INSTRUCTOR'S MANUAL

Essentials of Geology

SIXTH EDITION

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Instructor's Manual by
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Other Instructor Resources Available with *Essentials of Geology, 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: videos, animations, simulations, lecture slides, clicker questions, 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/essgeo6/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 *Essentials of Geology* Instructor's page.

Test Bank

The Test Bank has been written to correlate to the learning objectives found in *Essentials of Geology,* 6e 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 *Essentials of Geology* Instructor's page.

PowerPoints

Several types of powerpoints are available, downloadable via the Essentials of Geology 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 the *Essentials of Geology* 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 diamonds.
- 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.
- Research in geology can be guided by the scientific method.

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 United 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 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. In addition, 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?

Adaptation:

- The video could be used with this chapter's "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 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, for which two opposing points of view are often at odds, science can provide the best source of trusted information.

Classroom Use: 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** for a review). Show the video as one example of a controversial topic. Then, divide the class into groups of two to three students, and ask students to come up with another example of a controversial issue that geologists could evaluate in an impartial way. Examples 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 being referenced? What factors influence their views 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)

Activities

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 (depends on class size and depth of discussion)

Recommended Group Size: 1–4 students

Materials: Internet access

Classroom Procedures Ask students to visit the USGS Science Snippets website (http://www.usgs.gov/news/science-snippets) and select an article of interest to read. While reading, students should focus on how the scientific method (see **Box P.1**) is being implemented by answering the following questions: What is the problem being solved or hypothesis being tested? What kinds of data are being collected? How are data collected? Then have students summarize what they learned from the article and discuss the ways in which geology provides impartial scientific evidence that is relevant to contemporary world challenges.

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.

- "News in Review" on the American Association of Petroleum Geologists website (http://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 (detailed earlier in the chapter).

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 orally, 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 Objective 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 Objective 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 Objective 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 OBJECTIVE 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 OBJECTIVE 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 OBJECTIVE 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 OBJECTIVE COVERED:

- C. demonstrate how geologists employ the scientific method.

5. What are the main layers of the Earth's interior?

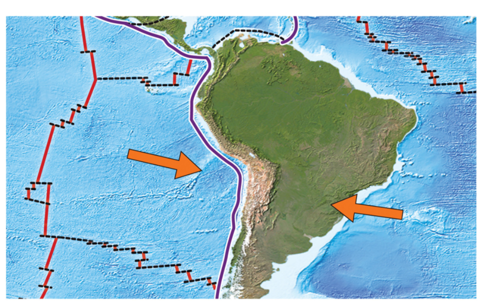
ANS: From outside to inside: crust, mantle, outer core, and inner core.

BLOOM'S LEVEL: Understanding

LEARNING OBJECTIVE COVERED:

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

6. What is the basic premise of the theory of plate tectonics? What are the arrows shown on the map?



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. The arrows on the map show the direction of movement for both plates.

BLOOM'S LEVEL: Remembering

LEARNING OBJECTIVE COVERED:

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

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 OBJECTIVE 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 OBJECTIVE 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 OBJECTIVE 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 OBJECTIVE COVERED:

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

CHAPTER 1

The Earth in Context

Learning Objectives

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

A. characterize 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. outline the premises of the expanding Universe and the Big Bang theories for the formation of our Universe.
D. explain the nebula theory, a scientific model that describes how stars and planets form.
E. describe the nature of the magnetic field and atmosphere that surround our planet.
F. list the distinct interacting realms within the Earth System.
G. distinguish the internal layers (crust, mantle, and core) of the Earth.
H. explain the relationship between the lithosphere and the asthenosphere.

Summary from the Text

- The geocentric model placed the Earth at the center of the Universe. The heliocentric model placed the Sun at the center.
- The Earth is one of eight planets orbiting the Sun. The Solar System lies on the outer edge of the Milky Way Galaxy. The Universe contains hundreds of billions of galaxies.
- Most astronomers agree that the Universe has been expanding since it began at the Big Bang, about 13.8 billion years ago.
- The first atoms (hydrogen and helium) developed within minutes of the Big Bang. These atoms formed vast gas nebulae.
- The Earth contains elements that could have been produced only during the life cycle of stars.

- Gravity caused nebulae to coalesce into disks with bulbous centers. The central ball of these accretion disks became protostars. Eventually, the balls became so hot and dense that fusion reactions began and true stars were formed.
- Planets developed from the rings of gas and dust surrounding newborn stars. These coalesced into planetesimals that then merged to form protoplanets, and finally true planets.
- The Moon formed from debris ejected when a protoplanet collided with the Earth in the very young Solar System.
- Large protoplanets differentiate into a core and mantle and assume a near-spherical shape.
- The Earth has a magnetic field that shields it from solar wind.
- The atmosphere consists of 78% N_2, 21% O_2, and 1% other gases. Air pressure decreases with elevation.
- The surface of the Earth hosts land (30%) and ocean (70%).
- Earth materials include organic chemicals, minerals, glass, rocks, metals, melts, and volatiles. Geologists recognize three classes of rocks.
- The Earth's interior can be divided into three distinct layers: the very thin crust, the rocky mantle, and the metallic core.
- Pressure and temperature increase with depth in the Earth. The rate of temperature increase is the geothermal gradient.
- The crust varies in thickness from 7 to 10 km (beneath the oceans) to 25 to 70 km (beneath the continents). Oceanic crust is mafic in composition, whereas average upper continental crust is felsic to intermediate. The mantle is composed of ultramafic rock. The core consists of iron alloy.
- The mantle can be subdivided into an upper mantle and a lower mantle. The core can be subdivided into the liquid outer core and a solid inner core.
- The crust plus the upper part of the mantle constitute the lithosphere, a rigid shell. The lithosphere lies over the asthenosphere, in which mantle can flow.

Narrative Art Videos

FORMATION OF THE SOLAR SYSTEM

Learning Objective Covered:

- 1D. explain the nebula theory, a scientific model that describes 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 accretion disk. Next, matter in the center of the disk becomes a protostar. Eventually, nuclear fusion reactions begin, and the star (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 a lecture for students to switch gears for a short time, a summary of how our Solar System formed, or a wrap-up.
2. After showing the video, ask students to 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 (such as gravitational pull, nuclear fusion, solar wind, accretion, and 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 Objective Covered:

- 1D. explain the nebula theory, a scientific model that describes 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 water condensed into oceans but the atmosphere remained oxygen-free until the evolution of photosynthesis.

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

Review and Discussion Questions:

1. Why do smaller protoplanets have irregular, lumpy shapes whereas 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 Objective Covered:

- 1E. describe the nature of the magnetic field and atmosphere that surround our planet.

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: 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 develop their hypotheses for a Think-Pair-Share activity.
- Include a 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/Goddard Space Flight Center; music credit: Ocean Travel by Laurent Dury from the KillerTracks Catalog.

RESEARCHERS DISCOVER THE EARTH'S INNER-INNER CORE

Learning Objective Covered:

- 1G. distinguish the internal layers (crust, mantle, and core) of the Earth.

Length: First 1:01 (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 from crystals in the outer portion of the inner core. This may lend insight into the formation and evolution of the Earth.

Classroom Use: 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.

Review and 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

HOW PLANETS ARE BORN

Learning Objective Covered:

- 1D. explain the nebula theory, a scientific model that describes 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 and 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 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" and have each group share with one other group or have a few groups present to the class.
3. Pause the video at 10, 20, and 30 seconds and have students create a quick labeled sketch of what they have observed.

Review and 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 Objective 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 Academy Level. Meanwhile, provide space on the board (or in a discussion board for an online class) 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, and 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 with their same Academy Level and compare answers.

Adaptations:

- Have students complete all three Academy 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 deep surveys help our understanding of black holes? How?

IMAGINE NUCLEOSYNTHESIS

Learning Objective Covered:

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

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?

SCALING THE EARTH'S INTERIOR

Learning Objectives Covered:

- 1G. distinguish the internal layers (crust, mantle, and core) of the Earth.
- 1H. explain the relationship between the lithosphere and the 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 8½- by 11-inch paper cut and taped), rulers or meter sticks, 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 then 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 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 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 in the preceding table would be increased by a factor of 10 to scale to kilometers. For example, the base 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 8½- by 11-inch 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 orally, 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>Is There Life Out There?</u>

   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 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 Objective Covered:

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

2. <u>Picturing the Big Bang</u>

   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 of only energy, but minutes later matter formed as the Universe cooled. In the beginning, the Universe was dark because 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. outline the premises of the expanding Universe and Big Bang theories for the formation of our Universe.

3. <u>Everyday Geologic Materials</u>

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

ANS: Answers will vary. Examples include rocks, minerals, sediment, soils, dirt, sand, silt, and mud.

Learning Objective Covered

- 1F. list the distinct interacting realms within the Earth System.

4. <u>Alien Earth</u>

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 features of Earth are 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 Objective Covered:

- 1F. list the distinct interacting realms within the Earth System.

5. <u>Earth's Hydrosphere</u>

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 Objective Covered:

- 1F. list the distinct interacting realms within the Earth System.

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 OBJECTIVE COVERED:

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

2. What is the ecliptic, and why are the orbits of the planets within the ecliptic? Why is Pluto no longer considered to be a planet?

ANS: The ecliptic is the plane on which the eight planets orbit the Sun. The orbits all lie within the ecliptic because they all formed from a rotating disk of material known as a protoplanetary disk. Pluto is no longer a planet because it cannot clear its orbit of other objects.

BLOOM'S LEVEL: Understanding

LEARNING OBJECTIVE COVERED:

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

3. Explain the expanding Universe theory.

ANS: The expanding Universe theory, based on observations by astronomers like Hubble, states that the Universe is expanding and increasing in volume. This is analogous to dough with raisins scattered throughout in which the raisins are moving away from each other as the dough bakes and expands. These observations were based on the fact that galaxies were moving away from the Earth in all directions and the fact that farther galaxies were moving away faster.

BLOOM'S LEVEL: Understanding

LEARNING OBJECTIVE COVERED:

- 1C. outline the premises of the expanding Universe and Big Bang theories for the formation of our Universe.

4. What is the Big Bang, and when did it occur?

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, 13.8 billion years ago.

BLOOM'S LEVEL: Remembering

LEARNING OBJECTIVE COVERED:

- 1C. outline the premises of the expanding Universe and Big Bang theories for the formation of our Universe.

5. 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 OBJECTIVE COVERED:

- 1D. explain the nebula theory, a scientific model that describes how stars and planets form.

6. 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 OBJECTIVE COVERED:

- 1D. explain the nebula theory, a scientific model that describes how stars and planets form.

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

ANS: The magnetic field of Earth is a region of space affected by the dipolar magnetic force of Earth (see **Fig**. **1.11b**). The aurorae is caused by an interaction between the atmosphere and magnetosphere as charged particles that stream along the magnetic field lines toward the pole interact with gases in the atmosphere. This interaction causes them to glow, which we see as the aurorae.

BLOOM'S LEVEL: Remembering

LEARNING OBJECTIVE COVERED:

- 1E. describe the nature of the magnetic field and atmosphere that surround our planet.

8. What is the Earth's atmosphere composed of? Why would you die of suffocation if you were to jump from a plane at an elevation of 12 km without an oxygen tank?

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 LEVELS: Remembering, Applying

LEARNING OBJECTIVE COVERED:

- 1E. describe the nature of the magnetic field and atmosphere that surround our planet.

9. What is the proportion of land area to sea area on Earth?

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).

BLOOM'S LEVEL: Remembering

LEARNING OBJECTIVE COVERED:

- 1F. list the distinct interacting realms within the Earth System.

10. Describe the major categories of materials constituting the Earth. On what basis do geologists distinguish among different kinds of silicate rocks?

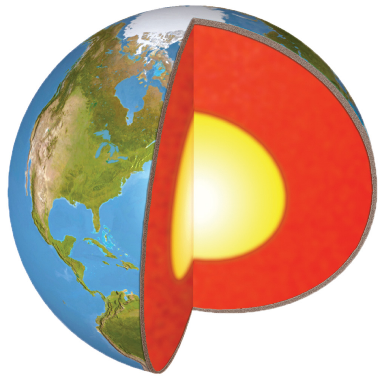
ANS: Organic chemicals make up the majority of living matter. These carbon- and hydrogen-based compounds (such as oil and natural gas) can be quite complex, sometimes incorporating oxygen (as in sugars, starches, and fats), sometimes nitrogen (as in proteins), and occasionally some phosphorus and sulfur. 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). 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. Silicate rocks are distinguished by their chemical composition, which is defined by the percentage of silica.

BLOOM'S LEVEL: Remembering

LEARNING OBJECTIVE COVERED:

- 1F. list the distinct interacting realms within the Earth System.

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



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

BLOOM'S LEVEL: Applying

LEARNING OBJECTIVE COVERED:

- 1G. distinguish the internal layers (crust, mantle, and core) of the Earth.

12. How do temperature and pressure change with increasing 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°C per km) in the upper crust and declines (to about 10°C per km) at greater depths.

BLOOM'S LEVEL: Remembering

LEARNING OBJECTIVE COVERED:

- 1H. explain the relationship between the lithosphere and the asthenosphere.

13. What is the Moho? Describe the differences between continental crust 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, mostly felsic to intermediate, and, overall, is less dense than oceanic crust.

BLOOM'S LEVEL: Remembering

LEARNING OBJECTIVE COVERED:

- 1G. distinguish the internal layers (crust, mantle, and core) of the Earth.

14. What is the mantle composed of? Is there any melt in it?

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 OBJECTIVE COVERED:

- 1G. distinguish the internal layers (crust, mantle, and core) of the Earth.

15. What is the core composed of? How do the inner and outer cores differ? Which produces the magnetic field?

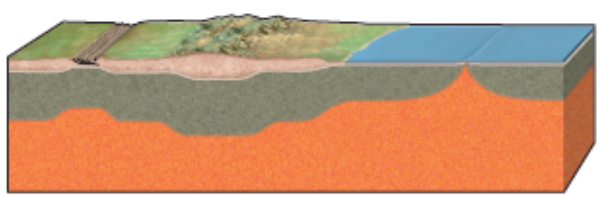
ANS: The core is mostly iron mixed with nickel and small amounts of sulfur, oxygen, silicon, and other elements. The inner core is solid, whereas the outer core is liquid. The magnetic field is generated by the rapid convective flow of the outer core.

BLOOM'S LEVEL: Remembering

LEARNING OBJECTIVE COVERED: G

- 1G. distinguish the internal layers (crust, mantle, and core) of the Earth.

16. What is the difference between lithosphere and asthenosphere? Identify each in the figure here.



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 km of depth.

BLOOM'S LEVEL: Remembering

LEARNING OBJECTIVE COVERED:

- 1H. explain the relationship between the lithosphere and the asthenosphere.

17. At what depth does the lithosphere-asthenosphere boundary occur? Is this above or below the Moho? Is the asthenosphere entirely liquid?

ANS: The boundary occurs where the temperature reaches about 1,280°C because at temperatures higher than this mantle rock becomes soft enough to flow. This generally lies below a depth of 100 to 150 km, which is below the Moho. The asthenosphere is not entirely liquid, but can flow like a soft plastic.

BLOOM'S LEVEL: Understanding

LEARNING OBJECTIVE COVERED:

- 1H. explain the relationship between the lithosphere and the asthenosphere.

On Further Thought

18. Are all the stars that we see today considered to be first-generation stars? What is the evidence for your answer?

ANS: This is incorrect. First-generation stars tended to be very massive and thus burned hotter and faster before running out of fuel and dying (a few million to a few tens of millions of years). In addition, these stars did not contain heavier elements, which form through supernovae (their explosive deaths). Therefore, the presence of heavier elements in the universe is evidence that the stars we see are primarily later-generation stars.

BLOOM'S LEVEL: Applying

LEARNING OBJECTIVE COVERED:

- 1D. explain the nebula theory, a scientific model that describes how stars and planets form.

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 OBJECTIVE COVERED:

- 1H. explain the relationship between the lithosphere and the asthenosphere.

CHAPTER 2

The Way the Earth Works: Plate Tectonics

Learning Objectives

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

A. explain Alfred Wegener's continental-drift hypothesis and the evidence he used to show that it takes place.
B. list observations from studies of the ocean floor that led Harry Hess to propose seafloor spreading.
C. explain how studies of paleomagnetism and marine magnetic anomalies prove continental drift and seafloor spreading.
D. sketch a cross section of the lithosphere, and contrast oceanic and continental lithosphere.
E. use a map of earthquakes to locate plate boundaries and triple junctions.
F. distinguish among the three types of plate boundaries, and characterize geologic features associated with each.
G. discuss rifting, continental collision, and hot-spot formation, and show where these processes happen today.
H. characterize the processes driving plate motion, the rates at which this motion takes place, and how rates can be measured.

Summary from the Text

- Wegener proposed that continents had once been joined together to form a single supercontinent (Pangaea) and then drifted apart. This idea is the continental-drift hypothesis.
- Wegener supported his hypothesis by studying the matching shapes of coastlines; the distribution of Paleozoic glaciers, climate belts, and fossil species; and the correlation of rock assemblages.

- Around 1960, Hess proposed the hypothesis of seafloor spreading, which states that new seafloor forms at mid-ocean ridges, then spreads symmetrically away from the ridge axis. Ocean floor sinks back into the mantle at deep-ocean trenches.
- Rocks retain paleomagnetism, a record of the Earth's magnetic field at the time the rocks formed. By measuring paleomagnetism, geologists could use studies of apparent polar-wander paths to prove continental drift.
- Geologists documented that the Earth's magnetic field reverses polarity every now and then. Magnetic reversals explain the existence of stripe-like marine magnetic anomalies.
- A proof of seafloor spreading came from the interpretation of marine magnetic anomalies.
- The lithosphere is broken into discrete plates that move relative to each other. 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.
- The three types of plate boundaries—divergent, convergent, and transform—are distinguished from each other by the relative movement of plates.
- At divergent boundaries, which are marked by mid-ocean ridges, seafloor spreading produces new oceanic lithosphere.
- Convergent boundaries are marked by deep-ocean trenches and volcanic arcs. At convergent boundaries, oceanic lithosphere subducts beneath an overriding plate.
- Transform boundaries are marked by large faults along which one plate slides sideways past another.
- At triple junctions, three plate boundaries intersect.
- Hot spots are places where volcanism occurs at an isolated volcano. As a plate moves over the hot spot, the volcano moves off and dies, and a new volcano forms over the hot spot. Hot spots may be caused by mantle plumes.
- During rifting, continental lithosphere stretches and thins. If it finally breaks apart, a new mid-ocean ridge forms.
- Convergent boundaries cease to exist when a buoyant piece of crust (a continent or an island arc) moves into the subduction zone. When that happens, collision occurs.
- Ridge-push force and slab-pull force contribute to driving plate motions. Plates move at rates of about 1 to 15 cm per year. GPS satellite measurements can detect these motions.

Narrative Art Videos

BREAKUP OF PANGAEA

Learning Objectives Covered:

- 2D. sketch a cross section of the lithosphere, and contrast oceanic and continental lithosphere.
- 2F. distinguish among the three types of plate boundaries, and characterize geologic features associated with each.
- 2G. discuss rifting, continental collision, and hot-spot formation, and show where these processes happen today.
- 2H. characterize the processes driving plate motion, the rates at which this motion takes place, and how rates can be measured.

Length: 3:45

Summary: First, maps of several supercontinents that have formed and broken up in the past are shown. The processes of supercontinent formation by subduction, and breakup by rifting and seafloor spreading, are 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 the age of the seafloor. Spreading rates of the Atlantic are quantified.

Classroom Use: 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 go 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 the current width (6,000 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 United States millions of years into the future?

CONTINENTAL COLLISION

Learning Objectives Covered:

- 2F. distinguish among the three types of plate boundaries, and characterize geologic features associated with each.
- 2G. discuss rifting, continental collision, and hot-spot formation, and show where these processes happen today.

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 denser 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 in the geologic record of past continental collisions.

Classroom Use: 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.

Review and 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:

- 2E. use a map of earthquakes to locate plate boundaries and triple junctions.
- 2F. distinguish among the three types of plate boundaries, and characterize geologic features associated with each.

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 Use:

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 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 this an important idea to understand, 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.

Review and 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:

- 2E. use a map of earthquakes to locate plate boundaries and triple junctions.

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 Use: 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, a summary of some of the important processes that influence Earth's surface, or 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.

Review and 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:

- 2A. explain Alfred Wegener's continental-drift hypothesis and the evidence he used to show that it takes place.
- 2B. list observations from studies of the ocean floor that led Harry Hess to propose seafloor spreading.
- 2H. characterize the processes driving plate motion, the rates at which this motion takes place, and how rates can be measured.

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 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 collisions and rifting are happening.

Review and 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:

- B. list observations from studies of the ocean floor that led Harry Hess to propose seafloor spreading.
- C. explain how studies of paleomagnetism and marine magnetic anomalies prove continental drift and seafloor spreading.
- F. distinguish among the three types of plate boundaries, and characterize geologic features associated with each.
- G. discuss rifting, continental collision, and hot-spot formation, and show where these processes happen today.

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. While showing the video, ask students to observe specific geologic features they see forming, 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 mark and ask students to observe the topography and determine the type of plate boundary.

Review and 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:

- 2F. distinguish among the three types of plate boundaries, and characterize geologic features associated with each.

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 thins and asthenosphere rises and eventually erupts along the rift. The convergence of two plates of oceanic crust results in the subduction of the denser plate. The convergence of two plates—one of continental crust and one of oceanic crust—results in the subduction of the oceanic crust beneath the continental crust. The 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 Use:

1. Divide the class into small groups of two to three students, 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 to 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 three 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.

Review and 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?

PLATE BOUNDARIES

See Chapter 4 for a discussion of the animation.

HOT SPOT FORMATION

See Chapter 5 for a discussion of the animation.

Activities

PUZZLING EVIDENCE FOR CONTINENTAL DRIFT

Learning Objectives Covered:

- 2A. explain Alfred Wegener's continental-drift hypothesis and the evidence he used to show that it takes place.

Activity Type: Hands-On Investigation

Time in Class Estimate: 10 minutes

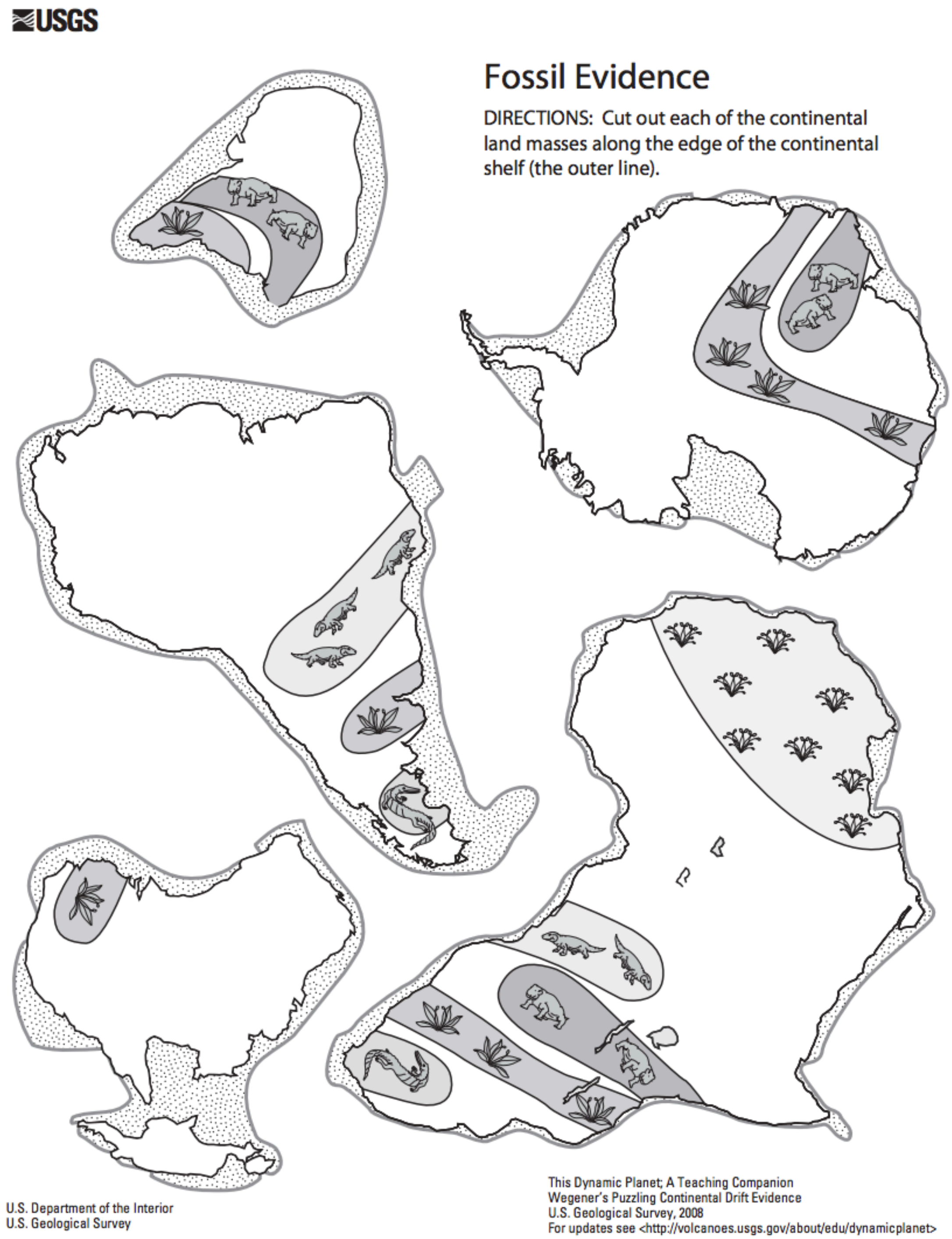
Recommended Group Size: 1–2 students

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/or 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 there. 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.



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:

- 2B. list observations from studies of the ocean floor that led Harry Hess to propose seafloor spreading.
- 2C. explain how studies of paleomagnetism and marine magnetic anomalies prove continental drift and seafloor spreading.

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:

- 2B. list observations from studies of the ocean floor that led Harry Hess to propose seafloor spreading.
- 2C. explain how studies of paleomagnetism and marine magnetic anomalies prove continental drift and seafloor spreading.

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 data table that follows, which shows 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. The data in this table came 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), 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?

PLATE BOUNDARY GALLERY WALK

Learning Objectives Covered:

- 2E. use a map of earthquakes to locate plate boundaries and triple junctions.
- 2G. discuss rifting, continental collision, and hot-spot formation, and show where these processes happen today.

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 whiteboard 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 five 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:

- 2E. use a map of earthquakes to locate plate boundaries and triple junctions.
- 2G. discuss rifting, continental collision, and hot-spot formation, and show where these processes happen today.

Activity type: Worksheet

Time in class estimate: 45 minutes

Group size: Individual

Materials: Copy of handout for all students

Classroom Procedures: The graphic organizer that follows can be used as a tool to synthesize and summarize students' lecture notes on plate boundaries and their characteristics. Students can use the 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 in combination with other active learning activities.

Adaptations:

- Hand out the worksheet after the lecture on the first type of boundary and have students fill out information incrementally after each boundary is discussed in class, rather than completing 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 the 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 and 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. Convincing Evidence for Seafloor Spreading and Continental Drift

   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 when you learned about them?

   ANS: Answers will vary.

   Learning Objectives Covered:

   - 2A. explain Alfred Wegener’s continental-drift hypothesis and the evidence he used to show that it takes place.
   - 2B. list observations from studies of the ocean floor that led Harry Hess to propose seafloor spreading.
   - 2C. explain how studies of paleomagnetism and marine magnetic anomalies prove continental drift and seafloor spreading.

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, then his ideas would have been more widely accepted. Of course, he died before either of those ideas came to be.

   Learning Objectives Covered:

   - 2A. explain Alfred Wegener's continental-drift hypothesis and the evidence he used to show that it takes place.
   - 2B. list observations from studies of the ocean floor that led Harry Hess to propose seafloor spreading.

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 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:

   - 2H. characterize the processes driving plate motion, the rates at which this motion takes place, and how rates can be measured.

4. 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:

- 2H. characterize the processes driving plate motion, the rates at which this motion takes place, and how rates can be measured.

5. 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:

   - 2G. discuss rifting, continental collision, and hot-spot formation, and show where these processes happen today.
   - 2H. characterize the processes driving plate motion, the rates at which this motion takes place, and how rates can be measured.

6. 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. Eventually, ocean basins get destroyed by subduction.

   Learning Objectives Covered:

   - 2G. discuss rifting, continental collision, and hot-spot formation, and show where these processes happen today.

7. 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 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:

- 2G. discuss rifting, continental collision, and hot-spot formation, and show where these processes happen today.
- 2H. characterize the processes driving plate motion, the rates at which this motion takes place, and how rates can be measured.

Answers to Review Questions

1. What was Wegener's continental drift hypothesis? What was his evidence? Why didn't other geologists accept Wegener's proposal of continental drift, at first?

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 OBJECTIVE COVERED:

- 2A. explain Alfred Wegener's continental-drift hypothesis and the evidence he used to show that it takes place.

2. How do apparent polar-wander paths show that the continents have moved?

ANS: Researchers have found multiple polar-wander paths on various continents, refuting the hypothesis that continents are fixed in position. Rather, the continents must have moved relative to a fixed pole and relative to each other. This confirmed Wegener's hypothesis that continents do move.

BLOOM'S LEVEL: Understanding

LEARNING OBJECTIVE COVERED:

- 2C. explain how studies of paleomagnetism and marine magnetic anomalies prove continental drift and seafloor spreading.

3. Describe the hypothesis of seafloor spreading.

ANS: Sea-floor 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. This process repeats continuously, so that the ocean basins grow wider over time. Seafloor spreading provided the mechanism for continental drift that was missing in Wegener's original hypothesis.

BLOOM'S LEVEL: Understanding

LEARNING OBJECTIVE COVERED:

- 2B. list observations from studies of the ocean floor that led Harry Hess to propose seafloor spreading.

4. Describe the pattern of marine magnetic anomalies across a mid-ocean ridge. How is this pattern explained?

ANS: Magnetic anomalies trend parallel to the axis of the nearest mid-ocean ridge, but they vary in width. Their patterns on one side of the axis look like the mirror image of the other side. These symmetrical reversals demonstrate that seafloor spreading takes place.

BLOOM'S LEVEL: Understanding

LEARNING OBJECTIVE COVERED:

- 2C. explain how studies of paleomagnetism and marine magnetic anomalies prove continental drift and seafloor spreading.

5. How did drilling into the seafloor contribute further proof of seafloor spreading? How did the seafloor-spreading hypothesis explain variations in ocean floor heat flow?

ANS: Drilling into the sediment layer of the ocean floor confirmed that the basal sediment in contact with basalt show an increase in age as you move further away from the mid-ocean ridge axis, proving seafloor spreading. The rate at which heat rises from the Earth's interior up through the crust is not uniform everywhere on the ocean floor. More heat rises beneath mid-ocean ridges than anywhere else (not counting hot spots). This led to the hypothesis that molten rock rises into the crust just below a mid-ocean ridge axis.

BLOOM'S LEVEL: Remembering

LEARNING OBJECTIVE COVERED:

- 2B. list observations from studies of the ocean floor that led Harry Hess to propose seafloor spreading.

6. What are the characteristics of a lithosphere plate? Can a single plate include both continental and oceanic lithosphere?

ANS: The lithosphere is the rocky outer portion of Earth, and is 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. A plate, such as the North American Plate, can have oceanic and continental lithosphere.

BLOOM'S LEVEL: Remembering

LEARNING OBJECTIVE COVERED:

- 2D. sketch a cross section of the lithosphere, and contrast oceanic and continental lithosphere.

7. How does oceanic lithosphere differ from continental lithosphere in thickness, composition, and density?

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

BLOOM'S LEVEL: Understanding

LEARNING OBJECTIVE COVERED:

- 2D. sketch a cross section of the lithosphere, and contrast oceanic and continental lithosphere.

8. How do we identify a plate boundary?

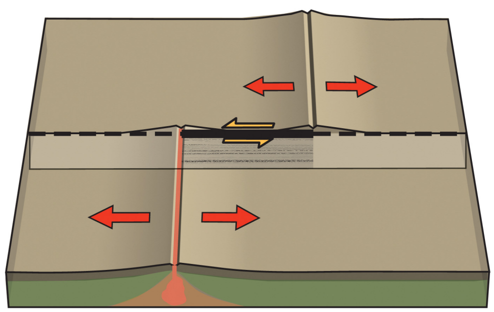
ANS: Plate boundaries are marked by linear or arc-like segments of relatively high earthquake frequency (earthquake belts); convergent and divergent plate boundaries are also the locations of increased volcanic activity. Modern geoscientists use GPS to delineate and distinguish different types of plate 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 OBJECTIVE COVERED:

- 2E. use a map of earthquakes to locate plate boundaries and triple junctions.

9. Describe the three types of plate boundaries. Which type of plate boundary does the line labeled with yellow arrows show in the figure?



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.
The plate boundary labeled with yellow arrows is a transform boundary.

BLOOM'S LEVEL: Remembering

LEARNING OBJECTIVE COVERED:

- 2F. distinguish among the three types of plate boundaries, and characterize geologic features associated with each.

10. How does 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 OBJECTIVE COVERED:

- 1D. sketch a cross section of the lithosphere, and contrast oceanic and continental lithosphere.

11. Why is the oldest oceanic lithosphere less than 200 Ma?

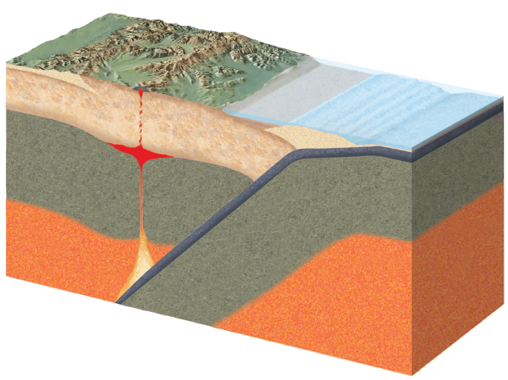
ANS: Over time, oceanic lithosphere is recycled as it moves away from where it formed at the mid-ocean Ridge. Eventually, oceanic lithosphere will be destroyed and recycled through subduction at an active margin, or incorporated into a passive margin.

BLOOM'S LEVEL: Understanding

LEARNING OBJECTIVE COVERED:

- 2D. sketch a cross section of the lithosphere, and contrast oceanic and continental lithosphere.

12. Identify the major geologic features of a convergent boundary in the figure shown.



ANS: At a convergent boundary, a subduction zone is present and is marked by a deep trench where the subducting oceanic plate bends downward in opposition to the horizontal overriding plate. Sediments scrape off of 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 OBJECTIVE COVERED:

- 2F. distinguish among the three types of plate boundaries, and characterize geologic features associated with each.

13. Why are transform plate boundaries required on an Earth with spreading and subducting plate boundaries?

ANS: Transform boundaries occur where one plate slips sideways past another along a vertical fault, meaning that no lithosphere is destroyed or created. These boundaries accommodate the movement at divergent and convergent boundaries, as not every boundary results in the creation or destruction of lithosphere.

BLOOM'S LEVEL: Understanding

LEARNING OBJECTIVE COVERED:

- 2F. distinguish among the three types of plate boundaries, and characterize geologic features associated with each.

14. What is a triple junction?

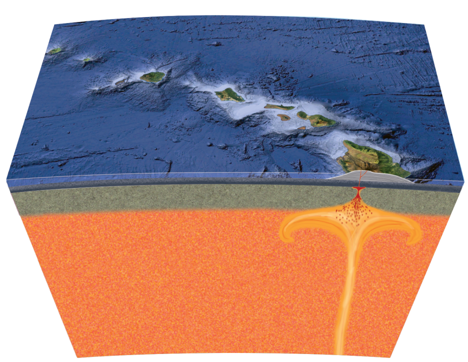
ANS: A triple junction is a point where three plate boundaries intersect, such as the triple junction north of San Francisco where the Cascadia trench, the San Andreas fault, and the Mendocino fracture zone intersect.

BLOOM'S LEVEL: Remembering

LEARNING OBJECTIVE COVERED:

- 2E. use a map of earthquakes to locate plate boundaries and triple junctions.

15. How is a hot-spot track produced, and how can hot-spot tracks be used to track the past motions of a plate? Which direction is the plate shown in the figure moving?



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 OBJECTIVE COVERED:

- 2G. discuss rifting, continental collision, and hot-spot formation, and show where these processes happen today.

16. Describe the characteristics of a continental rift and give examples of where this process is occurring 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 United States.

BLOOMS LEVEL: Understanding

LEARNING OBJECTIVE COVERED:

- 2G. discuss rifting, continental collision, and hot-spot formation, and show where these processes happen today.

17. 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 OBJECTIVE COVERED:

- 2G. discuss rifting, continental collision, and hot-spot formation, and show where these processes happen today.

18. 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 OBJECTIVE COVERED:

- 2H. characterize the processes driving plate motion, the rates at which this motion takes place, and how rates can be measured.

19. 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 OBJECTIVE COVERED:

- 2H. characterize the processes driving plate motion, the rates at which this motion takes place, and how rates can be measured.

On Further Thought

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

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 OBJECTIVE COVERED:

- 2C. explain how studies of paleomagnetism and marine magnetic anomalies prove continental drift and seafloor spreading.

21. The North Atlantic Ocean is 3,600 km wide. Seafloor spreading along the Mid-Atlantic Ridge occurs at 2 cm per year. When did rifting start to open the Atlantic?

ANS: 3,600 km ÷ (2 cm/year)(1 m/100 cm)(1 km/1000 m) = 3,600 km ÷ 0.00002 km/year = 180,000,000 years = 180 million years ago.

BLOOM'S LEVEL: Analyzing

LEARNING OBJECTIVE COVERED:

- 2H. characterize the processes driving plate motion, the rates at which this motion takes place, and how rates can be measured.