Lesson 2: Soil Formation

Many factors account for the differences in soils throughout the state of Missouri. For example, the climate varies considerably within the state, with the average seasonal rainfall and temperature gradually increasing from northwest to southeast. Also, the parent material from which soil forms varies from northern to southern Missouri. These factors contribute to the scarcity of gravelly soils in the north, and the abundance of gravelly soils in the south.

Soils form through processes that act on accumulated or deposited geologic (relating to the earth's natural crust) material. The characteristics of the soil are determined by the type of parent material, the organisms (plant and animal life on and in the soil), the climate under which the soil-forming factors were (and are presently) active, the topography, and the length of time that the forces of soil formation have been active.

Factors of Soil Formation

> ***Soil*** *is a living, naturally occurring dynamic system at the interface of air and rock. Soil forms in response to forces of climate and organisms that act on parent material in a specific landscape (topography) over a period of time.*

The key words in the definition of soil (dynamic, living, system, interface) tell something about how soil forms. Of the five soil-forming factors in Table 2.1, two of them, climate and organisms, are called active factors. They are catalysts that cause soil to form. The other three, parent material, topography, and time, are called passive factors. They respond to the forces exerted by climate and organisms.

Table 2.1 – Five Soil-Forming Factors

Active Factors	Passive Factors
1. Climate	3. Parent Material
2. Organisms	4. Topography
	5. Time

Climate

Climate affects soil most directly through temperature and rainfall. In warm, moist climates, rocks and minerals weather rather quickly. Temperature affects the rate or speed of chemical activity, the kind of vegetation, and biological (pertaining to living organisms) activity. The temperature and seasonal distribution of rainfall, therefore, have a great influence on the kinds of plants that grow and how rapidly plant residues are decomposed and incorporated into the soil. Average annual rainfall and temperature may or may not be good indicators of soil formation. High intensities of rainfall and high temperature during short periods may be the dominating factors.

Rainfall causes **leaching,** or the removal of soil materials by water flowing through the soil. Free lime is completely leached from most Missouri soils, making these soils acidic. Free lime (calcium carbonate) is still present in some alluvial soils of the Missouri River flood plain and upland soils of northwest Missouri, where there has not been enough rain or time to leach the soil completely. The amount of water moving down through the soil also affects the movement of clay particles into the subsoil.

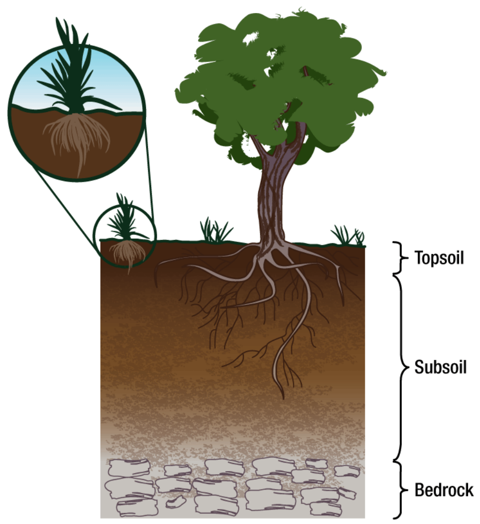
Organisms

Organisms are in three significant groups:
1. Living and dead macroorganisms
2. Living microorganisms
3. Finely divided nonliving material

Macroorganisms – Macroorganisms include large plants and animals, both living and dead. Plants die and decay, thereby building up organic matter in the soil. Living macroorganisms are the source of nearly all organic matter. The largest contributors, of course, are plants, such as grasses, woody vegetation, and trees. See Figure 2.1.

The positive effect of organic matter in the soil cannot be overemphasized. Organic matter enhances soil to influence healthy plant growth, although its presence is not considered an absolute necessity.

Figure 2.1 – Living Macroorganisms

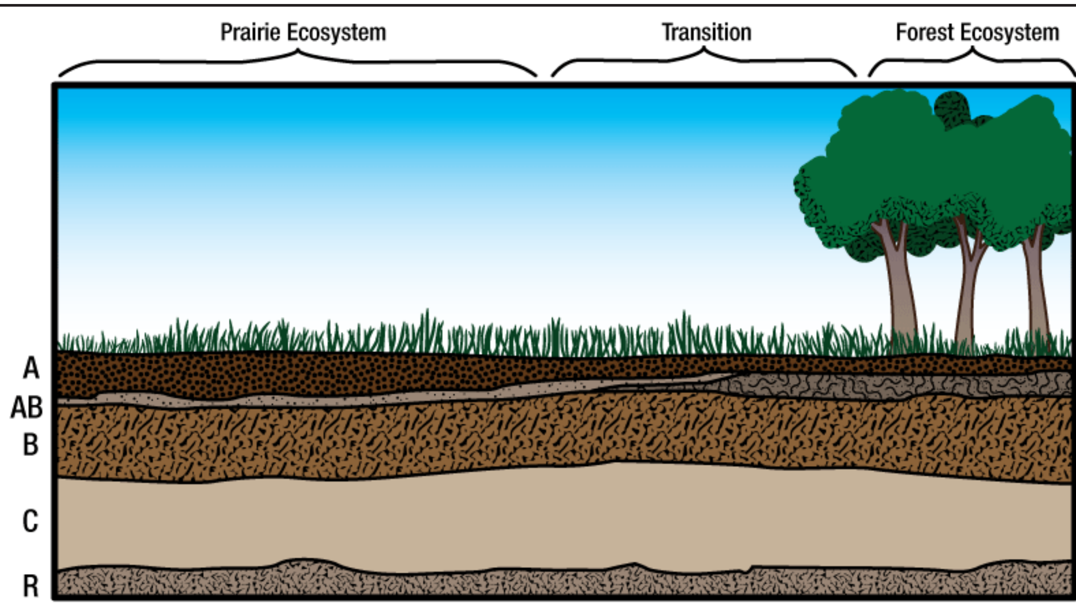


The state of Missouri has a fairly distinctive boundary between native prairie vegetation and native forest. Soils in the prairie regions of Missouri generally are high in organic-matter content because grasses have many fine roots that decay quickly each year. Soils in the forested areas generally have less organic matter because tree roots are large and woody and decay very slowly. Large plants are more than just the source of organic matter. They help break rocks apart and mix soil particles, and root channels provide pathways for water and air movement through the soil. See Figure 2.2.

Soil animals include large burrowing animals, earthworms, insects, rodents, snakes, and myriapods. Earthworms are the best known animal conditioners of the soil. Each year they ingest and excrete tons of soil per acre. This increases the strength of soil aggregates and leaves channels that increase permeability and aeration. All of these small animals are important because they help mix the soil. Animal mixing carries plant debris that lies on the soil surface down into the topsoil. This makes it easier for the microbes to do their job of changing plant material into humus.

Microorganisms – Microorganisms, or microbes, have an extremely important role in soil formation. They are the primary decomposers. The microbes in the soil are made up of many tiny animals and even more tiny plants. They are microscopic in size (they can be seen only with a microscope). Bacteria, fungi, protozoa, nematodes, and algae are the major ones. Microbes cause the organic matter to decompose. They change raw plant material into a complex, dark brown or black substance called **humus**. Plant and animal residues go through many changes to become humus. At the same time, they improve soil tilth and release soil nitrogen, which is an essential nutrient that plants need in large quantities. Thus, many topsoils

Figure 2.2 – Native Prairie and Native Forest

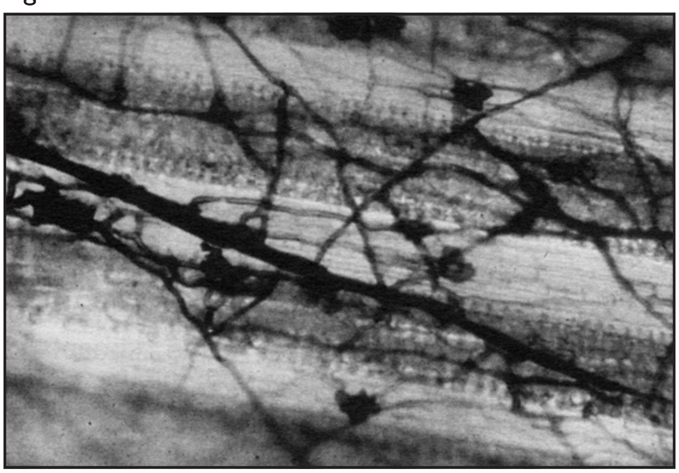


are rich and fertile because they are well supplied with humus. See Plate 2, p. 50-A. Even the earthy smell of moist, rich topsoil is caused by microorganisms.

Microbes and the humus they produce also act as a kind of glue to hold soil particles together in aggregates. Well-aggregated soil is ideal for providing the right combination of air and water to plant roots, as well as improving soil tilth and decreasing susceptibility to erosion. Without microbes, soil would be a virtually inert (lifeless) body. With them, soil is truly a living, dynamic system.

Finely divided nonliving material – Organic matter includes plant and animal residues at various stages of decomposition. Humus is the portion of the organic matter remaining after the major part of plant and animal residues have decomposed. It usually is amorphous (formless) and dark brown or black. The finely divided, nonliving materials are the major components of soil humus. See Figure 2.3.

Figure 2.3 – Humus Formation



Strands of fungus *surround a freshly clipped blade of grass. Decomposition is beginning and will soon convert the clipping to soil organic matter.*

Parent Material

Parent material is the original geologic material that has been changed into the soil of today, or it is the unconsolidated mass in which soil forms. Parent material is passive because it simply responds to the changes brought about by climate and biological activity.

Many parent materials are residual and formed in place from some kind of bedrock, like limestone, shale, or sandstone. This material is called **residuum** (reh-zij-you-um). The kind of bedrock influences the texture of the soil. For example, sandstone produces sandy textures, while shale produces clayey textures. Others are deposits of sediments carried by water, wind, or ice called **transported parent materials**. Alluvium (uh-loo-vee-um), loess (luss), colluvium (kuh-loo-vee-um), and glacial till are all examples of transported parent materials.

Topography

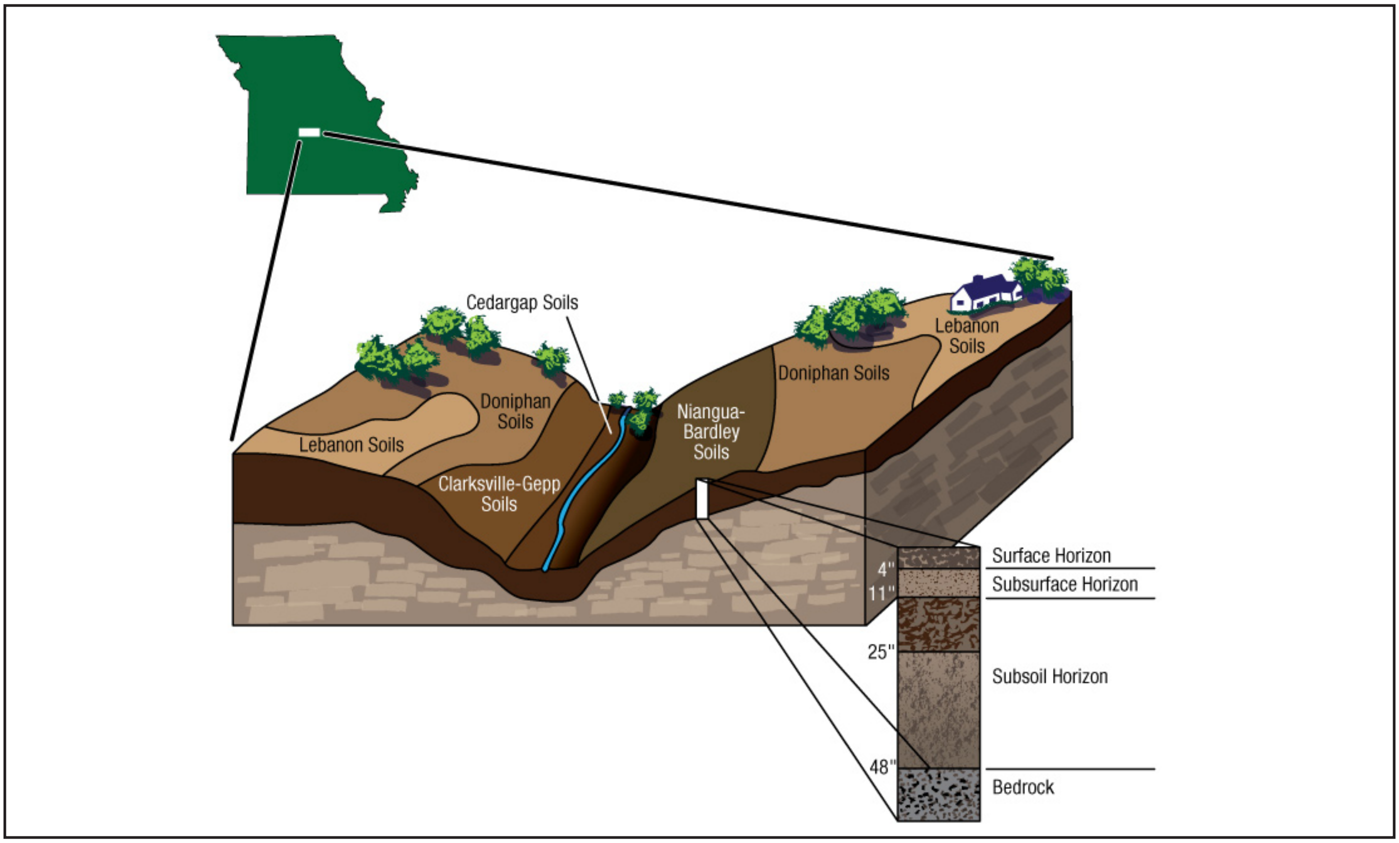
Topography refers to the relief or landscape. It is frequently called "the lay of the land." See Figure 2.4. Topography influences soil formation through its effect on drainage, runoff, erosion, and exposure to sunlight and wind. It causes localized changes in moisture and temperature. Soils on south-facing slopes are drier and are also subject to more freezing and thawing than north-facing slopes. Soils on hilltops are drier than soils at the bottom of hillslopes. When rain falls on a hillslope, for example, water runs down from the top of the hill. Excess water collects at the bottom of the hill. The drier soils at the top are quite different from the wetter soils at the bottom, even if both soils form under the same overall conditions of climate, organisms, parent material, and time.

Slope influences the amount of runoff, the rate of water infiltration, the rate of leaching, the movement of clay, and the thickness of the developed soil. In steep areas, runoff is rapid and very little water passes through the soil. As a result, soil formation is slow. In gently sloping areas, runoff is slow, erosion is minimal, and most of the water passes through the soil. The infiltration of water intensifies leaching, translocation of clay, and other soil-forming processes.

Time

Time is the great equalizer. Young soils inherit the properties of their parent materials. They tend to have the color, texture, and chemical composition of their parent materials. Later on, the influence of parent material is not as evident. The influence of time will vary with the kind of parent material. Some parent materials weather

Figure 2.4 – Topography



faster than others. Also, climate may change over time. The prairie areas of northern Missouri are a relic of a warmer, drier climate. The youngest soils form in alluvium on flood plains. The parent material is renewed after each flood. Soils on the broad, nearly level uplands have had centuries of weathering and are some of the older soils.

The five factors of soil formation are so closely interrelated in their effects on the soil that few generalizations can be made about the effect of any one factor unless conditions are specified for the other four. Soil-forming factors are not always present in the same intensity and degree; thus, there are many differences in soils.

Processes of Soil Formation

By the definition of soil used here, there are five **factors** of soil formation and four major **processes** that change parent material into life-sustaining soil. These processes are a result of the catalytic influences of the active factors organisms and climate. See Table 2.2.

Table 2.2 – Processes of Soil Formation

1. Additions	3. Translocations
2. Losses	4. Transformations

Additions

The most obvious addition to the soil is organic matter. As soon as plant life begins to grow in fresh parent material, organic matter begins to accumulate. Organic matter gives a black or dark brown color to the surface soil. This is why even very young soils may have a dark-colored surface layer.

Other additions come with rainfall. On average, rainfall adds about 5 pounds of nitrogen each year to every acre of soil. Rainfall can also be acidic, especially downwind of industrial areas. Acid rain may alter the rate of some soil processes. Rainfall, by causing rivers to flood, is indirectly responsible for the addition of new sediments to the soil on a river's flood plain.

Losses

Most losses occur by leaching. Water moving through the soil dissolves certain minerals and carries them out of the soil. Some minerals, especially salts (such as calcium chloride and sodium chloride) and lime (calcium carbonate), are readily soluble. They are removed early in a soil's formation. That is why most soils in humid regions do not contain free lime or salts. Many fertilizers, especially nitrogen fertilizers, are also quite soluble. They, too, are readily lost by leaching, either by natural rainfall or by irrigation water. Other minerals, such as iron oxides and sand grains, dissolve very slowly. They are the residual effects of weathering. They remain in the very old and highly weathered soils.

Losses also occur as gases or solids. Oxygen and water vapor are lost from soil as fresh organic matter decays. When soils are very wet, nitrogen can be changed to a gas and can be lost to the atmosphere. Solids are lost by erosion, which removes both mineral and organic soil particles. Erosion losses are very serious, for the surface soil is the most productive part of the soil profile.

Translocations

Translocation refers to the movement from one place to another (*trans* is Latin for "across" or "through"; *locus* is Latin for "place"). Usually the movement is out of a horizon near the soil surface into another horizon that is deeper in the soil.

One kind of translocation involves microscopic, very thin clay particles. Water moving through the soil can carry these particles from one horizon to another, from place to place within a horizon, or from the surface soil to the subsoil. See Figure 2.5.

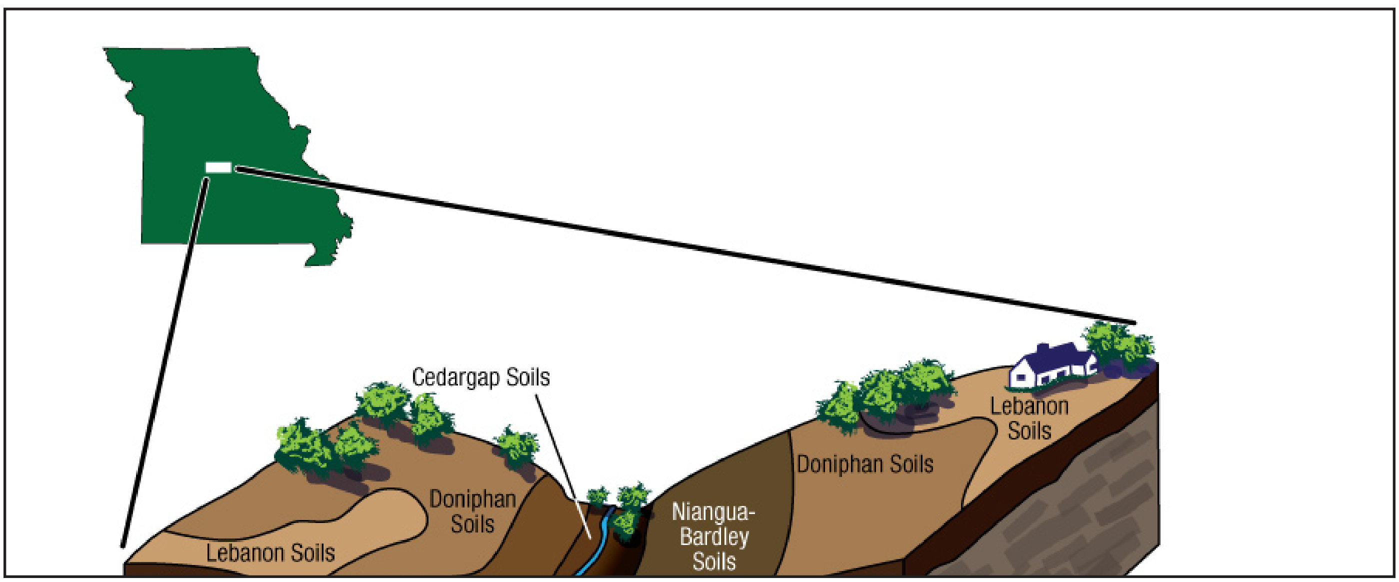
When the water stops moving, clay particles are deposited on the surface of soil aggregates. These coatings are called clay films. They have a dark, waxy appearance. A clay flow is shown in Plate 3, p. 50-A.

In low rainfall areas, leaching often is incomplete. Water moving through the soil dissolves soluble minerals. But there is not always enough water to move the soluble materials all the way through the soil. When the water stops moving and evaporates, the minerals (carbonates) are left behind. That is how subsoil accumulations of free lime are formed. A few of the soils in northern Missouri that formed in deep loess on uplands or in alluvium on flood plains have free lime throughout the soil.

Transformations

Transformations are changes that take place in the soil (from the Latin *trans* for "across" or "through" and *formis* for "form"). Microorganisms that live in the soil feed on

Figure 2.5 – Translocated Clay



fresh organic matter and change it into humus. Chemical weathering changes the primary minerals of parent materials. Some minerals are destroyed completely. Others are changed into secondary minerals. Many of the clay particles in soils are actually new minerals that form as a result of chemical changes.

An obvious transformation is the formation of definite structure. The rearrangement of individual soil particles into aggregates (granular, blocky, prismatic) allows greater porosity for water movement and root penetration.

Still other transformations change the form of certain elements. Iron oxide (ferric oxide) usually gives soils a yellowish-brown, reddish-brown, or red color. This process is called **oxidation**. See Plate 5, p. 50-B. In waterlogged (saturated) soils, however, iron oxide changes to a different form (ferrous oxide). This process is called **reduction**. Reduced iron oxide is quite easily lost from the soil by leaching. After the iron is gone, the soil has a gray or white color. See Plate 6, p. 50-B.

Repeated cycles of wetting and drying in the soil causes oxidation or reduction of iron and manganese. See Plate 7, p. 50-B. Part of the soil is gray because of the reduction of iron, and part remains yellowish brown, reddish brown, or red where the iron oxide is not reduced.

Processes Work Together to Form Soil

How do all these processes work together to form soil? Climate starts acting on a fresh parent material immediately. Physical weathering first decreases the size of the parent material and increases the surface area per unit volume. Chemical weathering begins to change minerals. Leaching removes salts first, then the free lime.

As soon as plants begin to grow, they add organic matter to the soil. Biological activity increases and humus forms. Soon a dark-colored surface horizon is present. This increases porosity and allows the leaching process to begin.

Weathering and leaching continue to change soil minerals and remove soluble components. More horizons develop beneath the surface. The upper part of the soil becomes more acidic. Clay minerals begin to form. Clay is translocated and clay films become visible.

As the amount of clay in subsoil horizons increases, the rate of water movement through the soil decreases. Weathering continues, but leaching is not as rapid. After a while, further change is very slow and the whole soil-plant-landscape system is in equilibrium.

Summary

The active factors of soil formation (climate and organisms), together with the passive factors (parent material, topography, and time) are so closely interrelated in their effects on the soil that few generalizations can be made unless conditions are known for all of them. The soil-forming processes (additions, losses, translocations, and transformations) add further variability.

Soils that formed at the same time from the same parent material can be different. For example, soils at the bottom of a hill are different from soils at the top or sides of a hill. Rainwater infiltrates the soil at the top of the hill, but the slope causes the water to rush down the sides of the hill as runoff. Soils at the bottom of the hill will be wetter and more developed than soils on the top or the adjacent slopes. Another factor to consider is the aspect of the hill. Soils on southerly aspects will be drier than those on northerly aspects. Additionally, in areas with both high rainfall and hot temperatures, soil materials weather faster than those in cool, dry areas. This explanation provides insight to the many differences in soils throughout the state.

Credits

Huddleston, J. Herbert, and Gerald F. Kling. *Manual for Judging Oregon Soils*. Corvallis: Oregon State University Extension Service, 1984.

Soil Survey Division Staff, Lincoln, Nebraska. N*ational Soils Survey Handbook* (Title 430-VI). Washington, DC: U.S. Department of Agriculture, Soil Conservation Service, 1993.

Thompson, L.M., and F.R. Troeh. *Soils and Soil Fertility,* 3rd ed. New York: McGraw-Hill, 1973.