LABORATORY MANUAL FOR INTRODUCTORY GEOLOGY

4E

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LABORATORY MANUAL FOR INTRODUCTORY GEOLOGY

FOURTH EDITION

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PREFACE

This laboratory manual is based on our collective 70-plus years of teaching and coordinating introductory geology courses. Those experiences have helped us understand not only how students best learn geologic principles, but also how to stimulate their engagement with the material to enhance their learning process. Our manual provides (1) an up-to-date, comprehensive background that addresses the hands-on tasks at the core of any introductory geology course; (2) patient step-by-step explanations that are more easily understood by students than those in textbooks; (3) text and exercises that lead students to think like geologists, engaging them in solving real-life problems important to their lives; and (4) the passion and excitement that we still feel after decades as teachers and geologists.

Students often ask us how we maintain this enthusiasm. Our answer is to share with them both the joys and frustrations of facing and solving real-world geologic problems. You will find many of those types of problems in the following pages—modified for the introductory nature of the course, but still reflecting their challenges and the rewards of solving them. This manual brings that experience directly to the students, *engaging* them in the learning process by *explaining* concepts clearly and providing many avenues for further *exploration*.

Unique Elements

As you read through this manual, you will find a pedagogical approach that incorporates many unique elements, which distinguishes it from other manuals. These elements include:

Hands-on, inquiry-based pedagogy

We believe that students learn science best by doing science, not by just memorizing facts.

New “Geotours” Google Earth activities in each lab, authored by M. Scott Wilkerson of DePauw University, allow students to apply the concept knowledge gained through their lab and lecture work to real-life sites and phenomena, as a geologist would. The **updated** “What Do You Think?” exercises in each chapter engage students in making assessments and decisions on topics relevant to their own lives, such as selecting building codes appropriate for local earthquake hazards (Ch. 2); determining how technological advances that have altered demands for various mineral resources have impacted their community (Ch. 3); and explaining what unforeseen and unintended results accompany human interactions with natural processes (Ch. 13).

Innovative exercises that engage students and provide instructors with choice

Tiered exercises are carefully integrated into the text, leading students to understand concepts for themselves by first reading about the concept and then immediately using what they just learned in the accompanying exercise. These unique exercises show students how important geologic principles are in our everyday activities. There are more exercises per chapter than can probably be completed in a single lab session. This is done intentionally, to provide options for instructors during class or as potential out-of-class assignments. The complexity and rigor of the exercises increase within each chapter, enabling instructors to use the manual for both non-majors and potential majors alike. Just assign the exercises that are most appropriate for your student population.

Superb illustration program

Readers have come to expect a superior illustration program in any Norton geology text, and this manual does not disappoint. The extensive and highly illustrative photos, line drawings, maps, and DEMs continue the tradition of Stephen Marshak's *Earth: Portrait of a Planet* and *Essentials of Geology*.

Reader-friendly language and layout

Our decades of teaching introductory geology help us to identify the concepts that are most difficult for students to understand. The conversational style of this manual and the use of many real-world analogies help to make these difficult concepts clear and enhance student understanding. The crisp, open layout makes the book more attractive and reader-friendly than other laboratory manuals, which are crammed with pages of multiple-column text.

Unique lab on global change

A new capstone lab on global change (Ch. 18) combines our understanding of the past and present to look to the future—not in geologic time, but rather within the next 50 years. The chapter addresses all components of the Earth System, with a particular emphasis on climate change and how changes in the atmosphere will potentially affect the hydrosphere, cryosphere, and biosphere. Exercises guide students to assess how the planet will likely change during their lifetimes, and to examine their role in furthering or mitigating those processes. The chapter ends with a series of thought-provoking questions designed to prepare students for their roles as intelligent citizens in evaluating issues they will face in the future.

Unique mineral and rock labs

Students learn the difference between minerals and rocks by classifying Earth materials in a simple exercise (Ch. 3). That exercise then leads to the importance of physical properties and a logical system for identifying minerals. In Chapter 4, students make intrusive and extrusive igneous "rocks," clastic and chemical sedimentary "rocks," and a foliated metamorphic "rock" to understand how the rock-forming processes are indelibly recorded in a rock's texture. The goal in studying rocks in Chapters 5–7 is to interpret the processes and conditions by which they form, not just to find their correct names.

Digital elevation models (DEMs)

Digital elevation models are used to enhance the understanding of contour lines and to build map-reading skills.

Improvements to the Fourth Edition

We are grateful to the many adopters of the first three editions for their detailed comments and suggestions, which have improved this Fourth Edition. This feedback has led to significant revisions, but the Fourth Edition still retains its core approaches from the previous editions—hands-on, inquiry-based learning through exercises interspersed throughout the chapters. As a result, this manual offers an integrated approach that mirrors the typical, logical sequence of laboratory sessions. This Edition incorporates reviewers' requests for even more hands-on, applied activities and for new approaches to make concepts more accessible to students. Updated content and exercises help turn geologic events in current headlines into teaching moments, emphasizing how Earth processes affect the lives of humans throughout world.

Also, in response to reviewer requests, we have reorganized the sequence of chapters to better align with how instructors structure their courses. Chapters on geologic structures, block diagrams, and maps; earthquakes and seismology; and geologic history have been moved earlier in the text, preceding the chapters on landforms and landscape evolution that most adopters discuss at the end of their courses.

New "Geotours" exercises, like those in Marshak's textbooks, have also been added to each chapter. These exercises enable students to "walk miles in the footsteps of geologists" and to see the world as geologists do.

Along with the new "Geotours" exercises, each chapter has also been revised with an eye toward clarifying core concepts, and new maps, photographs, and diagrams can be found throughout the manual. Other significant improvements include:

Chapter 1: [Setting the Stage for Learning about the Earth] New figures clarify the ways in which geologists respond to the challenges we face as we study the Earth.

Chapter 2: [Examining Plate Tectonics] The improved illustration program clarifies relationships among plates and processes that occur at different types of plate boundaries. New exercises help students follow the evolution of the plate-tectonic model.

Chapter 3: [Minerals] A section has been added on minerals as natural resources, and the role of minerals in state and national economies. A new "What Do You Think" exercise asks students to consider how rapid technological advances affect local industries and economies by making some resources obsolete while creating new needs.

Chapter 4: [Minerals, Rocks, and the Rock Cycle] This chapter features an improved transition from minerals to rocks, and an expanded section on the economic importance of rocks.

Chapter 5: [Using Igneous Rocks to Interpret Earth History] An expanded section on volcanoes includes new coverage of the 2018 eruptions in Hawaii and Guatemala, and new exercises on predicting and mitigating volcanic hazards.

Chapter 6: [Using Sedimentary Rocks to Interpret Earth History] The discussion of sediment maturity has been revised for better understanding.

Chapter 7: [Interpreting Metamorphic Rocks] This chapter has been completely reorganized and rewritten to make concepts more accessible to students.

Chapter 8: [Studying the Earth's Landforms] A new section has been added to discuss the difference between geographic (true) and magnetic north. A new "What Do You Think" exercise explores the differences between old maps and modern ones—in a practical and (potentially) financially rewarding way. And basic map elements are defined precisely.

Chapter 9: [Working with Topographic Maps] In response to reviewers, the introduction to contour lines has been shortened and students now get to focus more quickly on topographic contours. A new exercise has students examining contoured topographic maps of familiar areas—we suggest the area in which your campus is located.

Chapter 10: [Interpreting Geologic Structures on Block Diagrams, Geologic Maps, and Cross Sections] This chapter has been relocated to better fit the organization of most introductory courses. The content has not altered significantly, but the new location gives students practice in applying what they learned about contour lines in Chapter 9.

Chapter 11: [Earthquakes and Seismology] Two improvements enable students to more accurately determine the arrival times of seismic waves, allowing for a more accurate locating of an earthquake's epicenter: (1) seismograms are printed in a larger format, and (2) a new seismic overlay measuring tool has been added to the Geo Tools section at the back of the manual, making it possible to estimate arrival time to within a few seconds.

Chapter 12: [Interpreting Geologic History] A new exercise shows how ages of detrital zircons can help to constrain the numerical ages of sedimentary rocks that cannot be dated directly, and to interpret the provenance of those rocks.

Chapter 13: [Landscapes Formed by Streams] The concept of nick points forming during stream evolution has been added, with an explanation of the short life span (in geologic time) of even the largest waterfalls. A new section has been added on streams, society, and the environment, along with a new "What Do You Think" exercise that examines the geologic and socioeconomic effects of building the Aswan Dam across the Nile River.

Chapter 14: [Groundwater as a Landscape Former and Resource] New exercises have been added on (1) how the change in the water table affects local residents; and (2) the causes and results of salt-water incursion into coastal aquifers. The exercise on Florida karst has been revised to better illustrate karst hazards.

Chapter 15: [Glacial Landscapes] The presentation of depositional landforms associated with continental glaciation has been reorganized to emphasize the distinction between those deposited directly from the melting glacier and made of till, from those deposited by meltwater and made of outwash.

Chapter 16: [Processes and Landforms in Arid Environments] A new section has been added on desertification (natural and anthropogenic), including a new "What Do You Think" exercise.

Chapter 17: [Shoreline Landscapes] The discussion of coastal storms has been updated to include the effects of Hurricanes Harvey, Irma, and Maria in 2017, as well as Katrina and Sandy in earlier years. New illustrations have been added of new shorelines being formed by the recent lava flows from Kilauea, and overall, the chapter features more complete photo coverage of all shoreline types.

Chapter 18: [How Will Humans Be Affected by Changes in the Earth System] This new chapter has been added at the requests of several reviewers and many instructors to explore the ways in which changes in the Earth System affect humans, as well as ways in which humans impact natural Earth System processes. The focus is in terms of a human lifespan, examining predictions of how changes over the next 50 years will affect students' lives and those of their children. The complex relationships among all Earth System reservoirs are addressed by showing how changes in one reservoir potentially affect the others, with regards to climate change, a melting cryosphere, rising sea level, increased rate of extinctions, etc.

Supplements

(available for download at wwnorton.com/instructors)

Coursepacks. Available at no cost to professors or students, Norton Coursepacks bring high-quality Norton digital media into your course. This new supplement includes:

- Prelab quizzes, available as autograded assignments, or printable worksheets, and designed to assess if students have prepared their pre-lab material.
- On-line versions of selected lab exercises (a complete list is in the Instructor's Manual). For professors that need to offer this course in a blended or distance learning environment, we have adapted the best exercises for these formats into our coursepacks. Responses are either autograded or written to require brief responses. *Note:* students still need either a print or electronic version of the lab manual for access to figures and background reading. We have constructed labs to work with typical rock kits that can be purchased from many different suppliers.

Instructor's Manual. Available in electronic format, the revised Instructor's Manual contains word files of the solutions to each exercise, teaching tips for each lab, and a detailed conversion guide that shows the differences between the Third and Fourth Editions.

Electronic Figures. All figures, photographs, charts, and maps in this text are available for you to download and incorporate in your presentations, handouts, or online courses.

Videos and Animations. Animations and videos of core concepts in geology are available to download or stream from our site.

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We are indebted to the talented team at W. W. Norton & Company whose zealous quest for excellence is matched only by their ingenuity in solving layout problems, finding that special photograph, and keeping the project on schedule. We would like to thank Scott Wilkerson of DePauw University for authoring the dynamic and engaging "Geotours" exercises in each lab. We are also grateful to the professors who have provided accuracy reviews and feedback for earlier editions: Pete Wehner of Austin Community College–Northridge; Daniel Imrecke, Jinny Sisson, and Julia Smith Wellner of the University of Houston; Kurt Wilkie and Amanda Stahl of Washington State University; Michael Rygel of SUNY–Potsdam; and Karen Koy of Missouri Western State University. We also appreciate the detailed chapter-by-chapter review of the Second Edition by the core teaching faculty and teaching assistants at the University of Houston, and are grateful to Nathalie Brandes of Lone Star College and Geoffrey Cooke of UCSD for working closely with the authors and our team of editors at W. W. Norton to proofread and check accuracy for the Third Edition.

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Stephen Marshak is Professor Emeritus of Geology at the University of Illinois, Urbana-Champaign, where he also served as the director of the School of Earth, Society, and Environment. He holds an A.B. from Cornell University, an M.S. from the University of Arizona, and a Ph.D. from Columbia University. Steve's research interests lie in structural geology and tectonics, and he has participated in field projects on several continents. Steve loves teaching and has won his college's and university's highest teaching awards. He also received the 2012 Neil Miner Award from the National Association of Geoscience Teachers (NAGT), for "exceptional contributions to the stimulation of interest in the Earth sciences." In addition to research papers and co-authoring the *Laboratory Manual for Introductory Geology,* Steve has authored *Earth: Portrait of a Planet, Essentials of Geology*, and co-authored *Earth Science*, *Earth Structure: An Introduction to Structural Geology and Tectonics*, and *Basic Methods of Structural Geology*.

1

Setting the Stage for Learning about the Earth

This sunset over the red cliffs of the Grand Canyon on the Colorado River in Arizona, shows the Earth System at a glance—air, water, and rock all interacting to produce this stunning landscape.

LEARNING OBJECTIVES

- Understand challenges geologists face when studying a body as large and complex as the Earth
- Practice basic geologic reasoning and strategies
- Understand the concept of the Earth System and begin to learn how energy and matter are connected through geologic cycles
- Use concepts of dimension, scale, and order of magnitude to describe the Earth
- Review the materials and forces you will encounter while studying the Earth
- Learn how geologists discuss the ages of geologic materials and events and how we measure the rates of geologic processes
- Become familiar with the types of diagrams and images used by geologists

MATERIALS NEEDED

- Triple-beam or electronic balance
- 500-mL graduated cylinder
- Clear plastic ruler with divisions in tenths of an inch and millimeters (included in the Geo Tools section at the back of this manual)
- Calculator
- Compass

1.1 Thinking Like a Geologist

1.1.1 Introduction

Learning about the Earth is like training to become a detective. Both geologists and detectives need keen powers of observation, curiosity about slight differences, broad scientific understanding, and instruments to analyze samples. And both ask the same questions: What happened? How? When? Why? Much of the logical thinking is the same, but there are big differences between the work of a detective and that of a geologist. A detective's "cold" case may be 30 years old, but "old" to a geologist means hundreds of millions or billions of years. To a detective, a "body" is a human body, but to a geologist, a "body" may be a mountain range or a continent. Eyewitnesses can help detectives, but for most of Earth history there weren't any humans to witness geologic events. To study the Earth, geologists must therefore develop strategies different from those of other kinds of investigators. The overall goal of this manual is to help you look at the Earth and think about its mysteries like a geologist.

To help you begin thinking like a geologist, let's start with a typical geologic mystery. Almost 300 years ago, settlers along the coast of Maine built piers (like the modern pier shown in **FIG. 1.1**) to load and unload ships. Some of these piers are now submerged to a depth of 1 meter (39 inches) below sea level.

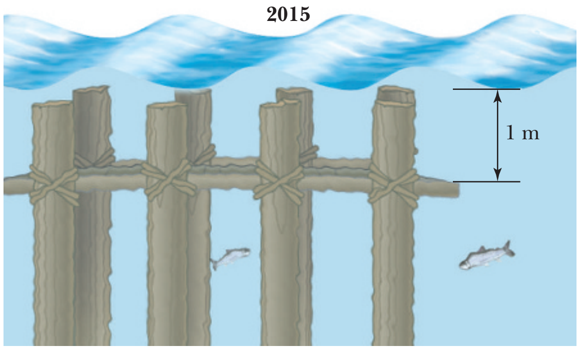
FIGURE 1.1 Subsidence along the coast of Maine.

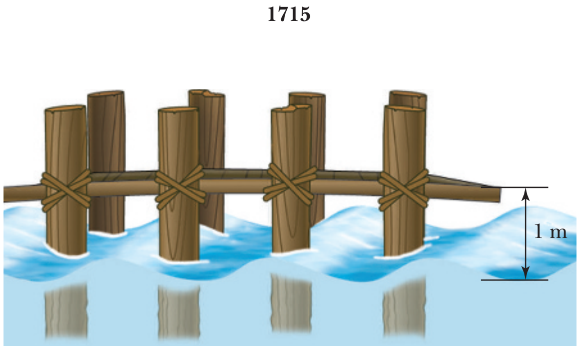
Tourists might not think twice about this phenomenon before heading for a lobster dinner at the local restaurant, but a geologist would want to know what caused the submergence and how rapidly the pier was submerged. How would a geologist go about tackling this problem? Exercise 1.1 outlines the problem and shows some of the basic geologic reasoning needed to get answers to the questions raised above. At the same time, this exercise will be your first of many opportunities to see that geologists solve real-world problems affecting real people.

EXERCISE 1.1 Submergence Rate along the Maine Coast

Name: ____ Section: __________

Course: ____ Date: ____________





The figure on the left illustrates a pier whose walkway sits 1 meter below the ocean's surface today. Because we weren't there when it was built 300 years ago, we have to make some assumptions—geologists often do this to make estimates. So let's assume that the pier's walkway was originally built 1 m *above* sea level at high tide, as many are built today (illustrated in the figure on the right), and that submergence occurred at a constant rate. With these assumptions, calculating the rate of submergence for the past 300 years becomes simple arithmetic.

(a) The rate of submergence is the total change in the elevation of the pier (__________ m) divided by the total amount of time involved (__________ years) and is therefore __________ cm/yr. (Remember, 1 m = 100 cm.)

Now consider a problem this equation might solve:

(b) A local restaurant owner is considering the purchase of a pier, whose walkway is 50 cm above the high-water mark, for use in outdoor events. The owner has been advised that piers with walkways less than 30 cm above the high-water mark should be avoided because they can be flooded by storms and very high tides. If submergence continues at the rate you calculated, how many years will pass before the high-water mark is less than 30 cm from the base of the walkway? __________ years

? **What Do You Think** Now it's time to try really thinking like a geologist. Given your answers to questions (a) and (b), would you recommend that the restaurant owner purchase this pier? In a sentence or two, on a separate sheet of paper, explain why. Then describe another issue that you think the owner should investigate before making a decision.

Congratulations! You've just tackled your first problem as a geologist-in-training. A veteran geologist, however, would also want to explain *why* the piers were submerged. When faced with a problem like this, geologists typically try to come up with as many explanations as possible. For example, which of the following explanations could account for the submergence?

☐ Sea level has risen.

☐ The land has sunk.

☐ Both sea level and land have risen, but sea level has risen more.

☐ Both sea level and land have sunk, but the land has sunk more.

If you think all four choices might be right (correctly!), you realize that explaining submergence along the Maine coast may be more complicated than it seemed at first. To find the answer, you need more **data—**more observations or measurements.

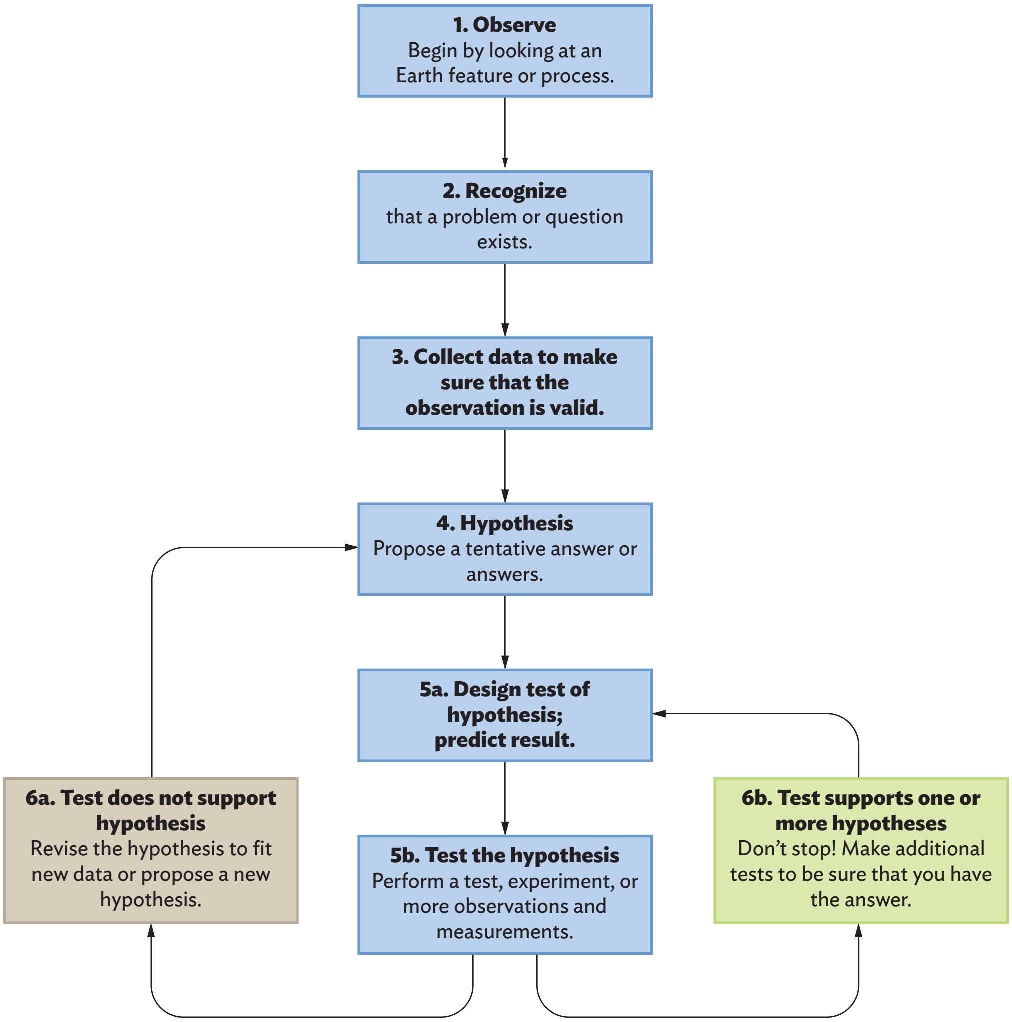
One way to obtain more data would be to see if submergence is restricted to Maine, or to the east coast of North America, or if it occurs worldwide. As it turns out, submergence is observed worldwide, suggesting that the first choice above (sea-level rise) is the most probable explanation—but not necessarily the only one.

With even more data, we could answer questions such as: "When did the submergence happen?" "Did sea level rise at a constant rate?" Maybe all the submergence occurred in the first 100 years after the pier was built and then stopped. Or perhaps it began slowly and then accelerated. Unfortunately, we may not be able to answer all of these questions because, unlike television detectives who always get the bad guys, geologists don't always have enough data and must often live with uncertainty. We still do not have answers to many questions about the Earth.

1.1.2 The Scientific Method

Like all scientists (and most people trying to find answers to problems they have identified), geologists follow a logical process that you are probably familiar with: the **scientific method**. You did so instinctively in Exercise 1.1 and will do so many times throughout this course. The scientific method begins with observations of Earth features or processes—such as, in Exercise 1.1, the observation that a colonial pier is now below sea level. The steps that constitute the scientific method are illustrated schematically in **FIGURE 1.2**.

FIGURE 1.2 The scientific method.



STEP 1 Observe an Earth feature or process (e.g., the submerged pier).

STEP 2 Recognize that a problem exists and define the problem by asking questions about it. Usually the problem is that we don't understand how what we've observed came to be: Why was the pier in Exercise 1.1 submerged? By how much has the pier been submerged? How fast did submergence take place? Was the rate of submergence constant or sporadic? We respond with the steps that follow.

STEP 3 Collect more data to (a) confirm that the observation is valid and (b) shed light on what is going on. In Exercise 1.1, for instance, we determined that it isn't just one pier being submerged, but many along the Maine coast.

STEP 4 Propose tentative answers to our questions, called **hypotheses** (singular, **hypothesis**). Some versions of the scientific method suggest proposing a single hypothesis, but when we first look at problems, we usually find that more than one hypothesis can explain our observations. We therefore come up with as many hypotheses as we can—a practice called *multiple working hypotheses*.

STEP 5 Test the hypotheses by getting more data. The new information may support some hypotheses, rule out others, and possibly lead to new ones. Some of this testing can be done in a classic laboratory experiment, but there are also other types of tests, such as field trips to gain additional information, detailed measurements where there had been only eyeball estimates, and so forth.

STEP 6 Based on the new information, reject or modify those hypotheses that don't fit, continue testing those that do, and propose new ones as needed to incorporate all the information. If your test supports a hypothesis, continue to perform additional tests to further verify your result.

Continue cycling through steps 4, 5, and 6 as needed until a single hypothesis remains. Then, to be sure, continue testing it. If this hypothesis survives years of further testing, it is considered to be a **theory**. Nonscientists often don't understand the difference between hypothesis and theory; when they say, "Oh, that's just a theory," they really mean, "That's just a hypothesis"—a *possible* explanation that has not yet been proved. A theory has been tested *and* proved. Some theories with which you may be familiar are the theory of evolution, the germ theory of disease, and Einstein's theory of relativity. And during this course you will become very familiar with plate tectonics theory, which explains how the Earth's major features form and change.

1.2 An Introduction to the Earth System

Now that you know *how* geologists study things, let's look at *what* we study. The Earth is a dynamic planet. Unlike the airless, oceanless Moon, which has remained virtually unchanged for billions of years, the Earth has gases in its atmosphere and water on its surface that are in constant motion and cause the solid planet beneath them to change rapidly (in relation to geologic time, that is). Modern scientists envisage an **Earth System** that includes all of the Earth's materials—gases, liquids, solids, and life forms—and the energy that drives their activity. The first step in understanding the Earth System is to understand the nature of its matter and energy and how they interact with each other.

1.2.1 The Nature of Matter

Matter is the "stuff" of which the Universe is made; we use the term to refer to any material on or in the Earth, within its atmosphere, or within the broader Universe in which the Earth resides. Geologists, chemists, and physicists have shown that matter consists of ninety-two naturally occurring elements and that some of these

TABLE 1.1 **Basic definitions**

- An **element** is a substance that cannot be broken down chemically into other substances.
- The smallest piece of an element that still has all the properties of that element is an **atom**.
- Atoms combine with one another chemically to form **compounds**; the smallest possible piece of a compound is called a **molecule**.
- Atoms in compounds are held together by **chemical bonds**.
- A simple **chemical formula** describes the combination of atoms in a compound. For example, the formula H_2O shows that a molecule of water contains two atoms of hydrogen and one of oxygen.

elements are much more abundant than others. Keep the definitions in **TABLE 1.1** in mind as you read further about the composition of matter.

Matter occurs on the Earth in three states: solid, liquid, and gas. Atoms in *solids*, such as minerals and rocks, are held in place by strong chemical bonds. As a result, solids retain their shape over long periods. Bonds in *liquids* are weak enough that atoms or molecules move easily, and as a result, liquids adopt the shape of their containers. Atoms or molecules in *gases* are barely held together at all, so a gas expands to fill whatever container it is placed in. Matter changes from one state to another in many geologic processes, as when the Sun evaporates water to produce water vapor, or when water freezes to form ice, or when lava freezes to become solid rock.

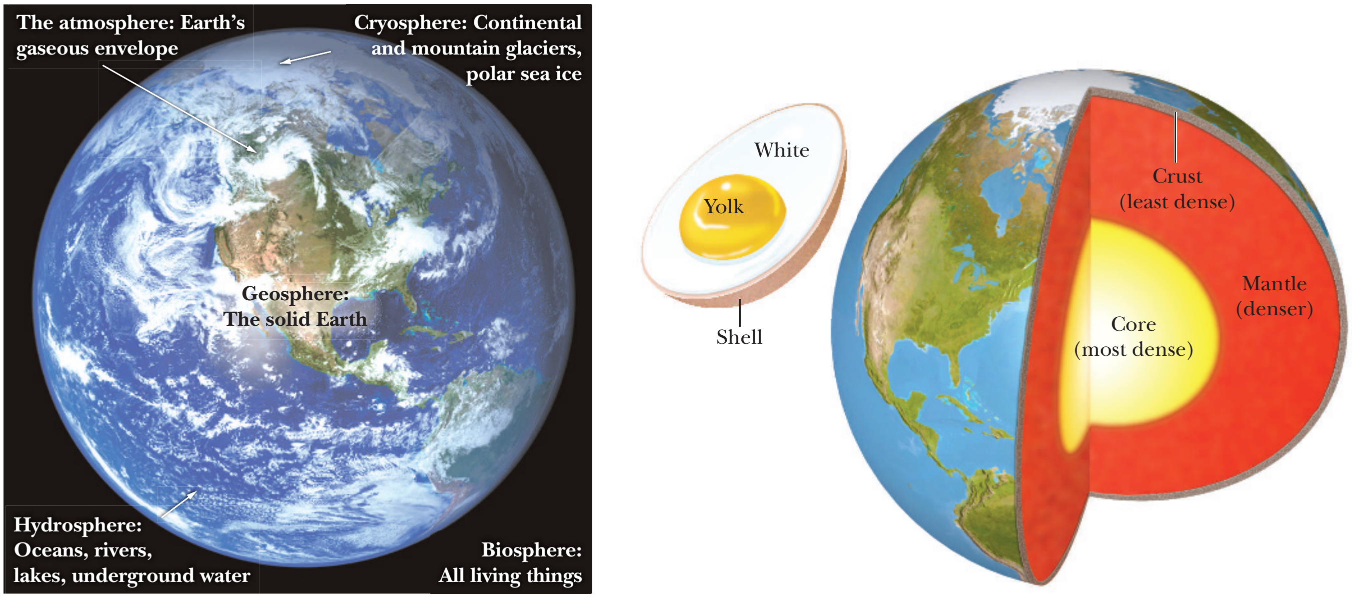
We describe the amount of matter in an object by indicating its **mass** and the amount of space it occupies by specifying its **volume**. The more mass packed into a given volume of matter, the greater the **density** of the matter. You notice density differences every day: it's easier to lift a large box of popcorn than a piece of rock of the same size because the rock is much denser—it has much more mass packed into the same volume and therefore weighs much more.

1.2.2 Distribution of Matter in the Earth System

Matter is stored in the Earth System in five major realms, or **reservoirs** (**FIG. 1.3a**). Most gases are in the **atmosphere**, a semi-transparent blanket composed of about 78% nitrogen (N_2) and 21% oxygen (O_2), as well as minor amounts of water vapor (H_2O), carbon dioxide (CO_2), ozone (O_3), and methane (CH_4). Nearly all liquids occur as water in the **hydrosphere**—the Earth's oceans, rivers, lakes, and groundwater, which is found in cracks and pores beneath the surface. Frozen water makes up the **cryosphere**, which includes snow, thin layers of ice on the surfaces of lakes or oceans, and huge masses of ice in glaciers and the polar ice caps.

Geologists divide the solid Earth, called the **geosphere**, into concentric layers like those in a hard-boiled egg (**FIG. 1.3b**). The outer layer, the **crust**, is relatively thin, like an eggshell, and consists mostly of rock. We say *mostly* because about 2% of the crust and mantle has melted to produce liquid material called **magma** (known as **lava** when it erupts on the surface). Below the crust is the **mantle**, which also consists mostly of different kinds of rock; it contains most of the Earth's volume, just as an egg white contains most of an egg's volume. The central part of the Earth, comparable to the egg yolk, is the **core**. The outer core consists mostly of a liquid alloy of iron and nickel, and the inner core is a solid iron-nickel alloy. Humans have never drilled through the crust; during this course, you will

FIGURE 1.3 The Earth System.



(a) The Earth's major reservoirs of matter.

(b) A simple image of the Earth's internal layering and the hard-boiled egg analogy for its pattern of layers.

learn how we figured out that our planet is layered, how thick those layers are, and what they are made of.

Continents, which are composed of relatively low-density rocks, make up about 30% of the crust. The remaining 70% of the crust is covered by the oceans. Oceanic crust is both thinner and denser than continental crust. Three types of solids are found at the Earth's surface: **bedrock**, a solid aggregate of minerals and rocks attached to the Earth's crust; **sediment**, unattached mineral grains such as boulders, sand, and clay; and **soil**, sediment and rock modified by interactions with the atmosphere, hydrosphere, and organisms that can support plant life.

The **biosphere**—the realm of living organisms—extends from a few kilometers below the Earth's surface to a few kilometers above. Geologists have learned that organisms, from bacteria to mammals, are important parts of the Earth System because they contribute to many geologic processes by exchanging gases with the atmosphere, absorbing and releasing water, breaking rock into sediment, and playing major roles in converting sediment and rock to soil.

The movement of materials from one reservoir to another is called a **flux**. Fluxes happen in many geologic processes. For example, rain is a flux in which water moves from the atmosphere to the hydrosphere. Rates of flux depend on the materials, the reservoirs, and the processes involved. In some cases, a material moves among several reservoirs but eventually returns to the first. We call such a path a **geologic cycle**. In this class you will learn about several geologic cycles, including the **rock cycle** (the movement of atoms from one rock type to another) and the **hydrologic cycle** (the movement of water in the hydrosphere to and from the other reservoirs). Exercises 1.2 and 1.3 will help you understand the distribution and fluxes of matter.

1.2.3 Energy in the Earth System

Natural disasters in the headlines remind us of how dynamic the Earth is: rivers flood cities and fields; mudslides, lava, and volcanic ash bury villages; earthquakes topple buildings; and hurricanes ravage coastal regions. However, many geologic processes are much slower and less dangerous, such as the movement of ocean

EXERCISE 1.2 Reservoirs in the Earth System

Name: ______________________________ Section: __________
Course: ______________________________ Date: __________

What Earth materials did you encounter in the past 24 hours? List at least ten in the following table without worrying about the correct geologic terms (for example, "dirt" is okay for now). Place each Earth material in its appropriate reservoir and indicate whether it is a solid (S), liquid (L), or gas (G).

Atmosphere	Hydrosphere	Geosphere	Cryosphere	Biosphere

EXERCISE 1.3 Selected Fluxes Involving the Hydrologic Cycle

Name: ______________________________ Section: __________
Course: ______________________________ Date: __________

You already have an instinctive sense of how water moves from one reservoir to another in the Earth System. Based on your experience with natural phenomena, complete the following table, in which the first column lists several geologic processes. Describe what happens during each process in the second column, using plain language. In the third column, indicate what transfer, if any, has occurred between the major reservoirs of the Earth System. The first process is given as an example.

Process	**What happens?**	**Did matter move from one reservoir to another? If so, from ________ to ________**
Sublimation	Solid ice becomes water vapor without melting.	Yes: cryosphere to atmosphere
Antarctic ice melts		
A puddle evaporates		

(continued)

EXERCISE 1.3 Selected Fluxes Involving the Hydrologic Cycle (*continued*)

Name: ______________________ **Section:** __________
Course: ______________________ **Date:** __________

A lake freezes		
Plant roots absorb water from the soil		
Clouds form in the sky		
Steam erupts from a volcano		

currents and the almost undetectable creep of soil downhill. All are caused by energy, which acts on matter to change its character, move it, or split it apart.

Energy for the Earth System comes from (1) the Earth's internal heat, which melts rock, causes earthquakes, and builds mountains (some of this heat is left over from the formation of the Earth, but most is being produced today by radioactive decay); (2) external energy from the Sun, which warms air, rocks, and water on the Earth's surface; and (3) the pull of the Earth's gravity. Heat and gravity, working independently or in combination, drive most geologic processes.

Heat energy is a measure of the degree to which atoms or molecules in matter—including those in solids—vibrate. When you heat something in an oven, for example, the atoms in the material vibrate faster and move farther apart. Heat energy drives the change of matter from one state to another and the flux of matter from one reservoir of the Earth System to another. For example, heating of ice causes **melting** (solid → liquid; cryosphere → hydrosphere) and heating of water causes **evaporation** (liquid → gas; hydrosphere → atmosphere). Cooling slows the vibration, causing **condensation** (gas → liquid, atmosphere → hydrosphere) or **freezing** (liquid → solid, hydrosphere → cryosphere). Exercise 1.4 explores evidence for the sources of the heat energy involved in geologic processes.

Gravity, as Isaac Newton showed more than three centuries ago, is the force of attraction that every object exerts on other objects. The strength of this force depends on the amount of mass in each object and how close the objects are to one another, as expressed by the equation

$$G = k\frac{m_1 \times m_2}{d^2}$$