CHAPTER 8

Soil and Soil Dynamics

IN THIS CHAPTER

Summary: The Earth is made up of a core, mantle, and crust affected by volcanic, climatic, water, and weathering processes. The rock cycle describes the creation, destruction, and metamorphosis of rocks and minerals. Soil conservation maintains soil richness and crop vitality by protecting against erosion and desertification.

KEY IDEA

Keywords

✪ Sedimentary, igneous, metamorphic, rock cycle, stratigraphy, lithology, magma, tectonic, geothermal gradient, weathering, dissolution, hydrolysis, runoff, tillage, soil horizon, topography, desertification

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Stratigraphic Classification

Unlike newly erupted volcanic rock, sedimentary rock strata or layers provide snapshots of regional climates and geological events throughout history. By studying different rock layers, geologists find windows into climate conditions during specific time periods.

Rock Stratigraphy

The study of rock, *stratigraphy,* is a grouping exercise. Figure 8.1 shows a cross section of the ancient (pre-Cambrian) and more recent (Paleozoic) sedimentary rock layers in the United States' Grand Canyon. Layers can be thin, thick, rocky, or smooth, but all have a place in the geological stack and time. The Grand Canyon is a good example of sedimentary rock layers above metamorphic and ancient rock.

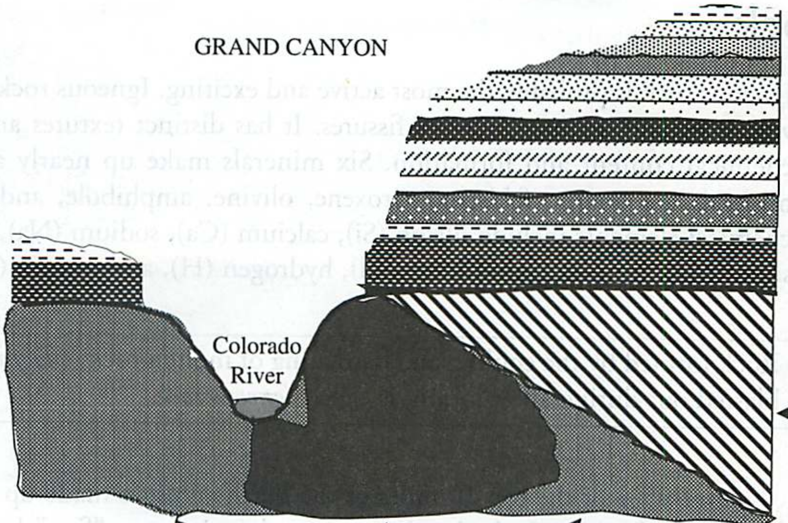

Figure 8.1 The Grand Canyon is a colorful stratigraphic record of sedimentary rock.

KEY IDEA

An individual band with its own specific characteristics and position is called a *rock–stratigraphic unit* or *rock unit.*

Rock units stacked vertically add up to a *formation,* which geologists can describe and map as part of the geological record. Formations are collections of many rock units grouped into a section with the same physical properties. Formations can be seen in places where strata layers are exposed. Igneous and metamorphic rock layers also have specific formations.

When studying sedimentary rock strata, it is important to remember huge stretches of time have led to layer upon layer of solidified rock. Thousands and millions of years piled atom upon atom, crystal upon crystal, building each layer.

KEY IDEA

Lithology is the visual study of a rock's physical characteristics using a handheld magnifying glass or a low-power microscope..

Different rock formations can be matched by their physical characteristics such as

- Grain size and shape
- Grain orientation
- Mineral content
- Sedimentary structures
- Color
- Weathering

The three main rock types are *igneous, sedimentary,* and *metamorphic.*

Igneous Rock

Igneous rock is probably the most active and exciting. Igneous rock is created by exploding volcanoes and boiling undersea fissures. It has distinct textures and colors depending on chemical content and formation. Six minerals make up nearly all igneous rock. These minerals are quartz, feldspar, pyroxene, olivine, amphibole, and mica. These minerals' chemical elements include silicon (Si), calcium (Ca), sodium (Na), potassium (K), magnesium (Mg), iron (Fe), aluminum (Al), hydrogen (H), and oxygen (O).

KEY IDEA

> Rock formed by the cooling and hardening of molten rock (*magma*), deep in the earth or blasted out during an eruption, is called *igneous rock*.

Over 95% of the top 10 miles of the Earth's crust is made up of igneous rock formed from lava eruptions. In Latin, the root word *ignis* means "fire." Igneous rock is formed in temperatures of at least 700°C; the temperature needed to melt rock. The deepest magma, near the Earth's superheated outer core, has a different chemical makeup from magma just beneath the crust, which has been squeezed up through cracks or conduits. Not all cooled magma is created equally. Depending on heating time and how it got to the surface, different magmas form very different rocks.

Chemical and Mineral Composition

Igneous rocks are divided into two types depending on composition: *felsic* and *mafic*. Felsic rock is affected by heat, either from magma coming to the surface from extreme depths in the Earth, or by the friction between continental plates. Felsic rock has high levels of silica-containing minerals (e.g., quartz and granite). Mafic rock has high levels of magnesium and iron (ferric) minerals. The word *mafic* comes from a combination of these two mineral names.

Sedimentary Rock

Sediment is made up of loose particulate matter like clay, sand, gravel, and other bits and pieces of things. Sedimentary rock is formed when the bits and pieces of different rocks, soils, and organic things are compressed under pressure.

KEY IDEA

> *Sedimentary rock* is formed from rocks and soils from other locations compressed with the remains of dead organisms.

Sedimentary rocks, originally formed from the buildup of material upon the Earth's surface, were compressed and cemented into solid rock over geological time. Beautiful multicolored layers of sedimentary rock are seen when highways or railroads cut across hillsides and mountains exposing the different types of sediments.

Rock Texture

In the late 1700s, while working in a field near his home in Scotland, James Hutton noticed coarse-grained granites cutting across and between layers of sedimentary rocks. Hutton thought physical changes in bordering sedimentary rock must have come from earlier contact with extreme heat. This gave him the idea that molten magma deep within the earth had squeezed into areas of sedimentary rock and crystallized.

KEY IDEA

Grain size and *color* are the two major ways geologists describe rock textures.

Mineral or crystal size, which makes up a rock's texture, is called *grain size.* Since color can change depending on lighting, mineral content, and other factors, it is considered less dependable when describing a specific rock.

When a rock's grains are easily seen with the eye (roughly a few millimeters across), they are classified as coarse-grained. When individual grains are not visible, the texture is reported as fine. Mineral grains or crystals have an assortment of different shapes and textures. They may be flat, parallel, needlelike, or equal in every direction like spheres or cubes. Granite has a coarse grain size compared to obsidian, which has a very fine grain size.

Lithification

TIP

Lithification comes from the Greek word *lithos,* meaning "stone." Lithified soil is made up of sand, silt, and organic organisms. Lithification can take place right after materials are deposited or much later. Compaction and cementation rate also play a big part in lithification. Additionally, the heat needed for lithification is less intense than that found deeper in the mantle, so lithification can occur in the top few kilometers of the crust.

Sandstone is formed when grains are squeezed together by the weight of overlying sediments during compaction, and formed into rock denser than the original sediments. These dense layers are then sealed by the precipitation of minerals in and among the layers.

Sediments become rock (lithified) through a process called *diagenesis.* Diagenesis is controlled by temperature. But instead of the hot igneous or metamorphic rock temperatures, diagenesis takes place at temperatures of around 200°C in sedimentary rock.

KEY IDEA

Diagenesis includes (1) compaction, (2) cementation, (3) recrystallization, and (4) chemical changes (like oxidation and reduction).

During diagenesis, unstable minerals recrystallize into a more stable matrix form or are chemically changed, like organic matter, into coal or hydrocarbons.

Compaction

Lithification through *compaction* is simple. As more and more sediments pile up, weight and pressure increase. The heavier the weight, the more the lower layers are compacted. The sediment's total volume is reduced since it is squeezed into a smaller space and dried. When shale grains are compacted, they align in the same direction, forming rock that splits along a flat plane in the same direction as the parallel grains.

Sediment *cementation* happens when compacted grains stick together. Minerals like calcite, silica, iron oxide, and magnesium cement into a dry, solid mass, becoming rock. Squashed sediments are so tightly ordered they shut out the flow of mineral-containing water and compact.

Sedimentary minerals can also be dissolved from flowing water creating pockets and places for other minerals to collect. Petroleum geologists look for oil in these pockets. When sedimentary minerals dissolve in water and form other compounds, it is called *dolomitization.*

KEY IDEA

Dolomitization happens when limestone turns into dolomite by a mineral substitution of magnesium carbonate for calcium carbonate.

Crystallization and Chemical Properties

Sedimentary rocks are classified by their chemical makeup and properties. Although silica (SiO_2) and phosphorus play a big part in the makeup of sedimentary rock, they are found in small amounts in seawater. When the water evaporates, the ions crystallize to form rock.

TIP

Carbonate sediments come from the biochemical precipitation of the decayed shells of marine organisms. Chemical sediments high in calcium (Ca^{2+}) and bicarbonate (HCO_3^-) precipitate from seawater as calcium carbonate ($CaCO_3$) and carbonic acid (H_2CO_3) by inorganic processes.

Types of Sedimentary Rocks

Unlike igneous rock, most sedimentary rocks have a fine-grained texture. Layered or settled by water or wind, the sedimentary particles are usually small and fine.

Sedimentary rock deposition is also related to size. Fine silt grains are transported by wind, while water current tumbles rocks of larger sizes. The stronger the current, the farther it is carried. Rocks are grouped according to size when flowing in the same current stream.

Clastic

Clastic or *detrital* sedimentary rocks are formed when rocks have been carried to a different spot, weathered, and through pressure from overriding rock take a different form. They have a clastic (broken) texture made up of bigger pieces, like sand or gravel, and are grouped according to grain size. Table 8.1 lists the various clastic particles and their sizes.

KEY IDEA

> *Detritus* is igneous, sedimentary, or metamorphic rock, which has been moved from its original location.

Clastic sedimentary rocks have particles ranging in size from microscopic clay to boulders. Their names are based on clast or grain size with the smallest grains being clay, silt, and sand. *Shale* is a rock made mostly of clay, *siltstone* is made up of silt-sized grains, *sandstone* is made up of sand-sized clasts, and a *conglomerate* is made up of pebbles surrounded by a covering of sand or mud.

Table 8.1 Different sediment types are found in a range of different particle sizes.

SIZE OF PARTICLE (MM)	SEDIMENT	ROCK
<1/256	Clay	Claystone or shale
1/256–1/16	Silt	Siltstone or shale
1/16–2	Sand	Sandstone
2–64	Pebble	Conglomerate or breccia
64–256	Cobble or gravel	Conglomerate or breccia
>256	Boulder	Conglomerate or breccia

Uniform Layer

A sedimentary rock layer made up of particles of about the same size is known as a *uniform layer.* A uniform clastic rock layer has single-sized particles tumbled by a constant-speed current. A uniform bed has single-sized particles, which have experienced different speed water currents and subsequently formed layers at different geological times.

Water, wind, and ice all work together to break down solid rocks into small rocky particles and fragments. These bits of rock are swept away by rain into streams. Gradually these particles get deposited at the bottom of stream beds or in the ocean. As more sediment builds up, it is crushed and compacted into solid rock.

Around 600 million years ago, minerals and microscopic organisms mixed with sediment to form layers. Extreme weight and pressure turned the ocean sediments into sedimentary rock.

Metamorphism

The term *metamorphism* comes from the Greek words, *meta* and *morph,* which mean "to change form." Geologists have found that nearly any rock can undergo metamorphism. When sedimentary and igneous rocks are exposed to extreme pressure and/or heat, they melt and form a denser, compacted *metamorphic rock* deep in the Earth's crust.

KEY IDEA

Metamorphic rocks are formed when rocks originally of one type are changed into a different type by heat and/or pressure.

Metamorphism changes a rock's original chemical and physical conditions. The three main forces responsible for the transformation of different rock types to metamorphic rock are the internal heat from the Earth, the weight of overlying rock, and the horizontal pressures from previously changed rock. Common metamorphic rocks include *slate, schist, gneiss,* and *marble.*

Rock Cycle

The deeper sedimentary layers are buried, the more the temperature rises. Extreme rock weight causes increased pressure and temperature. This heat and pressure cycle, describing the transformation of existing rock, is called the *rock cycle.* It is a constantly changing feedback system of rock formation and melting, which links sedimentary, igneous, and metamorphic rock. Figure 8.2 illustrates how the three rock types feed into a simple rock cycle.

TIP

During weathering, rock is either worn away or shifted from one spot to another. In the course of geological time, rock goes through an entire life cycle or rock cycle. One rock's lifetime might include being blasted out of a volcanic vent to the surface, settling back on the earth as a layer of volcanic ash, being lithified with other sediments into a sedimentary rock layer, and then being pushed down at a subduction zone to be transformed by pressure to metamorphic rock. Should the metamorphosed rock come in contact with a magma chamber or hot spot, it might melt and be shot to the surface. The cycle would be complete or could start all over again.

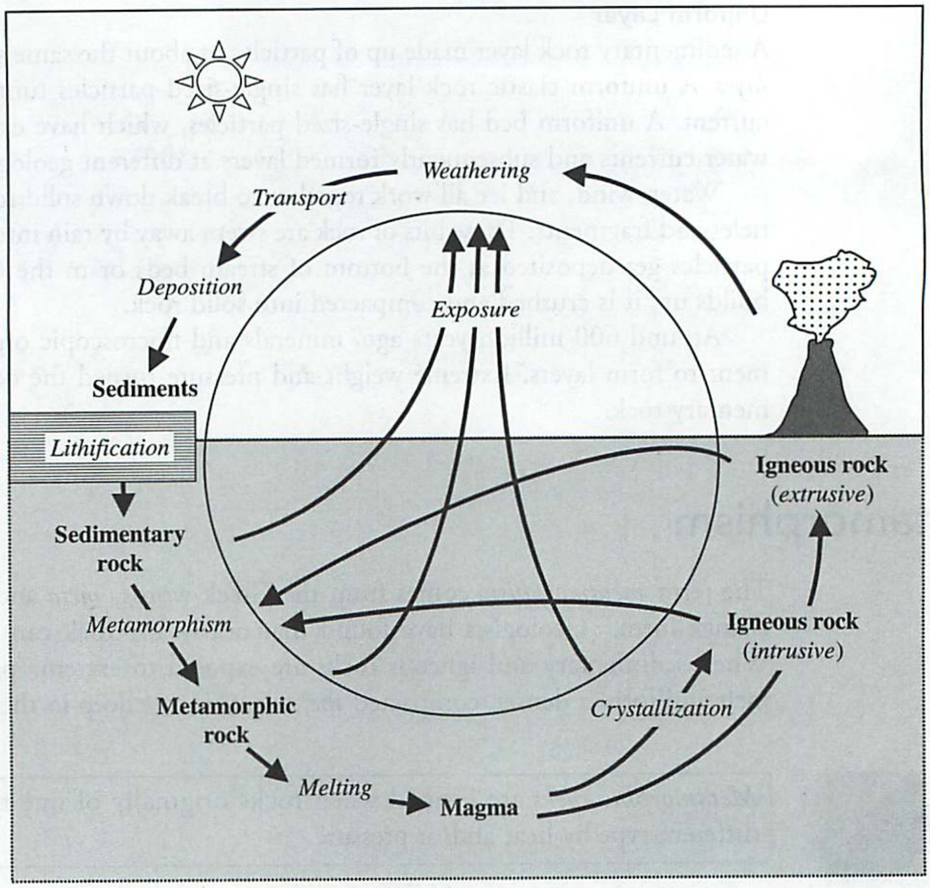

Figure 8.2 Weathering and transport of rock can follow many paths.

Like people, rocks are affected by their environment. We have learned how different rocks form; now let's look closer at the factors that play a part in aging.

Physical Weathering

The activities of physical and mechanical weathering create cracks in rock, which act as channels for air and water to get deeper into a rock's interior. During weathering, rock is constantly being broken into smaller pieces. The associated surface area, exposed to air and water, gets larger.

KEY IDEA

Physical weathering happens when rock gets broken (cracked, crumbled, or smashed) into smaller pieces without a change in its chemical composition.

Physical or mechanical weathering is the breakdown of large rocks into smaller bits that have the same chemical and mineralogical makeup as the original rock. Everyone is familiar with the breakdown of rock into smaller and smaller portions:

Boulders ⇒ pebbles ⇒ sand ⇒ silt ⇒ dust

This size-graded breakdown takes place in different ways. Table 8.2 shows the relationship between rock characteristics and the rate of weathering.

Table 8.2 Rocks weather at different rates depending on their characteristics.

ROCK CHARACTERISTICS	WEATHERING RATE		
Solubility	Low	Medium	High
Structure	Immense	Has weak points	Highly fractured
Rainfall	Low	Medium	High
Temperature	Cold	Moderate	Hot
Soil layer	No soil (bare rock)	Thin to medium	Thick
Organic activity	Negligible	Moderate	Plentiful
Exposure time	Brief	Moderate	Lengthy

Joints

Many rocks are not solid all the way through. They have many different size cracks and fractures, called *joints,* which are caused by stress.

Most jointing occurs in rock as a result of internal and external forces. These include:

- Cooling and shrinking of molten matter
- Flattening and tightening of drying sedimentary strata
- Plate tectonics

Joints are often arranged in sets of vertical parallel lines. The largest, most visible fractures are called *master joints.* Sometimes, multiple sets of joints intersect at nearly right angles and create a joint system made up of crossing vertical and horizontal joints.

In sedimentary rocks, various sets of joints often match planes separating strata. Along with joints, rocks can also fracture between individual crystals or grains. Weathering factors, like wind or water, enter tiny gaps between grains, leading to grain-by-grain disintegration of rocks.

TIP

The two most important forms of physical rock breakdown are *joint block separation* and *granular disintegration.* Rocks break in several different ways. Some of these include:

- Frost
- Salt crystal growth
- Unloading (weight)
- Expansion and contraction due to the change of temperature and wetting-drying cycles
- Chemical weathering
- Biological weathering

Frost

Frost wedging is a type of mechanical weathering (i.e., weathering involving physical rather than chemical change). Frost wedging is caused by the repeated freeze–thaw cycle in extreme climates where water collects in the cracks or joints of rocks.

As the day cools and temperatures drop below freezing at night, the water inside the joints freezes and expands. Within rock fissures, expanding ice puts pressure on cracks until the pressure gets too high and the crack expands. Sometimes, rock splits the first time it expands, but often it takes many freezes and thaws until finally a joint succumbs and cracks.

KEY IDEA

> *Frost wedging* happens when rock is forced apart by the alternate freezing and thawing of water.

Frost action is best seen in wet climates with many freezing and thawing cycles (arctic tundra, mountain peaks). Frost splits rocks into blocks and wears away block edges grain by grain, rounding the surfaces.

Salt Wedging

Most people think of deserts as barren, dry, windy, inhospitable landscapes with circling vultures to keep you company. Everything in a desert environment is *desiccated* (dried out) much of the time and subject to weathering.

TIP

Salt wedging, caused by salt crystal growth, is an important rock-breaking force in the desert. In dry and semi-desert environments, surface water and soil moisture evaporate quickly. When this happens, dissolved salts fall out of solution and crystallize. Growing salt crystals, such as halite (NaCl), calcite ($CaCO_4$), and gypsum ($CaSO_4$), put pressure on the rock. Over time, this pressure wears bedrock away grain by grain.

Unloading

Rocks buried within the crust are under extreme pressure from the weight of overlying rock. Over time, erosion and mass wasting remove upper rock layers, and the pressure on lower rock layers becomes less. When this happens, the internal rock volume expands and the outer rock layers crack away. This shedding of outer layers from internal pressure changes is called *unloading*. It's like a snake that sheds its skin as it grows larger.

KEY IDEA

> *Unloading* happens when there is a release of internal rock pressure from erosion and outer rock layers crack off.

When rock is worn away on the surface, it is called *exfoliation*. Exfoliation occurs when large sheets of rock expand upward and shear away from the primary rock mass forming a dome. The majestic Half Dome in Yosemite Valley, California, is an exfoliation dome.

Chemical Weathering

When mechanical weathering breaks a rock apart, the larger exposed surface allows *chemical weathering* to take place. These chemical and structural changes happen over millions of years. However, human-made industrial pollutants in the air and water have caused some forms of chemical weathering to increase.

KEY IDEA

> When rock and its component minerals are broken down or altered by chemical change, it is known as *chemical weathering*.

Chemical weathering takes place in one of the following ways:

- *Oxidation* = reaction with O_2
- *Hydrolysis* = reaction with H_2O
- *Acid action* = reaction with acid substances (H_2CO_3, H_2CO_4, H_2SO_3)

The most important natural acid is *carbonic acid*, formed when carbon dioxide dissolves in water ($CO_2 + H_2O \leftrightarrow H_2CO_3$). Carbonate sedimentary rocks, like limestone and marble, are extra sensitive to this type of chemical weathering. Gouges and grooves seen in carbonate rock outcrops are examples of chemical weathering.

Acid rain is the result of a chemical reaction between atmospheric chemicals and water. When it falls to Earth, it speeds chemical weathering through a process called *dissolution*. When acid rain comes into contact with limestone, monuments, and gravestones, it dissolves, discolors, and/or disfigures the surface by reacting with the rock's composition. Historical statues and buildings, hundreds to thousands of years old, suffer from chemical weathering, a by-product of industrial pollution.

- *Oxidation* takes place when oxygen anions react with mineral cations to break down and form oxides, such as iron oxide (Fe_2O_3), which softens the original element.
- *Solubility* is the ability of a mineral to dissolve in water. Some minerals dissolve easily in pure water. Others are even more soluble in acidic water. Rainwater combined with carbon dioxide forms carbonic acid ($CO_2 + H_2O = H_2CO_3$) becoming naturally acidic.
- *Hydrolysis* takes place when a water molecule and a mineral react to form a new mineral.
- *Dissolution* occurs when environmental acids like carbonic acid (water), humic acid (soil), and sulfuric acid (acid rain) react with and dissolve mineral anions and cations.

Biological Weathering

Biological weathering is a blend of both physical and chemical weathering. Tree and plant roots grow into rock fissures to reach collected soil and moisture. As they grow, roots get thicker and push deeper into the crack. Eventually, this constant pressure cracks the rock. The more rock is fractured, the easier it cracks. Root growth and burrowing in rock gaps cause rock fractures to open wider and become more exposed to future weathering.

In biological weathering, element and nutrient exchange occurs. Bacteria and algae in cracks and on rock surfaces have acidic processes, which add to chemical weathering. Plants get needed minerals from rock and soil.

Soil Erosion

Erosion converts soil into sediment. Chemical weathering produces clays on which vegetation can grow. A mixture of dead vegetation and clay creates soil that contains minerals plants need for growth.

> *Soil* exists as a layer of broken, unconsolidated rock fragments created over hard, bedrock surfaces by weathering action.

Most geologists classify soil into three layers called *soil horizons* or *soil zones*. These soil horizons are commonly recognized as horizons A, B, and C, but not all three horizons are found in all soils. Figure 8.3 illustrates the way soil horizons are stacked on top of each other.

Soil horizons are described from the top soil layer down to the lowest soil and bedrock level and are as follows:

- *Horizon A* includes the surface horizon, a zone of leaching and oxidation, where penetrating rainwater dissolves minerals and carries the ions to deeper horizons. It also holds the greatest amount of organic matter.

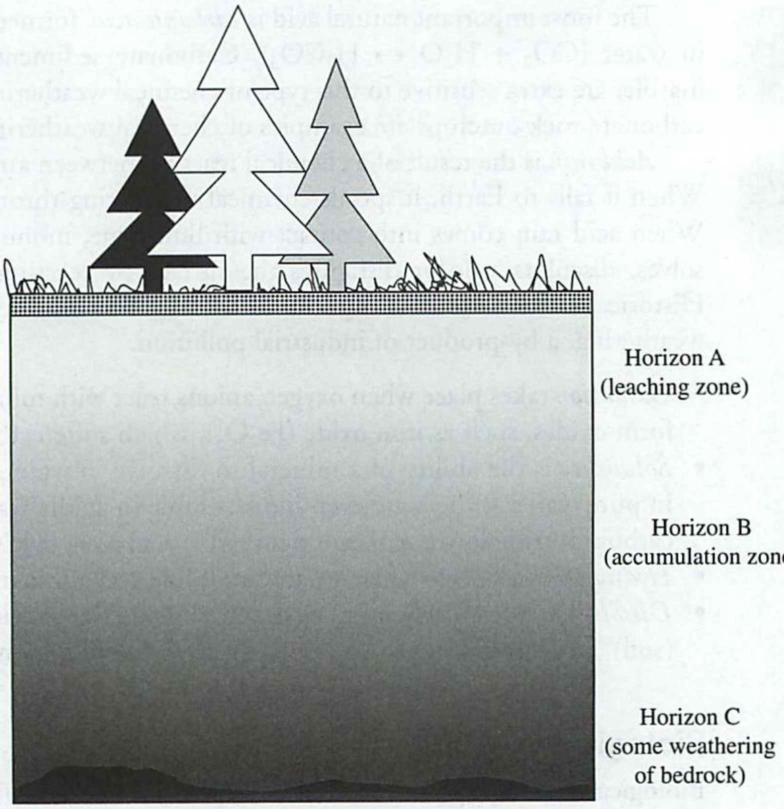

Figure 8.3 Rock can be divided into a gradient of soil horizons with bedrock at the bottom.

- *Horizon B* describes the middle horizon, a zone of accumulation, where ions carried down by infiltrating rainwater are reconnected to create new minerals. Blocky in texture, it is made up of weathered rock mixed with clay, iron, and/or aluminum.
- *Horizon C* includes the bottom horizon, which is a zone of unconsolidated, weathered original rock.

Soil Types

Just as there are three different soil horizons, there are also several factors that affect soil formation. These include structure, rainfall (lots or little), solubility, temperature (hot or cold), slope (gentle or steep), vegetation (types and amount), and weathering time (short or long). Singly or in combination, soils form as a result of many factors. A key factor in naming major soil types is rainfall amount. Everyone from toddlers making mud pies to petroleum geologists looking for oil can tell whether a soil is wet or dry, hard or soft.

TIP

Geologists have named three basic soil types based primarily on water content. These are the *pedocal, pedalfer,* and *laterite.*

Pedocal, found in dry or semi-arid climates with little organic matter, has little to no mineral leaching and is high in lime. Most nutrient ions are still present. In places where water evaporates and calcite precipitates in horizon B, a hard layer called the *caliche* or *hardpan* is formed. Pedocal soil is found in dry climates with little rainfall. It supports mostly prairie plant growth.

Enriched with aluminum and iron, pedalfer soil is found in wetter environments and contains greater amounts of organic matter and leaching. Pedalfer is found in high temperatures and humid climates with lots of forest cover.

Laterite, the soggiest soil type, is found in tropical and subtropical climates and is high in organic matter. Because of heavy rainfall, there is widespread nutrient leaching of iron and aluminum hydroxides, which make laterite soils red.

Soil Conservation

TIP

Topsoil is the nutrient-rich soil layer, millimeters to meters deep, that contains a mixture of organic material and minerals. It is a renewable resource when replenished and cared for properly, but unfortunately billions of acres of land worldwide are bare due to erosion, nutrient depletion, overtillage, and misuse. It has been estimated that over 25 billion tons of soil are lost from cropland annually from wind and water erosion. In fact, roughly one-third of the world's land is at risk of *desertification*. However, there are several soil conservation methods that can help with sustainability including land management, soil enhancement, ground cover, and agricultural tillage methods.

Vegetation

Topsoil can be blown away by the wind or washed away by rainfall increasing erosion. Weakened land may also allow downstream flooding, reduced water quality, increased river and lake sedimentation, and the buildup of silt in reservoirs and navigation channels. It can also be a source of dust storms and air pollution. Wind-blown dust can increase health problems, including allergies, eye infections, and upper respiratory problems.

Topography

Since water runs downhill, it is easy for soil to be carried away during a heavy rainstorm. Slope percentage affects the speed of water's downhill path (e.g., a 5% grade contributes more to soil erosion than a 1% grade).

KEY IDEA

> *Topography* is the mapping of the land contours and physical features of an area.

Farmers have also found that by changing planting and harvesting methods, they protect their land's fertility. *Contour planting* across a hillside instead of up and down slows runoff. When combined with *strip farming*, planting alternating crops in strips across land contours, erosion is slowed further. With one crop in the field holding the soil, the other crop is harvested. Alternating rows hold water longer and let rainfall soak into the ground avoiding runoff.

Terracing is a lot like strip farming, but the land is shaped as well. Level ridges of land are created to hold water and soil in place. Although more expensive and time consuming at first, it allows cultivation on steep grades, while increasing sustainability. In Asia, rice has been cultivated in this way for centuries, taking advantage of all fertile land.

Planting and Tillage

Planting perennial plants is another tool in soil conservation. Plants like coffee and tea, which grow during several seasons, don't have to be harvested yearly and hold the soil longer. Ground cover crops like clover or alfalfa, planted right after initial harvest, also hold and protect the soil from erosion.

Leaving crop remnants in the fields and adding *mulch* cover (e.g., wood chips, manure, straw, leaves, and decomposed organic matter) to crops after harvest holds the soil and adds nutrients.

Plowing or *tillage* often increases soil erosion. Thought to increase nutrients, broad plow tillage was done in the United States for decades. Today, narrow chisel plows leave 75% of crop residue on the surface and open only a thin ridge for seeds. No-till methods pierce seeds through ground cover without opening up a seam in the earth. This keeps soil in place and prevents erosion.

› Review Questions

Multiple-Choice Questions

1. Lithification, comes from the Greek word *lithos*, meaning

(A) stone
(B) light
(C) paper
(D) seawater
(E) white

2. Diagenesis causes

(A) a red rash on the elbow
(B) miscalculations of circular core samples
(C) photosynthesis in most upper ocean layers
(D) lithification of sediment by physical and chemical processes
(E) drought in some areas

3. Which of the following is a common metamorphic rock type?

(A) Subjugate rock
(B) Slate
(C) Vermiculite
(D) Slant
(E) Magma

4. Metamorphic rock is known as a

(A) hard purple-colored rock
(B) surface-only rock
(C) chameleon of rock types
(D) good building material
(E) brittle rock type

5. When several rock–stratigraphic units are stacked vertically, they are called a

(A) metamorphic shelf
(B) gneiss
(C) lithification
(D) vertical unit
(E) formation

6. When rock on the Earth's surface is worn away, it is called

(A) foliation
(B) metamorphism
(C) exfoliation
(D) sedimentation
(E) coloration

7. Clastic sedimentary rocks are made up of

(A) pieces of other rocks
(B) gelatin from kelp
(C) the hardest granites
(D) boulders larger than 1 meter across
(E) petroleum distillates

8. Which of the following plays a big part in soil erosion?

(A) Fertilizer
(B) Conservation
(C) Tillage
(D) Plant type
(E) Rainfall

9. Which process wears away existing rocks and produces lots of small rock?

(A) Lithification
(B) Sedimentation
(C) Compaction
(D) Weathering
(E) Concretion

10. Salt wedging, caused by the growth of salt crystals, is an important rock-breaking force in the

(A) rain forest
(B) mountains
(C) ocean
(D) plains
(E) desert

11. The following are all tools in soil conservation except for

(A) cover crops
(B) deforestation
(C) planting of perennial plants
(D) adding mulch
(E) crop rotation

12. Which metamorphic rock is often used as a paving and building stone?

(A) Mica
(B) Marble
(C) Shale
(D) Sandstone
(E) Obsidian

13. Felsic and mafic are two types of

(A) metamorphic rock
(B) *clastic* formations
(C) sedimentary rock
(D) igneous rock
(E) multicolored clays

14. What percentage of the world's land is at risk of desertification?

(A) 10%
(B) 20%
(C) 30%
(D) 40%
(E) 50%

15. Pebbles surrounded by a covering of sand or mud is known as

(A) a conglomerate
(B) shale
(C) granite
(D) magma
(E) igneous clay

16. The description of an area's land contours and surface features is called

(A) geography
(B) cartography
(C) graphology
(D) topography
(E) photography

17. Pedocal, pedalfer, and laterite are three basic soil types based primarily on

(A) elevation
(B) soil type
(C) water content
(D) mineral base
(E) climate

18. Which soil horizon consists of a zone of accumulation, where ions transported by rainwater are reconnected to create new minerals?

(A) Horizon A
(B) Horizon B
(C) Horizon C
(D) Ions are not transported this way
(E) Mineralization occurs only in the topsoil

› Answers and Explanations

1. A

2. D—Diagenesis is controlled by temperature and takes place at temperatures around 200°C in sedimentary rock.

3. B—Other metamorphic rock types include schist, gneiss, and marble.

4. C—Internal heat from the Earth, overlying rock weight, and horizontal pressures from previously changed rock cause metamorphic rock changes.

5. E—This layering can easily be seen in the Grand Canyon.

6. C—It describes how atoms and layers are peeled away very slowly.

7. A—These are formed from rocks carried from a different spot, weathered, and turned into new rocks.

8. C—Breaking up large amounts of soil by tilling the land allows particles to erode.

9. D

10. E—When water evaporates, salt remains and slowly increases.

11. B—Removing trees often involves disturbing the soil as well.

12. B

13. D—Felsic rock has high levels of silica, and mafic rock has high levels of magnesium and iron (ferric) minerals.

14. C

15. A—This type has a mixed bumpy texture.

16. D—A topographical map shows specific features like rivers, canyons, and mountains.

17. C—They are found in various climates with different rainfall amounts.

18. B—Horizon A (surface horizon) is a zone of leaching and oxidation, while horizon C (bottom horizon) is a zone of unconsolidated, weathered original rock.

Free-Response Questions

1. A heat and pressure gradient promotes metamorphism in a graded way depending on depth. The deeper you go, the hotter the temperature and pressure, the greater the metamorphic changes. Depending on the conditions under which rock is changed, the rock gradient forms either high-grade or low-grade metamorphic rock.

$\uparrow$ Temperature and $\uparrow$ pressure $\Rightarrow$ high-grade metamorphic rock

$\downarrow$ Temperature and $\downarrow$ pressure $\Rightarrow$ low-grade metamorphic rock

Rock's crystalline structure changes as it adjusts to new temperatures and pressures. Ions are energized, breaking their chemical bonds and creating new mineral linkages and forms. Sometimes, crystals grow larger than those in the original rock. New minerals are created by the rearrangement of chemical bonds or reactions with fluids entering the rock.

(a) What role does metamorphism play in the rock cycle?
(b) Explain the correlation between pressure and depth.
(c) Are greater metamorphic changes likelier to occur at a depth of 170 km or 1,700 km in the Earth's crust?
(d) Give an example of each of the following rock types: sedimentary, igneous, and metamorphic. How do they differ?

Free-Response Answers and Explanations

1.
   a. Metamorphism is one process by which rocks undergo transition within the rock cycle. It occurs when rocks undergo changes due to the application of heat and pressure. Metamorphic rocks are created when igneous or sedimentary rocks undergo recrystallization due to extreme temperature and pressure changes.
   b. Greater depths produce greater pressure due to the gradual accumulation of weight at greater depths.
   c. Changes are more likely at 1,700 km due to greater temperature and pressure.
   d. Sedimentary: sandstone; metamorphic: slate; igneous: sand. The effects of heat and pressure from the three processes in the rock cycle cause differences in color and texture.

❯ Rapid Review

- Topography is the mapping of an area's land contours and physical features.
- When rock units are stacked vertically, they create a formation in the geological record.
- The three main rock types are sedimentary, igneous, and metamorphic.
- The pedocal is found in dry or semi-arid climates where there is little organic matter, little to no leaching of minerals, and a high lime content.
- Lithology is the study of the physical characteristics of a rock through visual recording or with a low-power microscope or handheld magnifying glass.
- Lithified soil is made up of sand, silt, and organic organisms.
- Physical weathering occurs when rock gets broken into smaller pieces without a change in its chemical composition.
- Sedimentary rock is formed from rocks and soils from other locations that are compressed with the remains of dead organisms.
- Metamorphic rocks are formed when rocks originally of one type are changed into a different type by heat and/or pressure.
- Diagenesis includes (1) compaction, (2) cementation, (3) recrystallization, and (4) chemical changes (e.g., oxidation/reduction).
- Igneous rock is formed by the cooling and hardening of molten rock (magma), deep in the Earth or blasted out during an eruption.
- Igneous rock is divided into two main types: felsic and mafic.
- Felsic rock has high levels of silica-containing minerals (e.g., quartz and granite).
- Mafic rock has high levels of magnesium and iron (ferric) minerals.
- An individual band with its own specific characteristics and position is called a rock–stratigraphic unit or rock unit.
- Grain size and color are the two main ways that geologists describe rock textures.
- Acid rain is a chemical reaction that speeds up chemical weathering.
- The most important natural acid is carbonic acid, formed when carbon dioxide dissolves in water ($CO_2 + H_2O \leftrightarrow H_2CO_3$). It is a big part of acid rain.
- Frost wedging happens when rock is pushed apart by the alternate freezing and thawing of water in cracks.
- Salt wedging, caused by salt crystal growth, is an important rock-breaking force in the desert.
- Unloading happens when there is a release of internal rock pressure from erosion and the outer layers of a rock are shed.
- Turning soil over by the plow or tillage often increases soil erosion.
- Dolomitization happens when limestone turns into dolomite by a mineral substitution of magnesium carbonate for calcium carbonate.