Weathering & Soils

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While the farmer holds title to the land, actually, it belongs to all of the people because civilization itself rests upon the soil.

Thomas Jefferson

When the soil is gone, men must go; and the process does not take long.

Theodore Roosevelt

If soil conservation cannot be made to work effectively in the United States, with all the advantages of research, extension, and conservation services, plus wealthy, educated farmers on good land with gentle climates - if with all these benefits conservation is not successful - then what hope is there for struggling countries that have few if none, of these advantages?

Norman W. Hudson
Introduction

- Weathering breaks down and alters rocks and minerals at or near Earth's surface and is divided into physical weathering and chemical weathering.
- The products of weathering combine with organic material to form the soils that yield the food that sustains us, the timber that shelters us, and the fibers that clothe us.

As human beings we wage a constant battle against a silent foe, weathering, the decomposition and disintegration of features at Earth's surface. Although it has little of the power and glory of volcanoes or earthquakes, weathering acts on all features at or near Earth's surface, modifies the landscape around us, and generates perhaps our most essential resource, soil. This chapter is divided into two parts. The first describes weathering; the second examines soils.

Weathering can be subdivided into two types: physical and chemical, and these are described in the first sections of the chapter. We can see the effects of both in our daily lives. Physical weathering is the disintegration of rocks and minerals into smaller pieces. We experience physical weathering firsthand as the potholes that form on paved streets of northern states during winter. Chemical weathering is the decomposition of materials by a series of chemical reactions that result in the rust on our cars or the corrosion or staining of building facades. Sometimes these effects are welcome. The aging of historical buildings from Greece's Parthenon to San Antonio's Alamo, contributes to the character and dignity of ancient structures. Today, a special high-strength weathering

Figure 1. New River Gorge bridge, West Virginia, the world's longest single-arch steel-span bridge. The bridge rises 265 meters above the river below, making it the second highest bridge in the U.S. Cor-Ten steel used to construct the bridge has weathered to a rust color and doesn't require painting.
steel is often used on exterior structures. The steel generates a patina of rust that prevents further corrosion and thus protects the structure (Fig. 1).

Emigrants forging westward on the Oregon Trail in the 1840s measured their progress against a series of landmarks formed by weathering (Fig. 2). Beginning with the spire of Chimney Rock in western Nebraska travelers continued west to carve their names in the soft sandstone of Register Cliff near Fort Laramie in eastern Wyoming. To the west, the rounded granite dome of Independence Rock provided a site for so many inscriptions that it was dubbed the Register in the Desert. Further on, the V-shaped notch in the crest of Split Mountain stayed in view to the north of the trail for several days. The slow rate of geologic weathering processes in the dry climate of the western plains ensures that these natural landforms look the same today as they did when the first emigrants passed them over 150 years ago; however, the inscriptions these early travelers left behind are slowly fading from the rocks. The third section of this chapter considers the factors that control weathering rates.

The second half of the chapter takes a closer look at soil. Soil is that portion of the regolith that supports plant life and includes organic material, water, and air. The quantity and quality of soil resources depend on natural factors (parent material, weathering rates, organic activity) and human activity.

We devote a separate section to soil erosion, a persistent threat to U.S. agriculture for centuries. By the 1700s, the negative consequences of early farming techniques were becoming apparent in the abandoned fields of eastern states. George Washington experimented with soil conservation strategies in 1769 and Thomas Jefferson lamented poor farmers who “... run away to Alabama, as so many of our countrymen are doing, who find it easier to resolve on quitting their country,
than to change the practices in husbandry to which they have been brought up”.

Soil is effectively a non-renewable resource as erosion occurs at rates that may outpace soil formation. Artificial soil formation is impractical, so we have little choice but to conserve the soil we have to ensure a continued supply of agricultural products. The final section of the chapter describes modern soil conservation methods that don’t differ markedly from those used by George Washington. Techniques such as deep plowing, crop rotation, and the application of artificial fertilizers, were adopted to improve depleted soils by the end of the eighteenth century. Many of these soil conservation techniques are supported by government programs that idle lands covered by potentially erodible soils.

Physical Weathering

- Physical weathering represents the disintegration of rocks and minerals into smaller pieces.
- Pressure release cracks are formed in rocks as a result of unloading following the erosion of overlying material.
- Wedging causes the expansion of cracks in rocks following the freezing of water, growth of salt crystals, or growth of plants.

Physical weathering represents the disintegration of rocks and minerals into smaller pieces. Physical weathering can be further subdivided into pressure release and wedging.

Pressure Release

Rocks below Earth surface support the weight of the overlying column of rock. Erosion strips away this overlying rock and decreases pressure on the buried rocks. All rocks are slightly elastic, so the buried rocks respond to the reduction of pressure by expanding upward. This results in the formation of pressure release fractures (cracks) that form parallel to the surface (Fig. 3). With continued erosion, these rocks are exposed on the surface and slabs of rock break off along the pressure release fractures. This weathering creates bare rock surfaces
that may be more resistant than surrounding rocks (Fig. 3). These features are termed **exfoliation domes**; the slabs of rock that break off are termed exfoliation sheets.

Wedging

Wedging occurs as the result of the expansion of water as it is converted to ice, the growth of salt crystals, or the growth of plants. Cracks filled with water are forced further apart when temperatures drop below freezing. Water has the unusual characteristic of increasing its volume on freezing by about 9%. This process, termed **ice wedging**, requires a range of temperatures to generate alternating freeze-thaw activity. Wedging breaks off angular slabs or blocks of rock (Fig. 4) that subsequently tumble downslope.

A similar result is achieved by the growth of salt crystals in fractures or pore spaces in rocks. The growth of plants that take seed in small cracks in rocks results in tree roots that force the rocks apart (Fig. 4).
Both pressure release and wedging break up rocks and minerals, creating more surface area for chemical weathering. Chemical weathering attacks the surfaces of rocks (and cars and buildings) and is accelerated by increasing the available surface area.

Figure 5. Physical weathering breaks rocks down into smaller pieces thus increasing the surface area over which chemical weathering can occur. The total surface area of the block above is doubled by physical weathering.

Chemical Weathering

- Chemical weathering represents the decomposition of rock by the chemical breakdown of minerals.
- Dissolution occurs when rocks and minerals are dissolved by water.
- Hydrolysis occurs when minerals react with water to form other products.
- Oxidation occurs when oxygen reacts with iron-rich minerals to form iron oxide minerals.

Chemical weathering represents the decomposition of rock by the chemical breakdown of minerals. A variety of chemical reactions result in changes in rock composition, typically replacing strong minerals with weaker minerals, thus hastening the breakdown of the rock. The three common chemical reactions associated with chemical weathering are dissolution, hydrolysis, and oxidation.
Dissolution

Dissolution occurs when rocks and/or minerals are dissolved by water (Fig. 6). The dissolved material is transported away leaving a space in the rock. One consequence of this process is the formation of caves in limestone areas (Fig. 7).

\[
\text{rain} + \text{carbon dioxide} \rightarrow \text{carbonic acid} \\
\text{from air} \quad \text{reacts with rocks} \\
\text{H}_2\text{O} + \text{CO}_2 \rightarrow \text{H}_2\text{CO}_3
\]

Carbon dioxide (CO$_2$) from the air is dissolved in rainwater to create a weak acid, **carbonic acid** (H$_2$CO$_3$), that preferentially dissolves certain rocks and minerals, e.g., limestone, marble. All rain is mildly acidic (average pH ~5.6) but the pH decreases significantly with the addition of pollutants generated from the burning of fossil fuels. This more acidic solution is termed **acid rain** and typically occurs downwind from large industrial cities or from coal-burning power plants.

**Caves** form when dissolution occurs along a series of fractures in limestone to create a larger opening (Fig. 7). Water passing through the rock enlarges the cave and associated re-precipitation can form a variety of features. The dissolved **limestone** is transported through the cave and may be precipitated to form new features such as stalactites that grow downward from the cave ceiling and stalagmites that grow up from the floor. If they meet they form a compound cave formation such as a column.

Figure 6. Facial features and other details of this marble statue were worn away by dissolution. Image courtesy of Dr. Annabelle Foos.

Figure 7. Crystal Ball Cave, Utah. Features hanging down from the ceiling are stalactites. Pillar-like features on the cave floor are stalagmites. Both stalagmites and stalactites are formed from the precipitation of limestone within the cave. Image courtesy of Dr. Ira Sasowsky.
Not all the products of dissolution are below ground. **Sinkholes** form at the surface from the collapse of the roof of an underlying cavern or by dissolution of rock along a series of fracture surfaces (Fig. 8).

![Figure 8. A sinkhole, (Watlings Blue Hole) in the Bahamas. Road at bottom left of image for scale. Image courtesy of Dr. Ira Sasowsky.](image)

**Hydrolysis**

Hydrolysis occurs when primary minerals react with water to form other products. **Hydrogen ions** (H+) in the water replace other ions in the minerals. More hydrogen ions will result in more rapid chemical weathering.

**pH** is a measure of how many hydrogen ions are present. There is an inverse relationship between pH and the concentration of hydrogen ions. The more hydrogen ions, the lower the pH value. Pure water is considered neutral with a pH 7; acidic solutions have pH values that range from pH 0 to pH 7; alkaline solutions have higher pH values (pH 7-14). pH is measured on a logarithmic scale (like the Richter scale for earthquakes) so for each increment on the scale there is a 10-times increase/decrease in the concentration of hydrogen ions per liter of solution.

\[
\text{carbonic acid} \rightarrow \text{hydrogen ion} + \text{bicarbonate ion} \\
H_2CO_3 \rightarrow H^+ + HCO_3^{-1}
\]

**Carbonic acid** ionizes (breaks down) into two ions, hydrogen (H+) and bicarbonate (HCO_3^{-1}). Feldspar, the most common mineral in rocks on the earth's surface, reacts with water and the free hydrogen ions to form a **secondary mineral** such as kaolinite (a type of clay) and additional ions that are dissolved in water. The weaker clay is readily worn away by physical weathering. Hydrolysis is more rapid in silicate minerals characterized by well-developed cleavage (e.g., feldspar, pyroxene, amphibole) and is less effective in quartz which
doesn't exhibit cleavage (see Minerals section of chapter, Rocks and Minerals, for information on cleavage).

**Reaction:**

\[
\text{feldspar} + \text{hydrogen ions + water} \rightarrow \text{clay + dissolved ions}
\]

\[
4\text{KAlSi}_3\text{O}_8 + 4\text{H}^+ + 2\text{H}_2\text{O} \rightarrow \text{Al}_4\text{Si}_4\text{O}_{10}(\text{OH})_8 + 8\text{SiO}_2
\]

**Oxidation**

Oxidation occurs when oxygen, the second most common element in the air we breathe, reacts with iron in minerals to form iron oxide minerals, e.g., hematite (rust), that give rocks a red or yellow coloration (Fig. 9). Because many minerals contain iron, it is not unusual to see red-colored rocks. A minute concentration of iron is necessary to change the rock color. All forms of chemical weathering tend to promote the decomposition of minerals in rocks to a less resistant form. Working in concert, physical and chemical weathering can reduce a once-resistant rock to nothing (dissolved limestone) or to easily eroded weaker materials (clays).

**Weathering Rates**

- Rock type, structure, and climate primarily control weathering rates.
- Rocks composed of quartz may be more resistant to weathering than rocks made up of less-resistant minerals.
- Weathering rates will be increased in rocks with high permeability and porosity.
- The presence of structures such as bedding planes and fractures increase weathering rates.
- Warm temperatures, a plentiful supply of water, and a temperature range that fluctuates about freezing increase weathering rates.

**Rock type**, structure, and climate primarily control weathering rates. Rocks composed of minerals that are relatively
unaffected by chemical weathering will be the most resistant to weathering. For example, quartz is rarely affected by dissolution, hydrolysis, and oxidation, therefore, rocks composed almost exclusively of the mineral quartz will break down more slowly than other common rock types. Sand on a beach is made up almost completely of quartz grains because chemical weathering alters less-resistant feldspar minerals and the resulting clays are deposited elsewhere by streams or shoreline currents.

Weathering is promoted where minerals are exposed to water and air. Rock weathering therefore is strongly influenced by porosity and permeability because these properties control the passage of water through rocks. The majority of grains in a high-porosity and high-permeability rock may be exposed to weathering thus accelerating the decomposition of the rock. In contrast, weathering will only occur on the surface or along fractures in rocks with low permeability. Highly porous rocks may be susceptible to ice wedging in cold climates or salt cracking in arid environments. (See Rock Properties section of chapter, Groundwater and Wetlands, for more on porosity and permeability.)

Rock structures such as bedding planes and fractures represent natural surfaces for physical and chemical weathering processes (Fig. 10). Almost all rocks have some naturally occurring fracture systems. These surfaces act as passageways for water that promotes chemical weathering or may freeze to cause ice wedging. Consequently, sedimentary rocks and any rocks that contain abundant fractures are typically weathered more rapidly than equivalent unfractured rocks. Weathering in limestones may exaggerate openings along fractures or bedding surfaces to form cave systems.
Climate is a third important factor in weathering rates (Fig. 11). Warm temperatures and a plentiful supply of water are necessary for chemical weathering. The amount of precipitation, differences between precipitation and evaporation, and the contrast between infiltration and runoff will all contribute to the availability of water. Total precipitation on its own is a poor guide to weathering potential. Plentiful rainfall coupled with low evaporation and easy infiltration will promote weathering. Low precipitation or evaporation that exceeds precipitation will reduce the volume of water available for weathering as will rapid runoff. Water will move through rock systems and remove weathering products where precipitation exceeds evaporation. In contrast, where evaporation exceeds precipitation there is upward movement of water and weathered materials are not removed from the rocks.

High temperatures promote chemical reactions and a temperature range that varies between freezing and thawing conditions are essential for ice wedging. Areas with low temperatures will have relatively slow rates of chemical weathering. The locations below are keyed to the map in Figure 11.

1. Tropical rainforest (equatorial regions including South America, Africa, Indonesia, southeast Asia). Chemical weathering rates would be rapid because these regions have both high temperatures and plenty of rainfall.

2. Hot desert (subtropical regions including North Africa, southwest South America, southwest Africa, central Asia, southwestern U.S., central Australia). Plenty of heat but insufficient water to cause significant physical and/or chemical weathering.

3. Temperate mountains (Rocky Mountains, Sierra Nevada Mountains, Alps, Andes Mountains). Insufficient temperatures for rapid chemical weathering but elevations contribute to freeze-thaw cycles necessary for ice wedging.
4. **Polar regions** (Alaska, Antarctica, Siberia). Too much cold weather to permit thawing for much of the year. Water in solid form (ice) is unable to react with rock.

**Think about it . . .**
During a study of weathering, a scientist examines two tombstones marking graves in separate cemeteries. The inscription on one tombstone is almost unreadable whereas the inscription on the other is sharp and clear. Provide three potential explanations to account for the differences in the present character of the inscriptions.

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**Soils: An Introduction**

- Soil is regolith that supports plant life and includes organic material, water and air.
- Organic activity, leaching, precipitation, eluviation, and illuviation result in the stratification of soil into a soil profile.
- Soil thickness increases with the rate of weathering.
- Pedalfers form in wet climates and are characterized by extensive leaching of ions from the A horizon.
- Pedocals are characteristic of warm, dry climates where evaporation exceeds precipitation.

**Regolith** is composed of rock and mineral fragments produced by weathering. If this material is transported by wind, water, or ice it is termed sediment. **Soil** is regolith that supports plant life and includes organic material, water, and air (Fig. 12).
Soil formation is dependent upon weathering and three additional processes - organic activity, leaching and precipitation, eluviation and illuviation - that stratify the soil column into distinct horizons (Fig. 13). Organic activity results in the accumulation of plant and animal material, the mixing of this material in the uppermost soil layer through burrowing of animals, and the sorting of soil materials by the action of organisms such as termites, ants, and worms. Leaching dissolves ions that are transported downward to be deposited in lower horizons by precipitation. Eluviation represents the physical transport of fine (clay) particles downward in groundwater and illuviation is the accumulation of these particles below.

Weathering rate controls soil thickness. Bare rock surfaces will take thousands of years to develop even thin soils in cold climates (e.g., Alaska), whereas soils will develop relatively rapidly on regolith in warm, wet climates. Soil is absent on bare rock surfaces in northern Canada that were scraped clean by glaciers thousands of years ago. In contrast, soils are up to one meter (3 feet) thick in the temperate Midwest where soil formation occurs at rates of approximately 1 mm per 10 years. The thickest soils may be over 30 meters deep in tropical regions with warm temperatures and plentiful rainfall. Unfortunately, soil erosion outpaces soil formation in much of the U.S.

Soil Profile

Soil can be divided into a series of distinct horizontal layers (soil horizons) that collectively are termed a soil profile (Fig. 13). Each horizon is designated by a letter. Beginning at the top the horizons and the processes that are active in them include the following;

**O horizon**: Organic debris, dead leaves, and other plant and animal remains.

**A horizon**: Topsoil, dark organic material mixed with mineral grains by organic activity. Soluble ions and fine particles are carried downward (leaching and eluviation) from the A horizon to the B horizon.

**B horizon**: Dissolved ions are precipitated in B horizon. Clays wash down to from the A horizon. Little organic material is present at this depth. The accumulation of iron oxide will give
the soil a red color, forming a pedafer soil. Accumulation of calcium carbonate will form a white layer creating a pedocal soil.

**C horizon**: Soil parent material, composed of either weathered bedrock or unconsolidated sediment.

### Soil Types

Soil scientists have identified thousands of soil types. Pedalfers and pedocals are simple designations given to soils on the basis of climate. **Pedafier**-type soils are common in the wetter regions of the U.S whereas **pedocals** are characteristic of dry climates (Fig. 14).

The relatively abundant precipitation in the eastern U.S. results in soluble ions being leached from the A and B horizons in **pedafer** soils (Figs. 14, 15). Less-soluble ions (iron, aluminum) remain behind in the B horizon. All soluble ions are removed from the soil in tropical climates characterized by heavy rainfall. These soils represent an extreme form of pedafer soils termed **laterite**. The concentration of aluminum in the B horizon produces an economic ore (bauxite). The character of the bedrock may overwhelm the impact of climate. For example, areas underlain by limestone would contain little iron or aluminum characteristic of pedafer soils.

**Figure 14.** Distribution of basic soil types in the U.S. Areas to the east of the blue line receive more than 30 inches of rain per year; areas to the west (except in the northwest and mountainous regions) receive less.

**Figure 15.** Idealized soil profiles for pedocals developed in arid environments, and pedalfers, characteristic of more humid climates. O horizon is absent in arid climates. The soil profile is thicker in humid environments.
In contrast, in dry regions calcium ions (Ca\(^{2+}\)) are leached as water passes downward through the A horizon of pedocal soils (Fig. 15). If evaporation exceeds precipitation the water is drawn back to the surface. Ions dissolved in the water are precipitated in the B horizon where they combine with carbonate ions (CO\(_3^{2-}\)) to form a hard layer of calcium carbonate (limestone) termed caliche.

**Think about it . . .**
1. Examine four images of different soils found at the end of the chapter and match them with the descriptions of soil orders.
2. Read the descriptions of the 12 USDA soil orders located at the end of the chapter and identify orders that are influenced by climate. Divide those orders into pedalfers or pedocals. Which order would include laterites?

**Soil Erosion**

- Soil is a renewable resource but is often depleted by soil erosion faster than it can be formed.
- Soil formation exceeds soil erosion in forested lands but lags far behind erosion in much of U.S. croplands.
- Soil erosion occurs because of the actions of wind and water.
- Wind erosion is greatest in Great Plains states with dry climates.
- Water erosion is most rapid in Great Lakes and southeastern states.
- Soil erosion occurs as a result of poor farming practices, deforestation, and construction.

Soil is a **renewable resource** that should be replenished constantly under ideal conditions. However, poor management has resulted in widespread soil erosion in the U.S. and around the world. Soil erosion rates are variable depending upon land use practices (Fig. 16) and climate. The highest erosion rates
are in Africa, South America, and Asia, the lowest are in Europe and North America. Average soil erosion from 1 hectare (2.5 acres) of U.S. cropland is ~17 tons per year. Rates are less for pasturelands (6 tons per year per hectare), and are practically non-existent for woodlands. In contrast, the average soil formation rate is 1 ton per hectare per year.

The economic cost of soil erosion in the U.S. has been estimated as $44 billion a year. This includes the cost of fertilizers to replace soil nutrients lost to erosion, energy used to spread additional fertilizers and replace water lost by erosion, sedimentation in waterways that have to be dredged to allow navigation, and property damage from the sand-blasting effect of wind erosion.
Wind vs. Water Erosion

Soil erosion continues to reduce the area of land available for cultivation and to flush sediment to stream systems (Fig. 17). The 100 cm (40 inches) per year rainfall line (isohyet) approximately separates those areas of the central U.S. affected by water erosion from the regions suffering from wind erosion (Fig. 18). Wind erosion occurs most frequently in the Great Plains states stretching from North Dakota and Montana southward to Texas. Wind erosion occurs preferentially in this area because it is favored by consistently strong winds and relatively dry climate. Wind erosion in west Texas may account for ~15 tons of soil per acre per year (Fig. 17).

The Dust Bowl represented the most dramatic example of soil erosion in U.S. history. Reporter Robert Geiger introduced the term into the national lexicon on April 15, 1935; “Three little words, achingly familiar on a western farmer’s tongue, rule life in the dust bowl of the continent - if it rains.” Geiger’s article followed Black Sunday, when huge dust clouds darkened the skies across the southern Great Plains (western Kansas, Oklahoma, north Texas, eastern Colorado; Fig. 19). Farmers throughout the Great Plains had converted native
grasslands to wheat fields after a series of wetter-than-average years and bountiful harvests in the late 1920s. An estimated 12 centimeters (5 inches) of topsoil were lost from 4 million hectares within the Dust Bowl region (total area was 24 million hectares) when the rains failed. The effects of the Great Depression exaggerated the cultural impact of the Dust Bowl.

The Dust Bowl provides a vivid but false perception of the nature of U.S. soil erosion. The bulk of current soil erosion occurs because of the effects of running water (Figs. 18, 20) in southeastern states and the region around the Great Lakes. Wind erosion has a greatest in the Great Plains states. Erosion due to the effects of running water occurs as non-channeled sheet erosion or as rill or gully erosion where runoff preferentially erodes channels. Rills are small channels; gullies are large channels that can't be plowed over.

Causes of Soil Erosion

Soil erosion is accelerated by human activities that leave the soil uncovered including poor farming practices, deforestation, and construction.

**Poor farming practices**
Farming practices may lead to soil erosion if they leave the soil bare where it is at the mercy of sun (drying) and wind (erosion).

- Exposing bare soil to wind and rainfall increases soil erosion. For example, one windstorm during the Dust Bowl removed 300 million tons of topsoil. Several crops, e.g., corn, have traditionally grown in rows with bare ground in-between, exposing soil to erosive agents.
- Plowing parallel to the slope of the land creates furrows that act as channels for runoff thus enhancing soil erosion.
Even dirt roads that parallel the slope of the land may concentrate runoff and promote soil erosion.

- Overgrazing by domestic animals (or wildlife) strips away protective vegetation to expose soils. Approximately a third of all worldwide soil erosion is due to overgrazing. Overgrazing in the Sahel region on the southern edge of the Sahara Desert of north Africa has stripped away vegetation and allowed the desert to encroach southward.

**Deforestation**
The destruction of forests to provide land for subsistence agriculture is an ongoing problem through much of the tropics. Poverty drives many families to convert marginal lands to croplands. Erosion follows the removal of the protective forest canopy. The soil is degraded even faster after a few years when the land is abandoned as nutrients are depleted. Massive flooding in China in the summer of 1998 was exaggerated by earlier deforestation that infilled stream channels with silt washed down from logged hillsides.

**Construction**
Soil erosion in urban settings occurs as vegetation cover is removed during construction projects. Erosion is more significant on slopes. Problems of urban soil erosion are becoming more evident as natural and cultivated lands are increasingly lost to expanding development. Most development occurs in midwestern and southeastern states (Fig. 21).

Figure 21. Cropland lost to development in conterminous U.S. per NRCS regions. Circles represent area of developed cropland each year. Over two-thirds of cropland is lost to residential development.
Soil Conservation

- Modern soil conservation methods involve covering soil to prevent erosion, constructing shelter belts, supplying crops with sufficient nutrients, and diminishing runoff on slopes.
- The U.S. government has attempted to encourage soil conservation through programs such as the National Grasslands, Soil Bank, and Conservation Reserve Program.
- U.S. soil erosion decreased by 22% during the first 10-years of the Conservation Reserve Program.

Soil is effectively a non-renewable resource because erosion occurs at rates that outpace soil formation. Artificial soil formation is impractical, so we have little choice but to conserve the soil we have to ensure a continued supply of agricultural products. Modern soil conservation methods don’t differ markedly from those George Washington used, the basic ideas remain the same:

1. **Keep soil covered** to prevent erosion by leaving crop debris on fields;

2. **Provide shelter** for fields exposed to prevailing winds by planting belts of trees (shelter belts) to break winds;

3. Ensure that a steady **supply of nutrients** is available by returning organic matter to soil, adding artificial fertilizers, or rotating crops with different needs;

4. Reduce soil lost to surface runoff by limiting the effects of slopes through contour plowing (plowing across the slope) and/or terracing. Collectively, these methods are known as **conservation tillage** (Fig. 22).

The U.S. government has created several programs that either bought or managed farmlands with potential for soil erosion. The **National Grasslands** began life as marginal farmlands in the Great Plains that were then purchased by the government during the 1930s. The **Soil Bank**, created as part of the 1956 Agricultural Act, paid farmers to idle land for up to 15 years, and to make improvements that aided conservation. Unfortunately, much of this land was returned to production when contracts expired in the 1970s and export markets expanded.
The Conservation Reserve Program (CRP) was begun as part of the 1985 farm bill. The CRP pays farmers not to cultivate potentially erodible farmland.

Farmers enroll in a 10-year program; at the end of this period the land can be returned to cultivation but owners must implement approved conservation measures if they intend to raise crops. Most of the contracts were issued to farmers in the Great Plains states (Fig. 23). Texas and North Dakota ranked first and second, respectively, in CRP acreage. Soil erosion decreased by 90% on CRP lands, reducing U.S. soil erosion by 22%. Contracts expired for two-thirds of the land under the CRP by the end of 1997. The latest version of the CRP, approved in 1996, restricts the number of farms that are eligible to those with significant erosion problems.
Summary

1. What is weathering?
Weathering breaks down and alters rocks and minerals at or near Earth's surface and is divided into physical weathering and chemical weathering. Physical weathering is the disintegration of rocks and minerals into smaller pieces. Chemical weathering is the decomposition of materials by a series of chemical reactions. Weathering can produce a thick mantle of unconsolidated material on slopes that may fail as a result of human activity or natural processes. The products of weathering combine with organic material to form the soils that yield the food that sustains us, the timber that shelters us, and the fibers that clothe us.

2. How does physical weathering occur?
Physical weathering represents the disintegration of rocks and minerals into smaller pieces. Physical weathering can be further subdivided into pressure release and wedging. Pressure release cracks are formed in rocks as a result of unloading following the erosion of overlying material. Wedging causes the expansion of cracks in rocks following the freezing of water, growth of salt crystals, or growth of plants.

3. How is chemical weathering accelerated by physical weathering?
Physical weathering breaks up rocks and minerals, creating more surface area for chemical weathering. Chemical weathering attacks the surfaces of rocks and is accelerated by increasing the available surface area.

4. How does chemical weathering work?
Chemical weathering represents the decomposition of rock by the chemical breakdown of minerals. A variety of chemical reactions result in changes in rock composition; typically replacing strong minerals with weaker minerals, thus hastening the breakdown of the rock.

5. What is hydrolysis and how is it related to the pH of a solution?
Hydrolysis occurs when primary minerals react with water to form other products. Hydrogen ions (H⁺) in the water replace other ions in the minerals. pH is simply a measure of how many hydrogen ions are present. More hydrogen ions will result in more rapid chemical weathering. There is an inverse relationship between pH and the concentration of hydrogen.

ions. Low pH values (acids) represent solutions with relatively high concentrations of $H^+$ ions.

6. What landforms are associated with dissolution?
Dissolution occurs when rocks and/or minerals are dissolved by water. The dissolved material is transported away leaving a space in the rock. Caves form when dissolution occurs along a series of fractures in limestone to create a larger opening. Water passing through the rock enlarges the cave and associated reprecipitation can form a variety of features.

7. How do rocks or soils obtain their red coloration?
Oxidation occurs when oxygen, the second most common element in the air we breathe, reacts with iron in minerals to form iron oxide minerals, e.g., hematite (rust), that give rocks a red or yellow coloration. As many minerals contain iron, it is not unusual to see red-colored rocks.

8. What factors influence the rate of weathering?
Rock type, structure, and climate primarily control weathering rates. Rocks composed of minerals that are relatively unaffected by chemical weathering will be the most resistant to weathering. Weathering rates are rapid in high-porosity and high-permeability rocks. Rock structures such as bedding planes and fractures represent natural surfaces for physical and chemical weathering processes. Sedimentary rocks and any rocks that contain abundant fractures are typically weathered more rapidly than equivalent unfractured rocks. Warm temperatures and a plentiful supply of water accelerate chemical weathering.

9. What is soil?
Regolith is composed of rock and mineral fragments produced by weathering. Soil is that portion of the regolith that supports plant life and includes organic material, water, and air.

10. What factors control soil formation?
Soil formation is dependent upon weathering, organic activity, leaching, and eluviation. These processes stratify the soil column into distinct horizons. Organic activity results in the accumulation of plant and animal material and the mixing of this material in the uppermost soil layer through burrowing of animals. Leaching dissolves ions that are transported downward to be deposited in lower horizons by precipitation. Eluviation represents the physical transport of clay particles downward in groundwater (illuviation is the accumulation of
these particles below). Soil thickness increases with increasing weathering rate.

11. What are the characteristics of soil profile horizons? Soil can be divided into a series of distinct horizontal layers (soil horizons) that collectively are termed a soil profile. Each horizon is designated by a letter. The O horizon is composed of organic debris, dead leaves, and other plant and animal remains. The A horizon lies below the O horizon and is characterized by dark organic material mixed with mineral grains by organic activity. Dissolved ions are precipitated in the underlying B horizon. Clays wash down from the A horizon. The accumulation of iron oxide will give the soil a red color. The C horizon is composed of soil parent material and is typically composed of weathered bedrock.

12. What is the difference between a pedocal and a pedalfer? Pedalfers and pedocals are simple designations given to soils in the wetter (pedalfer) and dryer (pedocal) regions. Relatively abundant precipitation results in soluble ions being leached from the A and B horizons. Less-soluble ions (iron, aluminum) remain behind in the B horizon. In dry regions where evaporation exceeds precipitation soil water is drawn back to the surface. Ions dissolved in the water are precipitated in the B horizon where they combine with carbonate ions to form a hard layer of calcium carbonate termed caliche.

13. Where is soil erosion greatest? Poor land management has resulted in most rapid erosion rates in Africa, South America, and Asia. In the U.S., erosion rates are greatest from croplands, less from pasture lands (grasslands), and are outpaced by soil formation in natural woodlands.

14. How does soil erosion occur? Soil erosion occurs by the action of running water and winds. Wind erosion is favored in areas with consistently strong winds and relatively dry climate. The bulk of current soil erosion occurs because of the effects of running water.

15. What are the principal causes of soil erosion? Soil erosion is accelerated by human activities that leave the soil uncovered including poor farming practices (plowing parallel to slope, overgrazing), deforestation, and construction.

16. What steps can we take to protect soil from erosion?
The principal soil conservation techniques include keeping soil covered, providing shelter for fields exposed to winds, ensuring a steady supply of nutrients, and limiting the effects of slopes through contour plowing (plowing across the slope) and/or terracing.

17. How does the Conservation Reserve Program reduce soil erosion?
The CRP pays farmers not to cultivate potentially erodible farmland. Farmers enroll in a 10-year program; at the end of this period the land can be returned to cultivation but owners must implement approved conservation measures if they intend to raise crops. Soil erosion decreased by 90% on CRP lands, reducing U.S. soil erosion by 22%.
Match the letter of the pictured soils with the description of the soil orders given in the table below.

<table>
<thead>
<tr>
<th>Letter</th>
<th>Soil description (soil order)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alfisols: Soils in semiarid to humid areas that have a clay and nutrient-enriched subsoil. They commonly have a mixed vegetative cover and are productive for most crops. Common soil type below farmlands in Ohio.</td>
<td></td>
</tr>
<tr>
<td>Ultisols: Soils in humid areas that have a clay-enriched subsoil that is low in nutrients. More strongly weathered than alfisols.</td>
<td></td>
</tr>
<tr>
<td>Mollisols: Soils that have a surface horizon enriched in organic material. These soils are formed from nutrient-rich parent material, and are commonly found in grasslands.</td>
<td></td>
</tr>
<tr>
<td>Aridisols: Soils formed in drylands. They may have a clay-enriched subsoil and/or cemented to non-cemented deposits of light-colored salts or carbonates (caliche) in the B horizon.</td>
<td></td>
</tr>
</tbody>
</table>
Soil Classification

The U.S. Department of Agriculture divides soils into 12 broad orders. The orders are alfisols, andisols, aridisols, entisols, gelisols, histosols, inceptisols, mollisols, oxisols, spodosols, ultisols, and vertisols. Orders are differentiated on the physical properties of the soils and many have little direct relationship with climate.

1. Read the descriptions of the orders below and circle the names of soil orders that are influenced by climate in the table.

<table>
<thead>
<tr>
<th>Soil Order</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alfisols</td>
<td>Soils in semiarid to humid areas that have a clay and nutrient-enriched subsoil. They commonly have a mixed vegetative cover and are productive for most crops.</td>
</tr>
<tr>
<td>Andisols</td>
<td>Soils that commonly formed in volcanic parent material. They are common in the volcanic areas of Alaska, Hawaii, and the Pacific Northwest.</td>
</tr>
<tr>
<td>Aridisols</td>
<td>Soils that are too dry to grow mesophytic plants. They may have a clay-enriched subsoil and/or may be cemented to non-cemented deposits of salts or carbonates. These soils are commonly in the deserts of western states.</td>
</tr>
<tr>
<td>Entisols</td>
<td>Soils that have little or slight development and properties that reflect their parent material. They include soils on steep slopes, flood plains, and sand dunes. They occur in many environments.</td>
</tr>
<tr>
<td>Histosols</td>
<td>Dark soils that have slightly decomposed to well-decomposed organic materials derived from sedges, grasses, leaves, hydrophytic plants, and woody materials. These soils dominantly are very poorly drained and occur in low-lying areas.</td>
</tr>
<tr>
<td>Gelisols</td>
<td>Soils that commonly have a dark organic surface layer and mineral layers underlain by permafrost. These soils are commonly in the tundra regions of Alaska.</td>
</tr>
<tr>
<td>Inceptisols</td>
<td>Soils that have altered horizons, but still retain some weatherable minerals. These soils occur in a wide range of temperature and moisture environments.</td>
</tr>
</tbody>
</table>
Mollisols  Soils that have a dark surface horizon. These soils formed from nutrient-rich parent material, and are commonly found in grasslands.

Oxisols  Soils in humid, tropic, or sub-tropic areas that have low-activity clay and few weatherable minerals. They commonly have reddish or yellowish soils that do not have distinct horizons.

Spodosols  Soils in humid areas that have a light gray eluvial horizon over a reddish, aluminum, and/or iron-enriched horizon. They commonly have coniferous tree cover.

Ultisols  Soils that are in humid areas and have a clay-enriched subsoil that is low in nutrients. With soil amendments they are productive for row crops.

Vertisols  Clayey soils that shrink and develop cracks as they dry and swell when they become moist. The shrinking and swelling can damage buildings and roads.

2. Use the descriptions above to decide which soil orders would be classified more generally as pedocal soils and which would be considered pedalfers. List the types below.

<table>
<thead>
<tr>
<th>Pedocals</th>
<th>Pedalfers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. Which soil order would include laterites?