INSTRUCTOR'S MANUAL

Earth: Portrait of a Planet

SIXTH EDITION

Stephen Marshak

Instructor's Manual by
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Other Instructor Resources Available with *Earth: Portrait of a Planet, 6e*

Interactive Instructor's Guide

All of the materials found in this Instructor's Manual are available online, searchable by chapter, keyword, or learning objective. The Interactive Instructor's Guide instantly provides multiple ideas for teaching: video clips, powerpoints, animations, and other class activities and exercises. This repository of lecture and teaching materials functions both as a course prep tool and as a means of tracking the latest ideas in teaching the Earth course.

To access the Interactive Instructor's Guide, to go https://iig.wwnorton.com/earth6/full.

Smartwork5 Online Homework

Smartwork5 is Norton's tablet-friendly, online activity platform. Both the system and its physical geology content were designed with the feedback of hundreds of instructors, resulting in unparalleled ease of use for students and instructors alike.

Smartwork5 features easy-to-deploy, highly visual assignments that provide students with answer-specific feedback. Students get the coaching they need to work through the assignments, while instructors get real-time assessment of student progress via automatic grading and item analysis. Th e question bank features a wide range of higher-order questions such as ranking, labeling, and sorting. All of the Narrative Art videos, animations, and interactive simulations are integrated directly into Smartwork5 questions—making them assignable. Smartwork5 also contains What a Geologist Sees questions that take students to sites not mentioned in the book, so they can apply their knowledge just as a geologist would. In addition, Smartwork5 offers reading quizzes for each chapter and Geotours-guided inquiry activities using Google Earth.

Based on instructor feedback, Smartwork5 offers three
types of pre-made activity:

- Chapter Reading Quizzes, designed to help students prepare for lecture
- Chapter Activities, consisting of highly visual exercises covering all chapter Learning Objectives
- Geotours Worksheets—guided inquiry activities that use Google Earth

Smartwork5 is fully customizable, meaning that instructors can add or remove questions, create assignments, write their own questions, or modify ours. Easy and intuitive tools allow instructors to filter questions

Smartwork5 is available for free with most newly purchased print or electronic versions of the text. Immediate online access can also be purchased at the text's Digital Landing Page. Smartwork5 is easy to implement, and your local Norton representative will be happy to help you get started.

Norton Coursepacks for Campus Learning Management Systems

Available at no cost to professors or students, Norton Coursepacks bring high-quality Norton digital media into a new or existing online course. Coursepacks contain ready-made content for your campus LMS. For Earth: Portrait of a Planet, Sixth Edition, content includes the full suite of animations, simulations, and videos keyed to core figures in each chapter; the Test Bank; reading quizzes; new European case studies; Geotour questions; vocabulary flashcards; and links to the ebook. To download the Norton Coursepack for your campus LMS, go to the Earth Instructor's page.

Test Bank

The Test Bank has been written to correlate to the learning objectives found in *Earth* and provides carefully vetted and well-rounded assessment. Every item in the test bank has been reviewed to ensure scientific reliability and to make sure it truly tests students' understanding of the most important topics in the text. Each chapter features 50 multiple-choice questions and 10 short-answer or essay questions that test student critical thinking and knowledge-application skills. Several of these questions are art-based and use modified images from the text. Each question is tied to sortable metadata fields including text section, learning objective, difficulty level, and Bloom's taxonomy.

To download the Test Bank in PDF, Word, or Examview formats, go to the Earth Instructor's page.

PowerPoints

Several types of powerpoints are available, downloadable via the Earth Instructor's page.

- *Lecture PowerPoints*—Designed for instant classroom use, these slides utilize photographs and line art from the book in a form that has been optimized for use in the PowerPoint environment. The art has been relabeled and resized for projection formats. Think-Pair-Share questions, animation, and video slides help incorporate active learning into lecture.
- *Clicker Question PowerPoints* for each chapter can be added as-needed to existing PowerPoint decks to check student comprehension in class.
- *Labeled and Unlabeled Art PowerPoints*—These include all art from the book formatted as JPEGs that have been prepasted into PowerPoints. We offer one set in which all labeling has been stripped and one set in which labeling remains. All art files for the text are also available in JPEG format for creating your own handouts and presentations
- *Update PowerPoints*—W. W. Norton & Company offers an update service that provides new PowerPoint slides, with instructor support, covering three recent geologic events for fall and spring semesters. These updates will help instructors keep their classes current, tying events in the news to core concepts from the text.

Animations, Simulations, and Videos

Marshak's online resources are designed to be easy to use and visually appealing. Animations, interactive simulations, narrative figure videos, and real-world videos cover the core topics and bring in-class presentations to life. The animations and videos may be accessed at no cost from the Digital Landing Page. They are also available in the Coursepack and integrated into Smartwork5 assessment.

- Animations and interactive simulations are perfect for in-class lectures or student self-study use. Covering the most important topics, these 2-4 minute clips are available to help students better visualize and master key concepts and processes. Selected animations are also simulations, which include interactive tools that allow students to experiment with geologic variables.
- Narrative Figure Videos were written and narrated by Marshak himself. These videos bring textbook figures and supplementary photographs to life, helping students to better understand key concepts from the course.
- Real-World Videos are a streaming source of real world video content that exists on Norton's servers without advertising or broken links.

Instructor USB

USB drives are available for instructors and contain the Test Bank, Animations and Simulations, Narrative Art Videos, Lecture Slides, labeled and unlabeled art from the book, the Instructor's Manual, and See For Yourself and GeoTours kmz files in one easy-to-access location. Request an Instructor USB via Earth Instructor's page.

CONTENTS

PRELUDE

And Just What Is Geology?

Learning Objectives

By the end of this prelude, you should be able to . . .

A. describe the scope and applications of geology.
B. explain the foundational themes of modern geologic study.
C. demonstrate how geologists employ the scientific method.
D. provide a basic definition of the theory of plate tectonics.
E. explain what geologists mean by the Earth System concept.
F. name the main layers of the Earth's interior.

Summary from the Text

- Geologists are scientists who study the Earth. They search for the answers to the mysteries of our home planet, from why volcanoes explode to where we can find minerals.
- Geologic study can involve field exploration, laboratory experiments, high-tech measurements, and calculations with computers.
- Geologic research not only provides answers to academic questions such as how the Earth formed, but also addresses practical problems such as how to find groundwater or how to avoid landslides. Many people pursue careers as geologists.
- A set of themes underlies geologic thinking. Key concepts are that the Earth's outer shell consists of moving plates whose interactions produce earthquakes, volcanoes, and mountains; that the Earth is very old; and that interacting realms of material on the planet constitute the Earth System.

Real-World Videos

SCIENCE FOR A CHANGING WORLD

Learning Objectives Covered:

- A. describe the scope and applications of geology.
- C. demonstrate how geologists employ the scientific method.

Length: 8:11

Summary: The U.S. Geological Survey (USGS) is the leading agency providing reliable scientific information for informed decision and policy making. This video outlines a brief history of the USGS, and the significance of USGS's work and mission in today's world. When it was founded in 1879, the primary focus of the survey was mineral resources and mining geology, as well as mapping, paleontology, and stratigraphy. Since its foundation, the USGS has evolved to provide fundamental scientific data relevant to water resources, changing Earth processes, and even the moon landings. Today, USGS scientists throughout the 50 states gather data in six science mission areas critical to the well-being of the nation and world:

- **Ecosystems**—monitors many functions vital to human populations, including soil formation, crop pollination, nutrient cycling, water purification, waste treatment, and atmosphere regulation.
- **Energy, minerals, and environmental health**—assesses the quantity and quality of resources (including environmental impacts of extraction and use).
- **Climate and land use**—uses research, monitoring, remote sensing, modeling, and forecasting to address human impact.
- **Natural hazards**—assesses the threat of natural hazards for public knowledge and policy making.
- **Water**—monitors resources.
- **Core science systems**—translates scientific data into formats that are accessible and understandable.

Classroom Use: This video helps students to understand some of the many ways in which geology solves significant and critical problems faced by human populations today. Before showing the video, ask students to reflect on what geologists do and what types of problems they solve. Additionally, ask them to create a list of what they believe to be some of the greatest risks facing human populations (regionally or globally). After viewing the video, facilitate a discussion about the relevance of geology to society. What types of problems (e.g., climate change, clean water, land use, agriculture, natural resources) does geology seek to solve?

Adaptations:

- This video could be used together with the "Geology in the News" activity (which would provide specific examples of USGS projects) to form a lesson on the relevance of geologic research to society.

Review and Discussion Questions:

1. What are some of the major areas of geology that the USGS supports?
2. What are some of the greatest challenges that the Earth System faces today?
3. How does the work of the USGS help to address some of the challenges that the Earth System faces today?

Credit: USGS

HYDRAULIC FRACTURING: USING SCIENTIFIC METHODS TO EVALUATE TRADE-OFFS

Learning Objectives Covered:

- A. describe the scope and applications of geology.
- C. demonstrate how geologists employ the scientific method.

Length: 3:07

Summary: This video uses the example of hydraulic fracturing ("fracking") in Colorado to discuss how scientists gather objective data that can be used to guide environmental regulations. Environmental engineers are investigating the potential impacts of fracking on water and air quality, human health, and energy sustainability, with an emphasis on neutrality. Stakeholders will be able to use the information—such as methane concentration in the atmosphere, and the persistence of fracking fluids in ecosystems—to create a decision framework to improve environmental policy. In the case of fracking, where two opposing points of view are often at odds, science can provide the best source of trusted information.

Classroom Use:

1. Remind students that the scientific method yields verifiable results, and therefore science can provide impartial evidence in cases where opposing “sides” may have a biased view about a topic (see **Box P.1** in the text for a review).
2. Show the video as one example of a controversial topic.
3. Working in small groups of two to three, ask students to come up with another example of a controversial issue that geologists could evaluate in an impartial way. Some examples might include: global climate change and sea level rise, earthquake and tsunami hazards, soil conservation and land use planning, or ecosystem impacts of coal mining.

Review and Discussion Questions:

1. The video references one “side” contradicting the other “side.” Who or what are the “sides” that are being referenced? What factors influence their view of fracking?
2. What are some of the questions that scientists are asking about hydraulic fracturing?
3. If you lived in Colorado where this fracking is happening, what sources of information would you turn to?

Credit: Science 360 News (NSF)

Activity

GEOLOGY IN THE NEWS

Learning Objectives Covered:

- A. describe the scope and applications of geology.
- C. demonstrate how geologists employ the scientific method.

Activity Type: Online Investigation

Time in Class Estimate: Variable (dependent on class size and depth of discussion)

Recommended Group Size: Individual to four students

Materials: Students will need to access websites with geology-related science news, including: U.S. Geological Survey Science Snippets (www.usgs.gov/news/science-snippets)

Classroom Procedures:

1. Visit the USGS Science Snippets website (www.usgs.gov/news/science-snippets) and select an article of interest to read.

2. While reading, focus on how the scientific method (see **Box P.1** for a review) is being implemented by answering the following:
    a. What is the problem being solved or hypothesis being tested?
    b. What kinds of data are being collected? How?
3. Summarize what you learned from your article and discuss the ways in which geology provides impartial scientific evidence that is relevant to challenges that our society faces.

Adaptations:

- For online classes, students can be assigned to groups to read and discuss the same article or all students can post summaries to a discussion board.
- For a less open-ended assignment, several articles could be preselected for the entire class.
- American Association of Petroleum Geologists News in Review (www.aapg.org/home/news-in-review) also has resources, and your state geologic agency may also have interesting news.
- This activity could be paired with the "Science For a Changing World" Real-World Video.

Reflection Questions: Do you think there are ever any cases where scientists might impart a bias on the data they collect? What safeguards are there in place to protect the integrity of scientists from things that might bias their work, such as political and financial influences?

THINK-PAIR-SHARE QUESTIONS

Classroom Procedures: Ask students to silently reflect on the question (and, optionally, write down an answer). Questions could be integrated into PowerPoint slides, asked verbally, or posted in discussion boards for online classes. After about a minute of reflection, cue students to share their thoughts with one or two people near them (or in assigned groups in online classes). After a minute or two of small-group discussion, ask students to report answers to the class—ask for volunteers, call on whole groups, or have groups submit consensus posts on a discussion board.

Questions/Answers:

1. Geology in Everyday Life
   How is geology relevant to your everyday life?

ANS: Answers will vary depending on demographics, location, and current events, but students might discuss natural resources, hazards, climate change, or recreation.

Learning Objectives Covered:

- A. describe the scope and applications of geology.

2. Geology and Society

   In what ways is geology increasingly important in today's society?

   ANS: Answers will vary depending on demographics, location, and current events but students might discuss climate change, oil and gas, rare-earth elements, groundwater, soils, or earthquakes.

   Learning Objectives Covered:

   - A. describe the scope and applications of geology.

3. Geology and You

   Whether or not you pursue further studies in geology, how might learning about geology affect your life?

   ANS: Answers will vary depending on demographics and location, but students might discuss an increased appreciation for the natural world, a better understanding of environmental issues, awareness of geologic issues (such as climate change or land use) in government and policy, and factors (such as hazards or climate change) that might influence personal decision making.

   Learning Objectives Covered:

   - A. describe the scope and applications of geology.

Answers to Review Questions

1. What are some of the practical applications of geology?

ANS: Geology is applied to a number of important problems, including: availability of resources (such as oil, minerals, and groundwater), pollution, and hazards such as earthquakes and landslides.

BLOOM'S LEVEL: Remembering

LEARNING OBJECTIVES COVERED:

- A. describe the scope and applications of geology.

2. Explain the difference between internal processes and external processes.

ANS: Internal processes include plate motion, mountain building, earthquakes, and volcanoes. These processes are all driven by heat from inside the Earth. External processes, which result from the movement of air and water, are driven by heat from the sun. Both internal and external forces, together with gravity, interact to shape the surface of our planet.

BLOOM'S LEVEL: Understanding

LEARNING OBJECTIVES COVERED:

- B. explain the foundational themes of modern geologic study.

3. How would the Earth's atmosphere differ if life didn't exist?

ANS: Without life, the Earth's atmosphere would not contain any oxygen, which is a product of photosynthesis in plants. Oxygen is an essential element for complex animals, and is important to chemical reactions that occur during the weathering process of rocks.

BLOOM'S LEVEL: Remembering

LEARNING OBJECTIVES COVERED:

- B. explain the foundational themes of modern geologic study.

4. Explain the difference between a hypothesis and a theory, in the context of science.

ANS: A hypothesis is a potential explanation for an observation. Hypotheses may be correct explanations or they may be incorrect; this is assessed by testing the predictions made by the hypothesis. If a hypothesis is tested in many ways by many individuals over an extended period of time, and passes all tests, it becomes a theory. There is more certainty about a theory than there is about a hypothesis. The scientific community will continue to test an idea even after it becomes a theory.

BLOOM'S LEVEL: Understanding

LEARNING OBJECTIVES COVERED:

- C. demonstrate how geologists employ the scientific method.

5. What is the basic premise of the theory of plate tectonics?

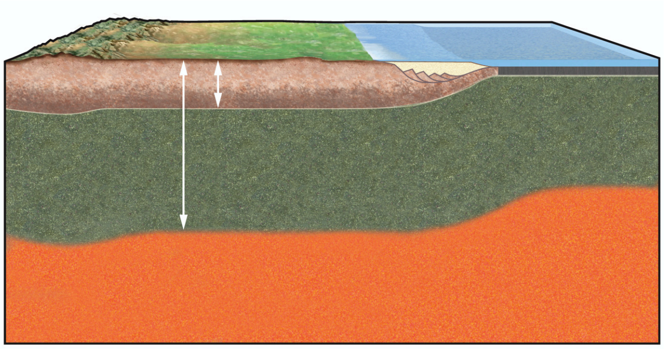
ANS: Plate tectonics is the theory that the outer layer of the Earth is broken up into rigid plates that move laterally relative to each other over the softer layer beneath them. This plate motion is responsible for earthquakes, volcanoes, and mountains. Plate tectonics is the foundational theory for understanding all geology.

BLOOM'S LEVEL: Remembering

LEARNING OBJECTIVES COVERED:

- D. provide a basic definition of the theory of plate tectonics.

6. What are the main layers of the Earth's interior? Label them in the diagram.



ANS: From outside to inside: crust, mantle, outer core, and inner core.

BLOOM'S LEVEL: Understanding

LEARNING OBJECTIVES COVERED:

- F. name the main layers of the Earth's interior.

7. What do geologists mean by the statement, "The Earth is a complex system"?

ANS: The Earth is a set of many interacting elements—including the surface, interior, oceans, atmosphere, and life—that cycle energy and matter, and change over time.

BLOOM'S LEVEL: Understanding

LEARNING OBJECTIVES COVERED:

- E. Explain what geologists mean by the Earth System concept.

8. What are the sources of data that geologists can use to understand the Earth?

ANS: Geologists use data from a large number of wide-ranging sources, including (but certainly not limited to) direct observation of rocks in the field, laboratory methods and equipment, microscopes, satellites, computers, and models.

BLOOM'S LEVEL: Remembering

LEARNING OBJECTIVES COVERED:

- C. demonstrate how geologists employ the scientific method.

9. What are the major subdivisions of geologic time? Which time unit is longer, the Precambrian or the Paleozoic?

ANS: The Precambrian (divided into the Hadean, Archean, and Proterozoic) spans from the birth of the Earth (4,565 million years ago) to 541 million years ago, and represents 88% of geologic time. The Paleozoic (divided into the Paleozoic, Mesozoic, and Cenozoic Eras) spans from 541 million years ago to the present day.

BLOOM'S LEVEL: Remembering

LEARNING OBJECTIVES COVERED:

- B. explain the foundational themes of modern geologic study.

10. This mine truck carries 100 tons of coal. Where does this resource, and others like it, come from?

ANS: Coal is a natural resource that comes from geologic materials.

BLOOM'S LEVEL: Remembering

LEARNING OBJECTIVES COVERED:

- B. explain the foundational themes of modern geologic study.

CHAPTER 1

Cosmology and the Birth of Earth

Learning Objectives

By the end of this chapter, you should be able to . . .

A. assess how people's perceptions of the Earth's place in the Universe have changed over the centuries.
B. explain modern concepts concerning the basic architecture of our Universe and its components.
C. assess the evidence for the expanding Universe and the Big Bang theory.
D. describe where the elements that make up matter came from.
E. explain the nebular theory, a scientific model that explains how stars and planets form.

Summary from the Text

- The geocentric model of the Universe placed the Earth at the center of the Universe. The heliocentric model, which gained acceptance during the Renaissance, placed the Sun at the center. The geocentric model remained popular until the 17th century.
- Eratosthenes measured the size of the Earth in ancient times, but it was not until fairly recently that astronomers accurately determined the distances from the Earth to the Sun, planets, and stars. Distances in the Universe are so large that they must be described in light-years.
- The Earth is one of eight planets orbiting the Sun. Our Solar System lies on the outer edge of the Milky Way Galaxy, which contains about 300 billion stars. Perhaps a trillion galaxies populate the Universe.
- The red shift of light from distant galaxies, a manifestation of the Doppler effect, indicates that all distant galaxies are moving away from the Earth. This observation supports the expanding Universe theory. Most astronomers agree that this expansion began after the Big Bang, a cataclysmic explosion that occurred about 13.8 Ga.

- The first atoms of the Universe (hydrogen and helium) developed within minutes of the Big Bang. These atoms formed vast gas clouds called nebulae.
- Gravity caused clumps of gas and ice in the nebulae to coalesce into flattened disks with bulbous centers. The protostars at the centers of these disks eventually became dense and hot enough that fusion reactions began in them. When this happened, they became true stars.
- Heavier elements form during fusion reactions in stars; the heaviest are mostly made during supernova explosions. The Earth and the life forms on it contain elements that could only have been produced during the life cycle of stars, so we are all made of stardust.
- According to the nebular (condensation) theory of Solar System formation, planets developed from the rings of gas and dust surrounding the proto-Sun. The gas and dust condensed into planetesimals, which then clumped together to form protoplanets and finally true planets. Inner rings became the terrestrial planets. Outer rings grew into the giant planets.
- The Moon formed from debris ejected when a protoplanet collided with the Earth in the young Solar System.
- During differentiation, the interior of a planet separates into layers. A planet assumes a near-spherical shape when it becomes so soft that gravity can smooth out irregularities.

Narrative Figure Videos

FORMATION OF THE SOLAR SYSTEM

Learning Objectives Covered:

- 1D. describe where the elements that make up matter came from.
- 1E. explain the nebular theory, a scientific model that explains how stars and planets form.

Length: 3:18

Summary: This video gives an overview of the nebular theory of Solar System formation, broken down into several stages. First, the gravitational pull of a dense region of a nebula, which contains both volatile and refractory materials, attracts material from elsewhere in the nebula. The nebula eventually turns into a rotating accretionary disk. Next, matter in the center of the disk becomes a proto-Sun. Eventually, nuclear fusion reactions begin, and the Sun emits solar wind, which removes volatile materials from the inner part of the protoplanetary disk. Particles in the disk accrete to form planetesimals (like chondritic meteorites), and finally protoplanets.

Classroom Use:

1. This video is well-suited for an engaging start to a lecture, a break in lecture for students to switch gears for a short time, a summary of our Solar System formation processes, or as a wrap-up.
2. After showing the video, ask students to draw a sketch or write a description of our Solar System at three different stages of formation: nebula, protoplanetary disk, and present day. Have students focus on comparing and contrasting the distribution of volatile and refractory materials, the dominant processes occurring, and the types of bodies present (proto-Sun, planetesimals, etc.) in each stage.
3. Challenge students to pick just five words or phrases to summarize what happened during Solar System formation (e.g., "gravitational pull, nuclear fusion, solar wind, accretion, planetesimals"). This also works great as a Think-Pair-Share activity.

Review and Discussion Questions:

1. What are some characteristics of volatile and refractory materials?
2. Compare and contrast a nebula and a protoplanetary disk.

FORMATION OF THE EARTH

Learning Objectives Covered:

- 1E. explain the nebular theory, a scientific model that explains how stars and planets form.

Length: 2:30

Summary: This video includes a description of the changes that occurred as the proto-Earth transformed into the Earth. Volatile elements were excluded, gravity transformed the lumpy protoplanet into a sphere, and differentiation resulted in iron accumulating at the center and rocky material convecting in the mantle. Meteorites bombarded the surface until the region was swept clean of all other material, at which point the Earth became a true planet. Cooling created a solid crust. A catastrophic impact remelted the crust, and debris from that impact eventually formed the moon. Volcanic gases created the atmosphere; atmospheric oxygen condensed into oceans but the atmosphere remained oxygen-free until the evolution of photosynthesis.

Classroom Use:

1. This video is well-suited for an engaging start to a lecture, a break in lecture for students to switch gears for a short time, a summary of the transformations of the early Earth, or as a wrap-up.

Discussion Questions:

1. Why do smaller protoplanets have irregular, lumpy shapes while planets are spherical?
2. Describe the interior of the Earth before and after differentiation.

Real-World Videos

THE FAINT YOUNG STAR PARADOX: SOLAR STORMS MAY HAVE BEEN KEY TO LIFE ON EARTH

Learning Objectives Covered:

- 1E. explain the nebular theory, a scientific model that explains how stars and planets form.

Length: 1:29

Summary: The early Earth was warm enough to support life because of a balance between the weaker Sun and a strong greenhouse effect in our atmosphere. The young Sun produced less heat, but more frequent solar flares. The young Earth's less-developed magnetosphere allowed solar particles from these flares to interact with the atmosphere and create nitrous oxide, a powerful greenhouse gas.

Classroom Use:

1. Introduce the idea of a faint young Sun, and ask students to pose some hypotheses that might explain why Earth was warm enough to sustain life despite receiving significantly less solar radiation. How might they test their hypotheses? Next, show the video. Engage students in a discussion comparing their hypotheses to the commonly accepted idea of nitrous oxide acting as a greenhouse gas.

Adaptations:

- Students can think-pair-share their hypotheses.
- Include discussion of challenges associated with testing hypotheses about past conditions, and the utility of computer models.

Review and Discussion Questions:

1. When it first formed billions of years ago, how did the Sun differ from today's Sun?
2. Explain some of the ways in which the Earth's atmosphere has changed over time.
3. How did the early Sun contribute to changing the composition of Earth's early atmosphere?

Credit: NASA's Goddard Space Flight Center; music credit: Ocean Travel by Laurent Dury from the KillerTracks Catalog.

HOW PLANETS ARE BORN

Learning Objectives Covered:

- 1E. explain the nebular theory, a scientific model that explains how stars and planets form.

Length: 0:38

Summary: This animation condenses billions of years into a little over half a minute to illustrate the nebular theory of Solar System formation. Initially, diffuse material spins around a young star. The material gradually accretes into wide bands of material, then planetesimals, protoplanets and, eventually, discrete planets.

Classroom Use:

1. Use this animation as a visual aid to enhance a description of the nebular theory.
2. Ask students to create a narration to go along with the video. Either provide a link to the video through the Digital Landing Page or your campus Learning Management System (if devices are available in the classroom) or project the video on a loop. Give students 5–10 minutes to write a narration. You may want to offer some hints. For example, break the video down into three or four main ideas and describe what is happening in each; every time the image changes, describe what you are seeing; trim down your language so that you can say everything you need to in 30 seconds; for each statement, ask yourself "Is it important to understand this idea, or is it extra?" Once all groups have written a narration, you could collect the "scripts," have them share with one other group, or have a few groups present to the class.
3. Pause the video at a 10, 20, and 30 seconds and have students create a quick labeled sketch of what they observe.

Discussion Questions:

1. How does the nebular theory explain the structure and elements of our Solar System, such as the type and distribution of planets and the location of icy comets?
2. Why is the nebular theory difficult to test directly?

Credit: NASA

Activities

THE HUBBLE DEEP FIELD ACADEMY

Learning Objectives Covered:

- 1B. explain modern concepts concerning the basic architecture of our Universe and its components.

Activity Type: Quantitative Data Analysis

Time in Class Estimate: 30 minutes

Recommended Group Size: 1–2 students

Materials: Internet access

Classroom Procedures: Assign each student or group of students a role: stellar statistician, cosmic classifier, or distance wizard. Have students access the Hubble Deep Field Academy (http://deepfield.amazingspace.org), complete the "orientation" section, and then record their observations and answers while working on their "level." Meanwhile, provide space on the board (or in a discussion board on for online classes) for each group to report their calculations: stellar statisticians record the estimated number of objects in the universe, cosmic classifiers record the shapes of objects, distance wizards record objects in order of distance. Once all students or groups have reported their observations, discuss the variation in reported data and its relationship to the astronomer's results (reported on the website). Finally, ask all students to become deep-field observers and attempt to identify the mystery object. Ask students to find other groups of students from the same level and compare answers.

Adaptations:

- Have students complete all three "levels" (instead of just one) and compare conclusions.
- The activity could be completed individually as homework to prepare for in-class discussion about the types of galaxies and overall structure of the Universe.

- This is a good opportunity to introduce the idea of composite datasets.

Reflection Questions: What are some questions astronomers are trying to answer by studying the Hubble Deep Field? What questions would you like to answer? Why do astronomers conduct surveys? Do you think they are useful? How “deep” can these surveys eventually go? Is there a limit? Could this help our understanding of black holes? How?

IMAGINE NUCLEOSYNTHESIS

Learning Objectives Covered:

- 1D. describe where the elements that make up matter came from.

Activity Type: Imagine Yourself . . .

Time in Class Estimate: 15–45 minutes (depending on degree of detail)

Recommended Group Size: Individual plus whole-group sharing

Materials: None

Classroom Procedures: Ask students to imagine themselves as a hydrogen atom that was just created in the Big Bang. Have students write a detailed description of what happens to them as they are transformed in stars and eventually end up as part of the Earth in the present day. After some period of writing time (determined by the degree of detail you expect), students can exchange stories with other students and compare or post their stories to discussion boards for an online class.

Adaptations:

- Assign the writing portion as homework and ask students to share at the beginning of class.
- Ask students to include illustrations of what is happening.
- Go over the main stages of stellar nucleosynthesis as a class, then break students up into small groups and have each group describe one phase in detail.

Reflection Questions: How were nebulae in the early Universe different from those found today? Where did the atoms that make up your body originate?

THINK-PAIR-SHARE QUESTIONS

Classroom Procedures: Ask students to silently reflect on the question (and, optionally, write down an answer). Questions could be integrated into PowerPoint slides, asked verbally, or posted in discussion boards for online classes. After about a minute of reflection, cue students to share their thoughts with one or two people near them (or in assigned groups in online classes). After a minute or two of small-group discussion, ask students to report answers to the class—ask for volunteers, call on whole groups, or have groups submit consensus posts on a discussion board.

Questions/Answers:

1. Is There Life Out There?

   Do you think life exists elsewhere in the Universe? What conditions would be necessary for life as we know it to exist elsewhere?

   ANS: While we do not have a definitive answer to this question yet, we do know that certain features are necessary for life as we currently understand it. These features include the presence of liquid water, the existence of a hospitable atmosphere, and a planet that is the right distance from a right-sized star so that the intensity of stellar radiation is sufficient to sustain life but not so high that it destroys life. The Earth is in a unique "Goldilocks" position in our Solar System.

   Learning Objectives Covered:

   - 1A. assess how people's perceptions of the Earth's place in the Universe have changed over the centuries.

2. Picturing the Big Bang

   Imagine we have the ability to watch the first moments of the formation of the Universe. Describe your observations from an astronomer's perspective.

   ANS: Answers will vary. About 13.8 billion years ago, all the matter and energy in the Universe was located in a singularity, a single point in space with an indescribably high temperature and density. The Universe came into being when this singularity exploded and began to expand, an event called the Big Bang. Why the singularity exploded is still unknown and the topic of much speculation. Just after the Big Bang, the Universe was made up only of energy, but minutes later matter formed as the Universe cooled. In the beginning, the Universe was dark, since all of its matter was scattered throughout diffuse nebulae. However, the first stars had formed by the time the Universe was 400 million years old, shining the first rays of light into the Universe.

   Learning Objectives Covered:

- 1B. explain modern concepts concerning the basic architecture of our Universe and its components.
- 1C. assess the evidence for the expanding Universe and the Big Bang theory.
- 1D. describe where the elements that make up matter came from.

Answers to Review Questions

1. Contrast the geocentric and heliocentric Universe concepts.

ANS: The geocentric concept, popularized by Ptolemy and European church leaders, placed Earth at the center of the Universe with the Sun and the other planets revolving around it. The heliocentric concept, described by Copernicus, Galileo, Kepler, and Newton, placed the Sun at the center with Earth and the other planets revolving around it.

BLOOM'S LEVEL: Understanding

LEARNING OBJECTIVES COVERED:

- 1A. assess how people's perceptions of the Earth's place in the Universe have changed over the centuries.

2. Describe how Foucault's pendulum demonstrates that Earth rotates on its axis.

ANS: Foucault used a heavy pendulum and the application of Newton's first law to observe the surface of the Earth rotating underneath the swinging pendulum. Foucault noticed that over time, the swing path of the pendulum appeared to rotate about a vertical axis. According to the property of inertia, a swinging pendulum will maintain its swinging plane unless a new force is added. Foucault concluded that Earth must be rotating in order for the plane to appear to change in this manner.

BLOOM'S LEVEL: Understanding

LEARNING OBJECTIVES COVERED:

- 1A. assess how people's perceptions of the Earth's place in the Universe have changed over the centuries.

3. How did Eratosthenes calculate the Earth's circumference?

ANS: Eratosthenes knew that when the Sun's rays were directly overhead at the town of

Syene, they were seven degrees from vertical in Alexandria, a city due north of Syene. He assumed that the Earth is a sphere and measured the distance between the two cities to calculate (using the equation in **Figure 1.8**) a circumference of about 40,000 km—extremely close to correct.

BLOOM'S LEVEL: Understanding

LEARNING OBJECTIVES COVERED:

- 1A. assess how people's perceptions of the Earth's place in the Universe have changed over the centuries.

4. Why do planets appear to move with respect to stars?

ANS: Stars are so relatively distant that they appear fixed with respect to one another as viewed from Earth. As Earth and the other planets traverse through their orbits around the Sun, the positions of the planets vary with respect to the "fixed" celestial sphere.

BLOOM'S LEVEL: Understanding

LEARNING OBJECTIVES COVERED:

- 1B. explain modern concepts concerning the basic architecture of our Universe and its components.

5. Imagine you hear the main characters in a low-budget science-fiction movie say that they will "return 10 light-years from now." What's wrong with their use of the term?

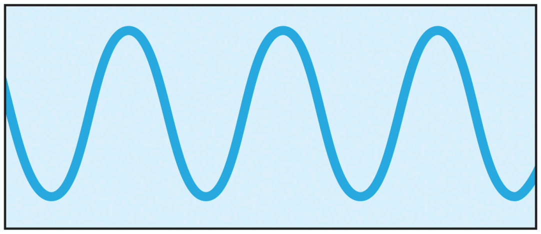
ANS: Light-years are a measure of distance (not time), specifically the distance light travels through a vacuum in one year. There are approximately 3.26 light-years in a parsec.

BLOOM'S LEVEL: Analyzing

LEARNING OBJECTIVES COVERED:

- 1B. explain modern concepts concerning the basic architecture of our Universe and its components.

6. Describe how the Doppler effect works. If the light you see from a distant galaxy has undergone a blue shift, is the galaxy traveling toward or away from you?



ANS: Sound and light waves emanating from an approaching source arrive at a higher frequency than they would if the object were stationary. This frequency shift arises because each successive sound wave is emanated from a closer distance than was the previous wave (see text **Fig. 1.9b**). Our brains interpret these high frequencies (after transmission through our ears) as a higher pitch. Once a wave source passes an observer, its sound waves have a reduced frequency, as each wave is emitted from a slightly more distant point. A blue shift in the light from a distant galaxy indicates that the light waves are being squeezed together into a shorter wavelength, which means the galaxy is moving toward us.

BLOOM'S LEVEL: Applying

LEARNING OBJECTIVES COVERED:

- 1C. assess the evidence for the expanding Universe and the Big Bang theory.

7. What does the red shift of the galaxies tell us about their motion with respect to the Earth?

ANS: All distant galaxies are moving away from our own, with the farthest galaxies moving the fastest.

BLOOM'S LEVEL: Applying

LEARNING OBJECTIVES COVERED:

- 1C. assess the evidence for the expanding Universe and the Big Bang theory.

8. What is the Big Bang, and when do astronomers conclude it occurred?

ANS: The Big Bang is the specific point in time at which all matter and energy began expanding from an infinitely small point. This was the beginning of our Universe, 13.7 billion years ago.

BLOOM'S LEVEL: Remembering

LEARNING OBJECTIVES COVERED:

- 1C. assess the evidence for the expanding Universe and the Big Bang theory.

9. When did hydrogen and helium atoms form?

ANS: Hydrogen and helium atoms formed during the cooling that occurred in the first few minutes after the Big Bang.

BLOOM'S LEVEL: Remembering

LEARNING OBJECTIVES COVERED:

- 1D. describe where the elements that make up matter came from.

10. This image shows a nebula formed by a supernova explosion. Would it contain heavier elements?

ANS: Yes. Nuclear fusion reactions inside stars generate all heavy elements, and these elements are distributed in nebulae across the Universe by supernova explosions.

BLOOM'S LEVEL: Applying

LEARNING OBJECTIVE(S) COVERED:

- 1B. explain modern concepts concerning the basic architecture of our Universe and its components.

11. Describe the steps in the formation of the Solar System according to the nebular theory.

ANS: (1) A swirling cloud of gas and dust called a nebula began to condense due to gravity. (2) At the center of the rotating nebula, most of the mass condensed to form a protostar, which became the Sun when it gained enough mass—and thus temperature—to fuse hydrogen into helium. (3) Light gases and other volatiles were ejected from the inner portion of the flat protoplanetary disk as the Sun's heat intensified. (4) Planets arose from gravity-driven accretion and the collisions of smaller planetesimals and protoplanets. Because of the lack of volatiles in the center of the disk, the inner terrestrial planets are made of relatively high-density refractory substances (rock and metal). Farther out, the gas-giant planets incorporated abundant volatiles, such as hydrogen and helium; therefore, they are much more massive but less dense than the terrestrial planets.

BLOOM'S LEVEL: Understanding

LEARNING OBJECTIVES COVERED:

- 1E. explain the nebular theory, a scientific model that explains how stars and planets form.

12. Describe a process that may have produced the Moon.

ANS: The Moon formed when a planetesimal or small protoplanet collided with Earth early in the history of the Solar System. The impact ejected material similar in composition to Earth's mantle, which coalesced around the Earth where it cooled and solidified, resulting in our Moon.

BLOOM'S LEVEL: Understanding

LEARNING OBJECTIVES COVERED:

- 1E. explain the nebular theory, a scientific model that explains how stars and planets form.

13. Why did the Earth differentiate into layers?

ANS: Heat (from collisions, compression, and radioactive decay) caused material in the middle of the planet to melt. Once molten, material was able to move freely and gravity pulled denser material (such as iron) to the center. Lighter silicate minerals surrounded the denser material. This resulted in Earth's differentiated layers: an iron core surrounded by rocky layers of decreasing density.

BLOOM'S LEVEL: Remembering

LEARNING OBJECTIVES COVERED:

- 1E. explain the nebular theory, a scientific model that explains how stars and planets form.

14. Why is the Earth round?

ANS: Gravity forces objects the size of Earth to be nearly spherical (the most compact shape, minimizing the distance of points from the center). Smaller planetesimals remain irregularly shaped because they are too small to have mobile, molten interiors.

BLOOM'S LEVEL: Understanding

LEARNING OBJECTIVES COVERED:

- 1E. explain the nebular theory, a scientific model that explains how stars and planets form.

On Further Thought

15. Could a planet with a composition similar to that of the Earth have formed around a first-generation star? Explain your answer.

ANS: No. The Earth contains many heavy elements that were not present in the Universe during this first generation of stars. Our Sun is likely a third-generation (or higher) star, so many of the elements found in our Solar System would not be present in a first-generation star.

BLOOM'S LEVEL: Evaluating

LEARNING OBJECTIVES COVERED:

- 1E. explain the nebular theory, a scientific model that explains how stars and planets form.

16. Astronomers discovered that distant galaxies move away from Earth more rapidly than do nearby ones. To see why, make a model of the problem by drawing three equally spaced dots along a cut rubber band. The dot at one end represents the Earth, and the other two dots represent galaxies. Stretch the rubber band to twice its length. This stretching represents Universe expansion. Pretend that it took 1 second to stretch the line (so Time = 1 second). Calculate the velocities of the two galaxies, using the equation: Velocity = Distance ÷ Time.

ANS: All galaxies have been moving away from the same point for the same amount of time. Therefore, those that are farthest away must be traveling at the highest velocity.

BLOOM'S LEVEL: Applying

LEARNING OBJECTIVES COVERED:

- 1C. assess the evidence for the expanding Universe and the Big Bang theory.

17. Why do all planets orbit the Sun in roughly the same plane?

ANS: The planets all orbit the Sun in roughly the same plane because they all formed from a rotating disk of material known as a protoplanetary disk.

BLOOM'S LEVEL: Understanding

LEARNING OBJECTIVE(S) COVERED:

- 1E. explain the nebular theory, a scientific model that explains how stars and planets form.

CHAPTER 2

Journey to the Center of the Earth

Learning Objectives

By the end of this chapter, you should be able to . . .

A. describe the objects besides the Sun and planets that make up the Solar System.
B. describe the nature of the magnetic field and atmosphere that surround our planet.
C. list the distinct interacting realms within the Earth System.
D. distinguish the internal layers (crust, mantle, and core) of the Earth.
E. explain the relationship between the lithosphere and the asthenosphere.

Summary from the Text

- A traverse from interstellar space into the Solar System passes through the Oort Cloud and crosses the edge of the heliosphere.
- Inside the heliosphere lies the Kuiper Belt, the outer planets, the asteroid belt, and the inner planets.
- A magnetic field surrounds the Earth. The field shields it from solar wind. Closer to the Earth, the field produces the Van Allen belts, which also trap cosmic rays.
- A layer of gas, the atmosphere, surrounds the Earth. Air in the atmosphere consists of 78% nitrogen, 21% oxygen, and 1% other gases. Air pressure decreases with elevation, so 99% of the gas in the atmosphere resides below 50 km.
- The surface of the Earth can be divided into land (30%) and ocean (70%). Most of the land surface lies within 1 km of sea level, and most of the seafloor is at a depth of 4 to 5 km. The land surface and the seafloor display great variation in elevation and depth, respectively.
- Earth materials include organic chemicals, minerals, glasses, rocks (igneous, metamorphic, and sedimentary), grains, sediment, metals, melts, and volatiles. Most rocks on the Earth

contain silica (SiO_2), so they are called silicate rocks. Felsic, intermediate, mafic, and ultramafic igneous rocks have different densities.

- The Earth's interior can be divided into three compositionally distinct layers: the crust, the mantle, and the core. The first recognition of this division came from studying the density and shape of the Earth. The image has been refined by studying seismic waves.
- Pressure and temperature both increase with depth in the Earth. The rate of increase in temperature with depth is the geothermal gradient.
- Studies of seismic waves reveal the existence of the liquid outer core and the solid inner core. The mantle can be divided into the upper mantle and the lower mantle.
- The crust varies in thickness from 7–10 km (beneath oceans) to 25–70 km (beneath continents). Oceanic crust has a mafic composition, whereas average upper continental crust has a felsic to intermediate composition. The mantle consists of ultramafic rock, and the core of iron alloy. Flow in the outer core generates the magnetic field.
- The crust plus the upper part of the mantle constitute the lithosphere, a relatively rigid shell up to 150 km thick. The lithosphere lies over the asthenosphere, mantle that can flow plastically and, therefore, can convect.

Real-World Videos

RESEARCHERS DISCOVER THE EARTH'S INNER-INNER CORE

Learning Objectives Covered:

- 2D. distinguish the internal layers (crust, mantle, and core) of the Earth.

Length: First 1:01 minutes of video (of 3:58 total)

Summary: The study of residual energy following an earthquake has revealed that the inner core is actually divided into two distinct layers—iron crystals in the inner portion of the inner core are aligned differently than crystals in the outer portion of the inner core. This may lend insight into the formation and evolution of the Earth.

Classroom Use:

1. This video is a complement to a larger discussion about the ongoing nature of scientific discovery. It is a great example of the way in which scientists continue to learn new things about long-held knowledge.

Discussion Questions:

1. How does the Earth's inner core differ from the outer core?
2. What data do we use to understand the characteristics of the Earth's inner layers?
3. Why do you think seismic waves might behave differently in the layers where iron crystals are aligned differently?

Credit: National Science Foundation

Activities

SCALING THE EARTH'S INTERIOR

Learning Objectives Covered:

- 2D. distinguish the internal layers (crust, mantle and core) of the Earth.
- 2E. explain the relationship between the lithosphere and asthenosphere

Activity Type: Model

Time in Class Estimate: 10–30 minutes (depending on the extent of the discussion)

Recommended Group Size: 1–2 students

Materials: Meter-long strips of paper (from a roll of adding machine paper, scraps of plotter paper, or 8 ½ x 11 paper cut and taped), colored pencils

Classroom Procedures: For this activity, students will create a scale drawing of the interior layers of the Earth. The radius of the Earth—6,371 km from the surface to the center of the core—is scaled to a single meter. The top edge of the meter-long strip of paper represents the surface of the Earth, and the bottom edge represents the center of the core. Have students mark boundaries between the interior layers using the following measurements, and label and describe each layer in detail:

Feature	Measurement from Top Edge of Paper
Base of oceanic crust	1 mm (0.1 cm)
Base of continental crust	1.00 cm
Base of lithosphere	2.50 cm
Start of the transition zone	6.50 cm
Upper/lower mantle boundary	10.25 cm
Mantle/outer core boundary	45.25 cm
Outer/inner core boundary	81.00 cm

Adaptations:

- This could also be done (as an entire class) on a kilometer scale instead of a meter scale, if sufficient space is available on campus—a quad, stadium, or other large open space. The scale above would be increased by a factor of one thousand in order to scale to kilometers. For example, the bottom of the oceanic crust would be at 1 m. It can be useful to use an average stride as an approximation for a meter.
- A meter stick marked with sticky notes, rubber bands, or push pins can be used instead of paper.

Reflection Questions: If we consider the entire volume of the Earth—not just the surface—what is the most abundant layer? What is this layer made of? Do you think you could draw a scaled representation of the Earth's interior on a standard 8 ½ x 11 sheet of paper? Why or why not? The deepest ocean trench (the Mariana Trench in the western Pacific Ocean) is over 12 km deep. Can you add this trench to your drawing? The deepest mine in the world (a gold mine in South Africa) is slightly less than 4 km deep. How does this compare to the thickness of the crust? Can you add the mine to your drawing? The deepest hole ever drilled (the Kula Superdeep Borehole in Russia) is over 12 km deep. How does this compare to the thickness of the crust? Can you add the borehole to your drawing?

THINK-PAIR-SHARE QUESTIONS

Classroom Procedures: Ask students to silently reflect on the question (and, optionally, write down an answer). Questions could be integrated into PowerPoint slides, asked verbally, or posted in discussion boards for online classes. After about a minute of reflection, cue students to share their thoughts with one or two people near them (or in assigned groups in online classes). After a minute or two of small-group discussion, ask students to report answers to the class—ask for volunteers, call on whole groups, or have groups submit consensus posts on a discussion board.

Questions/Answers:

1. Everyday Geologic Materials

   What types of geosphere materials do you interact with on a daily basis? How?

   ANS: Students will have a variety of responses. Examples include rocks, minerals, sediment, soils, "dirt," sand, silt, mud, and so forth.

   Learning Objectives Covered:

   - 2C. list the distinct interacting realms within the Earth System.

2. Alien Earth

   Imagine that an alien society is viewing the Earth using a sophisticated telescope from a great distance. What would they see?

   ANS: The most predominant feature of Earth is the liquid water-covered surface, and the oxygen-rich atmosphere. An alien view of Earth from afar would likely include a water-covered surface, clouds swirling in the atmosphere, and possibly the presence of plant life on the land. They would see that the surface topography is diverse and varied. It is also possible that aliens would observe human impacts such as light from large cities, deforestation, and space junk. Depending on the alien's capabilities to detect information other than visible light, they might notice the Earth's magnetosphere, the presence of abundant oxygen in the atmosphere, or the dynamic internal structure.

   Learning Objectives Covered:

   - 2C. list the distinct interacting realms within the Earth System.

3. Earth's Hydrosphere

   We know that about 70% of the Earth's surface is covered by water. Why then do we so frequently hear of drought being an issue?

ANS: Only 3% of the hydrosphere is fresh water, and of that only a small proportion (less than 1%) is readily available for consumption, mainly occurring as groundwater.

Learning Objectives Covered:

- 2C. list the distinct interacting realms within the Earth System.

Answers to Review Questions

1. What occupies the space between planets?

ANS: Interplanetary space is a vacuum with an extremely low concentration of atoms (5,000–100,000/liter). This is significantly more dense than interstellar space (less than 1 atom/liter).

BLOOM'S LEVEL: Remembering

LEARNING OBJECTIVES COVERED:

- 2A. describe the objects besides the Sun and planets that make up the Solar System.

2. Name the features that a spacecraft traversing the Solar System and its surroundings would encounter.

ANS: From the vacuum of interstellar space, a spacecraft would begin to detect the Sun's gravity at a distance of approximately 50,000 AU before entering the Oort Cloud (a region of diffuse icy bodies) at 3,500 AU. At 200 AU from the Sun, the spacecraft would detect mostly solar-wind particles within the heliosphere. Next, the spacecraft would pass by the icy bodies of the Kuiper Belt between 55 and 30 AU. Finally, the spacecraft would pass the ice- and gas-giant planets (Neptune, Uranus, Saturn, Jupiter), the asteroid belt, the terrestrial planets (Mars, Earth, Venus, Mercury), and finally the Sun.

BLOOM'S LEVEL: Remembering

LEARNING OBJECTIVES COVERED:

- 2A. describe the objects besides the Sun and planets that make up the Solar System.

3. What is the Earth's magnetic field? Draw a representation of the field on a piece of paper.

ANS: The magnetic field of Earth is a region of space affected by the dipolar magnetic force of Earth (see **Fig. 2.3c** for a sketch).

BLOOM'S LEVEL: Remembering

LEARNING OBJECTIVES COVERED:

- 2B. describe the nature of the magnetic field and atmosphere that surround our planet.

4. How does the magnetic field interact with solar wind and cosmic rays?

ANS: The magnetic field protects Earth from solar wind. Charged particles from solar wind are deflected by Earth's magnetic field and travel along field lines, accumulating in relatively great density in two regions known as Van Allen belts. Some of these particles are channeled toward the North Pole or South Pole by the field lines and interact with gases in the upper atmosphere to produce the aurorae.

BLOOM'S LEVEL: Understanding

LEARNING OBJECTIVES COVERED:

- 2B. describe the nature of the magnetic field and atmosphere that surround our planet.

5. What does the Earth's atmosphere consist of? Why would you die of suffocation if you were to parachute from an airplane at an elevation of 12 km?

ANS: Earth's atmosphere is mostly nitrogen (78.08%) and oxygen (20.95%) with minor amounts of argon, carbon dioxide, and other gases. The density of the atmosphere decreases with altitude; at 12 km, oxygen molecules are too sparse to support human life.

BLOOM'S LEVEL: Remembering and Applying

LEARNING OBJECTIVES COVERED:

- 2B. describe the nature of the magnetic field and atmosphere that surround our planet.

6. What is the proportion of land area to sea area? What is the average elevation of continents? Of seafloor?

ANS: The surface of the Earth is approximately 30% land (mostly less than 1 km in elevation), and 70% sea (average depth 4–5 km). The highest point on land is 8.9 km above sea level (Mt. Everest) and the lowest land elevation is 0.4 km below sea level (the Dead Sea). Deep ocean trenches are nearly 11 km deep. (**Fig. 2.7**).

BLOOM'S LEVEL: Remembering

LEARNING OBJECTIVES COVERED:

- 2C. list the distinct interacting realms within the Earth System.

7. What are the two most abundant elements in the Earth? Describe the major categories of materials constituting Earth.

ANS: Iron and oxygen are the two most abundant chemical elements within the Earth. Categories of materials include organic chemicals, which make up the majority of living matter. These carbon- and hydrogen-based compounds (including oil and natural gas) can be quite complex, sometimes incorporating oxygen (as in sugars, starches, and fats), sometimes nitrogen (as in proteins), and occasionally some phosphorus and sulfur. Minerals are solid, inorganic materials in which there is a fixed arrangement of atoms (often termed a crystalline lattice). Quartz and calcite are important, familiar examples. Mineral crystals are commonly weathered to produce fragments with rough or rounded surfaces, which are termed grains. Glasses are physically solid structures in which the atoms are internally disordered (as in liquids, but without the tendency to rapidly flow). Commercial glass is produced when quartz is melted and then cooled rapidly (quenched in cool water), so that atoms cannot align themselves into the quartz crystalline arrangement before the rigidity of cooling sets in. Rocks are cohesive aggregates of crystals or grains. Igneous rocks crystallize from molten (liquid) rock. Sedimentary rocks arise from the cementation of loose grains (sand, mud, pebbles, etc.) and through chemical precipitation (from the ocean or continental bodies of water). Metamorphic rocks arise from heat- and pressure-induced alteration of preexistent rock (without melting). Grains are crystals within rock or loose fragments of crystals. Sediments are loose accumulations of mineral grains. Metals are solids made up of metallic elements only (to a strong approximation), such as gold, iron, and copper. (Naturally occurring metals are a subset of minerals.) Melts are hot liquids that crystallize at surface temperatures to form igneous rocks. Melts within Earth are termed magma; melts extruded on the surface are termed lava. Volatiles are substances with a low boiling point that are stable in a gaseous state at relatively low temperatures at or near the Earth’s surface.

BLOOM’S LEVEL: Remembering

LEARNING OBJECTIVES COVERED:

- 2C. list the distinct interacting realms within the Earth System.

8. What are silicate rocks? Give examples of such rocks, and explain how they differ from one

another.

ANS: Silicate rocks are rocks made of up silicate minerals—containing silica plus oxygen. Igneous silicate rocks are classified based on the ratio of felsic to mafic minerals that they contain. Felsic rocks contain the most silica, then intermediate, mafic, and ultramafic with the least silica. Granite is a felsic rock (made of silicate minerals rich in silica, aluminum, and potassium). Gabbro and basalt are both mafic (mostly iron- and magnesium-rich silicate minerals). Peridotite is ultramafic (richer in iron and magnesium than the mafic rocks, and mostly consisting of olivine and pyroxene).

BLOOM'S LEVEL: Remembering

LEARNING OBJECTIVES COVERED:

- 2C. list the distinct interacting realms within the Earth System.

9. How did researchers first obtain a realistic estimate of the Earth's average density? What observations led to the realization that the Earth must be largely solid and that a particularly dense core lies at its center?

ANS: Maskelyne determined an estimate of the density of the Earth (4.5 gm/cm^3) by measuring the deflection of a plumb bob caused by a nearby mountain. Because this number is much higher than the measured density of rocks at the Earth's surface (approximately 3gm/cm^3), it was assumed that Earth's interior must be denser than that of surface rocks. The Earth does not exhibit dramatic changes in elevation due to tides, so the interior must be largely solid. Variation in surface elevation is evidence of a largely solid interior. Because the Earth is roughly spherical, not flattened along the equator like a disk, we assume that there is a great concentration of mass at the center.

BLOOM'S LEVEL: Understanding

LEARNING OBJECTIVES COVERED:

- 2C. list the distinct interacting realms within the Earth System.

10. What are seismic waves? Does their velocity change as they pass through the Earth?

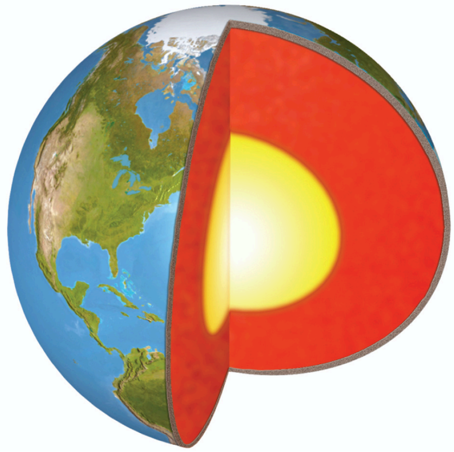
ANS: Seismic waves are vibrational waves that pass through Earth and are caused by the release of stress during an earthquake along a fault in Earth. The velocity of these waves is different in different materials, so sudden changes in velocity indicate a boundary between layers inside the Earth.

BLOOM'S LEVEL: Understanding

LEARNING OBJECTIVES COVERED:

- 2D. distinguish the internal layers (crust, mantle, and core) of the Earth.

11. Identify the principal layers of Earth in the figure.



ANS: The major layers of the Earth are the crust, mantle, and core.

BLOOM'S LEVEL: Applying

LEARNING OBJECTIVES COVERED:

- 2D. distinguish the internal layers (crust, mantle, and core) of the Earth.

12. How do temperature and pressure change with depth in the Earth?

ANS: Both temperature and pressure increase with increasing depth. The rate of temperature increase, which varies somewhat, is termed the geothermal gradient. The geothermal gradient is greatest (15–30 degrees Celsius per kilometer) in the upper crust and declines (to about 10 degrees Celsius per kilometer) at greater depths.

BLOOM'S LEVEL: Remembering

LEARNING OBJECTIVES COVERED:

- 2D. distinguish the internal layers (crust, mantle, and core) of the Earth.

13. What is the Moho? How was it first recognized? Describe the differences between continental and oceanic crust.

ANS: The Moho is the crust–mantle boundary, first recognized by Mohorovičić as an abrupt change in seismic-wave velocities. Oceanic crust, made of basalt and gabbro, is thinner (7–10 km). The thicker (25–70 km) continental crust is made of a variety of different rock types, and, overall, is less dense than oceanic crust.

BLOOM'S LEVEL: Remembering

LEARNING OBJECTIVES COVERED:

- 2D. distinguish the internal layers (crust, mantle, and core) of the Earth.

14. What material makes up the mantle? What are the sublayers of the mantle? Does melt exist within the mantle?

ANS: The mantle is made of an ultramafic silicate rock known as peridotite. The mantle is divided into layers based on abrupt changes in seismic wave velocity: the upper mantle, transition zone, and lower mantle. A very small portion of the upper mantle is molten, but the mantle is largely solid.

BLOOM'S LEVEL: Remembering

LEARNING OBJECTIVES COVERED:

- 2D. distinguish the internal layers (crust, mantle, and core) of the Earth.

15. What is the core composed of? How do the inner core and outer core differ from each other? How can we obtain samples of materials that resemble those of the core?

ANS: The core is mostly iron mixed with nickel and small amounts of sulfur, oxygen, silicon, and other elements. The inner core is solid, whereas the outer core is liquid. Iron meteorites are probably similar in composition to the Earth's core.

BLOOM'S LEVEL: Remembering

LEARNING OBJECTIVES COVERED:

- 2D. distinguish the internal layers (crust, mantle, and core) of the Earth.

16. What is the difference between a meteor and a meteorite? Are all meteorites composed of the same material?

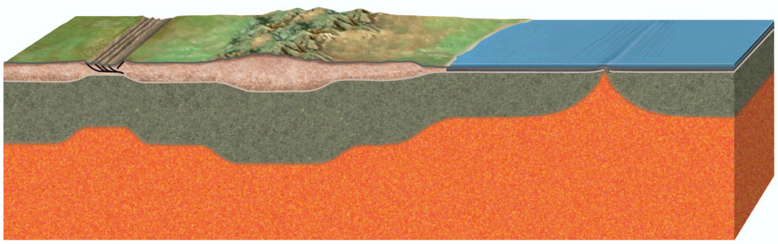
ANS: A meteor is an object from space that enters Earth's atmosphere and starts to evaporate due to friction with the atmosphere, to produce a glowing streak. Meteors that do not completely vaporize in the atmosphere impact Earth and are termed meteorites. Meteorites may be rocky or metallic or a combination of the two.

BLOOM'S LEVEL: Remembering

LEARNING OBJECTIVES COVERED:

- 2A. describe the objects besides the Sun and planets that make up the Solar System.

17. What is the difference between lithosphere and asthenosphere? Identify the layers and the Moho on the figure. At what depth does the lithosphere–asthenosphere boundary occur?



ANS: The lithosphere is the relatively cool and rigid outer layer of the Earth, made up of the crust and upper mantle. The underlying asthenosphere is hot and plastic; it flows and undergoes convection. The boundary between the lithosphere and asthenosphere occurs between 100 and 150 kilometers of depth.

BLOOM'S LEVEL: Remembering

LEARNING OBJECTIVES COVERED:

- 2E. explain the relationship between the lithosphere and the asthenosphere.

On Further Thought

18. Recent observations suggest that the Moon has a very small, solid core that is less than 3% of its mass. In comparison, the Earth's core is about 33% of its mass. Explain why this difference might exist. (Hint: Recall the model for Moon formation that we presented in Chapter 1.)

ANS: The Moon is thought to have formed when a Mars-sized body collided with Earth early in its history. The impact hurled a portion of Earth, mostly mantle material with no contribution from the core, into orbit about our Earth, where it solidified to form our Moon. The moon differentiated (as the Earth had earlier) but with a minute amount of iron compared to the

Earth (which had already seen most of its iron descend into its larger core).

BLOOM’S LEVEL: Analyzing

LEARNING OBJECTIVES COVERED:

- 2D. distinguish the internal layers (crust, mantle, and core) of the Earth.

19. Popular media sometimes imply that the crust floats on a “sea of magma.” Is this a correct image?

ANS: No, the plates that are often depicted as “floating” are made of the crust and the rigid mantle just beneath the crust—together known as the lithosphere. These lithospheric plates move around on the underlying asthenosphere, which is ductile but not liquid.

BLOOM’S LEVEL: Evaluating

LEARNING OBJECTIVES COVERED:

- 2D. distinguish the internal layers (crust, mantle, and core) of the Earth.
- 2E. explain the relationship between the lithosphere and the asthenosphere.

CHAPTER 3

Drifting Continents and Spreading Seas

Learning Objectives

By the end of this chapter, you should be able to . . .

A. explain the premise of the continental-drift hypothesis proposed by Alfred Wegener.
B. identify the observations that Wegener used to show that continental drift took place.
C. list the key observations from the study of the seafloor that led Harry Hess to propose seafloor spreading.
D. explain how studies of paleomagnetism later proved that continents indeed move relative to one another.
E. describe some observations that can be used to prove that seafloor spreading happens.

Summary from the Text

- Alfred Wegener proposed that continents had once been joined together to form a single huge supercontinent (Pangaea) and had subsequently drifted apart. This idea is the continental-drift hypothesis.
- Wegener drew from several different sources of data to support his hypothesis: (1) coastlines on opposite sides of the ocean match up; (2) the distribution of late Paleozoic glaciers can be explained if the glaciers made up a polar ice cap over the southern end of Pangaea; (3) the distribution of late Paleozoic equatorial climatic belts is compatible with the concept of Pangaea; (4) the distribution of fossil species suggests the existence of a supercontinent; (5) distinctive rock assemblages that are now on opposite sides of the ocean were adjacent on Pangaea.
- Despite all the observations that supported continental drift, most geologists did not initially accept the idea because no one could explain how continents could move. It took decades of new data collection before the idea could be reconsidered.

- Rocks retain a record of the Earth's magnetic field as it existed at the time the rocks formed. This record is called paleomagnetism. By measuring paleomagnetism in successively older rocks, geologists found that the apparent position of the Earth's magnetic pole relative to the rocks changes through time. Successive positions of the pole define an apparent polar-wander path.
- Apparent polar-wander paths differ for different continents. This can be explained if continents move in respect to one another as the Earth's magnetic poles remain roughly fixed.
- The invention of sonar permitted explorers to make detailed maps of the seafloor. These maps revealed the existence of mid-ocean ridges, deep-ocean trenches, seamount chains, and fracture zones. Other measurements showed that heat flow is generally greater near the axis of a mid-ocean ridge.
- Hess's hypothesis of seafloor spreading states that new seafloor forms at mid-ocean ridges, above a band of upwelling mantle, then spreads symmetrically away from the ridge axis. Therefore, an ocean basin grows wider with time, and continents on either side drift apart. Eventually, the ocean floor sinks back into the mantle at deep-ocean trenches.
- Magnetometer surveys of the seafloor revealed marine magnetic anomalies. Positive anomalies (magnetic field strength is greater than expected) and negative anomalies (magnetic field strength is less than expected) are arranged in alternating stripes.
- During the 1950s, geologists documented that the Earth's magnetic field reverses polarity every now and then. The record of reversals, dated by isotopic techniques, is called the magnetic-reversal chronology.
- A proof of seafloor spreading came from the interpretation of marine magnetic anomalies. Seafloor that forms when the Earth has normal polarity results in positive anomalies, whereas seafloor that forms when the Earth has reversed polarity results in negative anomalies. Anomalies are symmetric with respect to a mid-ocean ridge axis, and their widths are proportional to the duration of polarity chrons. Study of anomalies allows us to calculate the rate of spreading.
- Drilling of the seafloor confirmed that its age increases away from the mid-ocean ridge axis, proving seafloor spreading.

Real-World Videos

PLATE MOTIONS FROM 600 MILLION YEARS AGO TO TODAY

Learning Objectives Covered:

- 3A. explain the premise of the continental-drift hypothesis proposed by Alfred Wegener.
- 3E. describe some observations that can be used to prove that seafloor spreading happens.

Length: 0:28

Summary: This animation shows plate motion from 600 MA to today (no narration).

Classroom Use:

1. Ask students to work in small groups to provide a narration for the video (or assign this task as individual work outside of class time).
2. Pause the video at various points and ask students to indicate where either rifting or collisions are happening.

Discussion Questions:

1. Describe the processes happening in this video in one or two sentences.
2. At what point can you start to recognize some of the continents?
3. Describe some of the changes that have happened in North America over the last 600 million years.

Credit: USGS

DEEP OCEAN VOLCANOES NEAR TONGA TRENCH

Learning Objectives Covered:

- 3C. list the key observations from the study of the seafloor that led Harry Hess to propose seafloor spreading.
- 3E. describe some observations that can be used to prove that seafloor spreading happens.

Length: 1:50

Summary: 80% of volcanism occurs underneath the ocean and is therefore seldom witnessed. This video includes footage of the deepest ocean eruption ever recorded, the West Mata volcano. This volcano was discovered near the Tonga Trench, between Samoa and Fiji, nearly 4,000 feet below the surface of the Pacific Ocean.

Classroom Use:

1. This video is an engaging visual aid to show what sub-sea volcanic eruptions look like.

Discussion Questions:

1. What causes volcanoes to form at mid-ocean ridges?
2. Why is it important to be able to observe these deep-sea eruptions?

Credit: NOAA Ocean Today

Activities

PUZZLING EVIDENCE FOR CONTINENTAL DRIFT

Learning Objectives Covered:

- 3B. identify the observations that Wegener used to show that continental drift took place.

Activity Type: Hands-On Investigation

Time in Class Estimate: 10 minutes

Recommended Group Size: 1–2 students

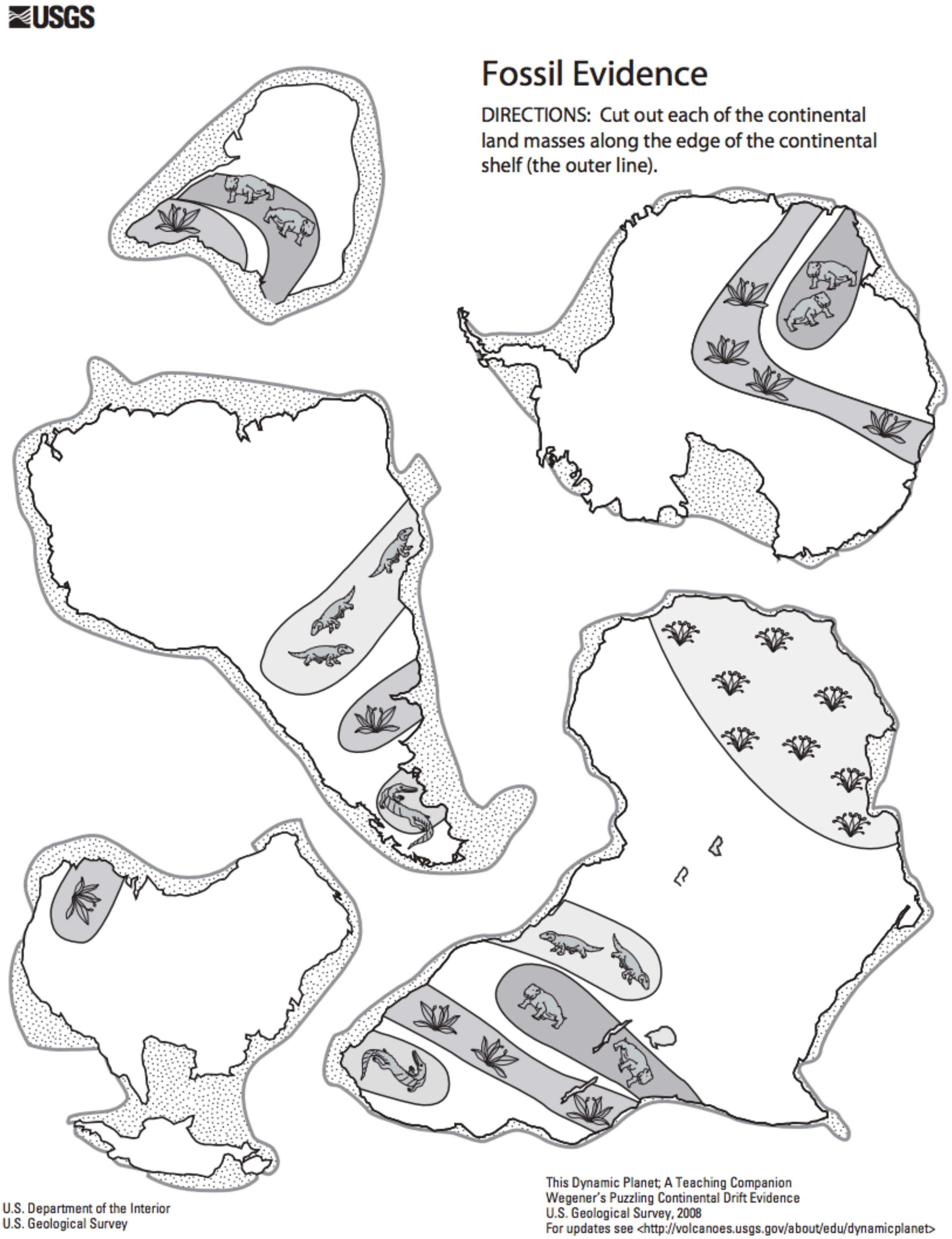
Materials: Printouts of the *USGS Fossil Evidence Map* (available at http://volcanoes.usgs.gov/about/edu/dynamicplanet), colored pencils

Classroom Procedures: Give each student or pair of students a copy of the USGS Fossil Evidence Map. Explain that the distribution of various plant and animal fossils as well as alpine mountains (geologic evidence for glaciation) have been drawn on each continent, and have students color the bands on the continents using a distinctive color for each type of fossil. Then, have students cut out the continents and rearrange them (like a puzzle) so that the continental margins fit together and the bands of fossils and alpine mountains are contiguous. Students can then compare arrangements with each other, and compare their arrangement to the maps in **Figures 3.3** and **3.4.**

Adaptations:

- Show students the animation of *Pangea Breakup and Continental Drift* at the Educational Multimedia Visualization Center (http://emvc.geol.ucsb.edu/2_infopgs/IP1GTect/aPangeaAnim.html), and have them compare their reconstruction to the reconstruction presented here. You could also show the Real-World Video PLATE MOTIONS FROM 600 MILLION YEARS AGO TO TODAY, although it is not oriented optimally to show Pangea.

- Give students a blank map without the bands of fossils drawn in, project an image of the fossil bands, and have them sketch in the approximate location.



USGS

Fossil Evidence

DIRECTIONS: Cut out each of the continental land masses along the edge of the continental shelf (the outer line).

U.S. Department of the Interior
U.S. Geological Survey

This Dynamic Planet; A Teaching Companion
Wegener's Puzzling Continental Drift Evidence
U.S. Geological Survey, 2008
For updates see <http://volcanoes.usgs.gov/about/edu/dynamicplanet>

Reflection Questions: What other possible explanations are there for the distribution of fossils that Wegener observed? What about the distribution of glacial rocks? How many different ways can you arrange the continents such that the fossil bands are contiguous? Can you observe any exceptions—parts of the data that do not fit perfectly?

NOAA OCEAN EXPLORER: SEAFLOOR SPREADING

Learning Objectives Covered:

- 3D. explain how studies of paleomagnetism later proved that continents indeed moved relative to one another.
- 3E. describe some observations that can be used to prove that seafloor spreading happens.

Activity Type: Online Investigation

Time in Class Estimate: 15 minutes

Recommended Group Size: 1–2 students

Materials: Device with internet access

Classroom Procedures: Students should access NOAA's Multimedia Discovery Missions (http://oceanexplorer.noaa.gov/edu/learning/welcome.html) and select "Lesson 2—Mid-Ocean ridges." You may or may not choose to have students watch the "Lesson" (a short video with lots of engaging visuals) before they select the "Seafloor Spreading Activity" in the "Explore" tab. This allows students to explore magnetic reversal data and make several quantitative determinations about the reversals over the last 4 million years.

Reflection Questions: How would the pattern you observed look different if this mid-ocean ridge had a slower spreading rate?

GRAPHING THE AGE OF THE SEAFLOOR

Learning Objectives Covered:

- 3E. describe some observations that can be used to prove that seafloor spreading happens.

Activity Type: Quantitative Data Analysis

Time in Class Estimate: 30 minutes

Recommended Group Size: 1–2 students

Materials: Graph paper

Classroom Procedures: Provide students with the following data table showing the age of the seafloor relative to increasing distance from the axis of the Mid-Atlantic Ridge. Have students create a graph that plots seafloor age versus distance from ridge axis, and then calculate the rate of seafloor spreading of the Atlantic Ocean over the last 130 million years. These data were derived from the Google Earth file of seafloor age, available at http://nachon.free.fr/GE/Welcome.html

Adaptations:

- If students have access to Google Earth and are able to download the .kmz file of seafloor ages (http://nachon.free.fr/GE/Welcome.html), then this activity could be greatly expanded. Students can generate additional data tables and graphs from the eastern side of the Mid-Atlantic Ridge (to compare symmetry), from a more northern or southern portion of the Mid-Atlantic Ridge (to compare rates along a single ridge), or from the East Pacific Rise (to compare rates between ridges).
- Use Microsoft Excel (or a free online graphing program) to plot the data digitally.

Distance from Ridge Axis (km)	Age of Seafloor (MA)
100	9
200	16
300	23
400	30
500	36
600	40
700	45
800	50
900	55
1000	61
1100	67
1200	72
1300	76

1400	80
1500	86
1600	90
1700	93
1800	98
1900	101
2000	106
2100	110
2200	115
2300	118
2400	120
2500	131
2600	141
2700	148

Reflection Questions: What is the general relationship between seafloor age and distance from the ridge axis? How does the age of the seafloor change with increasing distance from the ridge axis? How does the pattern you observed support Hess's idea of seafloor spreading? What is the rate of seafloor spreading in the Atlantic Ocean over the last 130 million years?

THINK-PAIR-SHARE QUESTIONS

Classroom Procedures: Ask students to silently reflect on the question (and, optionally, write down an answer). Questions could be integrated into PowerPoint slides, asked verbally, or posted in discussion boards for online classes. After about a minute of reflection, cue students to share their thoughts with one or two people near them (or in assigned groups in online classes). After a minute or two of small-group discussion, ask students to report answers to the class—ask for volunteers, call on whole groups, or have groups submit consensus posts on a discussion board.

Questions/Answers:

1. <u>Convincing Evidence for Seafloor Spreading and Continental Drift</u>

   Many different observations have been made in support of seafloor spreading and continental drift. Which single line of evidence was most striking and convincing to you?

ANS: Answers will vary.

Learning Objectives Covered:

- 3B. identify the observations that Wegener used to show that continental drift took place.
- 3C. list the key observations from the study of the seafloor that led Harry Hess to propose seafloor spreading.
- 3D. explain how studies of paleomagnetism later proved that continents indeed move relative to one another.
- 3E. describe some observations that can be used to prove that seafloor spreading happens.

2. Acceptance for Wegener's Continental Drift

Do you think that if Wegener had proposed his idea at a different time—after the discovery of some of the other evidence in support of seafloor spreading—it might have been more widely accepted by the scientific community? Why or why not?

ANS: Answers will vary. Perhaps if Wegener suggested continental drift as an explanation for apparent polar wander, or if seafloor spreading could have been cited as a mechanism for continental motion, his ideas would have been more widely accepted. Of course, he died before either of those ideas came to be.

Learning Objectives Covered:

- 3A. explain the premise of the continental-drift hypothesis proposed by Alfred Wegener.
- 3B. identify the observations that Wegener used to show that continental drift took place.

3. Evidence for Continental Drift

Alfred Wegener suggested, based on a variety of observations, that the continents have not always been in their current positions. How did other scientists who did not believe in continental drift explain these observations?

ANS: Most other scientists at the time believed that the matching features (like fossils and mountain belts) on distant continents were simply a coincidence. The puzzle-like fit of some continents was close, but not perfect, and also considered a coincidence.

Learning Objectives Covered:

- 3A. explain the premise of the continental-drift hypothesis proposed by Alfred Wegener.
- 3B. identify the observations that Wegener used to show that continental drift took place.

Answers to Review Questions

1. What was Wegener's continental-drift hypothesis?

ANS: It was widely believed that the continents were fixed in place, but Wegener hypothesized that they drifted over time. He suggested that the continents had once been contiguous, forming a supercontinent (which he termed *Pangaea*), and that they later moved apart to form their present configuration. Wegener observed many lines of evidence that convinced him of this hypothesis: the puzzle-piece like fit of several continental coastlines; a record of glaciation on continents presently found at low latitudes; and the alignment of climatic belts, fossils, and correlative geologic units across now-distant continents. Wegener was unable, however, to suggest a mechanism by which the continents might be moving; his ideas were widely rejected.

BLOOM'S LEVEL: Remembering

LEARNING OBJECTIVES COVERED:

- 3A. explain the premise of the continental-drift hypothesis proposed by Alfred Wegener.

2. How does the fit of the coastlines around the Atlantic support continental drift?

ANS: The Atlantic coasts of Africa and South America are complementary; the continents clearly seem to fit together like the pieces of a jigsaw puzzle, suggesting that at one time, the two continents were linked.

BLOOM'S LEVEL: Understanding

LEARNING OBJECTIVES COVERED:

- 3B. identify the observations that Wegener used to show that continental drift took place.

3. Explain the distribution of late Paleozoic glaciation.

ANS: Glaciers leave scratches (called striations) and distinctive sediment (called till) in the geologic record. Today, glaciers form at high latitudes and flow toward the ocean. Wegener noticed that there was evidence of past glaciation in Africa, South America, Antarctica, Madagascar, India, and Australia. Additionally, he observed that in many cases it appeared that the glaciers were moving away from what was then the coastline, rather than toward the coast as expected. This odd pattern made better sense if one assumed the continents were united and located at high southern latitudes; the glaciation that occurred spread from near the South Pole through midlatitudes in the southern hemisphere.

BLOOM'S LEVEL: Understanding

LEARNING OBJECTIVES COVERED:

- 3B. identify the observations that Wegener used to show that continental drift took place.

4. How does the distribution of climatic belts support continental drift?

ANS: There is evidence that ancient equatorial climates existed in regions that are now near the North Pole, as well as evidence for glacial conditions in what is now India.

BLOOM'S LEVEL: Understanding

LEARNING OBJECTIVES COVERED:

- 3B. identify the observations that Wegener used to show that continental drift took place.

5. Was it possible for a dinosaur to walk from New York to Paris when Pangaea existed? Explain your answer.

ANS: Yes. The cities of New York and Paris were, of course, not in existence, but lands that now make up North America and Europe were connected at the time (see **Figure 3.1b**).

BLOOM'S LEVEL: Applying

LEARNING OBJECTIVES COVERED:

- 3A. explain the premise of the continental-drift hypothesis proposed by Alfred Wegener.

6. Why were geologists initially skeptical of Wegener's continental-drift hypothesis?

ANS: Wegener could not explain how or why the continents would move. No geologists could conceive of forces great enough to move continents, and Wegener himself could not provide a sufficient mechanism. He suggested that the continents "plowed" through the ocean floor like boats, but geologists knew that the rock of the ocean floor is too strong for that to be possible. It was not until the 1960s and 1970s that new data allowed the scientific community to accept Wegener's idea.

BLOOM'S LEVEL: Remembering

LEARNING OBJECTIVES COVERED:

- 3A. explain the premise of the continental-drift hypothesis proposed by Alfred Wegener.

7. Describe the basic bathymetric characteristics of mid-ocean ridges, deep-ocean trenches, and seamount chains.

ANS: Sonar technology developed during World War II allowed for a detailed bathymetric profile of the ocean floor. Mid-ocean ridges are long mountain chains found below sea level. They are relatively symmetrical about a central crest, or ridge axis. Deep-sea trenches, common around the perimeter of the Pacific Ocean, are long narrow depressions (troughs) up to 10 km deep. They are associated with volcanic chains. Seamount chains contain only one active volcano trailed by a number of extinct volcanic islands and submerged islands known as guyots.

BLOOM'S LEVEL: Remembering

LEARNING OBJECTIVES COVERED:

- 3C. list the key observations from the study of the seafloor that led Harry Hess to propose seafloor spreading.

8. Describe the hypothesis of seafloor spreading.

ANS: Seafloor spreading is the idea that new oceanic basalt is produced at mid-ocean ridges and spreads laterally to either side. In 1960, Hess suggested that molten mantle material solidifies at mid-ocean ridges to form new oceanic crust, which then splits apart and moves away. These processes repeat continuously and the ocean basins grow wider over time. Seafloor spreading provides the mechanisms for continental drift that was missing in Wegener's original hypothesis.

BLOOM'S LEVEL: Understanding

LEARNING OBJECTIVES COVERED:

- 3C. list the key observations from the study of the seafloor that led Harry Hess to propose seafloor spreading.

9. What is paleomagnetism and how does it form? What does the red arrow in the figure represent?

ANS: Paleomagnetism is the weak magnetic field preserved in rocks, which records the paleopole at the time they were formed. Paleomagnetism exists because iron in molten rock is mobile and can align itself to the Earth's magnetic field. Once molten material solidifies into rock, the alignment is frozen in place in magnetite crystals. The red arrow indicates the apparent polar-wander path. Before continental drift was widely accepted, it was believed that this path represented movement of the Earth's magnetic pole; now, geologists understand that the path represents the drift of the continents relative to a fixed pole.

BLOOM'S LEVEL: Understanding

LEARNING OBJECTIVES COVERED:

- 3D. explain how studies of paleomagnetism later proved that continents indeed move relative to one another.

10. Describe how the angle of inclination of Earth's magnetic field varies with latitude. How

could paleomagnetic inclination be used to determine the ancient latitude of a continent?

ANS: The magnetic field of Earth approximates a dipole, much like the field of a bar magnet. At the equator, the field is oriented horizontally; moving north, field lines begin to angle downward, becoming vertical over the north magnetic pole. Many ancient volcanic rocks contain iron-rich magnetic minerals, which develop their own alignment with Earth's magnetic field. After cooling, the fields of these crystals preserve information about the latitude of crystal formation (provided that they are not sufficiently reheated to destroy this remnant magnetism).

BLOOM'S LEVEL: Remembering

LEARNING OBJECTIVES COVERED:

- 3D. explain how studies of paleomagnetism later proved that continents indeed move relative to one another.

11. How did the observations of heat flow and seismicity support the hypothesis of seafloor spreading?

ANS: High heat flow and the presence of earthquakes suggested to Hess that the seafloor was cracking apart and molten material was rising up to solidify and form new crust at mid-ocean ridges. This addition of new material at a mid-ocean ridge pushed older material away in a process known as seafloor spreading.

BLOOM'S LEVEL: Understanding

LEARNING OBJECTIVES COVERED:

- 3E. describe some observations that can be used to prove that seafloor spreading happens.

12. What is a magnetic reversal?

ANS: A Magnetic reversal is a period of time during which the Earth's magnetic field had a polarity opposite of what is observed today. This reversed polarity is recorded in magnetite crystals within many rocks, especially the basalt of the seafloor.

BLOOM'S LEVEL: Remembering

LEARNING OBJECTIVES COVERED:

- 3D. explain how studies of paleomagnetism later proved that continents indeed move relative to one another.

13. What is a marine magnetic anomaly? How is it detected?

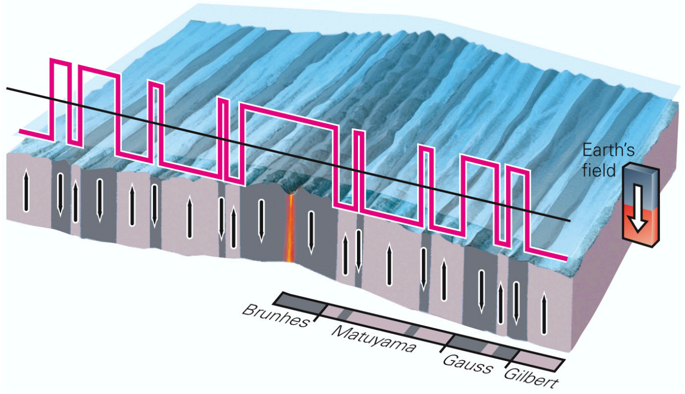
ANS: A marine magnetic anomaly is an unexpectedly high or low measure of the strength of the seafloor's magnetic field. Anomalies are detected by a device that measures magnetic field strength (a magnetometer) when towed behind a ship. Marine anomalies have a distinctive, symmetrical pattern of positive and negative stripes parallel to the mid-ocean ridge axes. This pattern is an important line of evidence in support of seafloor spreading.

BLOOM'S LEVEL: Remembering

LEARNING OBJECTIVES COVERED:

- 3D. explain how studies of paleomagnetism later proved that continents indeed move relative to one another.

14. What do the steps in the figure represent? Why aren't they all the same width?



ANS: The steps represent switches between positive and negative magnetic anomalies. They are different widths because of the rate of seafloor spreading and because the lengths of each polarity reversal are not uniform. The widths are symmetrical about the mid-ocean ridge axis.

BLOOM'S LEVEL: Understanding

LEARNING OBJECTIVES COVERED:

- 3E. describe some observations that can be used to prove that seafloor spreading happens.

15. How did geologists calculate rates of seafloor spreading?

ANS: Rate equals distance divided by time. Geologists first determine the age of a parcel of seafloor (using fossils in sediments, marine magnetic anomalies compared to the reversal time scale, or careful radiometric dating of basalt) and its distance from the axis of the ridge that created it. Dividing the latter by the former yields a spreading "half rate." This rate is multiplied by two to account for spreading on the opposite side of the ridge (seafloor spreading rates measure the relative motion of materials on adjacent plates).

BLOOM'S LEVEL: Understanding

LEARNING OBJECTIVES COVERED:

- 3E. describe some observations that can be used to prove that seafloor spreading happens.

16. Did drilling into the seafloor contribute further proof of seafloor spreading? If so, how?

ANS: Drilling into the seafloor sediments provided additional evidence for seafloor spreading. Sediments atop oceanic basalts become thicker farther away from mid-ocean ridges, and the lowermost (oldest) layers become progressively older with increasing distance from the ridge.

BLOOM'S LEVEL: Remembering

LEARNING OBJECTIVES COVERED:

- 3E. describe some observations that can be used to prove that seafloor spreading happens.

On Further Thought

17. The geologic record suggests that when supercontinents break up, a pulse of rapid evolution, with many new species appearing and many existing species becoming extinct, takes place. Why might this be? (Hint: Consider how the environment, both global and local, might change as a result of breakup, and keep in mind the widely held idea that competition for resources drives evolution.)

ANS: Continents break apart due to rifting, driven by massive amounts of volcanism, which could lead to extinction through short-term cooling (stratospheric aerosols filtering sunlight) and associated sea-level fall, longer-term warming (buildup of carbon dioxide) and associated sea-level rise, or oxygen depletion of seawater. New species would arise to fill adaptive zones left behind by extinct ones, to inhabit the new shallow seas that open up between continents, and (on the continents) through the genetic isolation of populations that once spanned the massive supercontinent. Marine life would diversify because of the significant increase in continental shelf area following rifting.

BLOOM'S LEVEL: Analyzing

LEARNING OBJECTIVES COVERED:

- 3E. describe some observations that can be used to prove that seafloor spreading happens.

18. Why are the marine magnetic anomalies bordering the East Pacific Rise in the southeastern Pacific Ocean wider than those bordering the Mid-Atlantic Ridge in the South Atlantic Ocean?

ANS: The East Pacific Rise is spreading faster than the Mid-Atlantic Ridge, so it produces a greater width of basalt in the time intervals between polarity reversals.

BLOOM'S LEVEL: Applying

LEARNING OBJECTIVES COVERED:

- 3D. explain how studies of paleomagnetism later proved that continents indeed move relative to one another.

CHAPTER 4

The Way the Earth Works: Plate Tectonics

Learning Objectives

By the end of this chapter, you should be able to . . .

A. sketch a cross section of a lithosphere plate that shows its variation in thickness and its relationship to the crust and the asthenosphere.
B. explain why plates move and how to determine the rate of plate motion.
C. use a map showing the distribution of earthquakes to locate plate boundaries and identify continental margins that are not plate boundaries.
D. distinguish among the three types of plate boundaries and characterize the assemblage of geologic features associated with each type.
E. compare a rift with a mid-ocean ridge, and a continental collision zone with a subduction zone.
F. provide a model explaining the concept and consequences of a hot spot.

Summary from the Text

- The lithosphere, the rigid outer layer of the Earth, consists of discrete plates that move relative to one another. Plates include the crust and the uppermost (cooler) mantle. Lithosphere plates sit on the underlying soft asthenosphere. Continental drift and seafloor spreading are manifestations of plate movement.
- Most earthquakes and volcanoes occur along plate boundaries; the interiors of plates remain relatively rigid and intact.
- There are three types of plate boundaries—divergent, convergent, and transform—distinguished from one another by the movement that the plate on one side of the boundary makes relative to the plate on the other side.
- Divergent boundaries are marked by mid-ocean ridges. At divergent boundaries, seafloor

spreading, a process that forms new oceanic lithosphere, takes place.

- Convergent boundaries are marked by deep-sea trenches and volcanic arcs. At convergent boundaries, oceanic lithosphere of the downgoing plate subducts beneath an overriding plate.
- Transform boundaries are marked by large faults at which one plate slides sideways past another. No new plate forms and no old plate is consumed at a transform boundary.
- Triple junctions are points where three plate boundaries intersect.
- At a hot spot, volcanism occurs at an isolated volcano. As a plate moves over the hot spot, the volcano moves off and becomes inactive, and a new volcano forms over the hot spot; the chain of volcanoes defines a hot-spot track. Hot spots may form above mantle plumes.
- A large continent can split into two smaller ones by the process of rifting. During rifting, continental lithosphere stretches and thins. If it finally breaks apart, a new mid-ocean ridge forms and seafloor spreading begins.
- Convergent boundaries cease to exist when a buoyant piece of crust moves into the subduction zone. When that happens, collision occurs. Collision can thicken crust and build large mountain belts.
- Ridge-push force and slab-pull force contribute to driving plate motions. Plates move at rates of about 1 to 15 cm per year. We can describe the motions of plates relative to one another or relative to a fixed point. Modern satellite measurements can detect these motions.

Narrative Figure Videos

BREAKUP OF PANGAEA

Learning Objectives Covered:

- 4A. sketch a cross section of a lithosphere plate that shows its variation in thickness and its relationship to the crust and the asthenosphere.
- 4B. explain why plates move and how to determine the rate of plate motion.
- 4D. distinguish among the three types of plate boundaries and characterize the assemblage of geologic features associated with each type.
- 4E. compare a rift with a mid-ocean ridge, and a continental collision zone with a subduction zone.

Length: 3:45

Summary: First, maps of several supercontinents that have formed and broken up in the past are shown. The process of supercontinent formation by subduction and breakup by rifting and seafloor spreading is outlined. Next, the formation and breakup of Pangea is described in detail. Finally, the last 100 million years of continental drift is shown, including colored bands to indicate age of the seafloor. Spreading rates of the Atlantic are quantified.

Classroom Uses: This video can be used as part of a predict-observe-explain exercise. Play the video up to the 1:29 mark—this will summarize the processes of supercontinent formation by subduction/collision and breakup by rifting. Ask students to note all of the features (such as shallow versus deep ocean basins, mid-ocean ridges, and volcanic island arcs) and determine what types of plate boundaries they see. Next, ask students to make a prediction about where Pangea will rift and the directions in which some of the continents will move. Once students have made their predictions, continue playing the video and remind students to observe what happens. You may want to play the video between 1:29 and 1:55 a few times so that students have sufficient opportunity to observe everything. Finally, ask students to explain if what they observed matched their prediction or not. If not, why not?

Adaptations:

- Provide a printout of the map pictured at 1:29 and ask students to label features and draw boundaries, or ask some students to come up to the board and share their thinking.
- Pause video at 0:41, 0:46 and 0:50 and ask students to identify the location of the plate boundary and passive margins.
- Pause on a plate reconstruction at any point between 1:29-1:55 and have students identify the location of plate boundaries and passive margins.
- Have students think-pair-share their predictions.

Review and Discussion Questions:

1. Compare all three of the supercontinents shown (Pangaea, Rodinia, and Pannotia). In what ways are they all similar? What are some differences between them?
2. Considering the rate of seafloor spreading (3 cm/yr) and current width (6000 km) of the Atlantic Ocean, what will its width be in 50 million years?
3. What do you think the continental configuration of the Earth will look like many hundreds of millions of years in the future?
4. What will happen to the passive margin on the east coast of the US millions of years in

the future?

CONTINENTAL COLLISION

Learning objectives covered:

- 4D. distinguish among the three types of plate boundaries and characterize the assemblage of geologic features associated with each type.
- 4E. compare a rift with a mid-ocean ridge, and a continental collision zone with a subduction zone.

Length: 3:07

Summary: This video outlines the plate interactions at each type of convergent boundary. Oceanic lithosphere subducts beneath the overriding plate (either oceanic or continental lithosphere) into the mantle at convergent boundaries. Metamorphism transforms oceanic lithosphere into eclogite, which is more dense that the warmer mantle and therefore it continues to sink. Because continental lithosphere is less dense than the asthenosphere, it is buoyant and cannot be subducted. Orogeny, metamorphism, thrust faulting, and extensive erosion occur when two continents collide. There is abundant evidence of past continental collisions in the geologic record.

Classroom uses: After watching the video, ask students to sketch both a subduction zone and a continental collision. They should label the sketches with distinctive features and rock types, and focus on the differences between the two types of boundaries.

Discussion Questions:

1. List some geologic features that would be evidence of the subduction of oceanic lithosphere.
2. List some geologic features that would be evidence of a continental collision.
3. What features distinguish the mountain ranges associated with a continental collision from other types of mountains (for instance a volcanic arc)?

Real-World Videos

SUBDUCTION TRENCH GENERATING TSUNAMI WAVES

Learning Objectives Covered:

- 4C. use a map showing the distribution of earthquakes to locate plate boundaries and identify continental margins that are not plate boundaries.
- 4D. distinguish among the three types of plate boundaries and characterize the assemblage of geologic features associated with each type.

Length: 0:37

Summary: This video does not have any narration. It shows a subduction zone in Indonesia, and illustrates how a tsunami is generated along this type of boundary. Stress accumulates in the overriding plate, which is pulled down at its edge by the subducting plate. When the fault ruptures, the overriding plate rebounds to its previous geometry and this sudden shift in the seafloor displaces a significant volume of water upward. This displaced water travels outward in both directions as a tsunami wave. Note that the significant volume change in the overriding plate depicted between 0:15 and 0:20 of the video is an inaccurate representation of strain accumulation. In real rocks, there is no change in volume associated with strain accumulation. You may or may not choose to clarify this issue with your students.

Classroom Uses:

1. First, play the video a few times through and ask students to just watch what is happening. Next, tell them that because the video lacks narration, they are going to work in groups of 2–3 to create their own. Either provide a link to the video through the Digital Landing Page or your campus Learning Management System (if devices are available in the classroom) or project the video on a loop. Give students 5–10 minutes to write a narration. You may want to offer some hints (for example: break the video down into 3 or 4 main ideas and describe what is happening in each; every time the image changes, describe what you are seeing; trim down your language so that you can say everything you need to in 30 seconds; for each statement, ask yourself, “is this important to understand the idea, or is it extra?”). Once all groups have written a narration, you could collect the scripts, have them share with one other group, or have a few groups present to their scripts to the class.
2. After watching the video, ask students to draw a diagram (or series of diagrams) that shows what happens to the plates during subduction that results in a tsunami.
3. This video could simply be used as is to show the process of tsunami formation or as an example of elastic rebound.

Discussion Questions:

1. The subduction zone shown was a volcanic island arc. Do you think this process would have differed if one of the plates had been continental?
2. Do you think that tsunamis can be generated along a mid-ocean ridge? Why or why not?
3. Are tsunamis a risk along the [coastline closest to your region, or one of your choosing]? Why or why not?

Credit: Geoscience Australia

THE HOLOGLOBE PROJECT

Learning Objectives Covered:

- 4C. use a map showing the distribution of earthquakes to locate plate boundaries and identify continental margins that are not plate boundaries.

Length: 6:20 (most relevant to plate tectonics from 3:25–4:35)

Summary: This video outlines the relationship between the oceans, atmosphere, climate, and geology of the Earth. It opens with a comparison of Earth to Venus and Mars. There are several characteristics that make Earth unique: it is covered in liquid water, it is geologically active, and is home to diverse life. Satellites have allowed us to see that the land, oceans, atmosphere, and life are interconnected and influenced by energy from the Sun. A rotating globe shows patterns of cloud movement, and maps of water vapor show hurricane formation in the Atlantic. Changes in sea surface temperature are also shown, and El Niño is described. From 3:25–4:35 the rotating globe is drained of its oceans and the seafloor topography becomes visible. Narration describes that the crust is divided into a “mosaic of moving plates”, and the boundaries are indicated by colored dots (earthquakes) and triangles (volcanoes) on the globe. Finally, seasonal changes in vegetation and human influences (light pollution and controlled burning) are illustrated.

Classroom Uses: This video is best suited for an engaging start to a lecture, a break in lecture for students to switch gears for a short time, as a summary of some of the important processes that influence Earth’s surface, or as a wrap up. Alternatively, just the portion from 3:25–4:35 can be shown to illustrate the relationship between earthquakes, volcanoes, and plate boundaries.

Discussion Questions:

1. What are some of the features that make Earth unique in our solar system?
2. How have satellite images influenced our understanding of the Earth?
3. What are some processes that link the oceans, atmosphere, and geology of Earth?
4. How does the distribution of types of lithosphere influence the distribution of water on Earth?
5. How is the distribution of earthquakes on a continental collision different from the distribution of earthquakes along a subduction zone or mid-ocean ridge?

Credit: NASA/Goddard Space Flight Center - Scientific Visualization Studio, Smithsonian Institution, Global Change Research Project (GCRP), National Oceanic and Atmosphere Administration (NOAA), United States Geological Survey, National Science Foundation (NSF), Defense Advanced Research Projects Agency (DARPA), Dynamic Media Associates (DMA), New York Film and Animation Company, Silicon Graphics, Inc. (SGI), Hughes STX Corporation

PLATE MOTIONS FROM 600 MILLION YEARS AGO TO TODAY

Learning Objectives Covered:

- 4B. explain why plates move and how to determine the rate of plate motion.

Length: 0:28

Summary: This animation shows plate motion from 600 Ma to today (no narration) from the perspective of a fixed North American plate.

Classroom Uses:

1. Ask students to work in small groups to provide a narration for the video (or assign this task as individual work outside of class time).
2. Pause the video at various points and ask students to indicate where collisions or rifting are happening.

Discussion Questions:

1. Describe the processes happening in this video in one or two sentences.
2. At what point can you start to recognize some of the continents?
3. Describe some of the changes that have happened in North America over the last 600 million years.

4. What are some locations where new crust is being formed? Where is old crust being consumed?

Credit: USGS

DEEP OCEAN VOLCANOES NEAR TONGA TRENCH

Learning Objectives Covered:

- 4D. distinguish among the three types of plate boundaries and characterize the assemblage of geologic features associated with each type.
- 4E. compare a rift with a mid-ocean ridge, and a continental collision zone with a subduction zone.

Length: 1:50

Summary: Eighty percent of volcanism occurs underneath the ocean and is therefore seldom witnessed. This video includes footage of the deepest ocean eruption ever recorded, the West Mata volcano. This volcano was discovered near the Tonga Trench, between Samoa and Fiji, nearly 4,000 feet below the surface of the Pacific Ocean.

Classroom Use: This video is an engaging visual aid to show what submarine volcanic eruptions look like. Before showing the video, direct students to observe specific geologic features they see forming in the video, and to note clues that might suggest what type of plate boundary this volcano is associated with. Following the video, return to and pause at the 0:45 second mark and ask students to observe the topography and determine the type of plate boundary.

Discussion Questions:

1. What type of plate movement occurs at deep ocean trenches?
2. Based on the features shown on the map (around 0:45), what type of plate boundary is this volcano associated with?
3. What causes volcanoes to form at subduction zones?
4. What geologic features did you see forming in the footage of the lava erupting on the seafloor?
5. Why is it important to be able to observe these deep sea eruptions?

Credit: NOAA Ocean Today

Animations

PLATE BOUNDARIES

Learning objectives covered:

- 4D. distinguish among the three types of plate boundaries and characterize the assemblage of geologic features associated with each type.

Summary: This animation provides an overview of the process of formation of each of the three types of plate boundaries (divergent, convergent, and transform). Seafloor spreading ridges form when two oceanic plates move apart and molten asthenosphere solidifies to form new crust which is subsequently moved away from the ridge axis. Continental rifting occurs when lithosphere things and asthenosphere rises and eventually erupts along the rift. Convergence of two plates of oceanic crust results in subduction of one of the plates, which is more dense. Convergence of two plates – one of continental crust and one of oceanic crust – results in subduction of the oceanic crust beneath the continental crust. Convergence of two continental plates results in a collision and associated deformation. Transform boundaries form by the lateral offset of seafloor spreading ridge segments, or where two plates slide sideways past each other.

Classroom uses:

1. Divide students up into small groups of 2-3, and assign each group one of the topics (divergent, convergent, and transform). There may be more than one group covering a topic.
2. Ask students to review the information in their topic and prepare for peer teaching of the information.
3. Shuffle students into new groups such that each group has at least one student from each topic. Groups should still have 3 students, but each student should have prepared a different topic.
4. Have each group collaborate to write a paragraph or draw a diagram that explains how each type of plate boundary forms. Paragraphs can be read aloud; paragraphs and diagrams can be posted to an online discussion board, or posted around the room as a gallery walk.

Discussion questions:

1. Compare and contrast volcanism at each of the types of plate boundaries.
2. In what ways are island and continental volcanic arcs similar? In what ways are they different?

Activities

PLATE BOUNDARY GALLERY WALK

Learning Objectives Covered:

- 4C. use a map showing the distribution of earthquakes to locate plate boundaries and identify continental margins that are not plate boundaries.
- 4D. distinguish among the three types of plate boundaries and characterize the assemblage of geologic features associated with each type.
- 4E. compare a rift with a mid-ocean ridge, and a continental collision zone with a subduction zone.
- 4F. provide a model explaining the concept and consequences of a hot spot.

Activity Type: Gallery Walk

Time in Class Estimate: 45 minutes

Recommended Group Size: 6 groups of 3–4 students each

Materials: 6 pieces of large paper, poster boards, sticky notes, or white board space sufficient for 6 groups; markers

Classroom Procedures: Prepare the posters ahead of class by writing one of the following categories on each poster: mid-ocean ridge, continental rift, subduction zone, continental collision, transform boundary, hot spot. Hang the posters around the room or space them out on desks. Give students approximately 10 minutes to list all of the important geologic features of their topic (earthquake location, relative plate motion, surface features, volcanic processes, specific types of rocks formed, faults, etc.), and encourage students to include a drawing or diagram. When the time has elapsed, groups rotate to the next poster, read what is already written and continue where the first group left off. They can also elaborate on what previous groups have written or correct any mistakes. Rotations should be a shorter time interval, perhaps 5 minutes. Repeat until all groups have seen and contributed to all posters. End the activity by asking each group to report a brief summary of the information on a poster to the entire class.

Adaptations:

- Assign each group a color, which makes it easy to track who contributed each idea on the finished posters.

- This can be used in conjunction with the Chapter 4 activity, “Plate Boundary Graphic Organizer.” Students can fill out the organizer from their notes or the textbook beforehand and use it as a reference for the poster, or it can be distributed after the posters are completed.
- Have two simultaneous rotating groups, such that there are two copies of each poster. This adaptation can accommodate larger class sizes, and provides a point of comparison for each poster.

Reflection Questions: What are some features that all plate boundaries have in common? What is one unique feature (or combination of features) that distinguishes each type of boundary?

PLATE BOUNDARY GRAPHIC ORGANIZER

Learning Objectives Covered:

- 4C. use a map showing the distribution of earthquakes to locate plate boundaries and identify continental margins that are not plate boundaries.
- 4D. distinguish among the three types of plate boundaries and characterize the assemblage of geologic features associated with each type.
- 4E. compare a rift with a mid-ocean ridge, and a continental collision zone with a subduction zone.

Activity type: Worksheet

Time in class estimate: 45 minutes

Group size: Individual

Materials: Copy of handout for all students

Classroom Procedures: The graphic organizer shown below can be used as a tool to synthesize and summarize notes taken during lecture on plate boundaries and their characteristics. Students use notes to complete the chart, listing the most important features of each type of plate boundary. This can be implemented as a lecture wrap-up, a collaborative activity, a review, or combined with other active learning activities.

Adaptations:

- Hand out worksheet after lecture on first type of boundary and have students fill out info incrementally after each boundary is discussed in class, rather than complete the entire worksheet at once after all boundaries are discussed.

- This can be used in conjunction with the “Plate Boundary Gallery Walk” activity, also from Chapter 4. Have students fill out worksheet individually as homework to prepare for the gallery walk or have students use completed gallery walk posters as a resource for filling out the chart.

Plate Boundary Summary						
	Divergent Boundaries		Transform Boundary	Convergent Boundaries		
	Mid-Ocean Ridge	Continental Rift		Subduction Zone	Continental Collision	Island Arc
Relative Plate Motion & Stress						
Lithosphere created or destroyed? Type?						
Topography/ landscape Features						
Earthquakes (size, depth, frequency)						
Volcanic activity						
Distinctive geologic features						
Examples						

Other Notes						

Reflection Questions: What are some features that all plate boundaries have in common? What is one unique feature (or combination of features) that distinguishes each type of boundary?

THINK-PAIR-SHARE QUESTIONS

Classroom Procedures: Ask students to silently reflect on the question (and, optionally, write down an answer). Questions can be integrated into PowerPoint slides, asked verbally, or posted in discussion boards for online classes. After about a minute of reflection, cue students to share their thoughts with one or two people near them (or in assigned groups in online classes). After a minute or two of small group discussion, ask students to report answers to the class—ask for volunteers, call on whole groups, or have groups submit consensus posts on a discussion board.

Questions/Answers:

1. Evidence for Continental Drift

   Alfred Wegener suggested, based on a variety of observations, that the continents have not always been in their current positions. How did other scientists who did not believe in continental drift explain these observations?

   ANS: Most other scientists at the time believed that the matching features (like fossils and mountain belts) on widely separated continents were simply a coincidence. The puzzle-like fit of some continents was close but not perfect, and also considered a coincidence.

   Learning Objectives Covered:

   - 4B. explain why plates move and how to determine the rate of plate motion.

2. Geologic Activity and Plate Tectonics

   We know that tectonic plates move at varying rates both absolutely and relative to each other. How might the relative velocity between two plates affect the geologic activity taking place at their boundary?

ANS: In general, the faster that two plates move relative to each other, the more severe the geologic activity that takes place at their boundary. For example, the most powerful earthquakes occur when a lot of motion happens in a short period of time at a plate boundary—that is, when two plates are moving very quickly relative to each other.

Learning Objectives Covered:

- 4B. explain why plates move and how to determine the rate of plate motion.

3. Hot Spots and Plate Tectonics

Hot-spot volcanoes are not necessarily related to plate boundaries, yet they provide valuable evidence in support of plate motion and therefore the theory of plate tectonics. Explain this evidence.

ANS: Volcanism at a hot spot is caused by mantle plumes, and hot-spot *tracks* are evidence of plate motion. As the plate moves over a mantle plume, a track of older, inactive volcanoes is left behind.

Learning Objectives Covered:

- 4B. explain why plates move and how to determine the rate of plate motion.
- 4F. provide a model explaining the concept and consequences of a hot spot.

4. Ocean Basin Evolution

Describe the evolution of an ocean basin over time. How does it form, how is it destroyed, and what happens in between?

ANS: Ocean basins form by the process of rifting. Stretching of the continental crust leads to rifting and melting of the underlying asthenosphere. Volcanoes erupt and eventually the continent breaks in two and a new mid-ocean ridge forms. Seafloor spreading continues until eventually one or both of the halves of the continent collide with other continents and form tall mountain ranges.

Learning Objectives Covered:

- 4D. distinguish among the three types of plate boundaries and characterize the assemblage of geologic features associated with each type.
- 4E. compare a rift with a mid-ocean ridge, and a continental collision zone with a subduction zone.

5. **Title:** Spreading Rate and Topographic Features

The rate of seafloor spreading at mid-ocean ridges varies. For example, the Mid-Atlantic Ridge spreads relatively slowly (about 3 cm per year) compared to the East Pacific Rise, which spreads at a rate of up to 18 cm per year. How do you think that spreading rate might affect the shape (topography) of a mid-ocean ridge? (Hint: Remember what happens to the lithosphere as it gets older and cools.)

ANS: A ridge is wider along fast-spreading divergent boundaries because the crust is pushed away faster, and therefore is farther from the ridge axis before it cools and sinks.

Learning Objectives Covered:

- 4B. explain why plates move and how to determine the rate of plate motion.
- 4D. distinguish among the three types of plate boundaries and characterize the assemblage of geologic features associated with each type.

Answers to Review Questions

1. What are the characteristics of a lithosphere plate?

ANS: The lithosphere is the rocky outer portion of Earth, relatively cool and rigid in comparison to underlying mantle material (the hotter, weaker asthenosphere). The lithosphere is composed of the crust and the uppermost portion of the mantle (called lithospheric mantle). A lithosphere plate is a piece of the lithosphere that moves relative to the other plates.

BLOOM'S LEVEL: Remembering

LEARNING OBJECTIVEs COVERED:

- 4A. sketch a cross section of a lithosphere plate that shows its variation in thickness and its relationship to the crust and the asthenosphere.

2. How does oceanic lithosphere differ from continental lithosphere?

ANS: Oceanic lithosphere is thinner, has more mafic crust (largely basalt, whereas continental crust is granitic), is denser, and has lower surface elevation.

BLOOM'S LEVEL: Understanding

LEARNING OBJECTIVES COVERED:

- 4A. sketch a cross section of a lithosphere plate that shows its variation in thickness and its relationship to the crust and the asthenosphere.

3. What are the basic premises of plate tectonics?

ANS: The lithosphere is divided into discrete plates that move relative to each other by slip along plate boundaries; the interior of the plate is largely undisturbed by this motion. These plates include the continents, which move along with them. The surface of the Earth changes as a result of this dynamic process.

BLOOM'S LEVEL: Remembering

LEARNING OBJECTIVES COVERED:

- 4B. explain why plates move and how to determine the rate of plate motion.

4. How do we identify a plate boundary?

ANS: Plate boundaries are marked by linear or arc-like segments of relatively high earthquake frequency (earthquake belts); plate boundaries are also the locations of increased volcanic activity. Modern geoscientists use GPS to delineate and distinguish different types of plate boundaries based on the relative motion of the crust across the boundary. Different types of plate boundaries can also be differentiated by the topographic features that are formed by the processes unique to each type. For example, trenches form at subduction zones, and rift basins only form at continental rifts.

BLOOM'S LEVEL: Applying

LEARNING OBJECTIVES COVERED:

- 4C. use a map showing the distribution of earthquakes to locate plate boundaries and identify continental margins that are not plate boundaries.

5. Describe the three types of plate boundaries.

ANS: Divergent-plate boundaries exist where lithosphere on either side moves away from the boundary. At convergent-plate boundaries, lithosphere on either side comes together, bringing either subduction (if oceanic lithosphere is involved) or collision (of two continental plates). At transform-plate boundaries, plates slide past each other.

BLOOM'S LEVEL: Remembering

LEARNING OBJECTIVES COVERED:

- 4D. distinguish among the three types of plate boundaries and characterize the assemblage of geologic features associated with each type.

6. How does oceanic crust form along a mid-ocean ridge?

ANS: The depressurization of upward moving mantle material causes it to melt, forming magma, which is relatively light and rises to the surface. Some of the magma crystallizes beneath the surface (as gabbro or in thin basaltic dikes), and some erupts to form volcanic lava, which flows onto the seafloor and ultimately solidifies to form pillow basalt.

BLOOM'S LEVEL: Understanding

LEARNING OBJECTIVES COVERED:

- 4E. compare a rift with a mid-ocean ridge, and a continental collision zone with a subduction zone.

7. Describe the process of subduction at a consuming boundary.

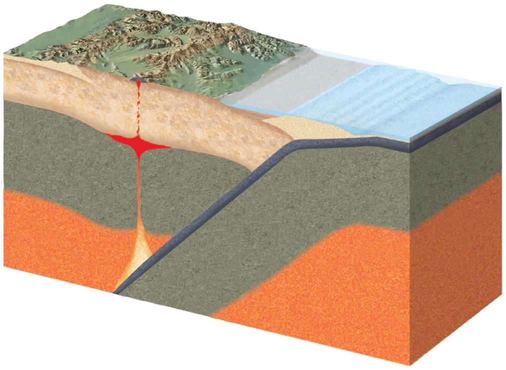
ANS: When at least one of the two plates at a convergent boundary is oceanic, a process known as subduction will occur. During subduction, old oceanic lithosphere (known as the downgoing plate) is consumed as it bends and sinks into the asthenosphere beneath the overriding plate. The overriding plate may be younger oceanic crust or continental crust. This slow sinking (about 15 cm per year) is associated with large earthquakes, trenches, accretionary prisms, and volcanic arcs.

BLOOM'S LEVEL: Understanding

LEARNING OBJECTIVES COVERED:

- 4E. compare a rift with a mid-ocean ridge, and a continental collision zone with a subduction zone.

8. Describe the major features of a convergent boundary. Identify them in the drawing.



ANS: At a convergent boundary a subduction zone is present, which is marked by a deep trench where the subducting oceanic plate bends downward in opposition to the horizontal overriding plate. Sediments scrape off the subducting plate to form an accretionary prism at the edge of the overriding plate. Behind the prism, melting associated with the subducting plate produces either a volcanic continental arc or a volcanic island arc.

BLOOM'S LEVEL: Applying

LEARNING OBJECTIVES COVERED:

- 4D. distinguish among the three types of plate boundaries and characterize the assemblage of geologic features associated with each type.

9. Describe the motion that takes place on a transform boundary.

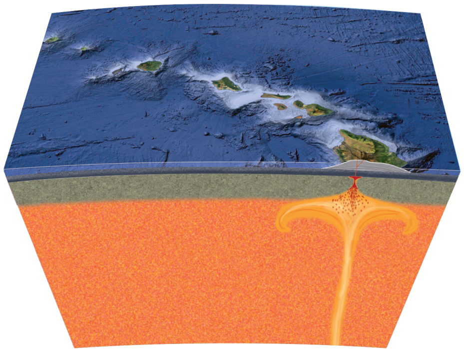
ANS: At a transform boundary, the materials of the two opposed plates slide past each other laterally, and lithosphere is neither formed or destroyed.

BLOOM'S LEVEL: Remembering

LEARNING OBJECTIVES COVERED:

- 4D. distinguish among the three types of plate boundaries and characterize the assemblage of geologic features associated with each type.

10. What phenomenon may produce a hot-spot track, and how can hot-spot tracks be used to track the past motions of a plate? What direction is the Pacific Plate moving in the figure?



ANS: A large volume of very hot rock from within the mantle rises at the hot spot, producing magma that erupts onto the surface of the lithospheric plate and forms a volcano. Hot spots are relatively stable points, whereas the plates that overlie them and bear the associated volcanoes are moving. Over periods of millions of years, as a plate slides over the hot spot, volcanoes are ferried in the direction of plate motion and become extinct as they are removed from their source of magma, while new volcanoes are formed at the hot spot. In the figure, the Pacific Plate is moving to the northwest.

BLOOM'S LEVEL: Understanding

LEARNING OBJECTIVES COVERED:

- 4F. provide a model explaining the concept and consequences of a hot spot.

11. Describe the characteristics of a continental rift, and give examples of where rifting takes place today.

ANS: Continental rifts appear as elongate valleys bounded on either side by faults. Volcanism occurs along the rift as asthenosphere rises to accommodate the thinning lithosphere and melts. Active rifts can be found in East Africa and in the Basin and Range Province of the western US.

BLOOM'S LEVEL: Understanding

LEARNING OBJECTIVES COVERED:

- 4E. compare a rift with a mid-ocean ridge, and a continental collision zone with a subduction zone.

12. Describe the process of continental collision, and give examples of where this process has

occurred.

ANS: Continental rock is not dense enough to subduct beneath an overriding, opposed continental plate and will thus collide with it, suturing itself to the adjacent plate, folding the rocks in the zone of collision, and thickening the crust locally to form a nonvolcanic mountain range. The most notable example of continental collision on Earth is the Himalayan mountain range where India is colliding with Eurasia. There are many locations on Earth that preserve evidence of past continental collisions, such as the Appalachian Mountains, where modern day Africa once collided with North America to form Pangea.

BLOOM'S LEVEL: Understanding

LEARNING OBJECTIVES COVERED:

- 4E. compare a rift with a mid-ocean ridge, and a continental collision zone with a subduction zone.

13. Discuss the major forces that move lithosphere plates.

ANS: Ridge-push force is a driving force that arises because elevated lithosphere at a ridge pushes downward on less-elevated lithosphere to either side. Mantle convection drags plates along, and slab-pull force is a driving force that arises at subduction zones due to old, cold, dense oceanic lithosphere sinking like an anchor into the less dense asthenosphere and dragging the lithosphere down with it.

BLOOM'S LEVEL: Understanding

LEARNING OBJECTIVES COVERED:

- 4B. explain why plates move and how to determine the rate of plate motion.

14. Explain the difference between relative plate velocity and absolute plate velocity.

ANS: Relative plate velocity describes rates of motion of one plate with respect to another plate (or with respect to a plate boundary). Absolute plate velocity is the velocity of a plate with respect to a hot spot or other fixed point of reference on Earth.

BLOOM'S LEVEL: Understanding

LEARNING OBJECTIVES COVERED:

- 4B. explain why plates move and how to determine the rate of plate motion.

On Further Thought

15. The Pacific Plate moves north relative to the North American Plate at a rate of 6 cm per year. How long will it take Los Angeles (a city on the Pacific Plate) to move northward by 480 km, the present distance between Los Angeles and San Francisco?

ANS: 480 km ÷ (6 cm/year)(1 m/100 cm)(1 km/1000 m) = 480 km ÷ 0.00006 km/year = 8,000,000 years = 8 million years.

BLOOM'S LEVEL: Applying

LEARNING OBJECTIVES COVERED:

- 4B. explain why plates move and how to determine the rate of plate motion.

16. Look at a map of the western Pacific Ocean, and examine the position of Japan with respect to mainland Asia. Japan's crust contains rocks similar to those of eastern Asia. Presently, many active volcanoes occur along the length of Japan. With these facts in mind, explain how the Japan Sea (the region between Japan and the mainland) formed.

ANS: East Asia rifted, with Japan drifting toward the east. The seafloor of the Sea of Japan formed from basalt eruptions associated with the rifting and spreading. The Sea of Japan is considered a *back-arc basin* because it was formed by rifting behind a volcanic arc (Japan).

BLOOM'S LEVEL: Analyzing

LEARNING OBJECTIVES COVERED:

- 4C. use a map showing the distribution of earthquakes to locate plate boundaries and identify continental margins that are not plate boundaries.

CHAPTER 5

Patterns in Nature: Minerals

Learning Objectives

By the end of this chapter, you should be able to . . .

A. explain why the term *mineral* has a very special meaning in a geologic context.
B. describe the processes by which minerals can form.
C. explain how geologists organize thousands of different minerals into just a few classes.
D. specify which minerals are the most common ones on the Earth, and describe how they are classified.
E. identify common mineral specimens based on their properties.
F. distinguish ordinary minerals from gems, and describe how to produce the shiny facets of gems.

Summary from the Text

- Minerals are naturally occurring, solid substances, formed by geologic processes, with a definable chemical composition, and are characterized by an orderly arrangement of atoms, ions, or molecules in a crystalline structure. Most minerals are inorganic.
- In the crystalline structure of minerals, atoms occur in a specific pattern—one of nature's finest examples of ordering.
- Minerals can form by the solidification of a melt, precipitation from a water solution, diffusion through a solid, biomineralization (precipitation by organisms), and precipitation from a gas.
- About 4,000 different types of minerals are known, each with distinctive physical properties (such as color, streak, luster, hardness, specific gravity, crystal habit, and cleavage).
- The unique physical properties of a mineral reflect its chemical composition and crystal structure. By observing these physical properties, you can identify minerals.

- Minerals can be classified according to their chemical composition. Mineral classes include silicates, sulfides, oxides, halides, carbonates, native metals, and sulfates.
- The silicate minerals are the most common on the Earth. The silicon-oxygen tetrahedron, a silicon atom surrounded by four oxygen atoms, provides the fundamental building block of silicate minerals.
- Groups of silicate minerals are distinguished from one another by the ways in which the silicon-oxygen tetrahedral that constitute them are linked.
- Gemstones are minerals known for their beauty and rarity. Gem cutters produce facets on cut gems used in jewelry by grinding and polishing the stones with a faceting machine.

Animations

MINERALS

Learning Objectives Covered:

- 5A. explain why the term *mineral* has a very special meaning in a geologic context.

Length: Varies

Summary: This animation includes definitions for and discussion of six features that define a mineral: naturally occurring, created by geologic processes, solid, crystalline structure, inorganic, and definable composition. Minerals form in the natural world, although recently chemists have been able to manufacture synthetic minerals (some of which have industrial uses). Minerals form geologically, although the activity of living things can produce biogenic minerals (such as hydroxylapatite, calcite, and aragonite). The atoms in a mineral are arranged in an orderly pattern known as a crystal lattice. All minerals can be expressed by a specific chemical formula (with some limited variations).

Classroom Use:

1. Divide the class into small groups of 2–3 students, and assign each group one of the topics (naturally occurring, geologic processes, solid, crystalline structure, inorganic, and definable composition). There may be more than one group covering a topic.
2. Ask students to review the information in their topic and prepare for peer teaching of the information.
3. Shuffle students into new groups such that each group has at least one student from each

topic. Groups should now have six students (one representative from each topic), but there may be some groups with one or two extra representatives.

4. Have each group collaborate to write a paragraph defining the characteristics of a mineral. Paragraphs can be read aloud, posted to an online discussion board, or posted around the room as a gallery walk.

Review and Discussion Questions:

1. Minerals are naturally occurring. Why would scientists seek to recreate them in a laboratory setting?
2. Minerals are generally created by geologic processes. What are some examples of exceptions to this definition?
3. Compare and contrast the properties of minerals and glass.

Activities

BREAKING MINERALS

Learning Objectives Covered:

- 5E. identify common mineral specimens based on their properties.

Activity Type: Demonstration

Time in Class Estimate: 15 minutes

Recommended Group Size: Whole class

Materials: One small euhedral quartz crystal and one rhombohedral calcite crystal (both will be destroyed), hammer, hand lens, tray (optional to help contain the mess), safety googles for instructor and students near the demo

Classroom Procedures: This demonstration is best included before the idea of cleavage has been introduced, so that students do not have a preexisting mental model for minerals breaking along cleavage planes.

1. Students make detailed observations of a sample of quartz and a sample of calcite.
2. Students predict what will happen when the samples are hit with a hammer.
3. Instructor hits the quartz with a hammer (which should break into a number of irregular pieces exhibiting conchoidal fracture), and students observe the resulting fragments.

Repeat with the calcite (which should break into rhombohedral fragments with flat surfaces).

4. Ask students why they think the two minerals broke in such different ways, and introduce the idea of cleavage planes.

Adaptations:

- Have students observe some additional pieces of other minerals with conspicuously broken surfaces—garnet, pyrite, olivine, fluorite, gypsum, feldspar, and galena are good choices—and determine if cleavage is present or absent.
- If it is not feasible to get a large number of crystals to smash, class after class, record a video of a single smash, and show the resulting fragments to students.
- For online classes or large lecture halls, record a video of the crystals being smashed and take detailed photos of the broken fragments for observation.
- If supplies are sufficient you can also have small groups of students each smash and observe their own crystals.

Reflection Questions: What features do the two minerals have in common? In what ways are they different? How many directions of cleavage did the calcite have? How would you expect a mineral with one direction of cleavage to break compared to the calcite? What are some clues to look for that could help you distinguish cleavage planes from crystal faces?

GROW YOUR OWN MINERAL

Learning Objectives Covered:

- 5B. describe the processes by which minerals can form.

Activity Type: Hands-On Investigation

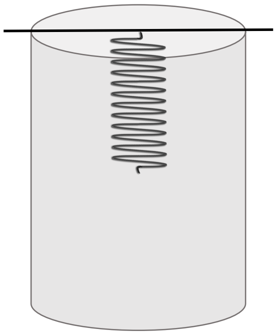
Time in Class Estimate: 20 minutes on day one, 5–10 minutes for observation and clean up on day two

Recommended Group Size: Individual–whole class

Materials: Borax powder, distilled water, beaker(s), plastic spoons, pipe cleaners, beakers, hot plate or electric kettle

Classroom Procedures:

1. Heat some water to almost boiling in a beaker and slowly add borax powder one spoonful at a time (stirring to dissolve) until the liquid becomes supersaturated. Keep the solution hot but do not boil.
2. Prepare the crystal nucleation armature: Wrap the pipe cleaner around a pen or pencil to form a spring (with a bit of space between each coil), and then attach the spring to a second pipe cleaner that can sit across the top of the beaker such that the spring hangs down into the beaker and is submerged in the borax solution (see diagram).



3. Leave the beaker and pipe cleaners to cool undisturbed. Small crystals will start to grow within a few hours, and by the next day most of the borax will have precipitated onto the pipe cleaners (and sides of the beaker).

Adaptations:

- For online classes, instructions can be provided for students to complete the activity at home (borax is readily available at the grocery store). Alternatively, a time lapse video of the borax crystal precipitating could be provided.

Reflection Questions: What determined the shape of the crystal that you grew? What determined the size of the crystal that you grew? How does the shape of the small crystals compare to the shape of the large crystals?

THINK-PAIR-SHARE QUESTIONS

Classroom Procedures: Ask students to silently reflect on the question (and, optionally, write down an answer). Questions could be integrated into PowerPoint slides, asked verbally, or posted in discussion boards for online classes. After about a minute of reflection, cue students to share their thoughts with one or two people near them (or in assigned groups in online classes). After a minute or two of small-group discussion, ask students to report answers to the class—ask for volunteers, call on whole groups, or have groups submit consensus posts on a discussion board.

Questions/Answers:

1. Minerals as Natural Resources

   What are some items in this classroom that are made of minerals?

   ANS: Answers will vary, but common examples might include: rare earth elements, gold, and copper in cell phones, graphite in pencils, copper in wires, iron and aluminum in furniture and building materials, gypsum in drywall, gypsum and calcite in concrete.

   Learning Objectives Covered:

   - 5D. specify which minerals are the most common ones on the Earth, and describe how they are classified.
   - 5E. identify common mineral specimens based on their properties.

2. Mineral or Not?

   Decide if each of the following is a mineral or not, and why: ice, water, plastic, bricks, copper wire, salt, sugar, glass, lava, coal.

   ANS: Ice, salt, and copper wire are all minerals; water and lava are not minerals because they are not solid; plastic, glass and bricks are not minerals because they are not formed by geologic processes (also, glass is not crystalline); sugar and coal are not minerals because they are organic.

   Learning Objectives Covered:

   - 5A. explain why the term *mineral* has a very special meaning in a geologic context.

3. Minerals and Gems

   Imagine that you are trying to identify an unknown gemstone using only the physical properties that you can observe. What might be some challenges you face in identifying it?

   ANS: Because gemstones have been faceted, the geometric relationship between natural crystal faces is no longer preserved. This may also make it particularly difficult to identify cleavage planes in the mineral.

   Learning Objectives Covered:

   - 5F. distinguish ordinary minerals from gems, and describe how to produce the shiny facets of gems.

Answers to Review Questions

1. What is a mineral, as geologists understand the term? How does this definition differ from the everyday usage of the word?

ANS: A mineral is a solid substance with a crystalline structure and a definable chemical composition. Minerals are naturally occurring, although in some cases synthetic minerals with identical characteristics can be manufactured. Most minerals are inorganic, although some biogenic minerals can be produced by organisms. In everyday language, the term mineral is sometimes used to describe substances that do not fit these criteria.

BLOOM'S LEVEL: Applying

LEARNING OBJECTIVES COVERED:

- 5A. explain why the term *mineral* has a very special meaning in a geologic context.

2. Why isn't glass considered to be a mineral?

ANS: Glass does not have a fixed crystalline arrangement. Because there is no fixed spatial arrangement for the atoms within glass, glass fails the "crystalline structure" requirement in the definition of a mineral.

BLOOM'S LEVEL: Understanding

LEARNING OBJECTIVES COVERED:

- 5A. explain why the term *mineral* has a very special meaning in a geologic context.

3. Salt is a mineral, but the plastic making up an inexpensive pen is not. Why not?

ANS: Salt is a naturally occurring, inorganic, crystalline solid with a definable chemical composition (NaCl). The plastic is not a mineral because it lacks crystal structure, is not formed by geologic processes, and does not occur naturally.

BLOOM'S LEVEL: Applying

LEARNING OBJECTIVES COVERED:

- 5A. explain why the term *mineral* has a very special meaning in a geologic context.

4. Describe the several ways that mineral crystals can form.

ANS: Crystal growth occurs when atoms are attached to the outside faces of a seed crystal.

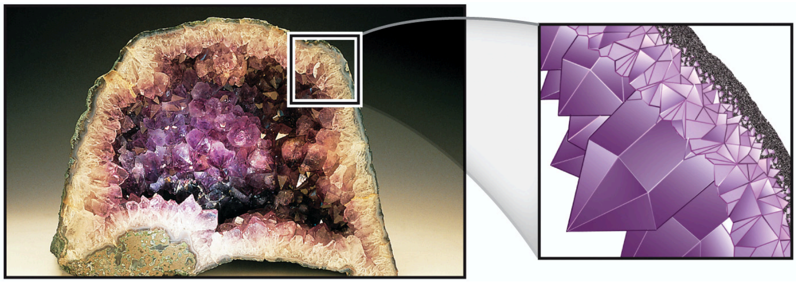
Crystals form in five ways: freezing from a melt (igneous rocks), precipitation from solution or gas (associated with volcanism), solid state diffusion (in which atoms are rearranged into a new crystal structure during metamorphism), and biomineralization.

BLOOM'S LEVEL: Understanding

LEARNING OBJECTIVES COVERED:

- 5B. describe the processes by which minerals can form.

5. Why do some minerals occur as euhedral crystals, whereas others occur as anhedral grains? Which describes the crystals in the figure?



ANS: Crystals grow by the addition of molecules along crystal faces; during this process the geometry of the faces, determined by the internal crystal structure, is maintained. Therefore, the shape of a crystal is the same whether it is small or large. If a crystal is growing into open space, with nothing to interfere with the growth of the crystal faces, a euhedral crystal (with clearly defined faces and edges) will develop. More commonly, numerous crystals form more or less simultaneously in a tightly packed space. In this case, the crystal faces form irregular boundaries where they touch and are termed anhedral. Both euhedral and anhedral grains are shown here—euhedral grains are growing into the open space at the center of the geode and anhedral grains are packed together along the margins of the geode.

BLOOM'S LEVEL: Understanding

LEARNING OBJECTIVES COVERED:

- 5B. describe the processes by which minerals can form.

6. List and define the principal physical properties used to identify a mineral.

ANS: The physical characteristics of a mineral reflect its chemical composition and crystalline structure, and are therefore unique to each mineral. These characteristics—including hardness (resistance to scratching), cleavage (tendency of crystals to break along planes of weakness), color, luster (the way in which the mineral reflects light), crystal form or habit (the shape of visible crystals or crystal aggregates), streak (the color of the mineral in powdered form), and specific gravity (mass per unit volume of the mineral)—can be used to identify a mineral.

BLOOM'S LEVEL: Remembering

LEARNING OBJECTIVES COVERED:

- 5E. identify common mineral specimens based on their properties.

7. How can you determine the hardness of a mineral? What is the Mohs hardness scale?

ANS: Mineral hardness is determined through scratch tests. A relatively hard mineral is able to scratch a softer mineral, but a soft mineral cannot scratch a harder material. Put another way, soft minerals can be scratched by harder materials but not softer ones. The Mohs hardness scale ranks minerals from softest (1—talc) to hardest (10—diamond), and the hardness of everyday substances, such as fingernail (2.5), pennies (3.5), glass (5.5) and steel (6.5) can also be ranked on the scale. The resistance (or lack thereof) of a mineral to scratching by any of these materials can be used to determine hardness.

BLOOM'S LEVEL: Applying

LEARNING OBJECTIVES COVERED:

- 5E. identify common mineral specimens based on their properties.

8. How do you distinguish cleavage planes from crystal faces on a mineral? How does each type of surface form?

ANS: Crystal faces are the outside surfaces of a mineral, which result from the growth of a mineral. In contrast, cleavage planes result from planes of relatively weak bonds within a crystal, and are persistent and consistent throughout the entire crystal. Cleavage planes appear as parallel sets of flat planes that can be seen in the interior of a mineral along broken surfaces.

BLOOM'S LEVEL: Applying

LEARNING OBJECTIVES COVERED:

- 5E. identify common mineral specimens based on their properties.

9. On what basis do geologists separate minerals into classes?

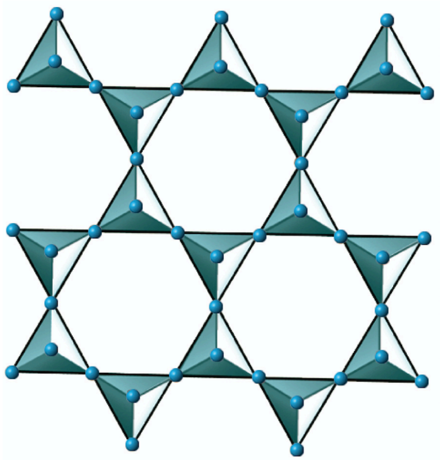
ANS: Minerals are divided into the following classes based on chemical composition (specifically, the anion[s] present): silicates (contain SiO_4), sulfides (metal cation + sulfide), oxides (metal cation + oxygen), halides (contain a halogen such as Cl or F), carbonates (contain CO_3), native metals (a single element), and sulfates (metal cation + sulfate).

BLOOM'S LEVEL: Remembering

LEARNING OBJECTIVES COVERED:

- 5C. explain how geologists organize thousands of different minerals into just a few classes.

10. On what basis do mineralogists organize silicate minerals into distinct groups? What type of silicate group does the diagram portray?



ANS: The silicate minerals are divided into groups based on the geometric arrangement of the SiO_4 tetrahedra. This geometry is determined by the degree to which oxygen atoms are shared by multiple tetrahedra, and determines the Si:O ratio of the mineral. Independent tetrahedra do not share oxygen atoms and are held together by ionic bonds. Single chain silicates share two oxygen atoms, and double chain silicates share two or three oxygen atoms. In sheet silicates, tetrahedra are linked into two-dimensional sheets by sharing three oxygen atoms. When all four oxygen atoms are shared, a three-dimensional framework silicate results. The tetrahedral structure in the figure is a sheet silicate.

BLOOM'S LEVEL: Understanding

LEARNING OBJECTIVES COVERED:

- 5D. specify which minerals are the most common ones on the Earth, and describe how they are classified.

11. How does the bonding in mica determine cleavage in mica crystals?

ANS: In micas, each silicon-oxygen tetrahedron shares three oxygen atoms with other adjacent tetrahedra, forming a sheet silicate. The shared silicon-oxygen bonds within the sheets are very strong, but bonds between two sheets are much weaker. Therefore, micas cleave strongly in one direction along these planes of weak bonds.

BLOOM'S LEVEL: Applying

LEARNING OBJECTIVES COVERED:

- 5E. identify common mineral specimens based on their properties.

12. Why are some minerals considered gemstones? How do gem cutters make the facets on a gem?

ANS: Gemstones, including diamond, ruby, sapphire, and emerald, are minerals that are considered especially valuable because of their rarity or unique beauty. Gemstones are faceted by creating flat planes using a machine. These facets generally do not represent crystal faces or cleavage planes of the mineral.

BLOOM'S LEVEL: Remembering

LEARNING OBJECTIVES COVERED:

- 5F. distinguish ordinary minerals from gems, and describe how to produce the shiny facets of gems.

On Further Thought

13. Compare the chemical formula of magnetite with that of biotite. Why do we mine magnetite to obtain iron supplies, but we don't mine biotite?

ANS: Magnetite (Fe_3O_4) and biotite ($K(Mg, Fe)_3(AlSi_3O_{10})(OH)_2$) both contain iron and oxygen, but biotite also contains a variety of other elements, including silicon, magnesium, and hydrogen. Magnetite is an oxide mineral, with Fe cations bonded to oxygen anions. Biotite is a silicate mineral built of silica oxygen tetrahedra. The ratio of iron to other elements is much higher in magnetite; the iron content of biotite is too small to make its extraction worthwhile.

BLOOM'S LEVEL: Analyzing

LEARNING OBJECTIVES COVERED:

- 5C. explain how geologists organize thousands of different minerals into just a few classes.

14. Imagine that you are given two milky white crystals, each about 2 cm across. You are told that one of the crystals is plagioclase and the other is quartz. How can you determine which is which?

ANS: Quartz and plagioclase differ in two fundamental ways that are easy to distinguish in small, isolated hand samples: hardness and cleavage. Quartz is harder than plagioclase, so the quartz can scratch the plagioclase but cannot be scratched by it. Both quartz and plagioclase are hard enough to scratch glass, so that test will not help distinguish between the two. Quartz lacks cleavage, and plagioclase has strong cleavage in two directions. Also, plagioclase occasionally exhibits striations that can be seen when the specimen is rotated in light.

BLOOM'S LEVEL: Applying

LEARNING OBJECTIVES COVERED:

- 5E. identify common mineral specimens based on their properties.

15. Could you use crushed calcite to grind and form facets on a diamond? Why or why not?

ANS: You could not; diamond is much harder than calcite, and the result of such efforts would be to grind the calcite.

BLOOM'S LEVEL: Evaluating

LEARNING OBJECTIVES COVERED:

- 5E. identify common mineral specimens based on their properties.

INTERLUDE A

Introducing Rocks

Learning Objectives

By the end of this interlude, you should be able to . . .

A. provide a geologic definition of rock.
B. explain the basis that geologists use to classify rocks into three classes.
C. discuss the tools that can be used to study rocks.

Summary from the Text

- Rock is a coherent, naturally occurring solid, consisting of an aggregate of minerals or of a body of glass. Nonglassy rocks can be classified as crystalline or clastic.
- Bedrock consists of rock that remains connected to the underlying crust. Outcrops, exposures of bedrock at the Earth's surface, can be natural or human-made.
- Geologists classify a rock as igneous, sedimentary, or metamorphic based on how the rock formed.
- A variety of characteristics prove helpful in describing rocks. Examples include grain size and shape, composition, texture, and the nature of layering.
- Hand lenses, petrographic microscopes (after making thin sections), and sophisticated electronic equipment help geologists interpret the origin of rocks.

Animations

ROCK GROUPS

Learning Objectives Covered:

- A. provide a geologic definition of rock.
- B. explain the basis that geologists use to classify rocks into three classes.

- C. discuss the tools that can be used to study rocks.

Summary: This animation defines rocks as coherent, brittle solids composed of crystals of one or more minerals or shards of volcanic glass. It makes clear the distinctions between igneous, sedimentary, and metamorphic rocks, and emphasizes the difference between the interlocking texture of crystalline rocks and the cemented texture of clastic rocks. The animation also explores the disparate techniques geologists use to study rocks at outcrops and in the laboratory in thin-section, including a very detailed description of the process of creating thin sections.

Classroom Use:

1. Divide the class into small groups of 2–3 students, and assign each group a topic (definition, rock type, rock analysis). There may be more than one group covering a topic.
2. Ask students to review the information in their topic and prepare for peer teaching of the information.
3. Shuffle students into new groups such that each group has at least one student from each topic. Groups should now have three students (one representative from each topic), but there may be some groups with one or two extra representatives.

Have each group collaborate to create a poster or infographic sheet about rocks, and how they are classified and analyzed. Posters/infographics can be posted around the room as a gallery walk or posted to an online discussion board.

Review and Discussion Questions:

1. Is a jigsaw puzzle a good analogy for rocks with cemented texture or interlocking texture? What kind of texture does a rice crisp cereal treat represent?
2. A geologist examines a rock carefully under a microscope and notes that it consists of grains of quartz cemented together by smaller, interlocking crystals. Is this an igneous, sedimentary, or metamorphic rock?

Activities

CATEGORIZING ROCKS

Learning Objectives Covered:

- B. explain the basis that geologists use to classify rocks into three classes.

Activity Type: Observe and Describe

Time in Class Estimate: Variable (depending on how many rock samples are used)

Recommended Group Size: Whole class

Materials: Various hand samples, or access to digital hand samples at https://www.virtualmicroscope.org/content/uk-virtual-microscope

Classroom Procedures:

1. Remind students of the three types of rocks (igneous, sedimentary, and metamorphic) and create a list of features that can be observed that might indicate which category a rock belongs to (e.g., layering in sedimentary or metamorphic rocks, grains cemented together in sedimentary rocks).
2. Show examples of rocks (physical hand samples, images in a PowerPoint presentation, or virtual samples from the UK virtual microscope) and have students observe & describe them in detail.
3. Determine the classification of each sample based on the physical features observed.

Adaptations:

- For online classes (or if no hand samples are available), the UK Virtual Microscope website has high resolution, zoomable and rotatable images of hand samples.

Reflection questions: What characteristics did you find most useful in identifying the different types of rocks? Which rock was easiest to classify? Which was most difficult? Why?

THINK-PAIR-SHARE QUESTIONS

Classroom Procedures: Ask students to silently reflect on the question (and, optionally, write down an answer). Questions could be integrated into PowerPoint slides, asked verbally, or posted in discussion boards for online classes. After about a minute of reflection, cue students to share their thoughts with one or two people near them (or in assigned groups in online classes). After a minute or two of small-group discussion, ask students to report answers to the class—ask for volunteers, call on whole groups, or have groups submit consensus posts on a discussion board.

Questions/Answers:

1. Concrete

   Is concrete a rock? Why or why not? What about “granite” countertops?

ANS: Concrete, although a coherent aggregate of minerals, is not naturally occurring and is therefore not considered a rock. Countertops marketed as “granite” are made of a spectrum of materials including a variety of rock types (not limited to granite) and synthetic materials. Although the countertop itself is cut and polished into a slab, the material is (in many cases) a naturally occurring rock.

Learning Objectives Covered:

- A. provide a geologic definition of rock.

Answers to Review Questions

1. How do geologists define the term *rock*? Can a brick be considered to be a rock? Explain your answer.

ANS: Geologists define a rock as a coherent, naturally occurring solid that consists of an aggregate of minerals (or a body of glass). Rocks are made up of interlocking mineral fragments, or mineral grains held together by natural cement. Bricks are not considered rocks because they do not occur naturally.

BLOOM’S LEVEL: Understanding

LEARNING OBJECTIVES COVERED:

- A. provide a geologic definition of rock.

2. Explain the difference between a clastic and a crystalline rock.

ANS: A clastic rock is composed of grains held together by cement; crystalline rocks hold together due to mineral crystals mutually interlocking.

BLOOM’S LEVEL: Understanding

LEARNING OBJECTIVES COVERED:

- A. provide a geologic definition of rock.

3. Give examples of different kinds of rock outcrops. Can you find outcrops everywhere? Explain your answer.

ANS: Natural outcrops include cliffs and stream cuts. Manmade outcrops include road and railroad cuts, and quarries. Outcrops are not found everywhere; in many places, rock is covered by sediment, soil, water, or urban development.

BLOOM'S LEVEL: Applying

LEARNING OBJECTIVES COVERED:

- A. provide a geologic definition of rock.

4. On what basis do geologists define rocks into three classes? What are these classes?

ANS: Geologists divide rocks into three classes on the basis of the way in which the rock forms. The three classes of rock are: igneous, which form by the solidification of molten rock; sedimentary, which form by cementation of grains or precipitation of minerals from solution at the surface of the Earth; and metamorphic, which form when preexisting rocks change because of changes in temperature and pressure conditions.

BLOOM'S LEVEL: Remembering

LEARNING OBJECTIVES COVERED:

- B. explain the basis that geologists use to classify rocks into three classes.

5. Distinguish between an equant and an inequant grain.

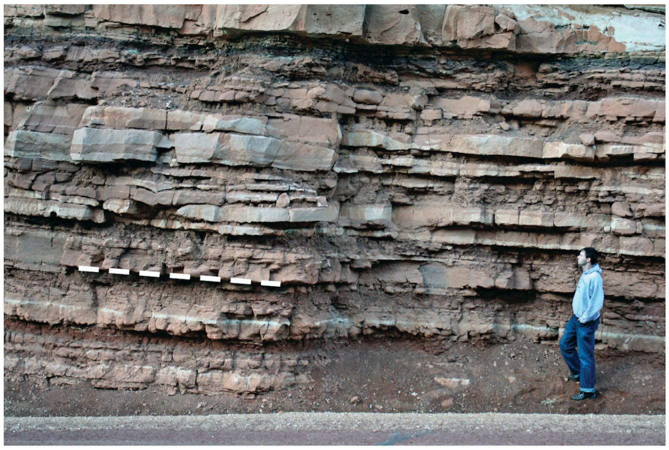
ANS: An equant grain is approximately the same linear size in all three spatial dimensions. An inequant grain has a least one dimension that is of unequal length to another.

BLOOM'S LEVEL: Understanding

LEARNING OBJECTIVES COVERED:

- B. explain the basis that geologists use to classify rocks into three classes.

6. What type of layering does the photograph show?



ANS: Sedimentary rocks may contain layers of differing composition, grain size, or texture, known as bedding. Metamorphic foliation is a type of layering in which inequant grains are aligned.

BLOOM'S LEVEL: Remembering

LEARNING OBJECTIVES COVERED:

- B. explain the basis that geologists use to classify rocks into three classes.

7. Give two examples of types of layering that can occur in rock.

ANS: Layering in sedimentary rocks, known as bedding, is a result of deposition of grains of different size, composition, or texture. Metamorphic foliation is layers of aligned mineral crystals.

BLOOM'S LEVEL: Understanding

LEARNING OBJECTIVES COVERED:

- B. explain the basis that geologists use to classify rocks into three classes.

8. What are thin sections, how are they examined, and what do they allow you to see?

ANS: Thin sections are slices of rock (approximated 0.03 mm thick) mounted on a glass slide so that they can be viewed through a microscope. The microscopic texture of a rock can be examined in this way, and minerals can be identified based on the color of transmitted polarized light.

BLOOM'S LEVEL: Understanding

LEARNING OBJECTIVES COVERED:

- C. discuss the tools that can be used to study rocks.

9. Name examples of high-tech equipment that can be used to study rocks. What extra information can geologists learn by using such equipment?

ANS: Rocks are often studied with such high-tech electronic equipment as: scanning electron microscopes, which allow for extremely high magnification; electron microprobes, which determine the chemical composition of individual mineral crystals; mass spectrometers, which measure the ratio of isotopes of certain elements; and X-ray diffractometers, which can determine the identity of minerals.

BLOOM’S LEVEL: Remembering

LEARNING OBJECTIVES COVERED:

- C. discuss the tools that can be used to study rocks.