A.1 Introduction

During the 1849 gold rush in the Sierra Nevada of California, only a few lucky individuals actually became rich. The rest of the "forty-niners" either slunk home in debt or took up less glamorous jobs in new towns such as San Francisco. These towns grew rapidly, and soon people from the American west coast were demanding large quantities of manufactured goods from east-coast factories. Making the goods was no problem, but getting them to California meant either a stormy voyage around the southern tip of South America or a trek with stubborn mule teams through the deserts of Nevada and Utah. The time was ripe to build a railroad linking the east and west coasts of North America, and, with much fanfare, the Central Pacific line decided to punch one right across the peaks of the Sierras. In 1863, while the Civil War raged elsewhere in the United States, the company transported six thousand Chinese laborers across the Pacific in the squalor of unventilated cargo holds and set them to work chipping ledges and blasting tunnels. Along the way, untold numbers of laborers died of frostbite, exhaustion, mistimed blasts, landslides, or avalanches.

Through their efforts, the railroad laborers certainly gained an intimate knowledge of how rock feels and behaves—it's solid, heavy, and hard! They also found that some rocks break easily into layers but others do not, and that some rocks are dark-colored while others are light-colored. They realized, like anyone who looks closely at rock exposures, that rocks are not just gray, featureless masses, but rather come in a great variety of colors and textures.

Why are there so many distinct types of rocks? The answer is simple: rocks can form in many different ways and from many different materials. Because of the relationship between rock type and the process of formation, rocks provide a historical record of geologic events and give insight into interactions among components of the Earth System. The next few chapters are devoted to a discussion of rocks and a description of how rocks form. This interlude serves as a general introduction to these chapters. We learn what the term "rock" means to geologists, what rocks are made of, and how to distinguish among the three principal groups of rocks. We also look at how geologists study rocks.

A.2 What Is Rock?

To geologists, **rock** is a coherent, naturally occurring solid, consisting of an aggregate of minerals or, less commonly, of glass. Let's take this definition apart to see what its components mean.

- *Coherent*: A rock holds together, and thus must be broken to be separated into pieces. As a result of its coherence, rock can form cliffs or can be carved into sculptures. A pile of unattached mineral grains does not constitute a rock.
- *Naturally occurring*: Geologists consider only naturally occurring materials to be rocks, so manufactured materials, such as concrete and brick, do not qualify.
- *An aggregate of minerals or a mass of glass*: The vast majority of rocks consist of an aggregate (a collection) of many mineral grains, and/or crystals, stuck or grown together. Some rocks contain only one kind of mineral, whereas others contain several different kinds. A few rock types consist of glass.

What holds rock together? Grains in rock stick together to form a coherent mass either because they are bonded by natural **cement**, mineral material that precipitates from water and fills the space between grains (**Fig. A.1a**), or because they interlock with one another like pieces in a jigsaw puzzle (**Fig. A.1b**). Rocks whose grains are stuck together by cement are called **clastic**, whereas rocks whose crystals interlock with one another are called **crystalline**. Glassy rocks hold together because they originate as a continuous mass (that is, they have no separate grains), because glassy grains were welded together while still hot, or because they were cemented together at a later time.

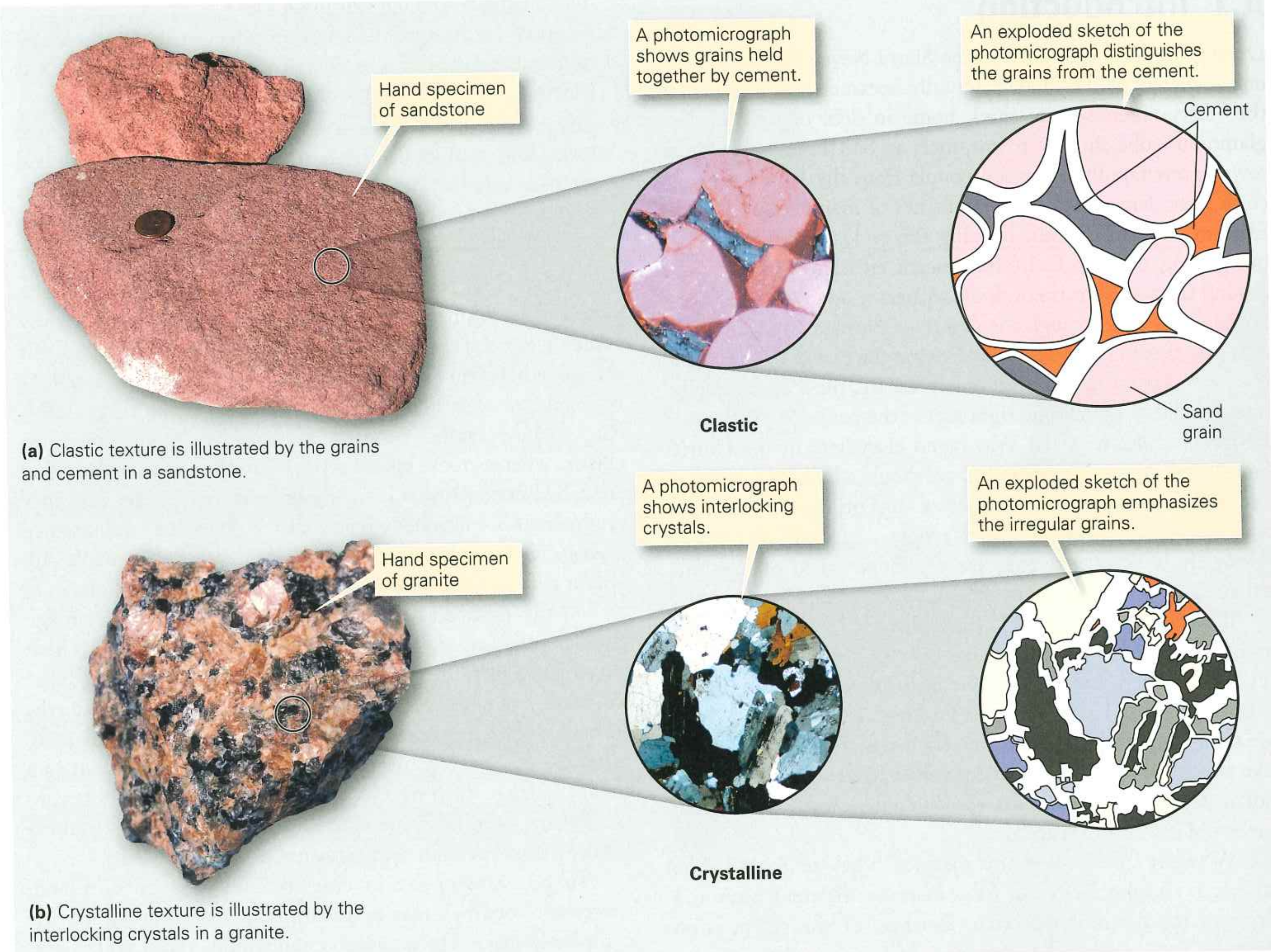
At the surface of the Earth, rock occurs either as broken chunks (pebbles, cobbles, or boulders; see Chapter 6) that have moved by falling down a slope or by being transported in ice, water, or wind, or as **bedrock** that is still attached to the Earth's crust. Geologists refer to an exposure of bedrock as an **outcrop**. An outcrop may appear as a rounded knob out in a field, as a ledge forming a cliff or ridge, on the face of a stream cut (where running water dug down into bedrock), or along human-made roadcuts and excavations (**Fig. A.2a–d**).

To people who live in cities or forests or on farmland, outcrops of bedrock may be unfamiliar, since bedrock may be completely covered by vegetation, sand, mud, gravel, soil, water, asphalt, concrete, or buildings. Outcrops are particularly rare in regions such as the midwestern United States, where, during the past million years, ice-age glaciers melted and buried bedrock under thick deposits of debris (see Chapter 18).

A.3 The Basis of Rock Classification

Beginning in the 18th century, geologists struggled to develop a sensible way to classify rocks, for they realized, as did miners from centuries past, that not all rocks are the same. Classification schemes help us organize information and remember significant details about materials or objects, and they help us recognize similarities and differences among them. By the end of the 18th century, most geologists had accepted the *genetic scheme* for classifying rocks that we continue to use today. This scheme focuses on the origin (genesis) of rocks. Using this

FIGURE A.1 Rocks, aggregates of mineral grains and/or crystals, can be clastic or crystalline.



(a) Clastic texture is illustrated by the grains and cement in a sandstone.

(b) Crystalline texture is illustrated by the interlocking crystals in a granite.

approach, geologists recognize three basic groups: (1) **igneous rocks**, which form by the freezing (solidification) of molten rock (**Fig. A.3a**); (2) **sedimentary rocks**, which form either by the cementing together of fragments (grains) broken off preexisting rocks or by the precipitation of mineral crystals out of water solutions at or near the Earth's surface (**Fig. A.3b**); and (3) **metamorphic rocks**, which form when preexisting rocks change character in response to a change in pressure and temperature conditions (**Fig. A.3c**). Metamorphic change occurs in the solid state, which means that it does not require melting. In the context of modern plate tectonics theory, different rock types form in different geologic settings, as we discuss in succeeding chapters (**Fig. A.4**).

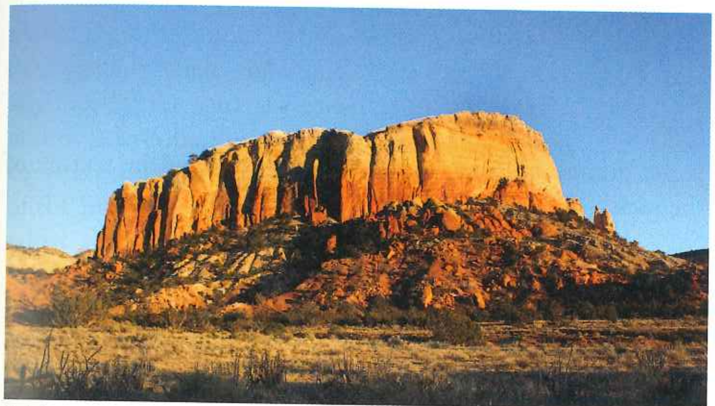
Each of the three groups contains many different individual rock types, distinguished from one another by physical characteristics.

- *Grain size*: The dimensions of individual "grains" (here used in a general sense to mean fragments or crystals) in a rock may be measured in millimeters or centimeters. Some grains are so small that they can't be seen without a microscope, whereas others are as big as a fist or larger. Some grains are **equant**, meaning that they have the same dimensions in all directions; some are **inequant**, meaning that the dimensions are not the same in all directions (**Fig. A.5a, b**). In some rocks, all the grains are the same size, whereas other rocks contain a variety of grain sizes.

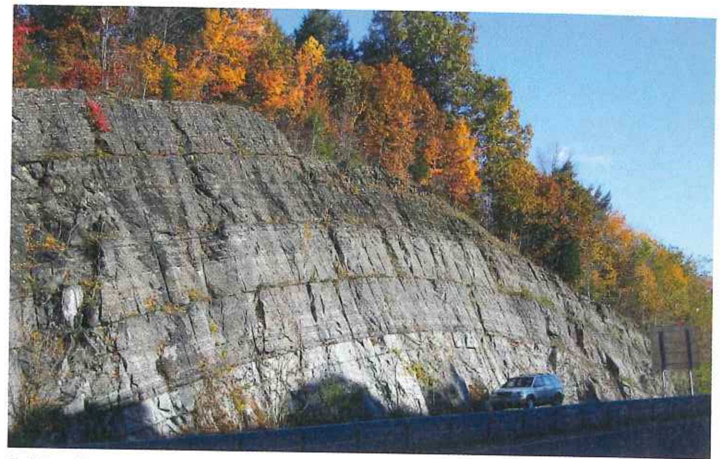
- *Composition*: A rock is a mass of chemicals. The term rock composition refers to the proportions of different chemicals making up the rock. The proportion of chemicals, in turn, affects the proportion of different minerals constituting the rock.

FIGURE A.2 Types of rock exposures.

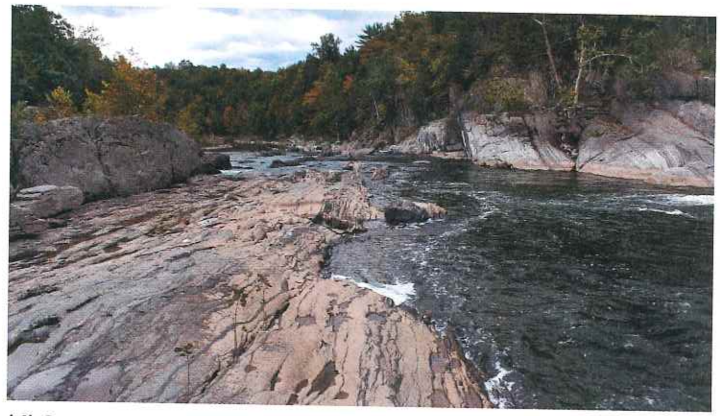
(a) Outcrops are natural rock exposures. These outcrops rise as cliffs above the forest of the Rocky Mountains in Colorado.



(b) In arid (dry) climates, a lack of vegetation leaves outcrops unobscured.



(c) By blasting into the ground to produce a more level grade for roads, highway engineers produce roadcuts.



(d) Stream cuts form where flowing water grinds into the land and strips away soil and vegetation.

- *Texture*: This term refers to the arrangement of grains in a rock, that is, the way grains connect to one another and whether or not inequant grains are aligned parallel to each other. The concept of rock texture will become easier to grasp as we look at different examples of rocks in the following chapters.
- *Layering*: Some rock bodies appear to contain distinct layering, defined either by bands of different compositions or textures, or by the alignment of inequant grains so that they trend parallel to each other. Different types of layering occur in different kinds of rocks. For example, the layering in sedimentary rocks is called **bedding**, whereas the layering in metamorphic rocks is called **metamorphic foliation** (**Fig. A.6a, b**).

Each distinct rock type has a name. Names come from a variety of sources. Some come from the dominant component making up the rock, some from the region where the rock was first discovered or is particularly abundant, some from a root word of Latin origin, and some from a traditional name used by people in an area where the rock is found. All told, there are hundreds of different rock names, though in this book we will introduce only about 30.

A.4 Studying Rock

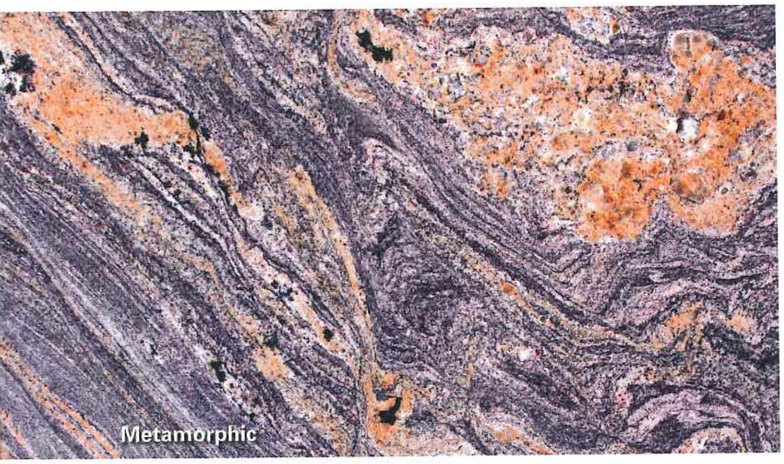
Outcrop Observations

The study of rocks begins by examining a rock in an outcrop. If the outcrop is big enough, such an examination will reveal relationships between the rock you're interested in and the rocks around it, and will allow you to detect layering. Geologists carefully record observations about an outcrop, then break off a **hand specimen**, a fist-sized piece, that they can examine more closely with a hand lens (magnifying glass). Observation with a hand lens enables geologists to identify sand-sized or

FIGURE A.3 Examples of the three major rock groups.

(a) Lava (molten rock) freezes to form igneous rock. Here, the molten tip of a brand-new flow still glows red. Older flows are already solid.

(b) Sand, formed from grains eroded off the rock cliffs, collects on the beach. If buried and turned to rock, it becomes layers of sandstone, such as those making up cliffs.



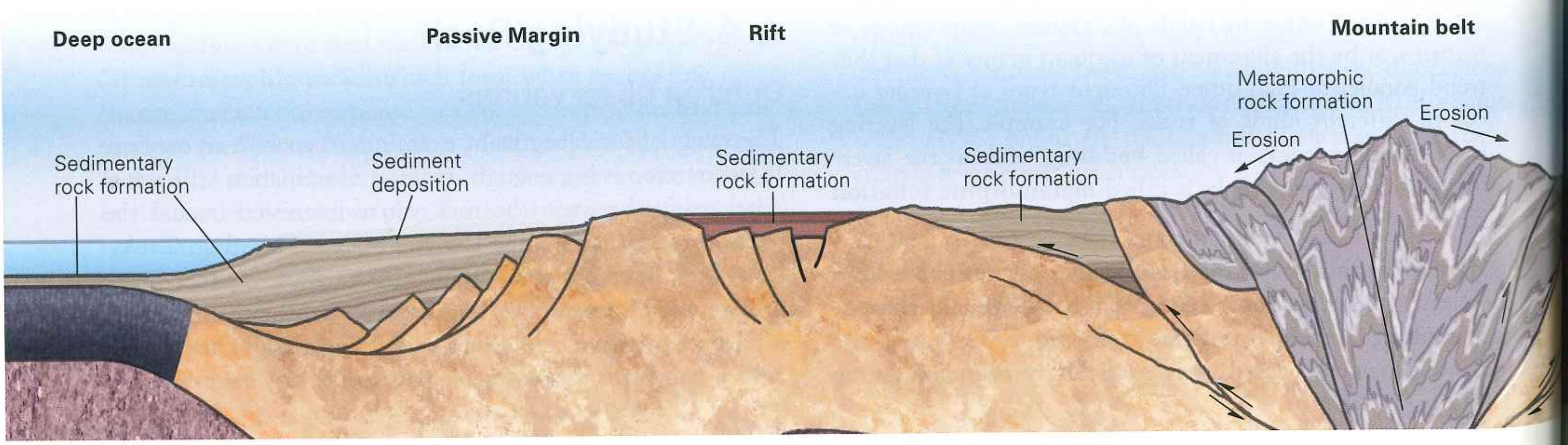
(c) Metamorphic rock forms when preexisting rocks endure changes in temperature and pressure and/or are subjected to shearing, stretching, or shortening. New minerals and textures form.

larger grains, and may enable them to describe the texture of the rock.

Thin-Section Study

Geologists often must examine rock composition and texture in minute detail in order to identify a rock and develop a hypothesis for how it formed. To do this, they take a specimen back to the lab, make a very thin slice (about 0.03 mm thick, the thickness of a human hair) and mount it on a glass slide (**Fig. A.7a–c**). They study the resulting **thin section** with a petrographic microscope (*petro* comes from the Greek word for rock). A petrographic microscope differs from an ordinary microscope in that it illuminates the thin section with transmitted polarized light. This means that the illuminating

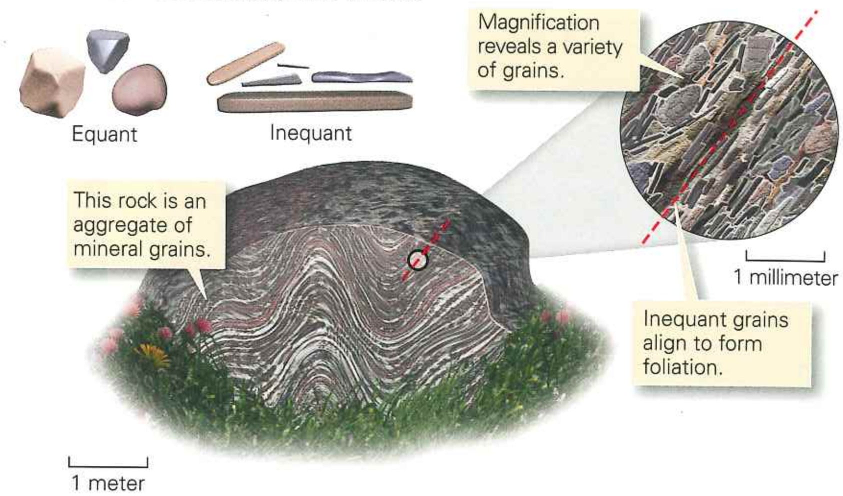
FIGURE A.4 A cross section illustrating various geologic settings in which rocks form.



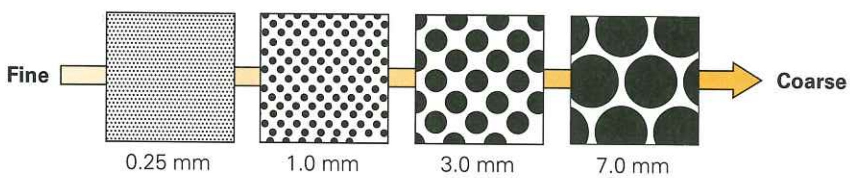
light beam first passes through a special polarity filter that makes all the light waves in the beam vibrate in the same plane, and then the light passes up through the thin section and then up through another polarizing filter. An observer looks through the thin section as if it were a window. When illuminated with transmitted polarized light, and viewed through two polarizing filters, each type of mineral grain displays a unique suite of colors (**Fig. A.7d**). The specific color the observer sees depends on both the identity of the grain and its orientation with respect to the waves of polarized light.

The brilliant colors and strange shapes in a thin section viewed in polarized light rival the beauty of an abstract painting or stained glass. By examining a thin section with a petrographic microscope, geologists can identify most of the minerals constituting the rock and can describe the way in which the grains connect to each other. They can make a record of the image by using a camera. A photograph taken through a petrographic microscope is called a **photomicrograph**.

FIGURE A.5 Describing grains in rock.



(a) Grains in rock come in a variety of shapes. Some are equant, whereas some are inequant. In this example of metamorphic rock, inequant grains align to define a foliation.



(b) Geologists define grain size by using this comparison chart.

High-Tech Analytical Equipment

Beginning in the 1950s, high-tech electronic instruments became available that enabled geologists to examine rocks on an even finer scale than is possible with a petrographic microscope. Modern research laboratories typically boast instruments such as electron microprobes, which can focus a beam of electrons on a small part of a grain to create a signal that defines the chemical composition of the mineral (**Fig. A.8**); mass spectrometers, which analyze the proportions of atoms with different atomic weights contained in a rock; and X-ray diffractometers, which identify minerals by measuring how X-ray beams interact with crystals. Such instruments, in conjunction with optical examination, can provide geologists with highly detailed characterizations of rocks, which in turn help them understand how the rocks formed and where the rocks came from. This information enables geologists to use the study of rocks as a basis for deciphering Earth history.

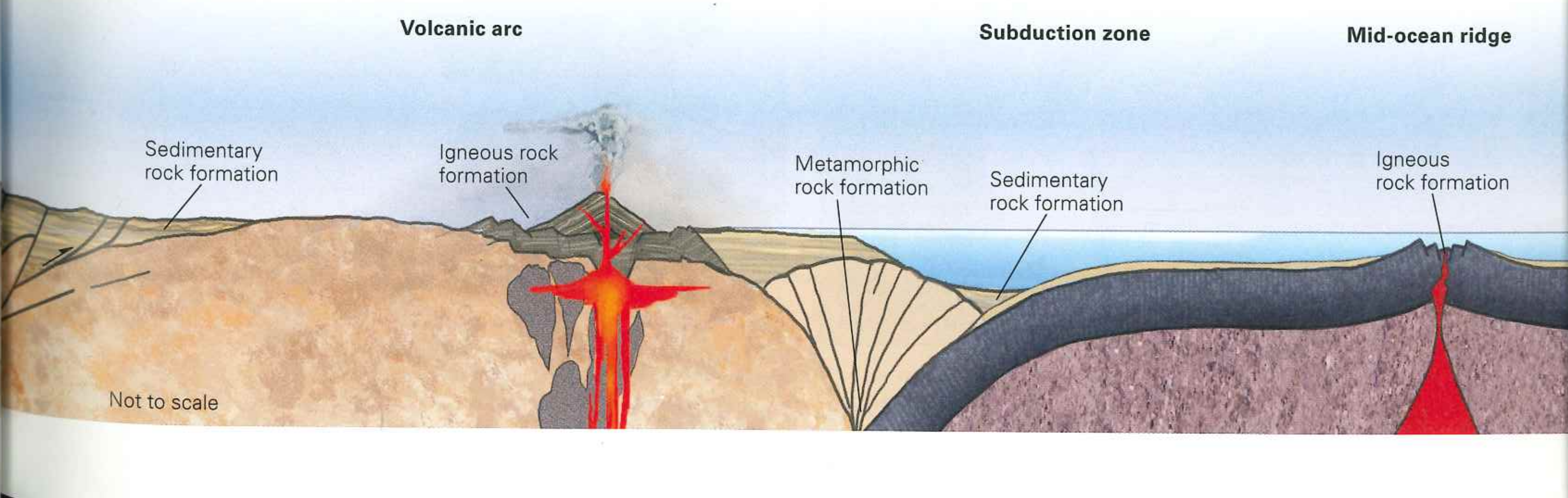
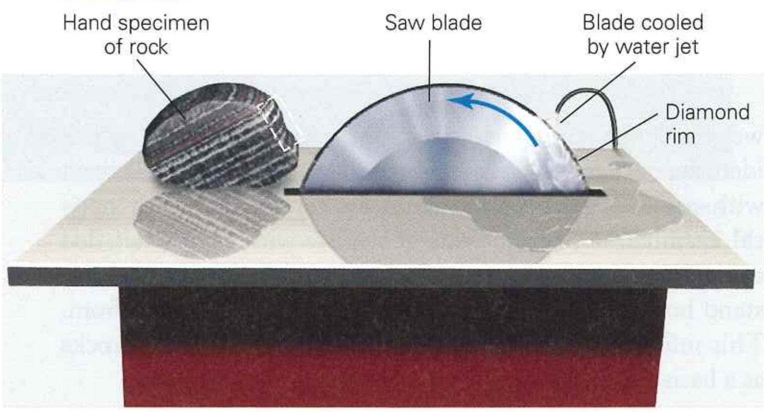


FIGURE A.6 Layering in rock.

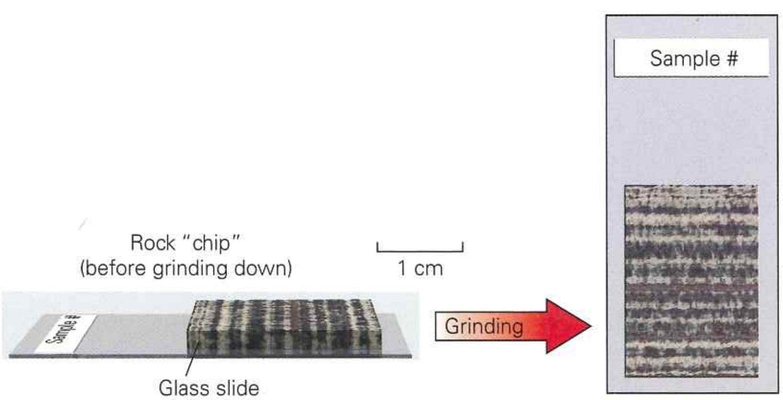
(a) Bedding in a sedimentary rock, here defined by alternating layers of coarser and finer grains, as exposed on a cliff along an Oregon beach. Older beds were tilted before younger ones were deposited.

(b) Foliation in this outcrop of metamorphic rock in Ontario, Canada is defined by alternating layers of light and dark minerals.

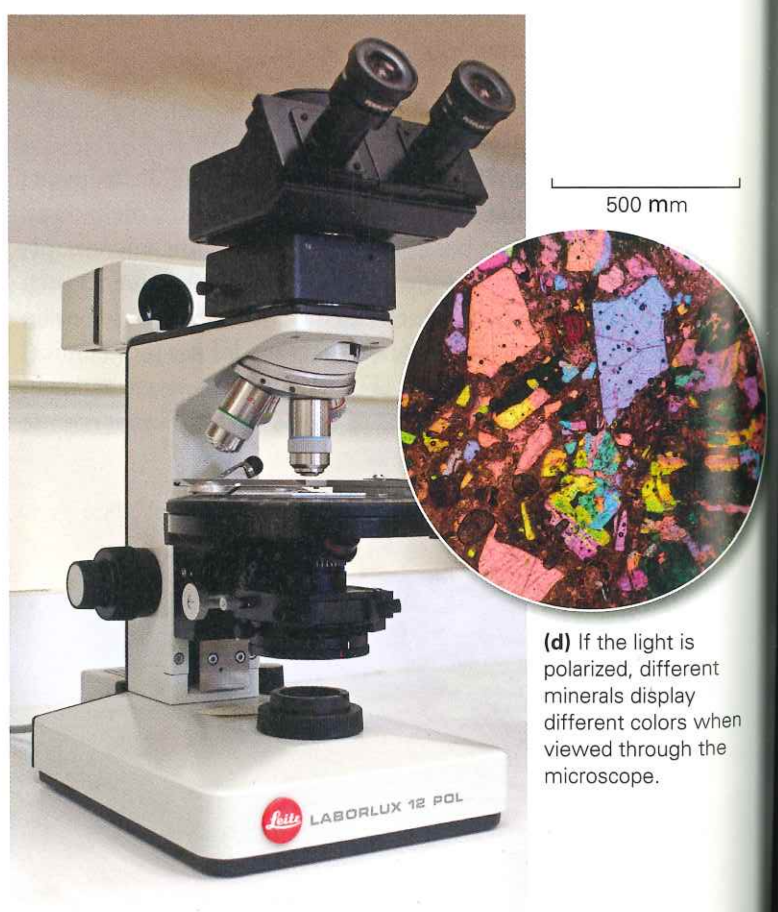
FIGURE A.7 Studying rocks in thin section.



(a) Using a special saw, a geologist cuts a thin chip of a rock specimen.



(b) The geologist glues the chip to a glass slide and grinds it down until it is so thin that light can pass through it.



(c) With a petrographic microscope, it's possible to view thin sections with light that shines through the sample from below.

(d) If the light is polarized, different minerals display different colors when viewed through the microscope.