or oceanic-continental), old rock is pulled down in a subduction zone
Some plates slide sideways past each other. This can produce earthquakes and mountains.	GPS data, photographs of surface faults	Plates are not restricted to moving perpendicular to one another. Places where plates grind past one another are called transform plate boundaries.

Support Materials

Immersion Unit Toolbox and CD

The Immersion Unit Toolbox is central to this curriculum. It is a separate guidebook that discusses the concepts inherent in teaching science through immersion units. These concepts include engaging in scientifically oriented questions, giving priority to evidence in responding to questions, and formulating explanations from evidence.

The Toolbox also describes several pedagogical approaches (Think-Aloud strategies, for example) that are key to how these units work. Most of the strategies in the Immersion Unit Toolbox support student engagement in scientific inquiry based on the Five Essential Features of Classroom Inquiry (NRC, 2000).

Before you use *Exploring Earth: Plate Tectonics*, it is recommended to read and become familiar with the concepts addressed in the Immersion Unit Toolbox.

This Immersion Unit comes with a data CD containing multimedia files for use at various points throughout the unit. It also contains resources and links to reputable Web sites that students can use during their region investigation. A CD icon in this unit highlights the points where many of these materials are referenced in the lessons.

Here is a brief overview of some of the strategies you can use in your classroom.

Science Inquiry Map

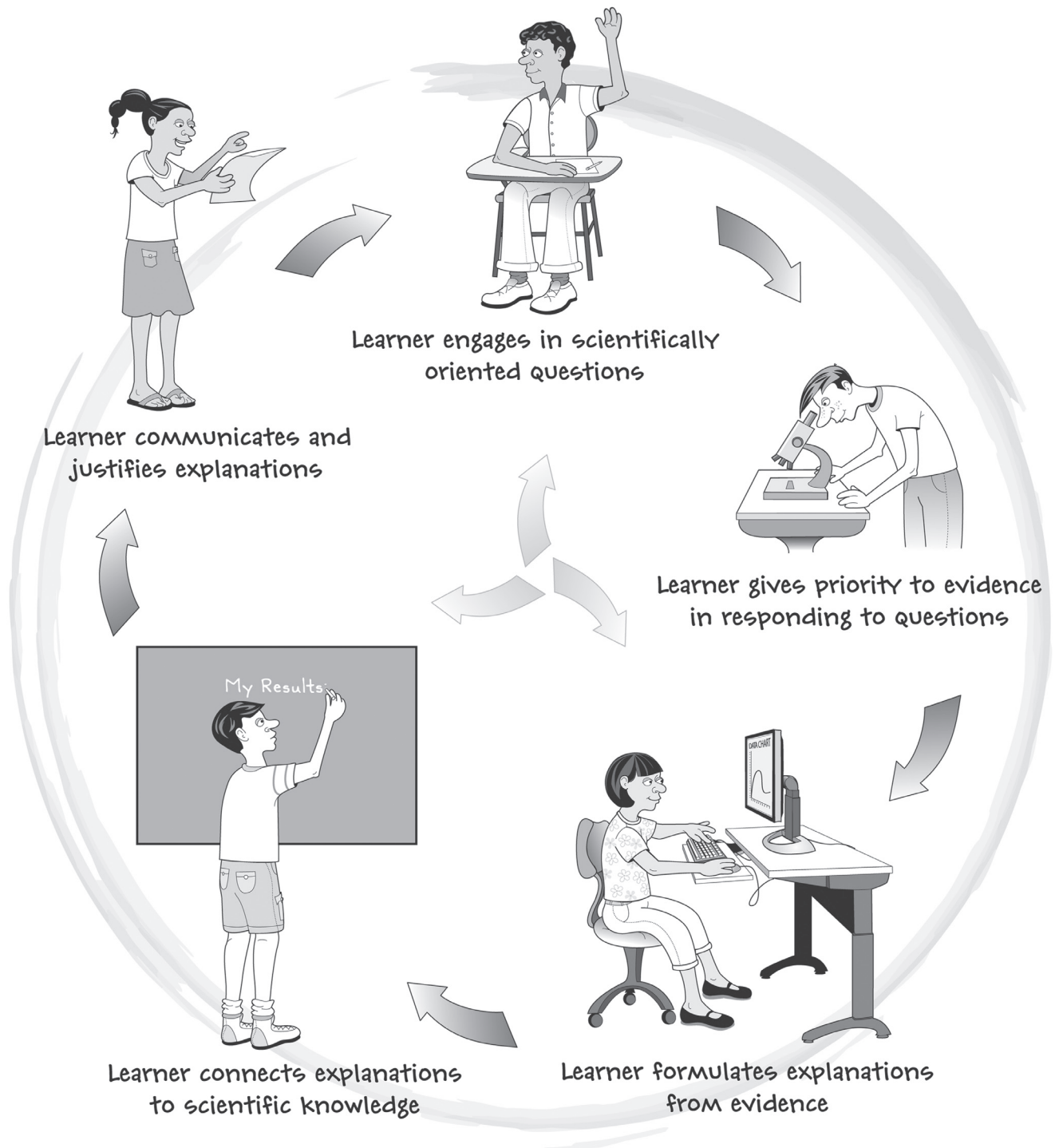
The Science Inquiry Map on the following page illustrates the Five Essential Features of Inquiry. You can use this map in your classroom when you introduce Immersion Units to your students.

The science inquiry process is dynamic and does not necessarily follow a linear order. For example, a student may develop an explanation that leads to a new scientific question, or that student may revisit evidence in light of alternative explanations. On some occasions multiple features of an explanation may overlap, or, depending on the type of lesson, some features may have more emphasis than others. These variations allow learners the freedom to inquire, experience, and understand scientific knowledge. The Five Essential Features of Inquiry describe how engaging in science inquiry unfolds in the classroom.

Student Groups

In this unit, students often work in groups. When working as a team in a group, the ideal is to have groups no larger than four students. Whatever the group size is, all students in the team need to have a job to do so they are individually accountable for focusing on the current science lesson. When assigning groups, keep in mind that the students will remain in the same groups for the duration of the region investigation throughout the unit. More information and suggestions for choosing groups is provided in specific lesson implementation guides.

SCIENCE INQUIRY MAP



Adapted from the National Research Council. 2000: Inquiry and the National Science Education Standards. Washington D.C.: National Academy Press

SCALE
SYSTEM-WIDE CHANGE FOR ALL LEARNERS AND EDUCATORS

Think-Aloud Strategies

Exploring Earth: Plate Tectonics uses Think-Aloud strategies throughout the unit. The Think Aloud is a teaching strategy whereby the teacher makes important thinking and reasoning processes explicit for learners by describing aloud the thinking process involved in a certain activity. Example Think-Aloud dialogs are included in most of the lessons.

Think-Pair-Share

Think-Pair-Share is a cooperative learning technique that allows students to think before they respond to a prompt, to test their response on their partner, and then to share their response (possibly revised) with a larger group. Specific instructions for implementing the Think-Pair-Share strategy are discussed in the Immersion Unit Toolbox. *Exploring Earth: Plate Tectonics* uses this technique throughout the unit.

REAPS

REAPS is a method of formative assessment that combines the time-tested ideas of Bloom's Taxonomy with new research on student assessment. The level of thinking increases from basic recall to complex analysis and predictions. On each Lesson Snapshot page is a series of REAPS prompts. This series of prompts is a simple tool that can be used throughout or at the end of each lesson. They can be used individually, in pairs or in groups to review what students know and are able to do. This provides an opportunity for the teacher to modify instruction as necessary based on student responses.

Here are the types of prompts included in the REAPS.

- R Recall** new knowledge: Determines whether the student has learned the basic knowledge that is related to and supports the key concept including lists, drawings, diagrams, definitions.
- E Extend** new knowledge: Determines whether the student can organize the basic knowledge related to the key concept such as compare, contrast, classify.
- A Analyze** knowledge: Encourages the student to apply or interpret what they have learned including developing questions, designing investigations, interpreting data.
- P Predict** something related to new knowledge: Engages the student in thinking about probable outcomes based on observations and to engage them in a new topic that builds on prior knowledge.
- S Self/Peer Assess:** Encourages students to take responsibility for their own learning. Includes methods and/or activities for students to assess their own learning and/or that of their peers.

The prompts increase in cognitive difficulty with Recall as the easiest and Predict as usually the most advanced. Students most likely demonstrate confidence and ability when responding to the first few prompts, while demonstrating continuous improvement in responding to the Analyze and Predict prompts. Students are not expected to master all of the skills, but are encouraged to extend their thinking.

Suggested responses are included in roman type after the boldface prompts. More detailed responses are included in the implementation guides for each lesson. While these are good responses, other responses may be valid with supportive evidence and reasoning.

Region Description Chart

Region # and name	Location (coordinates)	Plates and Boundary Type	Key Features of Region	Considerations for Student Investigations
1. Chile/West coast of South America	70 W to 80 W 20 S to 60 S	Nazca & S. American Convergent/ subduction zone	Andes Mountains; Peru-Chile Trench; large earthquakes	Supported in Step 6 of unit
2. Pacific Northwest United States	118 W to 130 W 45 N to 50 N	N. American & Juan de Fuca Convergent/ subduction zone	Volcanoes: Mt. Hood, Mt. Rainier, Mt. St. Helens;	Additional resources readily available, especially through USGS
3. Japan	125 E to 148 E 30 N to 48 N	Pacific, Eurasian, & Philippine Convergent/ subduction zone	Volcanoes: Fuji, Unzen, and others; Japan trench	No special considerations
4. Mariana Islands	140 E to 150 E 10 N to 25 N	Pacific & Philippine Convergent/ subduction zone	Mariana Trench, undersea ridge, island arc with volcanoes	Additional resources may be difficult to obtain for this region
5. Himalayas	70 E to 100 E 25 N to 40 N	Eurasian & Indian Convergent	Mt. Everest, High mountains and plateau	Used as a comparison region to CA in Step 7
6. Iceland	30 W to 0 60 N to 70 N	N. American & Eurasian Divergent	Mid-Atlantic ridge above sea level, geothermal activity	Only region with divergent boundary
7. Sumatra/ Andaman Islands	90 E to 110 E 15 N to 10 S	Australian & Eurasian Convergent/ subduction zone	Large EQ and tsunami, mountains near coast	Additional resources available due to 2004 Indian Ocean Tsunami
8. Alaska	130 W to 180 W 50 N to 70 N	Pacific & N. American Convergent/ subduction zone	Island arcs, large EQ	Additional resources readily available, especially through USGS
9. California	114 W to 125 W 32 N to 42 N	Pacific & N. American Transform in south, Convergent/ subduction in north	Mountains, earthquakes, large fault and some volcanoes	Teacher's region and geology resources are readily available

STEP 1

Overview

This unit begins by engaging students in the varied geography and geology of the world. After viewing photographs and video and beginning to cooperatively study a specific region of the world, students have an opportunity to take ownership in their learning, knowing that they will become experts in their region. This initial exploration informs the design of a simple physical model of the region. The models are later revised and made more scientific throughout the unit and will ultimately be used to explain how plate tectonics shapes Earth's surface.

Step 1 Lesson 1 Snapshot

Key Concept

- Regions of the world have diverse landforms that we can learn about by studying maps and photographs and by making observations.

Evidence of Student Understanding

The student will be able to:

- identify what a landform is and provide examples of common landforms;
- recognize that different places in the world have different landforms.

Time Needed

50 minutes (with suggested breakpoint)

Materials

For the class

- 3-piece world wall map, cut into pieces based on regions (see World Map Cutting Key as an example) 
- 1-piece world wall map 
- Step 1 landforms slideshow 
- computer and projector or other technology for displaying slideshow from the Unit's CD
- overhead transparency or chart paper like *Teacher Page 1.1b: Frayer Model Example*

For each region group of 3-5 students

- region coordinates slip from *Teacher Page 1.1c: Coordinates Slips*
- 1 **color** copy per group of their assigned Region Reading

(continued on following page)

Exploring Earth's Surface

1. Have pairs of students construct a Frayer Model graphic organizer like the sample on *Teacher Page 1.1b: Frayer Model Example* to introduce the definition of a landform and find out what students already know about landforms.

- Use the students' ideas to develop a class Frayer Model.

2. Introduce the Science Notebooks and your particular notebook procedure that students will use throughout this unit (see suggestions in the Immersion Unit Toolbox).

(continued on following page)

REAPS Questions

R What is a landform? A landform is a natural feature of the surface of Earth.

E Describe how landforms are different from place to place on Earth. Answers will vary. Example: Some places have high mountain ranges while others have deep trenches under the ocean.

A What kinds of things, besides landforms, are different in different places on Earth? Answers will vary but can include altitude, temperature, climate, or vegetation, for example.

P What do you think causes certain landforms to be in some places and not others? This question engages students' preconceptions about how landforms develop. Accept all answers and ask questions to clarify and assess what students are thinking.

S On an index card, write down what three regions you are most interested in and, in a sentence or two, describe what makes them interesting to you. When you are finished, give the card to your teacher.

(continued from previous page)

For pairs of students

- chart paper or other means for making Landform Frayer Models
- markers

For each student

- 1 **black and white** copy of the Region Reading for their group (alternatively, provide all students with a color copy of the region if possible)
- 1 copy of *Student Page 1.1A: World Political Map*
- science notebook (to be used throughout unit)
- 1 index card

(continued from previous page)

3. Present slideshow of photos and video clips about landforms and other engaging information about the regions of the world the class will study.

- Use a rapid and engaging approach to hook students' attention, and resist the temptation to explain images.

4. Revisit the class' Frayer Model about landforms and add any new ideas that students may have after watching the slideshow.

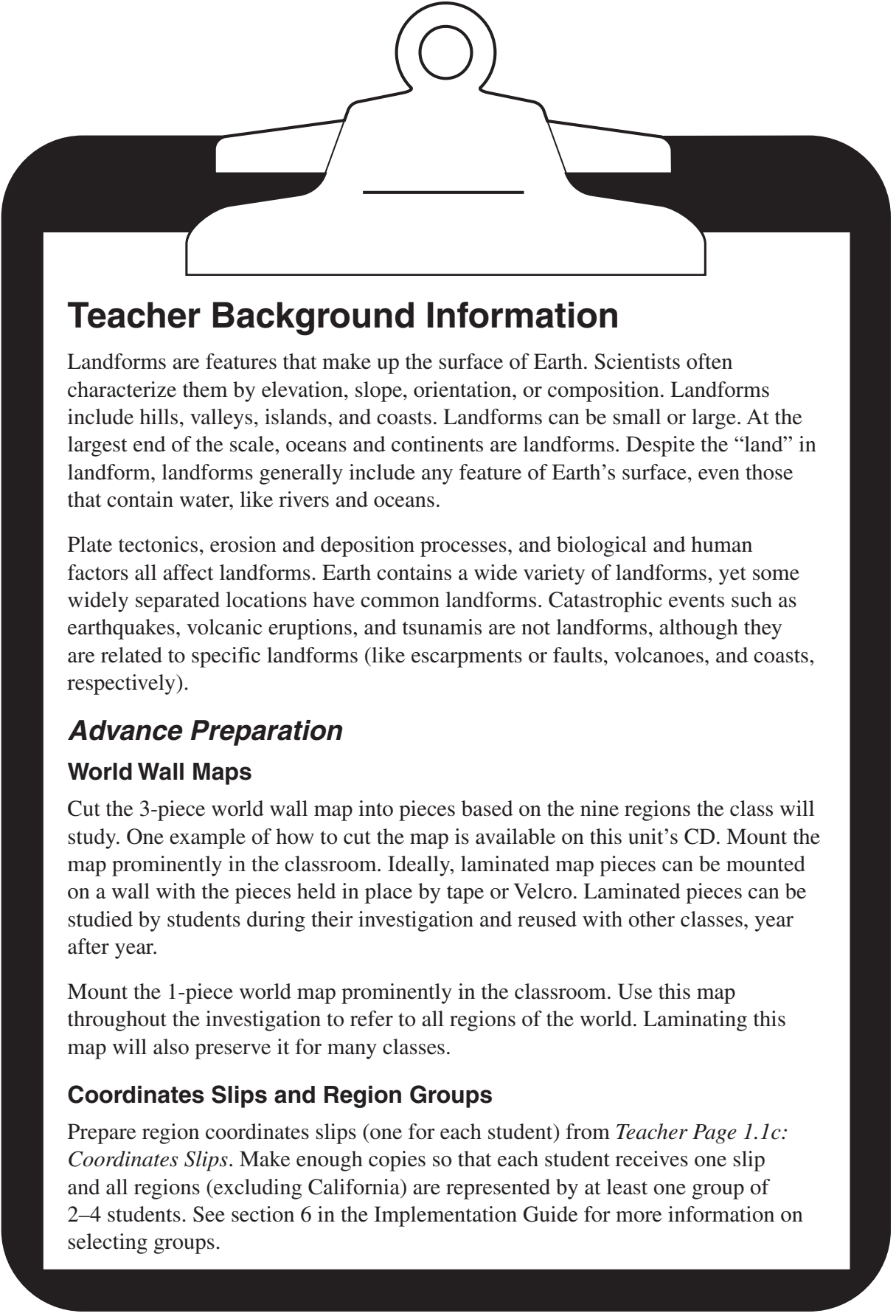
5. Use the REAPS questions to informally learn what students already know about landforms and the diversity of landforms on Earth.

- The "S" question gives information about the three regions students find most interesting to help with assigning regions.

6. Strategically assign groups of 3-5 students to study one of eight regions of the world using the coordinates slips on *Teacher Page 1.1c: Coordinates Slips*.

7. Direct each group to find their region on the world maps and/or *Student Page 1.1A: World Political Map* and take the corresponding piece(s) of the 3-piece world map.

8. Have students read the appropriate *Region Reading* provided in this unit. After reading, allow students to discuss the information they read with the other students who share the same region.



Teacher Background Information

Landforms are features that make up the surface of Earth. Scientists often characterize them by elevation, slope, orientation, or composition. Landforms include hills, valleys, islands, and coasts. Landforms can be small or large. At the largest end of the scale, oceans and continents are landforms. Despite the “land” in landform, landforms generally include any feature of Earth’s surface, even those that contain water, like rivers and oceans.

Plate tectonics, erosion and deposition processes, and biological and human factors all affect landforms. Earth contains a wide variety of landforms, yet some widely separated locations have common landforms. Catastrophic events such as earthquakes, volcanic eruptions, and tsunamis are not landforms, although they are related to specific landforms (like escarpments or faults, volcanoes, and coasts, respectively).

Advance Preparation

World Wall Maps

Cut the 3-piece world wall map into pieces based on the nine regions the class will study. One example of how to cut the map is available on this unit’s CD. Mount the map prominently in the classroom. Ideally, laminated map pieces can be mounted on a wall with the pieces held in place by tape or Velcro. Laminated pieces can be studied by students during their investigation and reused with other classes, year after year.

Mount the 1-piece world map prominently in the classroom. Use this map throughout the investigation to refer to all regions of the world. Laminating this map will also preserve it for many classes.

Coordinates Slips and Region Groups

Prepare region coordinates slips (one for each student) from *Teacher Page 1.1c: Coordinates Slips*. Make enough copies so that each student receives one slip and all regions (excluding California) are represented by at least one group of 2–4 students. See section 6 in the Implementation Guide for more information on selecting groups.

Implementation Guide

1. To elicit students' prior knowledge about Earth's landforms, begin with an activity using a Frayer Model. A Frayer Model is a graphic organizer originally developed to help students learn vocabulary. Here, it is a tool used to activate students' prior knowledge about landforms. Follow the sample on *Teacher Page 1.1b: Frayer Model Example*. Provide the definition of a landform in the top-left quadrant, and explain what types of things need to be in each box. Alternatively, work as a class to complete a Frayer Model on a term students are familiar with like "Holiday" or "Good Behavior". In pairs, have students take a few minutes to fill the "Characteristics", "Examples", and "Non-Examples" quadrants for their Landform Frayer Model.

- In this first engagement activity for the unit, the purpose of the Frayer Model is to start students thinking about a central aspect of the unit and show what they know at this point, NOT to explain what a landform is—that will come later. For now, have students fill in the quadrants based on their own prior knowledge and conceptions.

Circulate among the pairs; listen to what students are saying, and look for what they are writing in the quadrants. Notice any common misconceptions about landforms. For example, if a pair writes "skyscrapers" in the "Examples" quadrant, later in the lesson, once students have explored the slideshow of landforms, describe how the term *landform* refers to natural, not human-made, features.

After about 5 minutes, ask the pairs to share some of what they wrote down. On an overhead transparency or piece of chart paper, create a class Frayer Model from the collective responses. The goal here is to determine what students already know. The landform Frayer Model will likely have some inaccuracies. Address these when students revisit the model after the slideshow.

2. Set guidelines for using Science Notebooks and explain to students that they will use them throughout this unit to record questions, observations, procedures, explanations, diagrams, worksheets, and other work. Suggestions for how to establish criteria for notebook entries are included in the Immersion Unit Toolbox.

- Emphasize that at this point Science Notebooks are a place for students to record their wonderings and initial ideas.
- The Notebooks will include additional wonderings, responses to questions such as the REAPS, and scientific observations as the unit progresses.

3. **Note:** The slideshow contains some embedded links to video clips from a website called "Teachers' Domain," a non-profit repository of quality materials freely available for educational use. If possible, show the video clips where suggested in the slideshow. Internet access is required to show the video clips from the links, and you will need to register for a free account at www.teachersdomain.org.

The slideshow progresses from California to each region of the world that student groups will study in this unit. The California region is used as an example region for teacher Think Alouds and demonstrations for how to construct and revise scientific models throughout the unit. (Note: More about Think Alouds is included in both the Immersion Unit Toolbox and the lesson implementation guides in this unit where they appear as a recommended strategy to help students develop critical thinking skills.)

Present the slide show for Step 1 from this Unit's CD to generate student interest in the regions selected for study in this unit. As students make comments and watch the images, instruct them to write down what grabs their attention about particular regions in their Science Notebooks. Explain that they will have to choose three of their favorite regions (excluding California), one of which they will study in a group for the duration of the unit.

4. After viewing the slideshow, revisit the class' Landform Frayer Model and address any inaccuracies or missing information. Prompt students with questions like:

- Did you see anything in the slideshow that reminded you of something that could help us improve our Frayer Model?
- What examples of landforms did you see in the slideshow that you didn't think of before?
- Did we list any examples that also appeared in the slideshow? Did we list any that did not appear in the slideshow?
- Are all of our examples actually landforms, or do some belong in the non-examples box?

The developers recommend taking a picture of the class' Frayer Model when it is finished, if possible, to "capture the moment" and use it later in the *Exploring Earth's Surface* unit-level graphic organizer (introduced in the next lesson) to remind students what they did when they started this unit and what they initially thought about landforms.

5. Use the REAPS questions to review what students know about landforms, the diversity of landforms on Earth, and for students to choose their top three regions. Students can record these questions and their responses in their Science Notebooks. Have each student write their three favorite region names on an index card and collect them.

6. Consider allowing students to do other work or stop the lesson here to allow yourself time to strategically assign regions to students. Divide the class into groups of 2-4 students and assign regions of the world based, as much as possible, on student choices, but also considering group dynamics and the geologic complexity of each region.

Each region varies in how difficult it is to comprehend the region reading and/or find additional resources about the region. This allows for differentiation based on students with

different abilities. The *Region Description Chart* (see Unit Overview) provides information about the challenges and opportunities associated with studying each region.

7. Provide each student with the appropriate "coordinates slip" for their region of the world. These slips are found on *Teacher Page 1.1c: Coordinates Slips*.

- Keep in mind that no group will be assigned California. Instead, it will be used as the class example for teacher demonstrations and Think Alouds.

Students can use *Student Page 1.1A: World Political Map* and/or the wall maps to locate their region. Once students have located their region, ask them to locate the other students who have the same region, take the corresponding piece(s) of the 3-piece world wall map containing that region's coordinates for their group, and gather together. It may be necessary to support map skills at this point with additional activities about maps and/or latitude and longitude.

8. Distribute the appropriate *Region Reading* to each group.

- There are 8 *Region Readings* (plus the California reading for use as an example). Divide the class evenly into groups to receive each reading.

Explain that these readings provide information about landforms, catastrophic events, unusual features, and human-interest stories. Instruct students to read their region's essay.

Decide in advance an appropriate reading strategy for your students. For example, you may wish to have pairs read aloud parts of the reading to each other or have students first read individually. After reading, have students work individually to record in their Science Notebooks at least three questions that the reading raised for them. Questions might look something like:

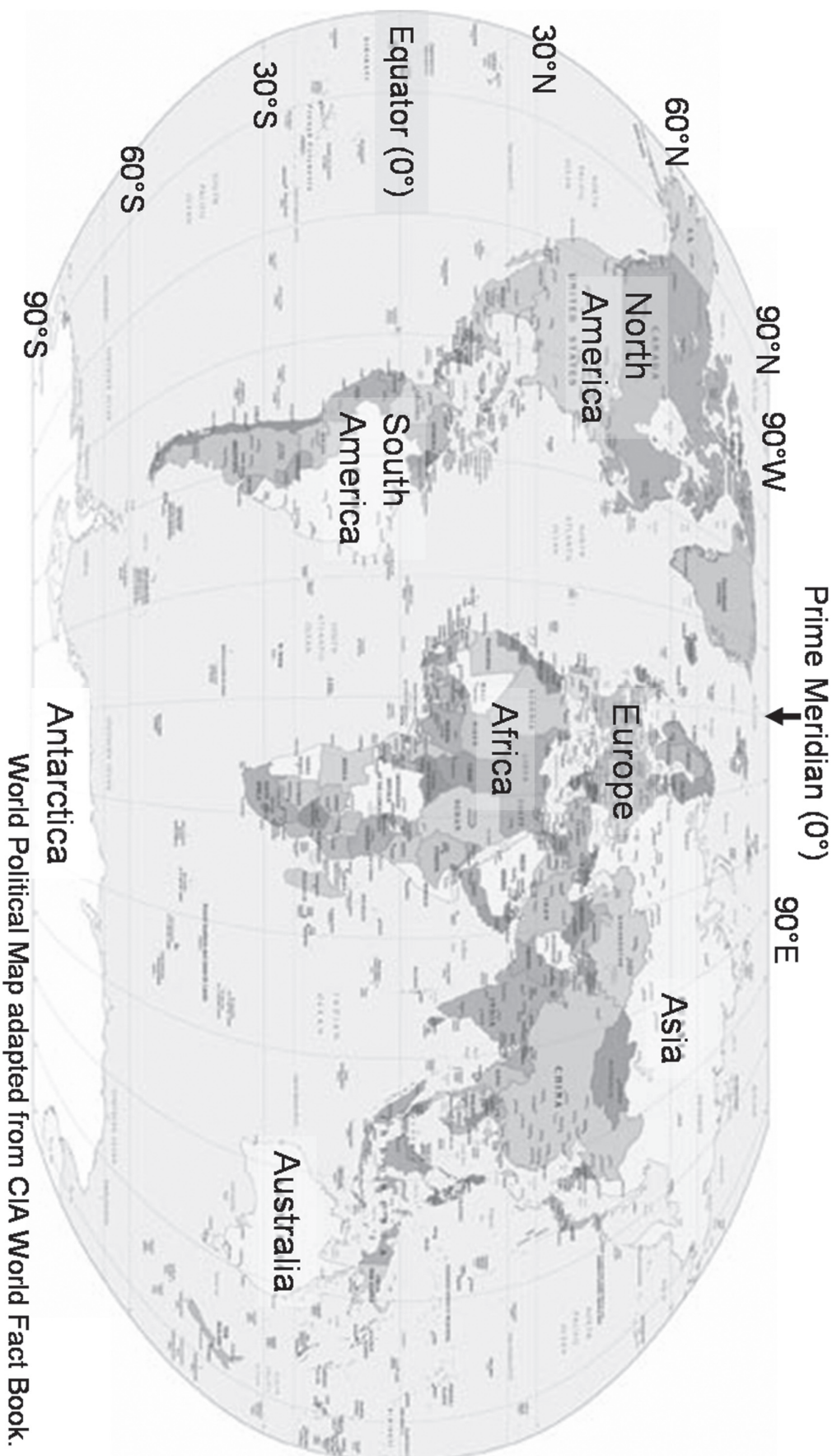
- What makes this region special or different?

- Do catastrophic events happen here?
- I want to know more about X in this region.

Encourage students to share their initial questions with their group and add questions if the group discussion leads to additional wonderings.

(Note: There are more resources provided on the Unit's CD for exploring each region further; however, information about the regions is **purposely limited** at this point so that students will see how collecting additional evidence influences possible scientific explanations later in the unit. Later in the unit, students can use these resources to find out more about their region.)

Student Page 1.1A: World Political Map



Teacher Page 1.1b: Landform Frayer Model Example

Definition:

(Noun) One of the features that make up Earth's surface.

Characteristics:

Contains earth (dirt, rock, sand, etc.); has some elevation, slope, and/or orientation.

Landform

Examples:

Berm
Mound
Hill
Cliff
Valley
Coast
Ocean
Continent

Non-Examples:

Avalanche
earthquake
tree
skyscraper

Teacher Page 1.1c: Region Coordinates Slips

Region 1 Latitude: 20 S to 60 S Longitude: 70 W to 80 W	Region 2 Latitude: 45 N to 50 N Longitude: 118 W to 130 W
Region 3 Latitude: 30 N to 48 N Longitude: 125 E to 148 E	Region 4 Latitude: 10 N to 25 N Longitude: 140 E to 150 E
Region 5 Latitude: 25 N to 40 N Longitude: 70 E to 100 E	Region 6 Latitude: 60 N to 70 N Longitude: 30 W to 0
Region 7 Latitude: 15 N to 10 S Longitude: 90 E to 110 E	Region 8 Latitude: 50 N to 70 N Longitude: 130 W to 180 W

Step 1 Lesson 2 Snapshot

Key Concept

- Scientists support their ideas with evidence such as facts found in books or articles, observations, and results of investigations.

Evidence of Student Understanding

The student will be able to:

- separate scientific evidence related to Earth's landforms from other interesting information in a reading;
- build a simple physical representation of Earth's surface in a specific region of the world;
- recognize that they are working like scientists by gathering evidence and creating models.

Time Needed

35 minutes

Materials

For the class

- 1 overhead transparency of *Student Page 1.2A: Evidence Separation Chart*
- 1 overhead transparency of *California Region Reading*

For each region group of 2–4 students

- variety of modeling materials (can include modeling clay, paper/cardboard products, cups, straws, cotton balls or other soft materials, etc.)

For each student

- 1 copy of *Student Page 1.2A: Evidence Separation Chart*

Modeling Earth's Surface

1. Preview the unit goals for students and introduce the graphic organizer, *Exploring Earth's Surface*. Work as a class to record a few lines on the chart based on what students learned in the first lesson.

2. Read the California *Region Reading* aloud and have students follow along.

- The California region is an example that is used throughout the unit.
- As you review the California Region Reading, explain how you look for evidence about landforms.

(continued on following page)

REAPS Questions

R List some of the evidence for landforms described in your region's reading.

Answers will vary, and evidence will come directly from the Region Readings.

E Describe how one part of your model represents a landform in the real world.

Answers will vary. Example: This egg carton, with the spacers removed, represents a deep ocean trench.

A What similarities or differences do you notice between the landforms in your region and the California region?

Answers will vary, and need to be based on the maps or Region Readings.

P How might you make something about your model more accurate? Students could measure the length and height of this cardboard piece, which represents a mountain range, and make sure that ratio is the same as what it shows on the map.

S Complete this sentence and write it in your Science Notebook: "I acted like a scientist today when I..." Example: ... reviewed my region's article and looked for evidence of landforms in my region.

3. Use an overhead of *Student Page 1.2A: Evidence Separation Chart* to demonstrate how to separate and record evidence related to Earth's surface and other interesting information based on the California *Region Reading*.

- Explain how this evidence will be important information that will be used to make physical models of the regions.
- Provide students with a copy of *Student Page 1.2A: Evidence Separation Chart* and have them work individually or in pairs to repeat the evidence separation process for their assigned region.

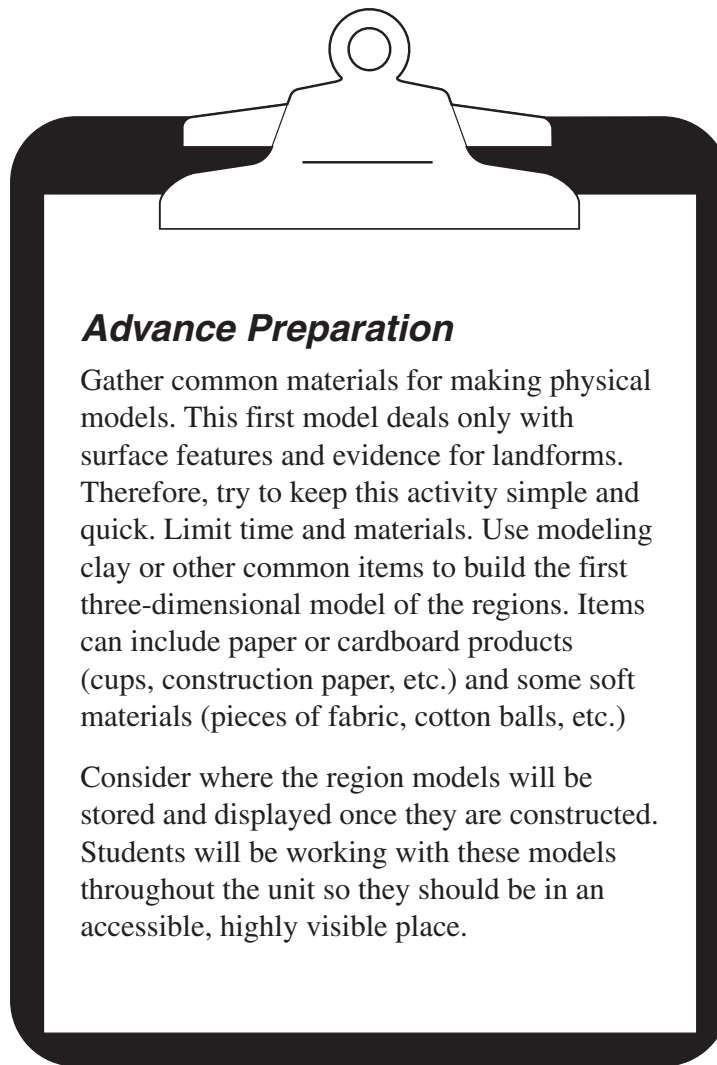
4. Once students are finished completing their Evidence Charts, use a Think Aloud to demonstrate how to begin the modeling process for California.

- Focus on landforms, and repeatedly seek and reference evidence from the map and region reading.

5. Allow student groups to design and build a very simple physical model of their region.

- Emphasize that this is their first version of the model and will be revised as new evidence is gathered.
- Limit the amount of time so that students do not become too invested in this first model version.

6. Use the REAPS throughout and after the lesson as appropriate.



Advance Preparation

Gather common materials for making physical models. This first model deals only with surface features and evidence for landforms. Therefore, try to keep this activity simple and quick. Limit time and materials. Use modeling clay or other common items to build the first three-dimensional model of the regions. Items can include paper or cardboard products (cups, construction paper, etc.) and some soft materials (pieces of fabric, cotton balls, etc.)

Consider where the region models will be stored and displayed once they are constructed. Students will be working with these models throughout the unit so they should be in an accessible, highly visible place.

Implementation Guide

1. Now that students have engaged in looking at some of the landforms and other interesting aspects of their region of the world, explain that each group will develop a scientific explanation for the landforms in their region by the end of the unit. Their explanation will involve creating and revising a physical model of their region and presenting it to the class to teach classmates about the region. The goal of this unit is to help students develop an explanation about how Earth’s surface forms and changes.

Explain to students that scientific explanations, like the ones they will be making, are based on evidence and logical reasoning. The more types of and amount of evidence there is to support an explanation, the stronger it is. Since they will be behaving like scientists during this unit, students are expected to collect and record evidence about Earth’s surface. To help keep this evidence organized and useful, students will use a graphic organizer kept in a Science Notebook to record evidence at points throughout the unit.

When introducing the Exploring Earth’s Surface graphic organizer, describe how the columns in this chart will be used to organize information about

- types of evidence,
- how each type of evidence is collected, and

- what the evidence tells them about Earth’s surface.

This chart will be completed as the unit progresses.

In this lesson, the implications of the evidence merely set the stage for trying to answer the overarching question, “What do scientists use to explain what we observe about Earth’s surface?” That is, it helps us recognize there is a problem to solve (Why is Earth’s surface the way it is?) and motivates us to want to study it in an organized way.

Ask students to think back to the first lesson in this unit and add as much information as appropriate at this early stage to their class chart. To guide students through this discussion, ask questions like:

- What kind of evidence did we learn about in lesson 1.1?
- How did we learn about that evidence? How was it collected?
- What did learning about these things tell us about Earth’s surface?

An example of how the *Exploring Earth’s Surface* Chart might look at this point in the unit follows.

Exploring Earth’s Surface

What did we observe about Earth’s surface today?	How were those observations made by scientists?	What can we learn from those observations?
We saw mountains, valleys, and oceans	First-hand observations, still and video cameras	Earth’s landforms are different in different places.

2. Remind students that in the last lesson they began to explore their region of the world by reading about the area. Explain that today they will continue to explore their region, but in a more scientific way. They will be focusing on evidence that will help them design and build a model of Earth's surface in their region. To set the stage for this process, the class will practice together using another region, California, as an example. Then, students will analyze their own region.

Begin by reading the California *Region Reading* aloud with an overhead displayed so students can see the images. Stop every few paragraphs and use the Think Aloud technique to explain how to navigate the region readings effectively.

3. Explain to students that their list of landform evidence will be used to begin building a model of their region (one per region group). After more evidence from the region is gathered and revisions are made to the model, it will ultimately be used to explain how the region's landforms developed and predict how they will change over time. Emphasize that this is an important start to an interesting and key part of this unit.

Continue using the Think Aloud technique to explain how to use the Evidence Separation Chart.

Example Think Aloud for Evidence Separation

As I read that section, I noticed that it contained a lot of information. Since we are investigating Earth's surface, I will need to figure out which parts of the reading contain information related to Earth's surface and which do not. To help keep my thinking and evidence organized, I will use this *Evidence Separation Chart*.

I'm going to write down anything from this paragraph that relates to Earth's surface in California on this side. If I read something that is interesting to me, but isn't related to Earth's surface and landforms, then I will write it down on the other side. Like a scientist, I will look back at our notes on landforms from the

last lesson to help me decide what is related to landforms and what isn't. I remember, I made notes in my Science Notebook and we made the Landform Frayer Model chart together.

Provide students with a copy of *Student Page 1.2A: Evidence Separation Chart* and allow students time to complete the student page in their region groups. They should work together to analyze the reading, yet each student should complete their own student page. Circulate among the groups to be sure students are accurately recording evidence for landforms and separating it from other interesting facts or human-interest stories. If some students have difficulty, ask them to think back to what you used as evidence during the Think Aloud (notes in Science Notebook and Landform Frayer Model), and use a similar strategy.

4. To help students create and revise their models throughout the unit, the class will practice together using California as an example, just as they did with the *Evidence Separation Chart*. In this lesson, the model will be very simple and needs to focus on basic information about the landforms. Be sure to emphasize how students will change their models multiple times, as they learn more about landforms and Earth's surface.

Use a Think Aloud to demonstrate how to begin the modeling process. Use a strategy similar to the one in the example below:

Example Think Aloud to Begin Modeling

I want to understand how the landforms in my region, California, developed over time and how they might change in the future. I know that scientists use models to explain things like this, so I'm going to make a model too. Right now, almost everything I know about my region comes from the article that I just read. That reading contains a lot of information!

I read about mountains, volcanoes, and other kinds of landforms. I also read about a big earthquake that happened in San Francisco

in 1906. Many people died in that event and many buildings were destroyed in fires. I used the *Evidence Separation Chart* to separate the information from the reading into two groups. Now I have a list of evidence for landforms in my region based on the reading. I also have a map of my region from the world wall map. This map shows me where some major landforms in my region are located.

Now I want to build a physical model with what I know about landforms in California. I will use some of these materials to represent the landforms. I will use a paper cup, placed upside down, to represent a mountain. Since Mt. Whitney is the tallest mountain in California, I will put the cup on a piece of cardboard and call it Mt. Whitney. I could use something else to represent it, but a cup seems easy to me. Next, I will use a piece of string to represent the coast of California along the Pacific Ocean. I will tape these items to this piece of cardboard and arrange them so they look somewhat like how the mountains and the coast look on my map. This model isn't very pretty or colorful, but I know it will change again, maybe several times, as I learn more about how to explain these landforms.

OK, I'm done! This is my first model of the landforms in California.

5. Provide an assortment of common materials and allow students to start designing and building a very simple physical model of their region (one per region group). Remember, this first model should focus on the region's landforms and WILL change as students learn more about plate tectonics.

At this point, the model simply represents landforms (concrete ideas), but later it will represent ideas that are more abstract and will better explain the region's landforms. Limit time and materials to keep this task simple and structured. Keeping the models from becoming art projects will help students let go of these original versions when it is time to revise and improve the models after uncovering more evidence in future lessons.

6. Use the REAPS throughout and after the lesson as appropriate. As students start building their region models, circulate among the groups and ask the Recall, Extend, and Analyze questions. Towards the end of the lesson, you could pose the Predict and Self-assess questions to the whole class as a homework assignment, a Quickwrite, or as an exit question.

Student Page 1.2A: Evidence Separation Chart

Evidence Separation Chart

There is a lot of information in your region reading. Some information is evidence for landforms. Some is not related to the landscape of your region. In the column on the left, write down things that you read about that relate to landforms. In the column on the right, list other things you read that are NOT related to landforms. After you do this, it will be easier to talk about the geology of your region.

Name: _____

Date: _____

evidence for landforms	other interesting facts

Latitude: 15S to 60S Longitude: 70W to 80W

Two great oceans, the Atlantic and Pacific, are separated by the continents of North and South America. How do ships get from one ocean to the other? Today they use a canal in Panama. But long ago they had to go around South America. The route was around the tip of Chile. It held great danger. Terrible storms rage in the open ocean between the southern tip of Chile and Antarctica. In 1520, the Spanish explorer Ferdinand Magellan discovered a slightly safer route. His ship sailed a narrow passage that cuts through the southern tip of Chile. It is now called the Strait of Magellan. It is a twisty and foggy passage. But it is safer than the open ocean.

Magellan was not the only explorer in this region. A recent explorer was very unusual: it was a robot named Nomad. Nomad was made for space



[Map adapted using ArcGIS/ArcMap software, ESRI World database.]

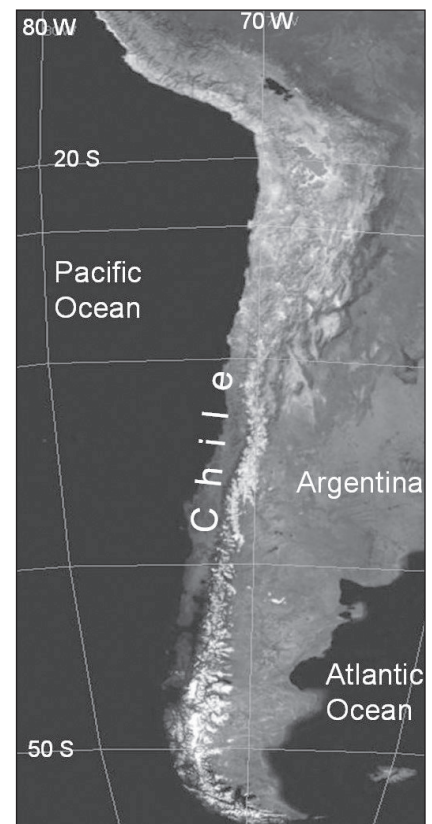
Region 1



Nomad in the Atacama Desert, Chile. [Photo © 1997 Carnegie Mellon/NASA, used with permission.]

exploration. It explored the region in the north, called the Atacama Desert. This is one of the driest spots on Earth. Scientists put Nomad in the desert to test how it might work on another planet. Scientists chose this spot because it is so dry and rugged that it is like another planet. This desert is located on the northwest coast of Chile. You can see it in this satellite image.

Why is the land so dry on the west here in the Atacama Desert? The key is in the high mountains to the east. This long, north-south range is called the Andes Range. It lies along



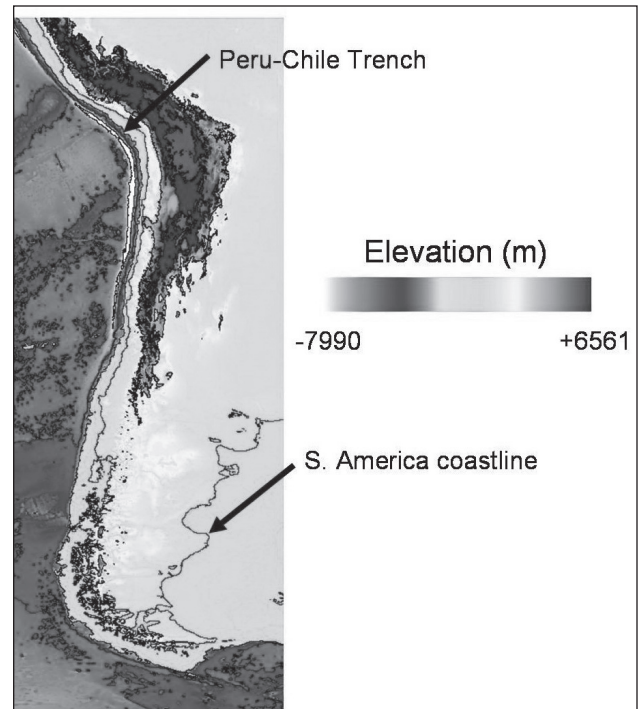
[Adapted using NASA World Wind software, NLT Landsat7 data.]



View of Aconcagua Peak in the Andes taken from an airplane. [Photo © Bill Caid, used with permission.]

the eastern border of Chile, running down the South American continent. The highest mountain in the Western Hemisphere is in Argentina, near the border with Chile. It is called Aconcagua. It is 6,960 meters tall. The Andes Range acts as a shield. It blocks wet air blown in from the Atlantic Ocean to the east. The wet air drops its water as rain in the area east of the mountains. The water does not make it over the mountains to the desert. Although the Atacama Desert is very dry, it is not hot. The high altitude makes it a cold desert.

In this region, there is also a very deep spot. It lies under the ocean 150 km west of Chile. Here the ocean is very deep. This is because of a deep gash in the ocean floor. This gash is called the Peru-Chile trench. It runs north-south following the line of the coast. It is 6 km deep! The image in the upper right shows this trench. It is a map of the height of the land and the depth of the sea compared to sea level (0 meters). The outline of South America is indicated on the image. The west coast of Chile has many small islands. In 1960, this was a very dangerous place to be. The biggest earthquake ever recorded happened here. It was a M9.5 quake. Many buildings were destroyed when the ground shook. There were huge landslides. And there was a huge wave called a tsunami. In some places, the tsunami was over 24 meters tall! That is taller than many buildings! Imagine living on an island off the coast of Chile during the



[Map adapted from NOAA/GEODAS ETOPO2 data using ArcGIS/ArcMap software.]

earthquake and tsunami. Here is a picture of what happened to houses in the coastal city of Valdivia.



[NOAA/NGDC photo by Pierre St. Amand]

Many people were saved because they knew to run up to the hills when the water began to pull out to sea as the tsunami started. The tsunami that followed the 1960 earthquake raced across the Pacific Ocean. It damaged things far away in Hawaii and Japan. On land in Chile, the earthquake ripped the ground along a north-south line (called a fault) almost 1000 km long!

Latitude: 45N to 50N Longitude: 120W to 130W

Region 2

In the early morning of May 18, 1980, a mountain exploded. It was Mount St. Helens in the state of Washington. The massive explosion blasted a shock wave of heat that traveled at 300 miles per hour. Ash and rock were thrown out of the mountain.



*Mt. St. Helens during the eruption.
[USGS photo by Austin Post]*



[USGS photo, Jan 14, 2005. Circle is where an instrument package (inset) was dropped to measure the volcanic activity. The package lasted 36 hours until it was destroyed in an explosion.]

The 1980 eruption started with a M5.1 earthquake. When it was over, the mountain was 400 meters shorter than the day before. Fifty-seven people died. Before the 1980 eruption, Mt. St. Helens was quiet for about 140 years. Recently, nearly 25 years after the 1980 explosion, Mt. St. Helens began a new kind of eruption. In September 2004, a swarm of tiny earthquakes announced an eruption. A giant lump of rock was pushed up from within the volcano. It is called a whaleback because it looks like a whale's back.

An eruption on another volcano in this region happened about 7000 years ago. What was left inside the mountain was a crater. It filled with water. This lake is now called Crater Lake. It is at the southern end of a range of volcanic mountains. They are called the Cascade Range. They contain 700 glaciers. This range stretches in a north-south line across Washington, Oregon and northern California. Some volcanic peaks in the Cascade Range are very close to large cities. Mount Rainier is very close to the city of Seattle, Washington. Over 1.5 million people live in Seattle. Mount



Mt. St. Helens after the eruption. [USGS photo by Lyn Topinka]



[Crater Lake, Oregon. USGS photo by W.E. Scott]



Mt. Hood and Portland, Oregon. [USGS photo by David. E. Wieprecht]

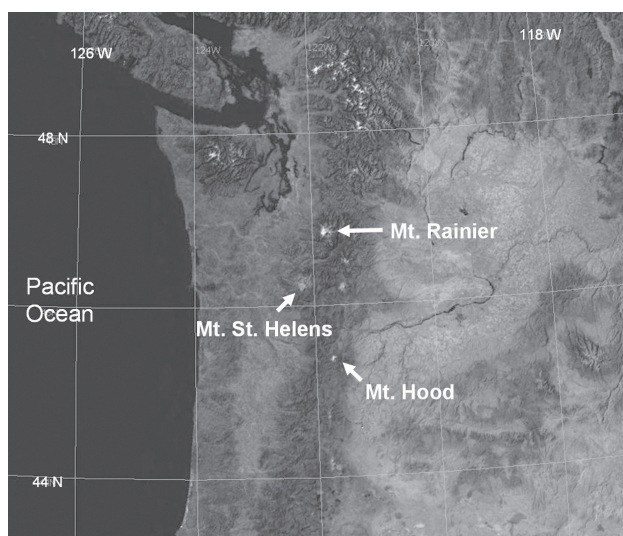
Hood is near the city of Portland, Oregon. Mt. Hood last erupted in 1865. Compare it to Mt. St. Helens. Could Mt. Hood violently erupt during your lifetime?

In the Pacific Northwest, not all interesting features are volcanoes. For example, directly west of Seattle is a very wet area. It includes the Olympic National Forest and the Olympic Mountains. In contrast, east of the Cascade Range in Washington, the land is dry. Seattle is a port city. It is located on a very large bay called Puget Sound. Many ocean-going ships come to this harbor from a long waterway that leads to the Pacific Ocean. This waterway is called the Strait of Juan de Fuca.

This image of the Pacific Northwest is made from data collected by a satellite. Compare it to the map at the right. Can you see the Olympic Mountains, Puget Sound and some of the Cascade Range volcanoes?



Olympic National Forest. [USGS photo]



[Image adapted using NASA World Wind software.]



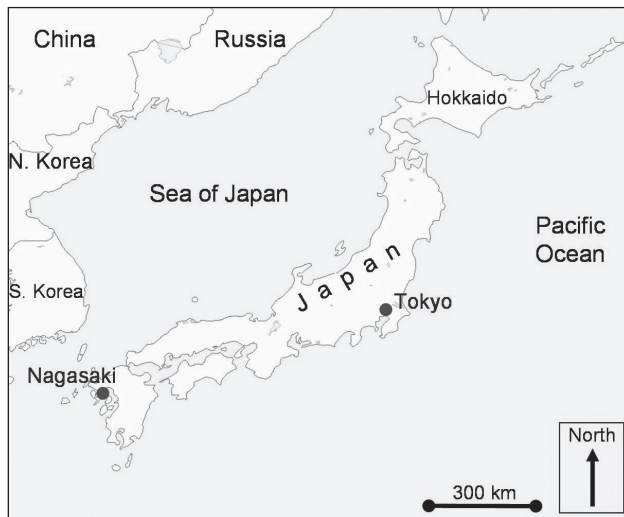
[Map adapted using ArcGIS/ArcMap software.]

Latitude: 30N to 48N Longitude: 125E to 148E

Region 3

Japan is a country made of many islands. No matter where you are in Japan, you are never far from the ocean. Japan is a country that has many contrasts. It has many miles of coastline but also has high mountain peaks. It is about the same size as California, but almost four times as many people live there. Even with so many people, forests cover most of the land in Japan. Half of the population lives in the three cities of Tokyo, Osaka, and Nagoya. Tokyo is the largest city in Japan, but is also one of the largest cities in the world!

Another interesting contrast is that Japan has very old things and very new things. Some of the oldest pottery in the world was made in Japan 12,000 years ago. Japan also has very advanced industries. Sony, Sega, and Nintendo are large electronics companies based in Japan. There are many coastlines in Japan. Because of this, many people make a living by fishing. This map shows that Japan is made of a long chain of islands.



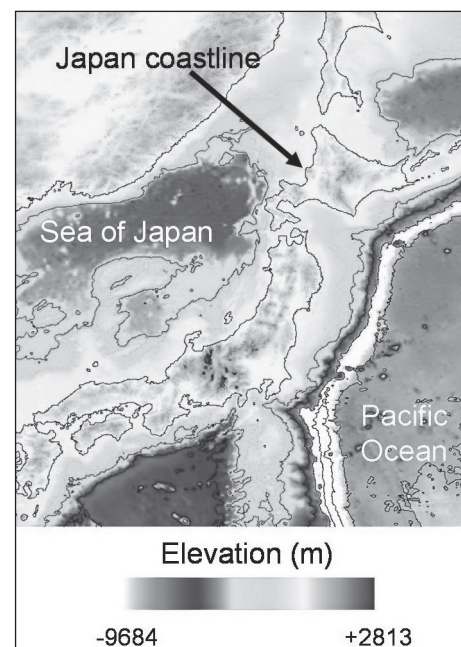
[Map adapted using ArcGIS/ArcMap software.]

The weather in southern Japan is warm and rainy. The northern part of Japan is much cooler. The temperature also is very different along the coast or up on a mountain. Typhoon is the Asian name for storms like hurricanes. Southern Japan often has typhoons that bring very heavy rain and high winds.



Mount Fuji. Japan's tallest volcano. (from volcano world—permission pending)

There are many earthquakes in Japan. Earthquakes cause problems because the shaking can destroy buildings. Earthquakes can also cause very large waves, called tsunamis. These waves are sometimes very destructive. Japan has very advanced warning systems for tsunamis. The warnings let people know when the tsunami is coming so they can get out of the way. The ocean to the east of Japan is very deep. On the west, it is very shallow. The map below shows this. It represents the height of the land and depth of the sea. The coastline of Japan is shown on the map. Interestingly, earthquakes occur more on the east side of Japan than on the west.



[Map adapted from NOAA/GEODAS ETOPO2 data using ArcGIS/ArcMap software.]

Besides storms and earthquakes, Japan has the most explosive volcanic eruptions in the world. Some volcanic peaks rise up from the ocean floor but not high enough to reach above the surface of the water. They are called submarine volcanoes.

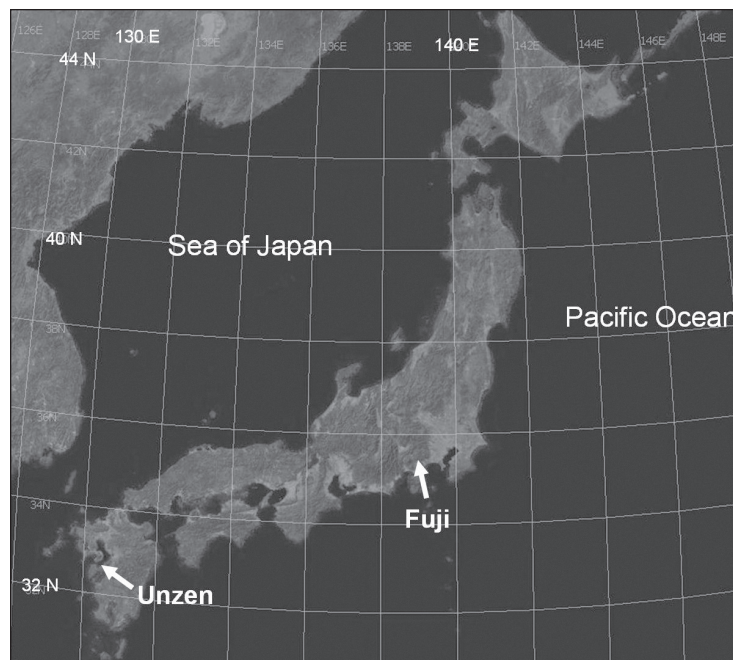
One of the most dangerous volcanoes in Japan is named Unzen. It is on the island at the southern tip of Japan. Unzen is near the city of Nagasaki. In 1792, part of Unzen collapsed and caused a landslide and tsunami that killed 15,000 people!

After “sleeping” for many years, Unzen erupted in 1991. It continued erupting for four years. The Unzen eruption was similar to the eruption of the U.S. volcano Mount St. Helens in 1980. Thousands of homes were destroyed and 43 people were killed in the 1991 Unzen eruption. There are over 75 active volcanoes in Japan. That is more than any other region in the world.

If you visited Japan, some things would seem familiar. The roads, trains, and cities look a lot like they do in the U.S. Other things might seem different. Some of the animals are very different from those in the U.S. There are monkeys throughout all of Japan except for the northern island of Hokkaido. There are also deer foxes and an animal called a raccoon dog. Raccoon dogs are related to dogs, but they look a lot like raccoons.



Raccoon dog. [Image used with permission by Wendy Baker and Michigan Science Art.]



[Image adapted using NASA World Wind software.]

Latitude: 10N to 25N Longitude: 140E to 150E

Flying over this region, a scientist took a picture of an island. It is called Farallon de Pajaros. This island is a volcano. It is about 2 km wide. No one lives there. Farallon de Pajaros has erupted about 16 times in the last 150 years. Most of the eruptions form lava flows. Can you see the result in this picture?



Farallon de Pajaros, as seen from an airplane in 1992. [USGS Image by Frank Trusdell]

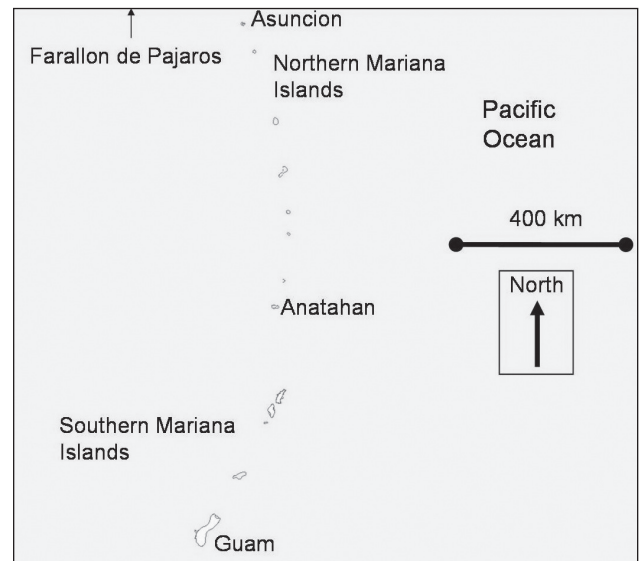
Farallon de Pajaros is at the northern end of a chain of volcanic islands in this region. They are called the Mariana Islands. These islands form an arc or crescent shape. They are very old. In fact, the islands are about 40 million years old! Flying south from Farallon de Pajaros along the line of islands, you would see the small island of Asuncion. It rises 857 meters above the ocean. Like the other Mariana Islands, it is a volcanic peak. The volcano does not start at the water's surface. Instead, it rises up from the ocean floor. The peak you see is the top of a volcanic mountain. The point is so tall it sticks out of the water. The top of Asuncion volcano is covered with clouds. The sides are very green and covered with palm trees. The shore is rough and rocky. But if you were flying near another of the Mariana Islands, Anatahan Volcano, you would have to be very careful. Anatahan erupts frequently. It throws ash as much as 10 km into the sky. This can be dangerous for airplanes. The first time in recent history that people observed Anatahan

Region 4



The small island of Asuncion. [USGS image by Frank Trusdell.]

erupt was on May 10, 2003. Days before the volcano erupted, the number of small earthquakes increased nearby. There were more than 100 small earthquakes per hour! Then at 5 PM an explosion sent ash high into the air. Many explosions happened in the next three weeks. South of Anatahan is the largest of the Mariana Islands, Guam. It is formed from two volcanoes. It is the shape of a foot. Almost all year long, the weather is hot and wet. The drier time is from January to June. From July to December, Guam gets a lot of rain. About 25% of the land in Guam is farmed. More than 168,000 people live there.

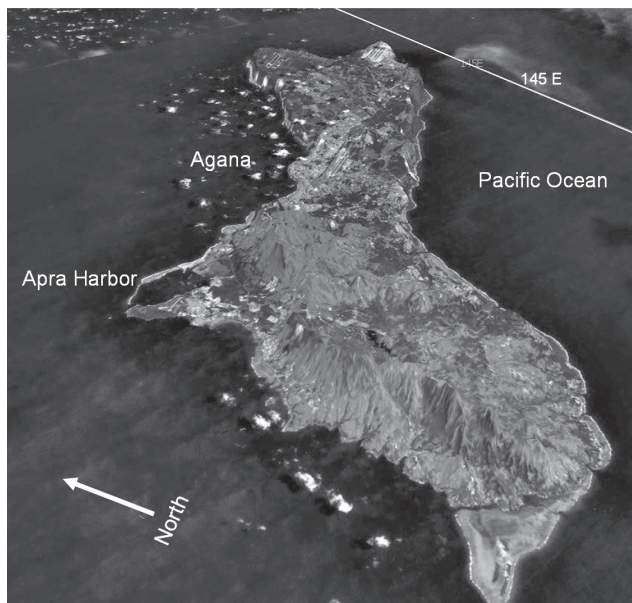


[Map adapted using ArcGIS/ArcMap software.]

The capital of Guam is Agana. There is a good harbor called Apra Harbor. There are many palm trees in Guam. In some places they grow as a forest. Here a geologist looks down at a palm tree

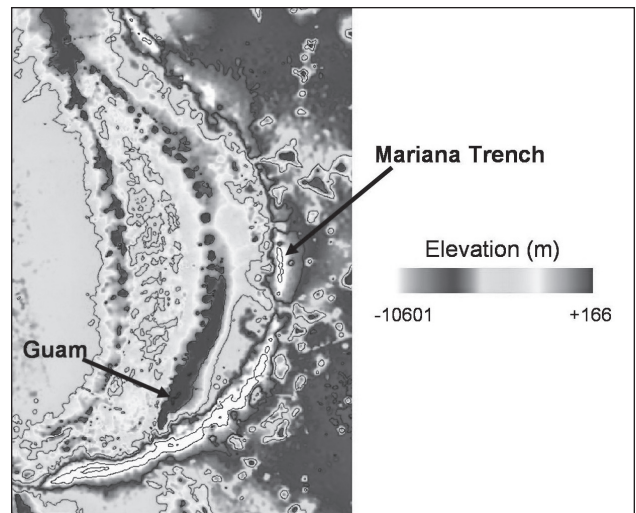


[Photo used with permission by Dr. John Keyantash, California State University, Dominguez Hills.]



[Image adapted using NASA World Wind software.]

forest. The north end of Guam is fairly flat. The middle area has low hills. Mountains are found in the southern part of Guam. The highest point is Mount Lamlam. It rises 406 meters above sea level. But this is just the tip. The entire mountain rises from a deep cut in the ocean floor that is east of Guam and all the Mariana Islands. This cut is called the Mariana Trench. It is 11 km deep! The highest mountain in the world, Mt. Everest, could sit in this trench and still have water above its peak! The Mariana Trench runs north-south following the line of the ridge that makes up the Mariana Islands. The trench can be seen in the image below. It shows the depth of the ocean below sea level. The outlines of Guam and some other islands are shown. West of the Mariana Islands is a second, slightly lower ridge, but it lies underwater. Compare how deep the ocean is on each side of the Mariana arc of islands.



[Map adapted from NOAA/GEODAS ETOPO2 data using ArcGIS/ArcMap software.]

Latitude: 25N to 40N Longitude: 70E to 100E

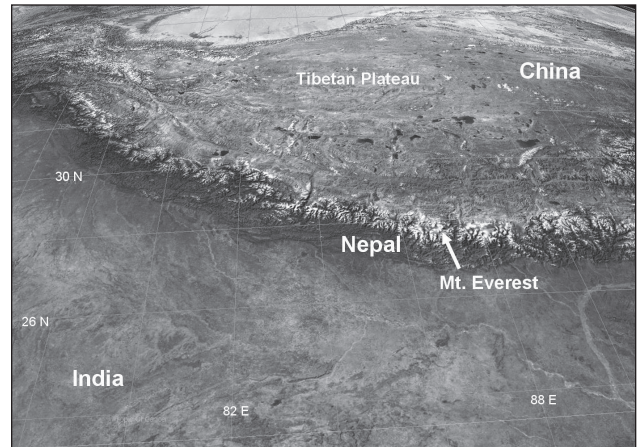
Region 5

“Abode of Snow”—this is what the word “Himalaya” means in the language called Sanskrit. The Himalaya region is a world of amazingly tall mountain peaks. They lie in a broad east-west band that twists across the region of southern Asia. Among the peaks is Mt. Everest. This is the highest mountain in the world. Mt. Everest stands 8,850 meters above sea level. The north half of the mountain is in Tibet, a region in southwestern China. The south half of the mountain is in the country of Nepal. The Himalaya mountain range contains many mountains almost as tall as Mt. Everest.



Kantega, a Himalayan peak near Mt. Everest, is 6,857 m above sea level. [Photo © Alan Arnette, used with permission.]

The valleys in the Himalaya mountain range are very deep. Some are over 3,000 meters deep. People live in the lower valleys. A few people live in the valleys that are part way up the mountains, but almost no one lives in the icy world at the highest areas. It is very cold there. The temperature is usually below -10°C . How far below freezing is that? At the tops of the peaks, it can be as cold as -38°C . Here winds blow almost all the time, sometimes at speeds of 150 km/hr. In April and May, the winds calm down a little. This is the time of year when some people try to climb



Satellite photo of Himalaya region. [Adapted using NASA World Wind software.]

the high peaks. It is very dangerous. Storms can come very quickly. This view of the Himalayas is from the south looking toward the north. It is a photograph taken from a satellite in space. The brown area to the north is a very high plateau. A plateau is a high, flat area of land. This plateau is called the Tibetan Plateau. The climate is dry on the plateau. There are lakes on the plateau, but the water in many of them is salty. North of the plateau is a huge desert. Do you see it?

South of the plateau, the Himalaya Mountains form a very high ridge. The ridge appears white in this picture because it is covered with snow and ice. There are many mountain glaciers here. This mountain ridge lies between the dry plateau and the wetter area to the south. India and most of Nepal lie in this wetter southern region. The area south of the ridge is also fairly flat. This type of land is called a plain. Clouds bring rain across the plains during the summer months. It rains and rains and rains. These heavy rains are called monsoons. The clouds can rarely carry water over the ridge of mountains. Instead, the water falls as rain on the plains and on the southern side of the mountain range. The range is a divide between the dry areas to the north and the wet areas to the south.

This region is an area of great contrasts. The dry Tibetan Plateau and the desert to the north are very different from the wet plains and the wet southern slopes of the mountains. On the wet side of the Himalayas, plants called giant rhododendrons grow at very high altitudes. Animals called yaks live at very high altitudes on the other, dry side of the Himalayas. They are ridden by people or used to carry heavy loads. Lower on the slopes are forests of conifers, plants such as pine trees. The monsoon climate makes the south side of the mountains and the southern foothills very wet, with many different kinds of plants. Here is a map that shows the boundaries of countries and the location of the Himalaya Mountains and the desert in China. This map covers about the same area as the satellite photo.



[Map adapted using ArcGIS/ArcMap software.]

Latitude: 60N to 70N Longitude: 30W to 0

If you were flying over this region, in the middle of the North Atlantic Ocean, you would see an island. This island is the country of Iceland. It is east of Greenland and west of Norway. Iceland is near the Arctic Circle. From the name “Iceland”, what would you expect it to look like as you flew in close? If you guessed “icy” you would be partly correct. Iceland has more land covered by glaciers than in all the rest of Europe. Iceland has the largest glacier in Europe called Vatnajökull. This glacier is located in the southeast part of Iceland, on its highest mountain. The elevation is 2119 meters. There are volcanoes and hot springs in many parts of the country. In some places in the south, you could be swimming in a hot spring and looking at icy mountain peaks. If you flew low over the Vatnajökull glacier in 1991, you might have seen something like this:



[USGS photo by Magnús Tumi Guðmundsson]

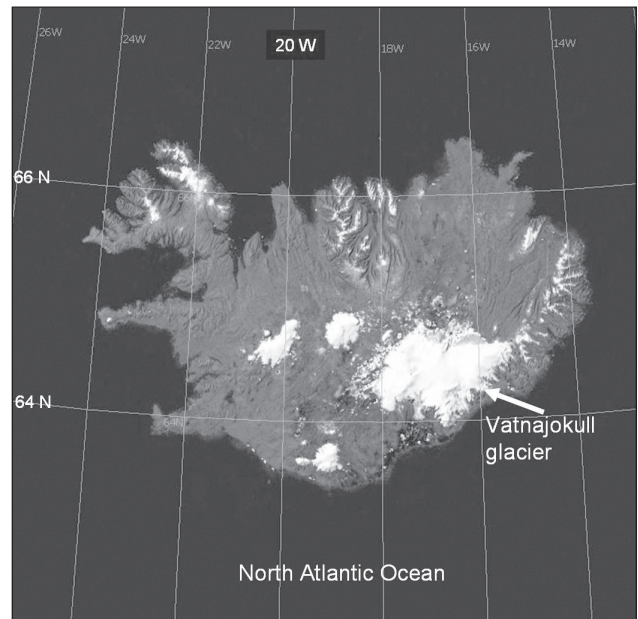
Less than two days later, the glacier looked like this:



[USGS photo by Magnús Tumi Guðmundsson.]

What do you think could be causing the glacier to melt?

Most of Iceland is not covered with ice! The land is mostly high plains with some mountain peaks. There are lakes and some high waterfalls. The average elevation is 500 meters. There are deep cuts in the coastline here, called fjords, which are steep-sided inlets of the sea. Iceland’s climate is surprisingly mild for a place so far north. The



[Image adapted using NASA World Wind software.]

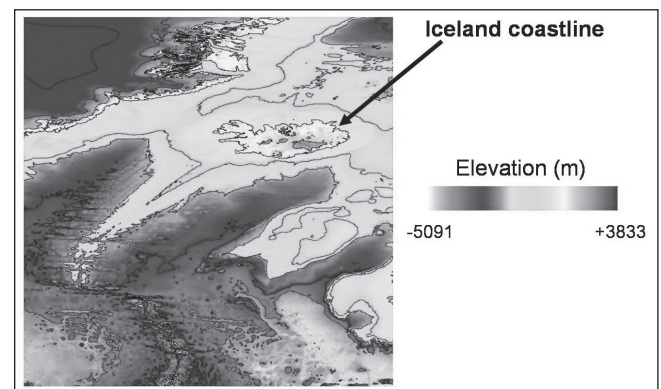


[Map adapted from CIA World Factbook.]

average temperature in July is 11°C. In the winter, the average temperature is about like that in New York City, around freezing. But in mid-winter in Iceland there are only about 4 hours of daylight. In mid-summer the light lasts almost all day!

About the same number of people live in Iceland as in the area around Madison, WI. The capital city is Reykjavik. This is the northernmost capital city in the world. There used to be trees in Iceland,

but most were cut down by the 1200s. Now, people are working hard to replant trees. Only a tiny portion of the land can be farmed. Fishing is an important source of food and income. Energy from Earth's internal heat, called geothermal energy, is also an industry in Iceland. Scientists have made measurements that show the shape of the ocean floor beneath the water. There are mountains and trenches in parts of the ocean floor around Iceland. This image shows what Earth's surface looks like near Iceland. The different colors represent different heights and depths above and below sea level. The coastline of Iceland is also shown.



[Map adapted from NOAA/GEODAS ETOPO2 data using ArcGIS/ArcMap software.]

Latitude: 15N to 10S

Longitude: 90E to 120E

Region 7

As you fly over this region of the world, you look down on an arc of islands. The cones of many volcanoes can be seen along this arc. The volcanoes in this arc rise thousands of meters from the sea floor. The tallest ones are exposed above the surface of the water. One island, Anak Krakatau, is new! It has grown since 1927 from many small eruptions and some large, explosive ones. It is in the Sunda Strait, a water passage between Sumatra and Java. Anak Krakatau means “Child of Krakatau.” It has this name because it replaced a famous volcano called Krakatau. Krakatau was destroyed in one of the largest explosions on Earth. This was in 1883. A volcanic eruption destroyed most of the island. Not all the volcanic islands are small. Some fused into a huge island called Java.



[Anak Krakatau 1960 © Robert Decker, permission pending.]

Java is about the size of California. It is crowded with people. In fact, it is the most populated island on Earth. Over 114 million people live there. That is a little more than one third of the number of people that live in the United States. Over 12,000 of Java’s people live in the collapsed remainder of a huge volcano called Ijen. When a volcano explodes and leaves an open shell, it is called a caldera. The caldera of Ijen has rich soil. People grow coffee there. Have you ever heard of coffee referred to as “java”?

One part of Ijen is an active crater. Steam rises from it. The mineral called sulfur is mined in the crater. In the center is an acidic lake. This lake is 200 meters deep. Northwest of Java is the large island of Sumatra.



[Photo courtesy Volcano World, University of North Dakota. Used with permission.]

Mountains run the length of Sumatra, mainly on the western side. Some are over 2900 meters high. The eastern coast has been a busy stop for ships for hundreds of years. Nature preserves on the island protect interesting animals and plants. This includes the biggest flower in the world, called rafflesia. Parks also protect elephants, tigers, and many birds. The climate here is very wet. Rain falls almost all year, but it is much heavier from fall to spring. Thick forests grow here, especially in the north end of Sumatra. There also are fields where people grow rice. Water flows down from the mountains in many streams and waterfalls. There are also many sandy beaches on Sumatra.

Northwest of Sumatra, the island arc ends with a string of small islands called the Andaman Islands. They belong to the country of India. There are no very high mountains in the Andaman Islands. Instead, there are many hills cut by narrow valleys. There are no rivers and only a few streams. Yet, when the monsoon rains come, the islands get a lot of water. Thick jungles cover the hills. The

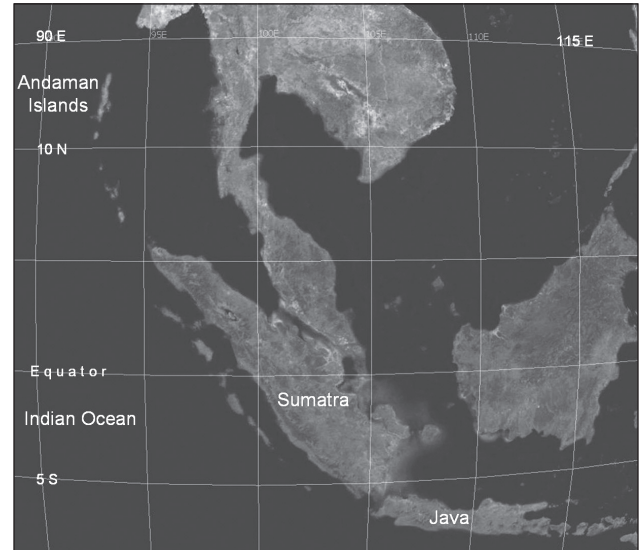
climate is always warm, with breezes from the ocean. It can be very hot in summer.

The main city of the Andaman Islands is Port Blair. In 2003, astronauts on the Space Shuttle were flying over the Andaman Islands. They saw steam

arising from a volcanic island 135 km northeast of Port Blair. This is Barren Island volcano. It has erupted many times. Only a few trees survived the 1991–1994 eruptions. A few animals live on Barren Island. The largest is a wild goat.



[Map adapted using ArcGIS/ArcMap software.]



[Image adapted using NASA World Wind software.]

Latitude: 50N to 70 N

Longitude: 130W to 180W

Think of Alaska. Is it cold or is it hot? When you think of Alaska, you may first think of snow and icy, high mountains. Alaska has all of those things. Alaska can be COLD. In fact, there are many glaciers in Alaska. Glaciers are rivers of ice. Here is a picture of a glacier where it flows into the sea.



[USGS photo by Bruce F. Molina.]

There are two main mountain ranges in Alaska. The northern one is called the Brooks Range. This mountain range continues into northern Canada. Another range is along the southern part of the state. It is called the Alaska Range. The tallest mountain in North America is found here. The Native American name for this mountain is Denali. It is sometimes referred to as Mount McKinley. This mountain is 6,194 meters tall.

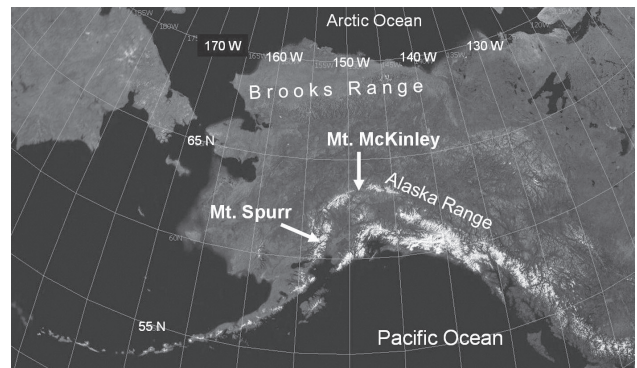
Between these mountain ranges is an area of low rolling hills and valleys. There are lakes here, too. Some of the land is farmed. There are many trees growing on the lower mountain slopes. Alaska has many lakes and rivers. One of the largest rivers runs east-west across the state. It is called the Yukon River.

Despite the many mountains and ice, Alaska can also be HOT. During the summer months, the weather often is warm, but the place where Alaska is really hot is in its volcanoes. The ground, rock, and steam are very hot. Heat from deep in Earth's interior causes steam to rise and melt through snow and ice. Small steaming vents are

Region 8



Mt. McKinley. [National Park Service photo by Karen Ward.]



[Satellite image adapted using NASA World Wind software.]

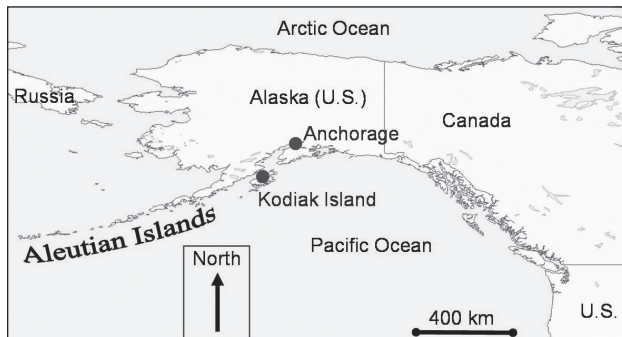


Mt. Spurr. [USGS image by C. A. Neal, Alaska Volcano Observatory]

called fumaroles. In one area, there are so many fumaroles that the place is called Valley of Ten Thousand Smokes.

One of the most famous of Alaska's volcanoes is called Mount Spurr. It is only 80 miles west of the

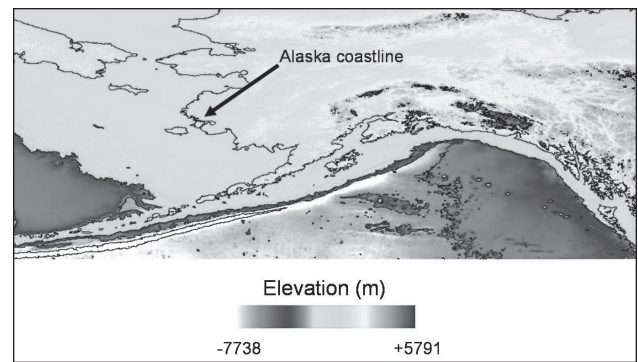
city of Anchorage, Alaska. Mount Spurr is one of 40 volcanoes in Alaska that are active. Scientists at the Alaska Volcano Observatory warned skiers and people flying planes to be careful of gases and huge areas of melting snow near the top of this peak in the spring of 2005. But these are just small events. A very large volcanic eruption in Alaska happened in 1912. This was the largest volcanic eruption on Earth in over 100 years. The volcano that erupted was southwest of Mount Spurr along the coast. Its name is Novarupta. The eruption lasted 3 days. So much ash came out of the eruption that it blew over North America in one day. Eight days after the eruption, ash from Novarupta blew all the way to Africa! Mount Spurr and Novarupta are just two in a long chain of volcanoes that stretch in a curve along the southern coast of Alaska. This line of volcanoes forms a set of islands called the Aleutian Islands. They stretch for 2500 km from Mount Spurr.



[Map adapted using ArcGIS/ArcMap software.]

Off the coast, south of the Aleutian Islands, the ocean is unusually deep. The ocean is deeper here because there is a trench in the ocean floor. It is called the Aleutian Trench. It follows the curve of the line of islands. You can see the trench in the image below. The following image shows the depth of the ocean below sea level and the height of land above sea level. The coastline of Alaska is also shown.

Volcanic eruptions are not the only earth-shattering events in Alaska. This state also has earthquakes. The largest earthquake ever to hit Alaska was in 1964. It was an M9.2 quake. This was the second largest earthquake in the world in over 100 years. In fact, three of the 10 largest



[Map adapted from NOAA/GEODAS ETOPO2 data using ArcGIS/ArcMap software.]

earthquakes in the world have been in Alaska. The epicenter of the 1964 earthquake was only 120 km from the city of Anchorage. This area is called Prince William Sound. During the quake, land lifted up from Kodiak Island toward Anchorage. There were landslides and a great wave (tsunami). There was also a very large earthquake recently in 2002. It had a magnitude of 7.9. This earthquake was located inland, far from the Aleutian Islands.



Turnagain Arm, railroad torn during 1964 earthquake. [USGS photo by Joseph K. McGregor and Carl Abston.]

Many more people live in Alaska now than did in 1964. Even so, there are few compared with many other parts of the United States. People who live in Alaska may fish or cut timber. Many work for the oil industry. There is a large oil field under the ground in Alaska. Oil is piped for many miles across the large state and is shipped to other parts of the world.

Latitude: 32N to 42N Longitude: 114W to 125W

Region 9

Would it surprise you to know that the city of Los Angeles is further west than San Diego? These are two large cities in the state of California. California is a very large state. It shares its southern border with Mexico. Yet California reaches over half way to our neighbor to the north, Canada. The state is the third largest in the U.S. Its most famous boundary is to the west, the Pacific Ocean.



Part of the California shoreline and the Pacific Ocean, near Los Angeles. [Photo courtesy M. D'Amato, used with permission.]

California is well known for its mountains. Some of these mountains rise steeply from the ocean. These include coastal mountains near San Diego and Los Angeles. The Santa Monica mountains are near the city of Los Angeles. They rise over a thousand meters above sea level just a few kilometers from the shore. This range runs from east to west.

Further north, the Coastal Range mountains run from Santa Barbara north to another range called the Klamath Mountains. Unlike the Santa Monica range, these ranges stretch from north to south.

The highest point in the state is Mount Whitney. This is also the highest point in the United States outside of Alaska. Mt. Whitney is 4418 meters above sea level. Compare this to the lowest point in the state and the U.S.: Death Valley. The elevation there is 86 meters below sea level. These two points are within only about 240 km of each other!



[Map adapted using ArcGIS/ArcMap software.]

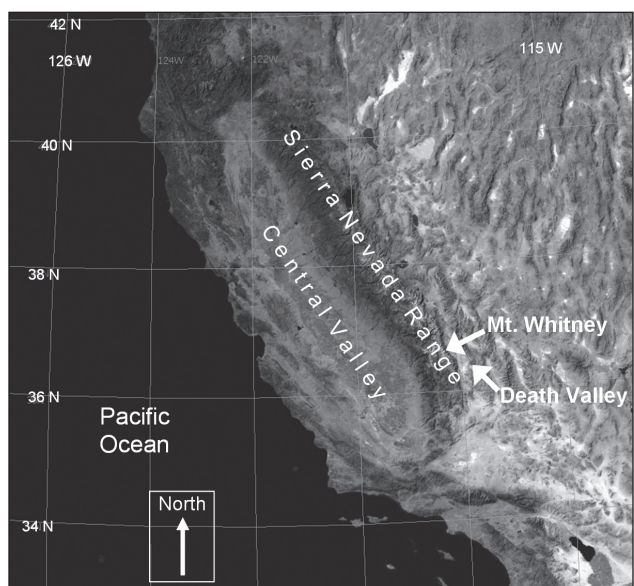
Mt. Whitney is part of the Sierra-Nevada Mountain range. This range runs from north to south. It lies along the eastern edge of California, near the border with Nevada. Glaciers have cut deep valleys into these mountains. The glaciers are now gone, but the valleys remain. Yosemite Valley and a famous rock formation called Half Dome are examples.



Half Dome, Yosemite National Park. [Image courtesy World ImageBank, © Dr. Roger Slatt, University of Oklahoma.]

Between the Coastal Ranges and the inland Sierra-Nevada range is a very large, flat area. It is called the Central Valley. When farmers add water through irrigation to this area, the Central Valley becomes a great place to grow food crops.

In the far north, a small part of the Cascade Mountains enters the state of California. This north-south range includes two famous mountain peaks. Mt. Shasta used to be an active volcano. Mt. Lassen is an active volcano now. It last erupted in 1921.



[Adapted using NASA World Wind software, NLT Landsat7 data.]

Some people do not know that California has volcanoes. But many people think of earthquakes when they think of California. An earthquake of long ago in San Francisco is particularly famous. This earthquake had a magnitude of 6.7. Almost immediately after the earthquake, a huge fire burned the city. Many people and animals died. Many buildings were destroyed. The fire caused much of the damage. The earthquake caused gas lines to break and start the fire. Today, many earthquakes occur in California. Most of them are small but every once in a while there is a large one that causes damage.



Collapse of City Hall at Santa Rosa, near San Francisco, 1906. [Image courtesy NOAA/NGDC, University of California-Berkeley.]



Lassen Peak. [Image courtesy World ImageBank, © Marli Miller, University of Oregon.]

STEP 2

Overview

Does Earth's surface move? Yes! Sometimes it moves suddenly and with serious consequences for Earth's surface. In Step 2, students explore sudden events as evidence that Earth's surface is dynamic. They learn about events like earthquakes and volcanic eruptions and the evidence scientists use to understand those processes, including seismic waves (vibrations of the earth) and location data from around the world. Students first study the types of waves that carry energy released by earthquakes and the tools that scientists use to study them. Then, students begin to think about how often and where earthquakes and volcanic eruptions take place. To do this, students investigate actual global data to discover patterns. Included in the patterns observed is the key observation that earthquakes and volcanoes do not occur randomly. Recognizing this worldwide pattern of earthquake and volcanic activity sets the stage for the rest of the unit.

Finally, students revisit their models from Step 1 to see that what was started initially needs to be revised to explain what they now know about their region. Using new evidence, students revise their original model and learn why models are important for the work scientists do.

Step 2 Lesson 1 Snapshot

Key Concepts

- Earthquakes and volcanic eruptions provide evidence that Earth's surface changes.
- Earthquakes and volcanic eruptions are sudden, local events but may affect large areas.

Evidence of Student Understanding

The student will be able to:

- identify earthquakes, volcanic eruptions, and tsunamis as evidence that Earth's surface changes suddenly.

Time Needed

20 minutes

Materials

For the class

- CD slide show of natural hazards images  (or printed slides on transparency film)
- data projector (if using CD) or overhead projector (if using transparencies)

Earth-shattering Events

1. Explain to students that today they will be making some observations and inferences about some photographs you are about to show. Provide them with this guiding question and ask them to write it down in their Science Notebooks:

- **What do you observe about how Earth's surface changes?**

2. Show students the natural hazards images on this unit's CD. Resist the temptation to explain what the class observes.

3. Allow students to do a Think-Pair-Share with the guiding question (from section 1 above).

- Remind students that the slide show contained images to be used as evidence when answering the question.
- Notice when students make inferences versus observations and record them in separate columns on the board or chart paper during the Share.

4. Lead a class discussion to highlight the difference between an observation and an inference. Students need to understand that difference to recognize what constitutes good evidence for an explanation.

- **Observations** are characteristics that someone notes about an object or event (either with their senses or with tools).
- **Inferences** are conclusions about an object or event based on pre-existing conceptions.

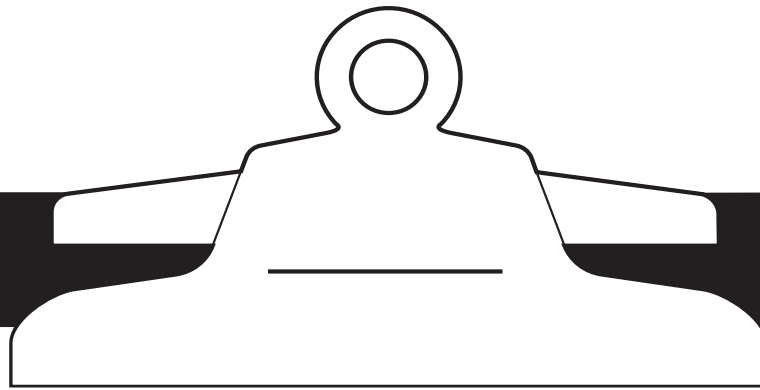
5. Use a Think Aloud to model the thinking that goes into making an observation versus making an inference so that students clearly see the difference.

6. The REAPS are designed to be used throughout and after the lesson as appropriate.

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REAPS Questions

- R What did you see in the images that showed how Earth's surface changes?** Answers may vary. Example: Damage due to earthquakes, volcanic eruptions, tsunamis, and related events.
- E Do sudden events like these affect large areas, small areas, or both? How do you know?** Answers may vary. Example: While earthquakes start in specific locations, damage from earthquakes and secondary events like tsunamis can affect very large areas. We know this from observations taken in different parts of the world after an earthquake.
- A Does Earth's surface change? What *observations* can you make as evidence for your answer? What *inferences* can you make about Earth's surface?** Earth's surface is changing, and observations that support that claim include the types of changes caused by sudden events like those studied in this lesson. Inferences that students could cite include any ideas based on what they already think and/or observations.
- P If earthquakes, volcanic eruptions, and tsunamis are evidence that Earth's surface changes suddenly, how do you think they could be related?** Listen for students' responses to gauge what current understanding they may have about the relationship between these sudden events.
- S Write in your Science Notebook one question that interests you about earthquakes, volcanic eruptions, or tsunamis.** Answers will vary. Inform students that they will have an opportunity to answer some of these questions, where appropriate, later in this unit or in their region investigations.



Teacher Background Information

“Earth-shattering events” in this unit refer to sudden, natural hazards like volcanic eruptions, earthquakes, and tsunamis. These events usually happen quickly, often with little or no warning, and can dramatically change Earth’s surface.

Earthquakes

Earthquakes are sudden shifts in large pieces of Earth’s crust. Cracking or displacement in the earth occurs but there are no gaping holes as sometimes depicted in science fiction movies. The earth may shift laterally and/or vertically and the release of energy during an earthquake causes the ground to shake.

Volcanoes

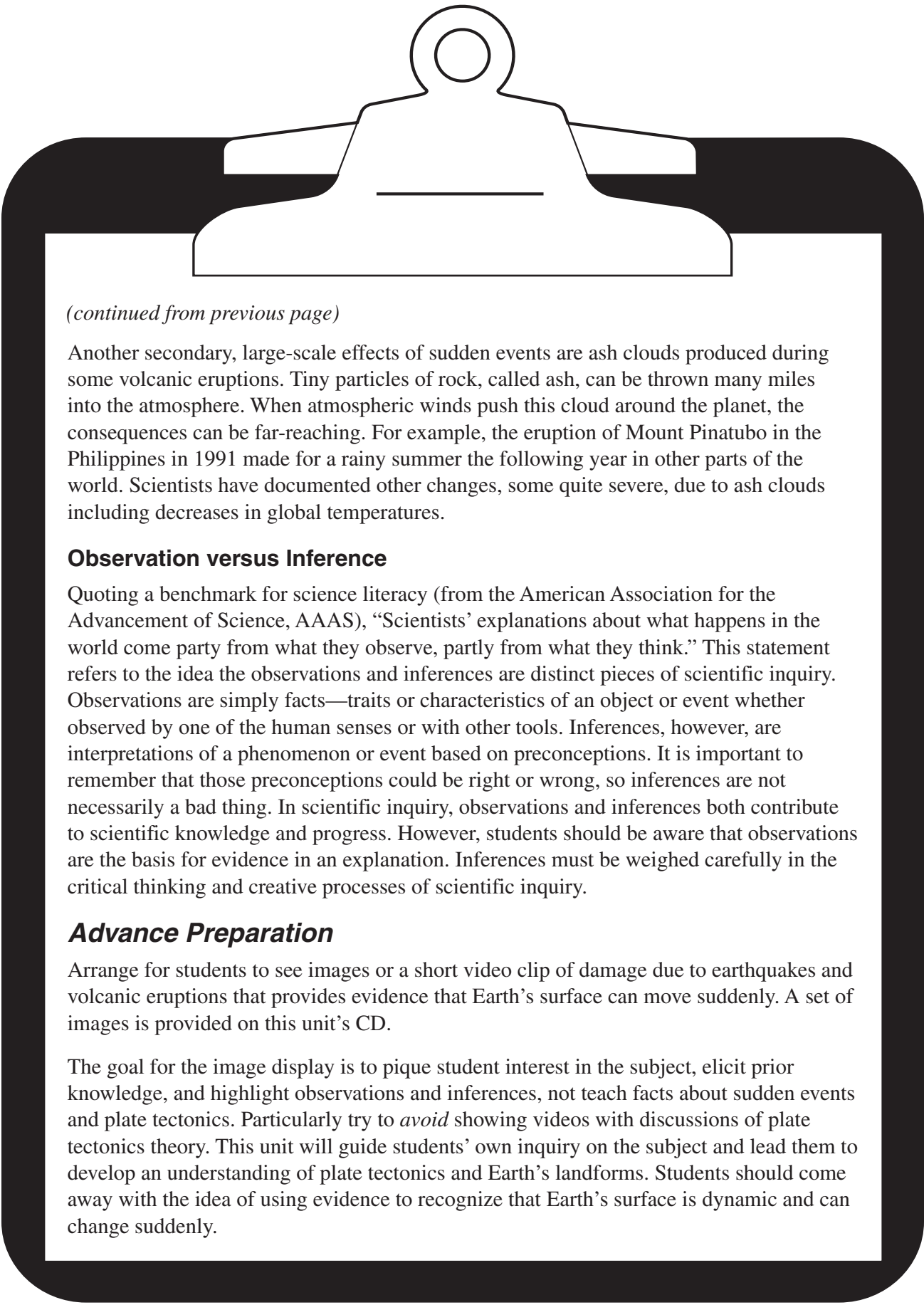
Volcanoes are mountains formed by one or more eruptions of molten rock that comes from deep beneath the surface. Scientists have classified several types of volcanoes and volcanic eruptions, but all involve certain kinds of rock and hot gases. Aside from lava flows or explosions of gas and hot rocks, volcanoes can also cause mudflows. These originate from the combination of ash and rain or melted snow and ice from the peak of a volcano. The term “volcano” does not only refer to an active, erupting mountain. Volcanoes may be inactive for many years between eruptions. Volcanic activity can produce sudden changes like spewing lava or the collapse of a peak. However, much volcanic activity takes place over many years. Many volcanic islands, like those in Hawaii for example, grow slowly over thousands of years.

Secondary Effects

Tsunamis are sometimes caused by large earthquakes, but are also caused by landslides or other events that rapidly displace large amounts of water. Because they are derived from another process, they are a secondary effect. A large earthquake beneath the ocean floor generated the 2004 Indian Ocean tsunami, for example. However, not all earthquakes produce a tsunami. Due to their extremely long wavelengths, tsunamis usually only appear large near shallow coastlines, perhaps just moments before landfall.

The word “tsunami” is often interchanged with the phrase “tidal wave.” “Tidal wave” is a misnomer for this event since large displacements of water cause tsunamis, not tidal forces. Tsunami, meaning “harbor wave” in Japanese, is the proper term for a very large ocean wave resulting from a large displacement of water.

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Another secondary, large-scale effects of sudden events are ash clouds produced during some volcanic eruptions. Tiny particles of rock, called ash, can be thrown many miles into the atmosphere. When atmospheric winds push this cloud around the planet, the consequences can be far-reaching. For example, the eruption of Mount Pinatubo in the Philippines in 1991 made for a rainy summer the following year in other parts of the world. Scientists have documented other changes, some quite severe, due to ash clouds including decreases in global temperatures.

Observation versus Inference

Quoting a benchmark for science literacy (from the American Association for the Advancement of Science, AAAS), “Scientists’ explanations about what happens in the world come partly from what they observe, partly from what they think.” This statement refers to the idea the observations and inferences are distinct pieces of scientific inquiry. Observations are simply facts—traits or characteristics of an object or event whether observed by one of the human senses or with other tools. Inferences, however, are interpretations of a phenomenon or event based on preconceptions. It is important to remember that those preconceptions could be right or wrong, so inferences are not necessarily a bad thing. In scientific inquiry, observations and inferences both contribute to scientific knowledge and progress. However, students should be aware that observations are the basis for evidence in an explanation. Inferences must be weighed carefully in the critical thinking and creative processes of scientific inquiry.

Advance Preparation

Arrange for students to see images or a short video clip of damage due to earthquakes and volcanic eruptions that provides evidence that Earth’s surface can move suddenly. A set of images is provided on this unit’s CD.

The goal for the image display is to pique student interest in the subject, elicit prior knowledge, and highlight observations and inferences, not teach facts about sudden events and plate tectonics. Particularly try to *avoid* showing videos with discussions of plate tectonics theory. This unit will guide students’ own inquiry on the subject and lead them to develop an understanding of plate tectonics and Earth’s landforms. Students should come away with the idea of using evidence to recognize that Earth’s surface is dynamic and can change suddenly.

Implementation Guide

1. Explain to students that today they will be making some observations and inferences about a video that you are about to show. It is not necessary to explain the difference between an observation and an inference at this point. Students will construct their understanding of these terms and practice using them later in the lesson.

Provide students with this guiding question for the video and ask them to write it down in their Science Notebooks:

- **What do you observe about how Earth's surface changes?**

2. Show the images of natural hazards from this unit's CD or project overhead transparencies of the images. Resist the temptation to explain what the class observes. The intention is to simply show the images, and encourage students to record what they see that has to do with Earth's surface changing.

3. Remind students that the video contained images to be used as evidence when answering the guiding question—**What do you observe about how Earth's surface changes?** Use a Think-Pair-Share strategy to engage students in developing responses to the guiding question. Travel around the groups and note instances when students make inferences about what they saw versus simply stating what they observed. The following table shows examples of observations and inferences students may make:

4. Ask students to call out some of their responses to the guiding question. As you record responses on the board, separate them into two columns: one for inferences and one for observations. Go through the list one-by-one and ask students how they know each statement is true. Guide students to use evidence rather than prior knowledge or inference to explain how they know statements are true. Explain that you want students to be able to support all observations about Earth's surface with statements such as "I know because I saw it in the photograph." Inferences are much harder to support. For example, review this student/teacher interaction:

- The crop rows used to line up and the ground moved over to the right during an earthquake.
- *How do you know that the crop rows used to be in a different spot?*
- Well, I guess I don't really know. I think that it used to be in a different spot, because I have never seen anyone plow a farm field like that on purpose.
- *Ok, let's assume that the field was plowed like every other farm field we've ever seen. How do you know that an earthquake moved the rows to the right? Did you see the earthquake do that?*

As you continue through the class list, ask students to identify what the differences are

Observations	Inferences
Crop rows on that farm don't line up.	The fences and crop rows on that farm used to line up and the ground moved to the right during an earthquake.
Parts of the road appear in large holes in the ground.	The ground under the road washed away into the ocean or fell into the center of Earth.
The shape of the mountain changed from a peak to a crater.	The part of the mountain that used to be a peak melted and turned into lava that ran down the side of the mountain.

between statements in the “Observation” column and statements in the “Inference” column. You can then label the different types of statements **Observations** and **Inferences**.

Provide students with clear definitions Observations and Inferences to be written in their Science Notebooks.

- **Observations** are characteristics that someone notes about an object or event (either with their senses or with tools).
- **Inferences** are interpretations about an object or event based on pre-existing conceptions.

Explain to students that they need to know the difference between observations and inferences to make logical and well-reasoned scientific explanations about their region’s landforms later in the unit, just as scientists would.

5. If students are still unclear about observations and inferences after the class discussion, use a Think Aloud to model what the difference between the two sounds like. For example:

Example Think Aloud for Observation versus Inference:

Let’s say one of your friends from another school visited our class today. They might walk into class and say, “There’s a chalkboard. Over there are some filing cabinets with lots of papers in them. Oh, and look at that piece of cardboard with string taped to it. I wonder what my friends in this class are studying.” Those are all *observations*. In fact, those are all things that your friend would see in our class. They might also smell the air in the room or touch the desks to find out if they are different from their classroom. I just said

things that someone would say if they were making observations.

Now, if I were the same person and came into the classroom making *inferences*, here’s what it might sound like: “There’s a chalkboard. The students in this class are so lucky they get to write on the chalkboard—my teacher does all the chalkboard writing in my class. Wow, look at all of those papers in the filing cabinets. These students have so much homework to do! Yuck! Oh, look at that piece of cardboard...and string. This class must be studying how recycling is good for the environment.”

Do you see the difference between observations and inferences? Why might the visiting student make an inference that students in this class have a lot of homework? Maybe this visitor has had a lot of homework, and the inference based on seeing all of the papers. However, more observations might have shown that those papers are the teacher’s papers and not homework assignments at all. Inferences can be incorrect. Another example of an incorrect inference would be if the student thought we were studying recycling! We are really studying Earth’s surface, but it is hard to tell what we are really doing if someone just looked at my model of California.

6. The REAPS questions in this lesson are focused on three things. First, the Recall and Extend questions highlight how Earth’s surface can move suddenly. Second, the Analyze question can be used to assess student understanding of observations versus inferences. Finally, the Predict and Self-assess questions can be used as in introduction to the next lesson, where sudden events like earthquakes and volcanoes will be explored.

Step 2 Lesson 2 Snapshot

Key Concepts

- Earthquakes cause vibrations called seismic waves that spread outward from a focus.
- Earthquakes are sudden motions along breaks in Earth's crust called faults.

Evidence of Student Understanding

The student will be able to:

- model the movement of seismic waves through the ground;
- identify which type of seismic waves seismometers detect first and how that helps locate the focus of an earthquake;
- explain how a brick & board demonstration is a simple model for how Earth's surface can move suddenly along faults, causing earthquakes.

Time Needed

50 minutes

Materials

For the class

- Brick & Board demonstration video clip 
- Computer and projector to view video clip
- *Teacher Page 2.2c: Brick & Board Model of Earthquakes*

For each student

- copy of *Student Page 2.2A: Earthquake Basics*
- copy of *Student Page 2.2B: Your Own P and S Waves*

For each pair of students

- Slinky™

Exploring Seismic Waves

1. Ask students to share what evidence they have for sudden movements of Earth's surface. Use the *Exploring Earth's Surface* chart as needed. Ask students what sorts of damage they have seen from earthquakes and then to predict:

- How do earthquakes cause the kinds of damage that they often cause?
- Explain that Student *Page 2.2A: Earthquake Basics* has some evidence to help them answer that question. Provide each student with a copy.

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REAPS Questions

R What causes damage during an earthquake? Seismic waves cause damage.

E Describe some characteristics of seismic waves. Example: Seismic waves are vibrations of the earth that spread out from the focus of earthquakes. There are two kinds, primary (P) and secondary (S) and they move in different ways. P waves move faster than S waves. They both cause damage in an earthquake.

A Describe what parts of the Brick & Board demonstration represent what parts of a fault or events during an earthquake. There are many correlations. Example: The bottom surface of the brick against the top surface of the board represents a fault.

P How often do earthquakes happen? Where do earthquakes happen? Answers may vary. Use this question to assess students' prior knowledge about where and when earthquakes happen in preparation for the next lesson.

S What do you still want to know about earthquakes or earthquake damage? What do you find interesting about earthquakes?

- Ask students to read the first two sections of the reading. Instruct them to record, in their Science Notebooks, any information from the reading that they could use to answer the question, How do earthquakes cause the kinds of damage that they often cause?
- Have students talk briefly in pairs about the evidence they collected from the reading.

2. Provide each pair of students a copy of *Student Page 2.2B: Your Own P and S Waves* and a Slinky™.

- Allow time for pairs to experience and practice modeling the P & S wave motion.

3. Ask students what they think scientists do to learn about seismic waves. Use a Think-Pair-Share strategy to find out what students already know about the question, **How do scientists measure and study seismic waves?**

- Explain that the rest of *Student Page 2.2A: Earthquake Basics* has evidence for answering that question.

- Have students finish the reading and again record any evidence for explaining how scientists measure and study seismic waves in their Science Notebooks.
- Collect student ideas on the *Exploring Earth's Surface* chart.

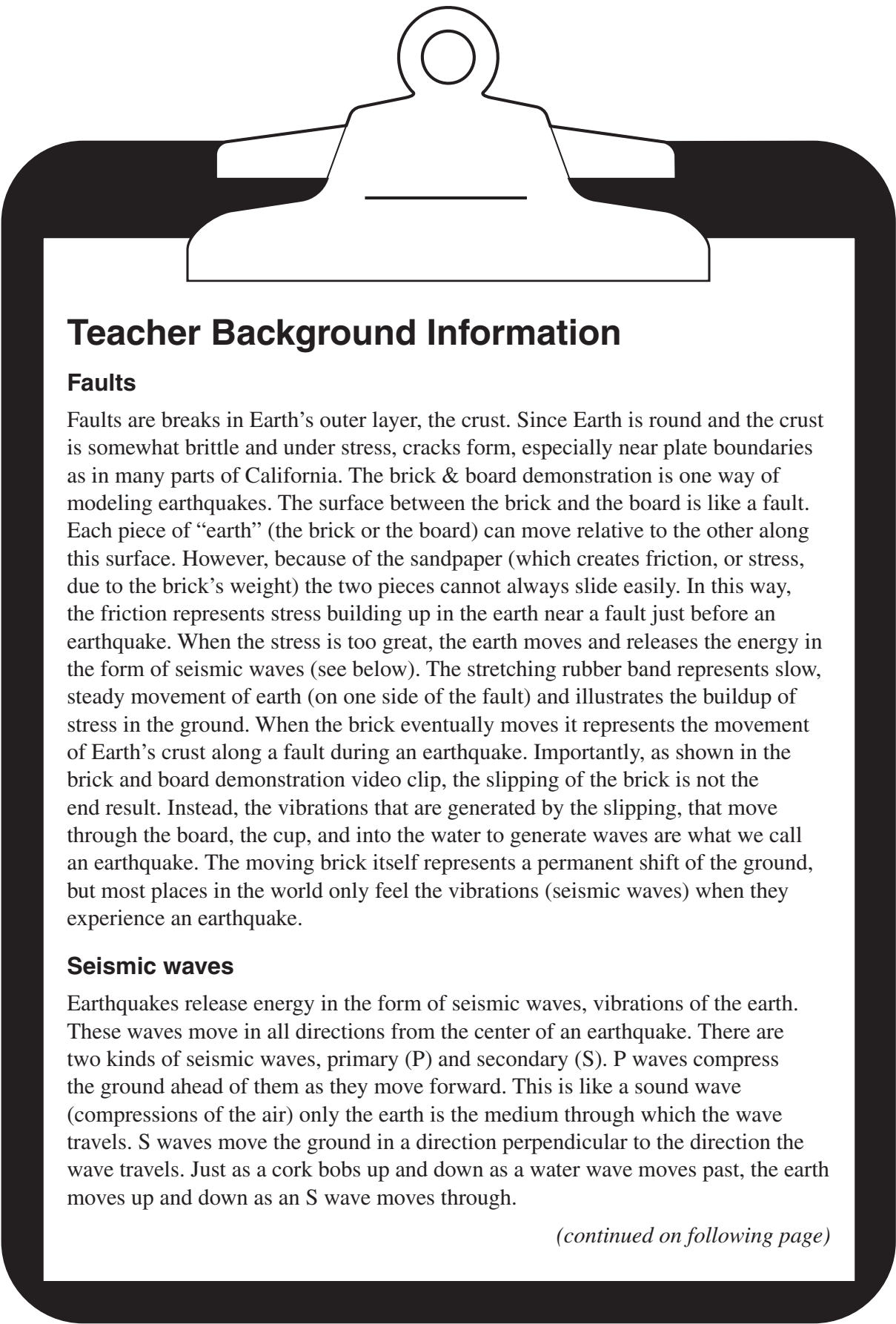
4. Ask students to predict what the root cause of an earthquake is. Explain that you have a demonstration to show that may provide more evidence for making their predictions.

- Show the brick and board demonstration video clip.
- Connect this model to earthquakes and faults using the T-chart on *Teacher Page 2.2c: Brick & Board Model of Earthquakes*.

5. Give students 2–3 minutes to reflect on what they learned during this lesson about earthquake causes and generate one entry for the *Exploring Earth's Surface* chart.

- Have students record ideas in their Science Notebooks before collecting and recording them on the class chart.

6. Use the REAPS throughout and after the lesson as appropriate.



Teacher Background Information

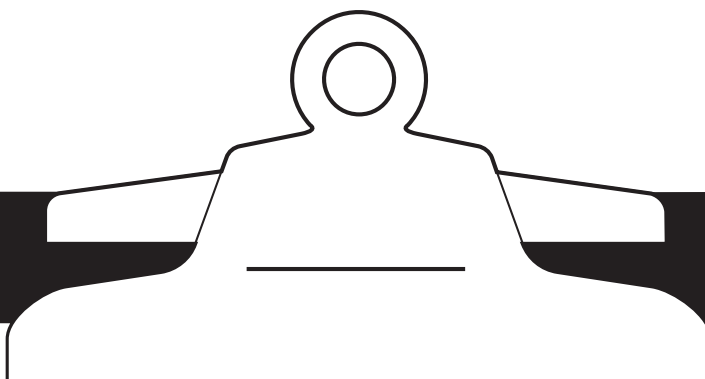
Faults

Faults are breaks in Earth's outer layer, the crust. Since Earth is round and the crust is somewhat brittle and under stress, cracks form, especially near plate boundaries as in many parts of California. The brick & board demonstration is one way of modeling earthquakes. The surface between the brick and the board is like a fault. Each piece of "earth" (the brick or the board) can move relative to the other along this surface. However, because of the sandpaper (which creates friction, or stress, due to the brick's weight) the two pieces cannot always slide easily. In this way, the friction represents stress building up in the earth near a fault just before an earthquake. When the stress is too great, the earth moves and releases the energy in the form of seismic waves (see below). The stretching rubber band represents slow, steady movement of earth (on one side of the fault) and illustrates the buildup of stress in the ground. When the brick eventually moves it represents the movement of Earth's crust along a fault during an earthquake. Importantly, as shown in the brick and board demonstration video clip, the slipping of the brick is not the end result. Instead, the vibrations that are generated by the slipping, that move through the board, the cup, and into the water to generate waves are what we call an earthquake. The moving brick itself represents a permanent shift of the ground, but most places in the world only feel the vibrations (seismic waves) when they experience an earthquake.

Seismic waves

Earthquakes release energy in the form of seismic waves, vibrations of the earth. These waves move in all directions from the center of an earthquake. There are two kinds of seismic waves, primary (P) and secondary (S). P waves compress the ground ahead of them as they move forward. This is like a sound wave (compressions of the air) only the earth is the medium through which the wave travels. S waves move the ground in a direction perpendicular to the direction the wave travels. Just as a cork bobs up and down as a water wave moves past, the earth moves up and down as an S wave moves through.

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Seismometers

Seismometers measure vibrations in the earth, recording P and S waves. P waves travel faster than S waves and since scientists record the time of arrival for each wave at a given seismometer location, they know how far away the seismometer is from an earthquake's center. If three or more seismometers are used, then the method of triangulation pinpoints the origin of an earthquake.

Magnitude and Intensity

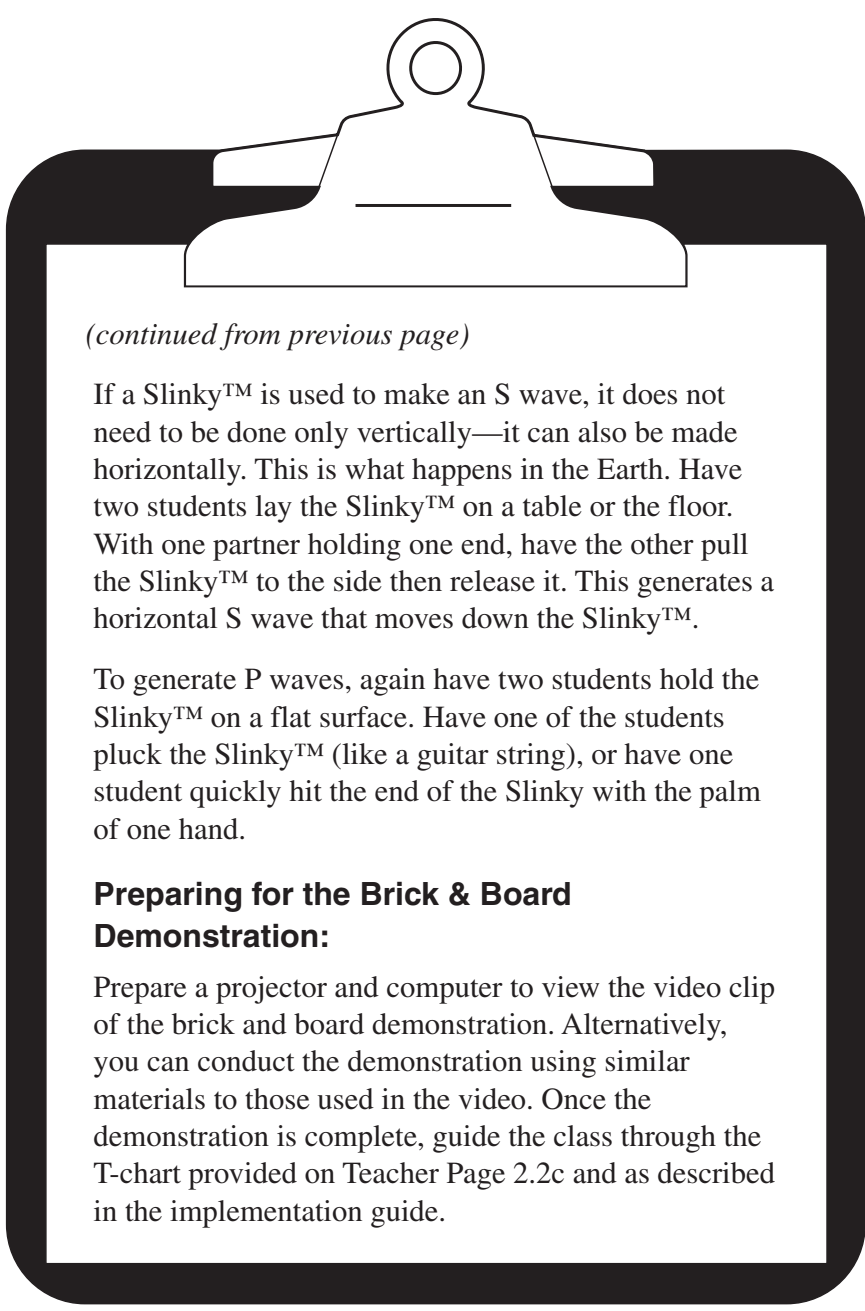
The terms magnitude and intensity describe earthquakes. Magnitude is a measure of how much energy an earthquake releases. Intensity refers to how much the ground shakes. Both are measured on logarithmic (not linear) scales because the amounts of energy and shaking vary tremendously between different earthquakes. On logarithmic scales, an increase by one unit represents a much larger factor. Scientists use the Moment Magnitude Scale to describe magnitude, though you may be familiar with the Richter Scale, a slightly older, but similar type of scale. On the Moment Magnitude Scale, a magnitude (M) 3 earthquake is one unit larger than a M2 earthquake. However, the M3 releases 32 times more energy than the M2! For each unit on the Moment Magnitude Scale, the energy released by an earthquake increases 32 times. This scale also relates to intensity. Each unit represents 10 times more capacity to shake the ground. For example, an M6 shakes the ground 1000 times harder than an M3 (difference of 3 units = $10 \times 10 \times 10 = 1000$). Intensity varies from place to place, depending on how far you are from an earthquake's center and what kind of ground you are on (solid rock, sand, or other sediments).

Advance Preparation

Planning for P & S wave modeling using a Slinky™:

When having students model an S wave, have them work in pairs. One partner holds the end of the Slinky™ and then shakes it once vertically. Understand that the harder they shake it, the larger the height of the wave that moves down the Slinky™. Scientists say this wave has larger amplitude. Large magnitude (M) earthquakes have the ability to generate P and S waves of large amplitude.

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If a Slinky™ is used to make an S wave, it does not need to be done only vertically—it can also be made horizontally. This is what happens in the Earth. Have two students lay the Slinky™ on a table or the floor. With one partner holding one end, have the other pull the Slinky™ to the side then release it. This generates a horizontal S wave that moves down the Slinky™.

To generate P waves, again have two students hold the Slinky™ on a flat surface. Have one of the students pluck the Slinky™ (like a guitar string), or have one student quickly hit the end of the Slinky with the palm of one hand.

Preparing for the Brick & Board Demonstration:

Prepare a projector and computer to view the video clip of the brick and board demonstration. Alternatively, you can conduct the demonstration using similar materials to those used in the video. Once the demonstration is complete, guide the class through the T-chart provided on Teacher Page 2.2c and as described in the implementation guide.

Implementation Guide

1. Engage the class by asking student volunteers to share what evidence they have for sudden movements of Earth's surface. Use the *Exploring Earth's Surface* chart as needed. Ask students what sorts of damage they have seen from earthquakes. Use a discussion strategy such as a Think-Pair-Share to involve students in discussing a prediction for the question:

- How do earthquakes cause the kinds of damage that they often cause?

Acknowledge that it is complicated even for scientists to answer that question. It may be simple to see the different types of damage caused by an earthquake, but explaining **how** the earthquake causes damage is challenging.

Share with the class that because they are behaving like scientists in this unit, they will need to rely on evidence to answer and explain questions. Explain that *Student Page 2.2A: Earthquake Basics* includes some evidence related to the question about earthquake damage that will help to develop a scientific answer.

- Have students individually read the first two sections of *Student Page 2.2A: Earthquake Basics* using an appropriate reading strategy. Instruct them to record, in their Science Notebooks, any information from the reading they might use to answer the question, How do earthquakes cause the kinds of damage that they often cause?
- Have students talk briefly in pairs about the evidence they collected from the reading.

2. Explain to students that understanding the way P and S waves move might be easier if they could see the P and S waves rather than just the damage that the waves cause or a picture of how the wave moves. Provide each pair of students a copy of *Student Page 2.2B: Your Own P and S Waves* and a Slinky™.

Allow students time to practice modeling the P & S wave motion. As an added challenge for advanced students, see if they can measure the difference in speeds between P & S waves modeled with the Slinky™. This can be done using a stopwatch to time the wave from start to finish along the Slinky™. (Note: a long Slinky™ works best to measure the difference).

3. Ask students what they know or think about what scientists do to learn about seismic waves. Use a Think-Pair-Share to find out what students already know about this question:

- How do scientists measure and study seismic waves?

Explain that the rest of *Student Page 2.2A: Earthquake Basics* has evidence to explain how scientists learn about these waves.

- Have students individually read the remainder of the article and again record in their Science Notebooks any evidence for answering the question, How do scientists measure and study seismic waves?
- Conduct a whole-class discussion, and collect student ideas on the *Exploring Earth's Surface* chart.

4. Explain to students that while they have learned a lot about what causes earthquake damage, an even bigger question is: What causes an earthquake?

Ask students to predict what the root cause of an earthquake is. Explain that you have a demonstration to show that may provide more evidence for making their predictions.

- Show the video of the brick and board demonstration that is provided on the Unit's CD. Use a "pause" feature on the movie to highlight particular observations that the class makes.

- To make connections between the brick and board model to the real world, use the T-chart on *Teacher Page 2.2c: Brick & Board Model of Earthquakes*.
- This chart lists the major pieces of the model and what they represent in nature.
- Note that some terms for the right-hand column will be introduced later (like “Plates”—large pieces of Earth’s crust).
- Use this chart to introduce terms students have not yet learned like ***fault***. The list could be generated first by students, in their own words, and the scientific terms can then be applied.

5. Give students 2–3 minutes to reflect on what they learned during this lesson about earthquakes

and their causes. Have students work individually to record in their Science Notebooks a list of things learned, unanswered questions, and ideas. Then, work with the whole class to generate one entry for the *Exploring Earth’s Surface* chart. The entry might look something like the table below.

6. Use the Recall, Extend, and Analyze questions to informally assess student understanding as they read, experience the Slinky™ activity, and analyze the brick and board demonstration, respectively.

The Predict question can be used near the end of the lesson to foreshadow the next lesson.

The Self-assess question can be used to guide students to seek extra resources such as those provided on this Unit’s CD for further investigation into earthquakes and other processes on Earth.

Earthquakes cause seismic waves (P and S waves)	seismometers	They help us locate the epicenter of an earthquake.
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Student Page 2.2A: Earthquake Basics

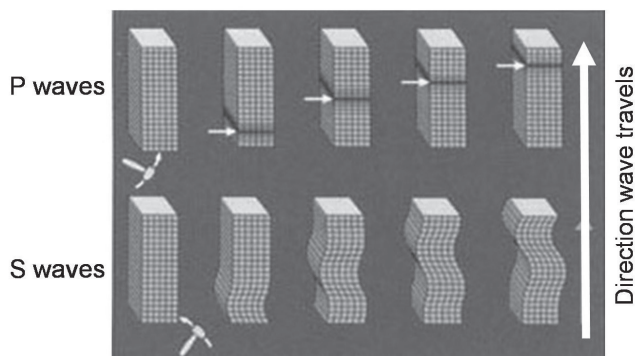
What is an earthquake?

An earthquake is the name for an event where the ground shakes and the earth moves. Earthquakes happen naturally all over the world. They usually happen suddenly, with no warning.

What happens during an earthquake?

When an earthquake occurs, the ground shakes, or vibrates. These vibrations can destroy buildings, roads, and cause other damage like you have probably seen in photographs or on video. Scientists call the vibrations **seismic waves**.

Earthquakes create two kinds of seismic waves. There are primary waves and secondary waves. Scientists often refer to them as P and S waves. These waves both travel away from the center of an earthquake, called the focus. However, they move in two different ways. P waves push and pull the earth in the same direction they are moving. S waves move the earth up and down or side to side. The picture below shows the idea by using a hammer to represent how the wave begins.

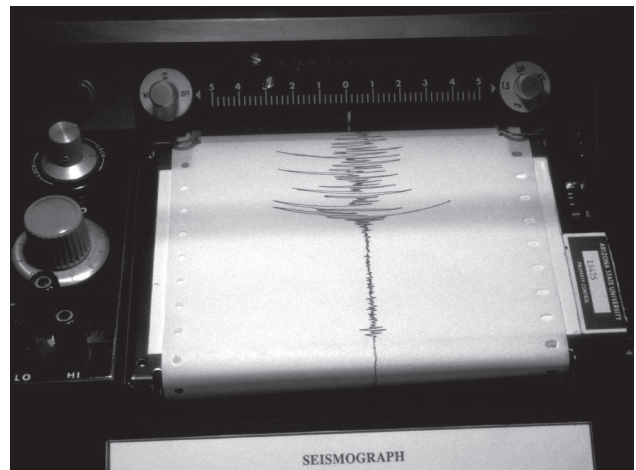


[Illustration adapted from USGS Earthquake Hazards Program.]

P waves travel faster than S waves. They reach a given point first. This is why they are called primary waves. S waves always arrive a little bit later.

How do scientists measure earthquakes?

To measure earthquakes, one of the tools scientists use is a seismometer. **Seismometers** measure seismic waves. Seismometers are measuring seismic waves right now all around the world! When a seismic wave shakes the ground, seismometers record the amount of shaking. Older seismometers mark the vibrations on a long roll of paper. They use a pen attached to the end of a small needle. The vibrations make the needle (and the pen) go back and forth across the paper. The measurement on the paper is a **seismogram**. Modern seismometers create seismograms using computers.



Seismometer recording an earthquake.

[Image courtesy Oklahoma University, photo by Albert Copley. Image source: Earth Science World ImageBank]

Since P & S waves move at different speeds, the recording station (seismometer) always records a P wave first. A seismometer records S waves a little bit later. The more time between the two waves, the further away the recording station is from the epicenter. The epicenter is the point on the surface of the earth directly above the source of the earthquake, or focus. By measuring P and S waves with seismometers, scientists can learn where and when earthquakes happen. They can also learn about the structure of Earth.

(continued on following page)

How big is an earthquake?

Have you ever heard someone talk about an earthquake by number? Scientists measure how big an earthquake is and use numbers to compare the sizes of different quakes. The size is called the **magnitude** (M) of the quake. An earthquake with larger magnitude is more energetic. Larger earthquakes release more energy and last longer, too.

Scientists use magnitude numbers to compare quakes. If two quakes have the same magnitude, they release the same amount of energy. An M6.7 earthquake is M6.7 no matter where you are. What about an M3 compared to an M2? The M3 is one unit of magnitude bigger than the M2. For each unit the magnitude increases, the energy released by the quake increases 32 times! For example,

an M3 is 32 times more energetic than an M2!

Magnitude also tells scientists about how much the ground shakes. For every unit the magnitude increases, the ground shakes 10 times harder.

For example, an M3 shakes the ground 10 times harder than an M2. Scientists call this earthquake rating system the Moment Magnitude Scale.

How much shaking you actually feel in an earthquake is called the **intensity**. Unlike magnitude, the intensity of an earthquake changes from place to place. It depends on how far you are from the center of the earthquake. It also depends on what kind of ground you are standing on. Why is this way of measuring earthquakes less consistent than magnitude?

Student Page 2.2B: Your Own P and S Waves

S Waves

You can make your own P and S waves by using a simple toy. Take the Slinky™ that your teacher provides. Hold onto one end while a partner holds onto the other end. Stretch it out. Then, shake one end up and down (or side to side) so that a small wave travels along the Slinky™. This wave is just like an S wave. The coils move up and down (or side to side) as the wave moves from one end to the other.

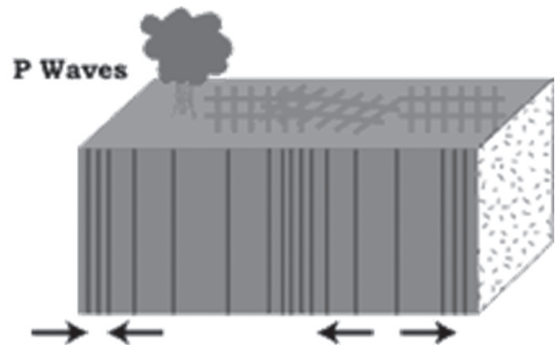


[Figure courtesy USGS]

P Waves

Now try to model a P wave. A P wave moves objects in the same direction that it travels.

Try to create a P wave using the Slinky™. In what directions do you have to move one end of the Slinky™ to create P waves?



[Figure courtesy USGS]

In your Science Notebook, draw a simple picture or write a few sentences to describe how you modeled P and S waves with the Slinky™.

Teacher Page 2.2c: Brick & Board Model for an Earthquake

Item in Demonstration	What it Represents in the Real World
Board	A piece of Earth (including solid rock)
Brick	Another piece of Earth
Brick/board interface	Break in Earth (Fault)
Rubber band & Sandpaper	Together, they represent the very slow build-up of force (stress or friction) in the rocks in Earth before an earthquake
Cup of water	The ground through which waves travel
Little waves in water	Seismic waves (P & S waves) THE EARTHQUAKE!
Sliding of brick	Permanent movement of ground

Key Concepts

- Earthquakes and volcanic eruptions occur in a pattern around the world.
- Volcanic eruptions often occur in regions that also have earthquakes.

Evidence of Student Understanding

The student will be able to:

- identify patterns in seismic data around the world.

Time Needed

80 minutes (with suggested breakpoint)

Materials

For each student

- 1 copy of *Student Page 2.3A: Investigating Sudden Events*

For each region group

- *Seismic/Eruption*  computer software—FULL version and computer station (or printed data and maps)

Analyzing Seismic Data

1. Have students reflect back on and share their ideas from the Predict question in Lesson 2.2: *How often do earthquakes happen and where do earthquakes happen?*
 - Share the latest USGS data, showing earthquake activity for the last few days, and compare it to students' ideas.
2. Ask students to recall from the previous lesson what information scientists need to determine the location of an earthquake.

(continued on following page)

REAPS Questions

- R** What type of earthquake is most common, large or small-magnitude? What size volcanic eruption is most common? Small earthquakes are frequent. Large earthquakes are less frequent. Volcanic eruptions vary in type and intensity.
- E** Describe where you find most earthquakes and volcanic eruptions around the world. Earthquakes happen mostly in the middle of the oceans and sometimes near large islands or the edges of continents. Volcanoes erupt in many of the same locations.
- A** Explain at least one pattern you observed in the information about where and when earthquakes and volcanoes occur. Answers will vary based on the investigation that students conducted but the general pattern is that they occur in similar places, forming lines on the map of Earth, and these lines do not consistently follow continent, ocean, or country borders.
- P** Explain why you think volcanic eruptions and earthquakes often occur together in particular regions of the world. Answers will vary. Use this statement to informally assess what students know about the relationship between earthquakes and volcanoes.
- S** Record one entry for the class *Exploring Earth's Surface* chart in your science notebook. Compare entries with a partner and then share with the class.

- Practice locating earthquake epicenters with the *epicenter plotting activity* that is as referenced in the LAUSD Middle School Science Instructional Guide pages 5–13.

3. Once students complete enough manual epicenter plotting to understand what procedures a software program automates so that scientists can work with large amounts of earthquake and volcano data, introduce the *Seismic/Eruption* software.

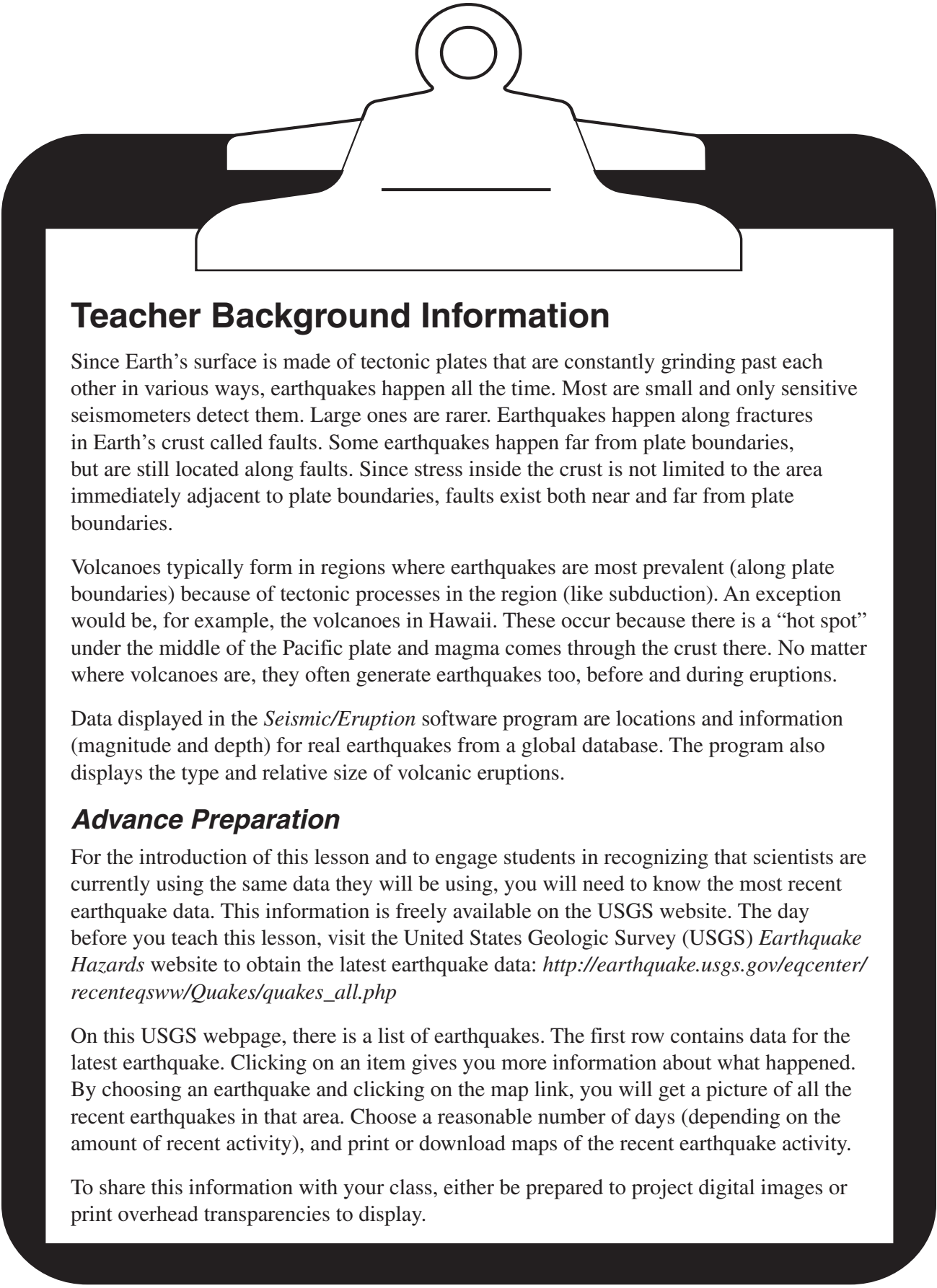
- Explain that this software plots data for earthquakes and volcanoes that have happened on Earth since 1960.

4. Guide students through using *Student Page 2.3A: Investigating Sudden Events*. Focus student attention on global patterns of earthquakes and volcanic eruptions.

5. Provide students with the *Seismic/Eruption* software and computer stations (or printed data). Monitor progress with the Student Page, especially the *Developing Explanations* section.

6. Use the REAPS questions to guide a discussion about patterns in earthquake and volcano locations.

7. Work as a whole class to add new evidence to the *Explaining Earth's Surface* chart, and explain that this chart is the primary resource for revising the region models in the next lesson.



Teacher Background Information

Since Earth's surface is made of tectonic plates that are constantly grinding past each other in various ways, earthquakes happen all the time. Most are small and only sensitive seismometers detect them. Large ones are rarer. Earthquakes happen along fractures in Earth's crust called faults. Some earthquakes happen far from plate boundaries, but are still located along faults. Since stress inside the crust is not limited to the area immediately adjacent to plate boundaries, faults exist both near and far from plate boundaries.

Volcanoes typically form in regions where earthquakes are most prevalent (along plate boundaries) because of tectonic processes in the region (like subduction). An exception would be, for example, the volcanoes in Hawaii. These occur because there is a "hot spot" under the middle of the Pacific plate and magma comes through the crust there. No matter where volcanoes are, they often generate earthquakes too, before and during eruptions.

Data displayed in the *Seismic/Eruption* software program are locations and information (magnitude and depth) for real earthquakes from a global database. The program also displays the type and relative size of volcanic eruptions.

Advance Preparation

For the introduction of this lesson and to engage students in recognizing that scientists are currently using the same data they will be using, you will need to know the most recent earthquake data. This information is freely available on the USGS website. The day before you teach this lesson, visit the United States Geologic Survey (USGS) *Earthquake Hazards* website to obtain the latest earthquake data: http://earthquake.usgs.gov/eqcenter/recenteqsww/Quakes/quakes_all.php

On this USGS webpage, there is a list of earthquakes. The first row contains data for the latest earthquake. Clicking on an item gives you more information about what happened. By choosing an earthquake and clicking on the map link, you will get a picture of all the recent earthquakes in that area. Choose a reasonable number of days (depending on the amount of recent activity), and print or download maps of the recent earthquake activity.

To share this information with your class, either be prepared to project digital images or print overhead transparencies to display.

Implementation Guide

1. To elicit students' thoughts about where and when they think earthquakes happen, ask them to share their answers from the Predict question in Lesson 2.2: *How often do earthquakes happen and where do earthquakes happen?*

After several students share their responses, continue the discussion, and re-focus it with questions that are more specifically targeted to reveal what students know or think about where and when earthquakes happen. Use questions such as:

- When do you think the last earthquake occurred? Yesterday? Last week? A few years ago?
- How often do you think there is an earthquake somewhere in the world?
- Does every part of the world experience earthquakes?

Once several ideas are part of the discussion, share recent earthquake data with the class. Present some data from the USGS *Earthquake Hazards* website as described in Advance Preparation. Discuss students responses by asking questions like:

- Is this the kind of data you predicted?
- Does this data support your ideas?
- Does it tell you something different?

2. Once students are familiar with some data, ask if they remember how scientists determine where an earthquake happens. Guide students to recall the information about seismometers and seismic waves from Lesson 2.2, and explain how in this lesson they will be working like scientists to locate some earthquakes. Practice the procedure for finding earthquake epicenters by referring to the activity referenced in the LAUSD Middle School Science Instructional Guide on pages 5–13.

Depending on how many examples students work through, this may be a good breakpoint for the lesson, setting the stage to start the second half by continuing to analyze data about earthquakes

and volcanic eruptions using the *Seismic/Eruption* software program.

3. After students complete enough manual epicenter plotting to understand what procedures a software program automates so that scientists can work with large amounts of earthquake and volcano data, introduce the *Seismic/Eruption* software.

- Explain that because earthquakes happen so often, there is a lot more data that they could plot. When scientists have so much data, they often use computers to help them do the same tasks that would take a lot longer to do manually.
- Explain that the computer software program, *Seismic/Eruption*, plots data for earthquakes and volcanic eruptions in a way that is similar to how the students did in the plotting activity.
- In addition, tell students that the program will plot the locations, magnitude, and depth of all earthquakes and the locations and type of volcanic eruptions that have happened on Earth since 1960.

4. Inform students that the computer program is a tool to explore evidence that may explain answers to some of their questions about where and when earthquakes occur. Distribute *Student Page 2.3A: Investigating Sudden Events*.

- Explain the type of data they have to work with:
 - locations
 - magnitude
 - depth
 - date of earthquakes around the world for the last 40+ years
 - locations and type of volcanic eruptions for the last 40+ years

Allow students to get into pairs and choose a question that they may be able to explore with the available data. Ask questions such as:

- Which of your questions could be answered with the data you will have?

Step 1 in the student page focuses on what question students hope to answer. Travel around the groups to make sure students are planning to investigate good questions. In general, questions should be answerable by the type of data they have. They can vary several things about what the program displays including the range of dates, size of earthquakes, and regions of the world. Here are some example questions that students could answer using the data available:

- Where do earthquakes occur?
- Where do volcanic eruptions occur?
- Do big earthquakes and small earthquakes happen in the same or different locations?
- Do earthquakes happen near volcanic eruptions?

Avoid questions that focus on single details or particular regions rather than comparisons. For example:

- Where was the biggest/smallest earthquake/volcanic eruption ever?
- How many earthquakes happened in California last year?

While these questions are interesting, they do not lead students to develop an understanding the global patterns of earthquakes and volcanic eruptions. Identifying this pattern is critical to developing an understanding of plate tectonics. If student questions are focused on a region instead of the world, explain that in the next lesson they will get to look at their specific regions, and that in this lesson they should focus on global patterns.

Work with students to revise questions that are too narrow to lead to an understanding of global patterns into comparison questions like:

- Do small and large earthquakes happen in the same places?
- Where are earthquakes most common?

Also, avoid “why” questions and those that focus on causes like, “Why do earthquakes happen?” and “What causes volcanic eruptions?”. The software shows data. It does not explain why the data is the way it is. It simply reports what happened when. Work with students to revise “why” questions into “where”, “what”, or “how” questions like:

- Where do earthquakes happen?
- What sizes of earthquakes are most common?
- How many volcanic eruptions happen at the same time or places as earthquakes?

Allow students time to complete steps 2 and 3 on their student page. Be sure that student predictions are based on what they know thus far about earthquakes and volcanic eruptions. Predictions are not just random guesses. A good prediction offers a logical explanation for the question. It may not be correct, but it should have some logic behind it. Step 3 focuses on getting students to think about what type of data they need the program to display in order to be able to answer their question. This is only a starting point for students. They may find that once they get started studying the data that they need to change the length of time or some other aspect of the data, in order to see the whole pattern.

4. Provide students with the *Seismic/Eruption* program and computer stations (or printed data). Guide students to set the software so it displays the data they indicated that they needed on their student page, and begin studying what the data looks like. Prompt them with questions like these to encourage them to notice global patterns:

- What patterns do you see in the data you have displayed?
- What similarities or differences do you see between the volcano and earthquake data?

- Would it help you to see the patterns if you changed what data is displayed?

When studying the data, students may begin to notice patterns aside from what their investigation question focuses them on. These patterns will likely generate additional questions. As the students progress through the activity, encourage them to write down other questions they develop and explain that this is a natural part of scientific inquiry.

Pay particular attention to how students are completing the “Developing Explanations” section. It is important to check that answers to students’ questions are based on data displayed by the program. To assist student’s in noticing patterns and developing evidence-based explanations draw the class’ attention to groups that are having high-quality discussions that can be used as examples.

If students develop more questions that can be answered using the program, have them complete another student page or record their questions, observations, and explanations in their Science Notebooks as time permits.

5. Continue developing an understanding of the worldwide patterns in earthquake and volcano locations by leading is meant to elicit students’ observations about how earthquakes and volcanoes generally exist together in a specific pattern around the world—they do not happen randomly in all parts of the world.

6. Use student notebook entries to add a line or two to the *Exploring Earth’s Surface* chart. Explain that this new evidence will be used in the next lesson when students revise their region models. At this point in the unit, the chart might look like the following:

Exploring Earth’s Surface

What did we observe about Earth’s surface today?	How were those observations made by scientists?	What can we learn from those observations?
We saw mountains, valleys, and oceans.	First-hand observations, still and video cameras.	Earth’s landforms are different in different places.
Sometimes the ground shakes.	First-hand observations, seismometer recordings.	Earth’s surface can move suddenly.
We saw damaged buildings and roads.	First-hand observations, photos of damage.	
Locations of earthquakes and volcanic eruptions.	Seismometers (and computers for display).	Earthquakes and volcanic eruptions happen in similar locations.
		Earthquakes and volcanic eruptions happen mostly in particular regions around the world.

Student Page 2.3A: Investigating Sudden Events

Name _____

Date _____

1. Scientific Question

What do you want to know about the locations and timing of earthquakes or volcanic eruptions?

2. Prediction

What do you think are possible answers and why?

3. Required Data

What data will you need to answer the question?

(continued on following page)

Student Page 2.3A: Investigating Sudden Events (continued)

If you are using the Seismic/Eruption software program...

How will you set the program so it shows you the data you need?

1. Will you look at earthquakes or volcanic eruptions or both?
2. Will you look at all the data since 1960 or will you look at a certain years? If you will look at only certain years, which ones?
3. Will you look at all magnitudes and/or intensities or specific magnitudes and/or intensities? If you will look only at specific ones, which magnitudes and/or intensities will you look at?

4. Describing the Data

What did the data tell you?

(continued on following page)

Student Page 2.3A: Investigating Sudden Events (continued)

5. Developing Explanations

What do you think is the answer to your question? Explain what you learned that helped you answer your question.

6. New questions?

What new questions do you have after seeing the data?

Step 2 Lesson 4 Snapshot

Key Concept

- Scientific models are based on evidence.

Evidence of Student Understanding

The student will be able to:

- modify a physical model to make it better represent and/or explain the evidence available about the landforms in a particular a world region.
- describe what a scientific model is and how scientists use them.

Time Needed

45 minutes

Materials

For each student:

- 1 copy of *Student Page 2.4A: What is a Scientific Model?*
- 1 copy of *Student Page 2.4B: Developing My Scientific Model*

For each group of 2–4 students

- Seismic/Eruption  computer software—SCALE version and computer station (or printed data and maps)
- modeling materials (can include modeling clay, paper, cardboard, popsicle sticks, tape, toothpicks, straws, paper cups, cotton balls, or other common materials that students will use to modify physical models of the regions)

Scientific Modeling

1. Allow students to study seismic data specific to their regions from the SCALE version of Seismic/Eruption.

- Focus students' attention on searching for patterns in the data by asking questions such as:
- Do earthquakes/volcanic eruptions occur everywhere on Earth?
- Do earthquakes/volcanic eruptions happen in the same or different locations?
- What patterns do you see in the data?
- Is there a relationship between the continents' coastlines and where the activity occurs?

2. Give students an opportunity to review their analyses of seismic data in their region groups.

- Explain that they will need to ask questions about their region models later in this lesson to see if they explain all that they know about that region.

(continued on following page)

REAPS Questions

- R Why do scientists use models?** Scientists use models to explain and predict things that are difficult to observe directly.
- E What changes did you make to your model to make it more scientific and reflect evidence of seismic activity?** Answers will vary. Use them to assess your students' level of familiarity with scientific modeling at this point.
- A Describe how the locations of landforms in your region compare to the locations of earthquakes and/or volcanic eruptions you just analyzed.** Answers will vary, but students may point out landforms in their region that coincide with earthquake and/or volcanic eruption data.
- P What might cause you to revise your model again in the future?** Uncovering new evidence.
- S** In your Science Notebook, write down one thing that scientists do that you did not know before today.

3. Ask for student ideas on what a scientific model is. Use an appropriate reading strategy for students to read individually or as a group *Student Page 2.4A: What is a Scientific Model?*

4. Review the Explaining Earth's Surface chart. Emphasize the evidence that students have learned about up to this point.

5. Use a Think-Pair-Share for students in region groups to list at least two questions they have about how well their models represent and explain the evidence available so far about their region.

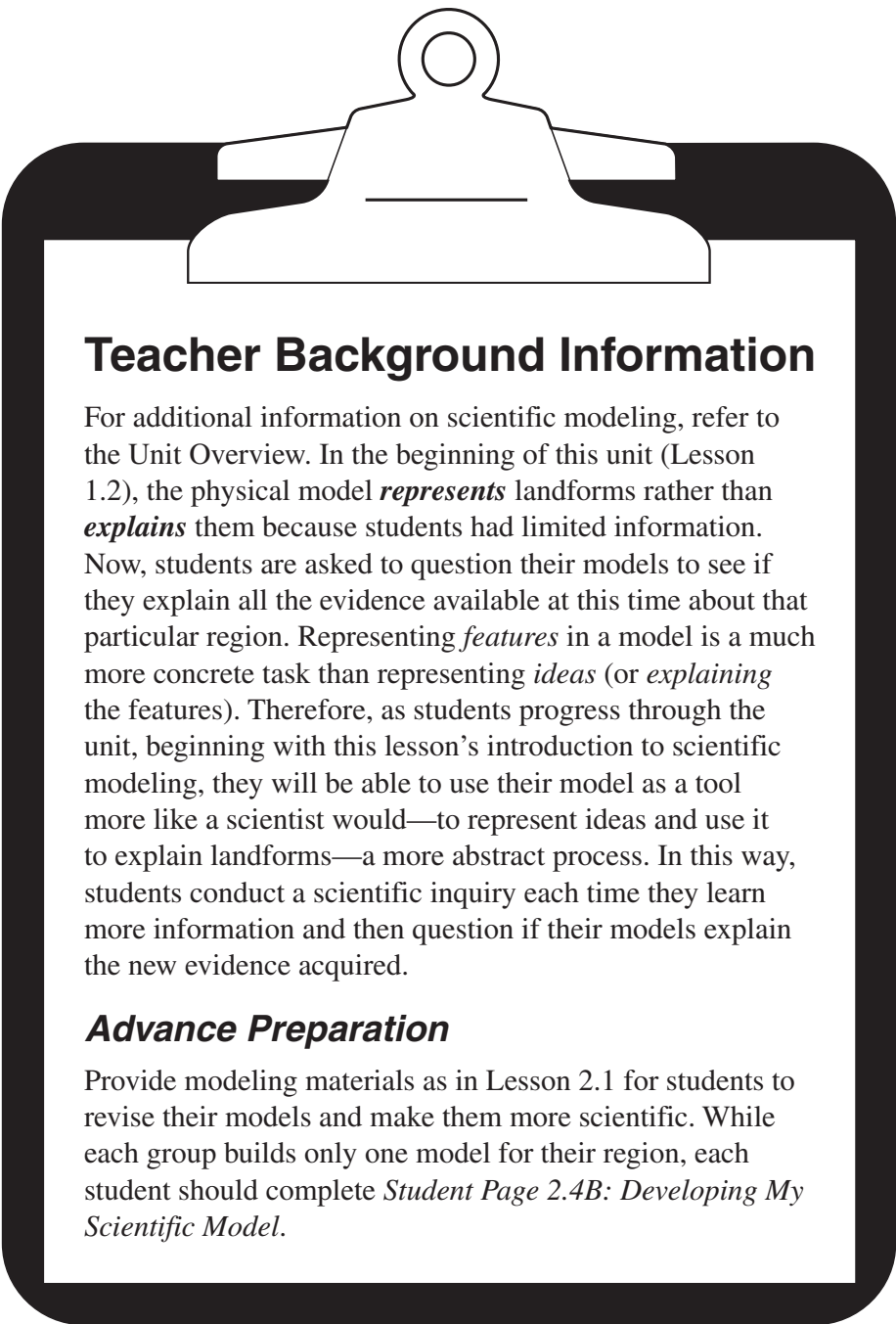
- Instruct students to plan the revision of their initial physical model to explain more

accurately the known evidence. Guide students through completing *Student Page 2.4B: Developing My Scientific Model*.

6. Provide modeling materials for students to modify models of their regions.

- Use a Think Aloud technique with the California region as an example before having student groups work on their regions.

7. Use the REAPS throughout and after the lesson as appropriate.



Teacher Background Information

For additional information on scientific modeling, refer to the Unit Overview. In the beginning of this unit (Lesson 1.2), the physical model **represents** landforms rather than **explains** them because students had limited information. Now, students are asked to question their models to see if they explain all the evidence available at this time about that particular region. Representing *features* in a model is a much more concrete task than representing *ideas* (or *explaining* the features). Therefore, as students progress through the unit, beginning with this lesson's introduction to scientific modeling, they will be able to use their model as a tool more like a scientist would—to represent ideas and use it to explain landforms—a more abstract process. In this way, students conduct a scientific inquiry each time they learn more information and then question if their models explain the new evidence acquired.

Advance Preparation

Provide modeling materials as in Lesson 2.1 for students to revise their models and make them more scientific. While each group builds only one model for their region, each student should complete *Student Page 2.4B: Developing My Scientific Model*.

Implementation Guide

1. Provide students with the SCALE version of the *Seismic/Eruption* software program. The *Seismic/Eruption* software is a tool used to visualize data for earthquakes and volcanic eruptions occurring around the world since 1960. By being able to select and view various combinations of data over the last 45+ years, students can identify patterns in the data which will help them understand the evidence scientists have for plate boundaries and plate movements—topics central to the theory of plate tectonics. Indeed, with this software, students themselves see the real data that scientists study. They can also manipulate that data to study questions they have about locations, magnitude, and depth of earthquakes and locations and types of volcanic eruptions.

Explain to students that an important part of thinking scientifically is to look for patterns in what we see and use those patterns as evidence to explain what we observe. Focus students' attention on searching for patterns in the *Seismic/Eruption* software data by asking questions such as:

- Do earthquakes/volcanic eruptions occur everywhere on Earth?
- Do earthquakes/volcanic eruptions happen in the same or different locations?
- What patterns do you see in the data?
- Is there a relationship between the continents' coastlines and where the activity occurs?

Note: *The Seismic/Eruption software is available on the Unit's CD. The SCALE version contains the same data that students saw in the FULL version, but it has been customized to contain groups of data specifically for the regions that students are studying. There are some minor bugs in this adapted program; however, it provides students with an opportunity to focus on evidence specific to their regions, and that will be important when asking questions about their models later in this lesson.*

2. Ask students to discuss in their region groups the patterns they observed while using the software.

- Explain that they will need to ask questions about their region models later in this lesson to see if they explain all that they know about that region.

One way students can organize their findings is to make a list of two or three major ideas that they gathered directly from the data. Students can use this list to develop questions about their models later in this lesson.

3. Introduce the idea that students are making scientific models in this unit. Ask the class what they think a scientific model is with prompting questions like:

- Do you know any scientists that work with models? What kinds of models do they use?
- What do you think makes a model scientific?

Once a “need to know” is established, use a classroom or individual reading strategy, and have students read *Student Page 2.4A: What is a Scientific Model?*

4. Use the Recall REAPS question and similar questions to check students' understanding after the reading. Also, emphasize how the class is going to be doing work like the work scientists do as they revise their region model in the next section. Review the *Exploring Earth's Surface* chart to see what new evidence was added since the class made their first physical models.

5. Use a Think-Pair-Share strategy to have students with the same region consider what questions they have about how well their models represent and explain the evidence available so far about their region. Have student groups develop at least two questions about their region and model. For example, students could ask:

- How does our model show that there are active volcanoes in our region?
- Where does our model need to represent earthquake activity to be accurate?

- What size does our model need to be to include important surrounding areas where there is earthquake activity that affects our region?
- Could we predict if an earthquake will happen in our region soon by looking at our model?

Discuss as a whole class the types of questions that the new evidence raises, and explain how this is what scientists do when they use models—they ask questions about how well the model explains and can predict what is known.

Have students plan their revision by using *Student Page 2.4B: Developing My Scientific Model*.

- You may choose to have students work in their region groups to plan the model revision. However, ***each student needs to complete the worksheet*** as it will be used later along with a collection with similar worksheets to explain how the model changed over time.

6. As in Lesson 1.2, provide simple modeling materials for students to revise their initial physical models based on the new evidence and questions it raised. Use a Think Aloud like the example below to demonstrate how to modify an existing model to improve its ability to represent, explain, and predict what is known:

Think-Aloud for first model update

Here is my physical model of California. A few lessons ago, I put a paper cup here representing Mt. Whitney, the tallest mountain in California, and I laid a piece of string along here to represent the coast along the Pacific Ocean. Now, I know a lot more about where and when earthquakes and volcanic eruptions occur in and around California. In fact, when I was looking at my own region with the computer program, I noticed that most of the earthquakes in California occurred along a line stretching from the southeast part of the state, north to the coast north of San Francisco,

which is about here on my piece of string.

How does my model show there are active earthquakes in this region? It does not. I want to represent those earthquakes because they are an important feature in this region and may be useful for explaining why California looks the way it does. I don't know why yet, but the pattern—earthquakes all in a line—seemed really striking, so I'm thinking there must be something going on there.

Here are some little stickers and toothpicks. I will stick a few toothpicks in the cardboard near where the largest earthquakes happened. There. Now I will mark the small earthquake locations with these little stickers. Okay, now I have represented some evidence that I just studied—the pattern of earthquakes around California. Wow, that looks interesting! Some of the mountains in California run right along this line of toothpicks and stickers. I am wondering if the earthquakes have something to do with the mountains.

Oh, but remember how the article told us about scale and legends? I wonder if anyone else who looks at my model will understand what the cup and the string represent. To be sure, I need to make a legend. So now, I'll take a marker, draw a little cup on the cardboard, and write that it means Mt. Whitney. And I'll take a little piece of string and write that it represents a coastline. Now someone else could understand my model even if I am not around to explain it.

Be sure to emphasize that students need to be sure their models represent all of the evidence they collected that fits their region. This includes earthquake data and volcanic eruption data. Some regions may have different amounts, but all contain evidence of some seismic or volcanic activity.

7. Use the rest of the REAPS (Extend, Analyze, Predict, and Self-Assess questions) as appropriate to assess student understanding by the end of this lesson.

Student Page 2.4A: What is a Scientific Model?

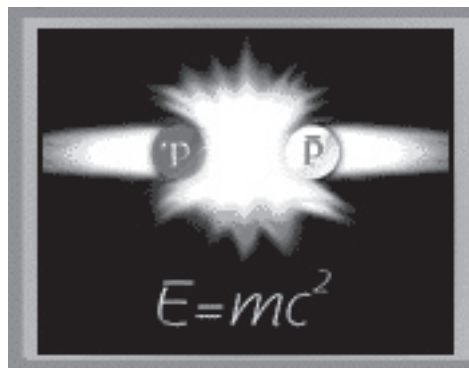
When you hear the word *model*, do you think of a toy car or airplane? Those objects are a kind of model known as replicas. There are other kinds of models, too. Scientists use models to investigate and explain their observations. For them, models are important tools. A **scientific model** is an idea or group of ideas that explains something in nature. A scientific model is a representation that helps scientists understand and predict events that are difficult to observe directly.

Different Kinds of Scientific Models

Some scientific models are similar to a model car or airplane. A model like that is called a **physical model**. A physical model is a real object that represents something in nature. Another kind of scientific model is called a conceptual model. A **conceptual model** is a particular explanation for relationships among ideas and/or observations. A conceptual model is invisible because it is made up of thoughts and reasoning. A conceptual model can be a mathematical expression. For example, have you ever seen the equation $E = mc^2$? That is a famous conceptual model developed by the scientist Albert Einstein.



Physical model of an airplane. (Photo courtesy NASA.)



*One of Einstein's famous conceptual models.
(Photo courtesy Fermilab, US Dept. of Energy)*

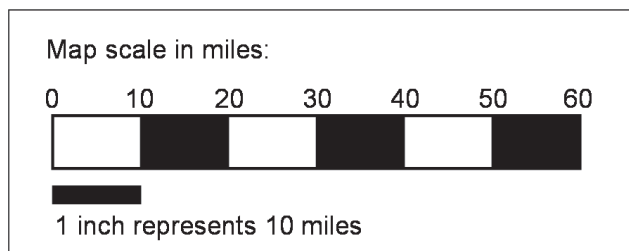
Scales and Legends

Some physical scientific models are the same size as the structure they represent. For example, a model may be a very accurate reproduction of a part inside a human being, like a heart or lung. Other models are built to a larger or smaller scale. **Scale** refers to a model that has all of its parts made bigger or smaller than the real object by the same amount. For example, the model of your region is a model of the surface of Earth in one part of the world. It may describe where hills and valleys are located. Since the whole surface of Earth (or even one continent) is too big to fit in the classroom, your region model is made to a smaller scale. A scientific model of the Earth's surface needs to be much smaller than the real surface to be useful.

If all the parts of a physical model are the same amount larger or smaller than the real object, then it is a **scale model**. A model that is 100 times smaller than what it represents has a scale of 1:100. A model that is 100 times larger than what it represents has a scale of 100:1.

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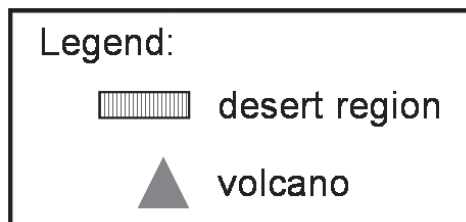
Student Page 2.4A: What is a Scientific Model? (continued)



Example of a scale bar that could be found on a physical model or map.

A model does not have to be a scale model. To bring attention to something, a model can have one unrealistically large part. For example, some of your class' region models may show mountains as being much taller than the rest of the features in the model. This emphasizes where the mountains are located. A model like this is still a physical model, but it is not to scale.

Some models contain a legend. A **legend** is a key to symbols that are used in a model. It tells people what the parts of the model show or represent. For example, on your region model you might draw a shaded region to show an area that is dry, like a desert. The legend would show that shaded pattern and explains what it represents. Similarly, a triangle might represent where a volcano is located. Then the legend would show a triangle and state that it represents a volcano. A legend makes it possible for other people to understand the model without the model-maker being present to explain it.



Example of a legend or key that could be found on a physical model or map.

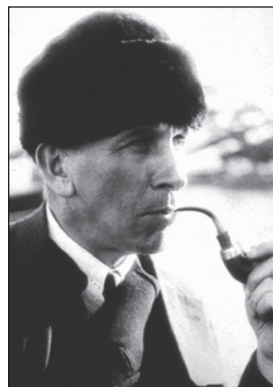
Scientific Models are Based on Evidence

Whether it is a physical or conceptual model, all scientific models are based on scientific evidence.

Scientific evidence is information that is directly observed about natural events, natural objects, or organisms. Scientists use evidence to design and test their models.

Do Models Ever Change?

Scientists are always testing their models. Sometimes, a model correctly predicts new evidence that is learned. Other times, learning new evidence causes scientists to change their models to be more accurate and to explain the new observations. If new evidence causes a model to be inaccurate, scientists may throw away an existing model and start all over with a new one. One example of someone who started building a model of Earth was a man named Alfred Wegener. In the early 1900s, he proposed a model to explain Earth's landforms and seismic activity, just as you are doing now. However, many scientists disagreed with him and did not accept his model. They disagreed until long after Wegener died. Then, new evidence was learned. When the new evidence was used to improve Wegener's first model, it more accurately explained Earth's surface. Many other scientists agreed with the improved model. It was able to predict things correctly. In fact, this is the model scientists still use today and which you will learn more about in this unit.



*Alfred Wegener (1880–1930)
Photo courtesy USGS.*

Whether they are testing, revising, or building new models, scientists use models in all types of scientific study. Both physical and conceptual models help us to make sense of the universe.

Student Page 2.4B: Developing My Scientific Model

Name _____

Date _____

What new evidence have I learned about my region that my model does not represent or explain? Now that I know more about my region and about scientific modeling, what is missing in my model?	What are my model's strengths? What does my model explain about Earth's surface in my region? List at least 2 questions you could ask about Earth's surface in your region that your model can answer.
What are my model's limits? What doesn't my model explain about Earth's surface in my region? List at least 2 questions you could ask about Earth's surface in your region that your model cannot answer yet.	Describe at least two different ways that you could get more information and evidence about your region and Earth's surface there.

STEP 3

Overview

Step 3 is a pivotal step in this Immersion Unit. Here, students learn something new and surprising—parts of Earth’s surface move slowly, in different directions, all the time! This movement is at an average rate of only a few centimeters per year, but it is significant. GPS technology measures this movement. Students explore a map of GPS data to see the direction and speed of movement of different areas of the world. Then, they simulate plate movement through a role-playing activity. This provides a basis for students to begin to think about what types of movement occur in the region they are modeling. Finally, students make a connection between GPS data and seismic data from Step 2. Once students have a chance to form their own explanation of plates, they learn how scientists describe plates. Students also revisit their scientific models to ask questions about how it explains Earth’s surface formations in their region.

The main purpose of this Step is to understand that Earth’s surface undergoes slow, steady movements in addition to the sudden movements learned in the last Step. Students connect this new idea to the location of earthquakes and volcanoes to discover tectonic plates and their interactions.

Step 3 Lesson 1 Snapshot

Key Concepts

- Earth's surface moves slowly and continuously, not just during catastrophic events.
- GPS is a tool used for direct measurement of slow surface movement.
- Different areas of Earth's surface move in different directions and at different speeds.

Evidence of Student Understanding

The students will be able to:

- recognize that different parts of Earth's surface move slowly, at different rates, and in different directions.
- describe how scientists measure slow movements of Earth's surface.
- calculate how fast a particular point on Earth's surface moves using GPS data.

Time Needed

45 minutes

Materials

For the class

- 3 pieces of string or yarn
- overhead transparency of *Student Page 3.1C: GPS Data Map*
- hand-held GPS (optional)
- Fingernail Activity extension (optional) 
- Geocache video clip 

For each student

- copy of *Student Page 3.1A: GPS Technology*
- copy of *Student Page 3.1B: GPS Data Analysis*
- copy of *Student Page 3.1C: GPS Data Map*

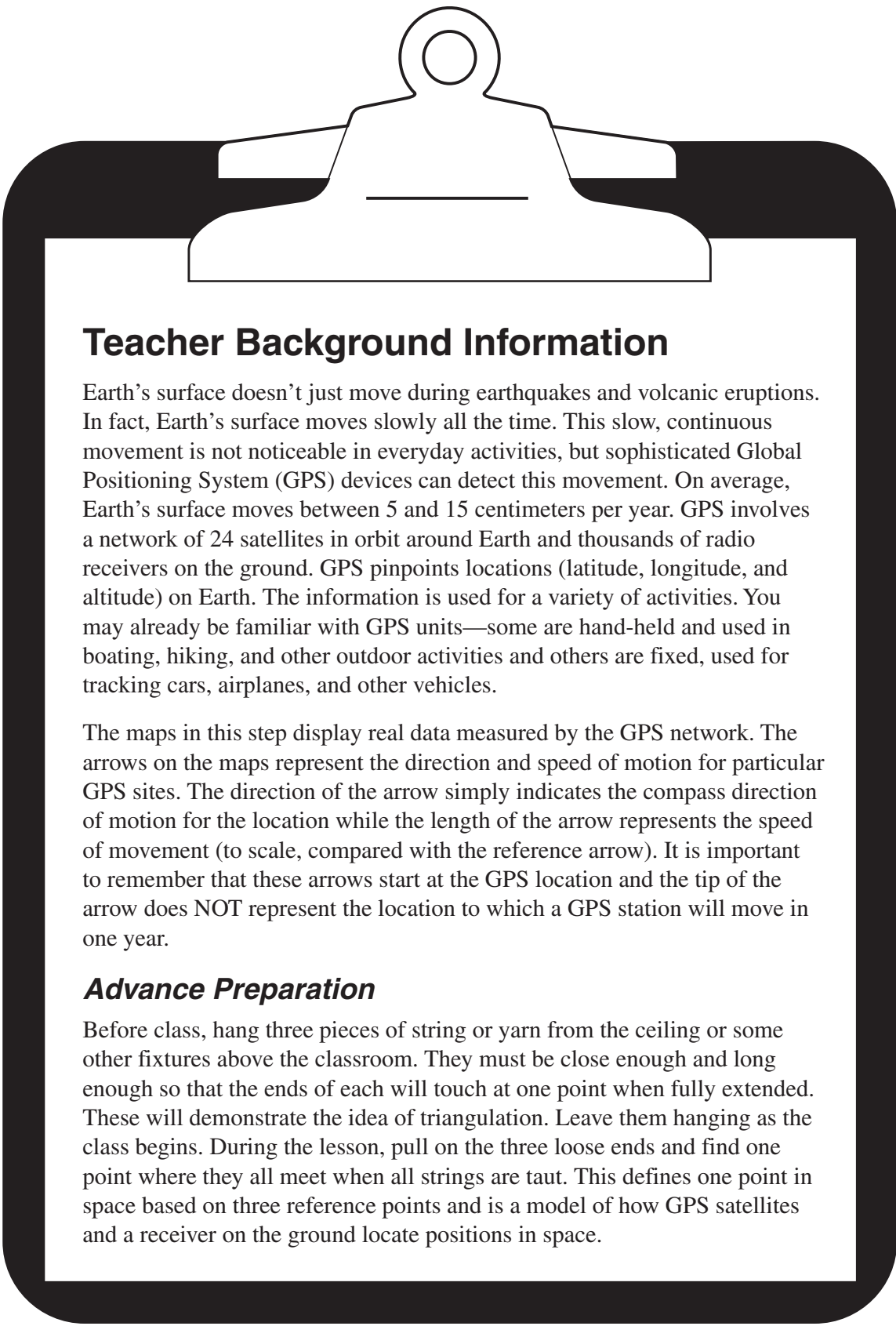
Tracking Slow Movements

1. To engage students in thinking about Global Positioning System (GPS) technology, begin this lesson by showing the class a video news story about geocaching, a popular hobby that uses GPS. Ask students if they have any experience with this hobby or other activities using GPS.
2. Have students read *Student Page 3.1A: GPS Technology* to explore GPS further.
3. Perform “How GPS Works” string demonstration. Explain how the 3-string model relates to the way that GPS satellites and receiver stations function.
4. Explain to students that there are fixed GPS stations located all around the world and scientists keep track of the locations for each of these stations.
 - Provide each student with *Student Page 3.1B: GPS Data Analysis* and *3.1C GPS Data Map*.
 - As a class, work through the first part of the *GPS Data Analysis* worksheet.
 - Have students get into groups to complete the remainder of the worksheet.
5. Conduct a class discussion about what the data reveals about Earth's surface.
 - Add the new evidence students collected to the *Exploring Earth's Surface* chart.
6. Use the REAPS throughout and after the lesson as appropriate.

(continued on following page)

REAPS Questions

- R What do the arrows on the GPS Data Map mean?** The arrows represent the direction and speed of motion for a particular GPS station on the ground. The length represents the speed based on a ratio to the reference arrow.
- E Describe why the arrows on your GPS maps are not the actual length that GPS stations move in a year. Are they shorter or longer, and why?** The arrows are shorter; they are scaled down to fit on the map.
- A What is different between slow movements of Earth's surface and earthquakes?** The differences are dramatic. Sudden movements can displace the earth by as much as several meters in a few seconds. Sudden movements also generate vibrations (seismic waves) which travel around the world and cause damage in an earthquake. Slow movements occur at the rate of centimeters per year and are not noticeable in everyday activities.
- P What do you think might happen close to where two stations on the GPS Data Map are moving in very different directions?** Answers may vary. Use this question to probe what students think about plate boundaries, which will be formally introduced in the next lesson.
- S Discuss with a partner your answers to the Predict question. Write down your ideas in your Science Notebook.**



Teacher Background Information

Earth's surface doesn't just move during earthquakes and volcanic eruptions. In fact, Earth's surface moves slowly all the time. This slow, continuous movement is not noticeable in everyday activities, but sophisticated Global Positioning System (GPS) devices can detect this movement. On average, Earth's surface moves between 5 and 15 centimeters per year. GPS involves a network of 24 satellites in orbit around Earth and thousands of radio receivers on the ground. GPS pinpoints locations (latitude, longitude, and altitude) on Earth. The information is used for a variety of activities. You may already be familiar with GPS units—some are hand-held and used in boating, hiking, and other outdoor activities and others are fixed, used for tracking cars, airplanes, and other vehicles.

The maps in this step display real data measured by the GPS network. The arrows on the maps represent the direction and speed of motion for particular GPS sites. The direction of the arrow simply indicates the compass direction of motion for the location while the length of the arrow represents the speed of movement (to scale, compared with the reference arrow). It is important to remember that these arrows start at the GPS location and the tip of the arrow does NOT represent the location to which a GPS station will move in one year.

Advance Preparation

Before class, hang three pieces of string or yarn from the ceiling or some other fixtures above the classroom. They must be close enough and long enough so that the ends of each will touch at one point when fully extended. These will demonstrate the idea of triangulation. Leave them hanging as the class begins. During the lesson, pull on the three loose ends and find one point where they all meet when all strings are taut. This defines one point in space based on three reference points and is a model of how GPS satellites and a receiver on the ground locate positions in space.

Implementation Guide

1. As an engaging introduction for this lesson, the Unit CD contains a video clip from a Pennsylvania TV news station about geocaching. This section is designed to engage students in learning about another area of scientific study that provides more evidence about how Earth's surface moves.

Begin this lesson by viewing the video clip as a whole class. It is about 4 minutes long. After watching the clip, gather student reactions to the story and ask if anyone has experience with geocaching or other activities involving GPS.

2. Explore GPS technology by providing students with *Student Page 3.1A: GPS Technology*. Use a classroom reading strategy or have students individually read the short article.

3. Use the three strings or pieces of yarn (set up before class) to demonstrate how GPS works. Introduce the idea of trilateration (a form of triangulation that is used by GPS receivers) by using the three strings:

- Where the three strings are attached to the ceiling represents three satellite locations.
- Where the three string-ends meet (when you hold them all together, and they are taut) defines one position in space—where the GPS would be located.

Explain that scientists use GPS to define points in space (latitude, longitude, and altitude) and to measure the movement of an object over time.

At this point, consider demonstrating GPS by using a handheld unit, if available. Doing an activity such as one in which students find their current location or where you set waypoints in advance for students to navigate through a schoolyard can be an engaging extension. Alternatively, if your school has a fixed GPS unit, the class could visit its station.

4. Explain to students that there are GPS stations located all around the world and scientists keep track of the location of these stations. Ask students to predict why scientists may want to keep track of the locations of GPS stations.

- Students may predict things like “after an earthquake, scientists could see how far the GPS station moved.”

Ask students if they think that the GPS stations would move any other time beside during something sudden like an earthquake, volcanic eruption, or landslide.

Explain that you have some data on the locations of GPS stations. Provide each student with *Student Page 3.1B: GPS Data Analysis* and *Student Page 3.1C: GPS Data Map*. Explain that the map shows the locations of GPS stations and the arrows represent how far and in what direction the GPS station moved in one year. Students may be surprised that GPS stations fixed in the ground are actually moving. Capitalize on that curiosity, by explaining that they are going to first figure out how far they move and then begin investigating what causes them to move that way.

As a class, work through the first procedure of the *GPS Data Analysis* student page. Make sure students know how to do the calculation. Have students get into groups to complete the second procedure, or allow students to work individually, and use the second calculation as a brief formative assessment.

Note: *There is an extension activity on this Unit CD that is appropriate for an ongoing investigation at this point to help students recognize how slow the motion of Earth's surface really is. In this extension activity, students learn that the movement is similar to the rate at which their fingernails grow. Refer to the Fingernail Extension Activity on the CD for details.*

5. Conduct a class discussion about the movements recorded by GPS. As you refer to a projection of the *GPS Data Map*, begin by asking students about the idea of scale:

- Why is there a reference arrow on this map?
- How far do the stations move each year?
- What does this tell us about the surface of Earth?
- How fast is the surface of Earth moving?

The REAPS Analyze and Predict questions could be used here to gauge student ideas about how

this evidence relates to sudden movements that students learned about in Step 2.

Use a Think-Pair-Share strategy to have students summarize the new information they learned in this lesson, and contribute ideas to form an entry for the *Exploring Earth's Surface* chart. At this point, the chart could look something like the table below.

6. Use any remaining REAPS questions to finish assessing student understanding after this lesson. The Self-assess question is particularly useful here for helping students make connections to the next lesson (discovering plates and plate boundaries).

What did we observe about Earth's surface today?	How were those observations collected?	What can we learn from those observations?
We saw mountains, valleys, and oceans	First-hand observations, still and video cameras	Earth's landforms are different in different places.
Sometimes the ground shakes	First-hand observations, seismometer recordings	Earth's surface can move suddenly
We saw damaged buildings and roads	First-hand observations, photos of damage	
Earthquakes cause seismic waves (P and S waves)	seismometers	They help us locate the epicenter of an earthquake.
Locations of earthquakes and volcanic eruptions	Seismometers (and computers for display)	Earthquakes and volcanic eruptions happen in similar locations
		Earthquakes and volcanic eruptions happen mostly in particular regions around the world
Land moves slowly	GPS stations and satellites	Parts of Earth's surface move slowly all the time

Student Page 3.1A: GPS Technology

Have you ever used a GPS unit to find your exact location? Or go on a treasure hunt called geocaching? Have you seen a GPS unit mounted in a car to give directions? Different people use GPS in different ways. Mountain climbers often carry a small, hand-held unit. They use it to keep from getting lost. Families, like the people in the news story, sometimes use GPS to find hidden treasure. Some taxi drivers have GPS units to provide them with directions.

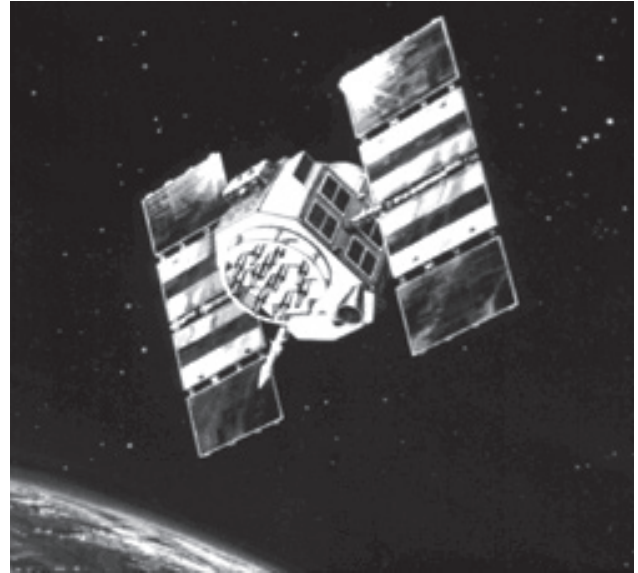
GPS units can be small enough to fit in your hand. They can also be larger and fixed to the ground or a building. The GPS unit in this photograph is at a school in Los Angeles.



[Image courtesy of Timothy P. Brown]

What is GPS?

GPS stands for **Global Positioning System**. Twenty-four GPS satellites orbit 20,000 kilometers above Earth's surface. They send special radio signals down to Earth. On the ground, there are GPS receivers. They pick up the radio signals from the satellites.



[Illustration of GPS satellite courtesy NASA]

How do these radio signals work? Think about how lighthouses communicate with boats. A lighthouse sends out signals in the form of flashes of light. A nearby boat captain sees the light signal. The signal tells the captain important information. The captain uses the signal to decide where to sail to avoid shallow water. The GPS system is similar. GPS satellites are like lighthouses. They send out signals with important information. The receivers on the ground are like boat captains. They receive the signal and use a computer to figure out their exact location. Then, different people use the information for different purposes.

How do scientists use GPS?

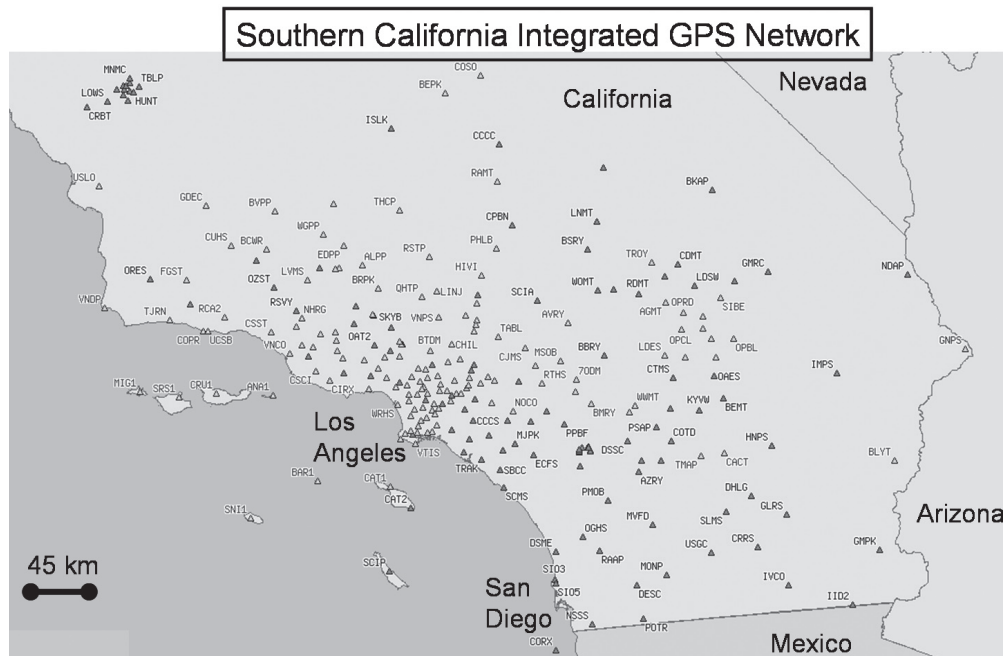
Scientists have thousands of special GPS receivers. These receivers (called stations) are fixed to the ground at specific locations around the world. Scientists study how the exact locations of these stations change. They use the information to figure out how Earth's surface moves. The GPS system is very accurate. Often, scientists can tell if a station has moved as little as one-half of a centimeter!

(continued on following page)

Student Page 3.1A: GPS Technology (continued)

There are 250 GPS stations in southern California. This group of stations is known as SCIGN. SCIGN stands for the Southern California Integrated GPS Network. It is an important tool for scientists who study how the earth moves in your area.

City Hall in Los Angeles was built in 1924. It is now about 3 meters closer to San Francisco than it was in 1924. How can a building on solid ground move?



Map showing locations of GPS stations in the SCIGN. Each small triangle represents a GPS station. [Image courtesy SCIGN.org]

Student Page 3.1B: GPS Data Analysis

Name _____

Date _____

Part 1: Do this part as a class

How can you figure out how fast a station moves? You have to take some measurements and then do some calculations.

How long is the legend arrow? Measure it with a metric ruler.

The Legend arrow is _____ cm long.

This distance represents 5 cm of movement in one year, even though it is not exactly 5 cm long.

How long is the data arrow? Measure the PAMA arrow.

The PAMA arrow is _____ cm long.

This distance represents how fast this station is moving.

How fast does the PAMA station really move? To figure this out you need to do a calculation.

Length of the Data Arrow / Length the Legend Arrow = Data-to-Legend Ratio

_____ / _____ = _____

Now, multiply this Ratio by the speed that the Legend Arrow represents (5 cm/yr).

Ratio x Legend Arrow speed = Speed of the GPS station (in centimeters per year)

_____ × _____ = _____

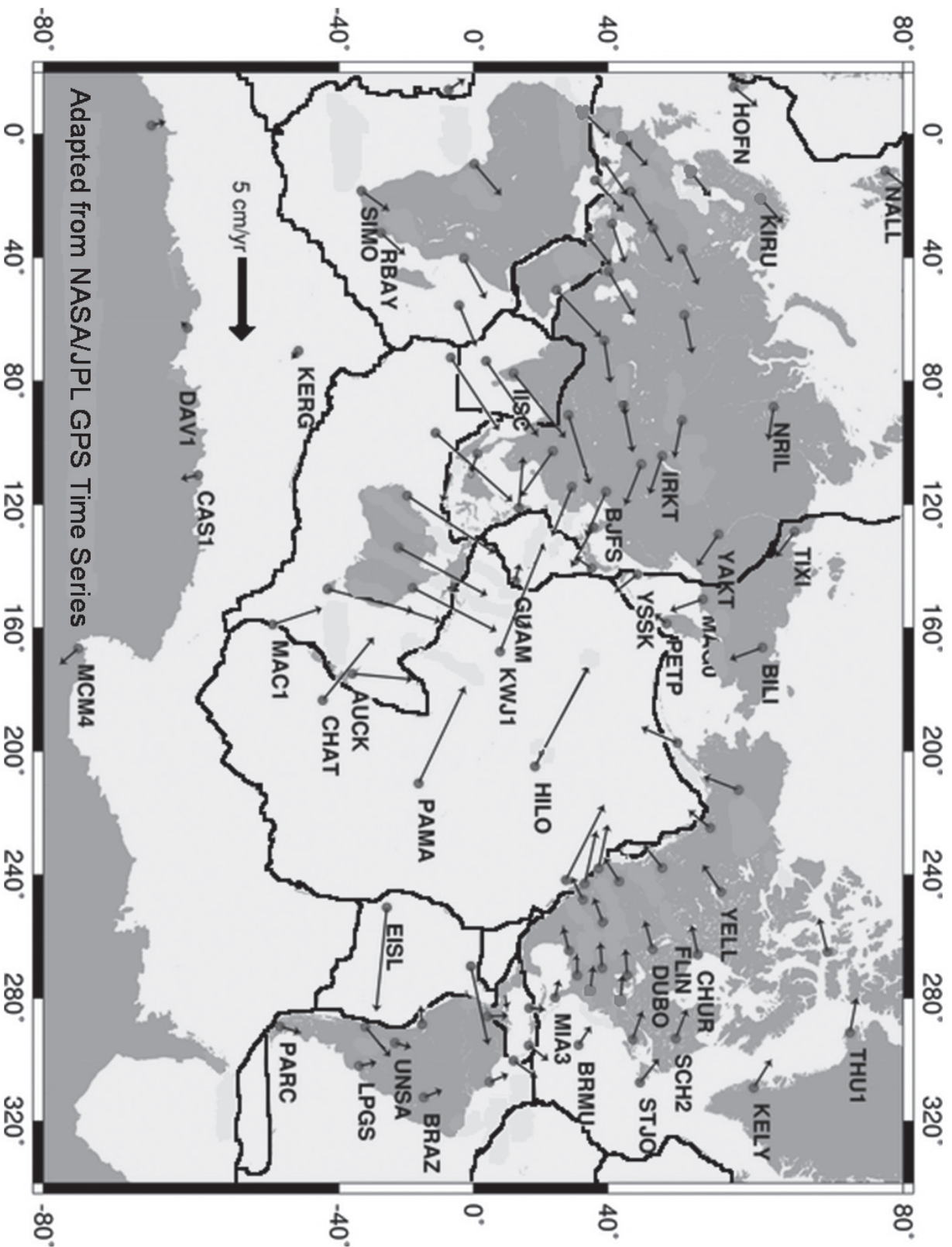
Part 2: Do this part in small groups or individually

How far does the HILO station move?

Locate the HILO station on the map. Measure the HILO Data Arrow. Use the data-to-legend ratio and the calculation above to figure out how far the station moves in one year.

Length of data arrow at HILO: _____

How far does the HILO station move in one year? _____



Step 3 Lesson 2 Snapshot

Key Concepts

- Areas of Earth's surface moving as a unit are outlined in a pattern similar to the locations of earthquakes and volcanoes.
- Scientists have discovered that Earth's surface is broken into large segments, called plates, which move slowly and continuously.

Evidence of Student Understanding

The student will be able to:

- identify a correlation between seismic data and tectonic plate boundaries and recognize the relative motion between plates.
- describe the relative motion between plates.

Time Needed

30 minutes

Materials

For the class

- *Teacher Page 3.2b: Demo Cards*
- Overhead transparency of *GPS Data Map* from Lesson 3.1
- marker for "North" (ribbon, rope, or tape)

For each student

- 1 copy of *Student Page 3.2A: Simulating GPS Movements*

Discovering Plates

1. To build on what students learned in the previous lesson, ask for one or two student volunteers to describe in their own words how a GPS receiver can give information about where it is located.

2. Facilitate the GPS station movement simulation and a class discussion about the results (see Implementation Guide).

3. Have students record their observations on *Student Page 3.2A: Simulating GPS Movements*.

- Use the Recall, Extend, and Predict questions in the REAPS to guide reflection on the simulation.

(continued on following page)

REAPS Questions

R In which direction and how fast is the HILO station moving? Generally, west-northwest at about 6–7 cm/year.

E By moving your whole body, demonstrate how far you would move in one year if you were a GPS station near Hilo, Hawaii. Student would step just 6 or 7 cm away from wherever they are positioned. This movement should hardly be noticeable.

A Compare the similarities between seismic data from the last few lessons and the GPS data in this lesson. Earthquakes and volcanoes occur in a pattern around the world that mirrors the dividing lines between sets of GPS stations with different directions and speeds of movement.

P If plates are always moving a little each year, where do you think your region will be in the future and how long might it take to get there? Answers may vary. Accept any reasonable estimates based on the GPS data and the given time frame.

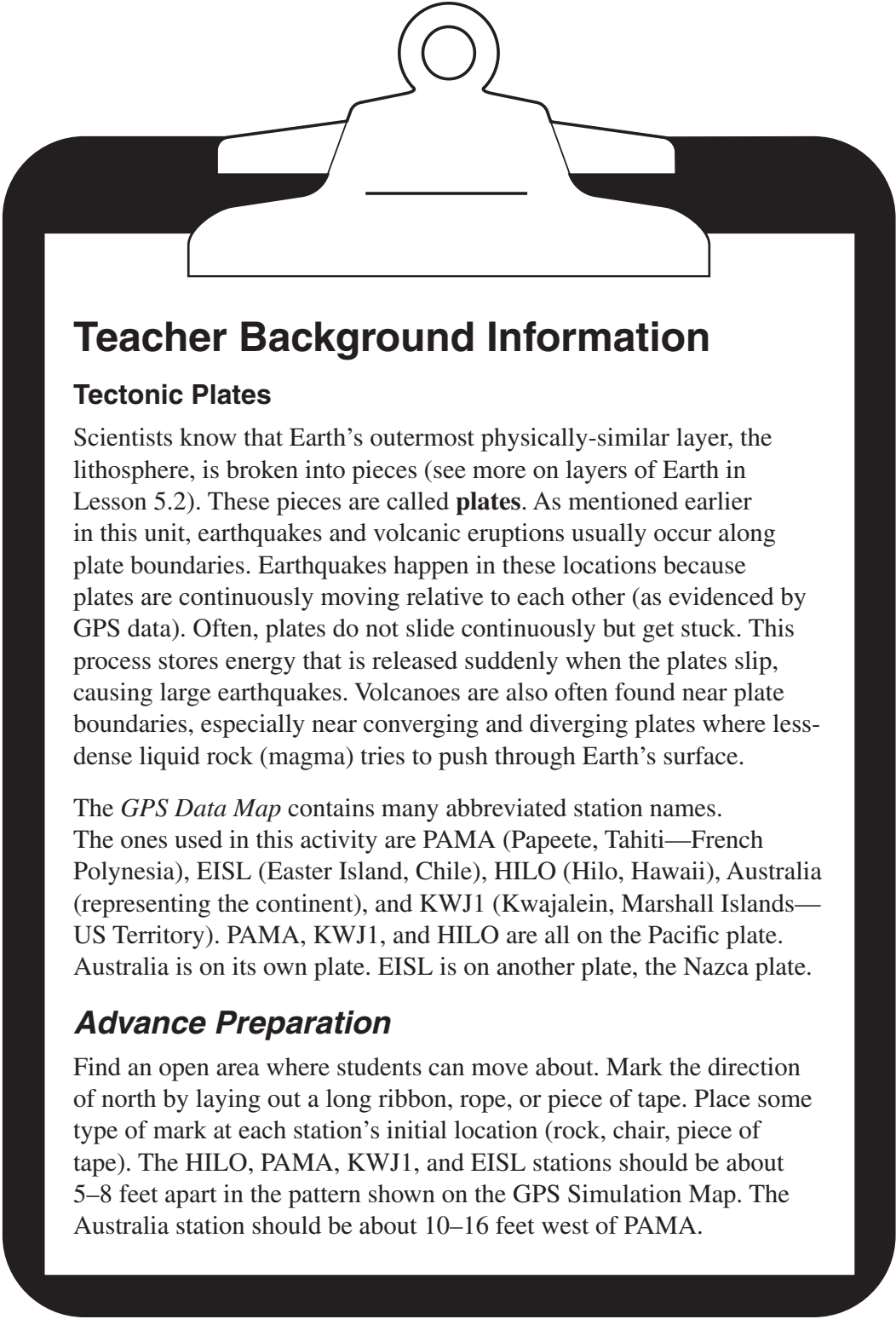
S What did you do in the GPS simulation that helped you learn how Earth's surface moves?

4. Show students the *GPS Data Map* overhead transparency. Ask if students have seen a pattern similar to the black lines on this map (like in the *Seismic/Eruption* software). Call attention to the locations of the stations they just simulated in relation to the sections on the *GPS Data Map*. Make sure students notice that HILO, PAMA, and KWJ1 are all contained within one section and that the Australia and EISL stations are in different sections.

5. Explain that each of the sections of Earth's surface outlined on this map are called **plates**. Encourage students to develop and share their own ideas about why earthquakes and volcanoes so often occur near plate boundaries.

6. Revisit the *Exploring Earth's Surface* chart and add new evidence or edit existing entries based on what students learned from this lesson.

7. Use the remaining REAPS questions as appropriate.



Teacher Background Information

Tectonic Plates

Scientists know that Earth's outermost physically-similar layer, the lithosphere, is broken into pieces (see more on layers of Earth in Lesson 5.2). These pieces are called **plates**. As mentioned earlier in this unit, earthquakes and volcanic eruptions usually occur along plate boundaries. Earthquakes happen in these locations because plates are continuously moving relative to each other (as evidenced by GPS data). Often, plates do not slide continuously but get stuck. This process stores energy that is released suddenly when the plates slip, causing large earthquakes. Volcanoes are also often found near plate boundaries, especially near converging and diverging plates where less-dense liquid rock (magma) tries to push through Earth's surface.

The *GPS Data Map* contains many abbreviated station names. The ones used in this activity are PAMA (Papeete, Tahiti—French Polynesia), EISL (Easter Island, Chile), HILO (Hilo, Hawaii), Australia (representing the continent), and KWJ1 (Kwajalein, Marshall Islands—US Territory). PAMA, KWJ1, and HILO are all on the Pacific plate. Australia is on its own plate. EISL is on another plate, the Nazca plate.

Advance Preparation

Find an open area where students can move about. Mark the direction of north by laying out a long ribbon, rope, or piece of tape. Place some type of mark at each station's initial location (rock, chair, piece of tape). The HILO, PAMA, KWJ1, and EISL stations should be about 5–8 feet apart in the pattern shown on the GPS Simulation Map. The Australia station should be about 10–16 feet west of PAMA.

Implementation Guide

1. To build on what students learned in the previous lesson, ask for one or two student volunteers to describe in their own words how a GPS receiver can give information about where it is located. If students need help, remind them about the string/yarn demonstration, and prompt them to recall that:

- Where the three strings are attached to the ceiling represents three satellite locations.
- Where the three string-ends meet (when you hold them all together, and they are taut) defines one position in space—where the GPS receiver would be located.

2. Explain to students that in this lesson they will act out some of the slow movements of the stations they studied on the *GPS Data Map* in the last lesson.

- a. Choose about three students for each of the five representative stations. The five stations are HILO, PAMA, KWJ1, EISL, and Australia. The rest of the class can watch.
 - You may want to repeat the simulation so everyone can participate.
- b. Give each student a demo card for their station from *Teacher Page 3.2b: Demo Cards*.
 - It may be helpful for the group of three students to hold a sign indicating what station they represent.
- c. Instruct each group to move to their pre-marked starting place. Explain what each card tells the students and how each group will move.
 - Each card has an arrow that indicates the direction of movement and what size step students should take when they move.
 - Review where the compass directions

are located to get everyone oriented in the proper direction.

- When students are told to move, they should do so together as one unit. It may be helpful for students to hold onto one another or to a rigid object (like a meter stick) so they all move as a unit.
 - Explain to students that their group will be moving a distance that would actually take about 15 years to occur.
 - Each group will take steps to move approximately 3 feet in the direction shown on their card (this represents the approximate amount of movement that takes place in 15 years).

NOTE: As it happens, all of the plates selected for this simulation move at similar rates. However, there are other plates that move at different rates.

NOTE: The first simulation will only use the HILO and KWJ1 groups. Other groups should wait in their starting places.

- d. Give students at HILO and KWJ1 time to orient their cards so they know which direction to walk. At your signal, have them walk approximately 3 feet and stop. Ask the class what happened with questions like:
 - Did every group move in the same direction?
 - If they kept moving this way, would they ever run into each other?
- e. Have the groups return to their starting positions. Now, have the HILO, KWJ1, and PAMA groups participate in the activity. Before anyone moves, ask the class some guiding questions:

- What do you think is going to happen?
 - PAMA is aimed right at KWJ1. Will those two groups collide?
- f. At your signal, have them walk approximately 3 feet and stop. Ask the class:
- What happened this time?
 - If they kept moving this way, would they ever run into each other?
- g. Have the groups return to their starting positions. Repeat the process again with EISL added. Ask the class what happened this time.
- h. Have the groups return to their starting positions. Repeat the process a final time with Australia too. Every group is participating now. After the groups stop, ask:
- What happened this time?
 - If each group kept moving this way, would they all collide?
- i. Continue to analyze the activity and ask students what they represented as a group. Focus the discussion with questions such as:
- How far did you move compared to the real GPS stations?
 - How did you know what direction to move? What provides evidence that particular groups should move in particular directions?
3. Have students record their observations about this simulation on *Student Page 3.2A: Simulating GPS Movements*. You may have them work in pairs or individually to record their observations. Alternatively, you could have students record these ideas in their Science Notebooks and/or use the questions as a brief formative assessment.
4. Display an overhead of the *GPS Data Map* from Lesson 3.1. Point out the black lines on the map.

Ask students to look at all the arrows inside one of the large shapes outlined with the black lines:

- What direction do these stations move?
- Do all stations within a black line move in the same direction?
- What does this tell you about Earth's surface?

Have them look at another area outlined in black:

- Do all of these stations move in the same direction?

Draw the connection between these stations moving as a unit and what students simulated in the previous section. Now, ask students to look specifically at the pattern of the lines. Ask students where they may have seen this pattern before.

- Have them think about the earthquake and volcano locations they studied in the previous step.
- Students may recall the pattern they observed for earthquake and volcano distribution.

Have students gather evidence for this idea that the patterns in the distribution of earthquakes and volcano locations may be similar to the outlines for the sections of Earth's crust that are moving together.

- Send students back to their Science Notebooks and the maps they used in Step 2.
- Remind them that in order to develop explanations and hypotheses, scientists always refer to what they already know—evidence they collected in previous investigations or articles they read.
- Ask students: Is the pattern similar?

The pattern may not be exact, but it is close.

5. Introduce the scientific term **plate** (or **tectonic plate**) as a piece of Earth's surface. Scientists define the areas contained by these lines as plates. Earth's plates move as a unit.

Ask students to propose an explanation for what they observe. Remind them that their explanation must be based on evidence. Have them refer to previous entries in their Science Notebooks: Remind students that they are doing work like what scientists do when they refer to evidence to propose an explanation. Encourage students to develop their own hypotheses about why seismic data and plate boundaries correlate so well.

Allow students to get into groups to discuss their evidence and develop explanations. Have the groups share their ideas with the class. Challenge student ideas that seem to lack evidence. Encourage students to question one another.

6. Refer to the *Exploring Earth's Surface* chart and ask students if they would like to add or edit any entries based on what they learned in this lesson. At this point, the implications for the last sample line could be completed similar to the example below.

7. Use the remaining REAPS questions to assess students' ability to predict how plate motions in their regions might affect their region's landforms. This is a segue into the next lesson where students will work once more to build their scientific models based on evidence collected in this step.

Exploring Earth's Surface

What did we observe about Earth's surface today?	How were those observations made by scientists?	What can we learn from those observations?
We saw mountains, valleys, and oceans.	First-hand observations, still and video cameras.	Earth's landforms are different in different places.
Sometimes the ground shakes.	First-hand observations, seismometer recordings.	Earth's surface can move suddenly.
We saw damaged buildings and roads.	First-hand observations, photos of damage.	
Locations of earthquakes and volcanic eruptions.	Seismometers (and computers for display).	Earthquakes and volcanic eruptions happen in similar locations.
		Earthquakes and volcanic eruptions happen mostly in particular regions around the world.
Land moves slowly.	GPS stations and satellites.	Parts of Earth's surface move slowly all the time.
		Earth's surface is broken into large pieces called plates.

Student Page 3.2A: Simulating GPS Movements

Name _____

Date _____

Think back to class simulation of the movement of the GPS stations.

1. In what direction did each group move?

HILO:

KWJ1:

PAMA:

EISL:

Australia:

2. Which groups seemed to move together in the same direction?

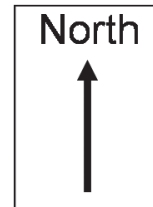
3. Which groups moved in different directions?

4. How did the Australia group interact with other groups?

5. Use the *GPS Data Map* to find two different GPS stations near your region. List the name of the station (if it is given) and describe how it moves. Include how much it moves each year and in which direction it moves.

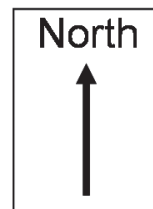
6. Math Extension: At a rate of 10 cm/year, how long would it take Australia to move 4000 km? Show your calculation. (There are 100,000 cm in 1 km.)

AUSTRALIA



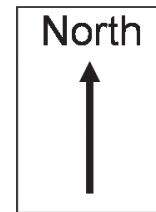
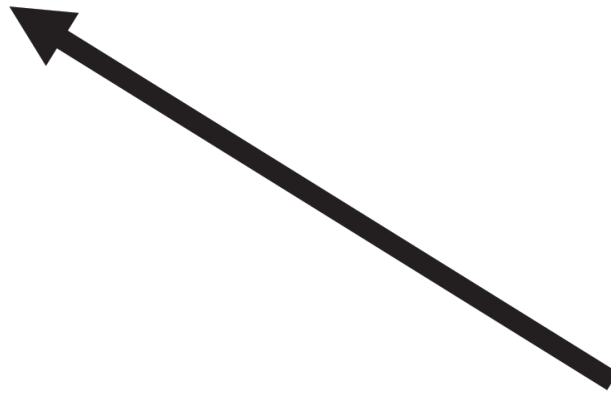
Rate of movement: 1 meter in 16 years

EISL (Easter Island)



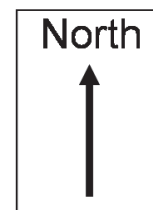
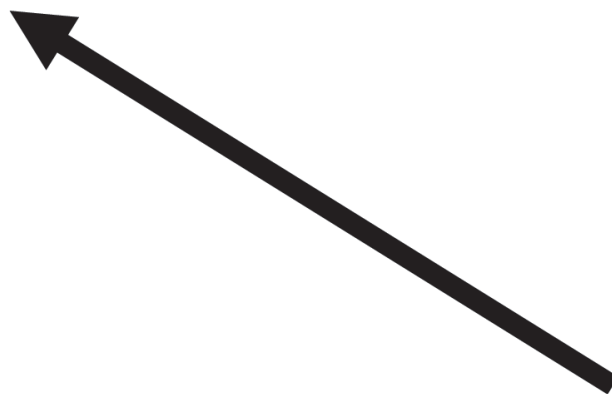
Rate of movement: 1 meter in 15 years

HILO (Hilo, Hawaii)



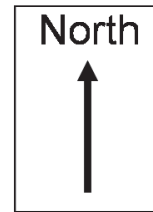
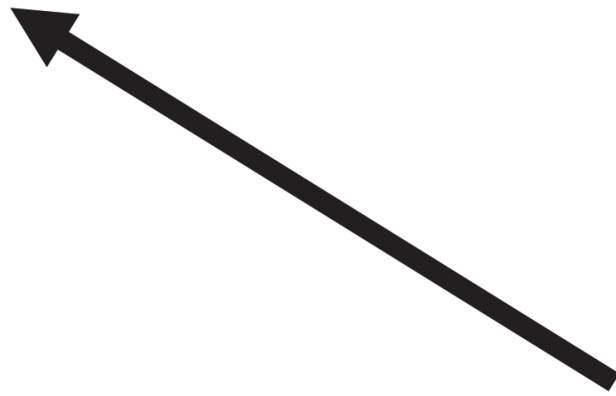
Rate of movement: 1 meter in 14 years

KWJ1 (Kwajalein, Marshall Islands)



Rate of movement: 1 meter in 14 years

PAMA (Papette, French Polynesia)



Rate of movement: 1 meter in 14 years

Step 3 Lesson 3 Snapshot

Key Concept

- Scientists revise models and explanations based on new information.

Evidence of Student Understanding

The student will be able to:

- revise their physical scientific model based on questions about how it represents and/or explains new evidence about plate motion in their region.

Time Needed

20 minutes

Materials

For each student

- 1 copy of *Student Page 3.3A: Identifying Plates*
- 1 copy of *Student Page 3.3B: Developing My Scientific Model*

For each region group

- modeling materials (can include modeling clay, paper, cardboard, popsicle sticks, tape, toothpicks, straws, paper cups, cotton balls, or other common materials that students will use to modify physical models of the regions)

Revising Region Models

1. Begin the lesson by having the class revisit the *Exploring Earth's Surface* chart and to discuss the evidence gathered so far about Earth's surface.

- Explain that today students will be using their new knowledge about GPS stations and slow movements of plates to ask new questions about their models and revise them to represent or explain all that they know about the region.

2. Distribute *Student Page 3.3A: Identifying Plates* to all students. Have students work individually to identify the GPS stations and plates that are located within their region.

3. Ask students to work in pairs to discuss and sketch how plates move and interact in their region.

4. Use a Think Aloud strategy to show how to ask questions of the existing models to inquire if they are able to accurately represent and/or explain all the evidence that is currently known about the region.

5. Have students complete *Student Page 3.3B: Developing My Scientific Model* to record their current thinking and plan for making model revisions.

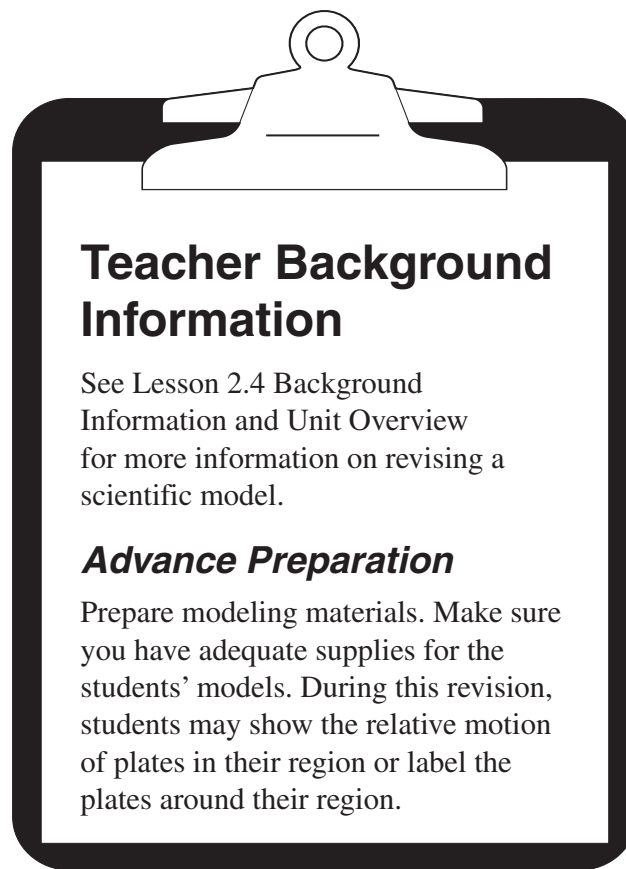
6. Provide students in region groups with time and materials to revise their region models.

7. Use the REAPS throughout and after the lesson as appropriate.

(continued on following page)

REAPS Questions

- R On what plate or plates is your region found?** Answers will vary. Check for accuracy using the Identifying Plates map.
- E How does your model explain what the GPS data tells about your region?** Answers will vary. Example: GPS data shows the Pacific Plate is moving faster than the North American Plate near California. My current model does not explain that the crust is moving or is divided into different plates, so I will color the two plates in my region and color the Pacific Plate darker to represent its faster motion.
- A How do you think the plate motions in your region affect its landforms?**
Answers will vary. Example: The plate motion near the Himalayas may cause mountains to form since the plates are moving towards each other and the land has nowhere to go but up.
- P How do you think the landforms in your region might change over time given the GPS data about plate movement for your region?** Answers may vary. Use students' responses to find out what they are thinking about how plate movement relates to landform development.
- S Meet with a student from another region group and discuss your answers to the Predict question.**



Teacher Background Information

See Lesson 2.4 Background Information and Unit Overview for more information on revising a scientific model.

Advance Preparation

Prepare modeling materials. Make sure you have adequate supplies for the students' models. During this revision, students may show the relative motion of plates in their region or label the plates around their region.

Implementation Guide

1. Briefly review the *Exploring Earth's Surface* chart, particularly the newest entries from Step 3, to remind students of the new evidence they have for what is happening in their regions. Explain that students will be using their new knowledge to ask questions about how accurately the model of their region represents, explains, and/or predicts the surface features in their region, similar to what they did in Lesson 2.4.
2. Provide students with *Student Page 3.3A: Identifying Plates*. Ask students if they can identify particular plates located within their region. Remind students that they can also use the *GPS Data Map* to locate specific GPS stations that may be in their region.
3. Ask students to work in pairs to discuss and sketch how plates move and interact in their region.
4. Use a Think Aloud like the example below to demonstrate how to modify an existing model to improve its ability to represent, explain, and predict what is known.

Think-Aloud for first model update

Here is my physical model of California. In Step 1, I used a paper cup to represent the tallest mountain in California, and a piece of string to represent the coast along the Pacific Ocean.

Then, in Step 2 I learned about earthquakes and volcanic activity in that region. I asked myself if my model represented or explained that evidence, and it did not. So, I used a few toothpicks in the cardboard near where the largest earthquakes happened and marked the small earthquake locations with little stickers. Still, I realized that my model only shows where earthquakes and volcanic eruptions have happened in my region, but it does not explain what causes them. That is a limitation it has at this time.

Now, I have learned a lot more about Earth's surface and evidence that scientists collect

and use to understand how it changes over time. I've learned about plates and how they move in my region, and that causes me to wonder about how well my model explains all the evidence I have at this time about Earth's surface in that region.

I'm asking myself, How could I revise my model so that anyone who looks at it could understand how plates are affecting this region? If I can do this well, my model will help me and others predict how Earth's surface might change in this region, so it is starting to become more useful as a scientific tool. That's cool! I'm starting to build a pretty impressive model!

Now I need to figure out what materials to use and how to use them . . .

5. With students in their region groups, ask them to discuss together what slow movements of plates are observed in their region and how they could represent that in their model. Distribute *Student Page 3.3B: Developing My Scientific Model* and have each student sketch and describe the changes the group will make to their model based on their questions regarding how it explains evidence of regional plates and plate movements.

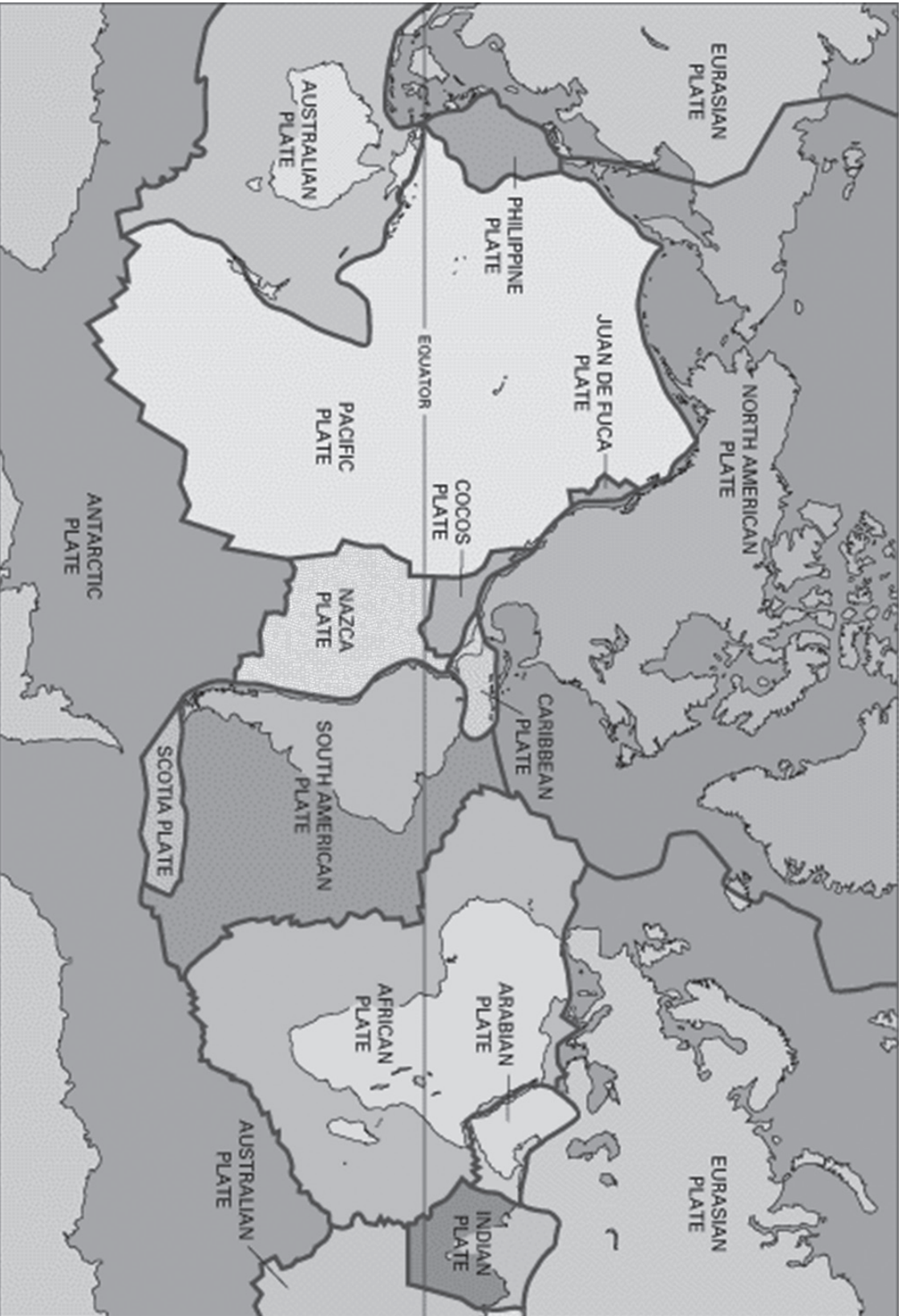
6. Provide students with time and materials to revise their region models as in Lessons 1.2 and 2.4. What would students need to change about their model so that it more accurately reflects data on plate boundaries and slow movements? This can vary, but students may identify on which plate or plates their region is located, how those plates are moving relative to each other, and other information they learned about slow movements in their region. Ask students to answer and discuss the following questions in their groups:

- Are there GPS stations located in your region?
- On what plate or plates is your region found?

- How do plates move or interact in your region?
- What effect do you think this has on other information you've already learned about your region?
- How can you model these interactions?

7. To guide and monitor student progress with revising their models, use the Recall and Extend questions. The Analyze and Predict questions could be used to get students thinking about how their model can become more explanatory, rather than simply representative. Self-assessing the Predict question is a non-threatening way for students to discuss their ideas at this point in the unit.

Student Page 3.3A: Identifying Plates



Map adapted from [This Dynamic Earth](#), USGS.

Student Page 3.3B: Developing My Scientific Model

Name _____

Date _____

What new evidence have I learned about my region that my model does not represent or explain? Now that I know more about my region and about scientific modeling, what is missing in my model?	What are my model's strengths? What does my model explain about Earth's surface in my region? List at least 2 questions you could ask about Earth's surface in your region that your model can answer.
What are my model's limits? What doesn't my model explain about Earth's surface in my region? List at least 2 questions you could ask about Earth's surface in your region that your model cannot answer yet.	Describe at least two different ways that you could get more information and evidence about your region and Earth's surface there.

STEP 4

Overview

If Earth's surface moves, how might it have looked in the past? In Step 4, this intriguing question extends what students learned in previous steps and introduces them to a geologic time frame for a larger picture of changes in Earth's surface.

This step presents several lines of evidence that scientists use to understand Earth's history. These include the outlines of continents, distribution of fossils and rocks, and evidence of ancient climatic zones. This step also provides a historic perspective on how the ideas that preceded the theory of plate tectonics slowly but gradually (and at times with much contention) took root in common scientific thought.

Step 4 Lesson 1 Snapshot

Key Concepts

- Continents have been in different positions during Earth's history.
- There are many important pieces of evidence for the arrangement of continents being different in the past.

Evidence of Student Understanding

The student will be able to:

- identify the scientifically accepted arrangement of the continents in the past;
- explain how at least two major lines of evidence support that arrangement.

Time Needed

50 minutes

Materials

For the class

- overhead of *Teacher Page 4.1d: Continent Puzzles*
- *Pangaea Animation*  or *Pangaea Images* 

For each group

- copy of either *Student Page 4.1B: Fossil Distribution* or *Student Page 4.1C: Rock Distribution*

For each pair

- 1 copy of *Student Page 4.1A: World Outline Map*
- scissors and tape

Geologic Time

1. Guide student attention to the *Exploring Earth's Surface* chart and ask students to summarize which entries support the idea that Earth's surface is moving.

2. Refer to the present-day world map. Ask students what the map shows (e.g. continents, oceans, islands, etc.). Ask students:

- **How might the map have looked different LONG ago, given that Earth's surface is moving?**

Share with students that this question also interests scientists.

3. Show students the overhead of *Teacher Page 4.1d: Continent Puzzles*. Share the Dutch mapmaker's story (found on *Teacher Page 4.1d*)

4. Have pairs of students cut out *Student Page 4.1A: World Outline Map* and work together to investigate possible arrangements for the continents.

5. Remind students that their explanation for the historical arrangement of continents would be stronger if they had lots of evidence to support their ideas.

- Use a Think-Pair-Share strategy to have students brainstorm what sorts of evidence might still exist today.

6. Provide groups of students with **either** *Student Page 4.1B: Fossil Distribution* or *Student Page 4.1C: Rock Distribution* and ask them to analyze if this evidence supports their arrangement or indicates that it needs to change. Divide the work so half the class works with each kind of evidence.

7. Have pairs write down an entry for the *Exploring Earth's Surface* chart and then share it with the class. Use the class chart to organize the evidence and help improve their world map continent arrangements.

8. Show the *Pangaea Animation* or the *Pangaea Images*. Ask students to evaluate the accuracy of their models based on these scientific models.

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9. Use a Think-Pair-Share strategy for students to develop a response to the following question:

- **The continents fit together like puzzle pieces when Pangaea was together. How could you explain why the shapes of continents do not “fit” together perfectly today?**

- Collect students’ ideas in a whole class discussion, and build to an understanding that **since Pangaea broke apart approximately 200 million years ago, erosion, mountain-building, and other changes have occurred to make the coastlines we observe today.**

10. Use the REAPS throughout and after the lesson as appropriate.

REAPS Questions

- R How does fossil evidence inform scientists about the position of continents in the past?** The same kinds of fossils found in what are now widely different locations mean that those organisms used to live in areas that were closer together.
- E If scientists find a fossil of a tropical plant in Antarctica, what does that tell them about the climate in Antarctica when that organism lived?** In order for a tropical plant to live in Antarctica, the climate must be warm—much warmer than it is now! In order for it to be warm, Antarctica must have been closer to the equator, not near the South Pole where it is today.
- A What other data do you know of that supports the idea that continents are moving?** The GPS data map shows direct measurements of GPS station movement.
- P What do you think it was like for the scientist who first presented the Pangaea model to other scientists in 1915? What makes you think that way? Answers may vary. Accept answers that are logically supported with a reason.** Possibilities include “the scientist’s idea was accepted, because they had evidence that the continents used to be connected” or “the scientist’s idea wasn’t accepted because they didn’t have GPS data to prove that the continents were moving”.
- S Explain why your world map arrangements changed during this lesson. How is this like what you are doing with your region model?**

Teacher Background Information

The theory of continental drift was the precursor to plate tectonics. In 1915, Alfred Wegener, a German meteorologist by training, published his work that showed how continents must have been joined together at some time in the past. He had many lines of evidence to support this idea including fossil and rock correlations, ancient climate indicators, and the outlines of continents. All of his data supported the idea that continents were once joined in a “supercontinent” (called Pangaea) and have drifted apart over time.

The following diagram, adapted from the US Geologic Survey, describes fossil evidence that scientists have in support of continents being joined approximately 200 million years ago. The continents shown are primarily southern-hemisphere landmasses, however there is also evidence for northern-hemisphere landmasses. Rock type data correlates in a similar manner.

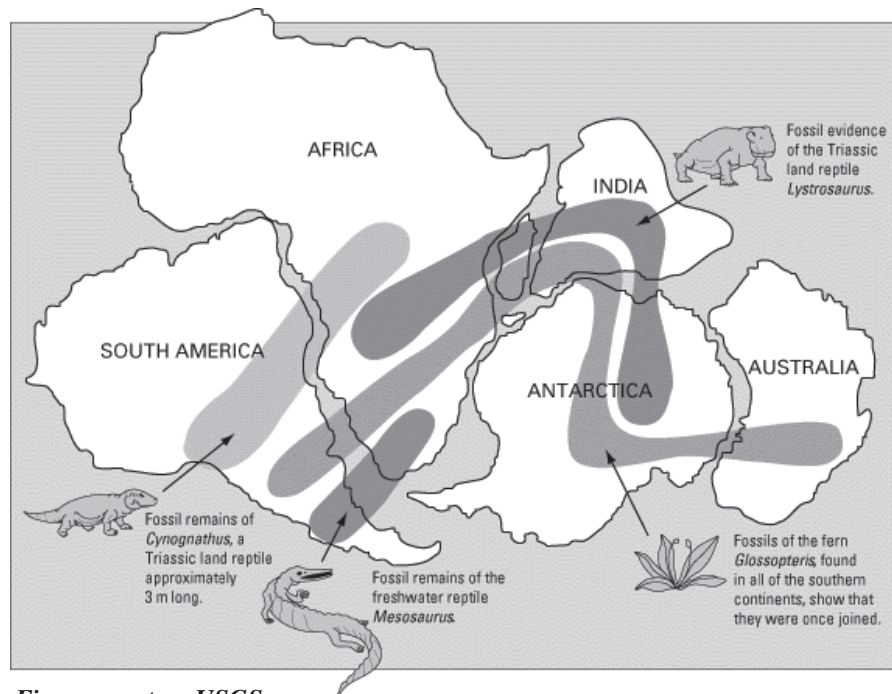
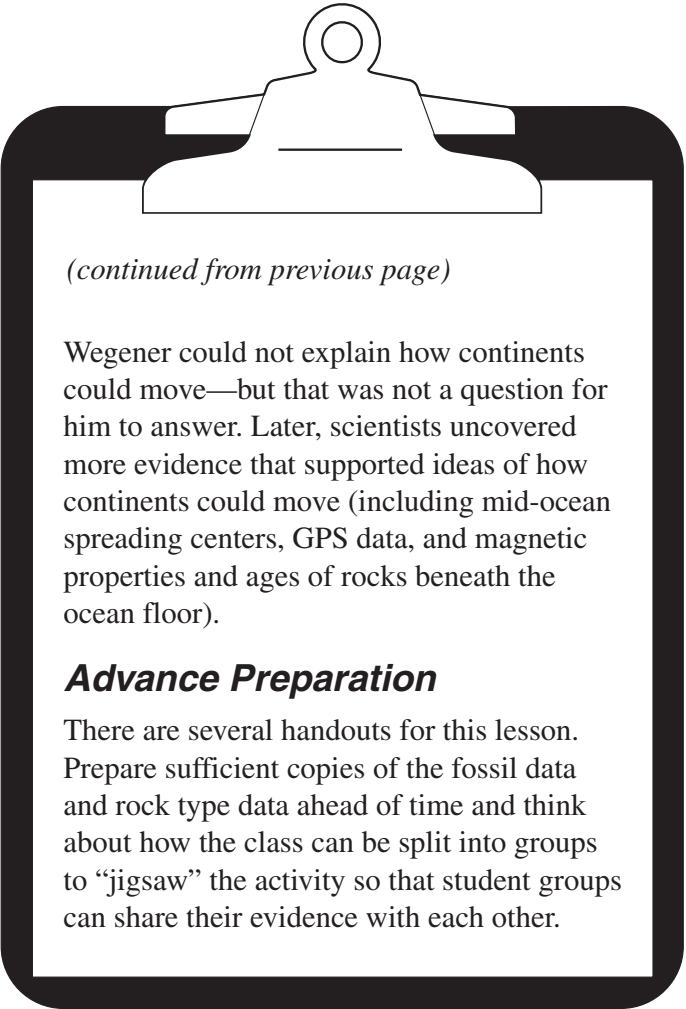


Figure courtesy USGS.

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Wegener could not explain how continents could move—but that was not a question for him to answer. Later, scientists uncovered more evidence that supported ideas of how continents could move (including mid-ocean spreading centers, GPS data, and magnetic properties and ages of rocks beneath the ocean floor).

Advance Preparation

There are several handouts for this lesson. Prepare sufficient copies of the fossil data and rock type data ahead of time and think about how the class can be split into groups to “jigsaw” the activity so that student groups can share their evidence with each other.

Implementation Guide

1. Guide student attention to the *Exploring Earth's Surface* chart and ask students to summarize which entries support the idea that Earth's surface is moving. Use a Think-Pair-Share strategy.

2. Call student attention to the present-day world map. Ask students to call out what sorts of things the map shows (e.g. continents, oceans, islands, etc.). List these on the board. Then, ask students to put the idea of Earth's surface moving together with a world map. Prompt students to discuss in pairs:

- How might the map have looked different LONG ago, given how Earth's surface is moving?

Share with students that this question also interests scientists and has for many years.

3. Show students the overhead of *Teacher Page 4.1d: Continent Puzzles*. Share the Dutch mapmaker's story. Use the present-day world map to show how South America would need to move to be able to fit with the coastline of Africa. Use the questions at the end of the story to generate interest in studying the possible fit of the continents. Ask students:

- How could we find out more information about whether or not the continents really fit together like a puzzle?

Guide the discussion to the idea that one way of finding more information about something is to investigate it directly.

4. Have pairs of students cut out *Student Page 4.1A: World Outline Map*. Remind them that since they are seeing if the coastlines of continents fit together, they need to cut them out somewhat carefully so that they get accurate results.

As students work together to investigate possible arrangements for the continents, travel around the room and ask students what evidence they have for the way they are placing the continents together. Make sure students do not flip their continents upside down. Continents may move around Earth's surface laterally, but they don't do back flips!

5. Remind students that in science, the more good evidence a person has to support an explanation, the stronger it is. So, their explanation for the historical arrangement of continents would be stronger if they had lots of evidence to support their ideas.

Use a Think-Pair-Share strategy to have students brainstorm a list of evidence that might still exist today that would show that continents used to be connected.

- Emphasize that the evidence has to be something that lasts for millions of years, because that is how long ago the continents were arranged like this.

If students suggest that the plants and animals would be the same in two continents, share that when the continents first split apart, the plants and animals would have been similar, but over time plants and animals can change and move and the climate changes.

- Explain that they would want to look at the plants and animals that were living around the time when the continents first split apart rather than focusing only on the plants and animals that are alive today.
- Ask students what evidence is available today that tells us something about plants and animals that lived millions of years ago.
 - Guide students to think about fossils as evidence.

6. Share that you have two types of evidence to look at that are evidence of what Earth was like millions of years ago. Explain that half the class will investigate one line of evidence, fossils, and the other half will investigate another, rock types.

- Each group has data from several, but not all, continents.

Ask students why they think you are providing them with two different kinds of evidence. Make sure students recognize scientific explanations are made stronger with additional evidence, and,

similarly, their explanations for the arrangement of continents will be stronger by having access to both types of evidence you are providing.

Provide groups of 2-3 students with either *Student Page 4.1B: Fossil Distribution* or *Student Page 4.1C: Rock Distribution*. Divide the work so half the class works with each kind of evidence.

Explain to students how the student pages are set up and how to use the legend to determine what the data represents.

Have students arrange the continents on their Student Page the same way they arranged blank continents earlier in the lesson.

Finally, direct students to look back at their original continent arrangements and determine if it is supported by the fossil or rock data shown on the continents. If it is not, prompt students to modify the arrangement of these continents so that the bands of data align. Then, use this new arrangement to revise their blank continents.

7. Have pairs write down an idea that comes from what they just learned about fossil or rock distribution (whichever they studied) for the *Exploring Earth's Surface* chart.

Then, hold a whole class discussion to collect the individual pairs' contributions and refine them into a few lines of evidence to add to the class' *Exploring Earth's Surface* chart. At this point in the unit, the chart may look similar to the chart on the following page.

8. Explain that scientists use computer modeling to turn data that is similar to what students have been looking at to animate how the continents may have changed over time.

- Show the *Pangaea Animation* or the *Pangaea Images* provided on this Unit's CD.
- Ask students to evaluate the accuracy of their models based on these scientific models. This could be done, for example, by listing things that are the same and different about the arrangement of continents the students had versus the arrangement of continents scientists developed.

9. Wrap up the study of Pangaea by using a Think-Pair-Share strategy for students to develop a response to the following question:

- **The continents fit together like puzzle pieces when Pangaea was together. How could you explain why the shapes of continents do not “fit” together perfectly today?**
- In a whole class discussion, ask each small group to share at least one idea they had to explain the present-day lack of “fit.”
- If possible, highlight student-generated ideas that relate to any of the following change processes that have occurred over the last approximately 200 million years (since Pangaea's breakup) to alter the coastlines:
 - erosion
 - mountain-building
 - sea level changes

10. Use the REAPS throughout and after the lesson as appropriate.

Exploring Earth's Surface

What did we observe about Earth's surface today?	How were those observations made by scientists?	What can we learn from those observations?
We saw mountains, valleys, and oceans	First-hand observations, still and video cameras	Earth's landforms are different in different places.
Sometimes the ground shakes	First-hand observations, seismometer recordings	Earth's surface can move suddenly
We saw damaged buildings and roads	First-hand observations, photos of damage	
Locations of earthquakes and volcanic eruptions	Seismometers (and computers for display)	Earthquakes and volcanic eruptions happen in similar locations
		Earthquakes and volcanic eruptions happen mostly in particular regions around the world
Land moves slowly	GPS stations and satellites	Parts of Earth's surface move slowly all the time
		Earth's surface is broken into large pieces called plates
Locations of fossils on several continents	Geologists collect fossils from the field	Continents used to be closer to each other and connected
		Continents now in one climate have been in extremely different climates in the past.
Locations of types of rock on several continents	Geologists collect rocks from the field and analyze them	Continents used to be closer to each other and connected

Student Page 4.1A: Continent of Africa



Student Page 4.1A: Continent of Antarctica



Student Page 4.1A: Continent of Asia



Student Page 4.1A: Continent of Australia



Student Page 4.1A: Continent of Europe



Student Page 4.1A: Continent of North America

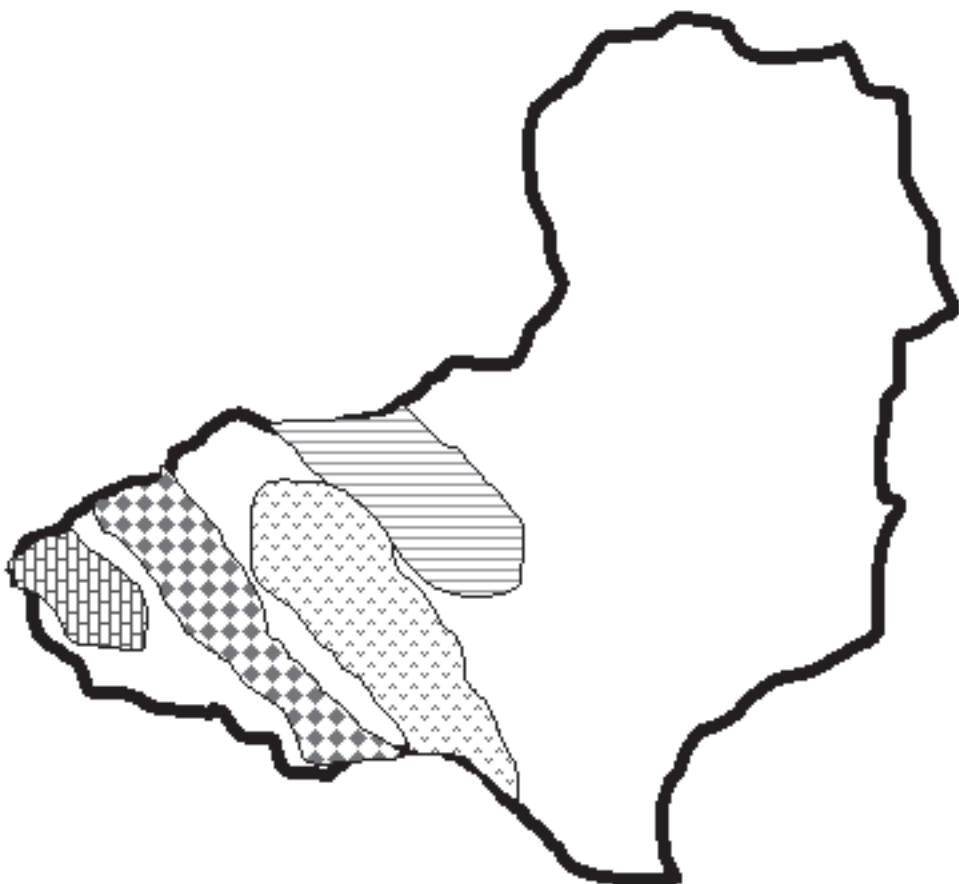
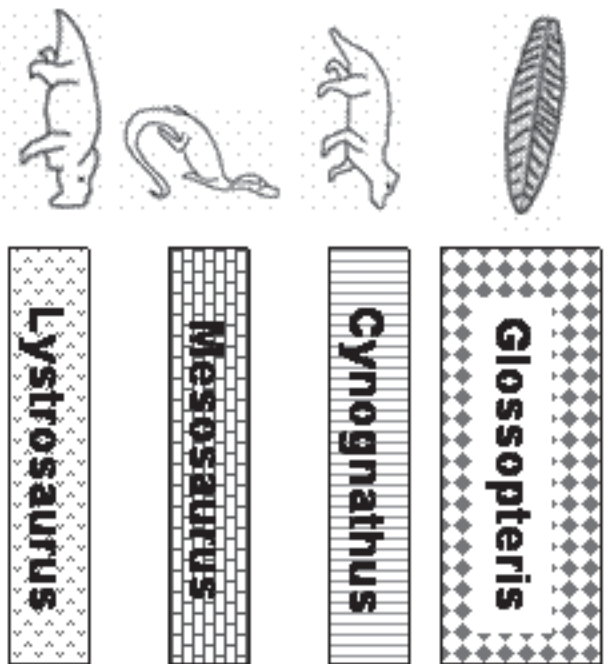


Student Page 4.1A: Continent of South America



Africa

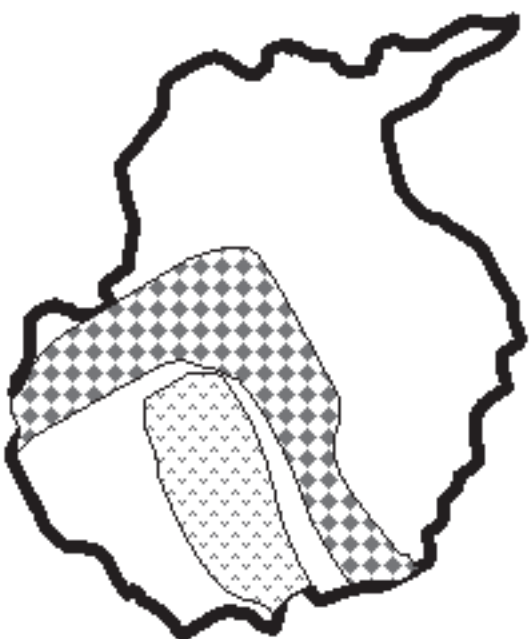
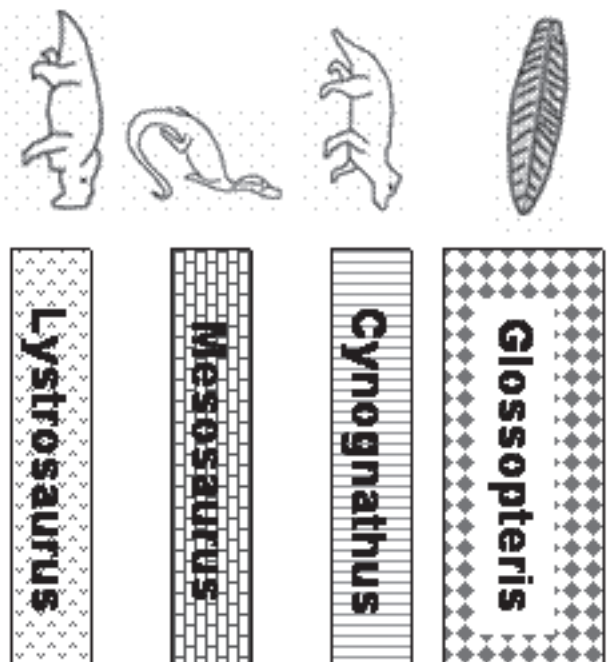
Fossil Data Legend:



Data adapted from USGS.

Antarctica

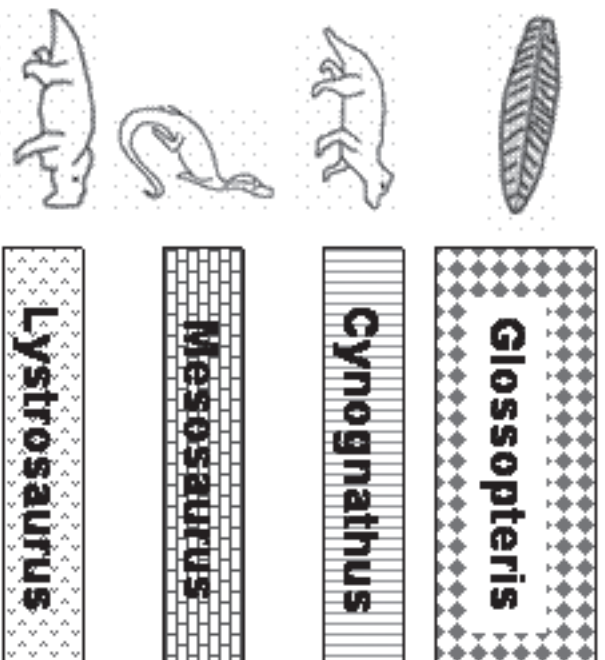
Fossil Data Legend:



Data adapted from USGS.

Australia

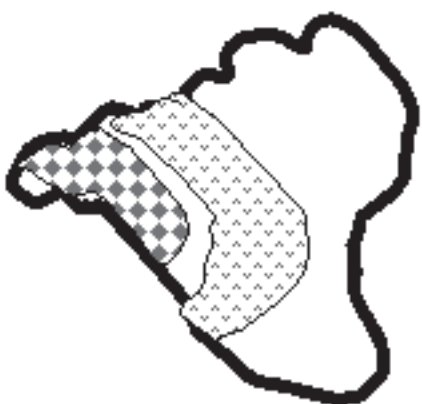
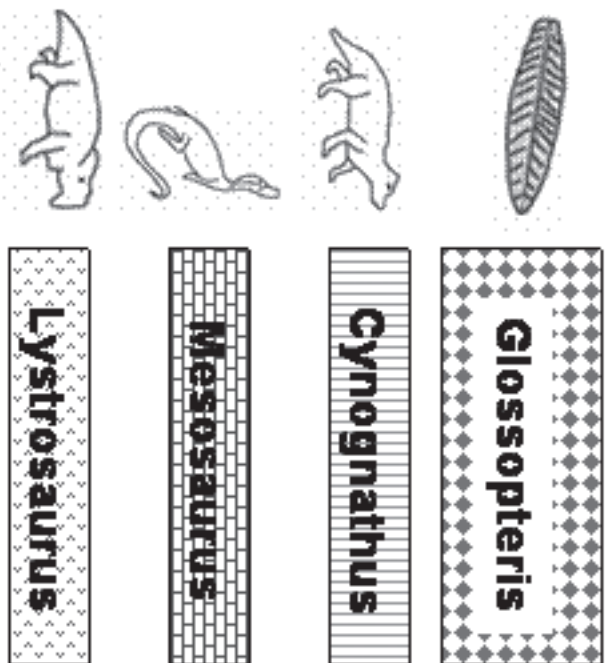
Fossil Data Legend:



Data adapted from USGS.

India

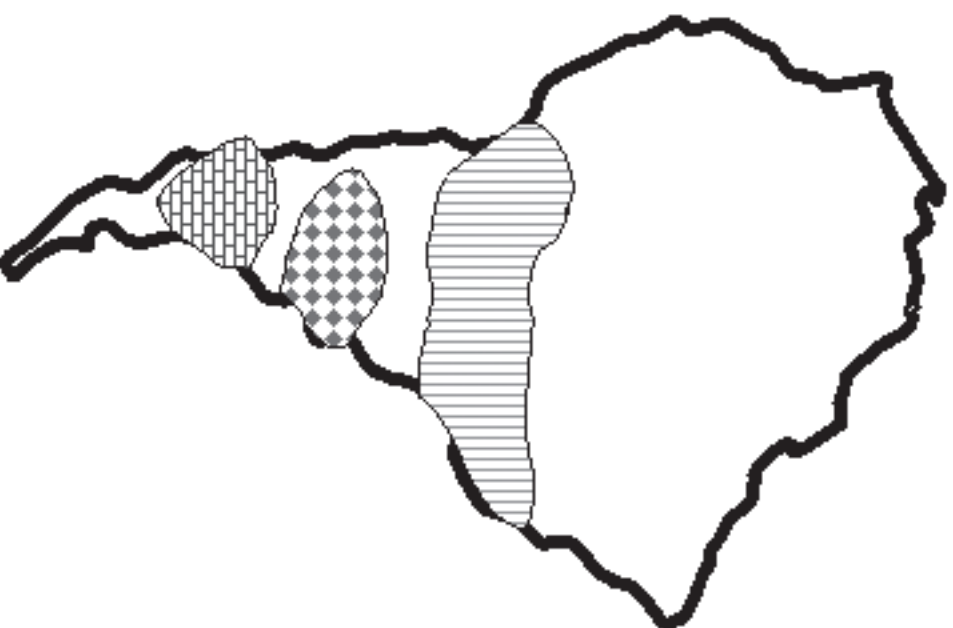
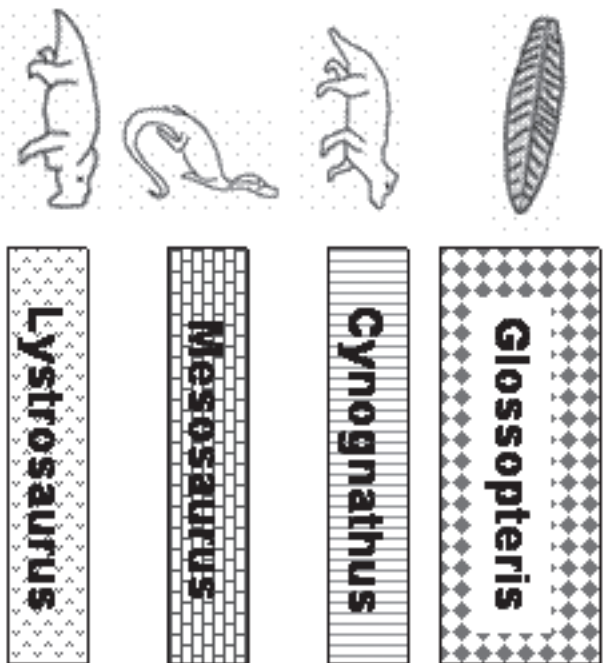
Fossil Data Legend:



Data adapted from USGS.

South America

Fossil Data Legend:

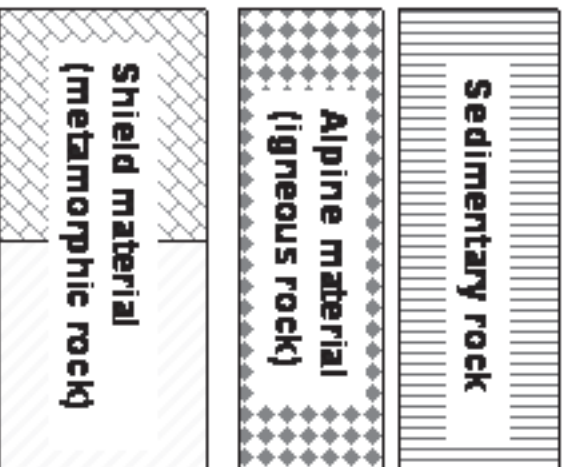


Data adapted from USGS.

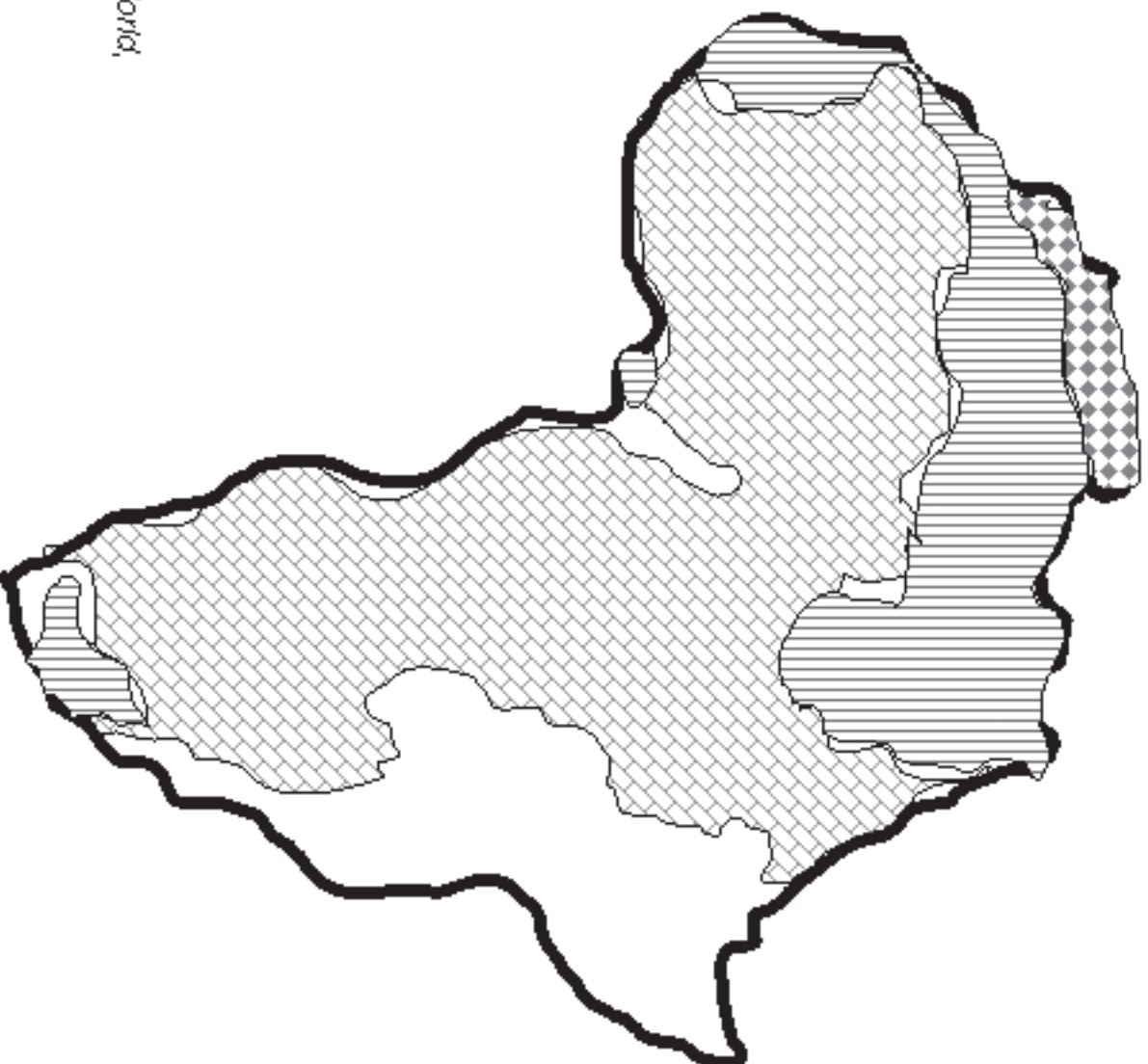
Africa

Student Page 4.1C: Rock Data of Africa

Rock Data Legend:

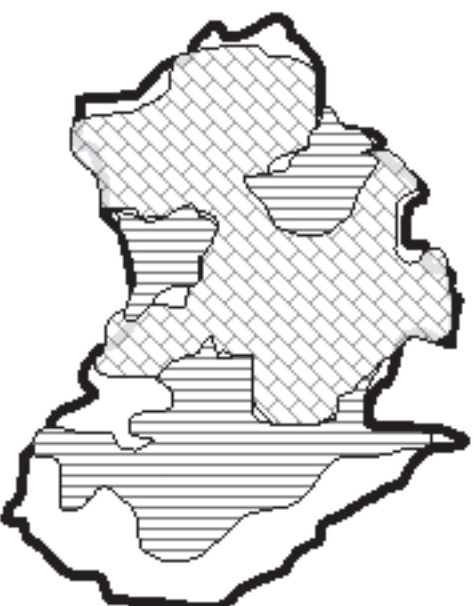
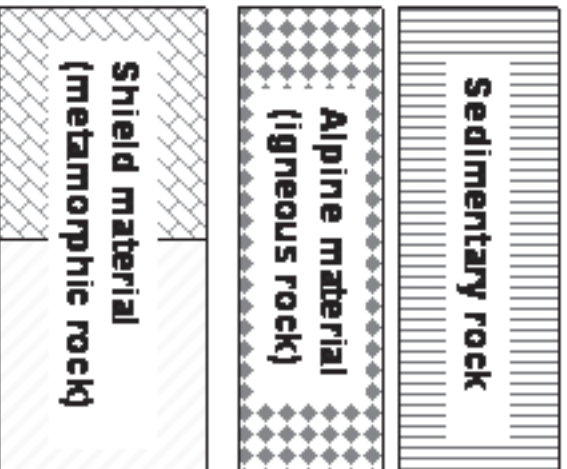


Data adapted from *Landforms of the World*,
Murphy/Bateman, 1968.



Australia

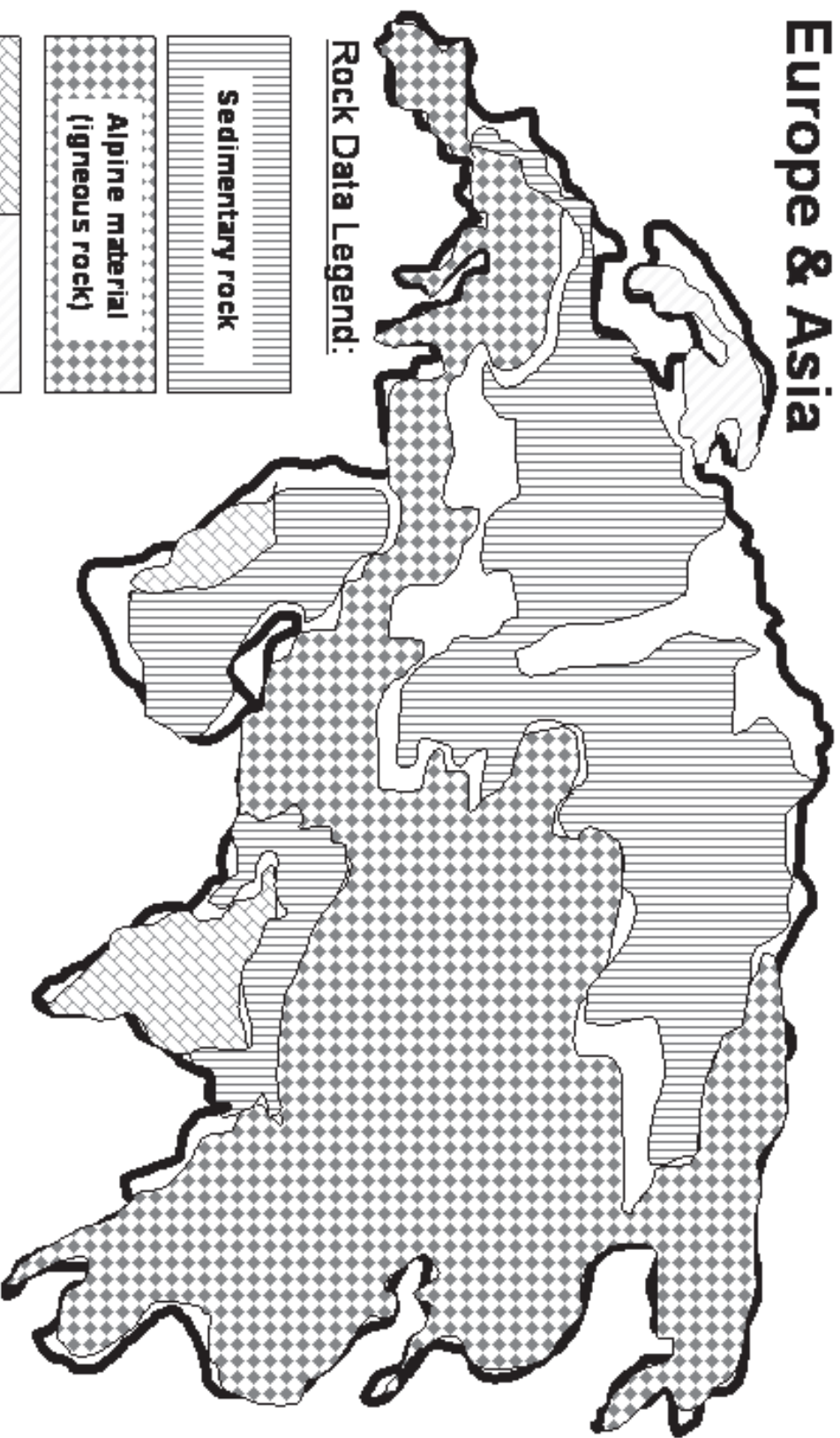
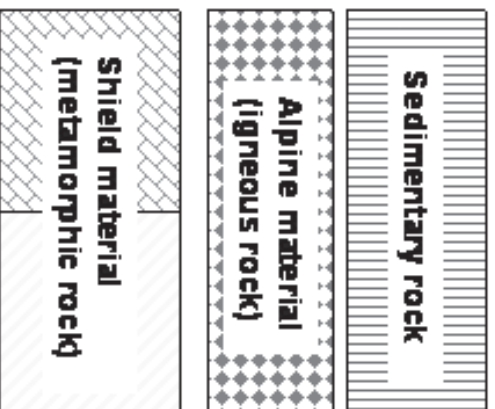
Rock Data Legend:



Data adapted from *Landforms of the World*,
Murphy/Bateman, 1968.

Europe & Asia

Rock Data Legend:



Data adapted from *Landforms of the World*,
Murphy/Bateman, 1968.

North America

Rock Data Legend:

	Sedimentary rock
	Alpine material (igneous rock)
	Shield material (metamorphic rock)



Data adapted from *Landforms of the World*,
Murphy/Bateman, 1968.

South America

Rock Data Legend:



Data adapted from *Landforms of the World*,
Murphy/Bateman, 1968.

Teacher Page 4.1d: Continent Puzzles?

In 1596, a Dutch mapmaker noticed that the coastlines of South America and Africa seemed to fit together like two puzzle pieces. All he had to do was pull South America over toward Africa and tip it sideways.

He continued to study the world map and claimed that all the continents used to fit together like a puzzle. He said that a very long time ago they all used to be connected. Somehow they must have moved apart.

Do you think the coastlines of South America and Africa fit together like puzzle pieces? What about the rest of the continents?



Step 4 Lesson 2 Snapshot

Key Concept

- Scientists are more likely to agree with claims if they are supported with evidence and a logical argument.

Evidence of Student Understanding

The student will be able to:

- communicate and justify an evidenced-based explanation about the historical locations of continents
- make a logical prediction about how continents could move

Time Needed

50 minutes

Materials

For the class

- Video clip from Teachers' Domain.org: *Plate Tectonics: The Scientist Behind the Theory*
- Computer and projector to view video clip

For each student

- 1 copy of *Student Page 4.2A: How Right Was Wegener?*

The Case for Continental Drift

1. Re-engage students in thinking about the Pangaea model of Earth's surface using the Predict question from Lesson

4.1. Ask:

- **What do you think it was like for the scientist who first presented the Pangaea model to other scientists in 1915? What makes you think that way?**

2. Explain that because Wegener was alive and practicing science only 75 years ago, there is a lot of evidence about how people reacted to his new ideas when they were presented.

- To learn more, show the video clip "Plate Tectonics: The Scientist behind the Theory",

3. Have students individually read *Student Page 4.2A: How Right Was Wegener?*

- Use an appropriate reading strategy to help students understand the evidence provided in the article that is needed for completing this lesson.
- Use the REAPS to review the key ideas in both the video and the article.

4. Explain to students that they will be writing a letter to the scientists who disagreed with Wegener. Students must:

- convince other scientists that Wegener's model was good because it explained all of the evidence about Earth's surface that scientists had at that time.
- include evidence that the class has collected, but that Wegener did **not** have at the time he lived, and use that evidence to further support his ideas.

5. Establish a due date, strategy for students to complete the assignment, and class criteria for:

- a strong scientific argument
- the assigned letter format and style

(continued on following page)

6. After students complete their letters, use a Think-Pair-Share strategy to develop responses to the questions:

- Wegener's model of continental drift explained that changes in Earth's surface happened because continents move.

- What evidence do we have that is not explained by continental drift?

7. Start students thinking about the key ideas in the next lesson by posing the question, **How can plates move?**

REAPS Questions

R What did Wegener claim Earth's surface used to look like?

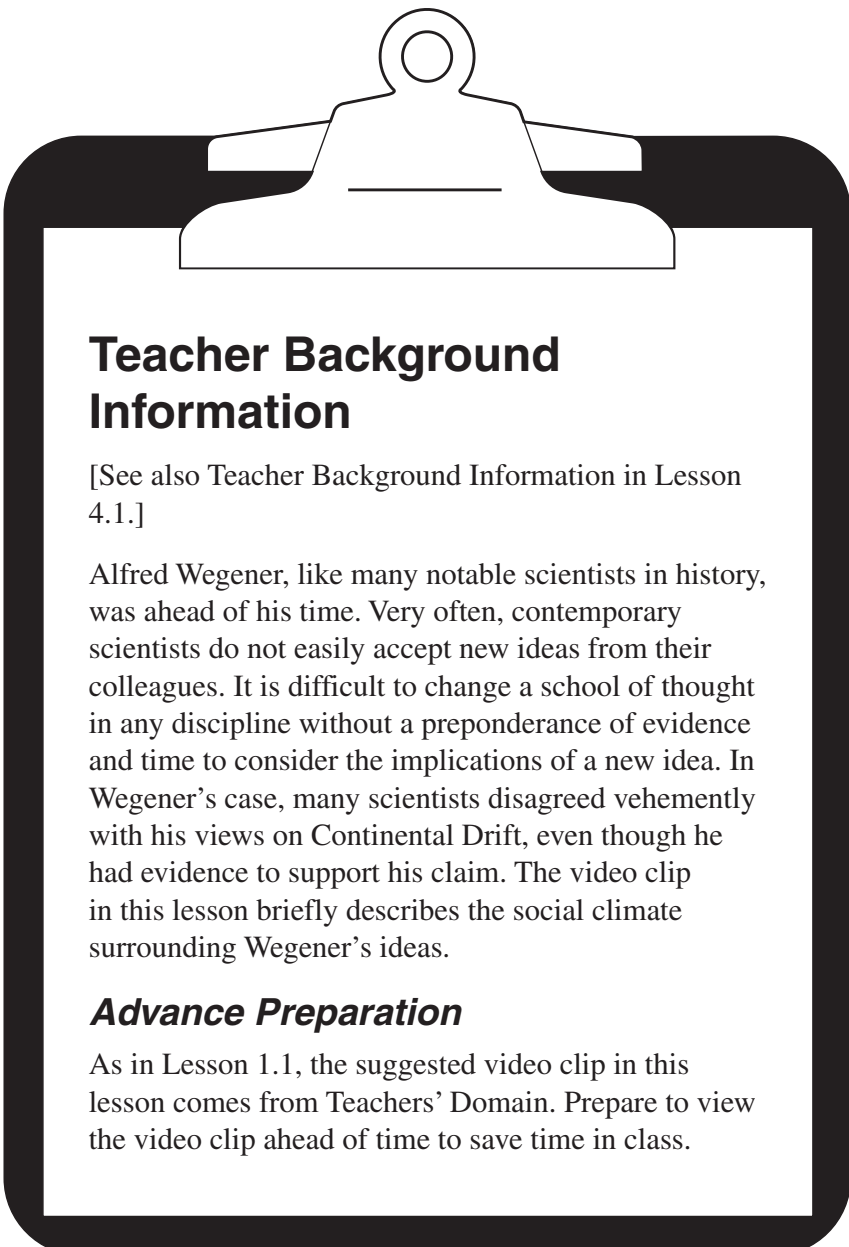
He claimed at one time all of the continents were brought together in one "supercontinent" called Pangaea.

E Why did other scientists challenge his model? He didn't have enough evidence to explain how the continents could have moved and couldn't prove that they were indeed moving.

A What kinds of things would you say if you were to make a logical argument that supported Wegener's model, Pangaea? Answers may vary but should include things like, "Wegener's model is good because it has at least three types of evidence supporting it, rock types, fossils, and outlines of continents."

P What is likely to convince the scientists that challenged Wegener's idea that Wegener had a good model? Telling them about all the evidence that supports Wegener's model.

S What do you think would be difficult about convincing one of these scientists that Wegener was correct?



Teacher Background Information

[See also Teacher Background Information in Lesson 4.1.]

Alfred Wegener, like many notable scientists in history, was ahead of his time. Very often, contemporary scientists do not easily accept new ideas from their colleagues. It is difficult to change a school of thought in any discipline without a preponderance of evidence and time to consider the implications of a new idea. In Wegener's case, many scientists disagreed vehemently with his views on Continental Drift, even though he had evidence to support his claim. The video clip in this lesson briefly describes the social climate surrounding Wegener's ideas.

Advance Preparation

As in Lesson 1.1, the suggested video clip in this lesson comes from Teachers' Domain. Prepare to view the video clip ahead of time to save time in class.

Implementation Guide

1. To review the Pangaea model of Earth's surface and introduce this lesson, pose the Predict question from Lesson 4.1 to the class:

- What do you think it was like for the scientist who first presented the Pangaea model to other scientists in 1915? What makes you think that way?

Briefly discuss a few students' responses to this question. Explain that the class will find more answers to this question by watching a short movie about Alfred Wegener's life as a scientist—the man who first presented the Pangaea model to other scientists.

2. Provide some context for Alfred Wegener's work. Explain why it is particularly interesting to study Wegener's story because it happened relatively recently (approximately 1912–1930) and his ideas were rejected until after his death.

Play the video clip “Plate Tectonics: The Scientist behind the Theory”, from the following Teachers' Domain website:

<http://www.teachersdomain.org/6-8/sci/ess/earthsys/wegener1/index.html>

3. Distribute *Student Page 4.2A: How Right Was Wegener?* and have students read it individually. Use an appropriate reading strategy to help students understand the evidence provided in the article.

- You may want to use a T-chart, like the Evidence Separation chart in Lesson 1.2 to help students identify the *evidence that Wegener used to support his ideas* and *other interesting ideas* in the reading.
- Alternatively, students can work in pairs to make a list of what they think are main ideas from the reading and share ideas with the class to build a single, class list.

To review the key ideas from both the video and the reading, use the Recall and Extend questions.

4. Explain to students that they will be writing an imaginary letter to the scientists who disagreed with Wegener. In this letter, students need to convince those other scientists that Wegener *did* have a good model (Continental Drift) because it logically explained the available evidence about Earth's surface features and processes.

Refer to the list of evidence from the reading that the class identified, and describe how Wegener indeed had a good model because there is strong evidence supporting his idea. In addition, remind students that they have collected evidence that Wegener did not have.

Encourage students to recall what additional data they know about that further supports this idea. Direct them to the Exploring Earth's Surface chart as needed.

- For example, a key piece of evidence students can cite is GPS technology. This evidence, available only from more recent technology, further supports Wegener's idea of Continental Drift and Pangaea.

5. In preparation for the writing letters to Wegener's opponents, establish a due date / timeline for the assignment. Then, as a class, develop the criteria for what a strong scientific argument would look like. Learning how to make a scientific argument is part of the process of understanding how scientists do their work and what the nature of science involves.

Three key criteria for making a strong scientific argument in this letter are:

- Authors make a claim—(i.e. tells the opposing scientists that Wegener had a good idea)
- Authors justify the claim—(i.e. “Wegener had a good idea because...”)
- Authors use and cite evidence throughout the letter

Finally, determine the desired format and style for the letter. Allow students time to review their science notebooks and the *Exploring Earth's Surface* chart and then to complete their letters.

6. Once students have finished with their letters, use a Think-Pair-Share strategy to generate responses to the questions:

- Wegener's model of continental drift explained that changes in Earth's surface happened because continents move.
- What evidence do we have that is not explained by continental drift?

It may be necessary to provide students with some supporting questions like:

- How can something as big as a whole continent move?
- Is it only the continents on Earth's surface that move?

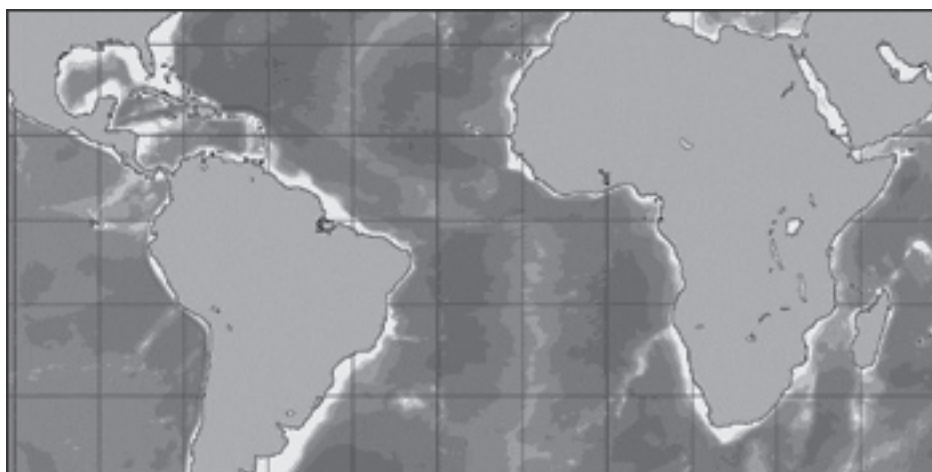
Use this line of questions to be certain students do not have the common misconception that that continents float around in Earth's crust.

7. Start students thinking about the key ideas in the next lesson by posing the question, **How can plates move?**

Student Page 4.2A: How Right Was Wegener?

What was Wegener's Idea?

Alfred Wegener was a scientist who started his greatest work with one idea. His idea was that South America and Africa were once joined together. He thought this because he noticed the outlines of these continents on a map. They looked very similar. Wegener set out to support his idea with evidence. Like you, he studied fossils, rocks, and landforms in different parts of the world. He noticed patterns in the evidence that supported his idea. When he published his idea in 1915, Wegener called it "Continental Drift".



Map of South America and Africa, separated by the Atlantic Ocean. [Image courtesy NASA/Earth Observatory]

What did other scientists think about the idea of Continental Drift?

In Wegener's time, many scientists did not agree with his idea of Continental Drift. They didn't think Wegener had enough evidence to claim that continents used to be in different places. They challenged him because he couldn't prove that continents could move. He had not explained how something as big as a continent could move. Many scientists were just not convinced.

How right was Wegener?

Wegener had a lot of evidence to support his idea. You investigated some of the same evidence in class. You came up with a similar idea. One difference between you and Wegener is that you have even more evidence than Wegener did. Science and technology has changed since Wegener's time. Wegener died before more evidence supporting his idea could be found. He died before the new technology was invented. Scientists now accept the idea that continents move and have been moving for a long time. The

scientists in Wegener's time did not have all the evidence to be convinced about Wegener's idea.

How do scientists learn from each other?

Scientists often write to each other to share their evidence for ideas. They want to know what evidence supports their ideas. Scientists also want to know what other

scientists think. What would you tell the scientists that disagreed with Wegener? You know of lots of evidence that supports Wegener's idea. You can use all the evidence that you know about to write a letter to the scientists that opposed Wegener's idea. Try to convince them that Wegener had a good idea. Try to convince them that there is a lot of evidence to support Continental Drift.

STEP 5

Overview

Previous lessons may have caused students to wonder, “How can continents move? I thought Earth was one big, solid rock.” In this step, students revisit and explore this idea. Here they learn about the missing concepts that underlie the theory of plate tectonics. Students learn that Earth is not solid; rather it is made of layers with different properties. In Step 3, they learned that plates are moving. In Step 4, they studied evidence that shows how plates, and the continents associated with them, have moved over time. Here, they begin to understand what causes plate movement.

Students read short pieces that deliver content and an engaging question. They participate in short activities and watch demonstrations that reinforce the concepts discussed in the readings. They also create a diagram of Earth on paper. As they learn more about Earth’s interior, they revise their diagram to reflect new understandings. Once students have a clear picture of what is under the surface of Earth, they return to their region models. They revise and add to their model, and begin to represent attributes of their region below Earth’s surface.

Step 5 Lesson 1 Snapshot

Key Concepts

- Plates are sections of Earth's outer layer, the crust.
- Developing and using a model is one instance in science where intuition and creativity are needed to make a model with explanatory power that will help others understand how things work.

Evidence of Student Understanding

The student will be able to:

- draw a cross-section of Earth that reflects the relative thickness of Earth's crust, plates in the crust, and the relative temperature of the center of Earth.

Time Needed

35 minutes

Materials

For the class

- *The Core* movie, TV and DVD/VCR for display

For each student

- 1 copy of *Student Page 5.1A: Core Samples*
- 1 copy of *Student Page 5.1B: Earth's Crust*

For each pair

- 1 unwrapped Milky Way® miniature
- 1 unwrapped Snickers® miniature
- 2 plastic straws
- 1 full round slice of apple
- 1 ruler with mm scale

Earth's Crust

1. Use the *Exploring Earth's Surface* chart to review ideas about the movement of plates and continents. Ask students to predict how something as big as a plate could move.

- Guide students to realize that knowing what is beneath plates may help explain how they move.

2. Ask students what they think is under Earth's surface. Have students work individually to make a drawing in their Science Notebooks of what they think Earth might look like if it were cut in half.

- Label this picture *Idea #1*.
- Resist the temptation to correct or suggest how this illustration ought to look—students will draw a second image after learning about Earth's interior later in the lesson.

3. Explain that generations of people have been intrigued by what is under Earth's surface and that there have even been science fiction movies made about it. Watch the recommended section of the movie, *The Core*. Ask:

- What did the movie show was under the surface of Earth?
- Is this reliable evidence for what is under Earth's surface?

4. Ask students to talk to a partner about how working scientists might gather evidence about what is below Earth's surface.

- Direct students to individually record their ideas in their Science Notebooks.
- Have students read *Student Page 5.1A: Core Samples* to learn about one tool that scientists have for gathering evidence about Earth's structure.

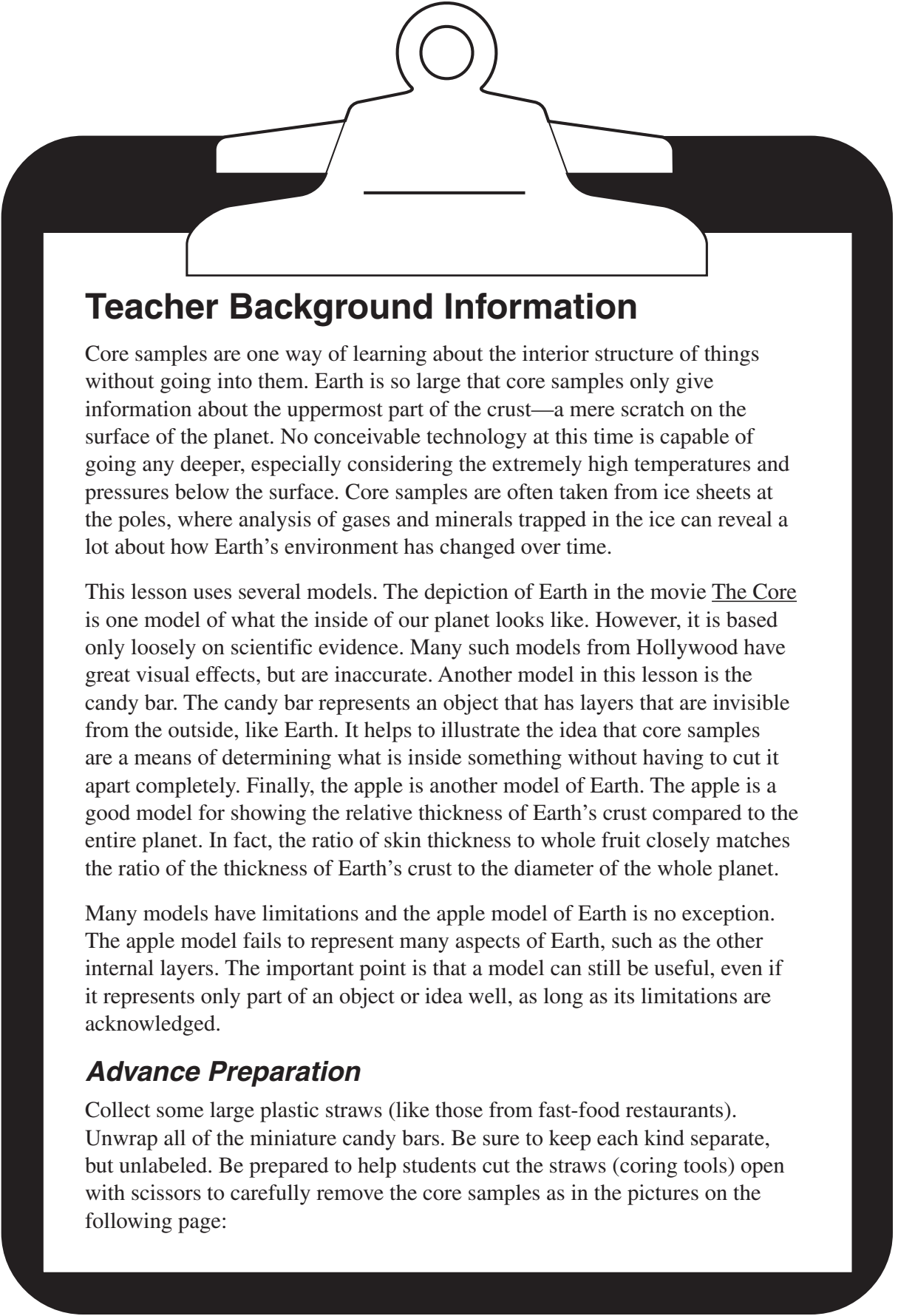
5. Explain that in this next activity, students are going to have an opportunity to explore how collecting core samples can provide evidence that is useful for understanding what is just beneath the surface.

(continued on following page)

- a. Pose the following question to the class:
If I give you and your partner two unwrapped miniature candy bars, how could you use a core sampling technique to identify what type they are?
 - b. Ask student volunteers to suggest a plan for using core sampling to identify the candy bars. Decide upon a class experimental method.
 - c. Name and describe (possibly draw) the interiors of the kinds of candy bars you will make available to provide a “candy bar key.”
 - d. Explain the “core sampling” procedure that students will follow (see the Implementation Guide).
 - e. Give student pairs two different kinds of unwrapped candy bars.
 - f. Allow pairs to take core samples and compare their evidence to the “candy bar key.”
 - g. Travel around the room to check for students’ understandings about how this activity relates to what scientists do to study Earth’s CRUST.
 - h. Have students write a 2–3 sentence evidence-based explanation for how they have identified the candy bars.
 - i. Clean up and then discuss as a class how taking a core sample provided information that they could not get by just looking at the surface of the candy bar. Relate this to how core samples help scientists understand what is just beneath Earth’s surface.
6. Give each student a copy of *Student Page 5.1B: Earth’s Crust*.
- Allow students time to complete their apple observations, measurements, and calculations.
 - Use the REAPS to make connections between core samples, modeling, apples, and Earth and to make a new drawing of Earth, *Idea #2*.

REAPS Questions

- R Can scientists use core samples to find out what is below Earth’s crust?** No, they can only go a relatively short distance into the crust (compared to the entire thickness of the crust), not below it.
- E How is the apple a good model of Earth? What are its limitations as a model?** The apple has the same ratio of skin thickness (crust) to overall diameter. Some limitations include: The apple’s surface is smooth while Earth’s surface is rough with mountains and trenches; the apple’s surface is uniform while Earth’s surface is covered in different kinds of material (soil, water, rock, sand).
- A Use your straw “coring tool” and apple to model how deep a core sample could be drilled into Earth.** The core sample would only go partially through the skin (crust). The apple core sample would not go into the fruit at all beyond a small part of the skin, which is hardly noticeable.
- P Do you think that the inside of the apple is a good model for the inside of Earth?** Accept all ideas supported with evidence and explain that the next lesson is an investigation into what is in the center of Earth.
- S Draw a new diagram of a cross section of Earth in your Science Notebook and compare your drawing of Earth (labeled *Idea #2*) to a partner’s drawing.**



Teacher Background Information

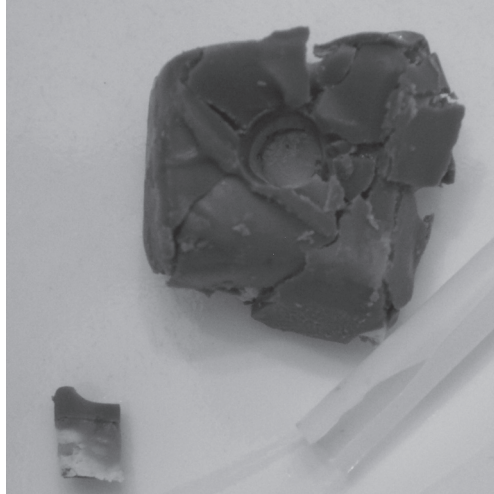
Core samples are one way of learning about the interior structure of things without going into them. Earth is so large that core samples only give information about the uppermost part of the crust—a mere scratch on the surface of the planet. No conceivable technology at this time is capable of going any deeper, especially considering the extremely high temperatures and pressures below the surface. Core samples are often taken from ice sheets at the poles, where analysis of gases and minerals trapped in the ice can reveal a lot about how Earth’s environment has changed over time.

This lesson uses several models. The depiction of Earth in the movie The Core is one model of what the inside of our planet looks like. However, it is based only loosely on scientific evidence. Many such models from Hollywood have great visual effects, but are inaccurate. Another model in this lesson is the candy bar. The candy bar represents an object that has layers that are invisible from the outside, like Earth. It helps to illustrate the idea that core samples are a means of determining what is inside something without having to cut it apart completely. Finally, the apple is another model of Earth. The apple is a good model for showing the relative thickness of Earth’s crust compared to the entire planet. In fact, the ratio of skin thickness to whole fruit closely matches the ratio of the thickness of Earth’s crust to the diameter of the whole planet.

Many models have limitations and the apple model of Earth is no exception. The apple model fails to represent many aspects of Earth, such as the other internal layers. The important point is that a model can still be useful, even if it represents only part of an object or idea well, as long as its limitations are acknowledged.

Advance Preparation

Collect some large plastic straws (like those from fast-food restaurants). Unwrap all of the miniature candy bars. Be sure to keep each kind separate, but unlabeled. Be prepared to help students cut the straws (coring tools) open with scissors to carefully remove the core samples as in the pictures on the following page:



Slice the apples ahead of time. Without use of a preservative, they will brown, but will still work for the activity. If you prefer, keep them in a bowl of water with a few drops of lemon juice or vinegar to prevent discoloration.

Implementation Guide

1. Review the class' current understanding about movement of plates and continents by using the *Exploring Earth's Surface* chart. Address students' ideas about how something as big as a plate could move from the end of the last lesson.

- Guide students to recognize that knowing what is under something may help explain how it moves by using an example like a moving walkway/escalator or bus ride. In those examples, people stand (or sit) on top of the devices and move. However, what actually does the moving is hidden underneath—under the mat or steps in the walkway/escalator example or under the floor/engine compartment in the bus example.

2. Generate interest in learning about what is under continents as a way to help explain how they move. Pose questions like:

- What have you learned before about Earth's interior?
- What do you think is under Earth's surface?

Have students draw a picture of what they think Earth looks like under the ground in their Science Notebooks. This quick sketch is meant to collect students' prior knowledge and pre-conceptions. Ask students to label this drawing **"Idea #1"**.

- Students will be making a second drawing after learning more about Earth's interior that they will label "Idea #2," and they will compare and contrast the two drawings at the start of Lesson 5.2.

3. Explain that many people, for a long time, have been fascinated with the question of what is beneath Earth's surface. Explain that one of the reasons that people have made a number of science fiction movies about what lies beneath the surface is because it is still an intriguing mystery since we cannot see directly what is there.

Show students a short portion of the movie The Core. There are several good parts to this 2003 PG-13 movie. In particular, scenes 10 or 11 (on the DVD) depict what it is like as a bunch of scientists travel into the center of Earth in a special vehicle. Scene 10 begins at approximately 54 minutes into the film and runs for about 7 minutes. It is particularly interesting because it begins with the vehicle traveling from the surface of the ocean. Scene 11 (from about 1:05 to 1:10) is also a good clip and shows the actors inside Earth.

After showing the movie, ask:

- What did the movie show was under the surface of Earth?
- Is this reliable evidence for what is under Earth's surface?

Conduct a short discussion about how science fiction movies are similar to and different from reality. Ask students if they think it is really possible for scientists to go inside Earth like they did in the movie. Conclude the discussion by asking students to think about where good evidence for what IS inside Earth comes from.

Note: A number of online sites analyze movies like The Core to expose the misconceptions and inaccuracies they depict. One such site can be viewed at <http://www.intuitior.com/moviephysics/core.html> and others can be found by searching for keywords like: "The Core" and "misconception".

4. Have pairs of students discuss how they think working scientists gather evidence for what is beneath Earth's surface.

- Ask students to individually record their ideas in their Science Notebooks to increase the level of engagement for all students.
- Explain that you have an article that explains one way scientists can collect data about what is under the surface of Earth.

- Distribute *Student Page 5.1A: Core Samples*, and have students read the article using an appropriate reading strategy.
- This reading also prepares students to take their own core samples later in the lesson.
- After reading, remind students that core samples are one way that scientists gather information about materials beneath the surface without having to make large tunnels.

5. Transition from the reading and discussion about core samples to this next activity in which students will explore how core samples can provide evidence that is useful for understanding what is just beneath the surface.

- Pose the following question to the class:
If I give you and your partner two unwrapped miniature candy bars, how could you use a core sampling technique to identify what type they are?

- Ask student volunteers to suggest a plan for using core sampling to identify the candy bars. Decide upon a class experimental method (the basic method is to take core samples from the candy bars and compare them to the known layers found in known candy bar types).

- Milky Way® and Snickers® or Mars® miniatures work well for this activity, but other candy bars will work too.

CAUTION: DO NOT use candy bars that contain any nut products to avoid the chance of allergic reactions among students.

- Emphasize how students should NOT eat the candy because they are acting like scientists, and scientists in the laboratory never eat or taste anything.
- Remind students, also, that the candy bars were not handled with care as would be done if they were intended as food, so they are most likely dirty.

- Name and describe (possibly draw) the interiors of the kinds of candy bars you will make available to provide a “candy bar key.”
- Provide each pair of students with straws and scissors so they may take core samples of their candy bars by pushing the straw from the surface through the bar. To expose the layers in the core sample, use scissors to carefully snip open the straw (students have a description of this procedure on Student Page 5.1A)
 - Explain that students need to record all of their observations in their Science Notebooks.
- Give student pairs two different kinds of unwrapped candy bars.
- Allow pairs to take core samples and compare their evidence to the “candy bar key.”
 - As students work, travel around the room to check for students’ understandings about how this activity relates to what scientists do to study Earth’s CRUST (core samples do NOT extend deeper than the shallow crust).
- Travel around the room to check for students’ understandings about how this activity relates to what scientists do to study Earth’s CRUST (core samples do NOT extend deeper than the shallow crust).
- Have students write a 2–3 sentence evidence-based explanation for how they have identified the candy bars.
- Clean up and then discuss as a class how taking a core sample provided important information that they could not get by just looking at the surface of the candy bar. Relate this to how core samples help scientists understand what is just beneath Earth’s surface.

- Ask students to share with each other, and then the whole class, how taking core samples enabled them to learn more about the candy bars than they knew just by looking at them from the outside.

6. Explain that core samples are one way that scientists can look at the outermost part of Earth. Provide students with *Student Page 5.1B: Earth's Crust*.

Have students read the article and then distribute apple slices and rulers so they can make observations and measurements as directed in the reading.

Allow students time to complete their apple observations, measurements, and calculations.

- Use the Recall and Analyze questions to emphasize how core samples cannot provide scientists with information below Earth's crust.
- Use the Extend and Predict questions to guide students to understand that the apple is a model of Earth.

To complete this lesson, ask students to return to their Science Notebooks and make a new drawing of what they think is inside Earth.

- Have students label this drawing "Idea #2".

Student Page 5.1A: Core Samples

How can a scientist learn about what is inside something?

Imagine that a scientist wants to learn about the inside of a tree. They could cut down the tree. Then, they could look directly at what is inside. But this would kill the tree! Scientists usually take great care not to damage what they are studying. A better idea would be to take a small sample of the tree instead of cutting the whole tree down.

Imagine that another scientist wants to see what is under the ice at the North Pole. They can't just cut the North Pole in half to see what's there. It is far too big. They have to take a sample of ice.

When scientists want to see inside something that they want to protect or that is too big to cut apart, they may take a core sample. A core sample gives them a little piece of what is inside something.



*A scientist pulls an ice core sample from a drilling tube.
[Image courtesy NOAA. Photo by Lonnie Thompson.]*

Core samples are taken with hollow, round tubes. The tubes are pushed into the sample. When they are pulled out, scientists can see into the sample. They can also pull the core sample out of the tube. Then, they can see all the layers that are inside something.

Think and Do

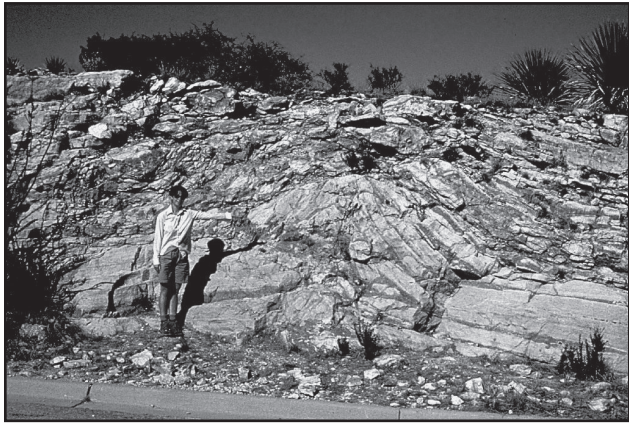
Time to practice taking core samples! *Warning: The candy bars may not be clean or fresh. Do not eat them!*

1. Take out your Science Notebook. Study your candy bars. Draw a picture of each bar. Record any observations that you make of your bar. Can you tell which bar is which just by looking at them from the outside?
2. Take a core sample of each bar. Push the straw into the middle of the bar slowly. Carefully remove the straw and cut out the core sample. Record in your Science Notebook what the inside of the bar looks like. Make a new drawing of each bar. What information does the core sample give you?

Student Page 5.1B: Earth's Crust

Core sampling is one way to see what is inside something without cutting the object open. Think about trying to see what is beneath Earth's surface. Do you think you could take a core sample?

Scientists can see what is on the surface of Earth. Most of Earth is covered with water. The land is made of soil, clay, sand, and rock. Scientists can dig holes in the ground and see that there is solid rock just under the surface. Scientists call this layer of rock Earth's crust.



Rock that is part of Earth's crust, near Carlsbad, New Mexico. [Photo courtesy Earth Science World ImageBank, © Society for Sedimentary Geology.]

Digging Deeper

Earth's outer layer is called the crust. Scientists can take core samples of the crust, but they can only dig so deep. How far do you think scientists have gone? Engineers dig deep holes when they build mines. The deepest mine in the world is a gold mine in South Africa. It is 4 kilometers deep. Even 4 kilometers down, Earth is still solid rock. This is still part of the crust. The deepest hole ever drilled was in Russia. This hole was 12 km deep. The drill was still in the crust.

One thing about the hole in Russia surprised scientists. It was very hot. It was much hotter than they predicted. The temperature was 1800 °C! The temperature on a hot summer day only reaches about 38 °C. Water boils at 100 °C. It is hard to imagine how hot 1800 °C would feel. Scientists can't drill much deeper than 12 km. Their tools get so hot that they will break. Even rock begins to melt at high temperatures.

Could scientists take a core sample all the way through Earth? Many scientists wish they could. Unfortunately, Earth is too big and too hot inside. Our planet is 12,756 km across. A core sample would have to be that long to go all the way through to the other side!

(continued on following page)

Student Page 5.1B: Earth's Crust (continued)

Name _____

Date _____

Think and Do

1. Earth's crust is about 100 km thick at its thickest point. Divide this number by the thickness of the entire Earth, 12,756 km. Then, multiply your answer by 100.

Earth's crust / Earth's diameter x 100 = _____%

This number is the thickness of Earth's crust compared to the whole planet.

2. Measure the thickness of the skin of an apple and record it. Then, measure the thickness of the whole apple.

The skin is _____ mm thick. The apple is _____ mm thick.

Compared to the whole apple, calculate how thick the apple skin is.

Apple skin / Apple diameter x 100 = _____%

Compare this number to the thickness of Earth's crust compared to the whole planet. Are the two numbers the same? If not, are they close (within 1 or 2)?

What do you think the apple represents? Is it a good model? How do you know?



[Apple photo courtesy US Dept. of Health and Human Services.]



[Earth photo courtesy NASA.]

Step 5 Lesson 2 Snapshot

Key Concepts

- The inside of Earth is made of layers with different properties.
- Convection currents inside Earth cause plates to move.

Evidence of Student Understanding

The student will be able to:

- draw a cross-section of Earth that reflects the relative thickness of Earth's crust, plates in the crust, names and basic physical properties of interior layers, and convection currents in the mantle.
- describe how convection currents cause plates to move.

Time Needed

35 minutes

Materials

For the class

- Convection current demonstration video 

For each student

- 1 copy of *Student Page 5.2A: Layers of Earth*
- 1 copy of *Student Page 5.2B: Convection Currents*

Inside Earth

1. Have students use a Think-Pair-Share strategy to compare and contrast their drawings from the previous lesson that were labeled **Idea #1** and **Idea #2**.

- Have students recognize and describe what caused them to change their drawings.
- Remind students that they are behaving like scientists when they change their models (drawings) because of new evidence.

2. Explain that today they will discover a few more pieces of evidence that can be used to improve their models of Earth's interior. Use a classroom reading strategy or have students individually read *Student Page 5.2A: Layers of Earth*.

(continued on following page)

REAPS Questions

- R** List the layers of Earth from the outside in. Chemically distinct layers: crust, mantle, core. Physically distinct layers: lithosphere, asthenosphere, mesosphere, outer core, inner core.
- E** Which layer of Earth is coolest? The crust or lithosphere.
- A** How can convection currents in a hot layer of molten Earth move the layer above it? As the hot layer rises, it must push the cooler layer out of the way and therefore causes the cooler layer to move.
- P** What might happen on Earth's surface where magma rises in convection currents? Magma may rise above the surface through a volcano or fissure.
- S** Review your Idea #1 through Idea #4 drawings. How is what you did here similar to what scientists do with models and to what you are doing with your region model?

3. Have students work in small groups or pairs to answer the Think and Write question. In their Science Notebooks, have students draw another cross-section of Earth and label it ***Idea #3***.

4. Hold a class discussion about what causes plates to move. Acknowledge that this is a complex question to answer.

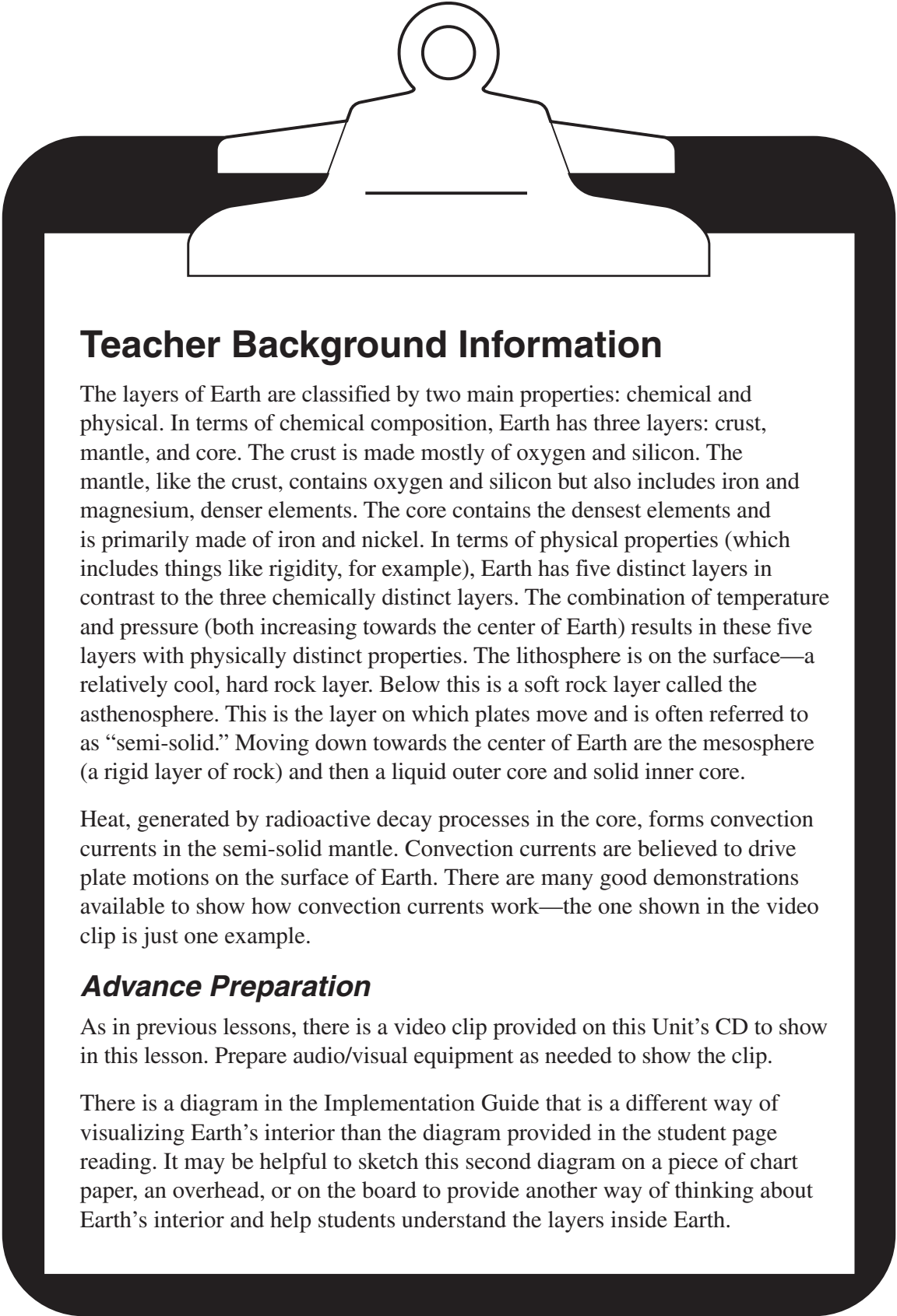
- Challenge the idea that “plates floating on the mantle” explains why plates move, by asking, “Is it possible for something to float without moving?”

5. Show the *Convection Current* demonstration video. Then, have students read *Student Page 5.2B: Convection Currents*.

- Have students work in pairs or small groups to develop a better answer to the question of how plates can move.
- Explain how knowing about what is in the interior of Earth helps scientists understand how plates move.

6. In their Science Notebooks, have students draw another cross-section of Earth that represents all of the evidence they now have about Earth’s interior. This diagram can be labeled ***Idea #4***.

7. Use the REAPS throughout and after the lesson as appropriate.



Teacher Background Information

The layers of Earth are classified by two main properties: chemical and physical. In terms of chemical composition, Earth has three layers: crust, mantle, and core. The crust is made mostly of oxygen and silicon. The mantle, like the crust, contains oxygen and silicon but also includes iron and magnesium, denser elements. The core contains the densest elements and is primarily made of iron and nickel. In terms of physical properties (which includes things like rigidity, for example), Earth has five distinct layers in contrast to the three chemically distinct layers. The combination of temperature and pressure (both increasing towards the center of Earth) results in these five layers with physically distinct properties. The lithosphere is on the surface—a relatively cool, hard rock layer. Below this is a soft rock layer called the asthenosphere. This is the layer on which plates move and is often referred to as “semi-solid.” Moving down towards the center of Earth are the mesosphere (a rigid layer of rock) and then a liquid outer core and solid inner core.

Heat, generated by radioactive decay processes in the core, forms convection currents in the semi-solid mantle. Convection currents are believed to drive plate motions on the surface of Earth. There are many good demonstrations available to show how convection currents work—the one shown in the video clip is just one example.

Advance Preparation

As in previous lessons, there is a video clip provided on this Unit’s CD to show in this lesson. Prepare audio/visual equipment as needed to show the clip.

There is a diagram in the Implementation Guide that is a different way of visualizing Earth’s interior than the diagram provided in the student page reading. It may be helpful to sketch this second diagram on a piece of chart paper, an overhead, or on the board to provide another way of thinking about Earth’s interior and help students understand the layers inside Earth.

Implementation Guide

1. For students to compare and contrast the Idea #1 and Idea #2 drawings from the previous lesson, have students work individually, in pairs, and then discuss as a whole class. Focus the whole class discussion on what caused students to change their drawings. Use guiding questions for the discussion like:

- What is the same in Idea #1 and Idea #2? What is different?
- Why did you make the drawing in Idea #2 different from the one in #1?

Remind students that scientists' models and representations change when they gather new evidence. Because they likely changed their drawings (models) of the inside of Earth as they learned new evidence, students acted like scientists.

2. Inform students that they will learn about more evidence in this lesson, and that will make it possible for them to again improve their models of Earth's interior. Give each student a copy of *Student Page 5.2A: Layers of Earth*. Use a classroom reading strategy or have students individually read the article.

Because there are many scientific terms in this reading, it may be useful to start a word bank or T-chart to help students keep track of them. In particular, keep track of terms relating to chemically-distinct layers versus those relating to physically-distinct layers. This is a common point of confusion when learners encounter this subject.

Drawing or projecting another diagram to represent the layers as shown on this unit's CD is one possible way of helping students distinguish between terms. This additional diagram shows the chemically-distinct and physically-distinct layers side-by-side to see how some layers in one set overlap layers in the other set.

3. Have students work in small groups or pairs to answer the Think and Write question at the end of the reading. This question asks about

how scientists know about the mantle. Seismic waves are one way of learning about Earth's interior. Since S-waves are slowed when they travel through the mantle; scientists know it is liquid, which supports the model of a semi-solid asthenosphere layer. In addition, scientists have evidence from volcanoes and fissures that molten rock, with specific chemical composition, exist somewhere below the solid crust. Therefore, volcanic eruptions are events that also support the model of a mantle layer.

After the discussion, ask students to take out their Science Notebooks, draw another cross-section of Earth, and label the drawing "**Idea #3.**"

4. Now that students have learned additional evidence for what the inside of Earth is made up of, ask them to discuss what causes plates to move. This could be done using a quick Think-Pair-Share or other brainstorming strategy to quickly elicit initial ideas.

If students say that "plates float on the mantle, so that's why they move", push them to explain more by countering with "Is it possible for something to float without moving?" For example, a Cheerio™ floating in a perfectly still bowl of milk does not move. However, if the milk were moving, it would move.

- Highlight examples where floating objects move because what lies beneath them moves.

Acknowledge the fact that this is a challenging question to answer and inform students that they will have yet another opportunity to uncover some evidence for how plates move.

5. Explain that you have a video clip that demonstrates how floating things move when the substance underneath them moves. Show the video clip of the convection current demonstration that is provided on this Unit CD.

- After the video, clarify any student questions about the demonstration, then distribute *Student Page 5.2B: Convection Currents*.

Have students work in pairs or small groups to refine answers to the question “How can plates move?” At this point, students ought to know enough about Earth’s interior layers, convection currents, and plate boundaries to give a logical explanation for how plates move.

Look for students to include most of these key ideas in their responses:

- The solid outer portion of Earth is made of separate plates. (Plates touch other plates on all sides, and there is no visible boundary between them).
- Continents and the seafloor beneath oceans are contained in these plates.
- All of Earth’s plates move very slowly.
- Plate motion causes neighboring plates to interact with each other along their boundaries and causes events such as earthquakes and volcanic eruptions
- Plate motions are driven by a combination of Earth’s heat and gravitational forces.
- Convection currents in the mantle cause the substance that the plates are floating on (the mantle) to move, and that influences the plates to move.

After the new explanations are shared, remind students how knowing about both the surface and

what is in the interior of Earth helps scientists understand how plates move. Share that scientists are still exploring and seeking more evidence about what makes up Earth’s interior. There are many more questions about Earth that scientists hope to answer.

For example, some scientists today wonder “How can objects as large and heavy as plates keep moving at such a steady pace?” Scientists are also anxious to know more details of how plates move and be able to predict the amount of convection and forces that must be happening inside Earth to cause the surface motion and events we observe.

6. Revisit the “Idea” diagrams of the interior of Earth once more. This time, the goal is to review the information learned in this lesson and the scientific process of revising models. Ask students to share what evidence they used to make each model. Finally, have students draw a new model to reflect what they now understand about the inside of Earth. This diagram can be labeled “**Idea #4**” and should represent all of the evidence students have learned about Earth’s interior.

7. The REAPS in this lesson are designed to be used throughout the activities as appropriate. Some questions can be used to review the readings. Others, like the Self-assess question, can be used to review the lesson and students’ understanding of the interior of Earth.

Student Page 5.2A: Layers of Earth

How do scientists know what is under the crust if they have never been there? Think back to how you figured out where the continents used to be. You couldn't go back in time and see where they were. You looked for evidence to figure it out. Scientists did the same thing to figure out what is under Earth's crust.

How do scientists know what is inside Earth?

Remember the P and S waves from earthquakes? Scientists use seismometers to measure P and S waves in order to locate the centers of earthquakes. Scientists also use P and S waves to figure out what is deep inside Earth. P waves not only move faster than S waves, but they travel through solids and liquids. S waves cannot move through liquids. In an earthquake, P and S waves move through the Earth. They travel in all directions away from the center of the earthquake. Scientists noticed that seismometers could detect P waves from an earthquake on the opposite side of Earth. Surprisingly, they did not detect any S waves. That told scientists part of the inside of Earth must be liquid! This is how scientists learned that at least one layer of Earth, the outer core, is liquid rock. Scientists know about other layers of Earth by using similar techniques.

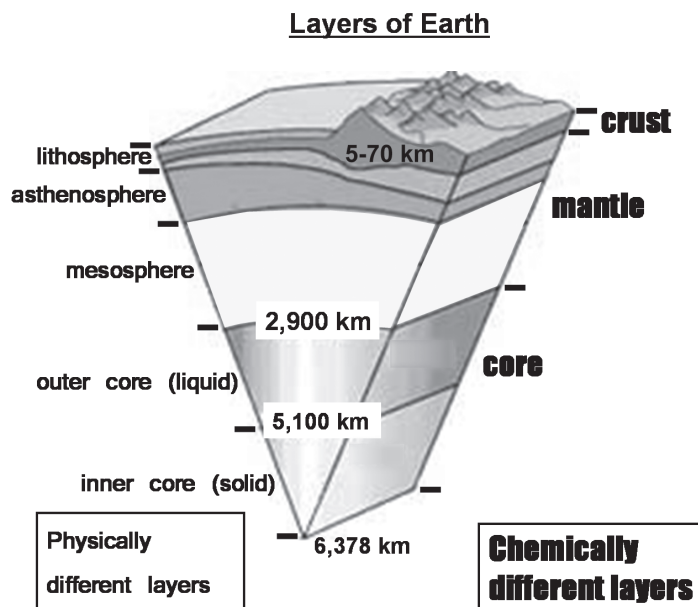
The Crust

From core samples and drill holes, scientists know the top surface of Earth is cool, but just a few kilometers down it is over 1000 °C. This top layer of Earth is called the crust. It is solid rock. The crust cracks easily. It is brittle. Cracks in the crust are called faults and this is where earthquakes happen.

The Mantle

Just below the crust is the mantle. The mantle is hotter than the crust. Together, the crust and upper mantle form the lithosphere. The lithosphere is

brittle and can crack if enough force is applied to it. Deep cracks in the lithosphere are plate boundaries. Do you remember the pattern of earthquakes around the world? This pattern tells scientists where there are cracks in the lithosphere.



[Illustration adapted from USGS This Dynamic Earth]

Below the lithosphere, the Earth is so hot that it is not solid. This layer contains semi-solid rock called magma. Magma is somewhere in between a liquid and a solid. Magma is bendable like taffy. It can stretch, fold, and compress without cracking. Yet it does not pour easily like water or other liquids. What materials have you touched with this texture? Scientists call the most flexible part of the mantle the asthenosphere. The lithosphere floats on top of the asthenosphere. The rest of the mantle is called the mesosphere, which means “middle sphere”. The mesosphere is in the middle of Earth.

The Core

Below the mantle is the core. The core is huge. It is bigger than the planet Mars! It has two layers, an outer core and an inner core. The core is made mostly of metal and is very dense. The core releases a lot of energy too. This energy heats up the layers above it.

(continued on following page)

Student Page 5.2A: Layers of Earth (continued)

Name _____

Date _____

Think and Write

1. What evidence can you think of that might have told scientists what the mantle is like?

2. Take out your Science Notebook. Study the diagrams of the inside of Earth that you made earlier—Idea #1 and Idea #2. You have gathered new evidence for what the inside of Earth is like. How do you need to change your diagram so that it agrees with the evidence? Draw a new diagram of Earth that is supported by all the evidence you have learned. Label it Idea #3. Think about:

- Where is it hottest?
- How thick are the layers?
- Are the layers solid, semi-solid, or liquid?
- Where are the plates?

Student Page 5.2B: Convection Currents

Convection Currents

When a burner heats water in a pan or beaker, the hot water rises from the bottom. When the hot water reaches the top, it cools a little and is pushed to the side by hot water rising from below. The hot water then cools some more and sinks back down to the bottom. This makes a current, or flow, of water in the container. Hot water rises, moves to the side, cools, and sinks. This process is repeated over and over again. This process is called convection. The flow of water in the container is a convection current.

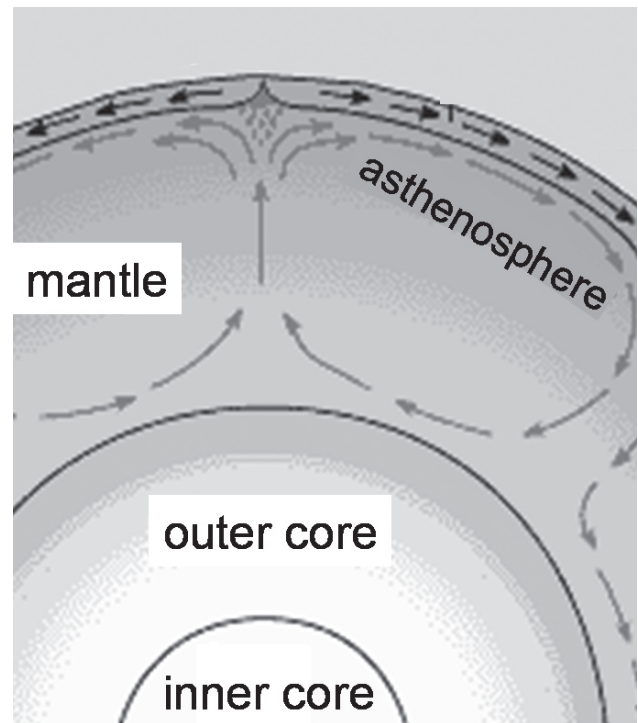


*[illustration courtesy
USGS This Dynamic
Earth]*

What does this have to do with moving plates?

Continents are parts of plates, and plates are pieces of the lithosphere. Plates float, but they do not float on the ocean. They float on the asthenosphere. They move wherever the asthenosphere pushes them.

There are convection currents inside Earth that work in the same way as the ones in a heated container of water. Earth is hottest in the middle. Hot magma in the mantle rises. As it reaches the asthenosphere, it moves to the side and cools. Then it sinks back down into the mantle. It is then heated again and rises. The rising magma pushes against the plates on the surface. They split apart and move.



[illustration adapted from USGS This Dynamic Earth]

Step 5 Lesson 3 Snapshot

Key Concepts

- Scientists often gather more than one type of evidence to support an idea.
- Scientists revise their models based on new evidence.
- Developing and using a model is one instance in science where intuition and creativity are needed to make a model with explanatory power that will help others understand how things work.

Evidence of Student Understanding

The student will be able to:

- modify a physical model to make it better represent and/or explain the evidence available about the landforms in a particular world region.
- explain what a scientific model is and how scientists use them.

Time Needed

20 minutes

Materials

For each student

- 1 copy of *Student Page 5.3A: Developing My Scientific Model*

For each group

- modeling materials (can include modeling clay, paper, cardboard, popsicle sticks, tape, toothpicks, straws, paper cups, cotton balls, or other common materials that students will use to modify physical models of the regions)

Revising Region Models

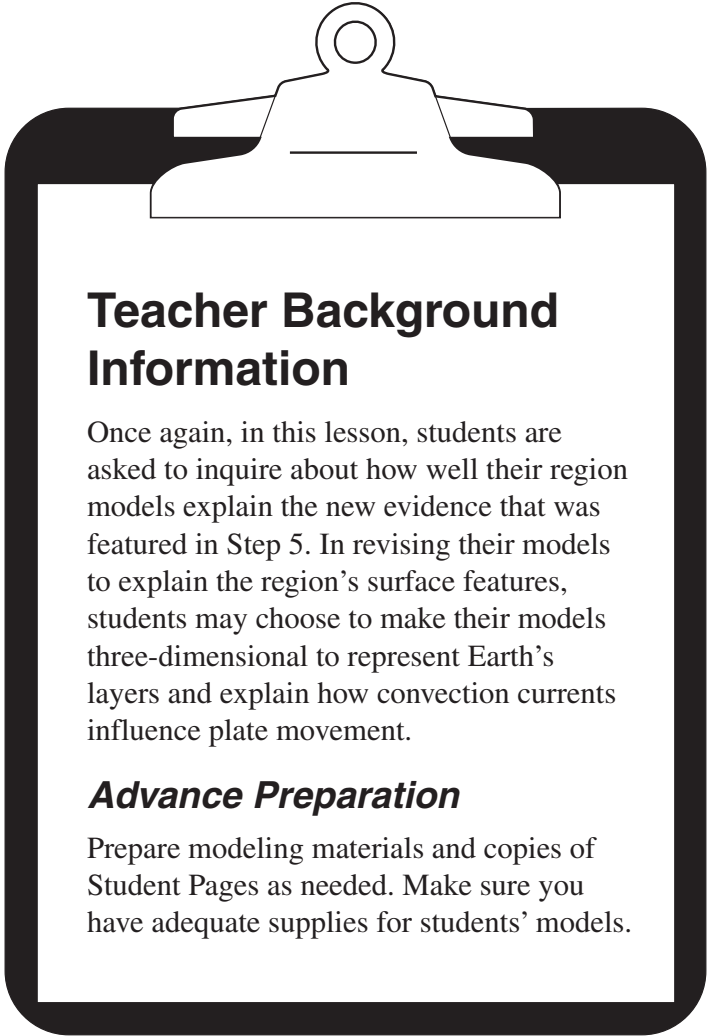
1. Use the class' *Exploring Earth's Surface* chart and the REAPS to review the new evidence gathered since the last model revision.
2. Explain that students will be asking questions about their region models in this lesson to see if they explain all that they now know about that region.

(continued on following page)

REAPS Questions

- R** List at least one additional piece of evidence about how Earth's surface features form that you gathered in Step 5. Answers may vary but can include information about Earth's crust, the layers of Earth, and convection currents that cause plates to move.
- E** How would you know if your region had semi-solid or liquid rock close to the surface? Any region that has volcanic activity has semi-solid or liquid rock near the surface.
- A** Explain why it is useful for scientists to develop models of Earth's interior. Because it is not possible to directly observe Earth's interior, scientists develop models that explain the evidence that is known about the interior, and then they test the model by seeing if it explains new evidence as it is learned.
- P** Imagine scientists could drill deep into Earth—all the way to the asthenosphere—and take a core sample. (Remember that is not actually possible because their drills would break in the intense heat.) If they could do this, draw a diagram in your Science Notebook of what the sample might look like. Look for students to accurately represent the chemical and/or physical layers of Earth as they would be found in a core sample. Check student understanding by asking them to support their drawings with evidence.
- S** Compare the diagram you drew in the Predict section to a partner's. Talk about how they are similar and how they are different.

- Distribute *Student Page 5.3A: Developing My Scientific Model* and ask students to plan their revision before they begin constructing.
3. Allow student groups a designated amount of time and available materials to modify their existing region models.



Teacher Background Information

Once again, in this lesson, students are asked to inquire about how well their region models explain the new evidence that was featured in Step 5. In revising their models to explain the region's surface features, students may choose to make their models three-dimensional to represent Earth's layers and explain how convection currents influence plate movement.

Advance Preparation

Prepare modeling materials and copies of Student Pages as needed. Make sure you have adequate supplies for students' models.

Implementation Guide

1. Review the *Exploring Earth's Surface* chart embedding the REAPS questions to both help students contribute new or edit existing entries and to check for student understanding. Focus students' attention on the entries that include

reference to evidence that the existing models may not yet represent or explain.

At this point in the unit, the *Exploring Earth's Surface* chart may look something like the following:

Exploring Earth's Surface

What did we observe about Earth's surface today?	How were those observations made by scientists?	What can we learn from those observations?
We saw mountains, valleys, and oceans.	First-hand observations, still and video cameras.	Earth's landforms are different in different places.
Sometimes the ground shakes.	First-hand observations, seismometer recordings.	Earth's surface can move suddenly.
We saw damaged buildings and roads.	First-hand observations, photos of damage.	
Locations of earthquakes and volcanic eruptions.	Seismometers (and computers for display).	Earthquakes and volcanic eruptions happen in similar locations.
		Earthquakes and volcanic eruptions happen mostly in particular regions around the world.
Land moves slowly.	GPS stations and satellites.	Parts of Earth's surface move slowly all the time.
		Earth's surface is broken into large pieces called plates.
Locations of fossils on several continents.	Geologists collect fossils from the field.	Continents used to be closer to each other and connected.
		Continents now in one climate have been in extremely different climates in the past.
Locations of types of rock on several continents.	Geologists collect rocks from the field and analyze them.	Continents used to be closer to each other and connected.
Earth gets hot as you go into the crust.	Core samples, deep mine shafts.	Inside of Earth is hot, unlike the surface.
There are no S waves in some places on the opposite side of the world from an earthquake focus.	Seismograph readings.	Part of Earth's interior is liquid.
		Earth has layers with different physical and chemical properties.

2. Explain that students will be asking questions about their region models in this lesson to see if they explain all that they now know about that region.

- Distribute to each student a copy of *Student Page 5.3A: Developing My Scientific Model* and ask students to plan their revision before they begin constructing.
- As before, although each group builds only one model, each student needs to complete this student page because it will be combined with the other pages at the end of the unit to tell a story about how the model has changed over time.

You may wish to model the thinking that students will engage in as they ask questions of their models to determine if they represent and/or explain the evidence about Earth's layers that the

class studied. If students need additional support to ask questions of their models and plan a revision, use the California region that was used in previous lessons with the Think Aloud strategy to help students understand what to do.

3. Provide students with time and materials to revise their region models as in Lessons 1.2, 2.4, and 3.3. At this point, encourage students to add more depth to their models and creatively represent the Earth's interior layers beneath their region. Students may choose to use color to represent the temperature difference among interior layers, and they can also add representations of convection currents.

By the end of this lesson, it is possible that students' models can include moving parts that explain how Earth's surface is dynamic in addition to representing various features.

Student Page 5.3A: Developing My Scientific Model

Name _____

Date _____

What new evidence have I learned about my region that my model does not represent or explain? Now that I know more about my region and about scientific modeling, what is missing in my model?	What are my model's strengths? What does my model explain about Earth's surface in my region? List at least 2 questions you could ask about Earth's surface in your region that your model can answer.
What are my model's limits? What doesn't my model explain about Earth's surface in my region? List at least 2 questions you could ask about Earth's surface in your region that your model cannot answer yet.	Describe at least two different ways that you could get more information and evidence about your region and Earth's surface there.

STEP 6

Overview

This step builds on students' knowledge of plate movement, layers of Earth, and convection currents. They learn that new rocks form at divergent plate boundaries, and at the same time, older crust is recycled back into the mantle at convergent boundaries in a process called subduction. As a result, the total size of Earth is unchanged.

Students work through a guided inquiry using new data and making connections to what they have already learned. By now, students are building a coherent view of plate tectonics and are practiced at using evidence to build explanations. A conceptual understanding of plate tectonics is also building and being analyzed in this step as the class completes a chart that describes all of the lines of evidence that support the theory of plate tectonics. In addition, students begin to practice making explanations for landforms and events that can be understood in terms of plate tectonics.

At the end of this step, students will improve their scientific models to explain how particular plate boundaries in their region could affect the region's landforms and will prepare to present their models to the class.

Step 6 Lesson 1 Snapshot

Key Concepts

- Plate boundaries are categorized as divergent, convergent, or transform.
- As plates diverge, new rock fills the gap and older rock moves away from the plate boundary.
- Scientists usually gather more than one type of evidence to support an idea.

Evidence of Student Understanding

The student will be able to:

- analyze data from a divergent plate boundary simulation and,
- relate the data to geologic information about where old and new rocks are found.

Time Needed

40 minutes

Materials

For the class

- 1 copy of *Student Page 3.1C: GPS Data Map*
- 1 color overhead of *Student Page 6.1B: Age of Rocks Map*

For each group of 2–3 students

- 2 pencils (better if unsharpened)
- masking tape
- 8×11 piece of paper cut in half lengthwise
- 2 markers (crayons do not work)
- clock with second hand or stopwatch

For each student

- 1 copy of *Student Page 6.1A: Modeling Divergent Plates*
- 1 copy of *Student Page 6.1B: Age of Rocks Map*
- 1 copy of *Student Page 6.1C: Divergent Plate Boundaries*

Divergent Plate Boundaries

1. Begin this lesson by asking students to recall what they know about what happens where two plates meet. Briefly hold a discussion to engage students in thinking about what they already know about plate boundaries.
2. Show an overhead of *Student Page 3.1C: GPS Data Map*. Call student attention to the area of the world where they previously modeled GPS station movement and review the GPS simulation from Step 3.
3. Ask students to describe what is happening near the Pacific/Nazca plate boundary.
 - Have two students model that movement for the class.
 - Then, introduce the term **divergent boundary**.
 - Repeat the series of steps for the **convergent boundary** (Nazca/South American) and the **transform boundary** (Pacific/North American in California).
 - In their Science Notebooks, have students record the three terms, definitions, and examples as a reference.
4. Explain to students that today they will be investigating what happens at divergent boundaries. In their science notebooks, have students individually record their predicted answers to the following questions, using any evidence they think might apply:
 - What fills the gap between the two plates?
 - Where would the newest rocks on the Nazca and Pacific plates be located? The oldest?
5. Ask for 2–3 volunteer students to share their predictions. Resist the temptation to confirm or give correct answers at this time; allow students to explore the data to look for patterns that will explain the answers.

(continued on following page)

6. Divide the class into groups of 2–3 students. Provide each team with the supplies for the activity and *Student Page 6.1A: Modeling Divergent Plates*.

- Allow students time to complete the activity and analyze their data.
- Travel around the room as students work, and check for students' understanding that they are using a model to learn about what happens at divergent plate boundaries.

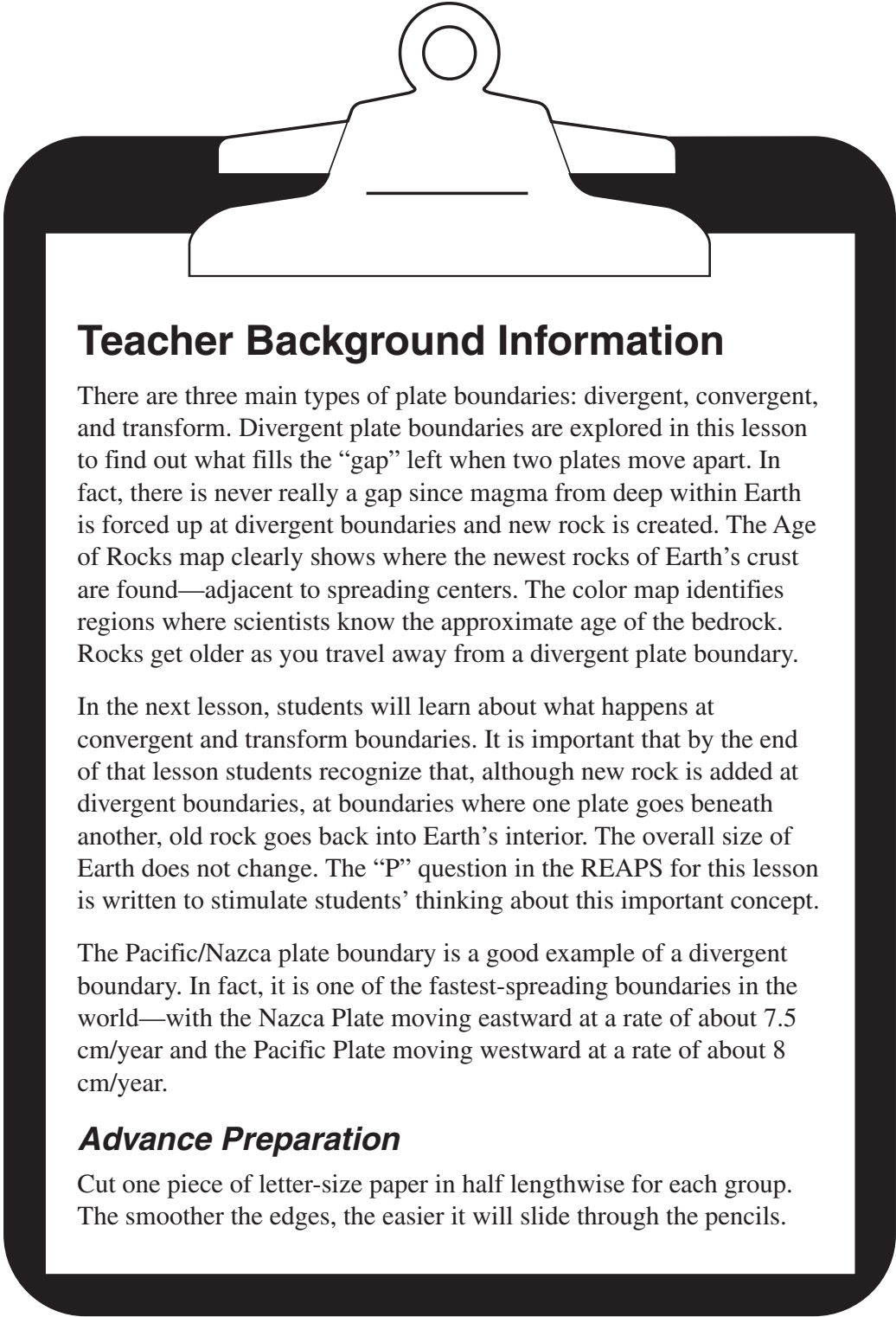
7. Introduce the color overhead of *Student Page 6.1B: Age of Rocks Map*. Use the REAPS to connect the *Age of Rocks Map* to the simulation and to foreshadow the next lesson.

- Emphasize the “P” question, **Is Earth’s size increasing because of the materials that are added at divergent boundaries?** as an important concept that will be further explored in the next lesson.

8. Have students read *Student Page 6.1C: Divergent Plate Boundaries* and discuss as review.

REAPS Questions

- R Where were the oldest rocks on the map? The newest?** The older rocks are toward the edges, away from the diverging plate boundary. The newest rocks are right next to the boundary.
- E How does this compare to your pencil/paper simulation?** The pattern is the same. The older marks are furthest from the middle.
- A Where does new rock come from to fill the gap between diverging plates?** Magma rises from the mantle/asthenosphere. Refer students to *Student Page 5.2B: Convection Currents*, if needed.
- P Is Earth’s size increasing because of the materials that are added at divergent boundaries?** Students may have the misconception that Earth’s size is increasing after studying only divergent boundaries; however, they will learn that old rock that makes up plate boundaries is recycled into Earth’s interior where one plate goes under another plate at a convergent boundary.
- S In your Science Notebook, make a list of questions you still have about plate boundaries.**



Teacher Background Information

There are three main types of plate boundaries: divergent, convergent, and transform. Divergent plate boundaries are explored in this lesson to find out what fills the “gap” left when two plates move apart. In fact, there is never really a gap since magma from deep within Earth is forced up at divergent boundaries and new rock is created. The Age of Rocks map clearly shows where the newest rocks of Earth’s crust are found—adjacent to spreading centers. The color map identifies regions where scientists know the approximate age of the bedrock. Rocks get older as you travel away from a divergent plate boundary.

In the next lesson, students will learn about what happens at convergent and transform boundaries. It is important that by the end of that lesson students recognize that, although new rock is added at divergent boundaries, at boundaries where one plate goes beneath another, old rock goes back into Earth’s interior. The overall size of Earth does not change. The “P” question in the REAPS for this lesson is written to stimulate students’ thinking about this important concept.

The Pacific/Nazca plate boundary is a good example of a divergent boundary. In fact, it is one of the fastest-spreading boundaries in the world—with the Nazca Plate moving eastward at a rate of about 7.5 cm/year and the Pacific Plate moving westward at a rate of about 8 cm/year.

Advance Preparation

Cut one piece of letter-size paper in half lengthwise for each group. The smoother the edges, the easier it will slide through the pencils.

Implementation Guide

1. Engage students in this lesson by beginning with a question or two about what the class knows at this time about plate boundaries. Ask students to recall what they know about what happens where two plates meet. Briefly hold a discussion to engage students in thinking about what they already know about plate boundaries without entering into explanations.

2. Display an image (overhead transparency or computer projection) of *Student Page 3.1C: GPS Data Map*. Remind students how they studied slow movements of Earth's surface and realized that large pieces of Earth's lithosphere, called plates, are defined by the continuous lines on the map.

- Draw students' attention to the area of the world around the Pacific Ocean, which they modeled in the GPS station movement simulation in Step 3.

3. Focus students' attention to the area near the Pacific/Nazca plate boundary on the GPS Data Map.

- Have two students model the movement of those two plates at that boundary for the rest of the class. They could do this by standing face to face with their hands in front of them, palms touching, and then walking as if they were the moving plates. In this case, they would move backwards away from each other.
- Introduce the term **divergent boundary** as a description of what happens at that plate boundary. Explain that whenever two plates are moving away from each other, it is called a divergent plate boundary.
 - The **Pacific/Nazca** plate boundary is an example of a divergent boundary.
- Briefly, repeat the process for highlighting a **convergent boundary**.
 - Use the **Nazca/South American** plate boundary for an example of a *convergent* boundary near Chile and the west coast of South America.

- Again, have pairs of students model how the plates are interacting—moving towards each other (converging).

- Briefly, repeat the process for highlighting a **transform boundary**.

- Use the **Pacific/North American** plate boundary for an example of a *transform* boundary in California.
- Again, have pairs of students model how the plates are interacting—moving parallel to each other (transform).

NOTE: Transform boundaries can be difficult to find on the GPS Data Map, especially since the Pacific Plate and North American Plate are both moving in the same direction in California (but at significantly different speeds). Therefore, highlight the fact that relative motion is what really matters and even if two students walk in the same direction parallel to each other at different speeds, they will still slide in opposite ways if they are modeling the plate boundary correctly.

4. Explain that the focus of this lesson will be on divergent plate boundaries. The other two boundary types will be investigated in the next lesson.

Ask students to predict answers to the following question as you refer to the example of the divergent boundary on the GPS Data Map (the Pacific/Nazca plate boundary):

- What fills the gap between the two plates?

If needed remind students to review their models of Earth's interior from Step 5. When students suggest that molten rock from below the plates rises to fill the gap, ask them to think about what that would mean for the age of rocks near that boundary. For example,

- If molten rock is coming to the surface to fill the gap, then where would you expect

to find the newest rocks on the Nazca and Pacific plates? The oldest?

Have students write their responses in their Science Notebooks.

Explain that to understand how plate movement affects the landforms on Earth's surface, it is important to understand all that happens at boundaries. In this lesson, the class will begin investigating what happens at divergent plate boundaries and what that means for the age of rocks near the gap.

- Remind students to relate what they learn about plate boundaries to what they know about their world region.

5. Ask for 2–3 volunteer students to share their predictions. During the discussion ask students to cite evidence from their Science Notebooks and the *Exploring Earth's Surface* chart as evidence for their ideas. Remind the class how they are behaving like scientists and that using evidence is something that is common in scientific discussions.

- Resist the temptation to confirm or give correct answers at this time; allow students to explore the data to look for patterns that will explain the answers.

6. Divide the class into groups of 2–3 students. Hand out or make available the materials to do the activity (see the materials list) and copies of *Student Page 6.1A: Modeling Divergent Plates*.

- Allow groups time to complete the activity, record, and analyze their data. Travel from group to group to listen to what students are predicting or concluding.
 - Check for students' understanding that they are using a model to learn about what happens at divergent plate boundaries.
 - Use this opportunity to reinforce the idea that a scientific model is an

important tool for understanding what happens in nature when it is difficult to observe directly.

7. Show students the color overhead transparency or projected image of *Student Page 6.1B: Age of Rocks Map*. Explain that scientists have been able to collect data that allows them to estimate the age of rocks beneath the ocean floor in order to make this map. Explain what the map shows and how the legend works. Focus student attention on the Nazca/Pacific Plate boundary.

Ask the students to work in pairs to write a sentence or two that summarizes what the map tells them about the age of rocks near that divergent plate boundary. They should be able to explain what the map shows about where the youngest and oldest rocks near that boundary are located. Use the REAPS to connect the Age of Rocks Map to the divergent boundary model. Make sure students understand the connection between the timing of the marks on the paper and the age of the rocks in the real world and how it must be caused by movement of the plates.

To check for understanding, consider having students color their paper to show how marks on the paper in the simulation correspond to bands of different colors in the map or asking students to identify other divergent plate boundaries elsewhere on the GPS Data Map and point out where they would expect to find the oldest and youngest rocks in that area.

Emphasize the “P” question, **Is Earth's size increasing because of the materials that are added at divergent boundaries?** as an important concept that will be further explored in the next lesson.

8. To help students review some of the terms and models that they learned about, have them read *Student Page 6.1C: Divergent Plate Boundaries*. This could be read in class either individually or using a group reading strategy. Alternatively, it could be assigned for homework and reviewed briefly at the start of the next lesson.

Student Page 6.1A: Modeling Divergent Plates

Name _____

Date _____

Jobs

To do this activity you will need to assign specific jobs to specific people.

You will need one timekeeper. The timekeeper will need to stay focused on the time and tell the group when to start and when to stop.

The timekeeper is _____.

You will need two movers. They need to slowly and steadily pull the paper out to the sides when the timekeeper says “Start!”, and stop when the timekeeper says “Stop!” They should always keep the paper touching the pencils. The movers are _____ and _____.

You will need 2 recorders. They will quickly and carefully mark their side of the paper when the timekeeper says, “Stop!” The recorders are _____ and _____.

Set up the activity

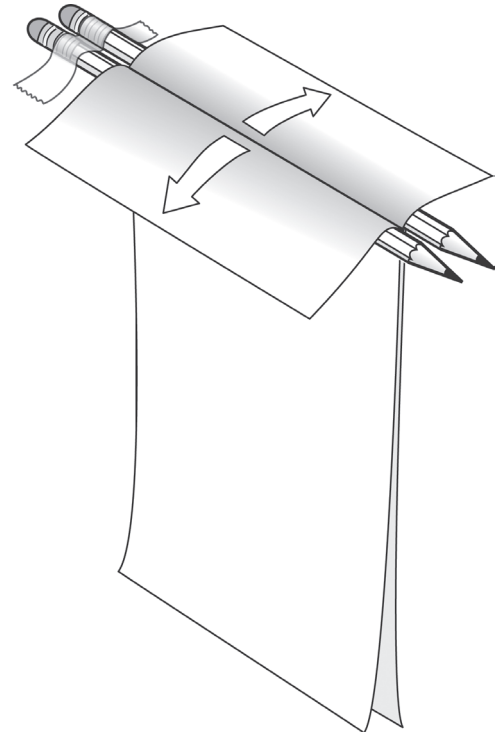
Follow these directions to set up the activity.

First, place the pencils side by side. Wrap a piece of tape around the eraser end of the pencils and another around the other end. Now, tape the eraser end securely to the edge of a desk. You may need to use a few pieces of tape.

Second, feed the two pieces of paper up into the space between the pencils. Have each mover hold one end of one piece of paper and bend it gently off to the side. Each piece of paper represents an ocean plate. The gap in the middle is where they diverge.

Instructions

The timekeeper says “Start!” and the movers pull the paper slowly toward them for 3 seconds until the timekeeper says “Stop!” Then, the recorders each label their side with the number “1”. Repeat the process. When the timekeeper says “Stop!” the recorders should label their paper with a number “2”. Keep going until there is no more paper left.



(continued on following page)

Student Page 6.1A: Modeling Divergent Plates (continued)

Analyze your data

How many seconds did it take to finish moving the paper through the gap between the pencils? _____

How old is the first mark on the paper? _____

How old is the last mark on the paper? _____

Where are the oldest marks? Close to where the two pieces of paper diverge or far from where the two pieces of paper diverge? _____

Connect your data to plate movement

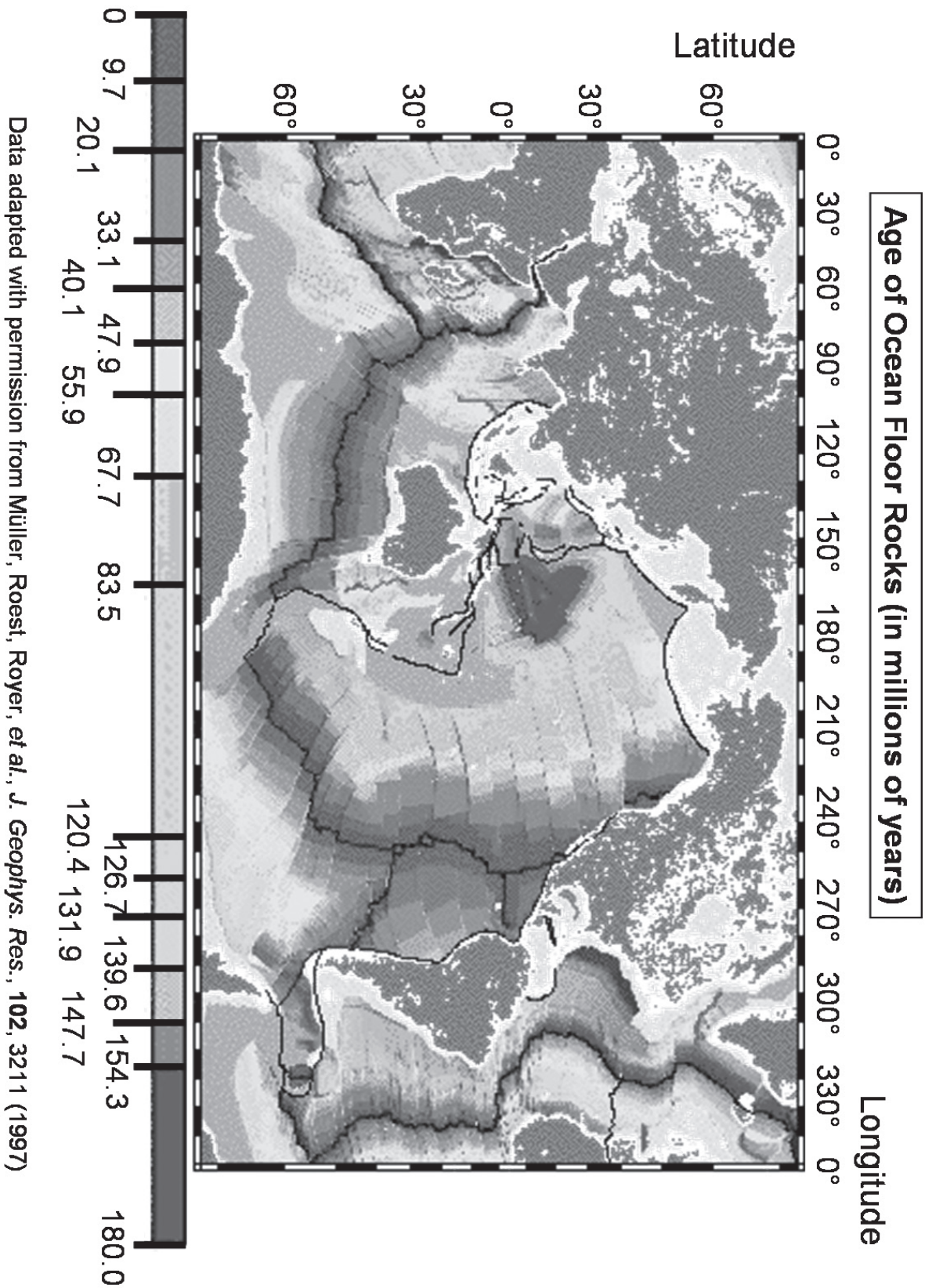
Think about what this activity represents. The paper represents the plates. Plates are made of rock. The two pieces of paper, like the plates, diverge at the plate boundary (the pencils). Use what you did in the activity to help you answer the following questions.

Where is the oldest rock on an oceanic plate compared to the plate boundary? _____

Where are the newest rocks on an oceanic plate? _____

Where does the new rock come from to fill the gap? _____

Student Page 6.1B: Age of Rocks Map



Student Page 6.1C: Divergent Plate Boundaries

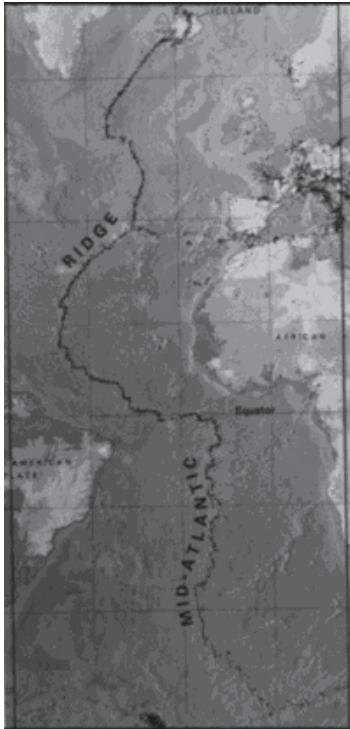
[Reading and figures adapted from This Dynamic Earth, USGS Publication]

What is a divergent boundary?

Divergent boundaries are places where plates move apart. These regions are sometimes called spreading centers. New crust develops in these places.

Where are divergent boundaries?

One divergent boundary is the Mid-Atlantic Ridge. It is an undersea mountain range. The Ridge stretches from the Arctic Ocean to beyond the southern tip of Africa. The rate of spreading along the Mid-Atlantic Ridge is about 2.5 centimeters per year. Does this seem slow? It might, but because it has been going on for millions of years, the plates on either side of the Ridge have moved thousands of kilometers!



A map of the Mid-Atlantic Ridge. This map shows the Ridge from Iceland in the north to near Antarctica in the south. Parts of Europe, Africa, and South America are also on the map.

Since most divergent boundaries are under the oceans, it is hard for scientists to study them. Fortunately, the Mid-Atlantic Ridge crosses land in the country of Iceland.

East Africa is near another divergent boundary. Look at a world map. Can you see how Saudi Arabia is separate from Africa? A new spreading center may be developing under East Africa. Seismic and GPS data can tell scientists where there are plate boundaries. Did you notice any patterns in the seismic and GPS data you looked at around East Africa?

What happens at a divergent boundary?

At a divergent boundary, magma rises through Earth's crust and squeezes through cracks, called fissures. Sometimes, the magma erupts and forms volcanoes. The rising magma, whether or not it erupts, puts pressure on the crust and creates more cracks.

East Africa may be the site of Earth's next ocean! If spreading continues, the plates that meet at the edge of present-day East Africa could separate completely. This would allow the Indian Ocean to flood the area and make the easternmost corner of Africa a large island! How long do you think this might take to happen?

This is an active "lava lake" in Ethiopia, a country in East Africa. Can you see the lava in the bottom of the crater? There are also two scientists (dressed in orange suits) standing on the edge of the crater.



Step 6 Lesson 2 Snapshot

Key Concepts

- Deep trenches, volcanic action, and mountain ranges can occur near convergent plate boundaries.
- Subduction is the process of one plate sliding under another, recycling old crust back into the mantle.

Evidence of Student Understanding

The student will be able to:

- model convergent plate boundaries;
- connect models to explain formation of the landforms commonly seen around convergent plate boundaries;
- explain how the combination of new rock formation and old rock recycling that occurs at different types of plate boundaries results in Earth's size staying constant.

Time Needed

45 minutes

Materials

For the class

- 1 overhead transparency of *Student Page 3.1C: GPS Data Map*

For each small group of 2-4 students

- Two pieces of light or medium-weight cardboard

For each student

- 1 copy of *Student Page 6.2A: Convergence and Subduction*
- 1 copy of *Student Page 6.2B: Transform Boundaries*

Convergent and Transform

1. Show the overhead transparency of *Student Page 3.1C: GPS Data Map*, and have students refer to it and answer the following:

- What happens on the eastern edge of the Nazca Plate near South America?
- What evidence do you have that supports your answer?

Discuss what evidence students are using to explain what happens in that area and review the *GPS Data Map* that helped them determine it is a convergent boundary. Acknowledge this is a complex question to answer and that today, like scientists, they will collect more evidence to help make a stronger explanation.

2. Explain that one way to learn more about what happens at plate boundaries is to engage in another modeling activity. Divide the class into groups of 2–3 students.

- Provide each group with two pieces of cardboard and a piece of paper.
- Explain that the two pieces of cardboard represent plates. Have the class proceed through the following steps together, after you orally give the instructions.
 - The first simulation models a **convergent** plate boundary.
 - Experiment 3 times with moving the plates (pieces of cardboard) toward each other.
 - After the 3 trials, stop and draw a simple diagram showing what happened with a brief description.
- Now ask students to make connections between their cardboard model and Earth's surface. Pose questions such as:
 - **How do you think that your model corresponds with the surface of Earth?**

(continued on following page)

- **What landforms might you expect to see on the surface of Earth for each of the options you drew and described?**

Have students record their predictions about landforms at convergent boundaries in the Science Notebooks.

3. In a class discussion, compare what the cardboard model predicted about Earth's surface near convergent plate boundaries to what is present at the plate boundaries in the regions that include the Himalayas and Chile (See the Implementation Guide for specifics).

4. Hand out copies of *Student Page 6.2A: Convergence and Subduction* for individual or group reading. Compare information from this reading with the ideas discussed previously by the class.

Check for understanding about how convergent boundaries can be regions where:

- old rock can be returned to Earth's interior and is recycled (if subduction occurs)
- events such as earthquakes, volcanic eruptions, and mountain building can

occur (both volcanic and non-volcanic mountain building events)

5. Ask students to recall the third type of plate boundary—transform. Have students look at the eastern edge of the Pacific Plate near the North American Plate and California as an example and then model using the cardboard pieces the behavior of the plates in that area.

6. Hand out copies of *Student Page 6.2B: Transform Boundaries* for individual or group reading. Compare information from this reading with the types of interactions modeled with the cardboard plates.

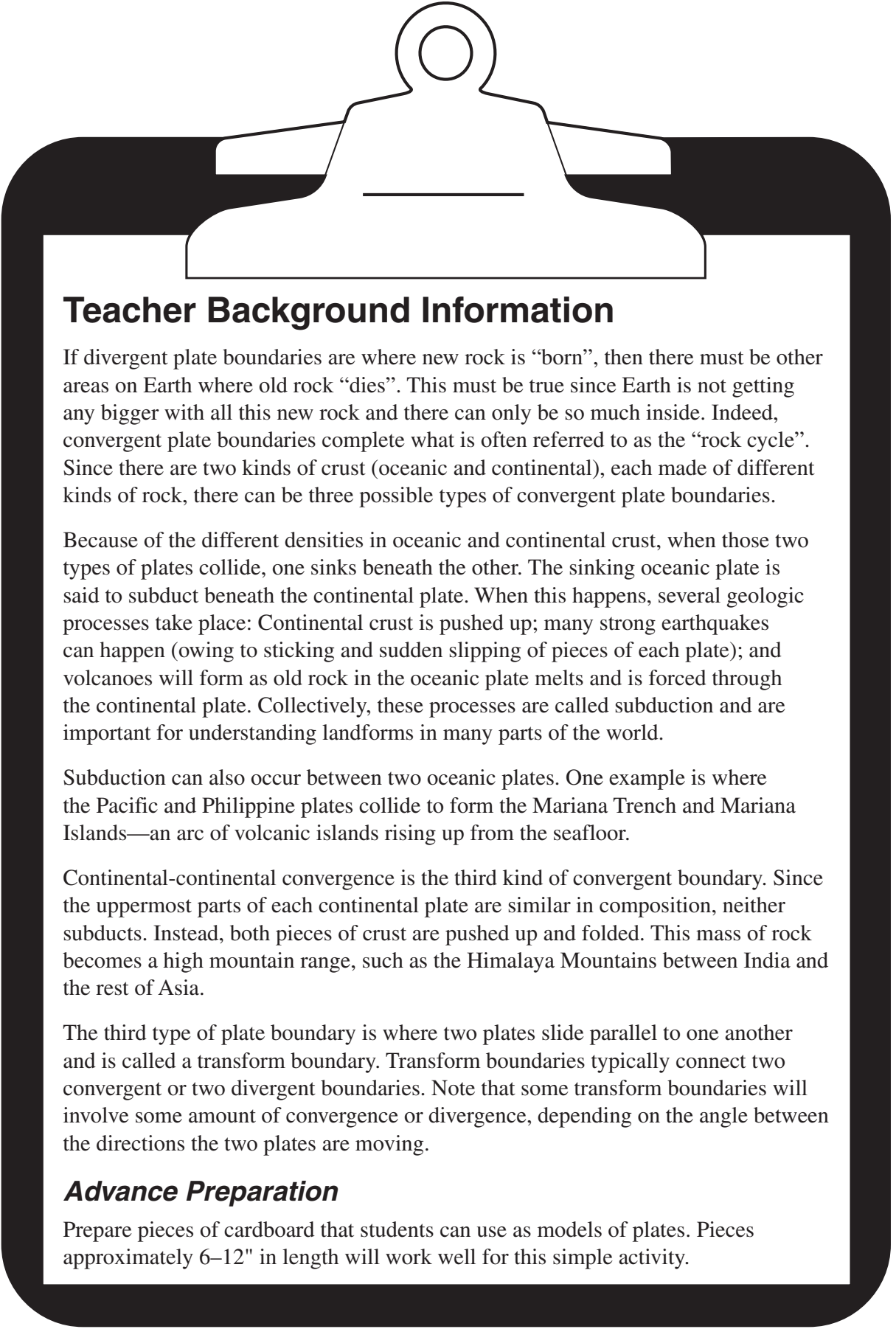
Check for understanding about how transform boundaries are typically regions where:

- faults and fault lines (areas of Earth's surface that show signs of relative movement) are present
- events such as earthquakes can occur

7. Use the REAPS questions to review what students have learned and to check for understanding before going on to the benchmark assessment in the next lesson.

REAPS Questions

- R What are the three ways plates can interact?** They can move away from each other (divergence). They can push into each other (convergence). They can slide by each other (transform).
- E What kind of plate boundary do you think you have in your region? What makes you think that way?** Answers will vary by region. Accept all that are based on what is known about plate motion and other evidence from that region.
- A Explain if Earth's size increasing or not because of the materials that are added at divergent boundaries.** The combination of new rock formation and old rock recycling that occurs at different types of plate boundaries results in Earth's size staying constant.
- P How does knowing about how plates move explain what earth's surface looks like?** In areas of divergence, we expect to see new rocks and cooling magma. In areas of convergence, we expect to see mountain building, volcanoes, and earthquakes. It would also explain how continents could move.
- S What evidence do you now have to help you explain what earth's surface looks like that Wegener didn't have? How has gathering more evidence improved your explanation?** GPS data, knowledge about Earth's interior, Earthquake/volcano data, etc.



Teacher Background Information

If divergent plate boundaries are where new rock is “born”, then there must be other areas on Earth where old rock “dies”. This must be true since Earth is not getting any bigger with all this new rock and there can only be so much inside. Indeed, convergent plate boundaries complete what is often referred to as the “rock cycle”. Since there are two kinds of crust (oceanic and continental), each made of different kinds of rock, there can be three possible types of convergent plate boundaries.

Because of the different densities in oceanic and continental crust, when those two types of plates collide, one sinks beneath the other. The sinking oceanic plate is said to subduct beneath the continental plate. When this happens, several geologic processes take place: Continental crust is pushed up; many strong earthquakes can happen (owing to sticking and sudden slipping of pieces of each plate); and volcanoes will form as old rock in the oceanic plate melts and is forced through the continental plate. Collectively, these processes are called subduction and are important for understanding landforms in many parts of the world.

Subduction can also occur between two oceanic plates. One example is where the Pacific and Philippine plates collide to form the Mariana Trench and Mariana Islands—an arc of volcanic islands rising up from the seafloor.

Continental-continental convergence is the third kind of convergent boundary. Since the uppermost parts of each continental plate are similar in composition, neither subducts. Instead, both pieces of crust are pushed up and folded. This mass of rock becomes a high mountain range, such as the Himalaya Mountains between India and the rest of Asia.

The third type of plate boundary is where two plates slide parallel to one another and is called a transform boundary. Transform boundaries typically connect two convergent or two divergent boundaries. Note that some transform boundaries will involve some amount of convergence or divergence, depending on the angle between the directions the two plates are moving.

Advance Preparation

Prepare pieces of cardboard that students can use as models of plates. Pieces approximately 6–12" in length will work well for this simple activity.

Implementation Guide

1. To begin this lesson, review the Predict question from Lesson 6.2:

- What happens on the eastern edge of the Nazca Plate near South America?
- What evidence do you have that supports your answer?

Discuss what evidence students are using to explain what happens in that area and review the GPS Data Map that helped them determine it is a convergent boundary. The group that studied Chile and western South America may be able to elaborate on this boundary.

Acknowledge this is a difficult question to answer and that today, like scientists, the students will collect more evidence to help them make a stronger explanation for what happens at a convergent boundary.

2. Because students need more evidence to understand what happens at plate boundaries, explain to the class that one way to learn more about what happens at plate boundaries is to engage in another modeling activity. Have them work through the following plate boundary modeling activity.

- Divide the class into groups of 2–3 students. Provide each group with two pieces of cardboard and a piece of paper.
- Explain that the two pieces of cardboard represent plates. Have the class proceed through the following steps together, as you orally give the instructions.
 - Tell students the first simulation they will do models a **convergent** plate boundary.
 - Have students experiment 3 times with moving the plates (pieces of cardboard) toward each other.
 - After the 3 trials, students need to stop and draw a simple diagram showing what happened with a brief

description. For example, students might say, “At first, one plate slid over the top of the other plate. During the second try, neither plate went under and instead both plates pushed up. On the third try, both plates pushed down.

- Now ask the students to make connections between their cardboard model and Earth’s surface. Pose questions such as:
 - **How do you think that your model corresponds with the surface of Earth?**
 - **What landforms might you expect to see on the surface of Earth for each of the options you drew and described?**

Have students record their predictions about landforms at convergent boundaries in the Science Notebooks.

3. Once students have recorded their predictions about the surface near various convergent boundary interactions, explain that as a class they are going to look at the surface features in regions that do have convergent plate boundaries and compare them to what the cardboard modeling predicted.

Show the overhead transparency of *Student Page 3.1C: GPS Data Map*, and point out the boundaries at the Himalayas and Chile.

- Explain that there is a convergent boundary in the Himalayan region, and show the topographic map of the area. Ask students if they modeled with their cardboard the type of plate movement that is forming the features seen here. (The option where both plates pushed upwards simulates this area well.)
- Next, show students the convergent boundary in the Chile region and show the topographic map. Ask students if they modeled with their cardboard the type of plate movement that is forming the features seen here. (The option where one plate slide under another simulates this area well.)

Ask students to talk in pairs or small group for a few minutes and compare these to regions. Prompt the discussion with a guiding question:

- **What is different about these two regions that might explain why the converging plates behave differently in each region?**

Have students share ideas as a class and thoroughly discuss any predictions that indicate that the type of plates matter. Students should notice that in the Himalayas there are two continental plates and in Chile there is a continental and an oceanic plate.

4. To conclude the discussion about convergent boundaries and emphasize key concepts, distribute *Student Page 6.2A: Convergence and Subduction*. Use a classroom reading strategy or have students individually read the student page and confirm or refute their predictions from the cardboard model.

Compare information from this reading with the ideas discussed previously by the class.

Check for understanding about how convergent boundaries can be regions where:

- old rock can be returned to Earth's interior and is recycled (if subduction occurs)
- events such as earthquakes, volcanic eruptions, and mountain building can occur (both volcanic and non-volcanic mountain building events)

5. Ask students to recall the third type of plate boundary—transform. Have students look at the eastern edge of the Pacific Plate near the North American Plate and California on the GPS Data Map. Allow students time to model a transform boundary with the cardboard pieces in their same small groups.

6. Distribute and have students read *Student Page 6.2B: Transform Boundaries*. Compare information from this reading with the types of interactions modeled with the cardboard plates.

Check for understanding about how transform boundaries are typically regions where:

- faults and fault lines (areas of Earth's surface that show signs of relative movement) are present
- events such as earthquakes can occur

7. The REAPS in this lesson are designed to help review the main ideas of plate boundaries and prepare students to revise their models one last time and use them to explain Earth's surface in particular regions of the world. Use the REAPS as appropriate and with various strategies (like a Think-Pair-Share or class discussion) to review and check for students' understandings before going on to the benchmark assessment in the next lesson.

Student Page 6.2A: Convergence and Subduction

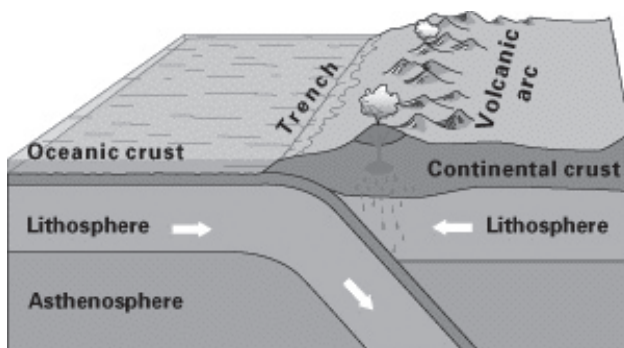
[Reading and figures adapted from This Dynamic Earth, USGS Publication]

Convergent Plate Boundaries

If new crust forms at divergent boundaries and Earth does not get any bigger, what happens to old crust? It must be taken away as new crust forms. This is what happens at convergent plate boundaries. This is where two plates are moving towards each other. Plates can be made of oceanic or continental crust. Since there are two kinds of crust, there are three kinds of convergence. Convergence can happen between one oceanic and one continental plate, two oceanic plates, or two continental plates.

Oceanic-continental convergence

Remember the trenches you learned about? Trenches are the deepest parts of the ocean floor. They form in a process called subduction. When one plate sinks under another, it is called **subduction**. The area where a plate sinks is called a subduction zone.



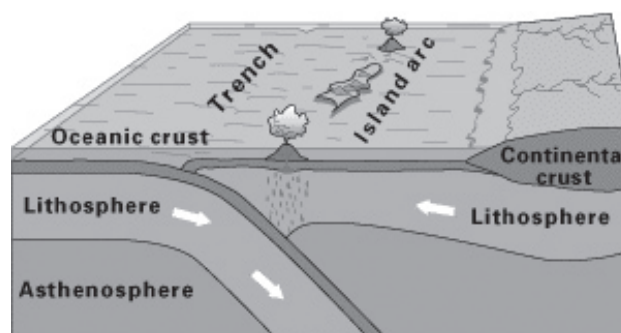
The west coast of South America is near a subduction zone. The Peru-Chile Trench is a very deep part of the ocean, not far from the coast. The oceanic Nazca plate is pushing into and sinking under the continental South American Plate. As the oceanic plate sinks, the continental plate is pushed up. What major landforms are on the west coast of South America? Many of these landforms are found near subduction zones.

What geologic events happen in western South America? Earthquakes! Strong, destructive earthquakes are common in this region. Sometimes, the deepest part of the subducting plate breaks into smaller pieces. These pieces become locked in place for a long time. Occasionally, they will suddenly move. This makes very large earthquakes. These earthquakes can raise the land by as much as a few meters at once!

Volcanoes and volcanic eruptions are also found near subduction zones. Oceanic-continental convergence causes volcanic eruptions. This is what happens in places like the Andes in South America and the Cascade Range in the Pacific Northwest. When older, oceanic crust sinks beneath the continent, the hot mantle heats the rock and melts it. This rock then gets pushed up through the surface to form volcanoes.

Oceanic-oceanic convergence

Subduction can also happen between two oceanic plates. The Mariana Trench in the Pacific Ocean is one example. This is where the Pacific Plate converges with the Philippine Plate.



Oceanic-oceanic convergence

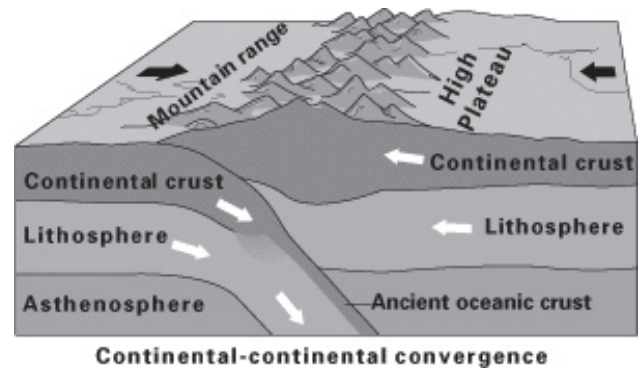
Volcanoes also form near oceanic-oceanic subduction zones. Over millions of years, the erupted lava and rock pile up on the ocean floor. Sometimes, the pile gets so high that the volcano rises through the surface of the ocean to form an island.

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Student Page 6.2A: Convergence and Subduction (continued)

Continental-continental convergence

Which region do you think is an example of continental-continental convergence? If you said the Himalayas, you would be right. When two continental plates meet head-on, neither subducts because the continental rocks are not as heavy as oceanic rocks. Instead, the crust is pushed up or sideways. The picture below shows the collision of two continental plates. This is like what is happening between India and the rest of Asia. During the slow collision, the convergence of the two plates pushes up the Himalaya mountains and the Tibetan Plateau.



Student Page 6.2B: Transform Plate Boundaries

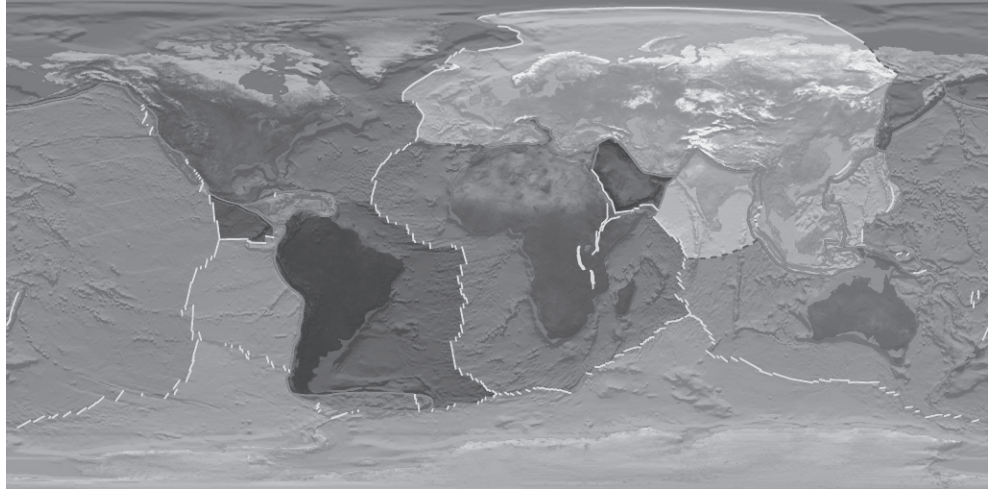
[Reading and figures adapted from This Dynamic Earth, USGS Publication]

When two plates slide next to each other they are part of a **transform boundary**. This is also sometimes called a transform fault or fracture zone.

Transform boundaries connect two divergent boundaries or sometimes two convergent boundaries. Most transform faults are on the ocean floor. They connect spreading centers and make zig-zag plate boundaries. This map shows where the three kinds of plate boundaries are found around the world.

The red lines show convergent boundaries; the green lines, divergent boundaries; and the purple lines show transform boundaries.

Most transform boundaries can be found by looking at the patterns of shallow earthquakes that happen near them. Only a few transform boundaries occur on land. There is a large one in California. It is called the San Andreas Fault Zone.



[Plate boundary map adapted from NASA.]



A photo of the San Andreas fault in California. [Image courtesy USGS, This Dynamic Earth.]

Key Concepts

- Plate tectonics explains the landforms, changing features, and catastrophic events of Earth's surface.
- Science knowledge advances through inquiry.

Evidence of Student Understanding

The student will be able to:

- recognize how science knowledge progresses over time;
- explain how studying natural phenomena through scientific inquiry advances knowledge;
- use multiple lines of evidence in a scientific explanation;
- describe what causes continents to move.

Time Needed

45 minutes

Materials

For the class

- overhead of *Explaining Earth's Features Chart*

For each student

- 1 copy of *Student Page 6.3A: Explaining Earth's Features Chart*

Explain That Feature

1. Review the class' progress through this unit by reviewing the *Exploring Earth's Surface* chart, especially the implications and/or patterns found in the right-hand column.

- Explain that while Wegener was alive, his idea of Continental Drift was not accepted, but now scientists have built on Wegener's ideas and all the findings that the class has been learning to support the **Theory of Plate Tectonics**. *Plate tectonics explains the landforms, changing features, and catastrophic events of Earth's surface.*
- Engage students in this lesson by explaining that they will be writing a letter to Wegener that he would have enjoyed receiving if he had lived long enough to see the new evidence that supports his ideas.

2. In small groups of 2–4, have students brainstorm a list of all the landforms and/or events they can think of that could be explained by the Theory of Plate Tectonics. The list may include landforms, events, or other items.

3. Collect student responses from their brainstorm lists on the board. To demonstrate how plate tectonics can explain many of Earth's events and landform development from the list, perform a Think Aloud to explain volcanoes.

- Record your explanation on an overhead of the *Explaining Earth's Features* chart.

4. Use a Think-Pair-Share strategy to have students explain earthquakes using their understanding of plate tectonics. After the class agrees on an explanation, have students record the explanation on a copy of *Student Page 6.3A: Explaining Earth's Features* chart.

5. Assign students to work in pairs or small groups to complete an explanation for mountain formation and record it into the chart on *Student Page 6.3A: Explaining Earth's Features*.

- Travel around the room to check students' understanding that mountain building can result from more than one type of event. Be certain students recognize that mountains typically can form when:

(continued on following page)

- a. plates are moving toward one another and solid rock is pushed upward (non-volcanic)
- b. volcanic events occur where plates are moving toward one another
- c. volcanic events occur where plates are moving away from one another

6. Use the REAPS with a Think-Pair-Share strategy to prepare students for writing letters to Wegener explaining Plate Tectonics.

- To guide students, first come to a consensus about what a high-quality letter includes.

7. Allow students time to write their letters. Provide support and feedback as needed.

REAPS Questions

R What was Wegner's explanation for the way Earth's surface looked 200 million years ago?

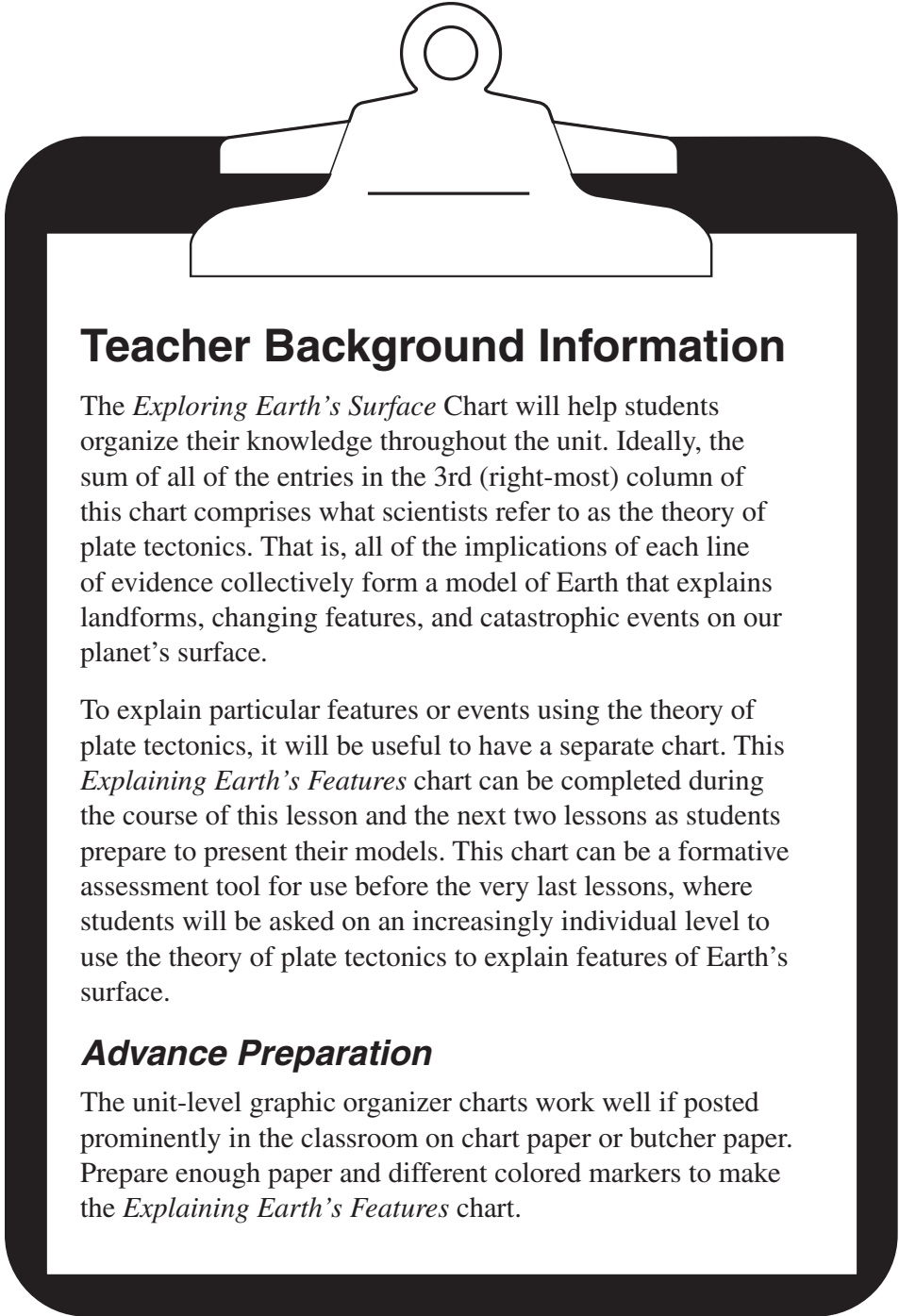
Wegener believed continents used to be connected and they had moved apart, but he could not explain how continents could move.

E Why didn't other scientists believe Wegener's ideas? Wegener only had evidence that the continents moved. He could not explain how they moved.

A How does the theory of Plate Tectonics explain how continents can move? Continents are attached to plates. Plates are part of Earth's solid crust. Convection currents in the liquid or semi-solid mantle move plates and, thus, continents.

P What would Wegner need to understand about Plate Tectonics to be convinced that it explains how continents move? He would need to know what moves plates and how scientists know about the interior structure of Earth. This includes maps of the ocean floor, showing mid-ocean ridges, maps of seismic activity, and descriptions of the layers of Earth based on evidence from seismic data and other sources.

S What will be difficult about writing this letter for you? What strategy will you use to help make it easier for yourself? Answers will vary. Students may suggest listing all the evidence they need to include, writing an outline, using a dictionary, referring to their Science Notebooks, etc.



Teacher Background Information

The *Exploring Earth's Surface* Chart will help students organize their knowledge throughout the unit. Ideally, the sum of all of the entries in the 3rd (right-most) column of this chart comprises what scientists refer to as the theory of plate tectonics. That is, all of the implications of each line of evidence collectively form a model of Earth that explains landforms, changing features, and catastrophic events on our planet's surface.

To explain particular features or events using the theory of plate tectonics, it will be useful to have a separate chart. This *Explaining Earth's Features* chart can be completed during the course of this lesson and the next two lessons as students prepare to present their models. This chart can be a formative assessment tool for use before the very last lessons, where students will be asked on an increasingly individual level to use the theory of plate tectonics to explain features of Earth's surface.

Advance Preparation

The unit-level graphic organizer charts work well if posted prominently in the classroom on chart paper or butcher paper. Prepare enough paper and different colored markers to make the *Explaining Earth's Features* chart.

Implementation Guide

1. Review the content for this whole unit by referring to the *Exploring Earth's Surface* chart (which can include adding to or editing the entries based on the latest, most accurate understanding that the class has). As the class goes through what they have learned in the various lessons, highlight the results shown in the third (right-most) column.

When the class is finished reviewing the chart, explain to students that scientists have constructed an explanation-based model for all of these different lines of evidence and their observations about Earth's surface. This explanatory model is called The Theory of Plate Tectonics. It is an evidence-based, scientific model that accurately explains and predicts the events and surface features that we observe.

The word *plate* refers to large pieces of the lithosphere moving around Earth's surface, accumulating new rock at divergent boundaries while losing old rock at convergent boundaries and bumping and sliding into each other at those boundaries. The word *tectonic* comes from a Greek word (tekton) that refers to building or sometimes carpentry. This refers to how features of Earth, like mountains, trenches, and all the landforms the class has studied in their regions, are built by the process of plate interactions. That is why the theory is given this name.

Finally, engage students in this lesson by explaining that they will be writing a letter to Wegener that he would have enjoyed receiving if he had lived long enough to see the new evidence that supports his ideas.

2. Ask students to pair up or gather in small groups and brainstorm a list of all the landforms and/or events they can think of that could be explained by the Theory of Plate Tectonics. Students may refer to their Frayer Models from Step 1 or notes in their Science Notebooks to help generate this list.

Later in this lesson, the class will sort through some of the landforms and events to see if they

can apply their understanding of plate tectonics to explain the processes that would lead to that type of event or landform development, just as a scientist would.

3. On chart paper or a chalkboard, develop a list of items from the groups' brainstorm. Have each of the groups share some of their examples to generate this list. make sure students suggest volcanoes as something that might be explained by plate tectonics.

To demonstrate how plate tectonics explains things on the list, perform a Think Aloud explaining volcanoes.

Think Aloud to explain volcanoes:

Since "volcanoes" are on the list of things this theory of plate tectonics is supposed to explain, I'm going to use what I know to figure it out.

I know plate tectonics happens all over the world, but volcanoes are not located all over the world. This tells me there must be something special about the conditions that are right to make a volcano. I know a volcano is made of cooled lava. Lava is magma that reaches the surface. If Earth is hot everywhere deep down, there should be magma everywhere deep down. But I wonder how this gets all the way through the crust, to the surface to make a volcano?

Well, since volcanoes are only in certain places, then the magma can't get to the surface everywhere. In some places, the crust could be very thick, so it would be a long way for the magma to travel to the surface. I bet there are only a few places in the world where it can rise to the surface. But what makes a place that has those conditions?

I noticed on maps that volcanoes tend to occur in locations that scientists call plate boundaries. What is special about these places? I remember that earthquakes also occur near plate boundaries. The weird thing

is that they usually happen near the same place. So do they make each other? I don't know how that would work. And, if they make each other, which one comes first?

Maybe something else makes both of them. What else is going on at plate boundaries? Well, I learned the plates there are sliding past one another, overriding, or subducting. Maybe this could somehow make magma. I don't think the plates get hot enough sliding past one another to completely melt—that would be a lot of friction! An overriding plate shouldn't go deep enough to melt, either. But a subducting plate could melt, because it sinks to a deeper place in the crust where the temperature is very hot. Maybe this is the source of the magma! This makes sense. The reason that volcanoes occur near plate boundaries—actually, plate boundaries where there is subduction (“subduction zones”)—is because the subducting plate sinks far enough into the crust to melt, and that magma eventually rises upward to the surface to make a volcano. It must rise because it is old crust and that kind of rock floats on top of the mantle (it is buoyant). The same subduction can also make big, deep earthquakes near the plate boundary. But it's not the earthquakes that make the volcano (or the volcanoes that make earthquakes!). The subducting plate makes both of them. And since plate tectonics explains subduction, this is how plate tectonics explains the locations of volcanoes (and earthquakes).

After the Think Aloud, record the explanation concisely on the example Explaining Earth's Features chart. This example should be left for all of the students to see as they work on the next example.

4. Provide students with *Student Page 6.3A: Explaining Earth's Features* and ask students to explain “earthquakes” in the same way that you did the Think Aloud. To help students develop an answer, have them complete this explanation as a Think-Pair-Share activity.

5. At this point, the class has two examples of features that are explained using the theory of plate tectonics. Now, ask them to work individually or in pairs to complete another explanation—mountains. Because every region contains mountains in some form, remind students that by doing this they are helping themselves prepare for the final lessons and their model presentation.

- Travel around the room to check students' understanding that mountain building can result from more than one type of event. Be certain students recognize that mountains typically can form when:
 - plates are moving toward one another and solid rock is pushed upward (non-volcanic)
 - volcanic events occur where plates are moving toward one another
 - volcanic events occur where plates are moving away from one another

6. Now that students have developed an initial list that shows how the theory of plate tectonics explains features of Earth's surface, explain again how they will be writing a letter with good news to Alfred Wegener.

- The purpose of this letter is to tell Wegener how the Theory of Plate Tectonics explains not only that continents are in different positions today than they were long ago, but also HOW they move. Today, scientists have more evidence than Wegener had and they can support with solid evidence ideas that Wegener could only begin to imagine.

Use the REAPS questions with a Think-Pair-Share strategy to prepare students to write letters to Wegener.

- Build on the letter-writing criteria developed in Lesson 4.2.
 - First, outline as a class what a good letter will look like.
 - Next, review the criteria for a good scientific argument.

- Finally, clarify the timeline and letter format guidelines.

7. Provide students with time (either in class, outside of class, or both) to write their letters to Wegener. Use the completed letters and their completed *Explaining Earth's Features* charts to formatively assess students' understandings of

plate tectonics and supporting key concepts. It is important that students receive help if they have misconceptions or incomplete understandings at this point because this is one of the last opportunities for clarification before this unit's summative assessments.

Student Page 6.3A: Explaining Earth's Features

Feature of Earth's Surface	How does Plate Tectonics explain this feature?	Is the development of this feature sudden or slow? Would you see it happen in your lifetime? Explain.
Volcano (and volcanic eruption)		
Earthquake		
Mountain		

Key Concept

- Scientists revise models based on new evidence

Evidence of Student Understanding

The student will be able to:

- modify a physical model to make it better represent and/or explain the evidence available about subduction zones or other plate boundaries in or near the region;
- explain to others how their physical models represent and explain the evidence for features and events in their region that are related to plate tectonics;
- recognize the strengths and limitations that their physical models have in representing and explaining plate boundary interactions in their region.

Time Needed

35–45 minutes

Materials

For each student

- 1 copy of *Student Page 6.4A: Model Revision Worksheet*
- 1 copy of *Student Page 6.4B: Explaining Regions of the World*

For each region group

- modeling materials (can include modeling clay, paper, cardboard, popsicle sticks, tape, toothpicks, straws, paper cups, cotton balls, or other common materials that students will use to modify physical models of the regions)

Revising Region Models

1. Call students' attention to the *Exploring Earth's Surface* chart and ask students to identify any new entries that have been made since their last region model revision.

- Use the REAPS to review the chart and to begin to make connections to the students' regions.

2. Use a Think-Pair-Share strategy for students in region groups to list at least two questions they have about how well their models represent and explain the evidence available so far about their region.

- Instruct students to plan the revision of their region model to explain more accurately the known evidence. Guide students through completing *Student Page 6.4A: Developing My Scientific Model*, and ask students to plan their final revision before beginning construction.

3. Share *Student Page 6.4B: Explaining Regions of the World* to explain your expectations for students' region presentations.

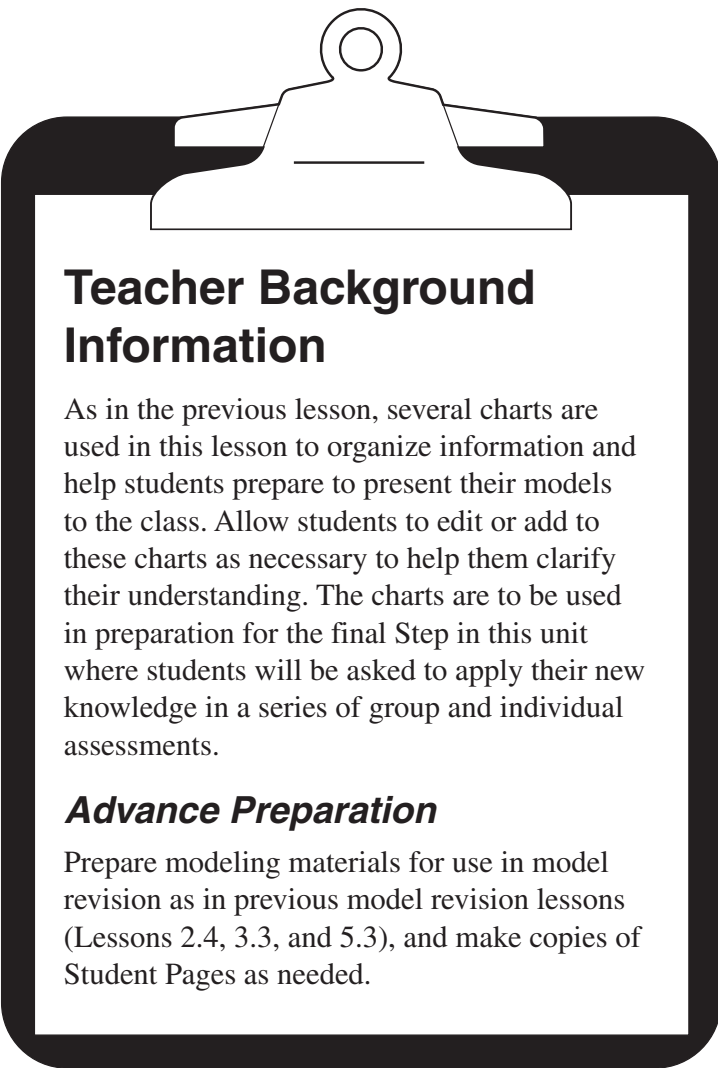
- Explain that during their presentations, students will need to instruct the rest of the class about these key elements in their region.
- Explain, also, that students will need to complete the chart shown in *Student Page 6.4B: Explaining Regions of the World* to capture what that they learn about the other regions during the presentations.
 - Students will need the notes they take during presentations to successfully complete the unit's final assessment.

NOTE: *By the end of today's lesson, students need to have this chart completed for their region so it can be reviewed and checked for accuracy before class presentations.*

(continued on following page)

REAPS Questions

- R** What are the three types of plate boundaries? Divergent, convergent, and transform.
- E** What evidence can you look for to tell if there are plate boundaries in your region and what type they are? Evidence includes seismic data, GPS data, and maps. The seismic and GPS data shows if there is a plate boundary and what type. Maps tell whether or not there is subduction (continental or oceanic crust) and confirm if there are specific features in the region like volcanoes or mountain ranges.
- A** What is missing in your model to represent what you now know about plate boundaries? How does that affect your model's ability to explain how the landforms in that region formed? Answers need to identify limitations the model has in representing the types of plate boundary interactions in the region and how the particular plate boundary interactions explain many of the landforms there.
- P** What do you think will be the most challenging for others to understand when you make your presentation to explain your region to the class? What will you do to help them understand? Encourage students to suggest visual aids they may make and use (additional diagrams and charts), demonstrations they might use (such as the cardboard plate boundary simulation), and other strategies.
- S** Compare and contrast the 4 Student Pages you have completed throughout this unit to document your model revisions. Explain how your thinking about your region, landforms, events like earthquakes and volcanic eruptions, and scientific models has changed since you started. This question provides an opportunity for students to reflect on their learning about all of the key concepts in this unit. You may choose to provide at least 10 minutes of class time for students to answer this question thoughtfully and collect the responses to assess the students' self-awareness of their own learning.



Teacher Background Information

As in the previous lesson, several charts are used in this lesson to organize information and help students prepare to present their models to the class. Allow students to edit or add to these charts as necessary to help them clarify their understanding. The charts are to be used in preparation for the final Step in this unit where students will be asked to apply their new knowledge in a series of group and individual assessments.

Advance Preparation

Prepare modeling materials for use in model revision as in previous model revision lessons (Lessons 2.4, 3.3, and 5.3), and make copies of Student Pages as needed.

Implementation Guide

1. To review what students have learned and can apply to revise their region models, draw attention once more to the *Exploring Earth's Surface* chart. Ask students to add to or edit any entries that need to be clarified or made more accurate to help them understand the new evidence from Step 6.

- Use the REAPS questions to guide the review of the evidence, particularly the new information from Step 6.
- Explain that students will be presenting their models in the next lesson to teach the rest of the class about plate tectonics and Earth's events and features in their assigned region.

2. Use a Think-Pair-Share strategy for students in region groups to list at least two questions they have about how well their models represent and explain the evidence available so far about their region.

- Have 2–3 region groups share one question that they listed, and discuss ideas for improving the models.
- Instruct students to plan the revision of their region model to explain more accurately the known evidence. Guide students through completing *Student Page 6.4A: Developing My Scientific Model*, and have students plan their final revision before beginning construction.

Once all students complete this worksheet within their region groups, they will have a collection of 4 similar documents that describe how their region model has changed over time to better represent and explain Earth's surface. Students will reflect

on all of these when responding to the “S” in the REAPS.

You may wish to model the thinking that students will engage in as they ask questions of their models to determine if they represent and/or explain the evidence about plate boundary interactions that the class studied. If students need additional support to ask questions of their models and plan a revision, use the California region that was used in previous lessons with the Think Aloud strategy to help students understand what to do.

3. Because this is the last model revision before students present their work to the class, use *Student Page 6.4B: Explaining Regions of the World* to explain your expectations for students' presentations. Students can take into consideration what to include in the presentation when making the final revision to make the model easier to share with others.

- *Student Page 6.4B* contains the four main points that students should focus on during their presentations.
- Remind students that they are all experts in the region of the world they have studied and will be teaching the rest of the class about their region in the next lesson.
- Students will use a chart like that in *Student Page 6.4B* to record what they learn about other regions.

Be sure that, by the end of today's lesson, students have the chart on *Student Page 6.4B* completed for their region. It can be reviewed and checked for accuracy before class presentations in the next lesson.

Student Page 6.4A: Developing My Scientific Model

Name _____

Date _____

What new evidence have I learned about my region that my model does not represent or explain? Now that I know more about my region and about scientific modeling, what is missing in my model?	What are my model's strengths? What does my model explain about Earth's surface in my region? List at least 2 questions you could ask about Earth's surface in your region that your model can answer.
What are my model's limits? What doesn't my model explain about Earth's surface in my region? List at least 2 questions you could ask about Earth's surface in your region that your model cannot answer yet.	Describe at least two different ways that you could get more information and evidence about your region and Earth's surface there.

Student Page 6.4B: Explaining Regions of the World

Region Name and location:

Landforms	Tectonic Events	Plate Names	Plate Movement and Boundary Type

In your model presentation, you must share the:

- name and location of the region that you modeled
- most significant landforms and tectonic events in your region
- names and types of plates found in your region
- kind of plate boundary or boundaries found in your region (including the direction the plates are moving and what kind of crust those plates are made of--oceanic or continental)

For the model presentation, you and your group must decide:

- Who will say that?
- When will each person speak?
- How can you explain the movement of those plates for the class?
- How can you focus your presentation more on the four main points rather than what you used to build your model?

STEP 7

Overview

This final Step is an opportunity for students to evaluate and apply their understanding of one of this Unit’s overarching concepts: Plate tectonics explains the landforms, changing features, and catastrophic events of Earth’s surface.

There are three lessons in Step 7, and all provide opportunities for you and your students to evaluate the learning that has taken place throughout this unit. Students present their models in the first lesson to share important information about different types of plate boundaries and their associated landforms. The second and third lessons involve students in evaluating information about each other’s models. Students apply what they have learned to two interesting geologic features: the Sierra Nevada mountain range and the San Andreas Fault Zone, both prominent features of California.

In Lesson 7.2, students are asked to explain how the Sierra Nevada range developed over time—an application of an activity they did in Step 6. Students use a graphic organizer to chart how they would explain that mountain range’s development, using evidence from other world regions. In Lesson 7.3, students examine evidence about earthquake activity and plate boundaries in present-day California. Again, students analyze the given evidence in light of the world region models to develop an explanation for the plate boundary movement and earthquake data.

Step 7 provides summative assessment opportunities that use both small group and individual accountability strategies. The first lesson provides an opportunity for students to present their region models and learn from each other, in a whole-class setting, about the key tectonic features represented in each region. The second lesson is completed in small groups, allowing for a level of formative assessment and additional instruction before the final lesson’s individual assessment. The last lesson guides students individually to write an essay to show their understanding of and ability to apply key concepts from the unit.

Step 7 Lesson 1 Snapshot

Key Concept

- Plate tectonics explains the landforms, changing features, and catastrophic events of Earth's surface.

Evidence of Student Understanding

The student will be able to:

- communicate an evidence-based explanation for what is observed about Earth's surface in their region;
- compare their region to other groups regions;
- identify evidence in presentations and the explanations it supports.

Time Needed

50 minutes

Materials

For each student

- 4 copies of *Student Page 7.1A: Explaining Regions of the World*

For each group

- region model

Model Showcase

1. Explain to the class how each region they have studied is important for all the students to know about because each features special examples of evidence for Plate Tectonics.

- In this lesson students will teach each other about their regions, and what they learn will be essential to know in the next lessons.

2. Have students sit with their groups and locate their copy of *Student Page 6.4B: Explaining Regions of the World*.

- Remind students that they need to instruct their classmates on these important features of their region.
- Reinforce that it is very important to take good notes on the regions because students will be comparing the regions and using them as examples for the rest of this unit.

3. Provide in- and out-of-class time for presentation preparations as needed.

(continued on following page)

REAPS Questions

- R** Does everyone in your group have the same data recorded for the region presented?
- E** What did you see or hear that tells you this group understands how plate tectonics explains what is observed about Earth's surface in their region?
- A** How does this region compare to yours?
- P** What features or events on Earth's surface do you think will change in this region in the future?
- S** How will (or would have) this presentation influence(d) your group's presentation?

4. Limit groups' presentation time to what you established for the class.

- Instruct students to take notes about each region during presentations using *Student Page 7.1A: Explaining Regions of the World*

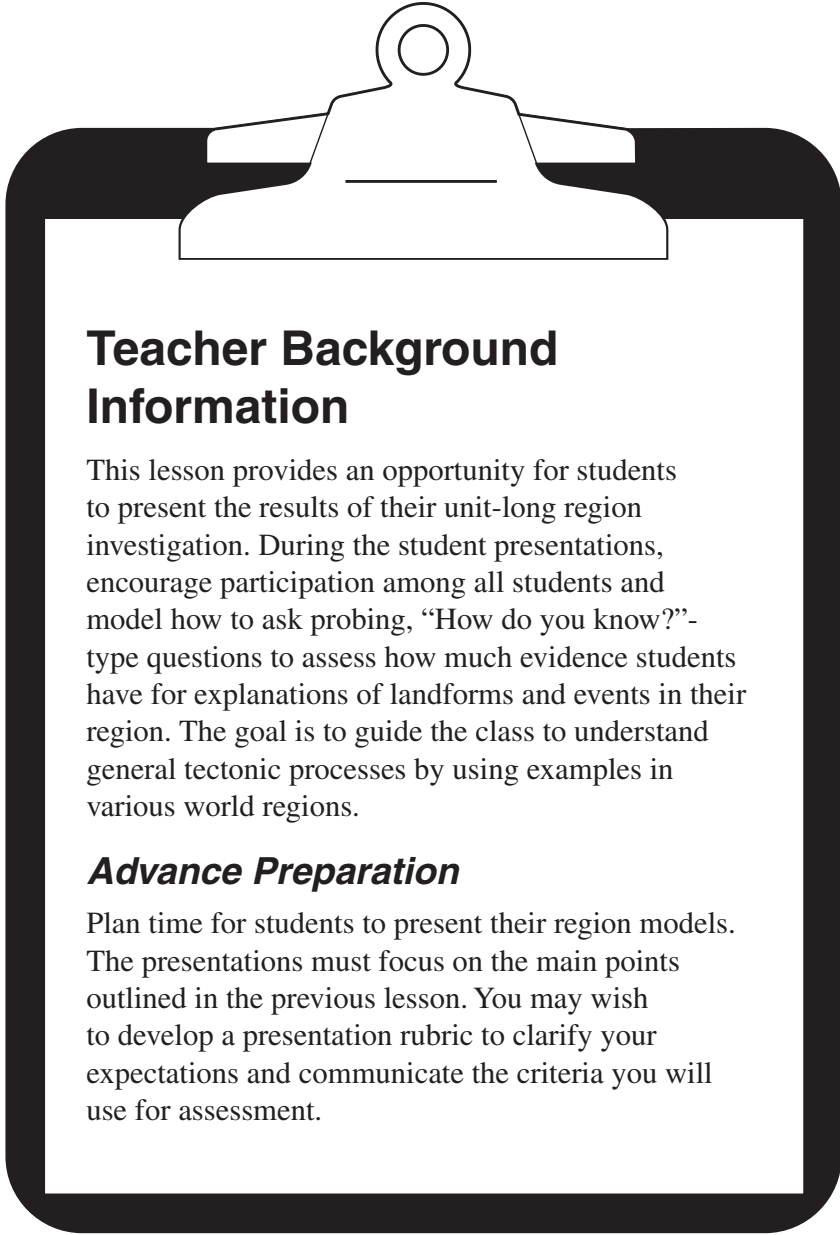
5. At the conclusion of each presentation, prompt the presenters to recap their main points and their region's key features.

6. Provide time for other region groups to discuss among themselves the region that was just

presented. The REAPS are designed to structure their conversations.

- Have students record their responses in their science notebooks to use in the next lessons.
- Allow time for clarifying questions back to the group who presented as needed.

7. After all presentations have been given, ask students, **Which of the regions that you learned about today might have processes taking place that are similar to those in California?** Have students explain their reasoning.



Teacher Background Information

This lesson provides an opportunity for students to present the results of their unit-long region investigation. During the student presentations, encourage participation among all students and model how to ask probing, “How do you know?”-type questions to assess how much evidence students have for explanations of landforms and events in their region. The goal is to guide the class to understand general tectonic processes by using examples in various world regions.

Advance Preparation

Plan time for students to present their region models. The presentations must focus on the main points outlined in the previous lesson. You may wish to develop a presentation rubric to clarify your expectations and communicate the criteria you will use for assessment.

Implementation Guide

1. Explain that students will present to the class the region models they have been working with throughout the unit. The goal of this is much more than just sharing what they have built or how they built it. They are responsible for teaching the other students about their region.

Provide students with the rubric that you developed to clarify expectations for the presentations. Explain that each group will have a minimum and maximum amount of time (3–5 minutes is suggested) to teach their classmates about their region, including the four main points highlighted on Student Page . While students may include additional information about their reading during the presentation, the focus needs to remain on the four main points.

2. Allow students time to prepare their presentations. Prompt them with questions like:

- Who will say that?
- When will each person speak?
- How can you explain the movement of those plates for the class?
- How can you focus your presentation more on the four main points rather than what you used to build your model?

3. Determine how much time groups will need to prepare effective presentations. You may wish to have groups practice giving all or part of their presentations to you on the side, while other groups prepare. Encourage students to use visual aids, particularly those that emphasize the key features related to tectonic processes.

4. Before presentations begin, explain that when students are not presenting, it is their responsibility to take detailed notes on the four main points for the region being presented. Remind students that they will need these notes when they work individually to explain landforms in a ninth region in the next lesson.

- Distribute 4 copies of *Student Page 7.1A: Explaining Regions of the World* to each student to use for recording notes during the presentations.
- Organized notes will help students access the information they will need in the next two lessons.

5. At the conclusion of each presentation, prompt the presenters to recap the four main points that students are responsible for knowing. Use the *Explaining Earth's Features* chart to guide note-taking, summarize each group's presentation, and provide a future reference.

- Allow students a minute or two to take notes and ask questions about the four main points.

6. Give student groups three to five minutes to compare their individual notes and discuss the presentation just seen. Focus their discussions with the REAPS questions. Travel around the room as groups discuss the REAPS questions and clarify key points that may have been difficult to understand or missed during the presentation. Repeat the process until all groups are finished.

- Allow time for clarifying questions back to the group who presented as needed.

7. Once the presentations have been completed, pose the question to the class, **Which of the regions that you learned about today might have processes taking place similar to those in California?** Students may recognize that California has mountains, like many of the regions they studied. In addition, students may compare the earthquakes in California to those in other parts of the world. Answers will vary to this question. The idea is to have students begin thinking about the processes and geology they studied in their region that could be applied to understanding the geology of California.

Student Page 7.1A: Explaining Regions of the World

Region Name and location:

Landforms found in this region	Tectonic events that occur in this region	Types of plate boundaries in this region	Type of plate movement(s) happening in this region

Other key Information for this region:

Region Name and location:

Landforms found in this region	Tectonic events that occur in this region	Types of plate boundaries in this region	Type of plate movement(s) happening in this region

Other key Information for this region:

Step 7 Lesson 2 Snapshot

Key Concept

- Plate tectonics explains major geological features of California, including mountains and locations of earthquakes and volcanoes.

Evidence of Student Understanding

The student will be able to:

- explain how mountains form in the specific context of the Sierra Nevada Range, in what is now east-central California.
- compare their explanation with the scientifically accepted explanation.

Time Needed

50 minutes

Materials

For the class

- Farallon Plate subduction animation 
- Computer and projector to display animation
- *Teacher Page 7.2c: Sierra Nevada Explanation Poster Template*

For each group of 3–4 students

- 1 copy of *Student Page 7.2A: Modern-day California*
- 1 copy of *Student Page 7.2B: Historic California Plate Boundaries*
- 1 poster-sized copy of *Teacher Page 7.2c Sierra Nevada Explanation Organizer*
- 1 medium point marker

Explaining Mountains

1. Use the class charts (*Exploring Earth's Surface*, and *Explaining Earth's Features*) to guide students to reflect on what they have learned in this unit. Explain that this lesson is students' opportunity to demonstrate what they know by using plate tectonics to explain a major landform in California.

2. Form student groups of 3–4 students. Assign each student in a group a number and assign each number a job:

- **Recorder** to chart the group's ideas
- **Monitor** to encourage./check for equal participation
- **Collector** to gather materials
- **Reporter** to share the group's key ideas

3. Explain to the class that in this lesson students will work in small groups to develop an evidence-based explanation for how the Sierra Nevada Mountain Range in California formed.

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REAPS Questions

- R** What world regions studied in this unit feature mountain ranges? To greater or lesser degrees, all regions contain mountains, volcanic or otherwise.
- E** Are high mountain ranges associated with convergent or divergent plate boundaries? Convergent boundaries are where plates come together, pushing up crust to form high mountains.
- A** Compare your explanation for how the Sierra Nevada mountain range formed to the geologists' explanation. Answers will vary. Students need to cite examples from each explanation in their analysis.
- P** What other features of California do you think can be explained using plate tectonics? Coastal mountain ranges, faults, earthquakes, volcanoes.
- S** Think about and write in your Science Notebook one or two things you have learned so far in this unit.

- Each group will receive maps that provide information about the Sierra Nevada area that can be interpreted much like the information about the world regions was used to learn about how plate tectonics explains their features and events.
- Groups will have 25–30 minutes to fill explanations into the 4 quadrants on their copy of the *Sierra Nevada Explanation Organizer* poster. They will need to:
 - identify other world regions with mountain ranges
 - identify other world regions with similar plate boundary types
 - identify other world regions with different plate boundary type
 - draw a model that most likely provides evidence for how this mountain range developed (this is to be a cross-section)

4. Explain the materials that each group will receive, and answer clarifying questions about the assignment before allowing the *materials person* to get what their group needs. For each group, provide:

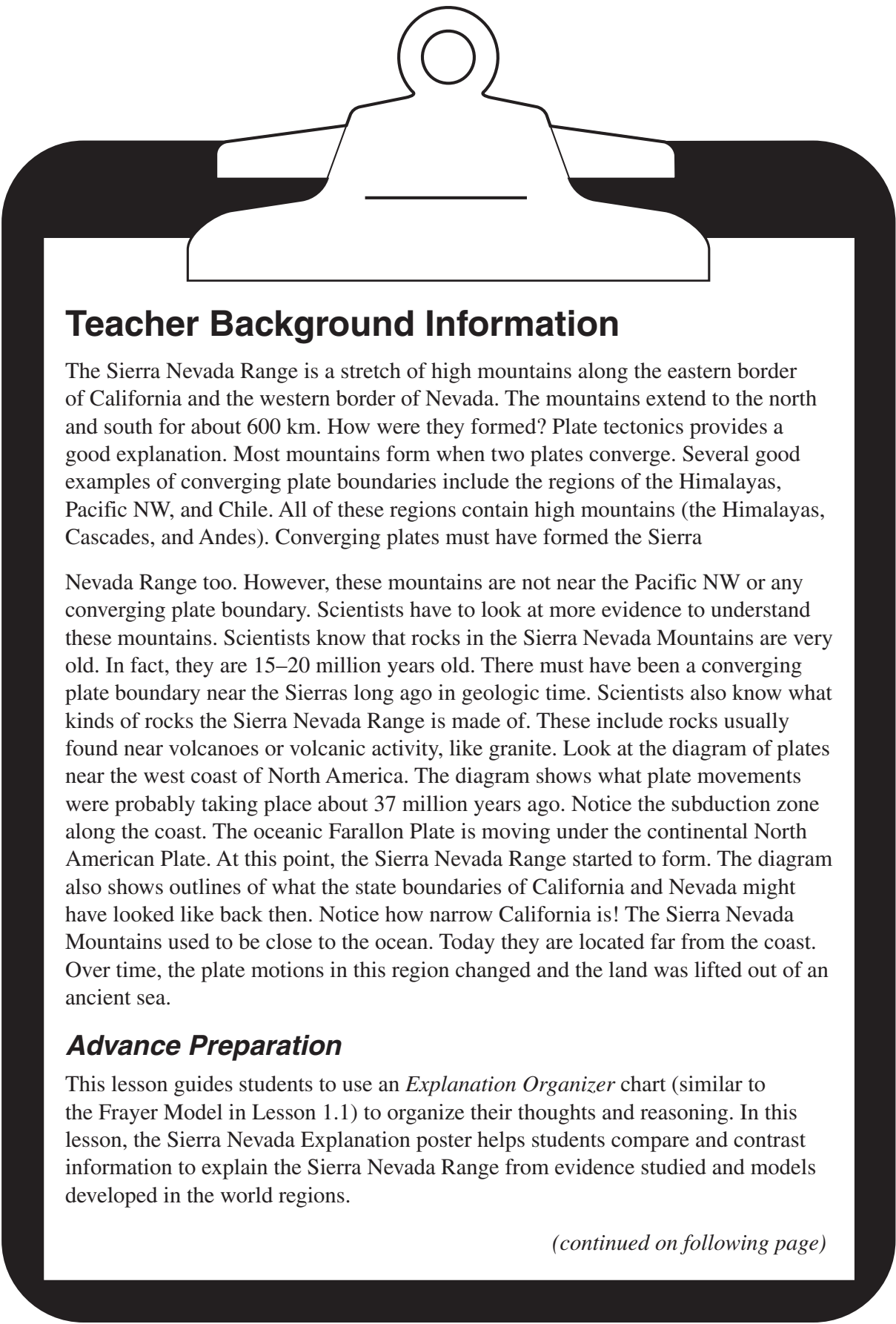
- 1 copy of Student Page 7.2A *Modern-day California*
- 1 copy of Student Page 7.2B *Historic California Plate Boundaries*
- 1 *Sierra Nevada Explanation Organizer* poster.

5. Tape the *Sierra Nevada Explanation Organizer* posters to the wall or other surface so that all group members can see and contribute as the recorder writes. Have the *materials person* get copies of the Student Pages for their group.

6. After 25–30 minutes, have groups prepare to share with the class their drawing and explanation for the region chosen that gives the most logical evidence for how this mountain range formed.

7. Follow presentations with discussion to compare groups' ideas to the geologists' explanations for how the Sierra Nevada range formed. Show the Farallon Plate subduction animation.

8. Use the REAPS throughout and after the lesson as appropriate.



Teacher Background Information

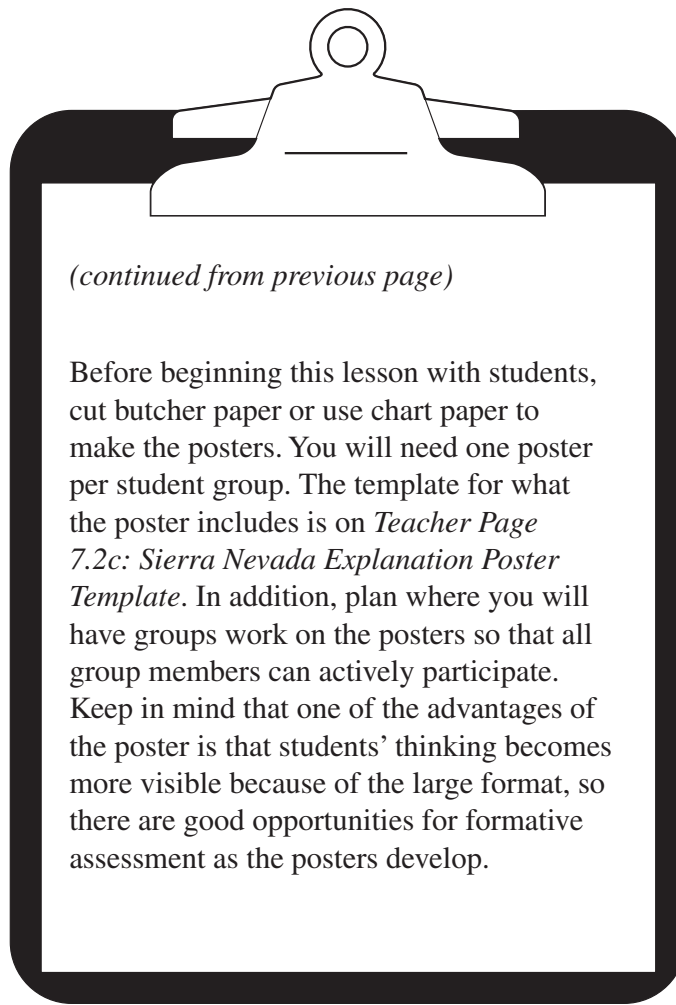
The Sierra Nevada Range is a stretch of high mountains along the eastern border of California and the western border of Nevada. The mountains extend to the north and south for about 600 km. How were they formed? Plate tectonics provides a good explanation. Most mountains form when two plates converge. Several good examples of converging plate boundaries include the regions of the Himalayas, Pacific NW, and Chile. All of these regions contain high mountains (the Himalayas, Cascades, and Andes). Converging plates must have formed the Sierra

Nevada Range too. However, these mountains are not near the Pacific NW or any converging plate boundary. Scientists have to look at more evidence to understand these mountains. Scientists know that rocks in the Sierra Nevada Mountains are very old. In fact, they are 15–20 million years old. There must have been a converging plate boundary near the Sierras long ago in geologic time. Scientists also know what kinds of rocks the Sierra Nevada Range is made of. These include rocks usually found near volcanoes or volcanic activity, like granite. Look at the diagram of plates near the west coast of North America. The diagram shows what plate movements were probably taking place about 37 million years ago. Notice the subduction zone along the coast. The oceanic Farallon Plate is moving under the continental North American Plate. At this point, the Sierra Nevada Range started to form. The diagram also shows outlines of what the state boundaries of California and Nevada might have looked like back then. Notice how narrow California is! The Sierra Nevada Mountains used to be close to the ocean. Today they are located far from the coast. Over time, the plate motions in this region changed and the land was lifted out of an ancient sea.

Advance Preparation

This lesson guides students to use an *Explanation Organizer* chart (similar to the Frayer Model in Lesson 1.1) to organize their thoughts and reasoning. In this lesson, the Sierra Nevada Explanation poster helps students compare and contrast information to explain the Sierra Nevada Range from evidence studied and models developed in the world regions.

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Before beginning this lesson with students, cut butcher paper or use chart paper to make the posters. You will need one poster per student group. The template for what the poster includes is on *Teacher Page 7.2c: Sierra Nevada Explanation Poster Template*. In addition, plan where you will have groups work on the posters so that all group members can actively participate. Keep in mind that one of the advantages of the poster is that students' thinking becomes more visible because of the large format, so there are good opportunities for formative assessment as the posters develop.

Implementation Guide

1. Spend a few minutes at the beginning of this lesson reviewing what the class has learned by studying the *Exploring Earth's Surface* and *Explaining Earth's Features* charts.

- Draw attention to the main lines of evidence for plate tectonics and how the theory explains specific landforms and events like mountains and earthquakes.
- Describe how this lesson is an opportunity for students to work in groups to use all they know about plate tectonics to explain a major landform in California, the Sierra Nevada Mountains.

Emphasize that students are expected to use correct scientific terms in their work, thoroughly explain their logic and thinking, and cite specific evidence in their responses.

2. Form student groups of three to four students. Four is the maximum suggested number because more than that makes it hard to actively involve all students in generating the *Sierra Nevada Explanation Organizer* poster.

Have group members count off to assign each a number. Then, assign each number a job:

- **recorder** to chart the group's ideas on the poster
- **monitor** to encourage and check for participation by all
- **collector** to get the chart and markers and post the group's chart
- **reporter** to share the group's key ideas with the rest of the class when asked

3. Before students get their materials, explain the assignment and what each group will receive. Explain that in this lesson students will work in small groups to develop an evidence-based explanation for how the Sierra Nevada Mountain Range formed in California.

- Each group will receive maps that provide information about the Sierra Nevada area that can be interpreted much like the information about the world regions was used to learn about how plate tectonics explains their features and events.
- Groups will have 25–30 minutes to fill explanations into the 4 quadrants on their copy of the *Sierra Nevada Explanation Organizer* poster. They will need to:
- identify other world regions with mountain ranges
- identify other world regions with similar plate boundary types
- identify other world regions with different plate boundary type
- draw a (cross-section) model that most likely provides evidence for how this mountain range developed

4. Explain the materials that each group will receive, and answer clarifying questions about the assignment. For each group, provide:

- 1 copy of Student Page 7.2A *Modern-day California*
- 1 copy of Student Page 7.2B *Historic California Plate Boundaries*
- 1 *Sierra Nevada Explanation Organizer* poster.

Describe the maps, and **state clearly the time that each map represents** (present-day or ancient). Next, refer to an example blank *Sierra Nevada Explanation Organizer* poster, and check for students' understanding of what each quadrant asks for.

- Explain that the diagram in the fourth quadrant needs to depict a cross-section of the chosen model.

- Provide time for students to ask questions and clarify the directions.

5. Decide ahead of time where to have students work on the posters so that all group members can see and contribute to the Sierra Nevada Explanation poster as the recorder charts. If the posters are on a table or the floor, it is more difficult than if they are on a wall for the students to gather around and participate in discussing the group responses.

Have the *materials person* get copies for their group. Remind the *monitor* to be certain that all group members get turns to examine the map, contribute to the conversation about the evidence, and listen to other students' ideas.

6. After 25–30 minutes, explain that each group will have a minute to explain which region's model they chose to diagram to the rest of the class. If substantial progress on the model is completed by twenty-five to thirty minutes, end the work and prepare for brief presentations.

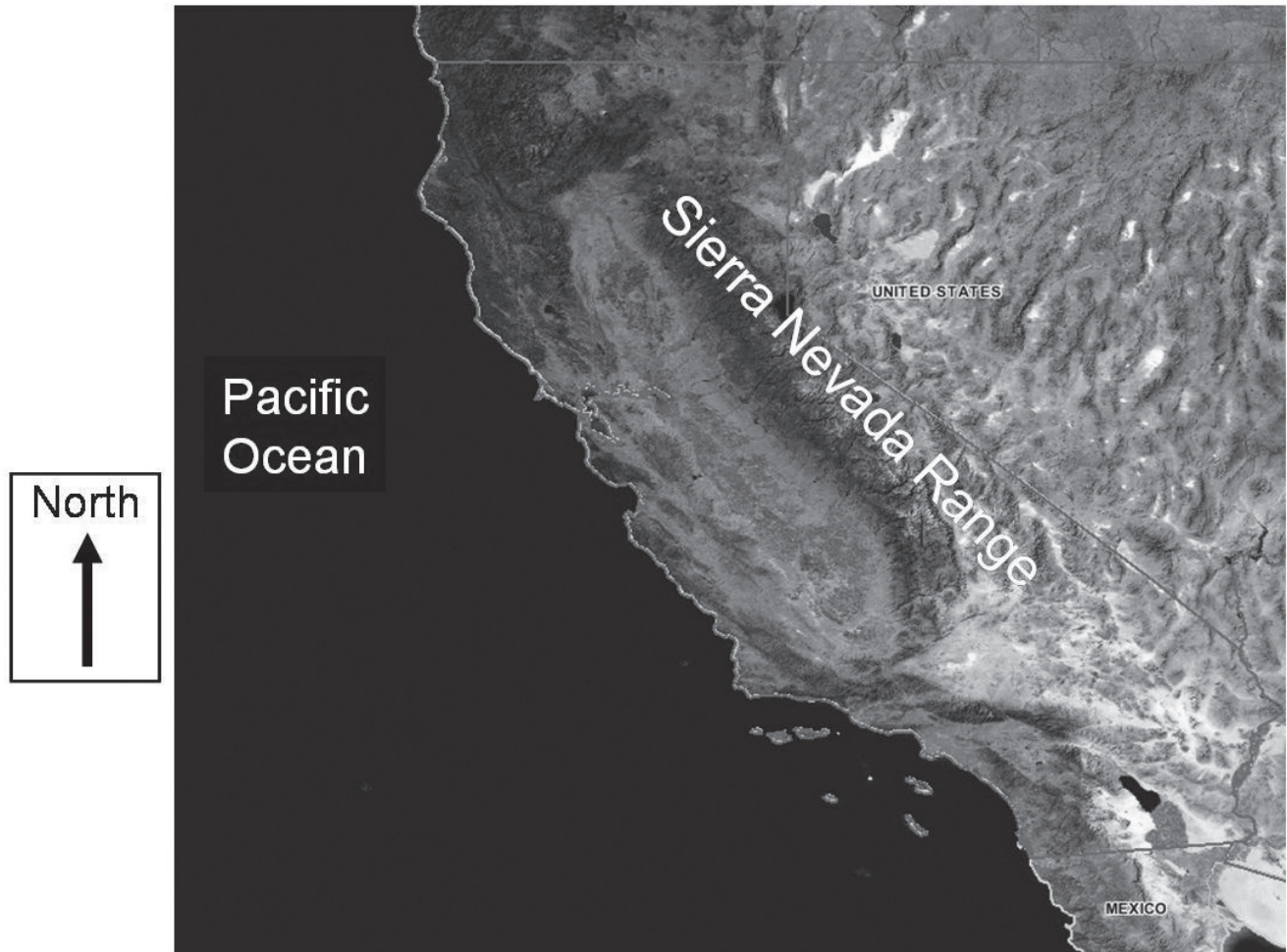
As each group presents, challenge them to explain their reasoning and evidence by asking, "How do you know?" Encourage other groups to ask respectful questions of the presenting group, too.

7. Following the presentations, read aloud the Background Information section from this lesson or summarize it clearly for students. You may wish to use a computer animation to further illustrate the geologists' explanation. This is available on this Unit's CD and is referred to as the Farallon Plate subduction video. It comes from the University of California-Santa Barbara Educational Multimedia Visualization Center and was developed by geologist Dr. Tanya Atwater.

Facilitate a discussion in which the students compare and contrast the class' explanations to geologists' explanations for how the Sierra Nevada Range formed. This question comes up in the REAPS questions and can be used as an individual assessment.

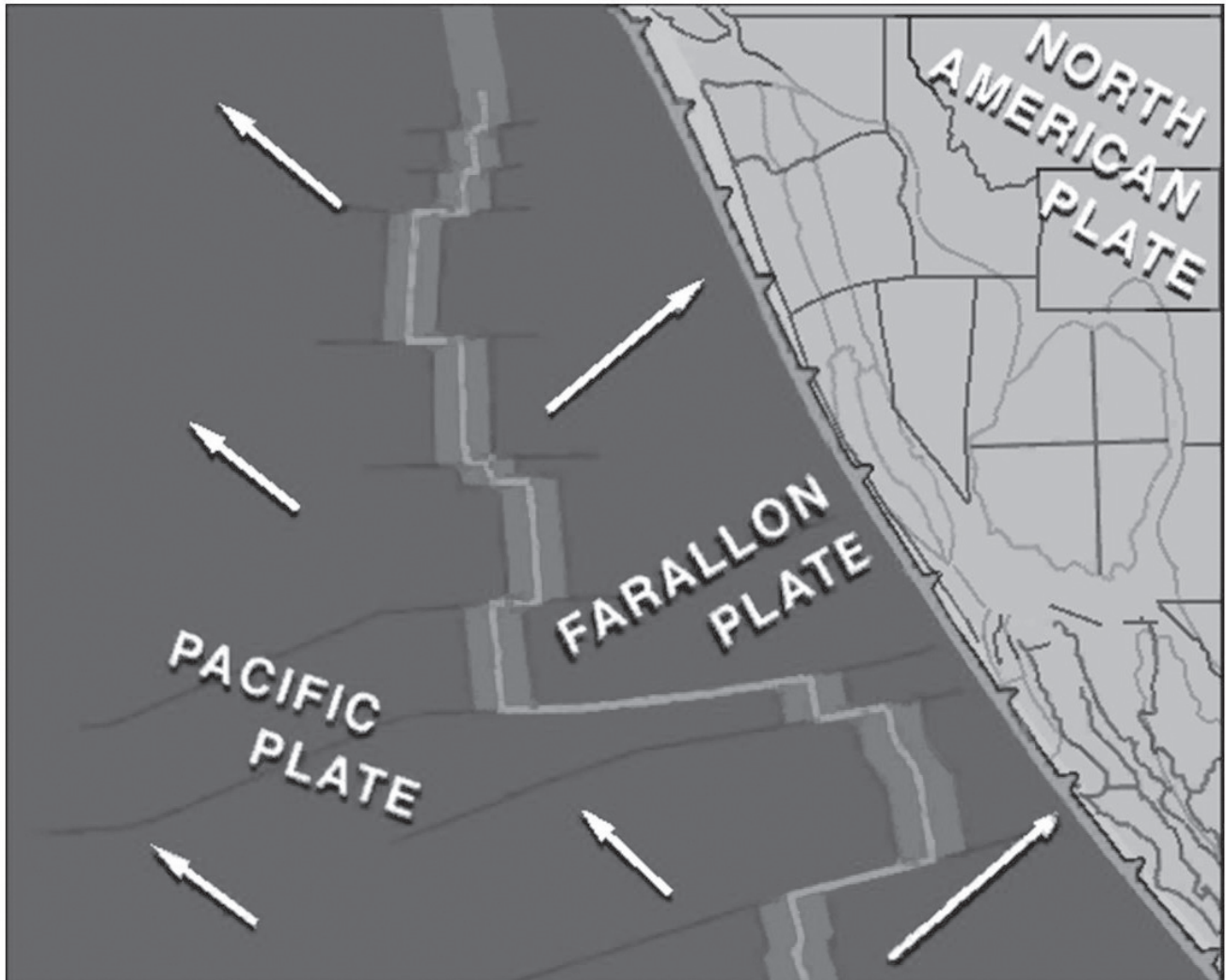
8. Use the remaining REAPS questions throughout and after the lesson as appropriate.

Student Page 7.2A: Modern-Day California



[Map adapted using ArcGIS/ArcMap software.]

Student Page 7.2B: Historic California Plate Boundaries



This figure describes a theory of plate movements (about 37 million years ago) along the west coast of North America. (adapted from Atwater). [Illustration adapted from Tanya Atwater, Educational Multimedia Visualization Center, UCSB]

*Other world regions
with mountain ranges:*

*Other world regions with
similar plate boundary types:*

**Sierra Nevada
Mountains**

*Other world regions
with different plate
boundary types:*

*Drawing of a model
that most likely
provides evidence for
how this mountain range
developed:*

Step 7 Lesson 3 Snapshot

Key Concept

- Plate tectonics explains major geological features of California, including mountains and locations of earthquakes and volcanoes.

Evidence of Student Understanding

The student will be able to:

- compare and contrast some of the features in California to the Himalaya region.

Time Needed

50 minutes

Materials

For each student

- 1 copy of *Student Page 7.3A: California Earthquake Activity Map*
- 1 copy of *Student Page 7.3B: Modern-day California Plate Movements*
- 1 copy of *Student Page 7.3C: California*
- notes about the class' world region models from Lesson 7.1

California on the Move

1. Explain to students that in this final lesson for the unit they will work individually to assess their ability to apply key concepts learned in this unit to explain another important region in California.

- Again, use the class charts (*Exploring Earth's Surface*, and *Explaining Earth's Features*) to guide students to reflect on what they learned in this unit.
- Explain that they will be comparing some major geologic features found in California to the Himalaya region.

2. Have students work individually to review their notes about the region models.

3. Display *Student Pages 7.3A California Earthquake Activity Map* and *7.3B Modern-day California Plate Movements* on an overhead or as a projected image, and discuss as a whole class what each Student Page depicts.

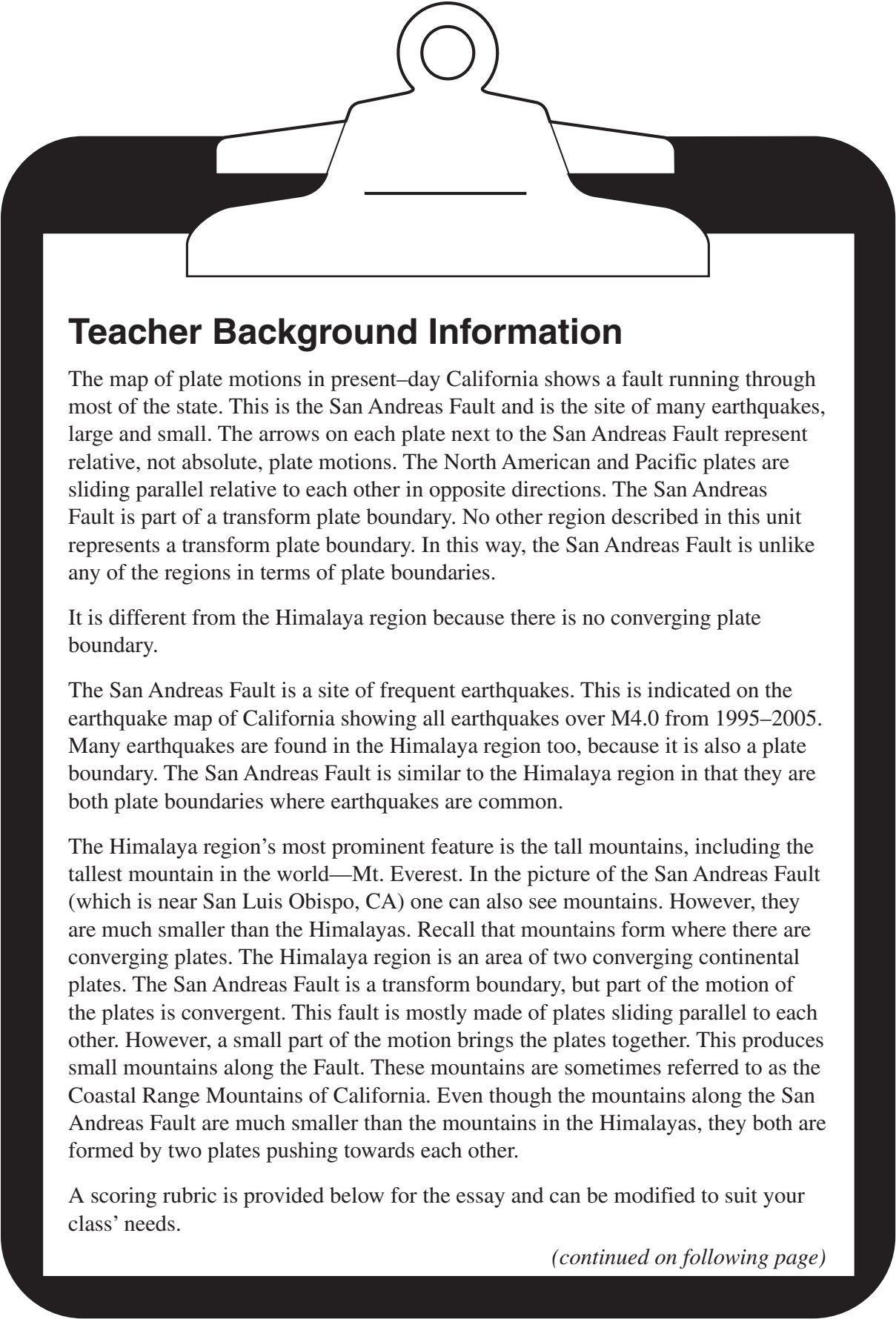
4. Hand out *Student Pages 7.3A–C* and review the instructions as a whole class.

5. Provide 20–30 minutes for students to work individually to write their response to the essay question.

6. Use the REAPS to wrap-up the unit.

REAPS Questions

- R** What was the most interesting thing you learned in this unit?
- E** What was most challenging to understand about plate tectonics? Why?
- A** How did using a science notebook in this unit help your learning?
- P** What is one thing that we did in this unit that we could keep doing that might help you learn the next science component better?
- S** How did you feel about learning science in this unit compared to other times that you have learned science?



Teacher Background Information

The map of plate motions in present-day California shows a fault running through most of the state. This is the San Andreas Fault and is the site of many earthquakes, large and small. The arrows on each plate next to the San Andreas Fault represent relative, not absolute, plate motions. The North American and Pacific plates are sliding parallel relative to each other in opposite directions. The San Andreas Fault is part of a transform plate boundary. No other region described in this unit represents a transform plate boundary. In this way, the San Andreas Fault is unlike any of the regions in terms of plate boundaries.

It is different from the Himalaya region because there is no converging plate boundary.

The San Andreas Fault is a site of frequent earthquakes. This is indicated on the earthquake map of California showing all earthquakes over M4.0 from 1995–2005. Many earthquakes are found in the Himalaya region too, because it is also a plate boundary. The San Andreas Fault is similar to the Himalaya region in that they are both plate boundaries where earthquakes are common.

The Himalaya region's most prominent feature is the tall mountains, including the tallest mountain in the world—Mt. Everest. In the picture of the San Andreas Fault (which is near San Luis Obispo, CA) one can also see mountains. However, they are much smaller than the Himalayas. Recall that mountains form where there are converging plates. The Himalaya region is an area of two converging continental plates. The San Andreas Fault is a transform boundary, but part of the motion of the plates is convergent. This fault is mostly made of plates sliding parallel to each other. However, a small part of the motion brings the plates together. This produces small mountains along the Fault. These mountains are sometimes referred to as the Coastal Range Mountains of California. Even though the mountains along the San Andreas Fault are much smaller than the mountains in the Himalayas, they both are formed by two plates pushing towards each other.

A scoring rubric is provided below for the essay and can be modified to suit your class' needs.

(continued on following page)

Criteria	Thorough and Detailed	Improving	Beginning
Concept: Showing understanding of the content	Essay identifies the types of plate boundaries in each region correctly and provides several comparisons and contrasts.	Essay identifies the types of plate boundaries in each region correctly, but does not provide more than one comparison or contrasting statement about the regions.	Essay incorrectly identifies the plate boundaries or provides no region for comparison.
Evidence in Explanation: Relation to evidence in models and maps	Essay shows clear understanding of the significance in patterns of earthquakes occurring along plate boundaries (in both regions) and refers to the data as evidence. Essay refers to specific aspects of the Himalaya region model to support claims.	Essay correctly describes a basic pattern found in earthquakes occurrences (EQs happen along faults) and cites some evidence, but does not relate the pattern to the big picture of plate boundaries and movements.	Essay incorrectly describes patterns in earthquake occurrences OR does not refer to or incorrectly refers to evidence in the explanation.
Presentation:	Author uses all assigned scientific terms and uses them correctly and appropriately. Author's ideas are logically organized and easy to read and understand. Grammar, spelling, and structure of the story are all accurate and strong.	Author uses 75% of the scientific terms correctly and appropriately. Author's ideas make a good story and are usually easy to understand. Most grammar, spelling, and structure is correct.	Author uses fewer than 50% or fewer of the assigned scientific terms or uses them incorrectly or inappropriately. Author's ideas are difficult to understand. Grammatical, punctuation, or spelling errors are significant and interfere with the story.

Implementation Guide

1. As in the introduction to the previous lesson, spend a few minutes again at the beginning of this lesson reviewing what the class has learned by studying the *Exploring Earth's Surface* and *Explaining Earth's Features* charts. Draw attention to the main lines of evidence for plate tectonics and how the theory explains specific landforms and events like mountains and earthquakes.

Describe how this lesson is an opportunity for students to work in groups to use all they know about plate tectonics to compare a major geologic feature of California to one of the world regions.

2. Have students work individually to review their notes about the class' world region models. Point out that each region featured specific plate boundary types and that they are responsible for knowing the types—this is a summative assessment step.

3. For the class, provide Student Pages 7.3A and 7.3B as an overhead or projected image and discuss what each depicts. Clarify any student questions about what the maps represent or how to interpret them.

4. Hand out Student Pages 7.3A–C for each student. Review the instructions for writing the essay as a whole class. Emphasize that students are expected to use scientific arguments, just as they did in previous assignments like the letters to Wegener and his opponents. Also, be sure that students know to use scientific terms for their ideas.

5. Provide 20–30 minutes for students to work individually to write their response to the following essay question:

- How is the plate boundary featured in the California map similar to and different from the plate boundary featured in the Himalaya region?

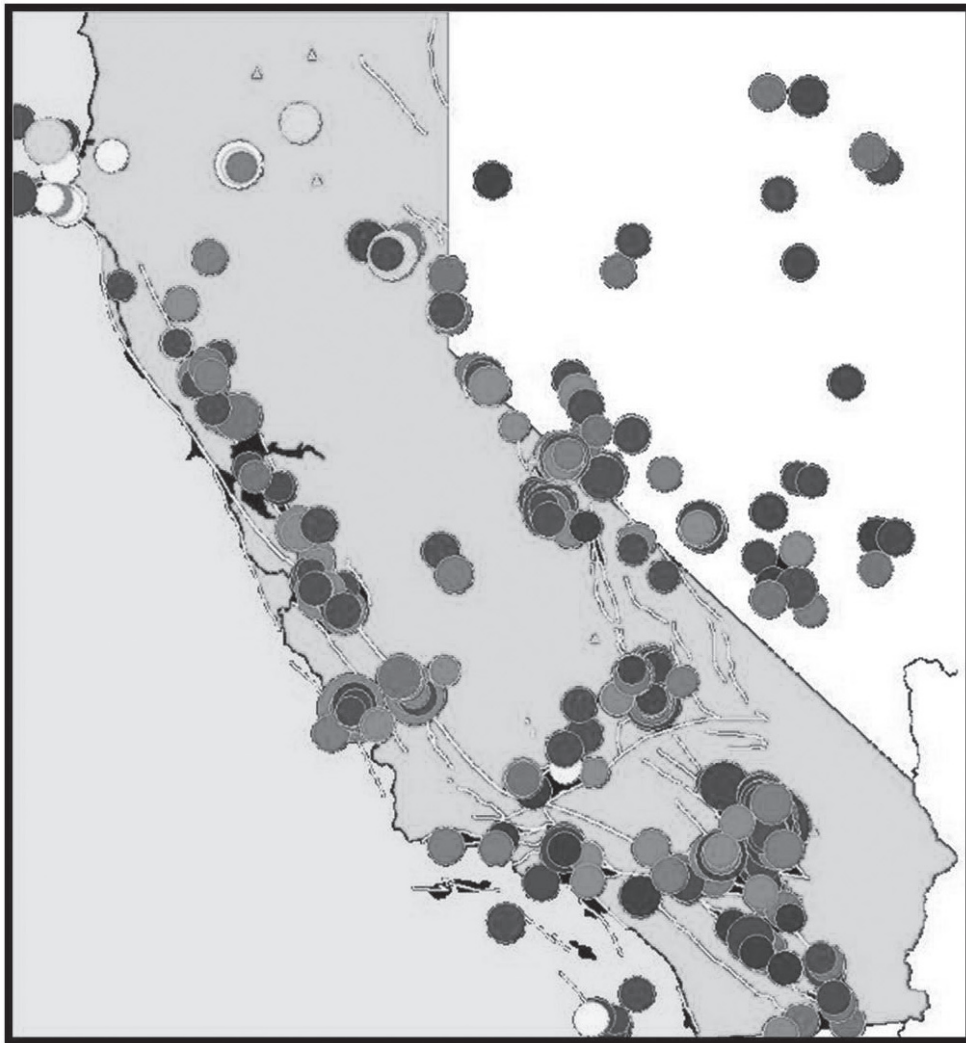
Remind students that they are to explain their answers using specific evidence from the Himalaya region model and the California maps. They may include diagrams to illustrate their points.

Write on the board and emphasize that explanations must include the following terms:

- Earthquake
- Fault
- Convergent
- Plate

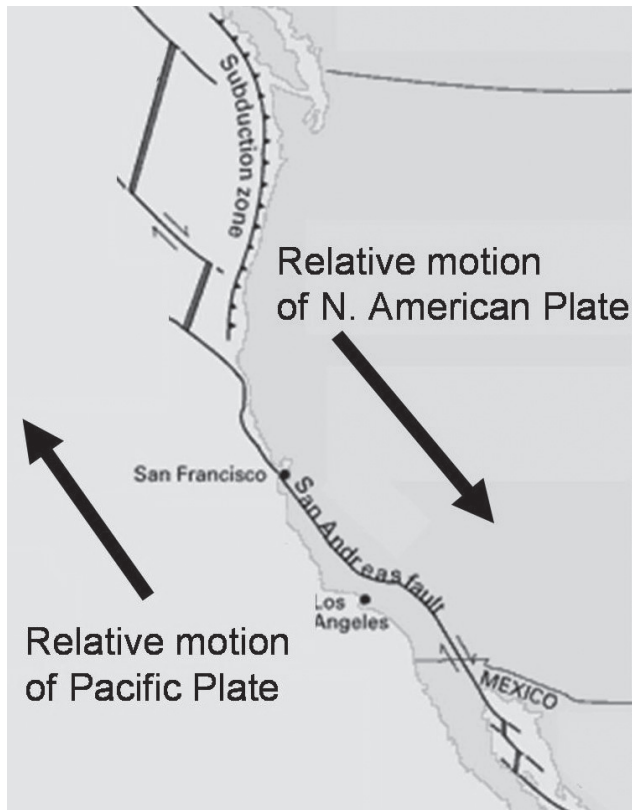
6. To end the unit, use the REAPS questions to probe what students liked, disliked, and learned about how all of the activities and lessons related to plate tectonics.

Student Page 7.3A: Present-day California Earthquake Activity Map

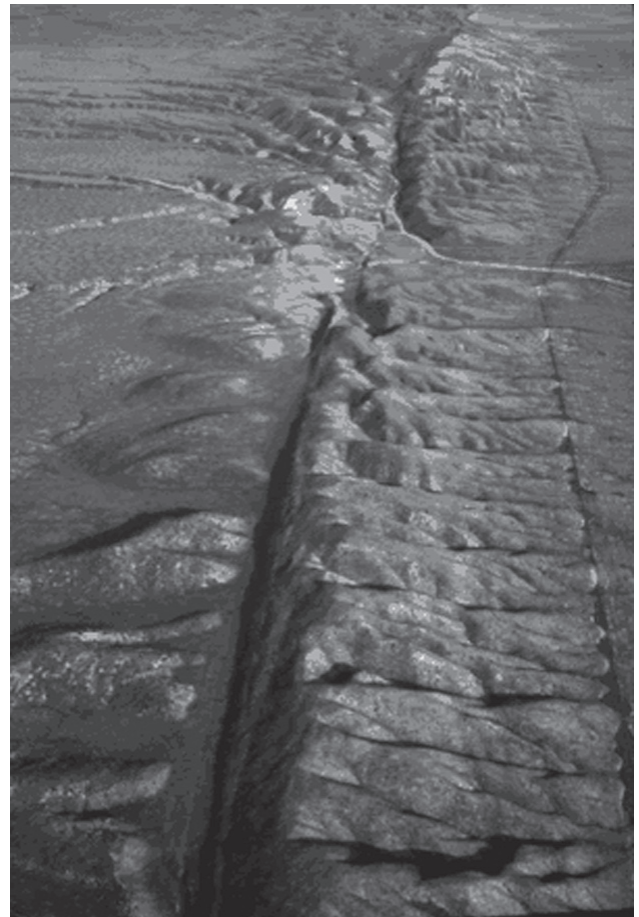


Earthquakes in the California region between 1995 and 2005 over M4.0. [Adapted from Seismic Eruption software program.]

Student Page 7.3B: Present-Day California Plate Movements



Adapated from USGS, This Dynamic Earth.



San Andreas Fault near San Luis Obispo. Photo courtesy USGS, This Dynamic Earth.

Student Page 7.3C: California

Name _____

Date _____

1. Study the two maps that your teacher gives you. You should see maps for *Present-day California Earthquake Activity* and *Present-day California Plate Movements*.

2. Use evidence from the two maps and your notes from the model presentations to write an essay. In your essay, try to answer the following question:

How is the plate boundary in California similar to and different from the plate boundary in the Himalaya region?

Explain your answer using specific evidence from the Himalaya model and the California maps. You may include drawings to illustrate your points. Include in your explanation the following terms:

- **Earthquake**
- **Fault**
- **Convergent**
- **Plate**

