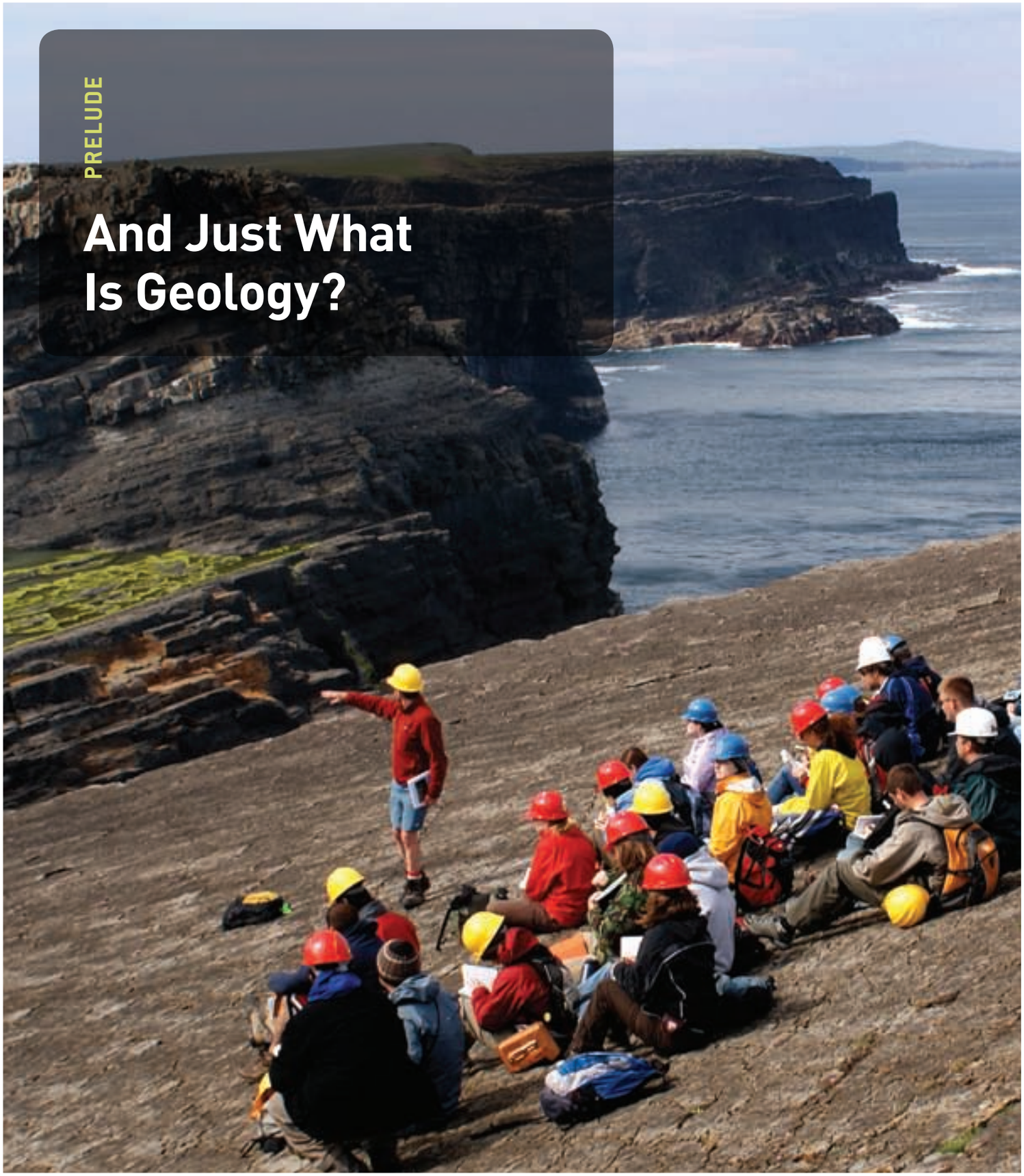
PRELUDE

# And Just What Is Geology?



Students can see the Earth System at a glance on a sea cliff along the coast of Ireland. Here, sunlight, air, water, rock, and life all interact to produce a complex and fascinating landscape.

## Prelude Objectives

**By the end of this Prelude you should know . . .**

- the scope and applications of geology.
- the foundational themes of modern geologic study.
- how geologists employ the scientific mathod.

*Civilization exists by geological consent, subject to change without notice.*

—Will Durant (1885–1981)

## P.1 In Search of Ideas

Our C-130 Hercules transport plane rose from a smooth ice runway on the frozen sea surface at McMurdo Station, Antarctica, and headed south to spend a month studying unusual rocks exposed on a cliff about 250 km away. We climbed past the smoking summit of Mt. Erebus, Earth's southernmost volcano, and for the next hour flew along the Transantarctic Mountains, a ridge of rock that divides the continent into two parts, East Antarctica and West Antarctica (**Fig. P.1**). Glaciers—sheets or rivers of ice that last all year—cover almost all of Antarctica. To the right of the plane we could see a continental glacier, a vast sheet of ice thousands of kilometers across and up to 4.7 km (15,000 ft) thick, that covers East Antarctica. The surface of this ice sheet forms a frigid high plain called the Polar Plateau. To the left we could see numerous valley glaciers, rivers of ice, that slowly carry ice from the Polar Plateau through gaps in the Transantarctic Mountains down to the frozen Ross Sea.

Suddenly, we heard the engines slow. As the plane descended, it lowered its ski-equipped landing gear. The loadmaster shouted an abbreviated reminder of the emergency alarm code: "If you hear three short blasts of the siren, hold on for dear life!" The plane touched the surface of our first choice for a landing spot, the ice at the base of the rock cliff we wanted to study. *Wham, wham, wham, wham!!!!* As the skis slammed into frozen snowdrifts on the ice surface at about 180 km an hour, it seemed as though a fairy-tale giant was shaking the plane. Seconds later, the landing aborted, we were airborne again, looking for a softer runway above the cliff. Finally, we landed in a field of deep snow, unloaded, and bade farewell to the plane. When the plane passed beyond the horizon, the silence of Antarctica hit us—no trees rustled, no dogs barked, and no traffic rumbled in this stark land of black rock and white

ice. It would take us a day and a half to haul our sleds of food and equipment down to our study site (see Fig. P.1). All this to look at a few dumb rocks?

**Geologists**—scientists who study the Earth—explore remote regions like Antarctica almost routinely. Such efforts often strike people in other professions as a strange way to make a living, as implied by Scottish poet Walter Scott's (1771–1832) classic description of geologists at work: "Some rin uphill and down dale, knappin' the chucky stones to pieces like sa' many roadmakers run daft. They say it is to see how the warld was made!"

Indeed—to see how the world was made, to see how it continues to evolve, to find its valuable resources, to prevent contamination of its waters and soils, and to predict its dangerous movements. That is why geologists spend months at sea drilling holes in the ocean floor, why they scale mountains, camp in rain-drenched jungles, and trudge through scorching desert winds (**Fig. P.2**). That is why geologists use electron microscopes to examine the atomic structure of minerals, use mass spectrometers to measure the composition of rock and water, and use supercomputers to model the paths of earthquake waves. For over two centuries, geologists have pored over the Earth in search of ideas to explain the processes that form and change our planet.

## P.2 The Nature of Geology

**Geology**, or geoscience, is the study of the Earth. Not only do geologists address academic questions such as the formation and composition of our planet, the causes of earthquakes and ice ages, and the evolution of life, but they also address practical problems such as how to keep pollution out of groundwater, how to find oil and minerals, and how to avoid landslides. And in recent years, geologists have made significant contributions to the study of global climate change. When news reports begin with "Scientists say . . . " and then continue with "an earthquake occurred today off Japan," or "landslides will threaten the city," or "chemicals from the proposed toxic waste dump will ruin the town's water supply," or "there's only a limited supply of oil left," the scientists referred to are geologists.

The fascination of geology attracts many to careers in this science. Tens of thousands of geologists work for oil, mining, water, engineering, and environmental companies, while a smaller number work in universities, government geological surveys, and research laboratories. Nevertheless, since most of the students reading this book will not become professional geologists, it's fair to ask the question, "Why should people, in general, study geology?"

**FIGURE P.1** Geologic fieldwork in Antarctica unlocks the mysteries of an icebound continent. A map of Antarctica emphasizes that the Transantarctic Mountains separate West Antarctica from East Antarctica.

**FIGURE P.2** Geologists in the field. Exploring an outcrop hidden in the woods of Ontario, Canada.

First, geology may be one of the most practical subjects you can learn. Ask yourself the following questions, and you'll realize that geologic processes, phenomena, and materials play major roles in daily life:

- Do you live in a region threatened by landslides, volcanoes, earthquakes, or floods (**Fig. P.3**)?
- Are you worried about the price of energy or about whether there will be a war in an oil-supplying country?
- Do you ever wonder about where the copper in your home's wires comes from?
- Have you seen fields of green crops surrounded by desert and wondered where the irrigation water comes from?
- Would you like to buy a dream house on a beach or near a river?

**FIGURE P.3** Human-made cities cannot withstand the vibrations of a large earthquake. These apartment buildings collapsed during an earthquake in Turkey.

- Are you following news stories about how toxic waste can migrate underground into your town's well water?

Clearly, all citizens of the 21st century, not just professional geologists, need to make decisions and understand news reports addressing Earth-related issues. A basic understanding of geology will help you do so.

Second, the study of geology gives you a holistic context for interpreting your surroundings. As you will see, the Earth is a complicated entity, where living organisms, oceans, atmosphere, and solid rock interact with one another in a great variety of ways. Geologic study reveals Earth's antiquity and demonstrates how the planet has changed profoundly during its existence. What our ancestors considered to be the center of the Universe has become, with the development of geologic perspective, our "island in space" today. And what was believed to be an unchanging orb originating at the same time as humanity has become a dynamic planet that existed long before people did and continues to evolve.

Third, the study of geology puts the accomplishments and consequences of human civilization in a broader context. View the aftermath of a large earthquake, flood, or hurricane, and it's clear that the might of natural geologic phenomena greatly exceeds the strength of human-made structures. But watch a bulldozer clear a swath of forest, a dynamite explosion remove the top of a hill, or a prairie field evolve into a housing development, and it's clear that people can change the face of the Earth at rates often exceeding those of natural geologic processes.

Finally, when you finish reading this book, your view of the world may be forever colored by geologic curiosity. If you walk in the mountains, you will think of the many forces that shape and reshape the Earth's surface. If you hear about a natural disaster, you will have insight into the processes that brought it about. And if you go on a road trip, the rock exposures along the highway will no longer be gray, faceless cliffs, but will present complex puzzles of texture and color telling a story of Earth's history.

## P.3 Themes of This Book

A number of narrative themes appear (and reappear) throughout this text. These themes, listed below, can be viewed as this book's overall take-home message.

- *The Earth is a unique, evolving system.* Geologists increasingly recognize that the Earth is a complex system; its interior, solid surface, oceans, atmosphere, and life forms interact in many ways to yield the landscapes and environment in which we live. Within this **Earth System**, chemical elements cycle between different types of rock, between rock and sea, between sea and air, and between all of these entities and life.

BOX P.1

CONSIDER THIS . . .

# Heat and Heat Transfer

The atoms and molecules that make up matter are not motionless, but rather jiggle in place and/or move with respect to one another. This activity produces **thermal energy**—the faster the atoms vibrate or move, the greater the thermal energy. Put another way, thermal energy in a substance represents the *sum* of the kinetic energy (energy of motion) of all the substance's atoms.

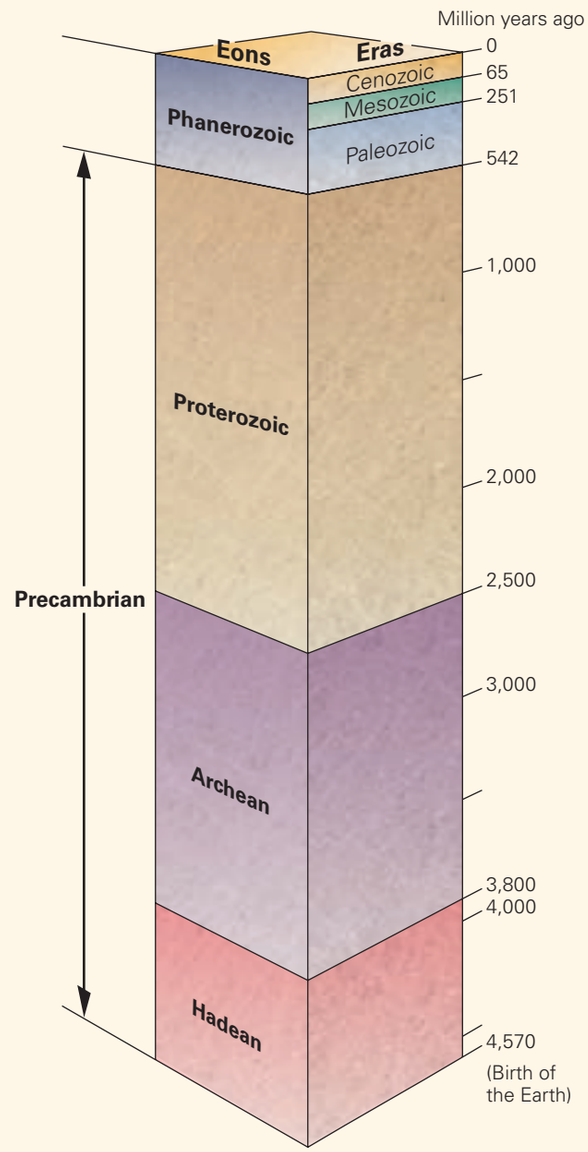
When we say that one object is hotter or colder than another, we are describing its **temperature**, a measure of warmth relative to some standard. Temperature represents the *average* kinetic energy of atoms in the material. We use the freezing and boiling points of water at sea level as a standard for defining temperatures. In the Celsius (centigrade) scale, the freezing point of water is 0°C and the boiling point is 100°C, whereas in the Fahrenheit scale, the freezing point is 32°F and the boiling point is 212°F. The coldest a substance can be is the temperature at which its atoms or molecules stand still. We call this temperature absolute zero, or 0K, where K stands for Kelvin, another unit of temperature. Degrees in the Kelvin scale have the same increment as degrees in the Celsius scale; absolute zero equates to −273.15°C. The term **heat** refers to the thermal energy *transferred* from one object to another. Heat can transfer from one place to another by four distinct means:

- Electromagnetic waves transport heat to a body as **radiation**. Radiation traveling from the Sun is responsible for heating the Earth's surface.
- If you stick the end of an iron bar in a fire, **conduction** takes place and heat moves up the bar. This happens because atoms in the bar at the hot end start to vibrate more energetically, and this motion incites atoms farther up the bar to start jiggling. Though heat flows along the bar, the atoms do not actually move from one locality to another.
- When you place a pot on a stove and heat it, water at the base of the pot gets hotter and expands, so its density decreases. The hot, less-dense water becomes buoyant relative to the colder, denser water, above it. In a gravitational field, buoyant material rises if the material above it is weak enough to flow out of the way. Since liquid water flows easily, the hot water can rise. When this happens, cold water sinks to take its place. The resulting circulation, during which flow of the material itself carries heat, is called **convection**, the path of flow defines **convective cells**.
- **Advection** happens when a hot fluid flows into cracks and pores within a solid, and heats up the solid. The hottness of a metal water pipe's surface, for example, comes from the hot water through the pipe. In the Earth, advection occurs where molten rock rises into the crust.

**FIGURE P.4** A simplified map of the Earth's plates. The arrows indicate the direction each plate is moving, and the length of the arrow indicates plate velocity (the longer the arrow, the faster the motion). We discuss the types of plate boundaries in Chapter 2.

- *Geology helps you understand physical science.* Geology incorporates many of the basic concepts of physics and chemistry because Earth materials are a form of matter, and energy drives geologic processes (**Box P.1**). Thus, studying geology can help you develop a better grasp of key ideas in physical science.
- *Plate tectonics explains many Earth processes.* Earth is not a homogeneous ball, but rather consists of concentric layers—from center to surface, Earth has a core, mantle, and crust. We live on the surface of the crust, where it meets the atmosphere and the oceans. In the 1960s, geologists recognized that the crust, together with the uppermost part of the underlying mantle, forms a 100- to 150-km-thick semi-rigid shell. Large cracks separate this shell into discrete pieces, called **plates**, which move very slowly relative to one another (**Fig. P.4**). The model that describes this movement and its consequences is called the **theory of plate tectonics**, and it is the foundation for understanding most geologic phenomena. Although plates move very slowly—generally less than 10 cm a year—their movements yield earthquakes, volcanoes, and mountain ranges, and cause the map of Earth's surface to change over time.
- *The Earth is a planet.* Despite its uniqueness, the Earth can be viewed as a planet, formed like the other planets of the Solar System from dust and gas that encircled the newborn Sun.
- *The Earth is very old.* Geologic data indicate that the Earth formed 4.57 billion years ago—plenty of time for life to evolve, and for the map of the planet to change. Plate-movement rates of only a few centimeters per year can move a continent thousands of kilometers. There is time enough to build mountains and time enough to grind them down, many times over. To define intervals of this time, geologists developed the **geologic time scale**. **Figure P.5** depicts major subdivisions of the geologic time scale. Chapter 10 discusses these in greater detail.
- *Internal and external processes drive geologic phenomena.* Internal processes are those phenomena driven by heat from inside the Earth. Plate movement is an example. Because plate movements cause mountain building, earthquakes, and volcanoes, we call all of these phenomena internal processes as well. External processes are those phenomena driven by heat supplied by radiation that comes to the Earth from the Sun. This heat drives the movement of air and of water, which grinds and sculpts the Earth's surface and transports the debris to new locations, where it accumulates. The interaction between internal and external processes forms the landscapes of our planet. As we'll see, gravity—the pull that one mass exerts on another—plays an important role in both internal and external processes.
- *Geologic phenomena affect our environment.* Volcanoes, earthquakes, landslides, floods, groundwater, energy sources, and mineral reserves are of vital interest to every inhabitant of this planet. Therefore, throughout this book we emphasize the linkages between geology, the environment, and society.
- *Physical aspects of the Earth System are linked to life processes.* All life on this planet depends on such physical features as the minerals in soil; the temperature, humidity, and composition of the atmosphere; and the flow of surface and subsurface water. And life in turn affects and alters physical features. For example, the oxygen in Earth's atmosphere comes primarily from plant photosynthesis, a life activity.

**FIGURE P.5** The geologic time scale.




**(a)** The scale has been divided into eons and eras.

One thousand years ago = 1 **Ka**
(Ka stands for kilo-annum)

One million years ago = 1 **Ma**
(Ma stands for mega-annum)

One billion years ago = 1 **Ga**
(Ga stands for giga-annum)

**(b)** Abbreviations for time units.

BOX P.2

CONSIDER THIS . . .

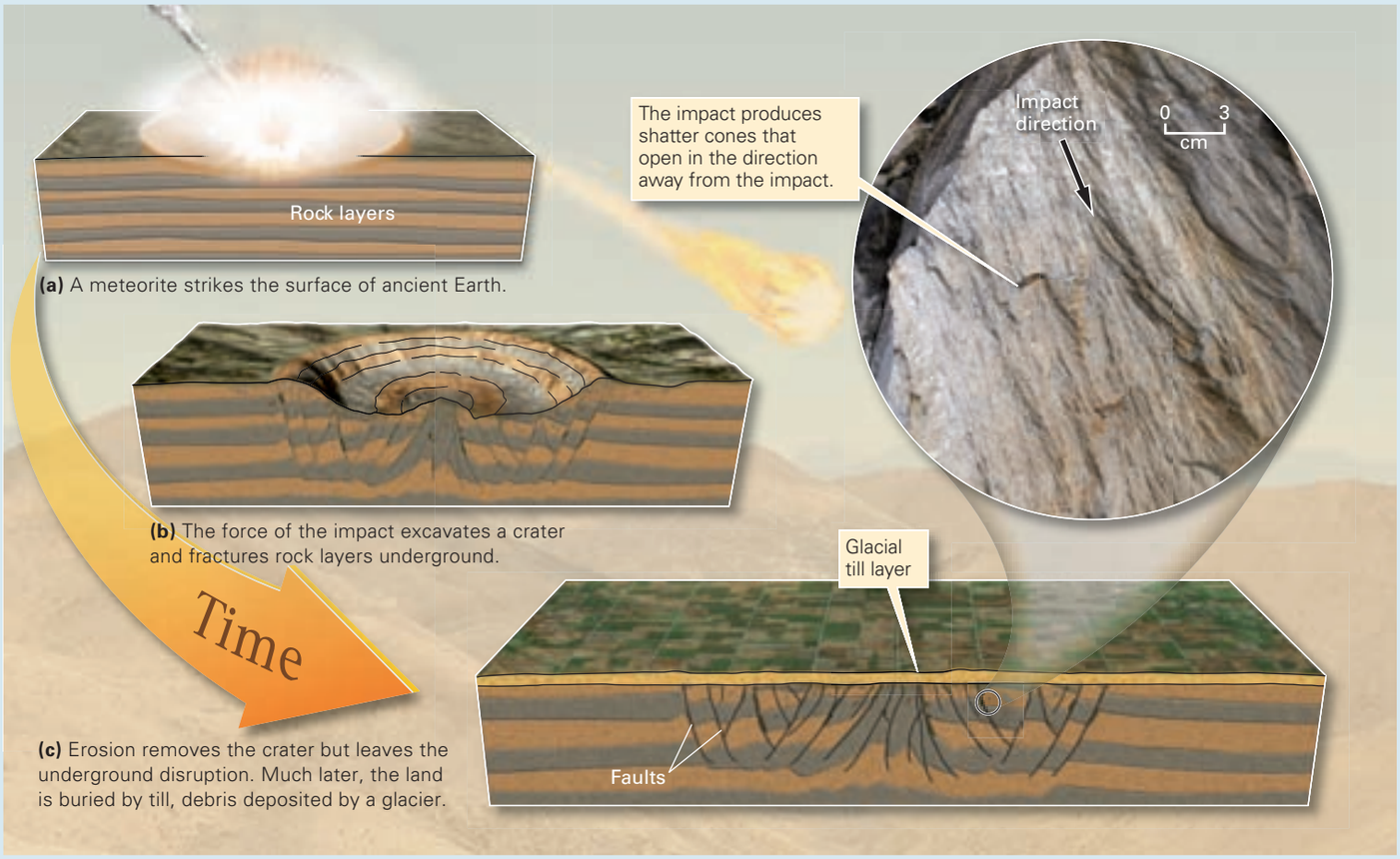
# The Scientific Method

Sometime during the past 200 million years, a large block of rock or metal, which had been orbiting the Sun, slammed into our planet. It made contact at a site in what is now the central United States, a landscape of flat cornfields. The impact of this block, a meteorite, released more energy than a nuclear bomb—a cloud of shattered rock and dust blasted skyward, and once-horizontal layers of rock from deep below the ground sprang upward and tilted steeply beneath the gaping hole left by the impact. When the dust had settled, a huge crater surrounded by debris marked the surface of the Earth at the impact site. Later in Earth history, running water and blowing wind wore down this jagged scar. Some 15,000 years ago, sand, gravel, and mud carried by a vast glacier buried what remained, hiding it entirely from view (**Fig. BxP.1a–c**). Wow! So much history beneath a cornfield. How do we know this? It takes scientific investigation.

The movies often portray science as a dangerous tool, capable of creating Frankenstein's monster, and scientists as warped or nerdy characters with thick glasses and poor taste in clothes. In reality, science is simply the use of observation, experiment, and calculation to explain how nature operates, and scientists are people who study and try to understand natural phenomena. Scientists carry out their work in the context of the **scientific method**, a sequence of steps for systematically analyzing scientific problems in a way that leads to verifiable results. Let's see how geologists employed the steps of the scientific method to come up with the meteorite-impact story.

1. *Recognizing the problem.* Any scientific project, like any detective story, begins by identifying a mystery. The cornfield mystery came to light when water drillers discovered limestone, a rock typically made of shell fragments, just below the 15,000-year-old glacial sediment. In surrounding regions, the rock beneath the glacial sediment consists of sandstone, a rock made of cemented-together sand grains. Since limestone can be used to build roads, make cement, and produce the agricultural lime used in treating soil, workers stripped off the glacial sediment and dug a quarry to excavate the limestone. They were amazed to find that rock layers exposed in the quarry were tilted steeply and had

**FIGURE BxP.1** An ancient meteorite impact excavates a crater and permanently changes rock beneath the surface.



been shattered by large cracks. In the surrounding regions, all rock layers are horizontal like the layers in a birthday cake, and the rocks contain relatively few cracks. Curious geologists came to investigate and soon realized that the geologic features of the land just beneath the cornfield presented a problem to be explained: What phenomena had brought limestone up close to the Earth's surface, had tilted the layering in the rocks, and had shattered the rocks?

2. *Collecting data*. The scientific method proceeds with the collection of observations or clues that point to an answer. Geologists studied the quarry and determined the age of its rocks, measured the orientation of the rock layers, and documented (made a written or photographic record of) the fractures that broke up the rocks.
3. *Proposing hypotheses*. A scientific **hypothesis** is merely a possible explanation, involving only natural processes, that can explain a set of observations. Scientists propose hypotheses during or after their initial data collection. In this example, the geologists working in the quarry came up with two alternative hypotheses. First, the features in this region could result from a volcanic explosion; and second, they could result from a meteorite impact.
4. *Testing hypotheses*. Since a hypothesis is no more than an idea that can be either right or wrong, scientists must put hypotheses through a series of tests to see if they work. The geologists at the quarry compared their field observations with published observations made at other sites of volcanic explosions and meteorite impacts, and they studied the results of experiments designed to simulate such events. If the geologic features visible in the quarry were the result of volcanism, the quarry should contain rocks formed by solidification of molten rock erupted by a volcano. But no such rocks were found. If, however, the features were the result of an impact, the rocks should contain **shatter cones**, small, cone-shaped cracks (see Fig. Bx P.1c). Shatter cones can be overlooked, so the geologists returned to the quarry specifically to search for them, and found them in abundance. The impact hypothesis passed the test!

**Theories** are scientific ideas supported by abundant evidence; they have passed many tests and have failed none. Scientists are much more confident in the correctness of a theory than of a hypothesis. Continued study in the quarry eventually yielded so much evidence for impact that the impact hypothesis came to be viewed as a theory. Scientists continue to test theories over a long time. Successful theories withstand these tests and are supported by so many observations that they become part of a discipline's foundation. However, some theories may be disproven and replaced by better ones.

In a few cases, scientists have been able to devise concise statements that completely describe a specific relationship or phenomenon. Such statements are called **scientific laws**. Note that the *law* of gravity does not explain why gravity exists, but the *theory* of evolution does provide an explanation of why evolution occurs.

- *Science comes from observation, and people make scientific discoveries.* Science does not consist of subjective guesses or arbitrary dogmas, but rather of a consistent set of objective statements resulting from the application of the **scientific method** (**Box P.2**). Every scientific idea must be tested thoroughly, and should be used only when supported by documented observations. Further, scientific ideas do not appear out of nowhere, but are the result of human efforts. Wherever possible, this book shows where geologic ideas came from, and tries to answer the question, "How do we know that?"

As you read this book, please keep these themes in mind. Don't view geology as a list of words to memorize, but rather as an interconnected set of concepts to digest. Most of all, enjoy yourself as you learn about what may be the most fascinating planet in the Universe. To help illustrate the geology of our amazing world, we have created "See for Yourself" features. Using *Google Earth*™, you'll be able to find examples of localities that illustrate geologic features and phenomena.

## Key Terms

advection (p. 4)
conduction (p. 4)
convection (p. 4)
convection cells (p. 4)
Earth System (p. 3)
geologic time scale (p. 5)
geologist (p. 2)
geology (p. 2)
heat (p. 4)
hypothesis (p. 7)
plate (p. 5)
radiation (p. 4)
scientific laws (p. 7)
scientific method (p. 6)
shatter cones (p. 7)
temperature (p. 4)
theory (p. 7)
theory of plate tectonics (p. 5)
thermal energy (p. 4)