Planet Earth

Land, Water, Sky

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Preface

For Teachers

Our Emphasis on Wonder, Integration, and Mastery

The goal at Centripetal Press has always been to transform the way science is taught. If you want science instruction in your school to realize the full potential of what students are capable of, teaching science the way it has been taught for the past several decades will not do. New methods and new points of emphasis are required. We summarize our contributions to the needed paradigm shift in terms of three categories—Wonder, Integration, and Mastery. These are addressed briefly below. A much fuller treatment is found in *From Wonder to Mastery*, by John D. Mays, scheduled for release in winter 2020–2021. This book may be found at ClassicalAcademicPress.com.

Wonder

The study of science should always begin with wonder. The world is a stunning place, full of surprises and jaw-dropping phenomena. But today there are many barriers standing in between our students and the world they might otherwise become fascinated with. Safety concerns interfere with kids playing and exploring outdoors. Liability concerns make it hard to find a decent chemistry set. And unfortunately, it is common today for young people grow up spending most of their time indoors with digital media. The natural draw of nature for developing youths is now commonly missed. Many people have never seen the night sky in an area that is completely dark and have no idea of the stunning beauty of the heavens at night. Most kids have not hiked or camped in the forests and have not learned to listen to the sounds made by animals, insects, and trees.

Additionally, the environmental challenges we face today from pollution, resource exploitation, and, especially, climate change require a new generation of people who care about the earth. But people usually do not care about what they do not love, and they do not love what they do not know about. Helping students to know the natural world has never been more important than it is today. Only if they know the world will students begin to love it, and only then will they be motivated to take care of it. To nurture this love, we begin with the natural wonder we feel when we encounter the natural world.

Integration

A second major aspect to the needed paradigm shift is that instruction must be integrative. The habit of compartmentalizing disciplines of learning must be eliminated. This habit currently pervades everything from problem assignments to lesson presentations to test design. Instead of isolating science content from everything else, critical points of effective integration must be developed. Some critical integration points include:

- frequent use of mathematical skills in science classes, and frequent science applications in math classes
- maximizing opportunities to develop good written expression on exams, lab reports, and papers
- developing key historical connections that serve to enhance understanding of science as a process; and
- treating, in addition to basic skills, the nature of scientific and mathematical knowledge, and the roles these play in leading us toward truth, goodness, and beauty.

Naturally, for integration to be effective, specific learning objectives must be developed, explained to students, and incorporated into assessments. Centripetal Press texts include clear learning objectives in every chapter.

Mastery

Mastery essentially means proficiency and long-term retention of course content. The first step toward mastery-learning is to change how we define success. The broken default pattern is what we call the Cram-Pass-Forget cycle: students cram for tests, pass them, and forget most of what they crammed in just a few weeks. Success in such an environment is a matter of jumping through assessment hoops. Students are not only cheated by this regimen, they are bored with it. And teachers are demoralized by the results.

By contrast, Centripetal Press advocates methods and curriculum designed to promote proficiency and long-term retention using a Learn-Master-Retain cycle. This first involves culling the content scope to an amount that truly can be mastered in the course of a school year. Many educators unthinkingly prioritize quantity over quality. But we believe students should be presented with a right amount of material they can learn deeply rather than a bloated scope of content they will neither comprehend nor remember. Even with a reduced scope, students who study for mastery typically outperform their peers as they move to higher level classes.

Second, leading students to mastery and retention requires teaching methods designed to produce these results. The standard approach used today involves teaching a chapter and giving a test on the chapter. By contrast, pedagogy designed for mastery and retention involves continuous review, ongoing accountability for previously studied material, and embedding of basic skills into new material. Of course, an effective method includes innovative strategies to enable students to master course content.

Considerations for Science Programming

This text has been specifically developed for application in grade seven or eight. If used in seventh grade, teachers may consider as optional parts of Section 4.1 on Atoms, Elements, and Crystals, especially Section 4.1.4 on Chemical Bonds. For students who study Physical Science in sixth or seventh grade and use this text in eighth grade, Section 4.1 will provide a good review of material covered in the physical science course.

Lab Journals and Lab Reports

The overall goal of experiment documentation for middle school students is to continue laying the foundation for writing full lab reports—from scratch—when they get to high school. The target is for students to begin writing lab reports in ninth grade, and the standard for such reports is presented in John D. Mays' book *The Student Lab Report Handbook* (available on our website). Toward that end, we believe lab reports at the middle school level should focus on students describing what they did, presenting their results, and engaging with the questions.

Part of integrating English language development into science instruction is accomplished through the use of lab journals. Each of the experiments included in this text requires students to document their work in a lab journal. Details about using lab journals are in the Preface for Students, as well as in the first chapter of *The Student Lab Report Handbook*.

In each of the Experimental Investigations, we have posed questions for students to engage with as they consider their results and observations. We have left decisions about the specifics of the student reports to the individual instructor; requirements should be based on the preparedness and background of the students in a given class.

Conducting Experiments

It is very important for all students to conduct the experiments included in this text. Interacting with content about the Earth through the text alone is an inadequate approach to this subject. Students need to study the actual topographic maps and handle actual minerals and rocks.

The instructions written in the Experimental Investigations provide the information students need. Additional details on resources, materials, suppliers, costs, and ways to enhance the lab activities are included in the Experiment Manual that is part of the Digital Resources for this text (available at ClassicalAcademicPress.com).

Companion Book and Digital Resources

As mentioned earlier, a mastery-based learning environment entails new teaching methods and new study techniques. These are described in detail in *From*

Wonder to Mastery, and we encourage teachers to read that book and implement the strategies discussed there. In particular, the discussion in Chapters 11–14 reviews the philosophy of mastery-based learning and methods necessary to realize it. Two of the most important strategies discussed in chapter are the weekly cumulative quiz and the Weekly Review Guides.

The Digital Resources available to accompany this text include a full year's worth of weekly quizzes, Weekly Review Guides, semester exams, and sample answers to questions. As described in *From Wonder to Mastery*, for students at this level we promote the use of a 30-minute, *cumulative* weekly quiz in place of chapter tests. Cumulative quizzes include questions each week from Objectives Lists throughout the portion of the text previously covered, all the way back to the beginning of the course. This assessment method is a thoroughly demonstrated way to realize significant improvements in student retention.

To enable students to succeed at the weekly cumulative quizzes, particularly after the sixth or eighth quiz when the quantity of material to remember becomes significant, teachers must consistently engage students with correct study methods. One of the essential components of the mastery-based program is the Weekly Review Guide. This important tool helps students to know how to study—and what to study—each week when long-term retention is the goal. The Digital Resources include a year's worth of Weekly Review Guides, which teachers should begin issuing to students in the third week of the course.

Notes on Using this Text

One of the major motivations behind the design of this text is for students to be delivered from the Cram–Pass–Forget cycle alluded to earlier. Compared to other texts, this book is small. An appropriate amount of content has been assembled for students to master in a single year of study.

But for mastery to be realized, certain practices need to be a regular part of the classroom experience. Regular review, rehearsal, and practice of older material must occur alongside the study of new material. Otherwise, students simply forget things a few weeks after being tested on them.

Here are a few specific practices that should be regularly present in classes using this text. These practices simply represent good teaching and should be part of any well-structured course.

1. *Class Discussion* Discuss concepts, ask questions, and give students opportunities to express concepts in their own words. Use the Learning Check questions at the end of each section and the Chapter Exercises as questions to stimulate discussion. All these questions should be discussed in class. Take time with this type of discussion and don't hurry. This is why the book is modestly sized—so there will be adequate time for extended discussion and deep engagement with the material.

2. *Group Study* Divide students into groups for teamwork on answering some of the more difficult questions in the Chapter Exercises. Then have teams take turns reporting their answers to the class. Stimulate discussion between teams about the merits of different answers to a particular question, and seek a class consensus on a well-formed answer.

3. *Review Discussion* Go through questions again from past chapters. It is also fun to create competitions among teams in which teams score points by giving good answers to review questions. Some kind of activity like this should occur at least once every 3–4 weeks throughout the duration of the course.

4. *Enrichment Activities* Although concepts are covered thoroughly in the text, understanding will be enhanced and memory will be strengthened when students engage with the content in activities outside the text. Classes should incorporate full-length instructional videos, classroom samples of different rocks and minerals, Internet images, YouTube videos, games, student presentations, projects, nature field trips, and other activities. Teachers should emphasize activities designed to make students *active* participants in the learning process, rather than simply passive observers.

5. *Learning Rock Names* The vocabulary list for Chapter 5 can appear daunting. Encourage your students to study these terms—as well as the terms from all other chapter vocabulary lists—using flashcards and frequent review. For challenging lists of terms such as the Chapter 5 vocabulary list, teachers should stretch out the learning process over an extended period of time. Mix class discussions with frequent use of classroom samples of the specific types of rocks listed in the vocabulary list, and use games and competition to make learning remembering the terms exciting and rewarding.

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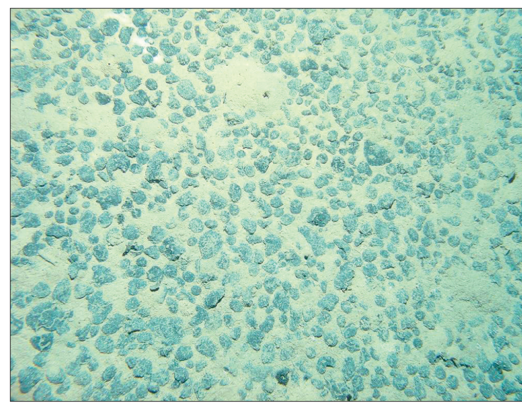
Preface

For Students

This text—*Planet Earth: Land, Water, Sky*—belongs to the academic discipline commonly known as Earth science. The world we live in is so full of surprises—and mysteries—that Earth science is one of the most fun of all the sciences to study. What kinds of processes could lead to formations as massive as the Grand Canyon? Why is the ocean floor covered with manganese nodules the size of baseballs? Why is there a gigantic magnetic field surrounding the Earth? What could possibly cause the orientation of that magnetic field to reverse direction every few million years? What causes the locations of active volcanoes to migrate over time? What causes the prevailing wind directions and ocean currents to be as they are? How in the world were scientists able to figure out what the deep interior of the Earth is made of? We address all these topics in this book, although there are still many questions we do not have answers for. (No one knows what causes the magnetic field reversals.)



Manganese nodules.

Stewarding Our Precious Planet

It is certainly an understatement to say that Earth is fascinating and fun to learn about. We have really enjoyed preparing this text and we hope you enjoy using it as part of your study of Earth science. One of our goals for you is that you develop a *love* for the Earth. We want you to appreciate its beauty and the delicate way the systems and organisms in this world are balanced. The intricate balance and beauty we see in nature are breathtaking!

It is important for us to act as good *stewards* of the planet we live on. The Earth is the only planet we have, and in our time the Earth is in need of our care and attention. But we humans generally do not properly care for things unless we love them, and we generally don't love things unless we spend time with them. We encourage you to find ways to spend time with the Earth—not just riding in cars around town, but exploring streams, walking in the woods, playing in the ocean, and hiking in the mountains. If you are going on vacation with your family, we encourage you to suggest to your parents to include stops at National Parks, National

Forests, or other natural spots during the trip so that you can experience the glories of this beautiful planet for yourself.

As you develop your understanding of Earth's processes, we hope you will also understand that our lovely planet is under a great deal of stress right now. The health of our environment and the millions of creatures that inhabit it cannot be sustained unless people everywhere work together to develop new habits of land management, new attitudes toward recycling and conservation, and new energy technologies. As a young person, you will soon be entering adulthood and making decisions about how to direct your energies as a member of the human community. We hope you will make your decisions with wise stewardship of the Earth well in mind.

Our planet needs stewarding if it is to continue to be the beautiful and life-sustaining world we know it to be.

Mastery

Another of our goals for you in this course is mastery: we don't want you simply to cram for tests, pass them, and then forget what you crammed about three weeks later. Instead, we want you to *learn*, *master*, and *retain* what you learn about the beautiful planet we inhabit. For this reason, the weekly quizzes we have made available to your instructor always include questions about things you studied in previous chapters. This happens all year long, and your quizzes when you are in Chapter 14 will still be asking you questions from Chapters 2, 4, 6, and all the other chapters.

To succeed at the weekly quizzes, you need to study in particular ways. First, we suggest that you make flashcards for the vocabulary terms in each chapter and that you review these flashcards regularly. Second, we suggest that you make use of the Weekly Review Guides that are available to your instructor. Go through the review activities carefully each week so that you can remember the material from early chapters. Third, you should also study the Objectives List at the beginning of each chapter and make sure you can perform every item on the list.

Learning any subject is frustrating if you feel like you are jumping through hoops but not accomplishing anything that is valuable or lasting. But learning is *a lot* more fun when you feel like you are truly learning, remembering, and growing. The study and review techniques listed above, and others that your instructor will introduce to you, will make the study of Earth science a wonderful experience.

Who knows? You may even find that you love this subject so much that you want to become a geologist, climate modeler, or environmental researcher!

Lab Journals

A third goal for our course is that you will expand your English language skills so that you can express yourself clearly and write accurate answers to scientific questions. One way to practice using English in scientific study is carefully to document your experimental work in your own lab journal. Here is some advice about using a lab journal with the Experimental Investigations in this text:

1. Keep your lab journal very neat and well organized. Don't doodle in it or mess it up.
2. Don't use a spiral notebook. Use a bound composition book with quadrille (graph) paper. (Quadrille paper makes it easy to set up tables and graphs.) A popular one to use is the Mead 09127, available at office supply stores and pictured to the right.
3. Put your name on it in case you misplace it.
4. For every experiment you work on, enter the following information:
    - the date (always enter the date again every day you work, as one always does with a journal)
    - the names of team members working with you (enter these also every day you work, so you have a record of who is there and who is not each time you meet)
    - a list of all equipment, apparatus, materials, and supplies you use in conducting the experiment
    - tables with *all* your data, with the original units of measure
    - calculations or unit conversions you perform as part of the experiment
    - observations or notes about anything that happens that you may need to write about in your report or remember later, including records of work that must be repeated and why
    - methods or procedures you use, and the reasons for using them

There are other items to enter in your journal that will become more important as you get into high school and college (such as sources, contacts, and prices for special chemicals or parts you have to order), but the list above should cover the things that you need to worry about for now. Take pride in maintaining a thorough lab journal. Make it your habit always to have it with you when you work on your experiments and always to document your work in it.

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Chapter 1

Earth In Space

In December 1968, three astronauts went into orbit around the Moon in the Apollo 8 spacecraft. This was the first time humans had gone further from Earth than just a few hundred kilometers above the surface. As they circled the Moon, the Apollo 8 crew were the first people to have a direct, close-up view of the desolate craters, plains, and mountains of another world. Since radio signals cannot go through or around the solid sphere of the Moon, they were out of radio contact with Earth for about thirty minutes each time they went behind the Moon. As they came back from their fourth journey behind the Moon, they saw something that caught their attention far more than the unexplored surface of the Moon—they saw Earth rising above the lunar horizon. The Moon was gray and barren; Earth on the other hand hung brilliantly in the sky with its blue oceans, white clouds and ice caps, and variously-hued continents. They journeyed 384,000 kilometers to the Moon, but then realized that the most important object in their view was not the Moon, but Earth.

Objectives

After studying this chapter and completing the exercises, you should be able to do each of the following tasks, using supporting terms and principles as necessary.

1. Define and describe the four major Earth systems.
2. Give examples of specialties practiced by different kinds of Earth scientists.
3. Describe Earth's location in the solar system, galaxy, and universe.
4. Define what a habitable zone is, and apply this definition to Earth's place in the solar system and the solar system's place in the Milky Way galaxy.
5. Give examples of ways in which Earth seems to be "just right" for complex life.
6. Describe Earth's orbit around the Sun.
7. Explain how the tilt of Earth's axis causes the seasons.
8. Explain why it is hot in the summer and cold in the winter in the Northern Hemisphere.
9. List, in order, the phases of the Moon throughout the lunar cycle.
10. Describe the position of the Sun, Earth, and Moon for each phase of the lunar cycle.
11. Explain what causes partial and total solar eclipses and explain why they do not occur every month.
12. Explain the cause of lunar eclipses.
13. Explain how solar, lunar, and lunisolar calendars work and give an example of each.
14. Compare the Julian and Gregorian calendars, explaining how the Gregorian calendar corrected a flaw in the Julian calendar.

Vocabulary Terms

You should be able to define or describe each of these terms in a complete sentence or paragraph.

1. Antarctic Circle
2. aphelion
3. Arctic Circle
4. atmosphere
5. autumnal equinox
6. biosphere
7. ecliptic
8. first quarter
9. full Moon
10. galaxy
11. geocentric model
12. geology
13. Gregorian calendar
14. habitable zone
15. heliocentric model
16. hydrosphere
17. Julian calendar
18. last quarter
19. lithosphere
20. lunar calendar
21. lunar phase
22. lunisolar calendar
23. meteorology
24. Milky Way galaxy
25. new Moon
26. oceanography
27. partial solar eclipse
28. penumbra
29. perihelion
30. solar calendar
31. solar eclipse
32. summer solstice
33. total lunar eclipse
34. total solar eclipse
35. Tropic of Cancer
36. Tropic of Capricorn
37. umbra
38. universe
39. vernal equinox
40. waning crescent
41. waning gibbous
42. waxing crescent
43. waxing gibbous
44. winter solstice

1.1 An Introduction to Earth Science

The image on the opening page of this chapter is a picture taken by astronauts on the spacecraft Apollo 17, the final mission to the Moon in 1972. From space, one can see that Earth is not a monotonous place. Some of its land surface is brown and barren, and other parts are covered with lush vegetation. Greater than 70% of the surface is covered by oceans. Both land and the oceans near the poles are covered with water in a different form: snow and ice. Forming a thin layer on top of all these is the atmosphere, with its ever-changing patterns of clouds.

1.1.1 Earth Systems

What you see from space can be categorized into different Earth systems, illustrated in Figures 1.1 through 1.5. Scientists think of these systems as concentric spheres, with the solid Earth at the center, then water, then the air. Living organisms are present in all three. This gives us four primary Earth systems: the lithosphere, the hydrosphere, the atmosphere, and the biosphere.

The *lithosphere* is the rigid outer layer of Earth, composed mostly of solid rock. The lithosphere includes Earth's crust and the upper part of the underlying mantle. The rocks of the crust are exposed in many places at the surface of Earth. There are two basic types of crust: continental crust and oceanic crust. The continental crust is composed largely of a lighter-colored rock called granite and averages about 30 to 40 km (20–30 mi) in thickness. On the other hand, the oceanic crust is typically about 5 km (3 mi) thick and composed of dark, dense igneous rocks (that is, rocks formed from molten rock) called basalt and gabbro. Beneath the lithosphere is the rest of Earth's rocky mantle, and beneath the mantle is Earth's iron core. We discuss Earth's crust, mantle, and core in Chapter 7.

The *hydrosphere* is the part of Earth that is made out of water. This water is present as a liquid in the oceans, seas, lakes, and rivers, and as groundwater in pores in rocks and soil. Additionally, water is present as a solid—snow and ice—on land and the polar oceans, and as a gas in the atmosphere. Most of Earth's water is present as salt water in the oceans. The greatest amount of fresh water—that is, non-salty water—is contained in ice, primarily in the ice caps that cover Greenland and Antarctica. Compared to the oceans and ice caps,

Figure 1.1. Lithosphere—the solid, rigid outer layer of Earth. This quarry is in Australia.

there is only a tiny amount of water in lakes and streams.

Earth is surrounded by a layer of gases called the *atmosphere*. The thickness of the atmosphere compared to the rest of the planet is like the peel of an apple compared to the rest of the fruit. The most abundant gas in the atmosphere is nitrogen (78%), followed by oxygen (21%). The remaining 1% is made up of argon, carbon dioxide, and a number of gases that are present in small proportions. The atmosphere also contains a variable amount of water vapor—water in its gaseous state.

Figure 1.2. Hydrosphere—Earth's water. Havasu Falls is in the Grand Canyon in Arizona.

The atmosphere serves a number of functions. The oxygen in the atmosphere is necessary for respiration for most living things, and the carbon dioxide is necessary for photosynthesis. The atmosphere also helps to maintain the temperature of the surface of Earth in a range that is suitable for advanced organisms such as plants and animals. In addition, the gases of the atmosphere help prevent various types of harmful radiation from the Sun and deep space from reaching Earth's surface.

The *biosphere* is made up of all organisms that live on Earth, together with the environments in which they live. Life exists in almost every environment on Earth:

Figure 1.3. Atmosphere—The gaseous layer that surrounds Earth. This thunderstorm occurred over New Mexico.

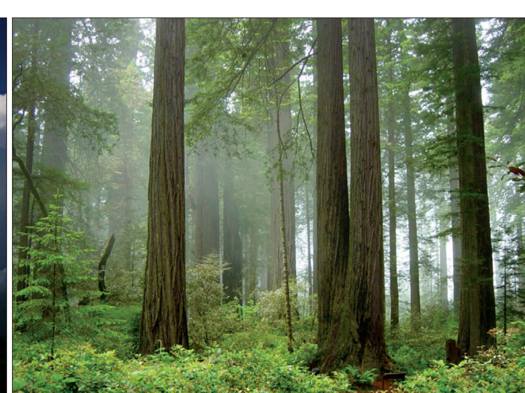


Figure 1.4. Biosphere—All living things on Earth. This temperate rainforest is in Redwood National Park in California.

Figure 1.5. All four Earth systems—lithosphere, hydrosphere, atmosphere, and biosphere—are interacting along this Atlantic Ocean coastline in Maine.

the surface, the soil, the air, the deep sea, hot springs, ice, and even cracks in hot rocks thousands of meters beneath the surface.

These four systems all interact with each other. It is obvious that organisms in the biosphere are dependent on the lithosphere, hydrosphere, and atmosphere for oxygen, water, nutrients, and space to live. However, not only does the biosphere use resources from the other systems, the biosphere in turn affects those systems as well. Plants have changed the atmosphere by producing oxygen. Plants also help to break down minerals in the soil by removing nutrients and exchanging water with the hydrosphere. Likewise, there are interactions between the lithosphere, hydrosphere, and atmosphere. For example, water—coming from the atmosphere—falls on Earth and causes erosion of the soil, which is part of the lithosphere. Many of the interactions between the solid Earth, water, air, and life are extraordinarily complex and are not fully understood.

1.1.2 Subdivisions of Earth Science

Figure 1.6. A geologist sampling 1150°C (2100°F) lava at Kilauea, a volcano in Hawaii.

Earth scientists work in a number of specialties. Traditionally, these are broken down into three major subdivisions: geology, oceanography, and meteorology, illustrated in Figures 1.6 through 1.8.

Geology is the study of the materials that make up Earth and the processes that change Earth over time. Geologists, of course, study rocks, but they also study a range of materials and processes that will be covered in this book, such as volcanoes, earthquakes, fossils, streams, glaciers, water resources, mineral resources, and energy resources.

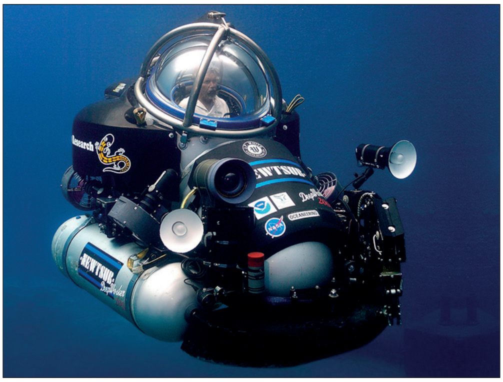


Figure 1.7. Oceanographers use submersibles such as DeepWorker *to explore the ocean's depths.*

Figure 1.8. Meteorologists using radar to study a tornado.

Oceanography is the study of the oceans. An oceanographer might study ocean currents, processes that occur on beaches, mineral resources on or beneath the ocean floor, or organisms that live in the ocean.

Meteorology is the study of the atmosphere. Meteorologists not only make weather observations and forecasts. They are also interested in studying air pollution and understanding long-term trends and changes in climate at various places.

1.1.3 Further Specializations

Due to the explosive growth of scientific knowledge, it is impossible for a geologist, oceanographer, or meteorologist to have complete knowledge of his or her subject. Usually, Earth scientists have a broad knowledge of the sciences and a specialty that is the focus of their work. Some specialties of Earth sciences include:

- Climatology — The study of climate, which is the long-term average of weather conditions in an area.
- Ecology — The study of the interactions between organisms and their environments. Ecology is often considered to be a topic in biology, but it is also an important topic in Earth sciences. Organisms affect Earth, and Earth affects the organisms that live on it.
- Geochemistry — The use of chemistry to understand Earth processes.
- Geophysics — The use of physics to understand Earth, including its shape, interior, magnetism, and surrounding space.
- Hydrology — The study of the movements and quality of water, either on Earth's surface or under it.
- Marine biology — The study of life and ecosystems in the oceans.
- Mineralogy — The study of the formation, composition, and distribution of minerals.
- Paleontology — The study of past life on Earth and how it has changed over time.
- Petroleum geology — The study of the location, migration, and production of oil and gas resources.

- Petrology — The study of rocks.
- Planetary geology — The application of geological principles to other worlds, such as planets, moons, and asteroids.
- Volcanology — The study of volcanoes.

This list represents only some of the many specializations within the Earth sciences. Even within these specialties, a scientist usually focuses on an even narrower topic. A climatologist might be most interested in desert climates, a paleontologist might specialize in coral fossils of the Jurassic Period, or a volcanologist might focus on the chemical composition of volcanic rocks produced from volcanoes like the ones in Hawaii. However, even within these specializations the best scientists are those who can relate their data to work being done by workers in other specializations. Because of this, scientists often work in teams and attend meetings with other scientists so they can exchange ideas and look for interactions and relationships between their work and that of others.

Learning Check 1.1

1. Distinguish among the lithosphere, hydrosphere, atmosphere, and biosphere.
2. Suggest two ways that the biosphere interacts with each of the other Earth systems.
3. Give a definition for each of the three major subdivisions of Earth science that you will learn about in this course.

1.2 Earth in the Solar System, Galaxy, and Universe

We cannot completely understand Earth without having an understanding of Earth's place in the solar system, galaxy, and universe. After all, things that happen at a great distance from Earth can greatly influence our planet. Energy from the Sun, produced by nuclear fusion of hydrogen and helium in the Sun's core, constantly bathes Earth's land, water, and air in the form of electromagnetic radiation. There is gravitational attraction between Earth and the Sun, Moon, and other planets in the solar system. Rare astronomic events can influence Earth as well, such as the collision of large meteorites or even asteroids with Earth.

1.2.1 Earth in the Solar System

Until the 16th and 17th centuries, most scientists believed that Earth was at the center of the physical universe. It was thought that the Sun, Moon, and five planets known at the time (Mercury, Venus, Mars, Jupiter, and Saturn) all orbited around Earth in perfectly circular orbits, as illustrated in Figure 1.9. In this model, the stars are points of light that also revolve around Earth. This Earth-centered picture of the universe is known as a *geocentric* model. The story of how scientists changed their minds about this model of the universe is fascinating and was an important turning point in the history of science, but it is a topic for another course. It took about one hundred years from the work of Nicolaus Copernicus (1473–1543) until after the death of Galileo (1564–1642) for most scientists to abandon the geocentric model of the universe.

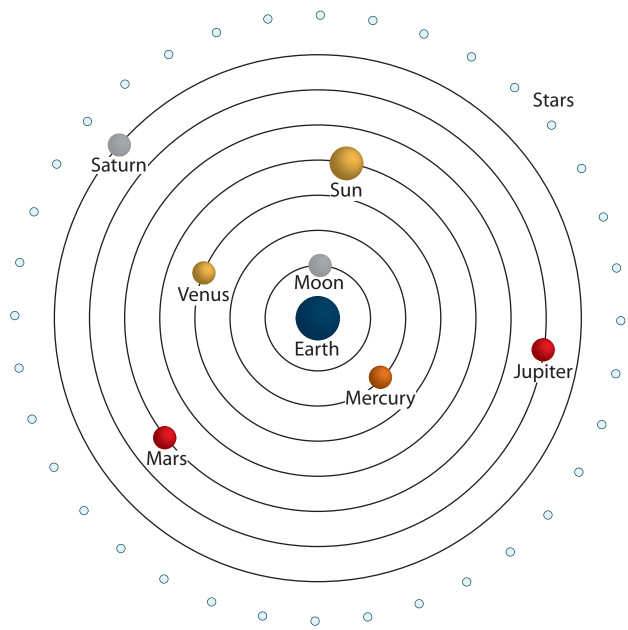


Figure 1.9. In the geocentric model, Earth is at the center of the universe, and all other bodies orbit Earth.

Today we have a very different picture of the place of Earth in the solar system and of the universe as a whole, illustrated in Figure 1.10. We now understand that the Sun, not Earth, is at the center of the solar system. This model of the solar system is known as a *heliocentric* model. Earth is one of eight planets that orbit the Sun. The four innermost planets—Mercury, Venus, Earth, and Mars—are com-

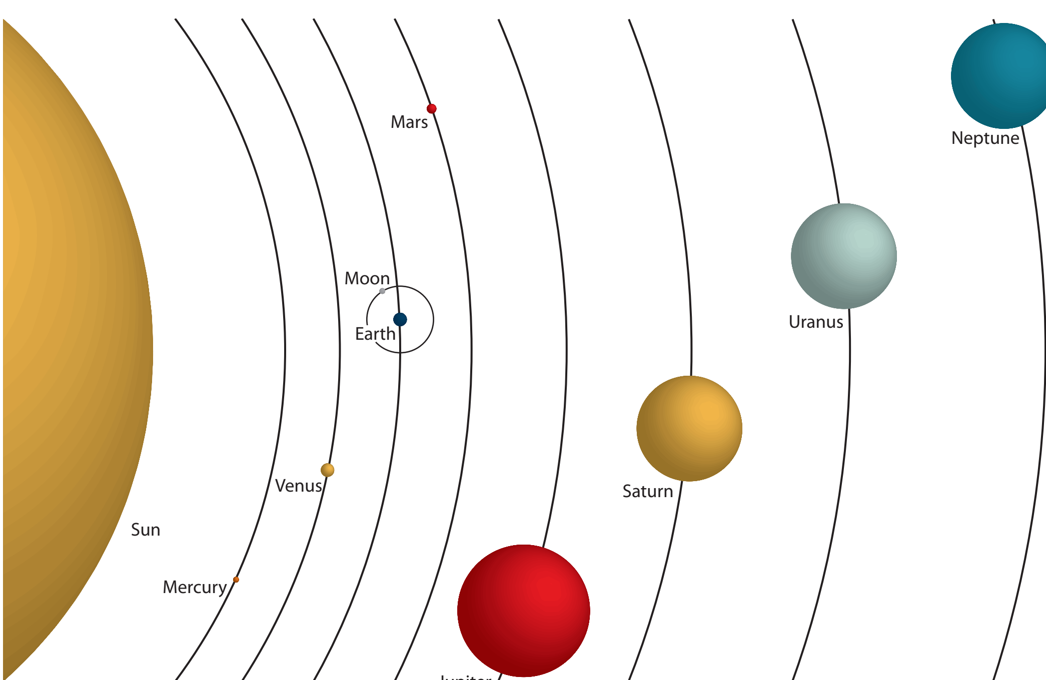


Figure 1.10. In the heliocentric model, planets, asteroids, comets, and other solar system bodies orbit the Sun. Our Sun is just one of over 100 billion stars in the Milky Way galaxy. This drawing is highly not to scale.

posed largely of rock and are known as the terrestrial (Earth-like) planets. As Figure 1.11 suggests, we can apply what we know about Earth to the study of the other terrestrial planets because they have similar compositions. Similarly, we can apply what we learn about Mercury, Venus, and Mars back to our study of Earth. The outer four planets—Jupiter, Saturn, Uranus, and Neptune—are much more massive. They are composed largely or entirely of gas and known as the gas giants.

Figure 1.11. The Curiosity rover on Mars, one of the four terrestrial planets. Many of the geologic features that occur on Earth, such as volcanoes, sand dunes, and stream channels, can also be studied on Mars.

1.2.2 Earth—A "Just Right" Planet

Most places in the solar system—and in the universe as a whole—are quite hostile to complex life. Complex life is life that is more sophisticated than bacteria, and includes all plants and animals. In most places in the universe, the temperatures are too hot or too cold, or there isn't water, or the right elements—such as carbon—aren't present, or there is too much damaging electromagnetic radiation for living organisms to thrive.

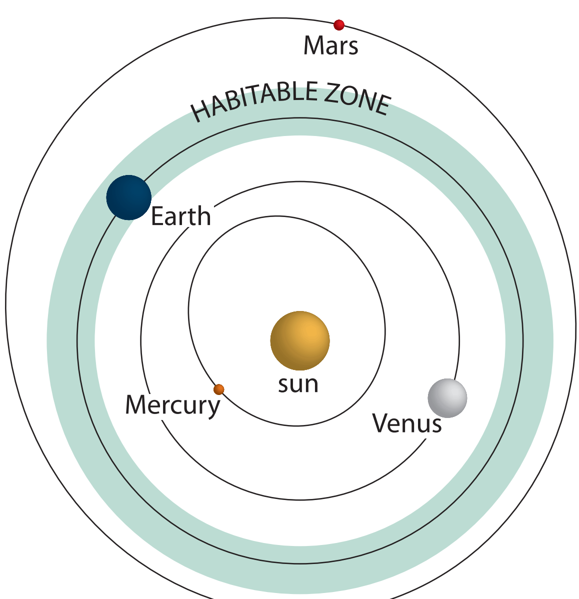


Figure 1.12. Our solar system's habitable zone, tinted in blue. There is debate about exactly where the inner and outer limits of the habitable zone are. The Sun and planets are not drawn to scale.

Within the solar system, Earth occupies a special location. If Earth were somewhat closer to the Sun, the temperature would be hot enough to boil the oceans. Living organisms, from bacteria to humans, are dependent on liquid water to exist. Even on Venus, the next planet closer to the Sun, the temperature on the surface is around 460°C (860°F)! On the other hand, if Earth were farther away from the Sun, it would be cold enough to freeze all water on the surface. As an example, consider Mars, with an average surface temperature of around −55°C (−67°F), though temperatures can rise above freezing (0°C) on a summer day near the Equator. So far as we know, Mars is currently a lifeless planet. It certainly cannot support the abundance of life that exists on Earth.

The region around a star in which liquid water can exist on the surface of planets—and which therefore can support advanced life—is known as the *habitable zone*, illustrated in Figure 1.12. Determining the inner and outer limits of the habitable zone is not a straightforward task, but certainly Venus is too close to the Sun, and Mars is at or near the outer edge of our solar system's habitable zone. Sometimes astronomers refer to planets in the habitable zone as "Goldilocks planets," where the temperature is neither too hot, nor too cold, but just right. There may be places outside of the habitable zone where conditions are just right for life—such as in warm water beneath the surface of some of the moons of Jupiter—but it is considered unlikely by most scientists that these environments could support life more sophisticated than microscopic bacteria.

Earth is also "just right" in other ways:

1. Earth seems to be an ideal size. If it were considerably smaller, it would not have strong enough gravity to hold onto most of its atmosphere. Mars has only 10.7 percent of the mass of Earth, and has a very thin atmosphere. If, on the other hand, Earth were considerably larger, it would probably have a much denser atmosphere due to stronger gravity. This would likely lead to much higher surface temperatures.
2. Earth has a good amount of water. There is enough water to support life, but not so much as to completely cover Earth with water.
3. Earth seems to have just the right chemical composition. For example, Earth has a small amount of carbon, an essential element for all the primary molecules of life, such as proteins, sugars, and DNA. But if it had considerably more carbon, the composition of both the solid Earth and the atmosphere would be radically different, and inhospitable to life. Earth also has an iron core, which causes Earth's magnetic field and helps to protect the surface from harmful radiation from space. The chemical composition of Earth's crust also seems to be just right for the long-term maintenance of life.
4. Many scientists believe that gravitational interactions between Earth and the Moon—the same interactions that cause ocean tides—keep Earth's axis tilted at a fairly constant angle near 23.5°. If Earth didn't have such a large Moon—all other moons in the solar system are small compared to the size of their parent planets—occasional changes in the angle of Earth's tilt could cause catastrophic changes to the climate, which would make the continued existence of complex life difficult. We take a closer look at Earth's axis in the next section.
5. Earth has plate tectonics, which, as we discuss in Chapter 6, is the process that moves continents and other parts of the lithosphere around on Earth's surface. It turns out that plate tectonics is a process which helps to make Earth a suitable home for the flourishing of life. Geologists believe that a number of factors have

to be just right for plate tectonics to occur, such as the presence of oceans, and having the right amount of radioactivity in the rocks of the lithosphere.

There are many more ways in which the universe as a whole, and our planet in particular, seem to be fine-tuned to support complex life—dozens more, in fact! Scientists believe that if all these factors were not fine-tuned the way they are, the complex life on Earth would not exist.

1.2.3 Earth in the Galaxy and Universe

On a very dark night, one can see up to two or three thousand stars, only a very tiny fraction of the total number of stars in the galaxy. A *galaxy* is a massive system of stars gravitationally bound to one another. Our Sun is but one of perhaps 200 billion (200,000,000,000) stars in the Milky Way galaxy, the spiral galaxy in which our solar system is located. If we were able to travel outside of the Milky Way galaxy—which would take millions of years to do with our current spacecraft—we would see that it looks something like the galaxy shown in Figure 1.13. As Figure 1.14 illustrates, our solar system is located at the edge of a spiral arm, roughly half way from the center of the galaxy to the outer edge. Our Sun is orbiting the center of the galaxy with a velocity of about 800,000 kilometers per hour, but even moving that fast, it takes over 200,000,000 years for the Sun to make one revolution around the galactic core.

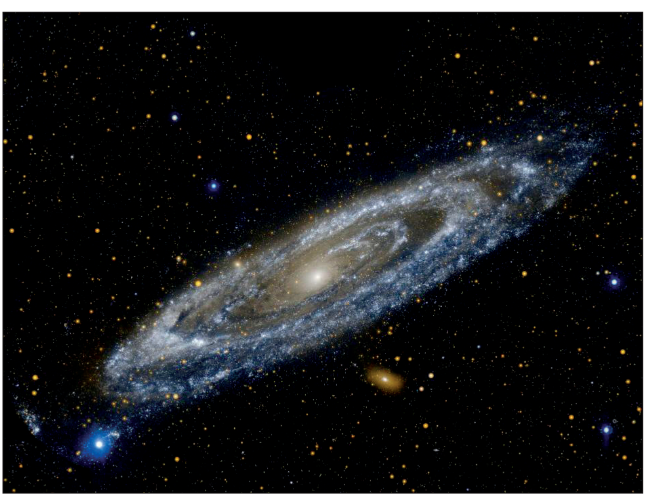


Figure 1.13. Our Milky Way galaxy is a spiral galaxy, like the Andromeda galaxy pictured here.

Just as there is a habitable zone in the solar system, where conditions are right for life to flourish, so there seems to be a galactic habitable zone in spiral galaxies where conditions are right for life to exist. Near the galactic core, stars are closer to each other than they are in our neighborhood of the galaxy, and it is believed that catastrophic events, such as stars passing close to one another and disrupting planetary orbits due to gravitational attraction, would make the entire central region of the galaxy inhospitable for complex life. On the other hand, it appears that solar systems near the outer edges of spiral galaxies do not contain a high enough proportion of atoms of elements heavier than hydrogen and helium to have terrestrial planets—worlds made of heavier elements such as iron, silicon, and oxygen.

The Milky Way galaxy is just part of the much larger *universe*. The universe is composed of all the matter and energy that exists, as well as space and time themselves. This includes everything we can see with our most powerful telescopes, such as the distant galaxies shown in Figure 1.15. The Milky Way galaxy is just one of hundreds of billions of galaxies. If there are 200,000,000,000 stars in our galaxy, and at least 100,000,000,000 observable galaxies in the universe, then how many stars are there in the entire universe? At a minimum, that number is 20,000,000,000,000,000,000,000 stars.

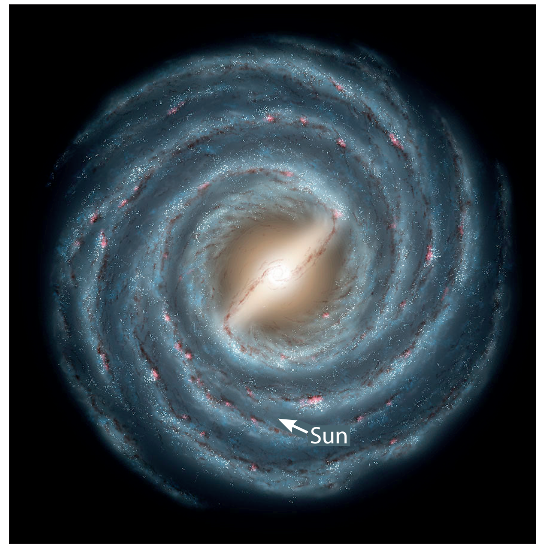


Figure 1.14. An artist's conception of the Milky Way galaxy showing the location of our Sun and solar system.

This enormous number is virtually incomprehensible to us. It would take over 600 trillion years to count 20,000,000,000,000,000,000,000 stars, taking one second per star. Because the universe is so enormous, and our Sun and planet are so small in comparison, it would be easy to conclude that we humans are rather insignificant. Earth is our home,

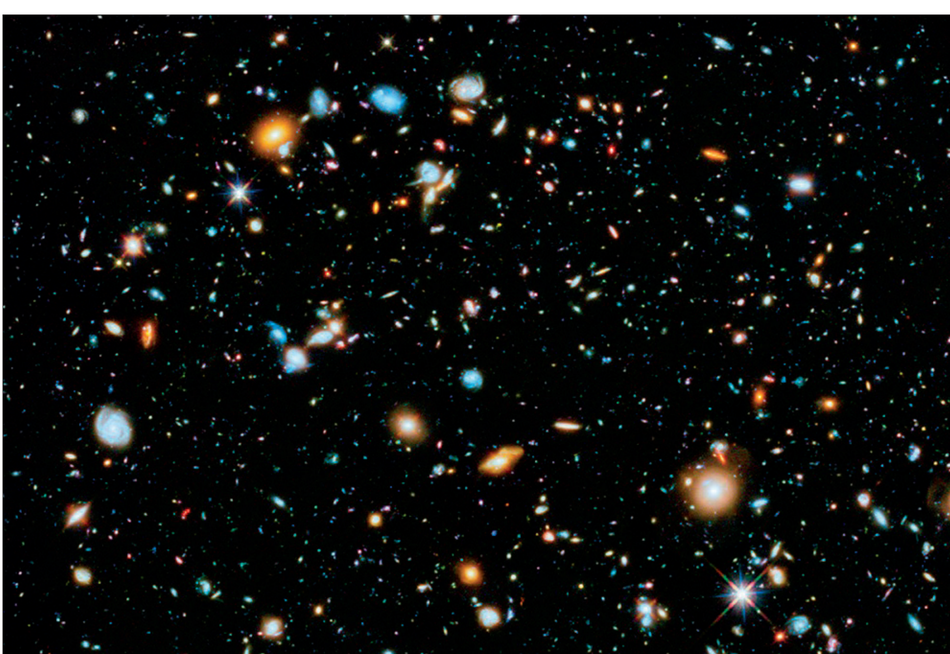


Figure 1.15. The universe is made up of many billions of galaxies. Almost every object in this image, taken by the Hubble Space Telescope, is a galaxy composed of billions of stars.

however, and it is an ideal home for both humans and the wide range of living organisms we share the planet with. So far as we know, planets as ideally suited for life are not common in the galaxy. If planets such as Earth are rare, then advanced, intelligent beings such as ourselves are perhaps even less common. We have a responsibility, therefore, to take care of the world we live in.

Learning Check 1.2

1. Contrast the geocentric model of the solar system with the heliocentric model.
2. Describe Earth's location in space, relative to the Sun and solar system, the galaxy, and the universe.
3. In what ways does Earth seem to be "just right" for complex life?
4. What is meant by a habitable zone, for both the solar system and galaxy as a whole?
5. How many stars do scientists estimate there are in the Milky Way galaxy?

1.3 Earth's Orbit and the Seasons

1.3.1 Earth's Orbit

Earth takes 365.24 days to make one complete orbit around the Sun. This orbit, however, is not circular. Instead, Earth's orbit around the Sun is slightly elliptical, meaning that Earth is slightly closer to the Sun at some times and farther away at others. At its closest, Earth is about 147,000,000 km from the Sun and at its farthest it is about 152,000,000 km from the Sun, for an average of about 150,000,000 km (93,000,000 mi). As illustrated in Figure 1.16, the point on the orbit of a planet, asteroid, or comet around the Sun where it is closest to the Sun is called the *perihelion*, and the point where it is farthest from the Sun is called the *aphelion*. The difference between the perihelion and aphelion for Earth's orbit is not all that great and from a distance Earth's orbit would appear to be nearly circular. One interesting thing about this elliptical orbit is that Earth is closest to the Sun (perihelion) during the first week of January and farthest from the Sun (aphelion) the first week of July. This means Earth is actually slightly closer to the Sun when it is winter in the Northern Hemisphere and slightly farther away from the Sun in the summer. This tells us that the distance from one of Earth's hemispheres to the Sun is not the primary cause of seasons. This distance does have a minor effect on seasons—the Northern Hemisphere winter is slightly

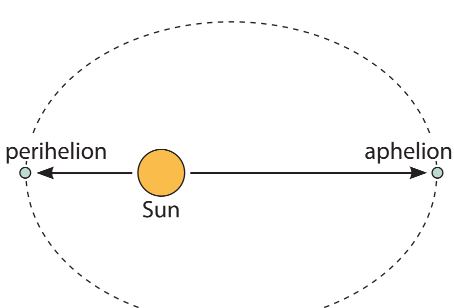


Figure 1.16. For an elliptical orbit, the aphelion is where a planet is farthest from the Sun; the perihelion is where it is closest to the Sun.

warmer than it would be if Earth's orbit were circular, and Northern Hemisphere summer is slightly cooler than it would otherwise be—but the main cause of Earth's seasons is the tilt of Earth's axis.

1.3.2 Solstices and Equinoxes

The plane in which Earth orbits the Sun is called the *ecliptic*. As Earth orbits the Sun, its axis of rotation is not perpendicular to the ecliptic; it is tilted at an angle of about 23.5° as Figure 1.17 shows. As Earth orbits the Sun, its axis always points in the same direction. In Figure 1.18, you see that no matter where Earth is in its orbit, its axis is inclined 23.5° to the right. As Earth completes its annual trip around the Sun, different parts of the planet receive different amounts of sunlight. At the far left of Figure 1.18, on about June 21, the Northern Hemisphere is tilted towards the Sun and receives more direct sunlight than the Southern Hemisphere does. This is the *summer solstice*—the moment of time when the Sun is highest in the sky in the hemisphere and regarded by many as the first day of summer. In general, the summer solstice is the day of the year with the most hours of sunlight. The *winter solstice* occurs on about December 21 in the Northern Hemisphere. This is when the Sun is lowest in the sky in the hemisphere, and the day with the least hours of sunlight. At the time the summer solstice occurs in the Northern Hemisphere, the winter solstice occurs in the Southern Hemisphere. About halfway between the solstices are the *equinoxes*, when Earth's axis neither tilts away nor toward the Sun, and there is approximately an equal amount of daylight and nighttime. The *vernal equinox* is the equinox that occurs between the winter solstice and summer solstice, on about March 22 in the Northern Hemisphere. The *autumnal equinox* occurs between the summer solstice and winter solstice, on about September 22 in the Northern Hemisphere.

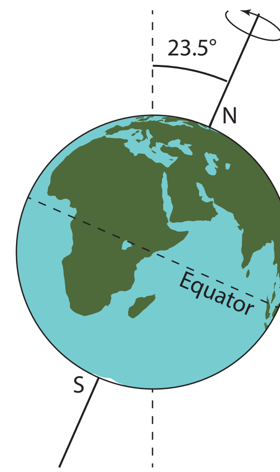


Figure 1.17. Earth's axis is tilted 23.5° from vertical, relative to the ecliptic.

The temperature on Earth's surface depends on the amount of heat received from the Sun, which is received in the form of electromagnetic radiation. Earth is always gaining energy from the Sun, but Earth also loses heat

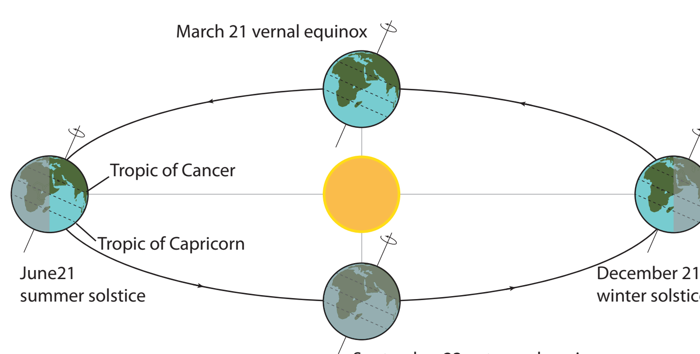


Figure 1.18. As Earth orbits the Sun, its axis is always pointed the same direction. This means that for part of the year, the North Pole is pointing more towards the Sun; at the opposite part of the year, the North Pole is pointing away from the Sun. Date names apply to the Northern Hemisphere.

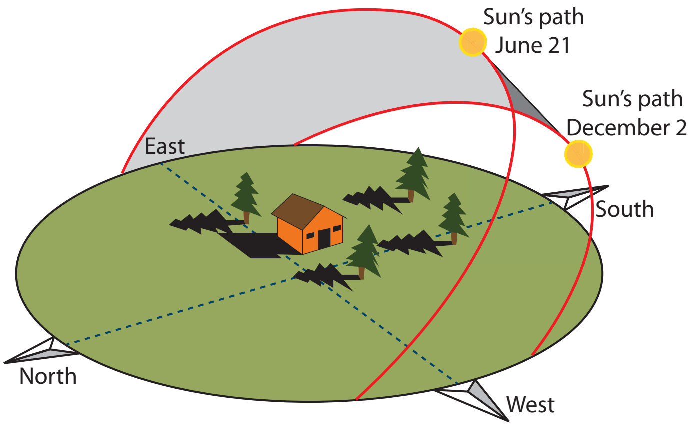


Figure 1.19. The path the Sun takes across the sky in the Northern Hemisphere at the latitude of the central United States on the summer solstice (June 21) and winter solstice (December 21).

energy into space at the same time. If Earth did not lose heat to balance out the energy it receives from the Sun, it would get hotter and hotter and eventually melt! The electromagnetic radiation from the Sun is primarily visible light, which is absorbed by Earth's surface and atmosphere, leading to warming. The warm Earth, at the same time, re-radiates electromagnetic radiation back out into space, mainly as infrared radiation. We can see this balance swinging back and forth on a daily basis: the temperature rises as the Sun warms Earth's surface during the day, but then drops at night. We also see this happening on a longer time scale, as the Northern Hemisphere warms up through the spring and summer and cools off through fall and winter. It is all about which is greater at the time: energy received from the Sun or energy radiated back into space from Earth.

There are two primary reasons why it is hotter in the summer than in the winter. Both reasons are related to the path the Sun takes across the sky. We think of the Sun as rising in the east and setting in the west. But as Figure 1.19 illustrates, in the summer the Sun actually rises in the northeast and takes a long, high path across the sky before setting in the northwest (from a Northern Hemisphere perspective). In the winter, on the other hand, the Sun rises in the southeast, and takes a much shorter, lower path across the sky before setting in the southwest. From these observations, it becomes apparent why it is hot in the summer. First, the Sun is in the sky for a long time on a summer day, so there is a long period of time for Earth's surface to absorb radiation from the Sun. Second, the Sun is higher in the sky on a summer day, so sunlight is concentrated on a smaller area than in the winter. The difference in sunlight concentration is illustrated with flashlight beams in Figure 1.20. The opposite is true in winter: the Sun is in the sky for

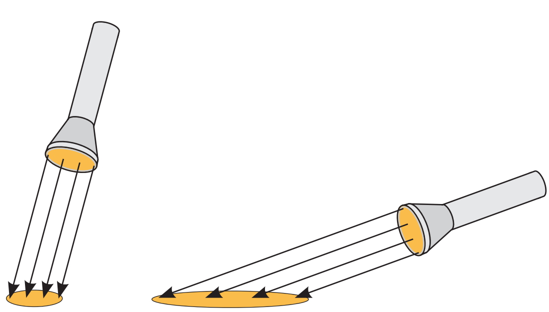


Figure 1.20. The flashlights illustrate the difference between having the Sun high in the sky (summer) and low in the sky (winter). In the summer, energy is concentrated in a smaller area, but in winter, energy from the Sun is spread out over a larger area, resulting in less heating of the ground.

a shorter period of time, so there is less time for Earth's surface to absorb sunlight and sunlight hits Earth's surface at a lower angle, spreading out the energy from the Sun over a greater area.

1.3.3 The Tropics and Polar Regions

Near Earth's Equator, changes in the Sun's position in the sky don't have as great of an effect on temperatures. Whether it is summer solstice, winter solstice, or an equinox, the Sun climbs up high in the sky every day and this part of Earth is generally warm year-round. Between latitudes 23.5°N and 23.5°S, there is at least one day in the year when the Sun is directly overhead at noon.[1] At latitude 23.5°N, the Sun climbs up to directly overhead at noon on the day of the Northern Hemisphere summer solstice. As Figure 1.21 illustrates, this latitude is known as the *Tropic of Cancer*. This latitude is the farthest north that the Sun can be seen directly overhead. The southern equivalent, at 23.5°S, is the *Tropic of Capricorn*. The region between the Tropic of Cancer and the Tropic of Capricorn is known as the *tropics*. Except in mountainous areas, this region is warm all year. In the United States, only Hawaii is in the tropics. In many tropical areas, the main difference in seasons is not between hot and cold, but between a wet season and a dry season.

The situation is quite different in polar regions. On the day of the Northern Hemisphere summer solstice, the Sun does not set at any location farther north than the *Arctic Circle*, which is at about 66.5°N. These regions are sometimes referred to as "the land of the midnight Sun." But the opposite situation occurs at the

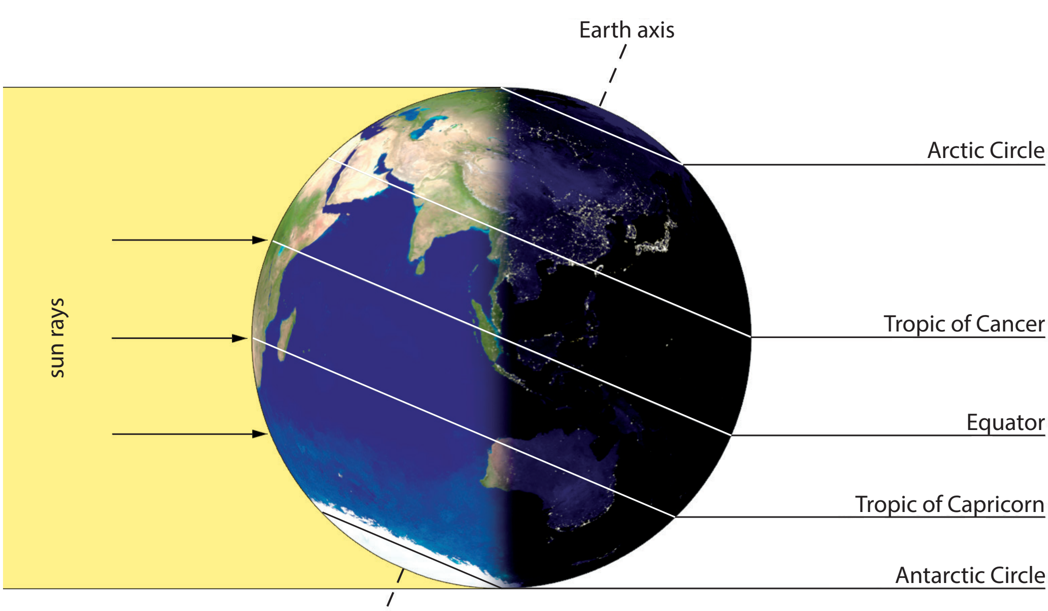


Figure 1.21. Earth at Northern Hemisphere winter solstice, showing the Tropic of Capricorn, Tropic of Cancer, Arctic Circle, and Antarctic Circle.

1 Latitude and longitude are discussed in Chapter 2.

winter solstice, when the Sun does not rise above the horizon north of the Arctic Circle. The Southern Hemisphere equivalent of the Arctic Circle is the *Antarctic Circle*, which is at approximately 66.5°S. Despite having up to 24 hours of sunlight, polar regions do not get hot in the summer because the Sun is always low in the sky.

Learning Check 1.3

1. Calculate the approximate speed at which Earth moves in its orbit around the Sun. You can simplify the problem by assuming that Earth's orbit around the Sun is circular.
2. What effect does the elliptical orbit of the Sun have on Earth's seasons?
3. Explain how the tilt of Earth's axis causes seasons.
4. Speculate as to what seasons would be like if Earth's axis were not tilted, and what seasons would be like if Earth's axis were tilted at 45° instead of 23.5°.

1.4 Phases of the Moon

There are nights when the Moon shines bright in the sky, bright enough to walk outside without the need for artificial lighting. There are other nights when it is pitch black and there is no Moon above, but thousands of stars shine in the dark sky. As the Moon orbits Earth, its appearance, as well as the time it rises and sets, changes from day to day. The phase of the Moon, or *lunar phase*, is the shape of the Sunlit portion of the Moon's face as seen from Earth. As the Moon orbits Earth, the same hemisphere of the Moon always faces us, but part of the near side of the Moon is in sunlight, and part of it is in darkness. The phases of the 29.5-day lunar cycle are outlined in Table 1.1.

A helpful way of visualizing how lunar phases work is shown in Figure 1.22, which shows the Moon revolving around Earth in a counter-clockwise direction. The phases of the Moon are determined by the positions of the Sun, Earth, and Moon. The Moon emits no light of its own; we only see light that is reflected off it. Note that the side of the Moon facing the Sun is illuminated and the side facing away from the Sun is dark. As the Moon orbits Earth, varying amounts of light and dark are visible from Earth's surface.

When the Moon is in the position represented by the right side of Figure 1.22, the side of the Moon facing Earth is completely in darkness, while the side of the Moon facing away from Earth is fully illuminated. This is called the *new Moon*. When the Moon is new, its position in the sky is close to the position of the Sun, so it rises in the morning, sets in the evening, and is invisible to us. A couple of days after the new Moon, the Moon has advanced in its orbit around Earth, and a thin sliver is visible in the western sky just after sunset. This is called the *waxing crescent*; the term waxing means increasing or growing. If you observe the Moon from night to night, you see that the line that separates light from dark slowly moves across the Moon's face from right to left. About a week after the new Moon, the

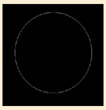
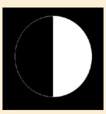
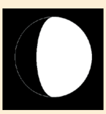
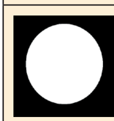
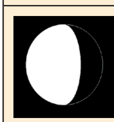
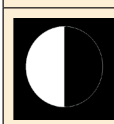
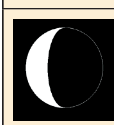
Phase	Moonrise	Moonset	Viewing
 New Moon	Sunrise	Sunset	Moon not visible
 Waxing Crescent	Just after sunrise	Just after sunset	Moon visible in the west just after sunset
 First Quarter	Noon	Midnight	Moon visible in afternoon and early evening
 Waxing Gibbous	Late afternoon	After midnight	Moon visible most of the night
 Full Moon	Sunset	Sunrise	Moon visible all night
 Waning Gibbous	Before midnight	Mid-morning	Moon visible late night until mid-morning
 Last Quarter	Midnight	Noon	Moon visible after midnight until noon
 Waning Crescent	Just before sunrise	Just before sunset	Moon visible in the east just before sunrise

Table 1.1. Phases of the Moon, with moonrise and moonset times.

Moon has completed a quarter of its orbit around Earth and it appears half illuminated. Rather than calling this a half Moon, however, it is referred to as a quarter Moon—in this case, the *first quarter* (top of Figure 1.22). After the first quarter, the near side becomes more fully illuminated, with more than half but less than all of the near side showing, a phase called the *waxing gibbous*. A full two weeks after the new Moon, the Moon is fully illuminated when viewed from Earth, and we see a *full Moon* (far left of Figure 1.22).

During the following two weeks, the process reverses (lower part of Figure 1.22). A few days after the full Moon, darkness starts to slowly creep across the Moon's face from right to left, leading to the *waning gibbous* phase. Waning means decreasing, the opposite of waxing. The *last quarter* occurs a week after the full Moon, and a few days later, the *waning crescent* appears in the sky shortly before

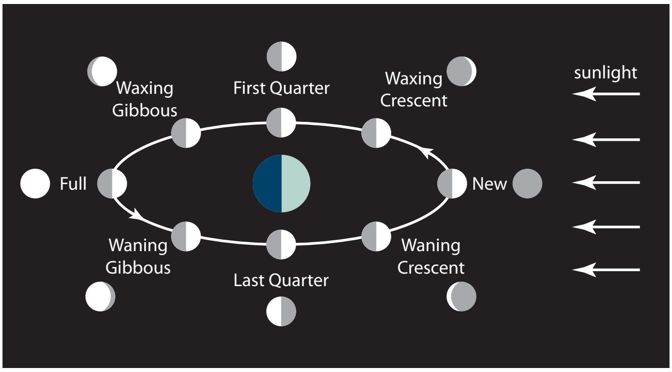


Figure 1.22. As the Moon orbits Earth, varying amounts of the near side of the Moon become illuminated by the Sun, causing lunar phases.

sunrise. After 29.5 days, the cycle repeats itself, starting with a new Moon.

Something many people don't realize is that the Moon is in the sky during the day time just as often it is in the sky during the night time. We don't notice the daytime Moon as often for a couple reasons. First, the sky is bright during the day and it is easy to miss a pale crescent or quarter Moon—or even a gibbous Moon—against the bright blue sky. Second, even though the Moon is in the sky when it is at or near the new Moon phase, there is simply not enough of the sunlit side of the Moon visible for us to see.

The time of day that the Moon rises and sets goes hand in hand with the phases of the Moon. For example, the full Moon is on the opposite side of Earth from where the Sun is, so the full Moon rises roughly when the Sun sets and sets roughly when the Sun rises. Each day, the Moon rises about 50 minutes later; thus three days after the full Moon, the waning gibbous Moon rises about 2.5 hours (150 minutes) later. Table 1.1 summarizes when the Moon rises and sets for different phases.

Learning Check 1.4

1. Explain why the Moon has phases.
2. Why does the full Moon rise at roughly the same time that the Sun sets?
3. If you were on the Moon, how would the appearance of Earth change throughout the 29.5-day lunar cycle?

1.5 Eclipses

In addition to phases, the orbit of the Moon around Earth causes another interesting phenomenon: *eclipses*. An eclipse occurs when one celestial body, such as Earth or the Moon, blocks the Sun from another celestial body.

1.5.1 Solar Eclipses

A *solar eclipse* occurs when the Moon passes in front of the Sun, causing the Moon's shadow to fall on Earth. In a *partial solar eclipse*, the Moon only covers part of the Sun's disk, as shown in Figure 1.23. In the case of a *total solar eclipse*, the Moon completely covers the Sun, as in Figure 1.24. During a total solar eclipse,

Figure 1.23. Partial solar eclipse. (Caution: looking directly at a partial eclipse can damage your eyes!)

the sky becomes dark, but the total part of the eclipse lasts for only a few minutes. Solar eclipses can only happen when the Moon is directly between the Earth and the Sun, when there is a new Moon, illustrated in Figure 1.25.

A shadow from a light source, such as the Sun or a light bulb, has multiple parts to it. The darkest, inner part of the shadow is called the *umbra*. During a solar eclipse, the Moon completely blocks the Sun within the umbra. The *penumbra* is the part of the shadow that is not completely dark. Within the penumbra, the Sun is not completely blocked, so a viewer sees a partial solar eclipse. The umbra and penumbra are easy to demonstrate, using a table lamp and a disk of some type, as shown in Figure 1.26.

Total solar eclipses are fairly rare events, and most people have never seen one. (I have seen a total solar eclipse once, in 1979). Looking back at Figure 1.22 (lunar phases), one might think that a solar eclipse should occur every month. But the Moon orbits Earth in a plane that is about 5° tilted relative to the ecliptic, the plane in which Earth orbits the Sun. This means that in most months, the new Moon passes either above or below the Sun in the sky rather than right in front of it. In some years, there are no total solar eclipses. In other years, there may be up to five solar eclipses, although this only happens rarely. Because of the small size of the umbra on Earth, total solar eclipses are only visible in narrow bands on Earth's surface.

Figure 1.24. Total solar eclipse. This is the only time that the solar atmosphere is visible from Earth.

There is actually more to the Sun than just the bright disk we normally see in the sky. When that disk is blocked, we can still see the solar atmosphere, appearing as a thin ring of pink light around the eclipse and a faint white glow that extends farther out (Figure 1.24). The solar atmosphere is made of hot glowing plasma, an ionized gas.

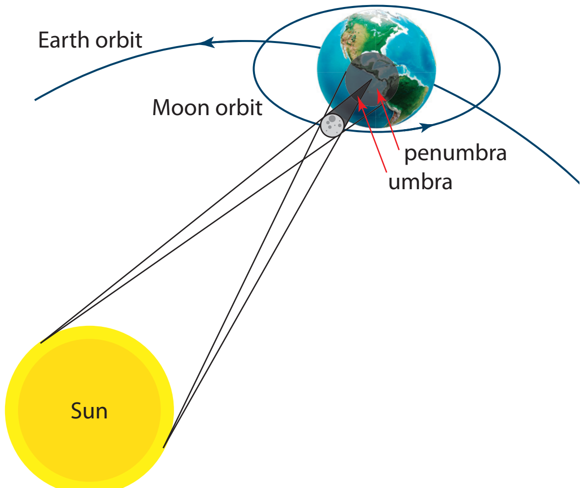


Figure 1.25. A solar eclipse occurs when the Moon blocks the light of the Sun. Viewers located in the umbra, which is very small on Earth, see a total solar eclipse; viewers located in the penumbra see a partial solar eclipse.

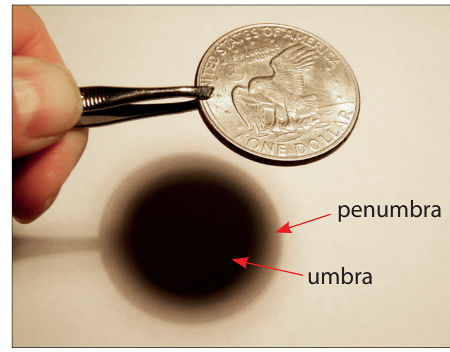


Figure 1.26. Umbra and penumbra. An ant within the umbra would not be able to see the light bulb, and an ant in the penumbra would be able to see part of the light bulb.

The Sun is 400 times as large as the Moon, but it is also 400 times farther away. The result is that the Moon and the Sun appear to be almost exactly the same size in the sky. It is truly amazing that we live on a planet that has total solar eclipses in which the Moon almost perfectly covers the Sun. This requires a Moon that is just the right size, at just the right distance from Earth. Being able to see solar eclipses is not just something that is cool, but something that has been critical in the development of science. For example, total solar eclipses helped us to understand the composition of the Sun, and helped to confirm the validity of Albert Einstein's general theory of relativity.

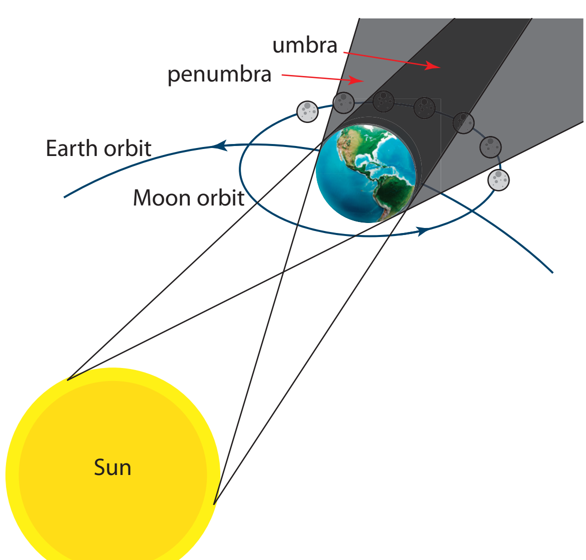


Figure 1.27. A total lunar eclipse occurs when the Moon passes through Earth's umbra.

1.5.2 Lunar Eclipses

Lunar eclipses occur when Earth's shadow covers the face of the Moon. This occurs when the Moon is full, when Earth is between the Moon and the Sun, but does not happen every time the Moon is full. Again, because the Moon's orbit around Earth is inclined at 5° to the ecliptic, the Moon usually misses Earth's shadow as it orbits.

Like all shadows, Earth's shadow has an umbra and penumbra, illustrated in Figure 1.27. When the Moon passes through Earth's penumbra, it becomes slightly darker, but this dimming can be rather subtle. A *total lunar eclipse* occurs when the Moon passes completely into Earth's umbra. During a total lunar eclipse, the Moon does not become completely dark, even though Earth completely blocks the Sun. If you were standing on the Moon at this time, you would see Earth completely blocking the Sun, with a brilliant red sunset forming a ring around the entire Earth. This red light actually illuminates the Moon during a total lunar eclipse, giving the Moon the reddish glow shown in Figure 1.28. For this reason, the eclipsed Moon is often referred to as a "blood Moon."

Figure 1.28. The Moon during a total lunar eclipse. The reddish glow is caused by sunlight bending through Earth's atmosphere.

Earth's shadow is much larger than the Moon's shadow. Because of this, Earth's umbra can completely cover the Moon (unlike the Moon's umbra, which darkens only a small area on Earth). During a lunar eclipse, anyone on the night side of Earth can see the full Moon, and therefore can see the eclipse occurring. People on the day side of Earth miss the eclipse.

Learning Check 1.5

1. Describe how the Sun, Earth, and Moon must be arranged for solar and lunar eclipses to occur.
2. During a solar eclipse, why do people in some places see a partial eclipse, while others see a total eclipse?
3. Explain why there aren't solar and lunar eclipses every month.

1.6 Calendars

Closely related to Earth's revolution around the Sun and the Moon's orbit around Earth is the topic of calendars. The calendar we use in much of the world today, including in all of Western society, is based on Earth's orbit around the Sun. However, before examining our Western calendar, we will take a brief look at some calendars that have been used in other parts of the world.

1.6.1 The Hebrew Calendar

Most calendars are systems that divide the passage of time into years, months, and days, but the details vary. We will start by looking at the Hebrew calendar, used by the Jews in biblical times as well as in modern Israel.

The Hebrew calendar is an example of a *lunisolar calendar*—one based on both the phases of the Moon and the orbit of Earth around the Sun. The Moon orbits Earth once every 29.5 days, so each month in the Hebrew calendar has either 29 or 30 days, giving a total of 354 days in twelve months. Each month starts with the new Moon. Earth does not completely orbit the Sun in 354 days, and the Hebrew calendar compensates for this by adding a thirteenth month in seven out of every nineteen years. This adjustment is necessary so the months occur in a consistent time of the year. Without this correction, the seasons—and associated religious holidays—would occur about eleven days earlier each year. For example, the original Passover, as recorded in the biblical book of Exodus, occurred in the spring. Without the addition of a leap month every few years, Passover would occur in April for about three years, then in March for a few years, and so on. The calendar was also used for agricultural purposes as well, such as determining times for planting and harvesting.

The numbering of years according to the Hebrew calendar is based on a medieval calculation of the date for the creation of the world. The Jewish New Year celebration, Rosh Hashanah, usually occurs in September, with the Hebrew year 5781 beginning in September of 2020.

1.6.2 The Islamic Calendar

The Islamic calendar is used by Muslims throughout the world for tracking religious holidays and as the day-to-day calendar for business and government in many Islamic countries. The Islamic calendar is a lunar calendar in which months are based strictly on the phases of the Moon. Each new day begins at sunset. Like the Hebrew calendar, each month in the Islamic calendar has either 29 or 30 days. A new month begins at the first sighting of the thin crescent Moon the day after the new Moon, shown in Figure 1.29. This determination is usually made by religious authorities for a given country, and if they do not see the crescent Moon for some

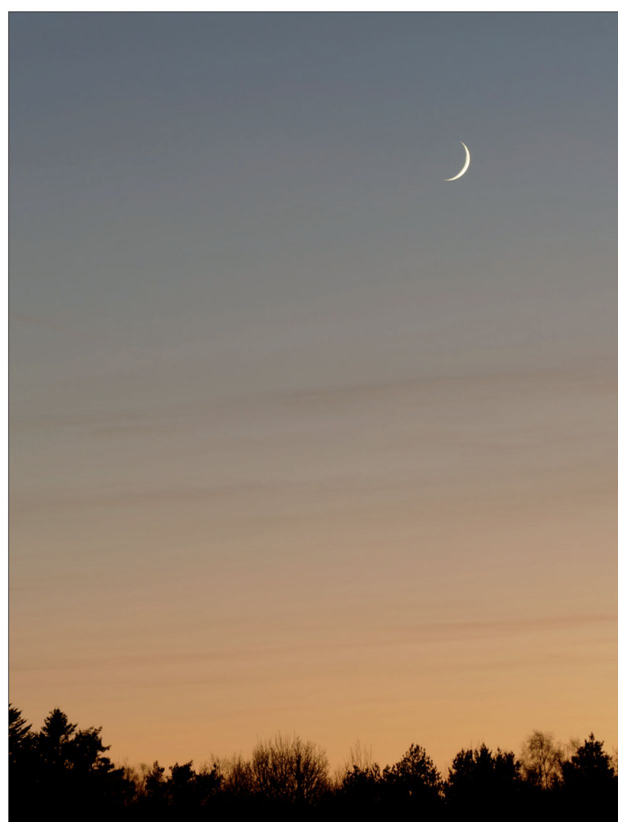


Figure 1.29. Months in the Islamic calendar begin with the first sighting of the waxing crescent Moon.

reason (such as cloud cover), then the new month doesn't begin until the next evening.

Traditionally, it has been difficult to create a calendar for future months of the Islamic year, or to make a firm appointment for a given date in a future month. A person could not predict in advance whether the current month would have 29 or 30 days; it depended on whether the crescent Moon was visible in the western sky at the end of the 29th day. Some Islamic countries now allow astronomical calculations to determine when new months will begin, but others continue to rely on actual observations of the sky.

The Islamic calendar has twelve months that average 29.5 days long, for a typical total of 354 days in a year. Unlike the Hebrew calendar and other lunisolar calendars, there are no leap months. In North America and Europe, we associate certain months and holidays with certain seasons—Christmas is in winter, and July is a summer month. Islamic months and holidays, on the other hand, come eleven days earlier each year, so the months and holidays migrate through the seasons. For example, the month of Ramadan—the month in which adult Muslims are obligated to fast from food and water from sunrise to sunset every day—occurs in the summer for a few years, then in the spring for a few years, and so on. The Islamic year 1442 begins in August of 2020.

1.6.3 Western Calendars

There have been two main calendars used in Western society over the past 2,000 years. They are both solar calendars, based primarily on Earth's orbit around the Sun. The first of these is the Julian calendar, named after Julius Caesar, who introduced it in 46 BCE (46 BC). It was very similar to the calendar we use today. There were twelve months with either 30 or 31 days, except February which normally had 28 days, making a total of 365 days in a year. Every fourth year was declared to be a leap year, with a 29th day in February.

Originally, the Julian calendar had no consistent way of numbering years. Sometimes a year would be indicated by the reign of an emperor, as in the sentence "In the fifteenth year of the reign of Tiberius Caesar." The idea of numbering the years starting with the birth of Jesus—Anno Domini (Latin for "year of the Lord"), or AD—originated in about AD 525, and gradually spread throughout the Western world. Unfortunately, the calculations for determining the birth of Jesus were off by a few years—Jesus was probably born around 4–6 BC (BC means Before Christ). There was no year zero; 1 BC was followed by AD 1. It is now common to use CE (Common Era) and BCE (Before Common Era) instead of AD and BC. Either way, the calendar we use has its origin date as the birth of Jesus.

There was a minor problem with the Julian calendar that grew with time. The average length of a year in the Julian calendar is 365.25 days, but Earth actually takes about 365.24 days to orbit the Sun. Over a period of many centuries, this means that months and religious holidays migrate relative to the seasons. Given enough time, the observance of Easter would eventually have become a winter, rather than a spring, event. In 1582, Pope Gregory XIII introduced a revision to the Julian calendar, known today as the Gregorian calendar. It took over three hundred years for all the countries of Europe to adopt the Gregorian calendar; Great Britain and its American colonies switched to the Gregorian calendar in 1752. It has become the international standard calendar, even in countries that use other calendars for religious or cultural purposes.

The main difference between the Julian and Gregorian calendars is the reduced number of leap years in the Gregorian calendar. According to the Julian calendar, any year divisible by four is a leap year. The Gregorian calendar requires that years divisible by 100 must also be divisible by 400 in order to be a leap year. The years 1700, 1800, and 1900 were leap years according to the Julian calendar, but not leap years according the Gregorian calendar. The year 2000 was a leap year because it is divisible by 400.

Some Christian holidays have fixed dates, such as Christmas, which falls on 25 December on the Gregorian calendar. Other church holidays, such as Easter, are actually based on a lunisolar calendar. Easter occurs on the first Sunday after the first full Moon following the March equinox—the vernal equinox in the Northern Hemisphere.

Learning Check 1.6

1. Contrast the Hebrew and Islamic calendars, distinguishing between the lunar calendar and the lunisolar calendar.
2. Describe the features of the Julian and Gregorian calendars. Explain why it was necessary to switch from one to the other.

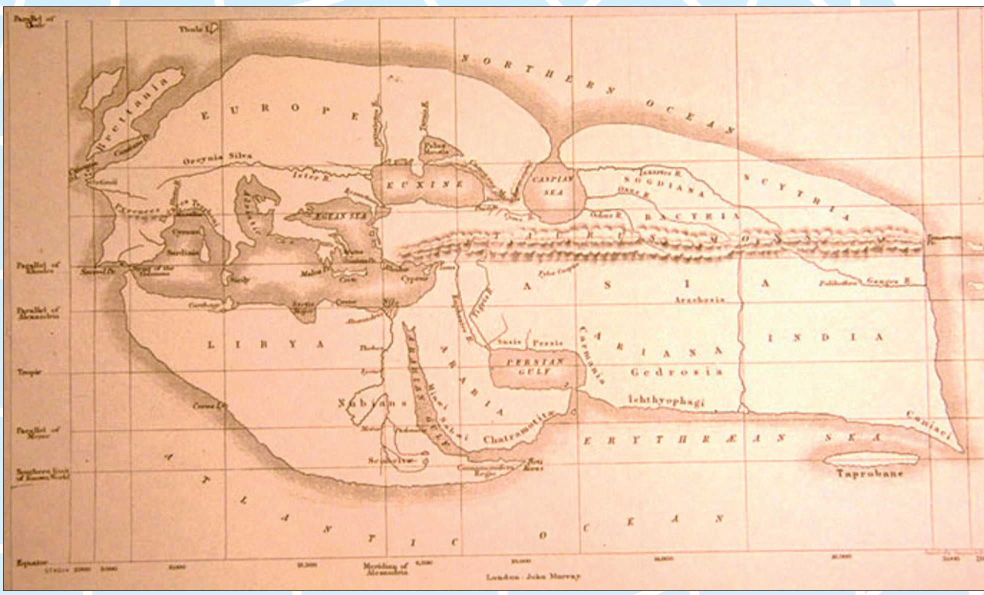
Chapter 1 Exercises

Answer each of the questions below as completely as you can. Write your responses in complete sentences unless instructed otherwise.

1. Give a definition for each of the four major Earth systems and describe how these systems interact with each other.
2. Draw a sketch of our solar system, showing the Sun, planets, and habitable zone.
3. What are some ways in which Earth appears to be specially designed for living organisms to thrive?
4. Describe what is meant by the term "galactic habitable zone."
5. Describe Earth's orbit around the Sun and explain why the shape of this orbit is not the primary cause of seasons.
6. Draw a sketch like Figure 1.18 and use it to explain the cause of Earth's seasons.
7. Explain why it is that, outside the tropics, summer days are warm or hot and winter days are cool or cold.
8. Predict what Earth's days and seasons would be like if Earth's axis were tilted at close to 90° rather than 23.5°.
9. Draw a sketch of Earth, showing the location of the Tropics of Cancer and Capricorn, and Arctic and Antarctic Circles.
10. Describe the path the Sun would take across the sky viewed from the North Pole on the summer solstice, autumnal equinox, and winter solstice.
11. Draw sketches of the eight phases of the Moon, in order, from the new Moon through the waning crescent.
12. Draw a sketch like Figure 1.22 and use it to explain the cause of lunar phases.
13. When people on Earth see a quarter Moon, what would Earth look like from the Moon?
14. Draw a sketch of a total solar eclipse with labels for the Sun, Moon, Earth, umbra, and penumbra.
15. Explain why solar eclipses are only visible in limited geographic areas, but lunar eclipses are visible from the entire night side of Earth.
16. Describe the similarities between the Hebrew and Islamic calendars, and then explain what the biggest difference is between how they work.
17. Compare the Julian and Gregorian calendars and explain how the Gregorian calendar corrected a problem with the Julian calendar.

Chapter 2

Visualizing Earth



The ancient Greek scholar Eratosthenes of Cyrene, who lived from about 276 to 195 BCE, is considered by many to be the first true geographer. Other Greek philosophers, such as Aristotle, had demonstrated that Earth was a sphere, but Eratosthenes was able to go further and use Sun angles at different locations to determine the actual circumference of the spherical Earth. He also determined that Earth is tilted on its axis. Eratosthenes wrote books about Earth, and correctly divided our world into polar, temperate, and tropical climate zones. He recognized that cities and countries at the same distance from the Equator—what we now call latitude—had similar climates. He created a map that showed latitude lines running parallel to the Equator, as well as lines that ran perpendicular to them—lines we now recognize as lines of longitude.

Objectives

After studying this chapter and completing the exercises, you should be able to do each of the following tasks, using supporting terms and principles as necessary.

1. Read latitude and longitude values from a map, with a precision of minutes.
2. Explain why navigators have been able to determine latitude since ancient times, but it wasn't until the 1700s that navigators could accurately determine longitude at sea.
3. Describe how GPS receivers use satellites to determine locations on Earth.
4. Explain what map projections are and why they are necessary for the creation of maps.
5. Describe the shape of Earth.
6. Define remote sensing and give examples of how remote sensing is used to study Earth.
7. Distinguish between GPS and GIS.
8. Interpret features on a topographic map, especially contour lines.
9. Calculate gradients and percent slopes from a topographic map.

Vocabulary Terms

You should be able to define or describe each of these terms in a complete sentence or paragraph.

1. azimuthal projection
2. cartographer
3. cartography
4. conic projection
5. contour interval
6. contour line
7. coordinate system
8. cylindrical projection
9. echo sounding
10. electromagnetic spectrum
11. Geographic Information System (GIS)
12. Global Positioning System (GPS)
13. gradient
14. index contour line
15. latitude
16. longitude
17. map legend
18. map projection
19. map scale
20. oblate spheroid
21. percent slope
22. prime meridian
23. remote sensing
24. scale bar
25. topographic map

2.1 Locations on Earth

We do not have an original copy of the ancient world map made by Eratosthenes, shown at the beginning of the chapter. The map shown in the image is a reconstruction based on written descriptions in the writings of Eratosthenes and other ancient scholars. But we know Eratosthenes had a good understanding of the size and shape of our planet, as well as of the distribution of climate and vegetation zones. He also introduced the general concepts of latitude and longitude, which have been refined in the centuries since.

You may have already discovered that maps are fascinating. It is easy to pick up a map to look up a location, only to find yourself studying all the details for an hour or more! *Cartography* is the art and science of making maps, and a person who makes maps professionally is a *cartographer*. Cartography is an art, since a cartographer must have creativity and a sense of what makes a map pleasing to the eye. It is also a science, because it involves measurements, analysis of data about Earth, and an understanding of topics such as ecology, landforms, and electromagnetic radiation. Obviously, modern cartographers have many more tools available to them than Eratosthenes did, such as computers, satellites, and advanced surveying equipment.

2.1.1 Latitude and Longitude

Locations on Earth are specified using a numerical *coordinate system*. You are familiar with coordinate systems in mathematics. The Cartesian coordinate system locates points with an *x-y* ordered pair on a graph. The most widely used coordinate system for specifying locations on Earth is the latitude-longitude geographic coordinate system, in which locations are given as angles. *Latitude* is the angle between lines drawn from the center of Earth to the surface, as illustrated in Figure 2.1. The 0° line is the Equator and other lines are measured north or south of the Equator. Lines of latitude run parallel to the Equator and to each other, so they are always the same distance apart. Because of this, lines of latitude are sometimes called *parallels*.

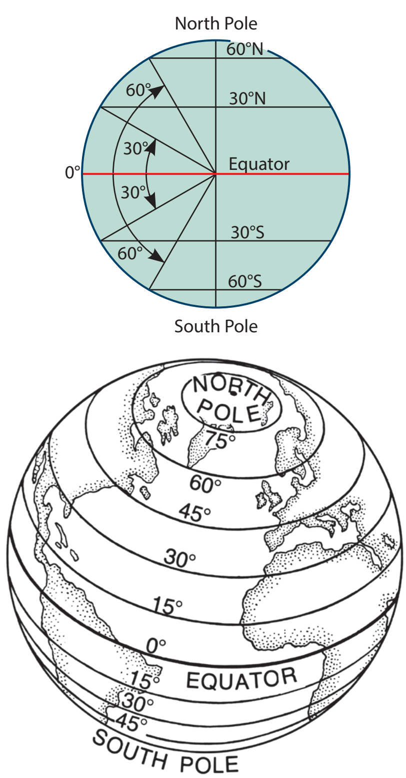


Figure 2.1. Angles from Earth's center are used to establish lines of latitude on the surface (top). Lines of latitude are parallel to each other and to the Equator, which is 0° (bottom).

Navigators at sea have been able to determine latitude since ancient times. On a clear night in the Northern Hemisphere, it is fairly easy to determine the latitude by observing Polaris, the North Star. For an observer on Earth's surface, the angle between the line of sight to the horizon and the line of sight to Polaris in the night sky is very close to the observer's latitude. Polaris is almost directly above Earth's North Pole, so if it is directly overhead, you know you are at 90°N (the North Pole). At a point half way between the Equator and the North Pole, Polaris is 45° above the horizon and the latitude is 45°N. There is no clearly visible star directly above the South Pole, so there is no commonly used pole star in the Southern Hemisphere.

Longitude is the angle east or west of a 0° line running from the North Pole to the South Pole. This 0° line is called the *prime meridian*. The lines of longitude, illustrated in Figure 2.2, are sometimes called *meridians*. Meridians are measured as angles east or west of the prime meridian, and longitude values range from 0° to 180°, for a total measurement of 360° around the entire planet.

In the past, many countries had their own prime meridians; there was a meridian of Paris, one of London, another of Washington DC, and many others. In 1884, an agreement was reached at an international conference to recognize the meridian going through Greenwich, England, to be the international standard prime meridian. The straight north-south boundaries between many of the western states in the United States were originally defined as a certain number of degrees west of the Washington DC meridian, rather than in terms of the longitude west of Greenwich.

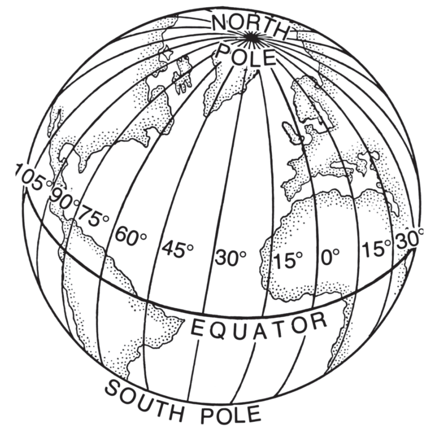


Figure 2.2. Lines of longitude. The prime meridian runs through Greenwich, England, and is designated as 0°.

Unlike lines of latitude, lines of longitude are not parallel—they come together at the poles. At the Equator, one degree of latitude and one degree of longitude cover very close to the same distance on Earth's surface. As one travels closer to a pole, the lines of longitude get progressively closer to one another, as Figure 2.2 shows.

Locations on Earth's surface are expressed with latitude first, then longitude. In Figure 2.3, you see that New York City is located at 41°N, 74°W (stated as 41 degrees north, 74 degrees west), and Sydney, Australia, is at 34°S, 151°E. On a global scale, this might be sufficient to locate a place, but on a local scale, latitude and longitude may be expressed with a much higher degree of precision. Each degree of latitude or longitude is divided into sixty minutes, and each minute is divided into sixty seconds. Minutes are represented by the symbol ′ and seconds by the symbol ″. This enables us to state locations more precisely. For example, the Statue of Liberty in New York City is at 40°41′21″N, 74°2′41″W. (These coordinates locate the statue to within about 30 meters.)

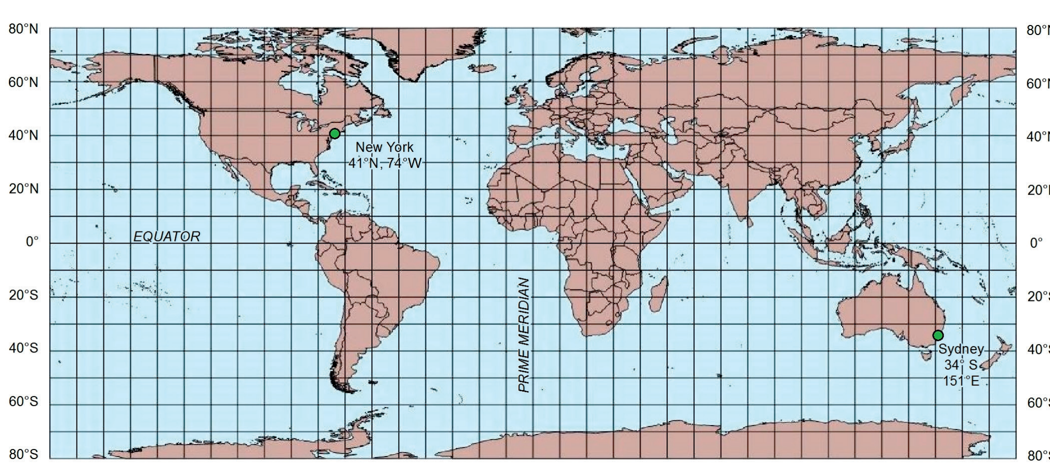


Figure 2.3. Latitude and longitude of New York City and Sydney, Australia.

Figure 2.4. One of Harrison's marine chronometers. The invention of accurate clocks in the 1700s enabled navigators to make accurate plots of their positions at sea for the first time.

Although mariners have known how to determine latitude at remote locations for many centuries, they did not have tools for accurately determining longitude until the mid-1700s. On land, people can use surveying techniques to measure distances and angles, and thus determine how far east or west a location is from a central meridian, but those methods cannot be used at sea. A common method for determining locations at sea was by dead reckoning, which was based on the estimated course of a ship. A ship would leave from a known location and the navigator estimated how far the ship had travelled based on the speed of the ship through the water. Sometimes this worked well enough and ships arrived at their planned destinations. However, there were numerous instances when ships or entire fleets missed their destination and got lost at sea, crashed into rocks, or encountered other disasters. Because of this, seafaring nations sought more accurate means of determining longitude.

A key step toward more accurately determining longitude at sea was the invention of highly accurate clocks. In the mid-1700s, British clockmaker John Harrison invented the marine chronometer, pictured in Figure 2.4. Harrison labored over a period of thirty years to produce a clock that was sufficiently accurate for navigation. The invention of the marine chronometer enabled navigators to use the positions of the Sun, Moon, planets, and stars at a specific time to make accurate determinations of both latitude and longitude. The navigator used a sextant like the one shown in Figure 2.5 to measure the angle between the horizon and an astronomical body—the Sun by day or Moon, planet, or star by night—and then consult books (called nautical almanacs) with printed tables of the positions of these bodies at various times. This allowed the navigator to determine a ship's position to within a few miles, usually accurate enough to get the ship to its destination and avoid disasters.

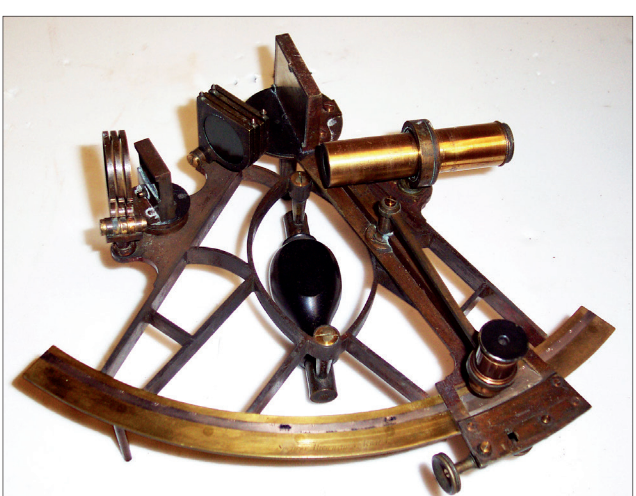


Figure 2.5. A sextant is used to measure the angle between the horizon and the Sun or other celestial body.

2.1.2 Satellite Navigation Systems

Today, locations on Earth can be precisely determined by using signals from satellite navigation systems. The most commonly used satellite navigation system is the *Global Positioning System*, or GPS. A GPS satellite is shown in Figure 2.6. The Global Positioning System always has a minimum of 24 satellites orbiting Earth. These satellites continuously transmit radio signals that are used to determine locations on Earth. Figure 2.7 shows how the satellites surround the planet. At any given moment, there are at least four satellites in the sky over any location. The radio signals sent by the satellites contain the time the signal was sent and the position of the satellite when the signal was sent.

Figure 2.6. A Global Positioning System (GPS) satellite, with solar panels to supply it with electricity.

Figure 2.8 shows a typical hand-held GPS receiver. The receiver determines the amount of time it has taken for the signal to travel from each of the satellites. Since the signals travel at the speed of light (300,000 kilometers per second), the receivers must be able to measure time intervals with a precision of billionths of a second. Some of the satellites are closer to the receiver and others are farther away. The receiver calculates the distance to four different satellites with known positions and uses these four distances to calculate its own position, as illustrated in Figure 2.9.

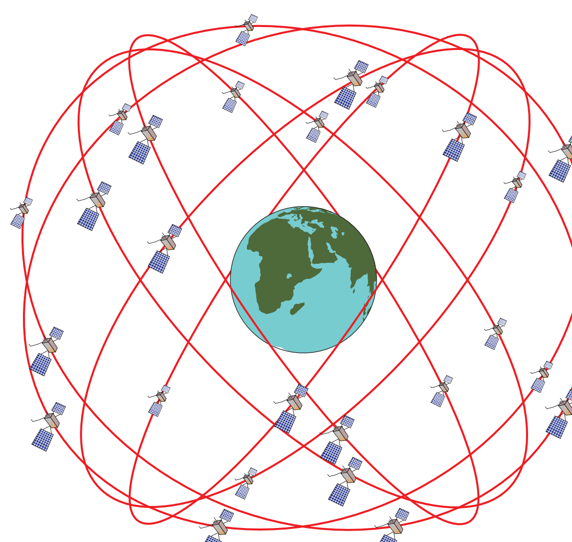


Figure 2.7. The 24 satellites of the Global Positioning System (GPS) provide worldwide service.

Figure 2.8. GPS receiver with a map showing the current location of the receiver.

Satellite navigation now has hundreds of applications. These systems were originally developed for military use, but now are used for airplane, ship, and car navigation; surveying;

studies of earthquakes and volcanoes; tracking wildlife; and recreational activities such as backpacking. Smart phones and tablet computers typically have GPS receivers built into them. The Global Positioning System is operated by the United States, but there are similar systems operated by Russia and China. Other satellite navigation systems are being developed by other countries.

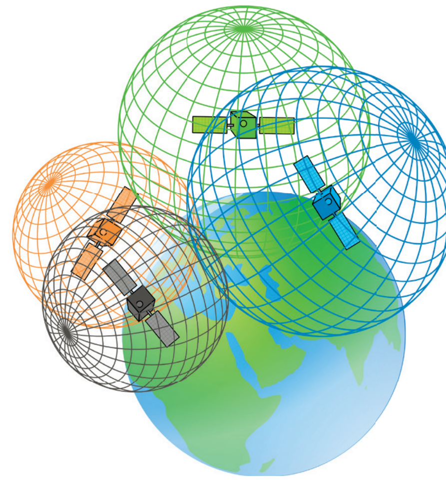


Figure 2.9. The spheres represent different distances from GPS satellites. The point where the surfaces of all four spheres intersect is the location of the receiver.

Learning Check 2.1

1. Compare lines of latitude to lines of longitude, explaining how they are similar and how they are different.
2. Explain how Harrison's invention of the first marine chronometer enabled navigators to determine their longitude while at sea.
3. Describe how the GPS system is used.

2.2 Map Projections and the Shape of Earth

Imagine a balloon with a map of the United States drawn on it. If we were to pop that balloon, it would be a challenge to lay that map completely flat on a table. As shown in Figure 2.10, we would have to stretch and distort the rubber in order to get the United States or any other portion of the balloon to be flat.

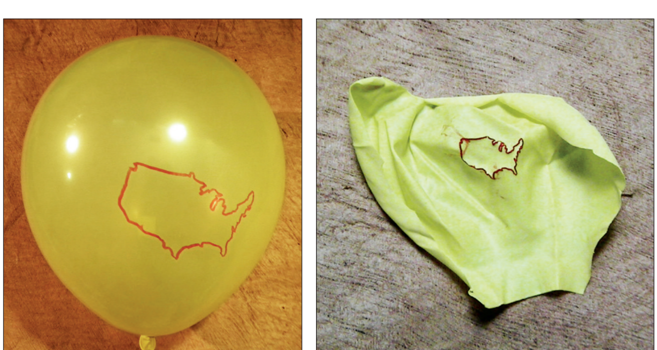


Figure 2.10. The curved surface of the United States fits properly on the inflated balloon, but the popped balloon has to be stretched for the United States to fit on a flat surface.

This is the same problem cartographers have when they take regions on the roughly spherical Earth and make maps on flat surfaces, such as a sheet of paper or computer monitor. The true sizes, angles, and shapes of features on Earth—continents, oceans, countries, and so forth—must be distorted in order to construct a flat map. These distortions are obvious on maps that show large areas, like those in Figure 2.11, but distortions exist even on maps of small areas, such as on a map of a city.

2.2.1 Map Projections

A *map projection* is a method by which the curved surface of Earth is portrayed on a flat surface. To visualize how projections work, imagine drawing lines from the center of the globe through features on Earth's surface, and extending these lines onto a surface that can be flattened out. There are numerous projections in use, but most of them fall into a few categories.

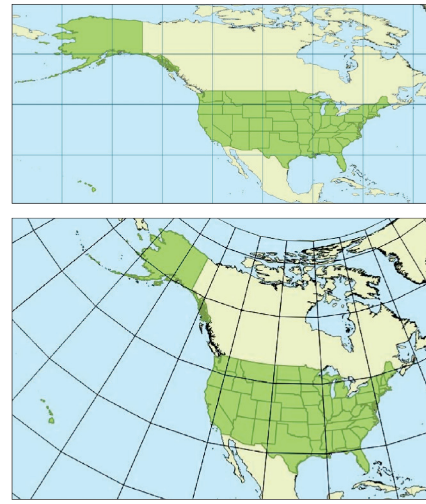


Figure 2.11. Both these maps distort the size and shape of the United States and Canada. The only true portrayal of the size and shape of features on Earth's surface is on a globe.

A common type of projection is a *cylindrical projection*, constructed by extending features on Earth's surface onto a cylinder wrapped around Earth, as illustrated in Figure 2.12. There are several ways of doing this. A common example is the Mercator projection, which portrays all lines of latitude and longitude as parallel to each other. Because lines of longitude in reality meet at the poles, the Mercator projection distorts the sizes of features closer to the poles. If you look at a globe—on which features are portrayed in their true proportions—you see that Greenland is considerably smaller than South America. However, on a Mercator projection, Greenland looks as large or larger than South America, as on the world map shown in Figure 2.13. The advantage of a Mercator projection is that both Greenland and South America are preserved in roughly their true shapes. Another advantage is that straight lines drawn on a Mercator projection map follow a constant compass direction, and thus are easy to use for navigation. Mercator projections are frequently used for world maps and are also often used for maps of smaller areas, such the topographic map shown in Figure 2.14.

A *conic projection* is constructed by extending features on Earth's curved surface onto a cone, as illustrated in Figure 2.15. This reduces distortion of features near the latitudes at which the imaginary cone intersects Earth's surface. Maps of entire countries or continents are commonly drawn using conic projections. The

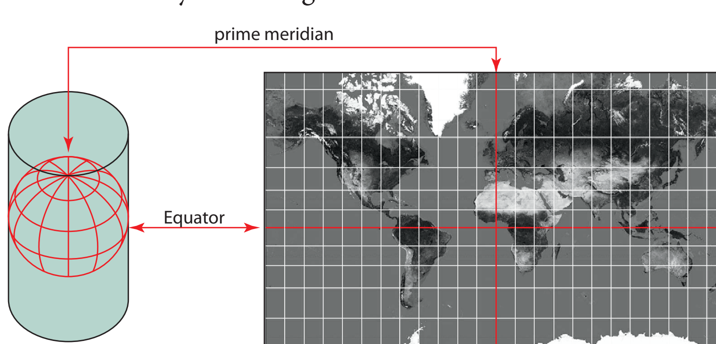


Figure 2.12. For a cylindrical projection, features on a globe are projected onto a cylinder that is wrapped around the globe.

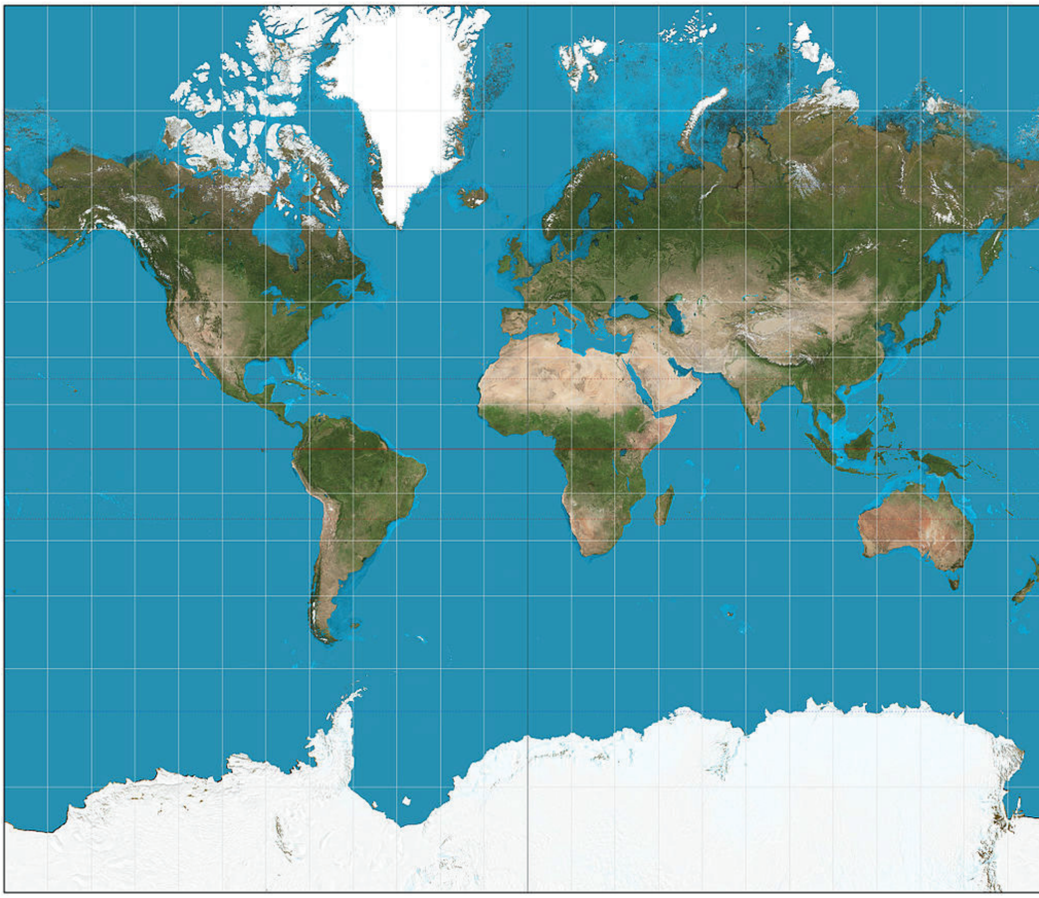
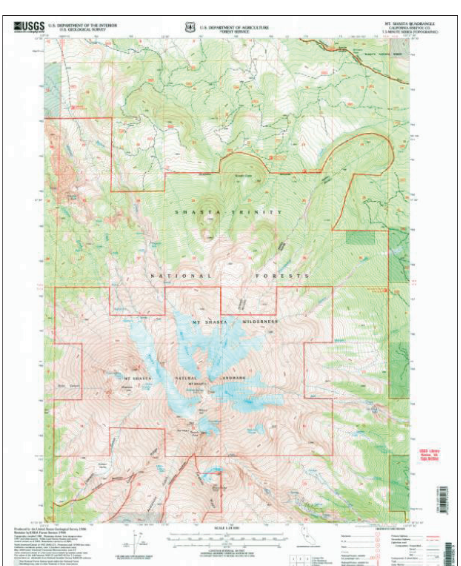


Figure 2.13. A world map on a Mercator projection, from 82° S to 82° N.



projection is designed so there is a minimum amount of distortion of size or shape in the area of interest. Usually, features farther from the center of the map are more distorted, as is apparent on the north and south edges of the map in Figure 2.16.

An *azimuthal projection*, shown in Figure 2.17, is created by projecting Earth's surface onto a plane that touches the planet at only one point. There is no distortion of features at this point, and the farther features are from that point the larger they become. The most

Figure 2.14. A topographic map of Mount Shasta, California, on a Mercator projection. For maps of small areas such as this, distortions due to the map projection are not significant for most purposes.

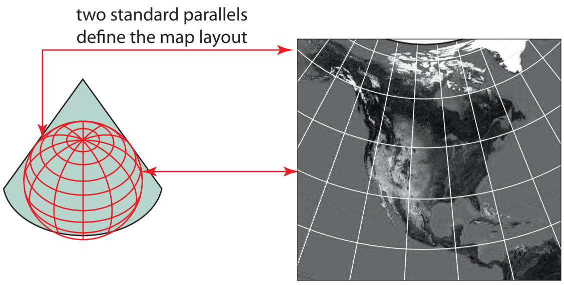


Figure 2.15. For a conic projection, features on a globe are projected onto a cone that is placed over a globe.

Figure 2.16. A map of North America on a conic projection. This projection preserves the size and shape of features near the central latitudes of the map, but distortions increase to the north and south.

common type of map that uses an azimuthal projection is one centered on one of Earth's poles. In Figure 2.18, the Arctic Ocean is portrayed much as it would be on a globe, with little distortion of size or shape. Features become increasingly distorted as the distance from the North Pole increases.

2.2.2 The Shape of Earth

There are many variations of each of these map projections, each with advantages and disadvantages. The only way to really portray Earth without significant distortions is on a globe. But a perfectly spherical globe still involves slight distortions. As I have described the Earth, I intentionally used phrases like "roughly spherical." In fact, Earth actually has an equatorial bulge—it is slightly flattened at the poles and has a greater circumference when measured around the Equator than when measured from pole to pole. A more accurate term for Earth's shape is *oblate spheroid*. An oblate spheroid, portrayed in Figure 2.19, is a flattened sphere where the Equator has a greater radius than the measurement from the center to a pole. If gravity were the only force acting on material in Earth, it would be a sphere, but Earth's daily rotation on its axis

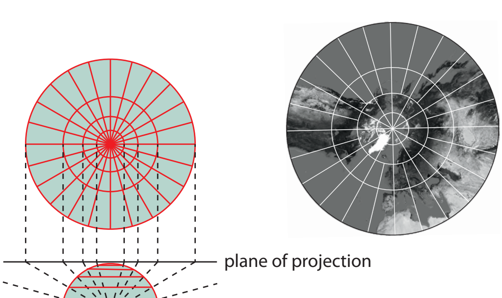


Figure 2.17. For an azimuthal projection, features on a globe are projected onto a plane that touches the globe at one point.

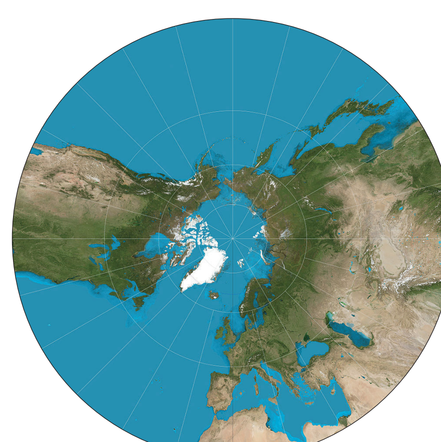


Figure 2.18. A map centered on the North Pole with an azimuthal projection. Features near the North Pole have little distortion of size or shape, but areas at a greater distance from the pole are noticeably stretched out.

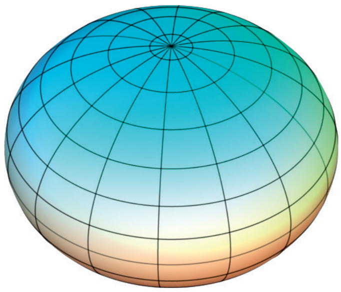


Figure 2.19. Rather than being a perfect sphere, Earth is slightly flattened at the poles and has a slight bulge at the Equator. This shape is called an oblate spheroid. The amount of flattening is greatly exaggerated in this diagram.

causes it to flatten at the poles relative to the Equator.

The difference between Earth's radius measured through the poles and through the Equator is less than 1%, which is why Earth seems spherical. However, all cartographic and scientific measurements of Earth, such as latitude and longitude, are actually made by considering Earth as an oblate spheroid rather than as a sphere. The most commonly accepted measurements for Earth's radius are indicated in Figure 2.20.

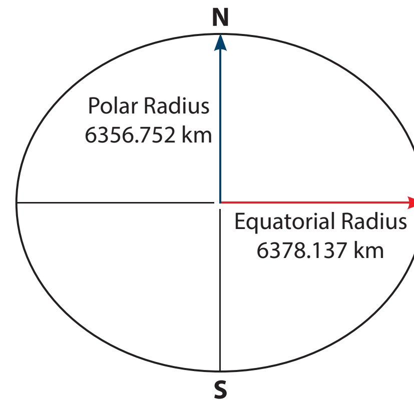


Figure 2.20. Earth's radius measured through the Equator is slightly greater than its radius measured through the poles.

Learning Check 2.2

1. Explain why it is impossible to make an accurate map of Earth on a flat sheet of paper without using a projection.
2. Describe the difference between cylindrical, conic, and azimuthal projections.
3. Describe the shape of Earth.

2.3 Remote Sensing

Remote sensing is the collection of information about Earth and the environment from a distance, usually by detecting and recording energy from the *electromagnetic spectrum* emitted from or reflected by Earth's surface, vegetation, water, or atmosphere. The electromagnetic spectrum, illustrated in Figure 2.21, includes electromagnetic energy ranging from high-energy gamma rays and X-rays to low-energy radio waves, with the visible light spectrum in the middle. All portions of the electromagnetic spectrum are used in remote sensing.

Radio waves, on the left side of Figure 2.21, have long wavelengths but low energy. You can remember that radio waves have low energy when you think of how many radio signals are going through you right now—from every radio and TV station in your area, from cell phones, and from other sources—with no apparent effect. X-rays and gamma rays are on the other end of the spectrum. They have very short wavelengths—measured in billionths or trillionths of a meter—but very high energy.

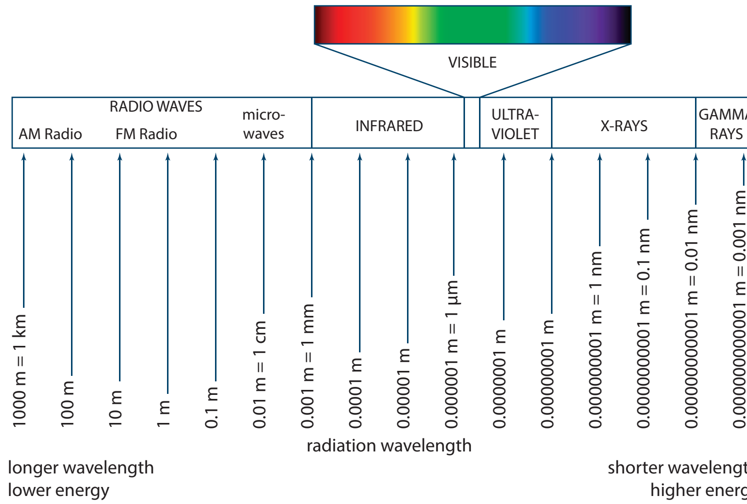


Figure 2.21. The electromagnetic spectrum.

Data from remote sensing is often presented in the form of pictures referred to as *imagery* (or sometimes referred to as *aerial* or *satellite photography*). If you have used internet sites or apps on mobile devices to view an overhead picture of your house, school, or other location, you have viewed remote-sensing imagery.

Some of the earliest aerial photography was taken using cameras mounted to balloons, kites, and even pigeons, as shown in Figure 2.22. Today, remote-sensing data are typically collected from above using airplanes or satellites, such as the NASA Landsat satellite shown in Figure 2.23. Much of this technology was initially invented for military and intelligence purposes, leading to the development of what are commonly referred to as "spy satellites," but many other uses have now been developed.

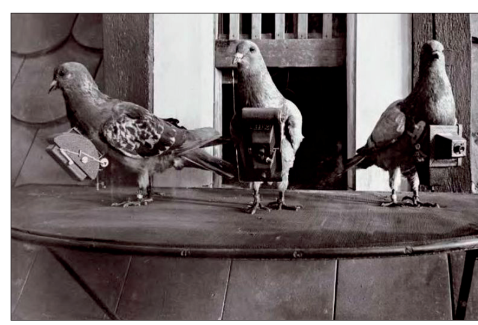


Figure 2.22. Before airplanes became common for aerial reconnaissance, attempts were made to use pigeons as aerial photographers.

Remote sensing satellites have provided regular coverage of most of Earth for over forty years. Imagery from these satellites is used to trace changes to forests, farmland, cities, water bodies, and other features. In addition to using visible light, many satellites record infrared radiation, which means the satellite detects wavelengths of light the human eye cannot see. This enables the sensor to distinguish changes in vegetation and soil moisture that are too subtle to be seen with visible light. Figure 2.24 shows the burn scar from a large forest fire in Colorado. Healthy trees are shown with

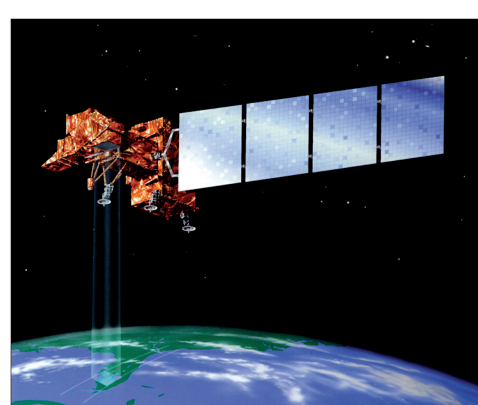


Figure 2.23. Landsat satellites capture images of the entire Earth once every 16 days.

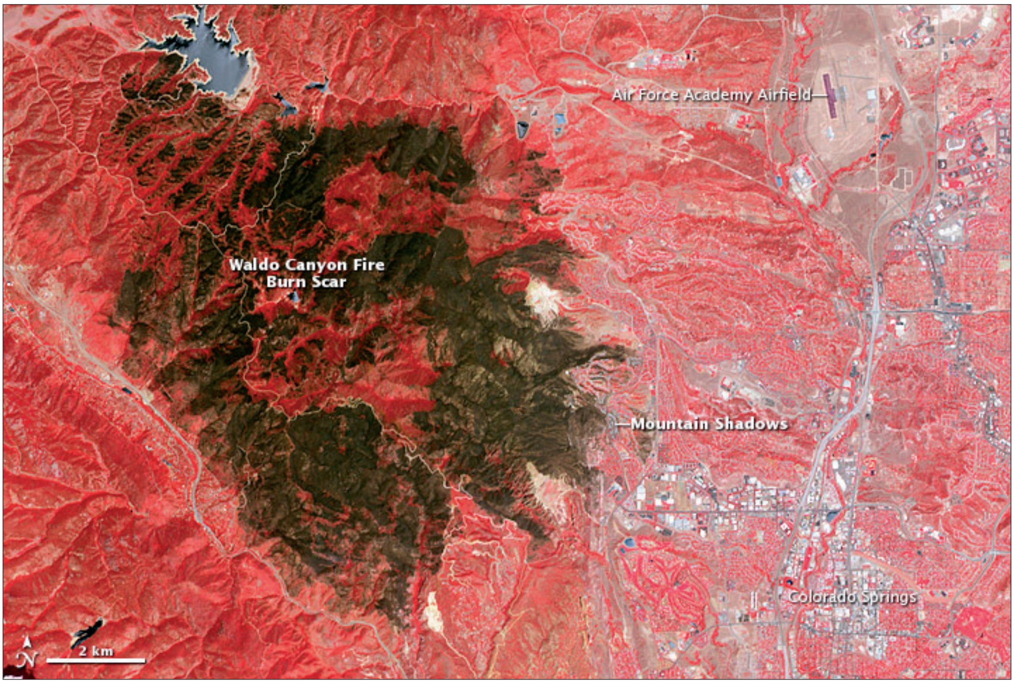


Figure 2.24. Satellite imagery is used to analyze damage to forests due to wildfires. In this image, red is healthy vegetation, gray is bare ground or man-made features, and dark brown is the burn scar from a wildfire.

Figure 2.25. Remote sensing images from weather satellites give detailed and timely information about Earth's atmosphere. In this image centered on North America, the highest clouds, which are associated with the tops of strong storm systems, are red and orange.

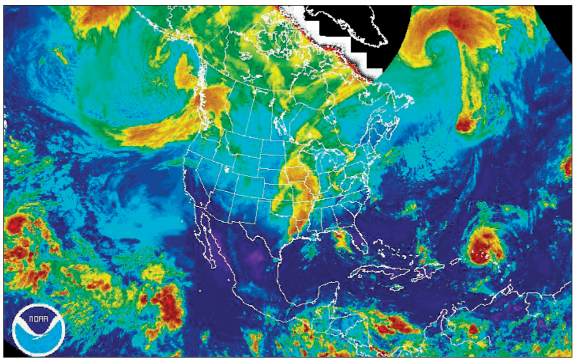


Figure 2.26. Echo sounding uses sound waves transmitted through water to determine water depth.

red to emphasize that these data were collected using infrared wavelengths, in addition to visible light. Infrared wavelengths are also useful for geological investigations, such as searching for mineral deposits.

Remote-sensing images are important for many uses in oceanography and meteorology. In the past, weather observations were limited to those made at manned weather stations and there were large parts of Earth where storms could develop without anyone knowing about them. Now we have a continuous global picture of what is happening in the atmosphere. The first weather satellites sent back images that enabled forecasters to see the extent of cloud cover, but not much more. Instruments on modern satellites detect the temperatures of cloud tops, as shown in Figure 2.25, and measure wind speeds, precipitation, lighting strikes, concentrations of various pollutants, and much more. Since Earth's land surface, oceans, and atmosphere emit infrared radiation at night as well as during the day, weather satellites even gather remote-sensing data in the dark.

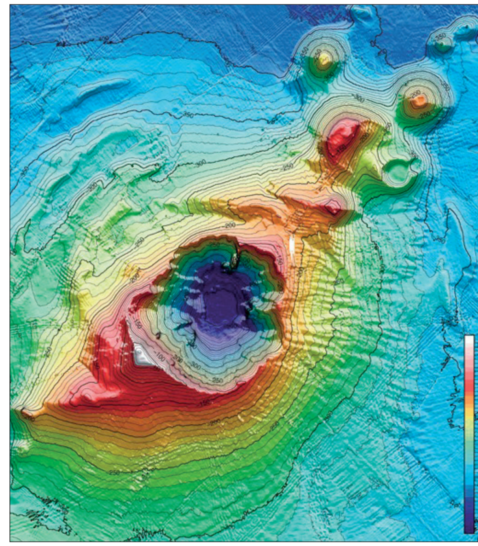


Figure 2.27. A map of a submarine volcano in the Aegean Sea, with elevations determined using echo sounding. The main crater is about 1.5 km (1 mi) across. The deepest part of the crater (purple) is about 500 m (1640 ft) below sea level, and the shallowest part of the crater rim (white and dark red) is about 10 m (33 ft) below the ocean surface.

Not all remote sensing data is produced using electromagnetic radiation. An example of a different technology is *echo sounding*, which uses sound waves rather than electromagnetic radiation to determine the depth of water in oceans or lakes. By measuring the time required for the sound waves to travel from the ship to the sea floor and back to microphones in the water, oceanographers are able to determine the depth of the water, as illustrated in Figure 2.26. It takes a large amount of echo-sounding data to map even a small part of the ocean floor, such as the map of a submarine volcano depicted in Figure 2.27. Sound waves are also transmitted into the solid Earth to determine the structure and layering of rocks in Earth's crust and deeper. This technique is commonly used by geologists exploring for petroleum deposits.

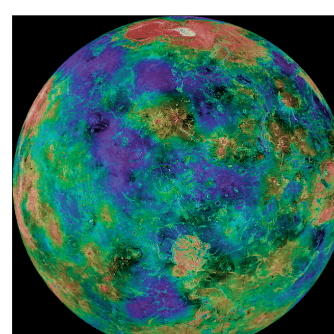


Figure 2.29. Use of radar on NASA's Magellan probe allowed scientists to make a complete map of Venus. The colors are added by computer software. As in Figure 2.27, blue areas are low in elevation and red and white areas are high. The surface of Venus is extremely hot and dry, with an average surface temperature of 462°C (863°F).

Figure 2.28. Because of its thick layers of clouds, it is impossible to see the surface of Venus from space using visible light.

Probes sent to other parts of the solar system also use remote sensing to gather information, using the same principles as those used for observing Earth. We would know very little about the surfaces of Mercury, Venus, Mars, or the moons of the outer planets if it were not for remote sensing. For example, Venus is enveloped by a thick layer of clouds, as shown in Figure 2.28, and its surface is never visible from space. However, the surface of Venus has been mapped in great detail using radar mounted on the Magellan probe. Radar determines distances using radio waves. The transmitter sends out radio waves that bounce off the surface of a planet and back to a receiver on the satellite. The Magellan probe was able to gather data to make an elevation map of almost the entire surface of Venus, as shown in Figure 2.29.

Learning Check 2.3

1. List the six main regions of the electromagnetic spectrum, from low energy to high energy.
2. Describe a way that remote sensing is used to study each of the four Earth systems (lithosphere, hydrosphere, atmosphere, and biosphere).

2.4 Mapping Earth

A map is a model of the world or part of the world, showing natural and man-made features. Constructing a map involves mathematics, computer skills, geographic knowledge, and a lot of patience. A well-made map is not just a technical document; it must also be pleasing to the eye. The "art" side of cartography involves making decisions about colors, text placement, and map symbols. These choices make the difference between constructing a well-made map and one that is difficult to read or even misleading. In the past, maps were usually printed on paper. Now, people increasingly turn to digital maps—on computer screens or mobile devices—on a day-to-day basis.

There are many types of maps—road maps, political maps, maps that show the spread of diseases, and on and on. Maps are used in Earth sciences to present information about all sorts of topics, ranging from weather maps and maps of ocean surface temperatures, to maps showing the topography of mountain ranges or the sea floor. You have heard the phrase, "a picture is worth a thousand words." The same concept applies to cartography: "a map is worth a thousand words." The use of maps powerfully and quickly communicates complex concepts to both scientific and general audiences.

Consider a map such as the one in Figure 2.30 depicting the average wind speed 80 meters above the ground for the United States. This map was constructed as part of an effort to identify the best locations for placing wind turbines. Wind turbines are used to generate electricity. The purple areas are those with the highest average wind speeds and the yellow and green areas are the areas with lowest average wind speeds. You can quickly look at the map and see that the areas with strongest winds are in the Great Plains, from northwest Texas up through North Dakota.

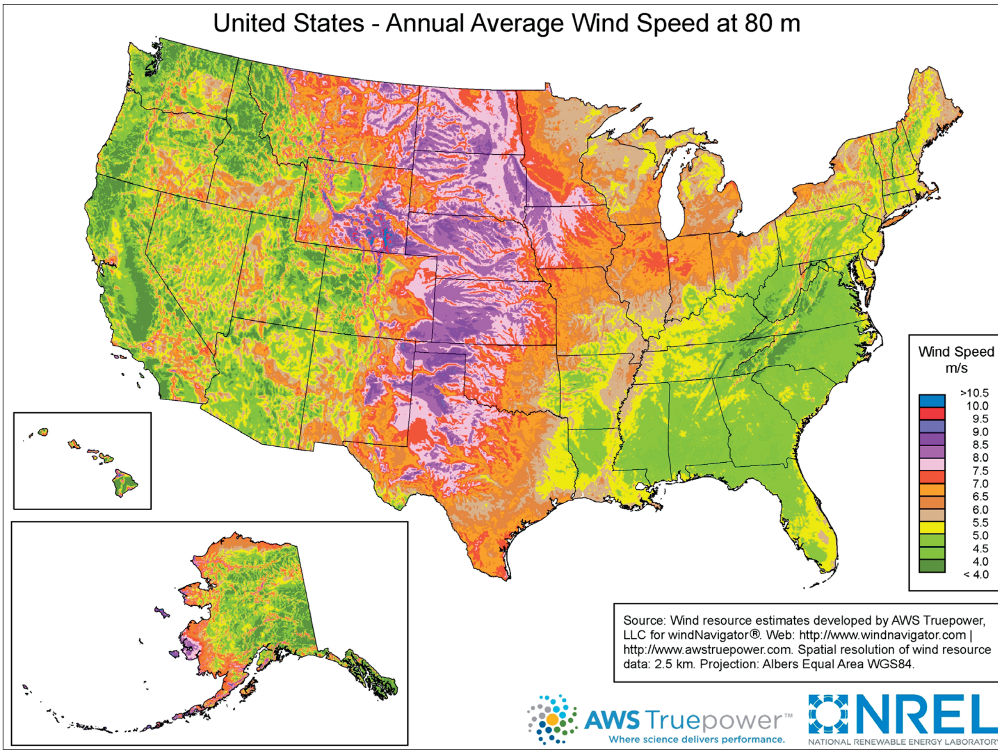


Figure 2.30. Map showing average wind speed, in meters per second, at 80 meters above the ground.

2.4.1 Geographic Information Systems

All maps are prepared using map projections because the features portrayed on the map must be distorted in order to fit on a flat surface. In the past, this was a laborious process, but it is now done quickly by computers. Almost all maps, whether paper or digital, are now made using Geographic Information Systems. A *Geographic Information System* (or GIS) is computer software that analyzes data about Earth and presents it in the form of maps. The data contained in the GIS may include imagery; elevation data; and points, lines, and polygons that represent natural and man-made features such as towns, roads, streams, lakes, and political boundaries. Using GIS software, maps that would have taken months to construct in the past are typically produced in a matter of hours or days.

There is much more to a GIS than just making maps. Cartographers or other GIS users also compare different sets of data to help make decisions. For example, a forester might use GIS to compare soil types, elevations, and sun angles in order to decide the best places planting tree seedlings after a forest fire. This was a very time-consuming task before the availability of GIS technology.

2.4.2 Topographic Maps

An important type of map in Earth sciences is the *topographic map*. A topographic map represents the surface of Earth, showing elevations by the use of contour lines or color tints (e.g., the color bands shown in Figure 2.27). Topographic maps also show other natural and man-made features, such as streams, lakes, forests, roads, and buildings. They are used by geologists, foresters, wildlife biologists, engineers, planners, military personnel, campers, and backpackers. In the United States, detailed topographic maps have been made for the entire nation by government agencies such as the U.S. Geological Survey and the U.S. Forest Service. A section from a U.S. Geological Survey topographic map is shown in Figure 2.31. The topographic maps made by these agencies are referred to as quadrangles. Most other countries have similar topographic mapping programs.

Most topographic maps portray elevation using *contour lines*—curves that connect points of equal elevation. The brown curves in Figure 2.31 are contour lines. Each point along the 900-foot contour represents an elevation of 900 feet above sea level, and each point along the 1,100-foot contour represents an elevation of 1,100 feet above sea level. The shapes of the contour lines on the map reflect the shape of the land surface. The starting point for measuring elevation is sea level, which is assigned a value of zero. Most topographic maps in the United States show el-

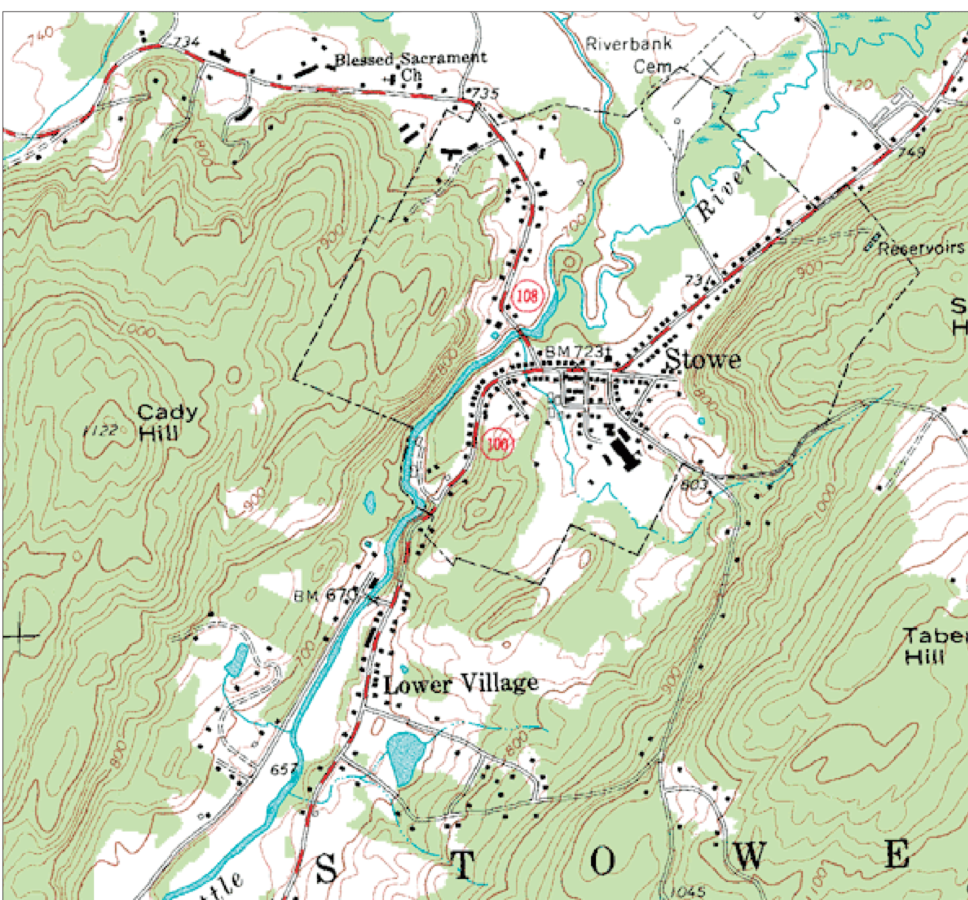


Figure 2.31. A part of a topographic map showing roads, buildings, water bodies, trees, and elevations.

evations in feet, but military topographic maps and topographic maps produced by other countries indicate elevations in meters.

Figure 2.32 illustrates the relationship between contour lines and landscape. In places where the land is relatively level, such as along the stream in the center of the diagram, the contour lines are far apart. Where the slope is steep, the contour lines are close to each other.

There are four basic principles associated with contour lines, illustrated in Figures 2.33, 2.34, and 2.35:

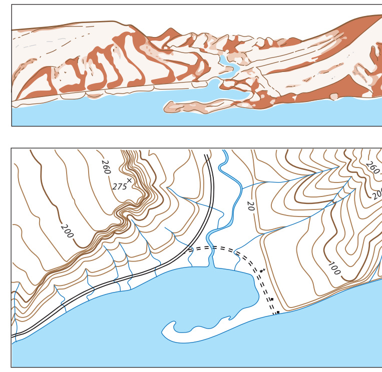


Figure 2.32. The relationship between landscape and contour lines.

1. As just stated, where contour lines are far apart the slope is gentle; where they are close together the slope is steep.
2. Contour lines never cross each other. On some topographic maps, they can touch each other where there are cliffs, but they do not actually cross each other.
3. Where a contour line crosses a stream on a topographic map, the contour line is V-shaped, with the V pointing upstream toward areas with higher elevation.
4. Contour lines form closed loops around elevated areas (e.g., hills) and depressed areas (e.g., craters). For example, a hill on a topographic map looks like a series of concentric, irregular loops. Often, the contour lines extend beyond the edges of an individual map so you don't always see the complete closed loop.

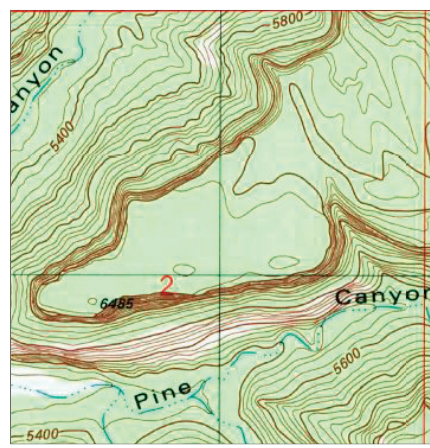


Figure 2.33. Principles 1 and 2—Contour lines are far apart in flat areas, and close to each other in steep areas, but contour lines never cross.

The *contour interval* of a topographic map is the difference in elevation between adjacent contour lines. If the contour interval is 20 feet, then contour lines are shown for every multiple of 20 feet, such as at 100, 120, 140, and 160 feet. In flat areas, there is not a great elevation difference from one part of a map to another, so a topographic map of an area of plains might have a contour interval of only 10 feet. Most hilly areas can be sufficiently portrayed with a 20-foot contour interval; mountainous areas typically

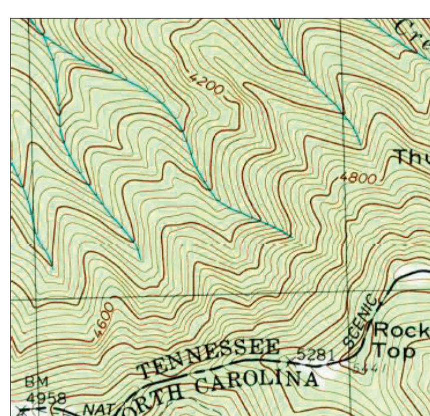


Figure 2.34. Principle 3—Contour lines make a V where they cross streams, with the V pointing upstream.

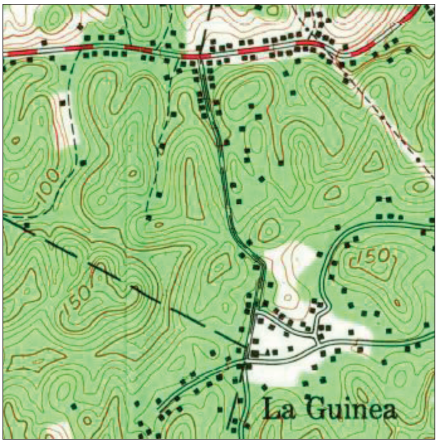


Figure 2.35. Principle 4—Contour lines form closed loops around hills.

have contour intervals of 40 feet. If a mountainous area were portrayed with a 10-foot contour interval, the contours would be so close to each other that they would blend together.

In order to make a map easier to read, every fourth or fifth contour line, known as an *index contour line*, is drawn with a heavier line weight and usually labeled to indicate its elevation. If the contour interval on a map is 20 feet, then every fifth contour line has a value that is a multiple of 100 feet and designated as an index contour line. Contour interval and index contours are depicted in Figure 2.36.

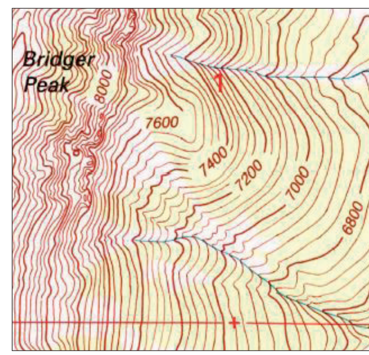


Figure 2.36. This map has a contour interval of 40 feet, with index contours every 200 feet.

2.4.3 Map Margin Information

Some of the most important features of a topographic map (or other types of maps) are found not in the main part of the map but in the margins around the map's edge. The margin gives information about the location of the map, publisher, date, and accuracy of the map. One important element of the map margin is the *map scale*. The map scale is the ratio between a length on a map and the corresponding horizontal distance on the ground. For example, a map scale of 1:100,000, means that features shown on the map are one-100,000th their true size. It also means that one unit of measurement on the map represents 100,000 of those same units on Earth. In this case, 1 cm on the map represents 100,000 cm on the ground. This is a convenient scale, because it means that 1 cm on the map also represents 1 km on the ground. (There are 100,000 cm in 1 km.) Another way of expressing map scale is with a *scale bar*. A scale bar graphically represents the scale of the map and consists of a line with marks like a ruler. The map scale and scale bar for a U.S. Geological Survey topographic map are shown in Figure 2.37.

Another important part of the map margin is the *legend*, an example of which is shown in Figure 2.38. A map legend is a key that indicates what each symbol on the map represents. Many sym-

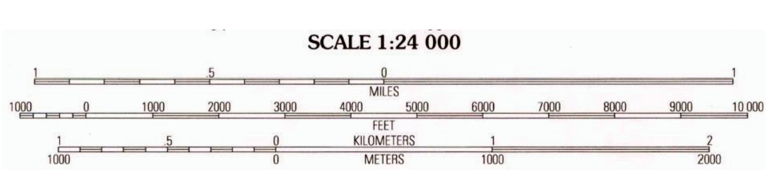


Figure 2.37. Scale bar and map scale from a topographic map.

bols on a map are designed to look like the features they symbolize. For example, trees are shown with a green tint and water bodies are depicted with blue. However, many other symbols are not the same color as the features they represent. Man-made features such as buildings are usually black, regardless of what color they really are.

2.4.4 Gradient and Percent Slope

We can describe the slope of a geographic feature such as a hillside, stream, or road as gentle or steep, or we can actually measure a slope to determine its *gradient*. Gradient is a mathematical measurement of the rate of change of the elevation of Earth's surface over a given horizontal distance. In algebra, the slope of a line is the ratio of "rise" over "run." The gradient of Earth's surface is measured in a similar way.

One way to express gradient is as the rise or drop in elevation per horizontal distance. For instance, if a stream drops in elevation 50 ft in 2.0 mi, its gradient is calculated as

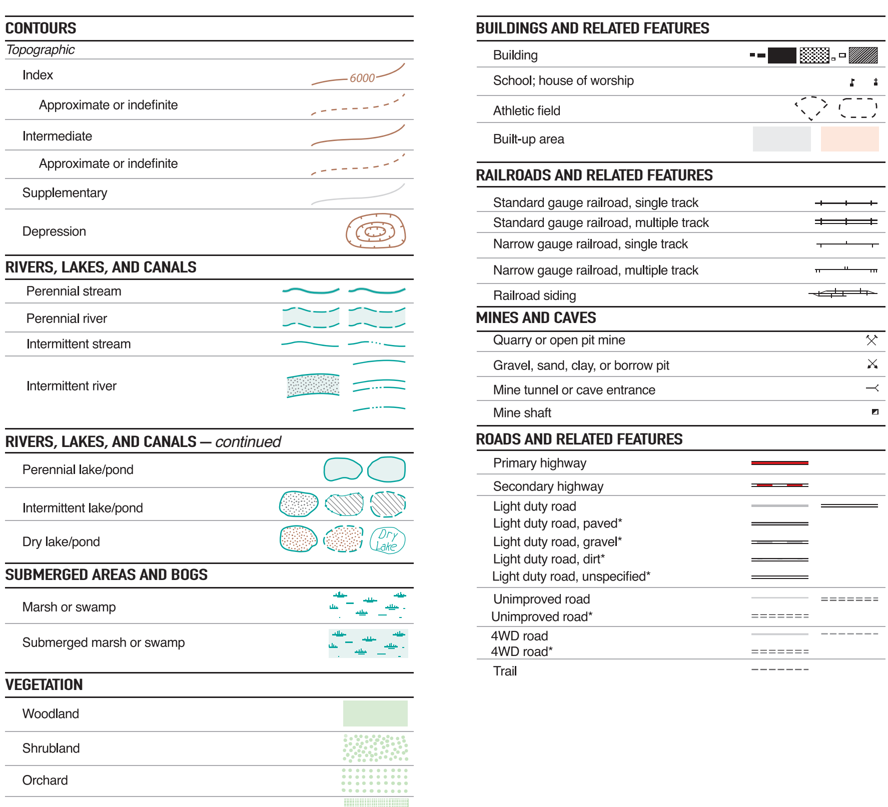


Figure 2.38. Simplified legend for U.S. Geological Survey topographic maps.

$$\text{gradient} = \frac{\text{rise (or drop)}}{\text{run}} = \frac{50\ \text{ft}}{2\ \text{mi}} = 25\ \text{ft/mi}$$

When expressed this way, the units of gradient are always distance of rise or drop per distance of run, such as feet per mile (ft/mi) or meters per kilometer (m/km).

Gradient is also often presented as a *percent slope*. Percent slope is the rise over run of Earth's surface multiplied by 100%, as illustrated in Figure 2.39. When calculating percent slope, the units for the rise and run must be the same, so the calculation uses an equation such as

$$\text{percent slope} = \frac{\text{rise feet}}{\text{run feet}} \times 100\%$$

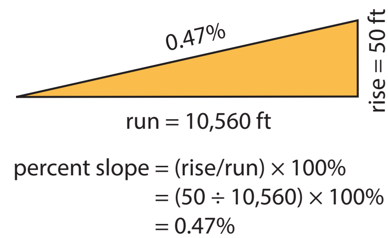


Figure 2.39. Calculating percent slope. (The sketch is not to scale; the slope is highly exaggerated to make it visible.)

Let's calculate the percent slope for the same stream. The stream drops 50 feet in 2.0 miles, but we must first convert the miles to feet. There are 5,280 feet in a mile, so the conversion is as follows:

$$2\ \text{mi} \cdot \frac{5280\ \text{ft}}{1\ \text{mi}} = 10{,}560\ \text{ft}$$

The stream's percent slope is calculated as follows:

$$\text{percent slope} = \frac{\text{rise feet}}{\text{run feet}} \times 100\% = \frac{50}{10{,}560} \times 100\% = 0.47\%$$

Note that because there are units of feet in both the numerator and denominator of this ratio, the length units cancel out and the result has units of percent; the answer is 0.47%, not 0.47 feet per foot.

Gradient can be determined by interpretation of contour lines on topographic maps. To calculate the gradient of a hillside, for example, one determines the rise by calculating the difference between the elevation for the highest contour line and the lowest contour line. The run is determined by using the map scale to measure the horizontal distance between those points. A sample calculation based on a topographic map is shown in Figure 2.40.

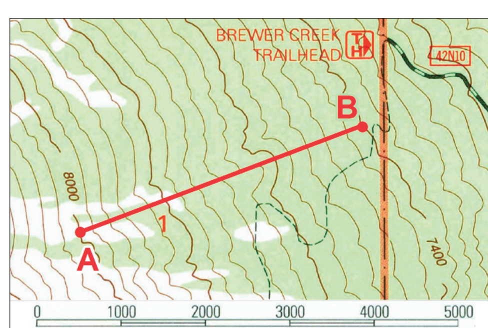


Figure 2.40. Point A has an elevation of 8000 feet, and point B has an elevation of 7400 feet, a rise of 600 feet. The horizontal distance between A and B is 3600 feet. The percent slope is (rise/run) × 100% = (600 ft/3600 ft) × 100 % = 16.7%.

Learning Check 2.4

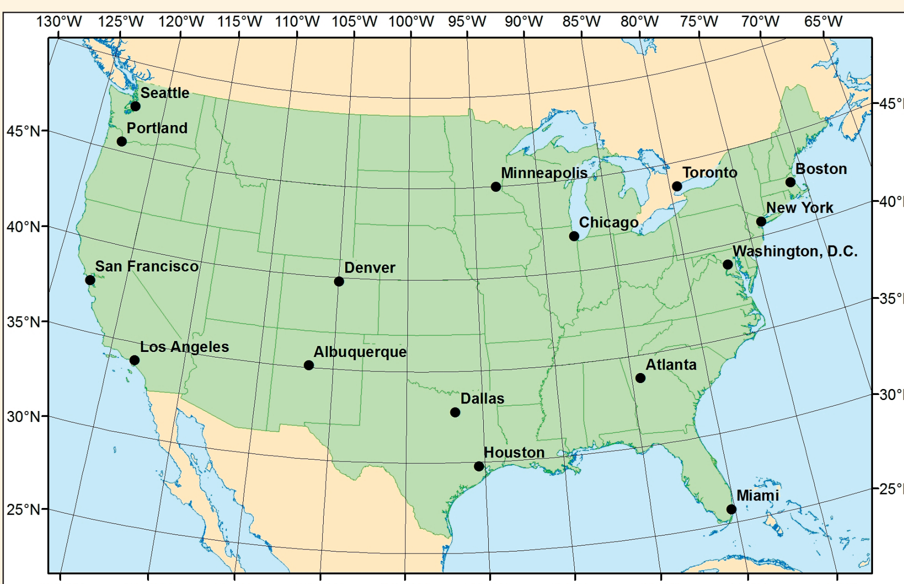
1. Explain what a Geographic Information System is.
2. Explain how contours are used to portray Earth's landscape on a topographic map.
3. What are the four basic principles of contour lines?
4. Explain what is meant by the term *map scale*.

Chapter 2 Exercises

Answer each of the questions below as completely as you can. Write your responses in complete sentences unless instructed otherwise.

1. Use the map of the United States below to determine the name of the cities with the following coordinates:

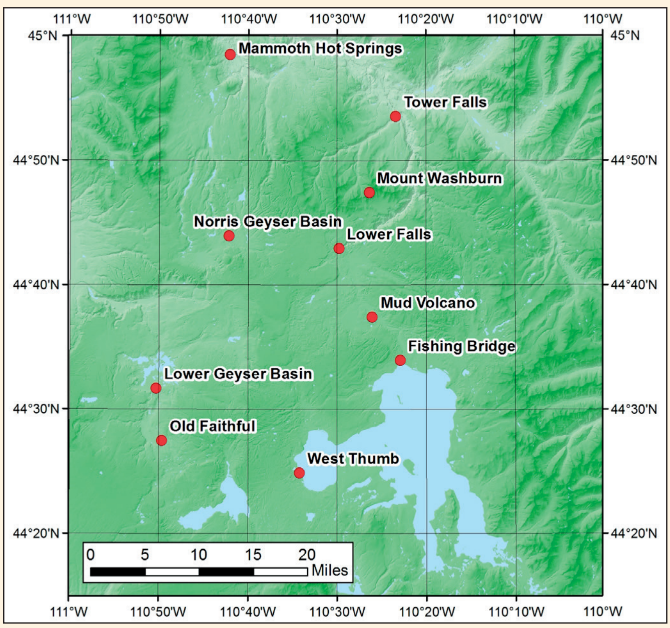
a. 40°N, 105°W	b. 42°N, 88°W	c. 26°N, 80°W	d. 46°N, 123°W
e. 41°N, 74°W	f. 34°N, 118°W	g. 42°N, 71°W	h. 30°N, 95°W



2. Use the map of the United States above to determine the latitude and longitude, to the nearest degree, of the following cities:

a. Albuquerque, New Mexico	b. Atlanta, Georgia
c. Dallas, Texas	d. Minneapolis, Minnesota
e. San Francisco, California	f. Seattle, Washington
g. Toronto, Ontario, Canada	h. Washington, DC

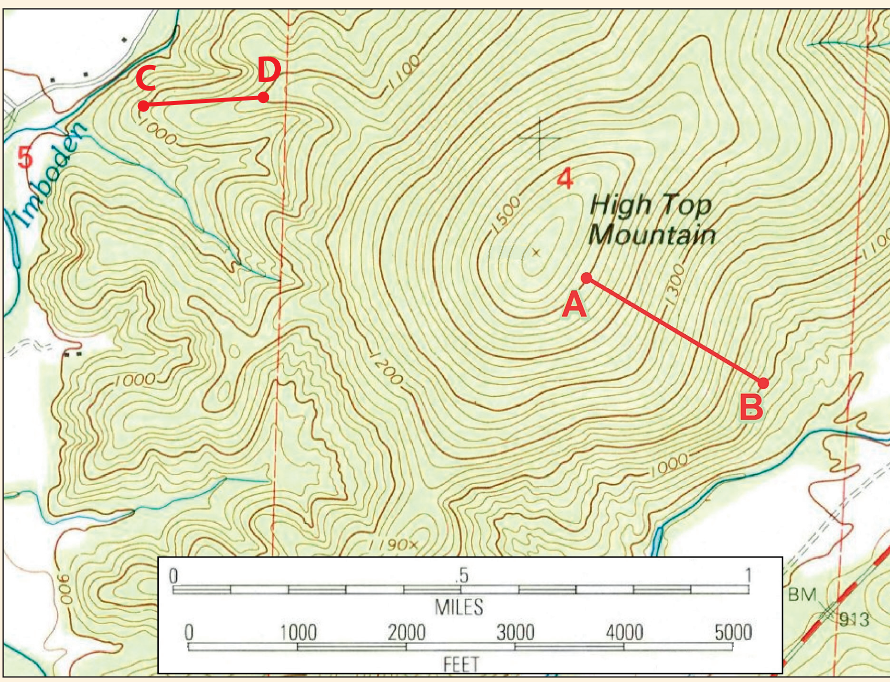
3. Use the map of a portion of Yellowstone National Park below to determine the names of the features with the following coordinates:
   a. 44°59′N, 110°42′W
   b. 44°48′N, 110°27′W
   c. 44°38′N, 110°27′W
   d. 44°32′N, 110°50′W
   e. 44°25′N, 110°34′W



4. Use the map of a portion of Yellowstone National Park above to determine the latitude and longitude, to the nearest minute, of the following features:
   a. Fishing Bridge
   b. Lower Falls
   c. Norris Geyser Basin
   d. Old Faithful
   e. Tower Falls
5. Illustrate how features on a globe can be projected onto a cylinder, cone, and plane.
6. Describe the shape of Earth and explain why it is not spherical.
7. Describe an example of remote sensing using one of the non-visible parts of the electromagnetic spectrum.
8. What are some advantages of using satellites to observe Earth's weather?
9. Explain why contour lines are far apart in flat areas and close together

in steep areas.

10. Use the topographic map of High Top Mountain below to answer the following questions (elevation values are in feet).
    a. What is the contour interval of this map?
    b. What is the interval between index contours?
    c. Estimate an elevation value for the × at the top of High Top Mountain.
    d. What are the gradients between A—B and C—D, measured in feet per mile?
    e. What are the percent slopes between A—B and C—D?



Answers

1. a. Denver b. Chicago c. Miami d. Portland e. New York f. Los Angeles g. Boston h. Houston
2. a. 35°N, 107°W b. 34°N, 84°W c. 33°N, 97°W d. 45°N, 93°W e. 38°N, 122°W f. 48°N, 122°W g. 44°N, 79°W h. 39°N, 77°W
3. Mammoth Hot Springs b. Mount Washburn c. Mud Volcano d. Lower Geyser Basin e. West Thumb
4. a. 44°34′N, 110°23′W b. 44°43′N, 110°30′W c. 44°44′N, 110°42′W d. 44°28′N, 110°50′W e. 44°54′N, 110°23′W
10. a. 20 ft b. 100 ft c. between 1580 and 1600 ft, e.g., 1590 ft d. 1400 ft/mi, 480 ft/mi e. 26%, 9%

Experimental Investigation 1: Interpreting Topographic Maps

Overview

Mount Shasta is a volcano in northern California, and is the second tallest volcano in the Cascade Range of western North America. Mt. Shasta last erupted somewhere between 200 and 300 years ago, and is considered to be a serious volcanic hazard. A good way to study and visualize a mountain like Mount Shasta is by interpreting a topographic map. In this investigation, you examine various features of a U.S. Geological Survey topographic map of the Mt. Shasta area. You also study how to construct topographic profiles, which are graphs showing cross sections along Earth's surface.

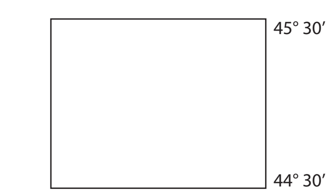
Mount Shasta. A newer volcanic cone called Shastina is forming on its west side (right side in this image).

Basic Materials List

- U.S. Geological Survey 1:24,000 topographic map of Mount Shasta, California, preferably 1998 edition.
- Ruler
- Graph paper (5 squares to an inch preferred)

Part 1—Topographic Map Interpretation

In your lab journal, record the latitude and longitude of each corner of the map, and draw a sketch of the map with labels as illustrated to the right. Then address the following questions:

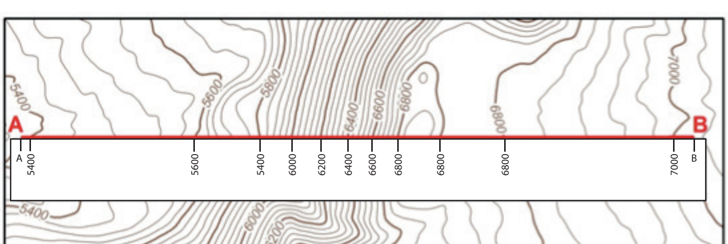


1. What is the scale of this map? What does that mean?
2. What is the distance, in a straight line, between the summit of Mt. Shasta and Clarence King Lake? Give your answer in miles and meters.
3. What is the contour interval of this map? What does that mean? What is the interval between index contours?
4. What is the elevation of the summit of Mt. Shasta? How do you know? What is this value in meters?

5. What is the elevation of Sisson Lake? How do you know? What is this value in meters?
6. What is the elevation difference between the top of Bolam Glacier and the bottom of Bolam Glacier? What is the overall gradient of Bolam Glacier in feet per mile? What is the overall percent slope of Bolam Glacier?
7. What is the gradient along Road 43N21 in the northwest corner of the map? How does this compare to the gradient of Bolam Glacier? Describe how the contour lines relate to the gradients at these two locations.
8. The trail heading south from the Bolam trailhead (at the end of road 43N21 in Question 7) does not follow a straight line. Why not?
9. Where is the lowest elevation on the map and what is the elevation at this location?
10. Compare the size of the glaciers (blue contour lines) on the north side of Mt. Shasta with the size of the glaciers on the south side of Mt. Shasta. Form a hypothesis as to why there is a difference in the areas of these glaciers.

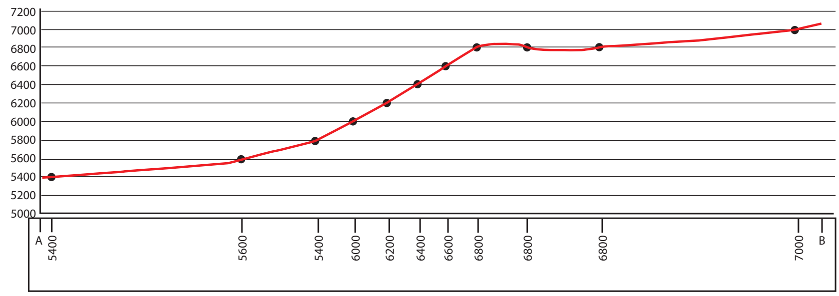
Part 2—Constructing a Topographic Profile

A *topographic profile* is a cross-section through Earth's surface along a line. One can think of a topographic profile as a graph of what Earth's surface would look like if one were to take a slice out of Earth's crust and view it from the side. The first step in constructing a topographic profile is to lay a strip of paper along the profile line, and transfer contour values to the paper, as shown below.



The second step is to take the strip of paper and transfer the values to a graph on graph paper, as shown by the black dots below. For the vertical scale on your graph, use the same scale as shown on the map.

On a 1:24,000 topographic map, one inch represents 24,000 in (2,000 ft) on Earth's surface. In the topographic profile above, the horizontal and vertical scales are both 1:24,000, so 1 inch in either the horizontal or vertical directions represents 2,000 ft. Since the scales on the horizontal and vertical axes of the graph are the same, the graph visually represents the true slope of Earth's surface.

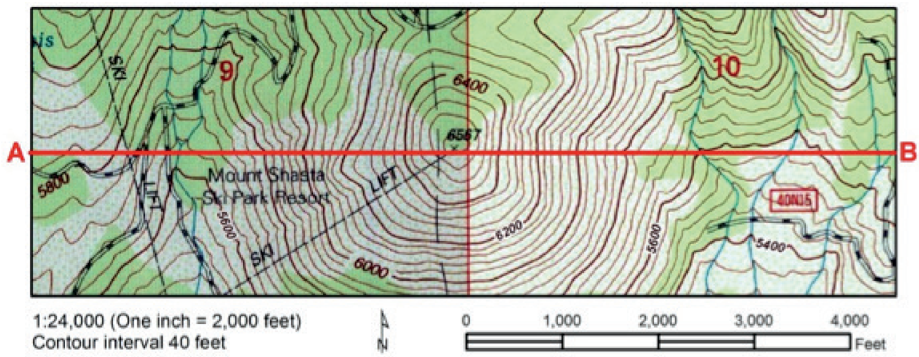


In some cases, such as in flat areas, it is preferable to have the vertical scale larger than the horizontal scale in order to emphasize subtle variations in the topography. This is called *vertical exaggeration*.

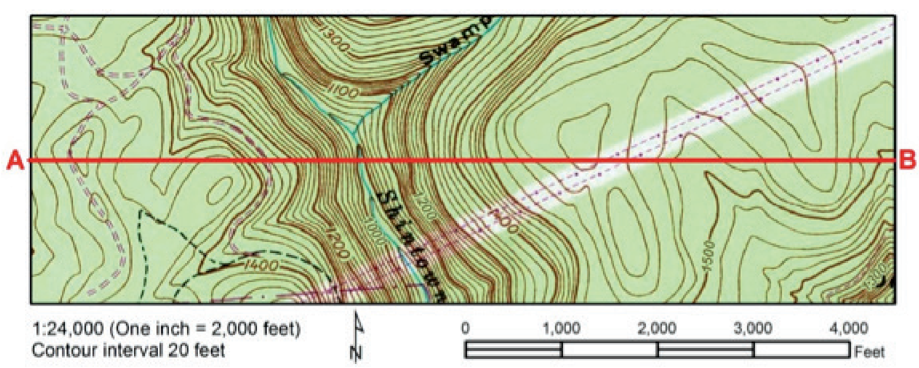
Finally, draw a smooth curve to represent Earth's surface along the profile line. Note that on the topographic profile, the curve is steeper where contour lines are closer together; the slope is more gentle where contour lines are farther apart.

Construct topographic profiles from A to B for the three topographic maps shown on the next page.

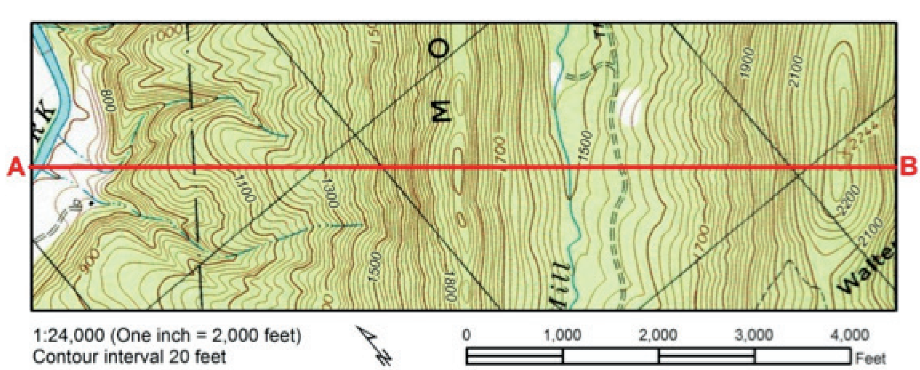
Map 1: McCloud, California



Map 2: Rileyville, Virginia



Map 3: Renova West, Pennsylvania



Chapter 3

Thinking About Earth

Back when I was a middle school student in the 1970s, dinosaurs were typically thought of as slow, stupid, overgrown, cold-blooded lizards. Dinosaur displays in museums made dinosaurs look rather awkward and cumbersome. Since that time, our thoughts about dinosaurs have radically changed. We now know that dinosaurs were much more mobile than we once thought, that some may have been warm-blooded, and that many species lived in social groups and raised their young, rather than just abandoning their eggs. It appears that, in many ways, dinosaurs were more similar to today's birds than to today's lizards. How have we learned such things? To answer questions like this, we must give more thought to how science works in Earth sciences.

Objectives

After studying this chapter and completing the exercises, you should be able to do each of the following tasks, using supporting terms and principles as necessary.

1. Describe the Cycle of Scientific Enterprise by describing each step in the cycle, explaining how the steps relate to each other.
2. Distinguish between theories and hypotheses, giving examples from Earth sciences.
3. Distinguish between experimental science and historical science.
4. Explain why scalability, accessibility, and complexity are challenges for much of the work done by Earth scientists.
5. Express ways in which observing the natural world might move a person to a sense of awe and wonder.
6. Identify ways in which Earth scientists can serve people through their work.
7. Explain what is meant by stewardship, in terms of natural resources.
8. Distinguish between renewable and nonrenewable natural resources.
9. Explain what is meant by sustainability.

Vocabulary Terms

You should be able to define or describe each of these terms in a complete sentence or paragraph.

1. controlled experiment
2. Cycle of Scientific Enterprise
3. experiment
4. experimental science
5. greenhouse effect
6. historical science
7. hypothesis
8. natural resource
9. nonrenewable natural resource
10. plate tectonics
11. oceanic circulation
12. renewable natural resource
13. scalability
14. scientific fact
15. stewardship
16. theory

3.1 The Cycle of Scientific Enterprise in Earth Sciences

The term *science* has been defined in many different ways. A basic definition would be that science is our attempt to understand the physical universe, using observation, experiments, and reason. Like scientists in other fields, such as physics or chemistry, Earth scientists use observation, experiments, and reason in order to come to a better understanding of how our planet works.

There are many ways of doing science, but a helpful overview or model of how science works is given by the *Cycle of Scientific Enterprise*, which is diagrammed in Figure 3.1. The Cycle of Scientific Enterprise is the process by which scientists form

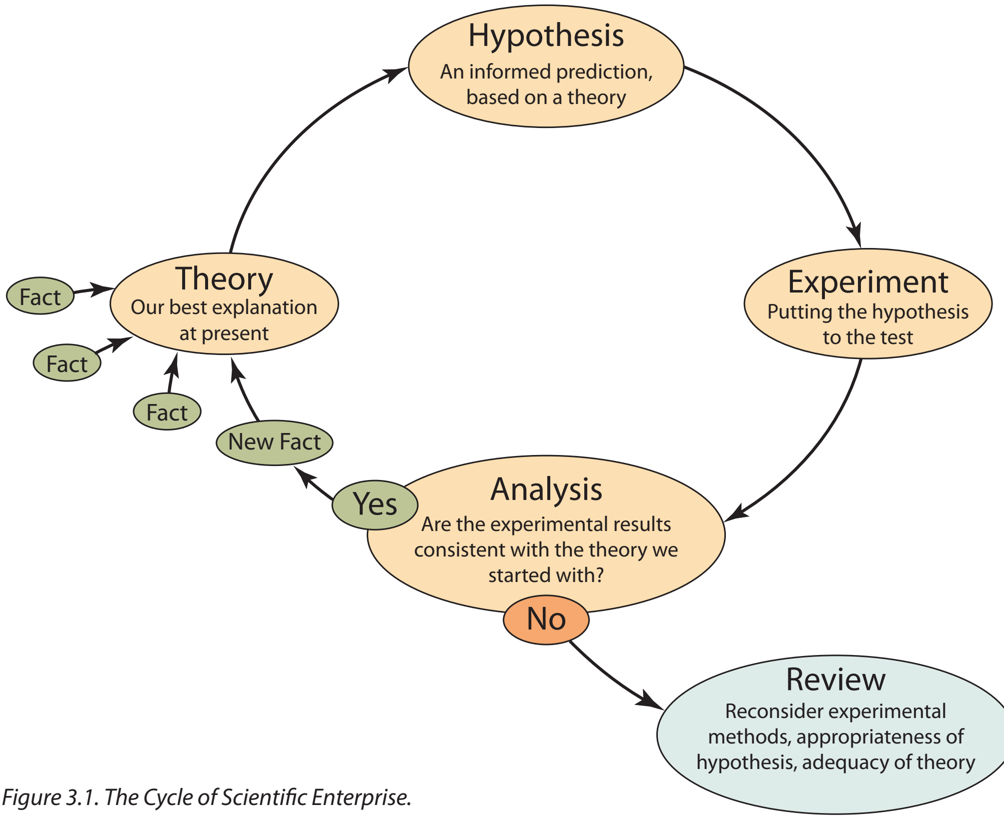


Figure 3.1. The Cycle of Scientific Enterprise.

theories and hypotheses, test those hypotheses with experiments, and analyze the results.

We can get a better idea of how science works in Earth sciences by going around the cycle step by step. We will begin on the left side of the diagram with the concept of scientific facts.

3.1.1 Scientific Facts

A *scientific fact* is a scientific statement that is supported by a large amount of evidence and that is correct so far as we know. Some examples of facts in Earth sciences include:

- Seawater contains, on average, 3.5% dissolved salts, primarily sodium chloride (NaCl), commonly known as table salt.
- Earth's atmosphere is composed primarily of nitrogen, oxygen, and argon, with a variable amount of water vapor and minor amounts of other gases.
- The temperature inside Earth increases with the depth below the surface at a rate of about 25°C per kilometer of depth (about 72°F per mile). Therefore, the temperature at a depth of 10 km (6 mi) is 250°C warmer than the average temperature on Earth's surface.

3.1.2 Scientific Theories

Science is much more than the mere collection of facts about the universe. We cannot really understand the natural world just by saying things like "seawater is salty," or even by measuring the precise amount of sodium chloride dissolved in a liter of seawater. A scientific *theory* is an explanation that seeks to account for all related facts in a particular field of study. A theory is a mental model that explains how something in the universe works. Sometimes theories are stated with mathematical equations, such as Newton's second law of motion. This equation tells us that the acceleration (a) of an object is directly proportional to the force (F) acting on that object, and inversely proportional to the object's mass (m):

$$a = \frac{F}{m}$$

In other cases, theories are more explanatory, such as theories about what causes volcanoes to erupt or why certain fossils occur in some types of rocks but not in others (though explanatory theories often involve some mathematics as well).

Some examples of important scientific theories in Earth sciences are:

- The theory of *plate tectonics*, which describes Earth's lithosphere as a mosaic of continent-sized plates that move around at rates of a few centimeters per year, and explains why these movements occur. Some of the plates are moving away from each other (North America is moving away from Europe), some are colliding (India is slowly moving northward into Asia, as illustrated in Figure 3.2), and others slide past each other. The theory relates the plate movements to other phenomena such as earthquakes and volcanoes.
- The *greenhouse effect* theory tells us that certain gases in Earth's atmosphere, such as water vapor and carbon dioxide (CO_2), absorb electromagnetic radiation in a way that keeps Earth's surface considerably warmer than it would be if Earth's atmosphere did not contain those gases. Without the greenhouse effect, Earth would be a frozen ice world. The theory explaining the greenhouse effect is an area of active research. Figure 3.3 shows a ba-

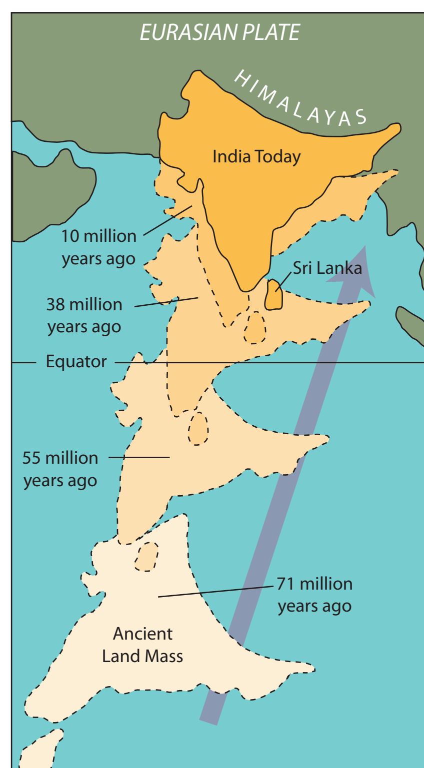


Figure 3.2. According to the theory of plate tectonics, the lithosphere beneath both continents and seafloor moves around on Earth. One result of this is the collision of India into Asia, which led to the uplift of the Himalayas.

sic diagram illustrating how the greenhouse effect works.

- The theory of *oceanic circulation* explains how Earth's rotation, wind, seawater density, and gravity interact to drive ocean currents. The fact has been known since ancient times that there are large-scale currents in the waters of the oceans—massive rivers of water within the seas. These currents move at speeds of a few miles per hour. The first map of the Gulf Stream, shown in Figure 3.4, was compiled by Benjamin Franklin.

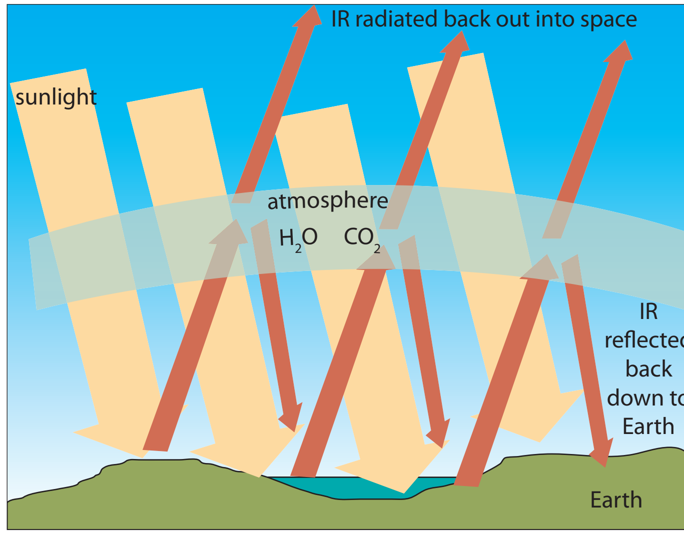


Figure 3.3. The greenhouse effect works because water vapor and carbon dioxide in the atmosphere absorb infrared radiation (IR) emitted by the warm Earth, preventing some of that energy from leaving the planet.

Figure 3.4. Benjamin Franklin's 1770 map of the Gulf Stream, an ocean current in the North Atlantic Ocean. The Gulf Stream flows to the northeast off the east coast of what is now the United States.

Each of these theories not only describes some natural phenomenon, but also *attempts to explain why* some aspect of the natural world behaves as it does. These theories are all well tested, are accepted by most scientists, and seem to explain many observations about Earth.

3.1.3 Hypotheses and Scientific Research (Experiments)

A theory not only explains certain facts, but provides a foundation for further scientific research. As scientists investigate the world, they continually uncover new facts, which lead to new questions about how those facts relate to existing theories. A *hypothesis* is a proposed answer to a scientific question, often stated in the form of a prediction of what a scientist expects to find next. The plural of *hypothesis* is *hypotheses*.

A hypothesis is not a wild guess. It is a prediction that is based on everything the scientist currently knows about the topic at hand. For example, based on our present understanding of the greenhouse effect, most scientists who study Earth's climate predict that as the amount of carbon dioxide increases in Earth's atmosphere—primarily as a by-product of the burning of fuels such as gasoline and coal—the greenhouse effect will become more intense and our climate will become warmer. This is a prediction based on our current theory of the greenhouse effect. We take a closer look at the complexities of the greenhouse effect and potential climate change in a later chapter.

A hypothesis is a statement that can be tested to see if the test results support the hypothesis. Often the test of the hypothesis is in the form of an experiment. A *scientific experiment* is an organized process by which a scientist tests a hypothesis. Often an experiment is conducted in a laboratory, where the scientist can attempt to establish ideal conditions for the study of some natural phenomenon. For example, Figure 3.5 shows a tornado created in a laboratory. This laboratory tornado is in reality only a model of tornadoes that exist in nature; it is much smaller than natural tornadoes, with lower wind speeds. But it still enables scientists to study wind currents within the spinning column of air and the damage tornadoes can cause to buildings and other structures.

Figure 3.5. A laboratory simulation of a tornado.

3.1.4 Analysis

After an experiment is conducted, it is important for scientists to analyze the results to see whether the initial hypothesis is supported by the experimental data. Support for the hypothesis adds support to the theory the hypothesis was derived from. A successful theory is supported by the results of a large number of experiments. A theory that does not lead to successful predictions is considered weak, and will eventually need to be revised or discarded.

Sometimes the results of an experiment are not what the scientist expected. This does not automatically mean that the hypothesis—or the theory it came from—were incorrect. Most theories account for most observations and experimental results, but not all. It could be that the experiment results in the modification of the theory. In this case, the unexpected results could lead to additional experiments that will end up strengthening the theory. Another possibility is that the experiment was somehow faulty. It could be that the experiment was poorly designed or that the equipment used in the experiment was defective. As scientists review the results of their experiments, they might discover and correct these flaws and conduct the experiment again.

Two of the most important activities done by scientists are actually reading and writing. You may have a mental picture of scientists in a laboratory filled with equipment or out in nature making observations, but scientists actually spend a large amount of their time reading technical papers in scientific journals. The journals are magazines with articles that are critiqued by other scientists before they are published. Reading these articles and interacting with other scientists allow scientists to keep up with the latest research done by other scientists from all over the world. Most scientists also spend a lot of time writing, whether writing reports that are used inside their own research group or papers about the results of their research that are published in the scientific journals. The publication of articles in scientific journals allows other scientists to review and critique the results of scientific studies.

Learning Check 3.1

1. Draw a sketch of the Cycle of Scientific Enterprise, with arrows and key words.
2. Give examples of theories in geology, meteorology, and oceanography. Try to use theories that were not mentioned in this section. (Hint: you can page through this book.)
3. Explain why reading and writing are important aspects of doing science.

3.2 Experimental Science and Historical Science

Work in Earth sciences often proceeds as described in the previous section, as scientists conduct experiments to test hypotheses. These experiments may be performed in a laboratory, as we saw in Figure 3.5, or may be done outdoors in a natural setting.

An example of an experiment conducted in the field—rather than in a laboratory—is an experiment conducted in the Swiss Alps in the late 1830s through the early 1840s by a geologist named Louis Agassiz.[1]

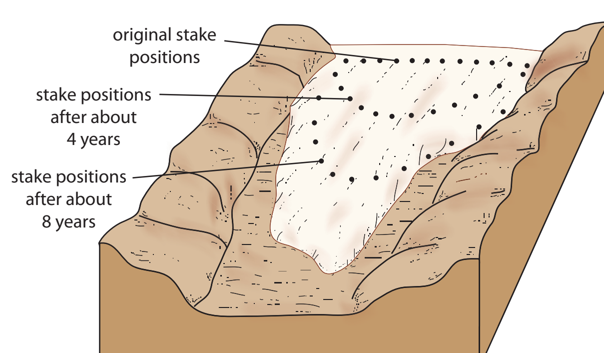


Figure 3.6. Movement of stakes in a glacier from one year to the next.

1 Pronounced LOO-ee AG-uh-see.

The higher parts of the Alps have areas of snow and ice year-round. Based on observations of a hut that had been built on the surface of a glacier in the 1820s, Agassiz formed the hypothesis that the ice in the glacier actually moved downhill, but at a rate too slow to be observed directly. Agassiz placed a series of wooden stakes in a straight line across the ice, and measured how the stakes moved over time. He demonstrated that the ice moved downhill at a rate of a few centimeters per day, which works out to tens of meters per year. But he also discovered something that went beyond his initial "glacier ice moves" hypothesis. Stakes pounded into the ice near the edges of the glacier move more slowly than stakes in the center of the glacier, as illustrated in Figure 3.6. One reason for this is friction between the moving ice and the rock walls of the glacial valley; the ice in the center of the glacier is not affected as much by friction along the edges of the glacier.

Agassiz's experiment is an example of *experimental science*. When doing experimental science, scientists test hypotheses by conducting planned, well-controlled experiments. Experimental science is valuable for evaluating many processes that are occurring today, but is not as directly applicable to events that occurred in the past. It is not possible to recreate historical events, such as the formation of the solar system, the deposition of the rock layers that cover much of Earth's continents, or the climate changes that led up to the ice ages. This does not mean these events cannot be studied scientifically, and it does not mean that scientists cannot form hypotheses and try to test them. But it does mean the investigation of historical events requires the use of different methods.

Figure 3.7. When archeologists reconstruct prehistoric events based on the evidence they find in an excavation, they are practicing historical science.

Geologists often study Earth using methods appropriate to what we call *historical science*. In sciences such as chemistry and physics, most hypotheses are tested by scientific experiments. In geology, and to some extent in climatology and oceanography, as well as in sciences such as astronomy and archeology, the "experiment" has already been run in nature. In these cases, the job of the scientist is very much like the job of a detective in solving a crime. A detective looks for evidence at a crime scene, and then attempts to reconstruct the events that happened. Likewise, the scientist's goal, when doing historical science, is to consider all the evidence and put together a credible story of what happened in the past. As scientists do further investigations, additional evidence might be uncovered that adds to the story or that perhaps contradicts the story.

Archeologists study events from human history by carefully excavating sites where humans once lived or worked. A photograph of the site of an archeological excavation is shown in Figure 3.7. Often there is no written record telling the history of the people who lived there, so the only way to reconstruct what their lives were like is to examine various things they left behind—items such as burial sites, fireplaces, pottery fragments, and the remains of their houses—and use these to figure out how the people lived and what happened to them. The archeologist then tries to put together a compelling story about the lives and history of the people who dwelt at the site. This story is a scientific hypothesis that can be tested by doing additional excavation or by comparing the results of the excavation to archeological facts from other nearby sites. This additional research may add details to the archeologist's story or even lead to a complete rewriting of the story.

Figure 3.8. Geologists use historical scientific reasoning to interpret the history of Earth, such as the events that led to the formation of the Grand Canyon.

Figure 3.9. The Coconino Sandstone in the Grand Canyon has numerous features that indicate it was formed in a desert rather than under water.

Archeologists study artifacts left by human beings. Going back further in time, many of the events studied by geologists occurred before there were any humans on Earth, but geologists use the same sort of historical reasoning used by archeologists. The Grand Canyon in Arizona contains many layers of rock, as Figure 3.8 shows. Each of these layers has distinctive properties and geologists use observations and reasoning to infer how each layer formed. Some of the layers appear to have been formed in warm, shallow seas with an abundance of living organisms. Others formed in deeper water, in fresh water, or along coastlines. Geologists use multiple types of evidence to make these interpretations, including analysis of the types of fossil organisms present in each layer.

Let's take a closer look at one of the layers of the Grand Canyon to get a better picture of how scientists use historical scientific reasoning. Geologists have hypothesized that a rock layer called the Coconino Sandstone near the top of the Grand Canyon was formed by sand dunes in an ancient desert. This layer is shown in Figure 3.9. The sand-dune hypothesis was based on comparisons of the solid rocks of the Coconino Sandstone to sandy deserts, such as sand dune areas found in parts of the Sahara Desert. In order to test the sand-dune hypothesis, geologists looked for the sorts of things one would find in a desert—indicators such as tracks of lizards, scorpions, spiders, and millipedes preserved in the rocks—and found these tracks in abundance. These footprints could not have formed under water in a stream or in an ocean. Additionally, scientists have not found any compelling evidence to suggest this layer was formed under water. For instance, the rocks of the Coconino Sandstone do not contain any fossils of water-dwelling organisms such as seashells or fish.

Both experimental science and historical science are used to come to a better understanding of the world we live in. Both methods fit within the Cycle of Scientific Enterprise, which is our method of taking scientific facts and developing theories through a process of forming hypotheses, testing of hypotheses, and analysis of experimental or investigative results. Both approaches to science give us tentative answers that lead to additional hypotheses that can be tested and evaluated.

Learning Check 3.2

1. Explain why some scientific hypotheses cannot be tested by conducting an experiment.
2. In what ways is historical science like detective work?

3.3 Challenges in Studying Earth

Earth scientists face additional challenges as they seek to understand Earth, past and present. The first of these challenges is *scalability*. Scalability in Earth sciences is the ability of processes in a scale model to work in the same way as processes do in nature. Earth scientists face this problem when they try to create laboratory or computer models of phenomena that occur on Earth, such as the tornado model shown in Figure 3.5. The tornado in the laboratory behaves like a real tornado in some ways, but not in others.

The indoor model of San Francisco Bay shown in Figure 3.10 is about 120 m (400 ft) long—longer than a football field. The hydrologists (water scientists) and

Figure 3.10. An indoor model of San Francisco Bay.

Figure 3.11. The lava lake in the crater of Mount Nyiragongo, Democratic Republic of Congo, is an inaccessible place. Red areas are molten rock; black areas are thin crusts of crystallized rock on top of the lava lake.

engineers who created this model included numerous design features to ensure that the little waves and currents in this gigantic model behaved similarly to waves and currents in the real San Francisco Bay. They did a good job, but the model has its limitations.

A second challenge is that of *accessibility*—the ease or difficulty of getting to a place. Often Earth scientists have to study some place or process that they cannot directly observe. For example, it is impossible at present for geologists to send instruments into the core of Earth. Another example is that meteorologists are able to observe tornadoes from the outside, but it has proven to be extraordinarily difficult to get inside a tornado to make direct measurements. Despite these challenges, we do know quite a bit about the core of Earth and the interior of tornadoes.

There are other places on Earth that are accessible, but not easily so. The deepest parts of the ocean are over 10 km (6 mi) deep and only a handful of people have briefly descended to those depths. There are also places on Earth's surface that are difficult to access. These include the bottoms of rivers, places far from civilization, and the lava lakes that exist in the craters of some volcanoes, such as the one shown in Figure 3.11.

A third challenge is *complexity*. In a laboratory experiment, scientists try to simplify conditions so they can focus on just one variable and observe how that variable changes as they change another variable. This process is called a *controlled experiment*. However, in nature conditions are almost never simple. Complexity is the opposite of simplicity; it is the state of having many different things happening at one place or one time. An example of a complex system is the greenhouse effect mentioned earlier. Figure 3.3 shows a simplified overview of the greenhouse effect, caused by the presence of carbon dioxide and water vapor. But carbon dioxide and water vapor are not the only greenhouse gases in Earth's atmosphere. Methane (CH_4) and ozone (O_3) are also important greenhouse gases, even though there are only tiny amounts of these gases present. The influence of these gases on the overall temperature of Earth's atmosphere is not completely understood.

An additional complexity in Earth's climate is the interaction between the greenhouse effect and clouds in the atmosphere. If an increase in the amount of greenhouse gases in the atmosphere causes Earth's temperature to increase, that will lead to greater evaporation of water from the oceans. More evaporation from the oceans may lead to greater amounts of cloud cover. More clouds forming will lead to more sunlight being reflected out to space because clouds are more efficient at reflecting light than either the oceans or land surface. More sunlight being reflected out to space means Earth will cool. So which is the more important factor in determining what will happen to Earth's temperature in the future: the increased heating due to an increase in greenhouse gases or cooling due to an increase in cloud cover? Climate scientists construct mathematical models of Earth's atmosphere on powerful computers to try to answer questions such as this, and most of them believe that the temperature of Earth's atmosphere will increase in upcoming years.

It is amazing to live in a world that is governed by natural laws so that we can understand it, but is also so incredibly complex that we cannot understand it fully. The challenges outlined in this section make doing Earth science difficult at times. However, for many Earth scientists these challenges are part of what makes their work so interesting.

Learning Check 3.3

1. Explain how scalability, accessibility, and complexity make Earth science work more challenging.
2. Describe a place on or in Earth that seems inaccessible and suggest a way scientists might be able to study that place.

3.4 Stewardship of Earth

When we are given something of value, we are responsible for using that thing well. *Stewardship* is the wise and prudent management of the things entrusted to us. We are all entrusted with various things, such as our time, money, abilities, and health. Some people steward things they have wisely, and in general this works out for their good, and for the good of those around them. Others are poor stewards of their time, money, abilities, or health, and this usually works out badly for themselves, and for those who depend on them.

3.4.1 Earth Resources

The world we live in is rich in living and nonliving *natural resources*. A natural resource is something provided by Earth that human beings can use. Living resources include the plants and animals we use for food, the cotton we use for clothing, and the trees we use for lumber. Nonliving resources include water, air, soil, and ores that are mined to obtain metals.

An important distinction that needs to be made in regard to natural resources is the difference between *renewable* and *nonrenewable* resources. A renewable natural resource is one that can be replaced as it is used. Trees are an example of a renewable resource. We can harvest trees to use as lumber, pulp for making paper, or fuel, but new trees can grow to replace the ones that are harvested. Likewise, water in streams and most water in groundwater supplies are renewable resources. We can use water in a stream knowing that the supply will be replenished by future rainfall or snow.

This does not mean that renewable resources are available to us in an unlimited way. The water in the Colorado River in the arid southwestern United States is renewable. Every winter, it snows in the Rocky Mountains. Every spring and summer, that snow melts and some of that meltwater ends up in the Colorado River. But in most years the demands for water—primarily for irrigation and drinking water—are greater than the amount of water flowing in the river. The result is that the Colorado River is usually completely dry before it reaches its outlet in the Gulf of California in Mexico.

A nonrenewable natural resource is one that is not replaced when it is removed from nature for human use. When a mineral, such as iron ore, is mined and removed from Earth, that iron ore is not immediately replaced in Earth's crust by any geological process.

Coal, which is burned as a fuel in power plants to produce electricity, is a widely used nonrenewable resource. Many billions of tons of coal are mined from Earth every year, but there are only so many billions of tons of coal in Earth's crust. The United States has more coal than any other country, but at the rate we are mining it, it will all be consumed within a few hundred years. That sounds like a long time from now, but in discussions about energy and resources we need to think not only about our present needs, but about how our present actions will affect future generations.

3.4.2 Sustainability

Good gardeners, good farmers, and good ranchers take care of their land in such a way that it remains productive for a long time. *Sustainability* is the ability to maintain the productivity of the natural world for a long, or even indefinite, amount of time. It is the ability to use natural resources to meet the needs of today without reducing the ability of future generations to have their needs met as well.

We can apply the principle of sustainability to our own lives. An example of this is an individual taking care of her health in a sustainable way. If a person maintains

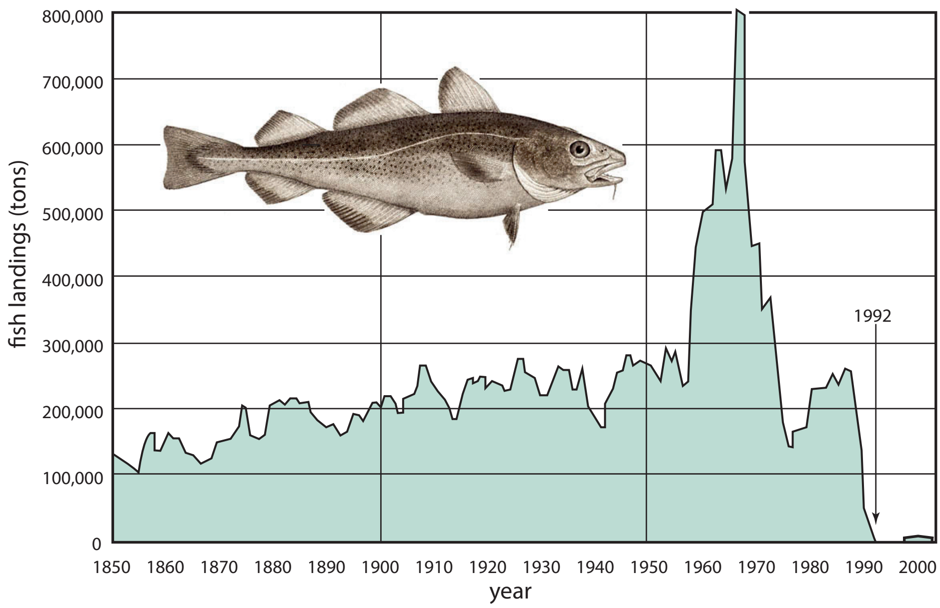


Figure 3.12. The harvest of cod from the northwest Atlantic Ocean was sustainable until sometime in the 1950s, and then climbed dramatically to unsustainable levels in the 1960s. This led to a collapse of the fishery to less than 1% of historic levels beginning around 1990.

a good diet, adheres to a good sleep routine, and exercises, she is likely to sustain good health over much of her lifespan. If, on the other hand, a person has a long-term lifestyle of getting only three hours of sleep per night, diets on French fries and donuts, and doesn't exercise, her health deteriorates. The long-term results of this lifestyle are likely to be poor health and an early death. In other words, she is living unsustainably.

The principle of sustainability works the same way in regard to Earth resources, both living and non-living. A sad example of people exploiting a natural resource in an unsustainable way is the overfishing of cod that occurred in the northwest Atlantic Ocean. Fishermen had been fishing for cod in the Grand Banks area of the North Atlantic, off the coast of eastern Canada, since the 1500s, and had been doing so in such a way that the population of cod never became depleted. There were always enough fish left over to reproduce and make up for those that were being harvested. In other words, fish were being harvested in a sustainable way. Technological developments such as larger fishing trawlers and larger nets were introduced in the 1950s, and for a few years these led to significantly greater harvests of fish. The graph in Figure 3.12 shows that the number of tons of cod caught off the east coast of Canada rose dramatically starting in the late 1950s, only to collapse to around 1% of earlier catches by the early 1990s.

There were a number of factors that led to unsustainable exploitation of the northwest Atlantic fisheries. Not only did fishing technology allow for overharvesting of cod, but people did little to change their fishing practices even when it became apparent that the cod population levels were plummeting. In 1992, the

Canadian government banned fishing for cod in its waters. People expected the cod population to recover quickly, but that did not happen. Somehow, overfishing not only eliminated most of the cod, but also changed the ecology of the ocean in such a way that cod could no longer flourish. Today, the population of cod in these waters is still well below historical levels.

3.4.3 The Degradation of Nature

Earth's systems exhibit astounding resilience. There are natural systems that regulate temperatures, purify water, move nutrients around the planet, and renew topsoil needed for plant growth. When things are working properly, the living world—including humans—can prosper.

Humans are capable of degrading nature in ways that greatly diminish its ability to support plants, animals, and even ourselves. Let's take a look at ways that these degradations affect the four Earth systems described in Section 1.1.

- *Degradation of water*—Water is polluted by garbage, human waste (sewage), toxic waste from industrial sites, and pesticides used in agriculture. For a long period of time—from the late 1800s until the 1970s—the Cuyahoga River in Ohio was so polluted that the river occasionally caught on fire. These disasters helped to raise citizen awareness about water pollution, leading to government regulations such as The Clean Water Act in the United States. The stream in Figure 3.13 has been polluted by iron associated with a nearby coal mine. The water is now unsuitable for fish, wildlife, agriculture, or human consumption.

Figure 3.13. A polluted stream near a coal mine.

- *Degradation of air*—Air is polluted by both visible and invisible pollutants. These pollutants come from a variety of sources, but the primary source is the burning of fossil fuels such as coal in power plants and petroleum-based fuels in cars and trucks. The Great London Smog of 1952 was caused by the burning of coal in many thousands of stoves, factories, and power plants. The smog was so thick that visibility was reduced to just a few feet. Some researchers estimate that as many as 12,000 people died in London because of that event. The word "smog" is a combination of "smoke" and "fog." Figure 3.14 shows a coal-fired power plant, which produces electricity.

- *Degradation of life*—By its nature, Earth is a planet teeming with life on the land, in the air, and in the sea. However, largely because of human activities thousands of species have been driven to extinction and many more types of organisms could share the same fate in the coming century. If humans were managing Earth well, our activities would tend to promote the abundance and rich diversity of the living world, rather than its destruction.

Figure 3.14. A coal power plant in Poland. Most of the visible emissions are just water vapor, but invisible gases include sulfur dioxide (SO_2) and various nitrogen oxides. Combustion of coal also produces a tremendous amount of carbon dioxide, a greenhouse gas.

- *Degradation of soil*—Healthy soil is essential for agriculture because plants depend on the soil for water, nutrients, and as a place to be anchored to the ground. In many agricultural areas around the world, soil is eroding away due to poor agricultural practices, as shown Figure 3.15.

Other degradations include reduction of habitat for a diverse range of plant and animal species, human-caused expansion of deserts, and accumulation of wastes in landfills and other places.

As humans use natural resources to provide for our food, fuel, and material needs, it cannot be avoided that we affect Earth and its life in various ways. If we live on Earth in a sustainable way, we can minimize the negative affects of our actions and preserve resources both for future human use—and for the long-term health of the living world.

Figure 3.15. Soil erosion in a wheat field in eastern Washington. Topsoil is essential for abundant plant growth, but it is the first part of the soil to be washed away when the soil is bare.

Learning Check 3.4

1. Explain ways in which stewardship of Earth is like stewardship of something in your life, such as money or time.
2. Using examples, explain the difference between renewable and nonrenewable natural resources.
3. Why is it important that humans use natural resources in a sustainable way?

Chapter 3 Exercises

Answer each of the questions below as completely as you can. Write your responses in complete sentences unless instructed otherwise.

1. Using the concept of the Cycle of Scientific Enterprise, describe how Earth scientists study Earth.
2. How do Earth scientists use experiments to study Earth?
3. Why is it sometimes necessary for Earth scientists to depend on historical science rather than experimental science?
4. Suggest ways in which an Earth scientist's work can serve people. Be as specific as possible and don't use examples from this chapter.
5. Why is it important for humans to be good stewards of natural resources?
6. Explain why it is important to use renewable natural resources wisely, even though they can be replenished over time.
7. Write a paragraph about a way in which some part of the natural world has been degraded in or near your community. Is this problem becoming better, worse, or staying about the same?