INSTRUCTOR'S MANUAL

EARTH SCIENCE

FIRST EDITION

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Instructor's Manual by

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Other Instructor Resources Available with *Earth Science*

Interactive Instructor's Guide

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

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

Smartwork5 Online Homework

The new Smartwork5 online assessment available for use with *Earth Science* features visual assignments with focused feedback. Because students learn best when they can interact with art as well as with text, Smartwork5 includes drag-and-drop figure-based questions, animation- and video-based questions, and What a Geologist Sees photo interpretations. Smartwork5 also provides questions based on real field explorations, via GeotoursGoogle Earth exercises, and helps students check their knowledge as they go by working with reading-based questions and pre-made and easy-to-assign reading quizzes.

Designed to be intuitive and easy to use for both students and instructors, Smartwork5 makes it a snap to assign, assess, and report on student performance, and to keep the class on track. Smartwork5 now works with tablet and mobile environments, and also has single sign-on capability with your institution's learning management system.

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.

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Available at no cost to professors or students, Norton Coursepacks bring high-quality Norton digital media into a new or existing online course. Working within your school's LMS, and without additional login, Norton course-packs offer a selection of Reading Quizzes for each chapter, featuring rich visual and media based questions. Instructors can also provide on-line access to all the videos and animations developed for *Earth Science*. Additional content includes links to our Test Bank, Geotour questions, and links to the ebook. Coursepacks were prepared with the consultation of the author and other instructors, especially Dr. Marianne Caldwellof Hillsborough Community College.

To download the Norton Coursepack for your campus LMS, go to the Earth Science Instructor's page.

Test Bank

The Test Bank, created by **the same authors behind the Instructor's Manual**, has been written to correlate to text learning objectives and to provide 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, 10 short-answer or essay questions that test student critical thinking and knowledge-application skills, and several art-based questions using 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, RTF, or Examview formats, go to the Earth Science Instructor's page.

PowerPoints

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

- Enhanced Art 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.
- 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.
- Clicker questions for each chapter can be added as-needed to existing PowerPoint decks to check student comprehension in class.

Animations, Simulations, and Videos

Marshak's online resources are designed to be easy to use and visually appealing. Animations, interactive simulations, narrative art 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 simulationsare 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.

InstructorUSB

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

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Conversion Guide

Marshak/Rauber **to** Tarbuck/Lutgens/Tasa

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Prelude

Welcome To Earth Science!

<u>Learning Objectives</u>

By the end of the chapter students should be able to . . .

A. describe the variety of subjects that an Earth Science course encompasses.
B. evaluate whether a news story pertains to an aspect of Earth Science, and how.
C. understand the concept of the Earth System and describe its key components.
D. explain why studying our Universe can help us understand our home planet and to address practical issues.
E. analyze an example of a scientific investigation.
F. recall some of the key themes of Earth Science.

<u>End of chapter question answers</u>

Review Questions

1. What are the various subjects that an Earth Science course might cover?
Answer: Earth Science includes geology, oceanography, atmospheric science (meteorology and climate science), and astronomy.

2. Describe the different components of the Earth System. Name the three principal layers of the geosphere.
Answer: The Earth System includes the geosphere (the part of the Earth that starts at the solid surface and goes down to the center), hydrosphere (the liquid or solid water of the Earth), atmosphere (the layer of gas that surrounds the Earth), and the biosphere (all living organisms on Earth and the part of Earth where they live). The solid portion of the hydrosphere is sometimes considered a separate realm called the cryosphere. The geosphere is comprised of three principal layers: the crust, mantle, and core.

3. What are the various kinds of energy that play a role in driving the activity of the Earth System and causing aspects of the system to change over time? What is a "cycle" in the Earth System?
Answer: The Earth System is powered by both internal and external energy. Internal energy allows Earth to remain hot and relatively soft inside, and this drives plate motions and all of their associated consequences. External energy for the Earth System travels to the Earth from the Sun in the form of light, which helps heat the Earth System. External energy and gravity drive the wind and currents as well as transport thermal energy and materials from one location to another. A cycle in the Earth System involves materials passing among different parts of a given realm, or realms, over time.

4. Describe some of the ways you might use your understanding of Earth Science to address problems that you might face in your community.
Answer: Understanding Earth Science can help you address problems in your community in many ways. Understanding Earth Science can help you to understand weather patterns and climate. It can help you decide where to live—is the location you have selected safe from natural hazards like floods, landslides, or earthquakes? Earth Science can help you question whether your drinking water is safe. Knowledge of Earth Science can also help you know when to worry about natural hazards, and it can help you to better understand and formulate opinions about issues that have societal consequences, like climate change.

5. Explain the difference between cosmologic and geologic time. Imagine that a continent moves at 5 cm per year. How long would it take to move 2,000 km? What percentage of geologic time does this represent?
Answer: Cosmologic time describes intervals of time related to the events in the history of the Universe, whereas geologic time is used for intervals of time related to the history of the Earth. Cosmologic time covers a far greater time span than geologic time (13.8 billion years verus 4.54 billion years, respectively).

For a continent moving at 5 cm/yr to travel 2,000 km:
5 cm/yr × 1 km/100,000 cm = 5×10^{-5} km/yr
2,000 km ÷ 1 yr/5×10^{-5} km = 40,000,000 years = 40 million years (Ma)

All of geologic time = 4.54 billion years (Ga)
40 Ma ÷ 4.54 Ga = 40,000,000 yr ÷ 4,540,000,000 yr = 0.88% ≈ 0.9% of geologic time

6. Name some of the practical applications of Earth Science. How can Earth Science help you understand sustainability and environmental issues?
Answer: Practical applications of Earth Science include deciding where to live, if your drinking water is safe, what the weather will be, when to worry about naturals hazards, and how to interpret issues with social consequences. Earth science can help you to understand sustainability and environmental issues because it discusses the origin and supplies of natural resources allowing us to analyze whether we can continue to maintain or improve our standard of living without running out of resources. It also helps us to understand why many activities of society can impact environmental quality.

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

Answer: Geologic resources, like coal, come from the Earth's crust, and are found in various places and concentrations throughout the world. Geologic processes, such as metamorphic, sedimentary, and igneous processes, are responsible for the concentration of minerals and rocks. Through geologic exploration, deposits of resources suitable for commercial exploitation, like coal, are extracted from the ground and put to use.

Real World Videos

SCIENCE FOR A CHANGING WORLD

Learning Objectives Covered:

- Pre.A: Describe the variety of subjects that an Earth Science course encompasses.
- Pre.C: Understand the concept of the Earth System and describe its key components.
- Pre.E: Analyze an example of a scientific investigation.

Length: 8:11

Summary: This video describes a brief history of the USGS and the significance of USGS's work and mission in today's world and its value in the past.

Classroom uses: This video helps students to understand the broad areas of science involved in studying the Earth System.

Discussion questions:

1. What are some of the major areas of Earth Science that the USGS supports?
2. What are some of the greatest challenges that the Earth System faces today?

HYDRAULIC FRACTURING: USING SCIENTIFIC METHODS TO EVALUATE TRADE-OFFS

Credit: Science 360 News (NSF)

Learning Objectives Covered:

- Pre.E: Analyze an example of a scientific investigation.

Length: 3.06

Summary: This video uses the example of hydraulic fracturing (fracking) to discuss how scientists turn data and information into useful knowledge that can guide environmental decisions. The video shows how several researchers are exploring fracking's potential impacts on water and air quality, human health, and energy sustainability.

Classroom Use: This video helps students to understand the importance of applying the scientific method to make objective decisions about important societal issues.

Discussion Questions:

1. What role does science play in determining the types of energy resources we use?
2. What are some of the questions that scientists are asking about hydraulic fracturing?

ARCTIC SEA ICE RETREAT

Credit: NASA Scientific Visualization Studio

Learning Objectives Covered:

- Pre.C: Understand the concept of the Earth System and describe its key components.

Length: 0:37

Summary: The cryosphere is an important Earth sphere. This animation shows the annual Arctic sea ice minimum from 1979 to 2015 with a superimposed graph showing the area of the minimum sea ice versus the year. The concentration and extent of sea ice in the Arctic has been on the decline since the 1980s.

Classroom Use: This video helps students to understand the importance of studying the crysphere.

Discussion Questions:

1. Why is the cryosphere an important part of the Earth System?
2. What hypothesis might explain why Arctic sea ice has been declining over the past several decades?
3. What might happen to sea levels around the world if Arctic sea ice continues to decline? Remember that further decline means more liquid water enters the world's oceans.

THE ROLE OF HYDROGRAPHY IN THE NATIONAL MAP

Credit: USGS

Learning Objectives Covered:

- Pre.C: Understand the concept of the Earth System and describe its key components.

Length: 6:33

Summary: This video describes the National Hydrography Dataset component of The National Map, maintained by the USGS, that provides detailed information about surface water in the United States. This information is used by scientists and local water boards to determine changes to surface water supplies, the best use of water resources, and threats to these resources. Users of the National Hydrography Dataset discuss its role in water rights management in California, fisheries management in Michigan, and drinking water threat analysis around the country.

Classroom Use: This video helps students to understand the importance of studying the hydrosphere and how a central federal database helps in these efforts.

Discussion Questions:

1. Why is it important to analyze and understand the locations of water and its flow?
2. What is an example of an environmental problem that can be addressed by analyzing water flow data?
3. What types of data can be added to The National Map to make it even more useful for scientists?

Activity

USING EARTH SCIENCE IN DAILY LIFE

Learning Objectives Covered:

- Pre.A: Describe the variety of subjects that an Earth Science course encompasses.

Activity Type: Think-Pair-Share

Time in Class Estimate: 5 minutes

Recommended Group Size: 2–4 students

Classroom Procedures: Pose the question, "How have you used Earth Science in your life so far without knowing it?" Have students engage in a think-pair-share discussion for about 5 minutes with 1–3 of their immediate neighbors.

Answer Key: Every student will have used Earth Science in their life, with the most common application probably being a weather report. Other common uses include deciding where to live, where to travel, or what environmental causes to support. Stargazing could also be considered a use of Earth Science, as a student sees the stars as tiny points of light and understands that they are immensely far away, thereby understanding our context in the universe.

Reflection questions:

1. Why is the study of Earth Science increasingly important in today's society?

2. Whether or not you choose to pursue a career in Earth Science, how will the study of it impact your life?

Tarbuck Correlation Guide

Marshak&Rauber	**Tarbuck, Lutgens&Tasa, 14e**
P.1 Introduction	n/a
P.2 What's in an Earth Science Course?	1.1 What is Earth Science
P.3 Narrative Themes of This Book	n/a
P.4 Why Study Earth Science?	n/a

Chapter 1

From The Big Bang To The Blue Marble

Learning Objectives

By the end of the chapter students should be able to . . .

A. provide the scientific explanation for the origin of the Universe and the elements in it.
B. describe how, according to the nebular theory, the Earth formed.
C. interpret features that a space probe would detect when approaching the Earth from space.
D. classify the great diversity of materials that the Earth contains.
E. create a model of the basic internal layers of the Earth.

End of chapter question answers

Review Questions

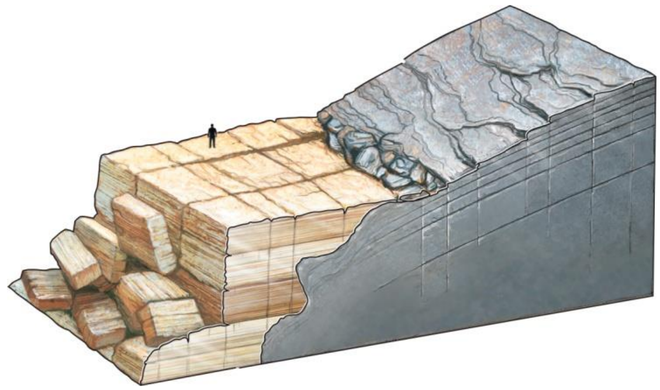
1. How many planets does our Solar System contain, and what is the position of the Solar System in the Milky Way Galaxy?
Answer: There are eight planets in the Solar System. The Solar System is located near the outer edge of a curving arm of the Milky Way.

2. What is the difference between a nebula and a vacuum?
Answer: A vacuum is a volume that contains virtually no matter. A nebula is a visible cloud of gas and dust.

3. Explain the expanding Universe theory and its relationship to the Big Bang theory. According to the theory, when did the Universe form?
Answer: The expanding Universe theory proposed by Edwin Hubble states that distant galaxies are moving away from the Earth at great velocity, and thus the Universe is expanding much like a ball of rising raisin-bread dough. The Universe has been expanding since the Big Bang, the cataclysmic blast that is the origin of our physical Universe, which took place at about 13.8 Ga.

4. Distinguish between Big Bang nucleosynthesis and stellar nucleosynthesis. Why is it fair to say that we are all made of stardust?
Answer: In Big Bang nucleosynthesis, hydrogen atoms collided and underwent nuclear fusion to form helium atoms as well as tiny amounts of other atoms with small atomic numbers. During stellar nucleosynthesis, elements up to and including iron form inside stars as smaller nuclei fuse together to form larger ones. It is fair to say that we are all made of stardust since the mix of elements we find on Earth, including within our own bodies, comes from the hearts of extinct stars.

5. The image shows a nebula formed by a supernova explosion. How many elements does it contain?
Answer: The nebula in the image (the Crab Nebula) contains a wide array of elements: light elements such as hydrogen and helium (formed during Big Bang nucleosynthesis), heavier elements such as carbon through iron (formed during a star’s later stages of life), and the heaviest elements such as iron through uranium (formed through conditions found in a supernova).



6. Describe the steps in the formation of the Solar System according to the nebular theory.
Answer: First, a nebula forms, and gravity pulls the gas and dust of the nebula inward to form an accretionary disk. A protosun forms in the center of the disk. Dust concentrates in the inner part of the disk while volatiles are blown into the outer part of the disk by the solar wind, where they freeze into ice. Dust and ice particles collide and stick together, forming planetesimals that grow by continuous collisions. Gravity reshapes the proto-Earth and other planets into spheres and allows differentiation to take place.

7. Why isn’t the Earth homogeneous, and why is it round?
Answer: Earth is heterogeneous and round because early in its formation it became large enough for its interior to become warm and soft. Gravity could then act on materials in the interior of the planet and cause them to flow. Materials separated into layers of different density, resulting in differentiation and producing a layered, heterogeneous Earth. Gravity also molded Earth into a rounded shape so that the force of gravity is nearly the same at all points on its surface.

8. What is the Earth’s magnetic field? How does the magnetic field interact with the solar wind?
Answer: Earth’s magnetic field is the region affected by the magnetic forces generated inside the Earth. Earth’s magnetic field is a dipole; it has a north and south pole. The solar wind, which contains charged particles, warps the Earth’s magnetic field into a huge teardrop pointing away from the Sun. Fortunately the magnetic field deflects most of the solar wind from Earth, acting like a shield.

9. What is the Earth’s atmosphere composed of? Why would you die of suffocation if you were to jump from a jet?
Answer: Earth’s atmosphere is the layer of gas that surrounds the Earth and is held in place by gravity. It is composed of 78% nitrogen, 21% oxygen, and 1% trace gases like carbon dioxide, methane, and argon. Air pressure—and thus the number of air molecules—decreases with increasing altitude. So if you were to jump out of a jet, which typically flies at an altitude of 12–15 km, the air pressure would be so low that there would not be enough oxygen to breathe, and you would suffocate.

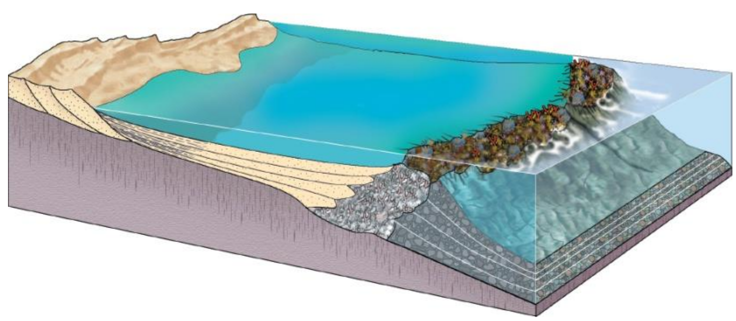
10. What is the proportion of land area to sea area on Earth? Is the seafloor completely flat? How about the land surface?
Answer: Water covers about 70% of the Earth's surface. Neither the land area nor the seafloor is completely flat.

11. Describe the major categories of materials constituting the geosphere.
Answer: The major categories of materials constituting the geosphere include melts (molten material), minerals (solid, naturally occurring substances with definable chemical compositions in which atoms are arranged in an orderly pattern), glasses (solids in which atoms are not arranged in an orderly pattern), sediments and soils (accumulations of loose mineral grains that are not stuck together), metals (solids composed of metallic atoms), and rocks (solid aggregates of mineral crystals or grains or of natural glass).

12. Distinguish among the various realms of the Earth System.
Answer: The Earth System is composed of a number of realms. The atmosphere is the layer of gas that surrounds the Earth. The hydrosphere includes both the liquid and frozen water on the planet. The geosphere is the solid Earth; it includes a variety of different materials. The biosphere consists of living organisms and the realm in which they can survive.

13. How do temperature and pressure change with increasing depth in the Earth?
Answer: Temperature and pressure both increase with depth in the Earth.

14. Label the principal layers of the Earth on the figure.
Answer: The Earth has three principle layers: 1) the thin, not-so dense crust, 2) a solid, high-density rock mantle, and 3) a very dense metal-alloy core.



15. What sources provide geologists with information about the character of the Earth's interior?
Answer: Scientists learn about Earth's interior by studying igneous rocks, pieces of asteroids, and by developing models of the interior. Additionally, geologists have been able to refine the image of the Earth's interior by measuring the speed and path of seismic waves that pass through the Earth from earthquakes.

16. What is the Moho? Describe basic differences between continental crust and oceanic crust.
Answer: The Moho is the boundary between the base of the crust and the top of the mantle. Continental crust, the crust beneath most land, has a thickness that ranges between 25 and 70 km. Continental crust has an average composition similar to granite. Oceanic crust, the crust beneath the seafloor, has a thickness that ranges between 7 and 10 km. The oceanic crust is composed of basalt and gabbro and is covered by a thin layer of sediment

17. What is the mantle composed of? Is the mantle rigid and unmoving?

Answer: The mantle is composed of peridotite. It is a solid, but most of it is hot enough to be able to flow very slowly.

18. What is the core composed of? How do the inner and outer cores differ? Which produces the magnetic field?
Answer: The core is composed of iron alloy (a mix of iron with 4% nickel and up to 10% oxygen, silicon, or sulfur). The inner core is solid, whereas the outer core is molten. Flow in the outer core produces the Earth's magnetic field.

On Further Thought

19. Could a planet like the Earth have formed in association with a first-generation star?
Answer: A planet like Earth could not have formed in association with a first-generation star because the mix of elements we find on Earth contains heavier elements that form during stellar nucleosynthesis and supernova nucleosynthesis.

20. Why are the Jovian planets, which contain abundant gas and ice, farther from the Sun than the terrestrial planets?
Answer: During the formation of the Solar System, the early Sun generated a strong solar wind that melted ice particles (made up of volatile materials) in the inner part of the protoplanetary disk and blew their volatile materials to the outer part of the disk. As a result, dust (particles of refractory materials) concentrated in the inner rings of the protoplanetary disk and eventually formed the terrestrial planets. The volatile materials blown away by the solar wind refroze into ice in the outer rings of the disk, where they eventually formed the Jovian planets. Thus, the Jovian planets, those containing abundant gas and ice, are found farther from the Sun.

21. At highway speeds (100 km per hour), how long would it take for you to drive a distance equal to the thickness of continental crust? Of the entire mantle?From the base of the mantle to the core?
Answer: The Earth's radius is 6,371 km. Continental crust is between 25 and 70 km thick. The mantle is 2,885 km thick, and the distance from the base of the mantle to the center of the Earth is 3,471 km.
It would take 15–42 minutes to drive the equivalent of the continental crust.

25 km × 1 hour/100 km = 0.25 hours

0.25 hr. × 60 minutes/1 hour = 15 minutes

70 km × 1 hour/100 km = 0.7 hours

0.7 hr. × 60 minutes/1 hour = 42 minutes

It would take about 29 hours to drive the equivalent of the mantle.

2,885 km × 1 hour/100 km = 28.85 hours

It would take about 35 hours to drive from the base of the mantle to the center of the Earth.

3,471 km × 1 hour/100 km = 34.71 hours

Real World Videos

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

Learning objectives covered:

- 1B: Describe how, according to the nebular theory, the Earth formed.

Length: 1:29

Summary: This video describes how the energy from our young Sun—4 billion years ago—aided in creating molecules in Earth's atmosphere that allowed it to warm up enough to incubate life.

Classroom uses: This video can help students understand how the early Sun and Earth were much different than they are today. It also helps students understand the role the Sun played in creating Earth's atmosphere.

Discussion questions:

1. When it first formed billions of years ago, how did the Sun differ from today's Sun?
2. After the Earth first formed, what type of atmosphere did it have, if any?
3. How did the early Sun contribute to creating the Earth's early atmosphere?

HOW PLANETS ARE BORN

Learning objectives covered:

- 1A: Provide the scientific explanation for the origin of the Universe and the elements in it.
- 1B: Describe how, according to the nebular theory, the Earth formed.

Length: 0:38

Summary: This animation shows how material around a young star is shaped into planets over billions of years.

Classroom uses: This animation can help students visualize how, over time, dust particles can combine to form pebbles, which evolve into mile-sized rocks, then into planetesimals, and finally into planets that orbit their star.

Discussion questions:

1. How does the nebular theory explain the formation of the Sun and planets?
2. Explain why the nebular theory is difficult to test directly.

RESEARCHERS DISCOVER THE EARTH'S INNER-INNER CORE

Learning objectives covered:

- 1E: Create a model of the basic internal layers of the Earth.

Length: First 1.01 minutes of video (of 3:58 total)

Summary: This video discusses the makeup and characteristics of the Earth's inner core.

Classroom uses: This video allows students to visualize the internal layering of the Earth and understand how we study these layers.

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?

Activities

MATERIALS OF THE GEOSPHERE

Learning Objectives Covered:

- 1D: Classify the great diversity of materials that the Earth contains.

Activity Type: Think-Pair-Share

Time in Class Estimate: 5 minutes

Recommended Group Size: 2–4 students

Classroom Procedures: Pose the question, "What types of geosphere materials do you interact with on a daily basis? How?" Have students engage in a think-pair-share discussion for about 5 minutes with 1–2 of their immediate neighbors.

Answer Key: Students will have a variety of responses. Examples include rocks, minerals, sediment, soils, "dirt," sand, silt, mud, etc.

Reflection question: Ask students to consider the diversity of materials necessary for life as we know it, and make connections to their own, everyday lives.

WATER AND THE HYDROSPHERE

Learning Objectives Covered:

- 1D: Classify the great diversity of materials that the Earth contains.

Activity Type: Think-Pair-Share

Time in Class Estimate: 5 minutes

Recommended Group Size: 2–4 students

Classroom Procedures: Pose the question, "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?" Have students engage in a think-pair-share discussion for about 5 minutes with 1–2 of their immediate neighbors.

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

Reflection question: Why is ocean water not currently a viable resource for our water needs?

DIFFERENTIATION

Learning Objectives Covered:

- 1E: Create a model of the basic internal layers of the Earth.

Activity Type: Demonstration

Time in Class Estimate: 5–10 minutes

Recommended Group Size: whole class

Materials: empty water bottle with lid (labels removed so that it is fully transparent), water, oil, food coloring

Classroom Procedures: During lecture, discuss differentiation as it applies to Earth. Then, in a class demonstration, model the process of differentiation by pouring some water, oil, and a few drops of food coloring into an empty water bottle. Shake the bottle vigorously to produce a pseudo-homogenous mixture. Then let the oil and water separate—differentiate—into layers while students observe.

Reflection question: Following the demonstration, ask students to consider how the separation of the liquids in the bottle is similar to the differentiation that took place within the Earth. How is it different? (Hint: consider timeframes.)

Tarbuck Correlation Guide

Marshak&Rauber	Tarbuck, Lutgens&Tasa, 14e
1.1 Introduction	1.1 What is Earth Science
1.2 A Basic Image of the Universe	n/a (Chapter 24)
1.3 Formation of the Universe and Its Elements	n/a (Chapter 24)
1.4 Formation of the Earth	1.3 Early Evolution of Earth
1.5 The Blue Marble: Introducing the Earth	1.4 Earth's Spheres 1.6 The Face of Earth
1.6 A First Glance at the Earth's Interior	1.5 A Closer Look at the Geosphere

Chapter 2

The Way The Earth Works: Plate Tectonics

Learning Objectives

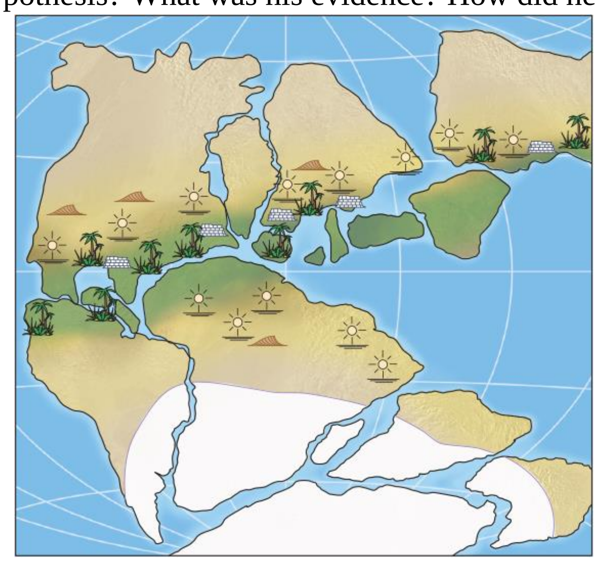
By the end of the chapter students should be able to . . .

A. discuss the evidence that Alfred Wegener used to justify his proposal that continents drift.
B. describe the process of seafloor spreading and the observations that allowed geologists to confirm it takes place.
C. contrast the lithosphere with the aesthenosphere, identify major plates of the lithosphere, and explain how the boundaries between plates can be recognized.
D. sketch the three types of plate boundaries, and describe the nature of motion that occurs across them.
E. relate types of geologic activity to types of plate boundaries, and explain how new plate boundaries can form and existing ones can cease activity.
F. outline the major ideas now included in the modern theory of plate tectonics, and reinterpret Wegener's observations in the context of this theory.
G. describe how measurements of paleomagnetism have helped to prove that plate tectonics happens.
H. explain the methods scientists use to describe and measure the velocity of plate motion.

End of chapter question answers

Review Questions

1. What was Wegener's continental-drift hypothesis? What was his evidence? How did he construct this map?



Answer: Alfred Wegener's continental-drift hypothesis suggested that the location of the continents had not remained fixed during the geologic past as had long been believed; instead he suggested that the continents had once fit together like pieces of a giant puzzle into one vast supercontinent. Over time the continents broke apart and moved into their present position. Wegener's evidence for his continental-drift hypothesis included the fit of the continents, distribution of climate belts in the past, distribution of fossils, and matching geologic units and mountain belts on different continents. His contemporaries argued that drift was impossible because no forces are strong enough to move the continents.

2. Describe discoveries made from the 1930s to the 1960s about the bathymetry of the seafloor.
Answer: Thanks to the invention of sonar, scientists were able to create a bathymetric map of the seafloor that revealed features of the ocean floor, including continental margins, ocean basins, abyssal plains, mid-ocean ridges, fracture zones, deep-sea trenches, and seamounts.

3. Do earthquakes occur randomly, or are they associated with bathymetric and topographic features? Does heat flow vary randomly, or are variations associated with bathymetric features? Explain your answers.
Answer: Earthquakes do not occur randomly; they occur in clusters along seismic belts. Seismic belts on the ocean floor correspond with trenches, mid-ocean ridge axes, fracture zones, and other faults. Heat flow does not vary randomly; heat flow beneath mid-ocean ridges is greater than that beneath abyssal plains. Bathymetric and topographic features on the ocean floor correspond with seismic zones and regions of increased heat flow; the seafloor is neither uniform nor random in nature.

4. What is the hypothesis of seafloor spreading as defined by Harry Hess? How did Hess explain how seafloor spreading could take place without an increase in Earth's circumference?
Answer: In his seafloor spreading hypothesis, Harry Hess suggested that the seafloor stretches apart along the axis of a mid-ocean ridge, and new oceanic crust forms from magma that rises and fills the void. Once formed, new seafloor moved away from the ridge, allowing oceans to grow larger with time. Because the circumference of the Earth remains constant, as new oceanic crust is created, older oceanic crust must be destroyed in a different location. Hess proposed that old seafloor is consumed by sinking back into the mantle at deep-sea trenches and that this movement generated the seismic belts observed along trenches.

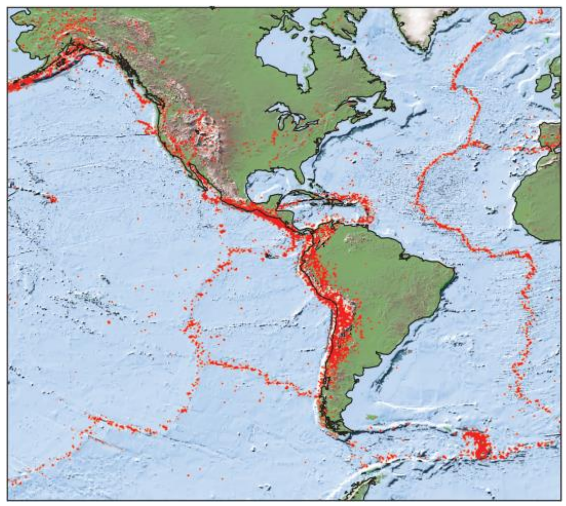
5. How did drilling into the seafloor help prove seafloor spreading?
Answer: Drilling of the seafloor helped prove seafloor spreading because it revealed that the thickness of seafloor sediments is not as great as expected, given the age of the Earth, and that the thickness of these sediments increases with distance from mid-ocean ridges. The former suggested that the seafloor is younger than the Earth, and the latter suggested that the mid-ocean ridges are younger than the abyssal plains. Thus, new seafloor must constantly be forming at the mid-ocean ridges.

6. What are the characteristics of a lithosphere plate? Is it composed of crust alone? What characteristic defines the boundary between lithosphere and asthenosphere?
Answer: The lithosphere is the rigid, outer shell of the Earth, which includes the crust and the uppermost portion of the mantle, known as the lithospheric mantle. The portion of the mantle that lies beneath the lithosphere is called the asthenosphere. The asthenosphere exhibits plastic behavior—that is, it can flow. The difference between the lithosphere and asthenosphere is behavioral, not compositional, and is the result of their different temperatures. At the base of the lithosphere, mantle rock reaches the temperature at which it can flow, 1,280°C (2,340°F).

7. How do active and passive continental margins differ?
Answer: Active continental margins coincide with plate boundaries; passive margins do not.

8. How does oceanic lithosphere differ from continental lithosphere, and how does this explain the existence of ocean basins?
Answer: Old oceanic lithosphere generally has a thickness of about 100 km, with the crustal part constituting only 7 to 10 km of the total. Continental lithosphere has a thickness of about 150 km, and the crustal part ranges from 25 to 70 km thick. The crustal part of continental lithosphere is less dense than that of oceanic lithosphere. Ocean basins exist because oceanic lithosphere is thinner and denser than continental lithosphere, so the surface of the continental lithosphere "floats" higher than the surface of oceanic lithosphere as they both rest on the underlying asthenosphere.

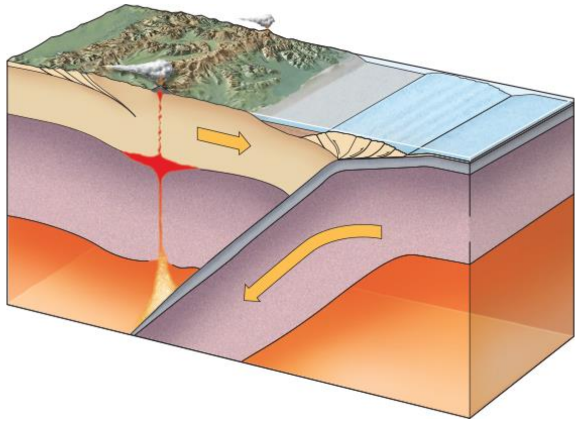
9. How do we identify a plate boundary? What plates appear on this map? Describe the three types of plate boundaries. For each, be sure to indicate the nature of relative plate motion, and name a bathymetric or topographic feature associated with that type of plate boundary.



Answer: Plate boundaries are identified by the presence of active faults. The three types of plate boundaries are divergent, convergent, and transform. Divergent boundaries, also known as spreading boundaries, occur where two plates move away from each other; this results in the formation of mid-ocean ridges and the creation of new oceanic lithosphere. Convergent boundaries are those where two plates move toward each other, allowing one plate to sink beneath the other; a subduction zone and associated volcanic arc and deep-sea trench result. Transform boundaries occur where one plate slides horizontally along the edge of another plate; this results in vertical transform faults.

10. How does oceanic crust form along a mid-ocean ridge? How does oceanic lithospheric mantle form?
Answer: As spreading takes place along a mid-ocean ridge, hot asthenosphere rises beneath the ridge. As it rises, it begins to melt, resulting in the formation of a magma chamber beneath the ridge axis. Some of this molten material erupts onto the surface and cools when in comes into contact with cold seawater. As new material makes its way to the surface, older material is forced away from the ridge axis, forming oceanic crust. At the ridge axis, lithospheric plates consist only of new crust. As this crust and the mantle directly beneath it move away from the ridge axis, further cooling takes place at greater and greater depths. Loss of heat from the mantle causes the boundary between cooler, rigid mantle and warmer, plastic mantle to become deeper. Because this boundary defines the base of the lithosphere, the oceanic lithosphere thickens as it ages.

11. Identify the major geologic features of a convergent boundary on this drawing.



Answer: Convergent boundaries, also known as subduction zones, are created as two plates come together, causing one plate to descend into the asthenosphere beneath the other. The resulting characteristic geologic features include a trench, an accretionary prism, and a volcanic arc.

12. Is new plate material formed or consumed at a transform boundary? Are all transform boundaries submarine?
Answer: At transform boundaries, plate material is neither formed nor consumed. All transform boundaries are not submarine. For example, large segments of the San Andreas fault of California are on land.

13. Describe the process of continental collision and give examples of where this process has occurred.
Answer: Continental collision occurs when two relatively buoyant pieces of crust converge at a plate boundary. Typically this takes place after the complete subduction of seafloor allows for the merging of two continental landmasses. Neither of these buoyant pieces of crust is able to subduct, so the continued convergence of the continents causes continuous mountain-building and the collisional boundary between the two landmasses to disappear. This occurred when India collided with Asia, and the Himalayas and Tibetan Plateau are the result. The Appalachian Mountains and the Alps are also consequences of continental collisions in the geologic past.

14. Describe the characteristics of a rift and give examples of where rifting takes place today.
Answer: The process of stretching and breaking a continent apart is called rifting. Near the surface of the continent, rifting leads to the formation of many faults. The faults bound blocks of crust that tilt and slip downward such that rift basins develop. The basins fill with sediments. Deeper down, where rock is warmer and softer, stretching takes place and the continental lithosphere thins. Some of the asthenosphere melts, producing magma that erupts as lava from volcanoes in the rift. Rifting is taking place today in several locations, including along the East African Rift.

15. What is a marine magnetic anomaly? How is it detected?
Answer: The term magnetic anomaly refers to the difference between the expected strength of Earth's main dipole field at a location and the actual observed strength of the magnetic field at that location. Marine magnetic anomalies define a distinct pattern of alternating bands aligned parallel to mid-ocean ridge axes. During times in Earth's history when polarity was normal, the basalt of the ocean floor indicates a positive anomaly. During times of reversed polarity, a negative anomaly occurs. These marine magnetic anomalies were discovered when magnetometers were towed back and forth across the ocean.

16. How is a hot-spot track produced, and how can hot-spot tracks be used to determine the past absolute motion of a plate?
Answer: A hot-spot track develops as a plate moves over a mantle plume; older, inactive volcanic islands are moved away from a hot spot, forming a chain of inactive islands and seamounts. The hot spot remains as a fixed spot in the mantle, and the lithospheric plate moves over the hot spot. As this motion takes place, volcanoes form, become extinct, and erode or subside. The remnants of these hot-spot volcanoes record past positions of the plate relative to the hot spot.

17. What is paleomagnetism? How did the discovery of apparent polar-wander paths serve as a proof that continents move?
Answer: The record of Earth's past magnetism recorded in rocks is called paleomagnetism. The apparent polar-wander path is the paleomagnetic record of the changing position of Earth's magnetic poles. If we assume that the continents have remained fixed throughout geologic time, the apparent polar-wander paths from different continents should all be the same. This was found to not be the case; each continent has a different, unique polar wander path. Thus, the continents must move relative to each other.

18. How did the observed pattern of marine magnetic anomalies form, and how did its existence help prove plate tectonics?
Answer: The observed pattern of marine magnetic anomalies formed as seafloor spreading took place. As ocean basins grew along mid-ocean ridge axes, bands of seafloor with different polarities formed and then moved away from the ridge axis, forming mirror-image patterns on either side of the ridge. The pattern of stripes and the direct relationship between the widths of the stripes and the durations of chrons serve as proof of plate tectonics.

19. Discuss the major forces that move lithosphere plates.
Answer: Convective flow, the process of circulation and heat transfer in a material that heats from below, takes place in the mantle and can influence long-term plate movements. Ridge-push force develops because the lithosphere beneath mid-ocean ridges sits higher than the lithosphere beneath adjacent abyssal plains. The elevated lithosphere spreads sideways due to gravity, and this motion drives plates in a direction pointing away from the ridge axis. Slab-pull force develops because the oceanic lithospheric mantle is cooler and denser than the warmer asthenosphere, so once a plate starts to subduct, it sinks. The subducted section slowly pulls the rest of the plate behind it.

20. Explain the difference between relative plate velocity and absolute plate velocity. Can we measure plate velocity directly?
Answer: Relative plate velocity describes the movement of one plate relative to another plate. Absolute plate velocity describes the movement of both plates relative to a fixed reference point that is not on one of the plates. Plate velocity can be measured directly using GPS, the global positioning system.

On Further Thought

21. Explain the bend in the Hawaiian-Emperor seamount chain in terms of the absolute motion of

the Pacific Plate.
Answer: Older volcanoes in the Hawaiian part of the chain run to the northwest, whereas those in the Emperor seamount portion trend more north-northwest. Because the hotspot remains stationary, we know that the absolute movement of the Pacific Plate was north-northwest as the Emperor seamount chain was forming. The movement of the plate then shifted more to the northwest during the formation of the Hawaiian Islands.

22. How does the existence of the Appalachian Mountains indicate that there was an ocean separating North America from Africa and Europe prior to the formation of Pangaea?
Answer: The Appalachian Mountains initially grew as a consequence of continental collision. For this to have taken place, an ocean basin separating North America from Africa and Europe must have been consumed by subduction as a result of convergent plate motion. Following the complete subduction of this ocean basin, North America collided with Europe and Africa, forming the Appalachian Mountains.

Narrative Art Video

BREAKUP OF PANGAEA
Length: 3 minutes, 44 seconds
Learning Objectives:

- 2C: Contrast the lithosphere with the asthenosphere, identify major plates of the lithosphere, and explain how the boundaries between plates can be recognized.
- 2F: Outline the major ideas now included in the modern theory of plate tectonics, and reinterpret Wegener's observations in the context of this theory.

Summary: This video uses paleogeographic maps to show how Pangaea formed and broke apart to produce the world we are familiar with today. Details include the rate of seafloor spreading and its variability along the mid-Atlantic ridge. The video also shows satellite imagery of folded rock in the Appalachian region that formed during the collisions that built Pangaea.
Classroom Use: This video can help the student visualize changes in the distribution of continents over time. It also gives the student an appreciation of the geological complexity of the Central American and Caribbean region. It can be viewed in shorter segments (e.g., breakup of Pangaea alone) or in its entirety.
Review and Discussion Questions:

1. Is Pangaea the only known supercontinent in Earth history?
2. Dinosaur fossils have been found on all major continents. Given that nearly all dinosaur species do not appear to be strong swimmers, how can you explain this finding?

Animations

PLATE BOUNDARIES
Learning Objectives:

- 2D: sketch the three types of plate boundaries, and describe the nature of motion that occurs across them.
- 2F: Outline the major ideas now included in the modern theory of plate tectonics, and reinterpret Wegener's observations in the context of this theory.

Summary: Relative plate motion for all major subcategories of divergent, convergent, and transform-plate boundaries are animated. The major geologic features of each boundary are described, and their origins are explained.
Classroom Use: This animation would be very helpful to students as they try to understand plate tectonics as a dynamic system. This animation can be used as a whole or as individual, self-contained components.
Review and Discussion Questions:

1. Where in the ocean basins would the oceanic lithosphere be thinnest?
2. What are the major differences between transform faults and fracture zones?

Real World Videos

SUBDUCTION TRENCH GENERATING TSUNAMI WAVES
Learning Objectives covered:

- 2F: Outline the major ideas now included in the modern theory of plate tectonics, and reinterpret Wegener's observations in the context of this theory.

Length: 0:37
Summary: This is ashort animation showing tsunami wave generation at a subduction trench.
Classroom uses: This animation allows students to visualize the mobile nature of Earth's crust.
Discussion questions:

1. How are subduction zones different from mid-ocean ridges?
2. What determines which plate will subduct below the other plate?

THE HOLOGLOBE PROJECT
Learning Objectives covered:

- 2F: Outline the major ideas now included in the modern theory of plate tectonics, and reinterpret Wegener's observations in the context of this theory.

Length: 1:09
Summary: This video describes the Earth's plate boundaries and their relationship to earthquakes and volcanoes.
Classroom uses: Use this video to help students visualize the Earth's plates and how they cause the movement of continents.
Discussion questions:

1. How many major plates make up the Earth's crust?
2. Why are volcanoes and earthquakes located near plate boundaries?
3. If new crust is formed at mid-ocean ridges, why does the size of the Earth not increase?

PLATE MOTIONS FROM 600 MILLION YEARS AGO TO TODAY
Learning Objectives covered:

- 2F: Outline the major ideas now included in the modern theory of plate tectonics, and reinterpret Wegener's observations in the context of this theory.

Length: 0:20
Summary: This video shows the Earth's plate motions from 600 million years ago to today.
Classroom uses: This video allows students to visualize the movement of continents from Pangaea to today.
Discussion questions:

1. How were the continents arranged on the planet 600 million years ago?
2. Are continents still moving today?

DEEP OCEAN VOLCANOES NEAR TONGA TRENCH
Credit: NOAA Ocean Today
Learning Objectives Covered:

- 2E: Relate types of geologic activity to types of plate boundaries, and explain how new plate boundaries can form and existing ones can cease activity.

Length: 1:50
Summary: This video describes the deepest ocean eruption ever found, the West Mata volcano. This volcano was discovered in an area between Samoa, Fiji, and Tonga nearly 4,000 feet below the surface of the Pacific Ocean.
Classroom Use: This video allow students to visualize volcanic activity in a deep ocean trench associated with a subduction zone.
Discussion Questions:

1. What type of plate movement occurs at deep ocean trenches?
2. What causes volcanoes to form at subduction zones?

Activities

ALFRED WEGENER
Learning Objectives Covered:

- 2A: Discuss the evidence that Alfred Wegener used to justify his proposal that continents drift.

Activity Type: Think-Pair-Share
Time in Class Estimate: 5 minutes
Recommended Group Size: 2–4 students
Classroom Procedures: Pose the question, “Consider the observations, or evidence submitted, by Alfred Wegener suggesting that the continents have not always been in their current positions. Based on knowledge at the time, how else could these observations have been explained?” Have students engage in a think-pair-share discussion for about 5 minutes with 1–2 of their immediate neighbors.
Answer Key: Much of the evidence that Wegener submitted for continental drift involved matching features on continents that are now widely separated, such as matching fossils, mountain ranges, and climate belts. Wegener proposed that these features formed as a single unit when the continents were once assembled into a single continent and then were broken apart when the continents drifted away from each other. These features could all have been instead explained as coincidence, that they just happened to occur on different continents at the same time. The way the continents fit together like a jigsaw puzzle is good, but not perfect, so the imperfect fit could be dismissed as coincidence as well.

Reflection question: Why do you think Wegener's hypothesis was initially rejected?

VELOCITY OF TECTONIC PLATES

Learning Objectives Covered:

- 2C: Contrast the lithosphere with the asthenosphere, identify major plates of the lithosphere, and explain how the boundaries between plates can be recognized.

Activity Type: Think-Pair-Share

Time in Class Estimate: 5 minutes

Recommended Group Size: 2–4 students

Classroom Procedures: Pose the question "We have learned that tectonic plates move at varying rates both absolutely and relative to each other. How might the relative velocity between two plates impact the geologic activity taking place at their boundary?" Have students engage in a think-pair-share discussion for about 5 minutes with 1–2 of their immediate neighbors.

Answer Key: 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. On average, normal movement along a plate boundary is only a few centimeters per year, much too slow for us to feel.

Reflection question: Can slow plate movements still cause major geologic activity?

OREO TECTONICS

Learning Objectives Covered:

- 2D: Sketch the three types of plate boundaries, and describe the nature of motion that occurs across them.
- 2E: Relate types of geologic activity to types of plate boundaries, and explain how new plate boundaries can form and existing ones can cease activity.

Activity Type: Hands-on demonstration

Time in Class Estimate: 10–15 minutes

Recommended Group Size: whole class

Materials: 1 unbroken Oreo (or Oreo-like) cookie for each student and the instructor

Classroom Procedures: Use the Oreo cookie to simulate each type of plate boundary, and to discuss the difference between the lithosphere (cookie portion) and asthenosphere (frosting).

- Divergent Boundary: Have students separate one of the cookies from the frosting, and break this cookie in half. Students then replace the cookie on the frosting, placing the two halves back together. To simulate a divergent boundary, gently press down and pull apart on the two halves. A small amount of frosting should well up in between the two halves, simulating a mid ocean ridge.
- Convergent Boundary: Students replace both halves on top of the frosting. They gently begin to force one half into the frosting at an angle beneath the other half. This represents subduction.
- Transform Boundary: Students once again place the two halves of the cookie next to each other on top of the frosting. The two halves are then slid laterally past each other. This results in some powdering of the cookie where the two halves meet. A transform boundary is simulated.

Reflection question(s):

1. What type of force is associated with each type of plate boundary?
2. What geologic and geographic features would likely be associated with each boundary type? Which of these features can be simulated using the Oreo?

Tarbuck Correlation Guide

Marshak&Rauber	**Tarbuck, Lutgens&Tasa, 14e**
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