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The Formation of Soil

John Breukelman

"A house, it is often said, does not become a home until it has been lived in. Neither does the surface of the earth become soil until it, too, is lived in by long generations of plants and animals. We know that soil is necessary for good plant growth. It may surprise us to learn that plant growth is necessary for soil.

This may suggest the old riddle of which came first, the hen or the egg, but an answer is easier. There had to be plants before there could be soil."

With these words Dr. Paul B. Sears, noted Yale ecologist, opened an article entitled "Plants as Makers of Soil," published in 1945 by the National Audubon Society,* in which he described the role of various kinds of plants in the formation of several different types of soil.

What is soil? How is soil formed? What are the main types of soil? What kinds of plants are most important in soil formation? What happens when plants are lost from the soil? Is the process of soil formation going on now? Can we see various stages of the soil-building process in Kansas? Can man aid in the process of soil formation? These are some of the questions we shall try to answer in this issue of The Kansas School Naturalist.


WHAT IS SOIL?

One dictionary says simply that soil is "the loose upper layer of the earth's surface." This may be correct as far as it goes but it does not tell us much. Another dictionary adds further information—"finely divided rock-material mixed with decayed vegetable or animal matter, constituting that portion of the surface of the earth in which plants grow or may grow; also, any particular variety of such earth; as good soil, alluvial soil." A third dictionary goes into still more detail, defining soil as "the upper layer or layers of earth which may be dug, plowed, excavated, etc.; specifically, the loose surface material of the earth in which plants grow, in most cases consisting of disintegrated rock with an admixture of organic matter and soluble salts." So much for dictionary definitions; let us turn to the 1957 Yearbook of the United States Department of Agriculture. In the chapter entitled What Soils Are, Roy W. Simonson says:

"Soil is continuous over the land surface of the earth, except for the steep and rugged mountain peaks and the lands of perennial ice and snow.

Soil is related to the earth much as the rind is related to an orange. But this rind of the earth is far less uniform than the rind of an orange. It is deep in some places and shallow in others. It may be red, as soils are in Hawaii, or it may be black, as they are in North Dakota. It may
The Badlands area of South Dakota is the result of natural erosion. The surface features have been exposed to the forces of water and wind for millions of years.

The soil mantle of the earth is far from uniform, but all soils have some things in common.

Every soil consists of mineral and organic matter, water, and air. The proportions vary, but the major components remain the same.

Every soil occupies space. As a small segment of the earth, it extends down into the planet as well as over its surface. It has length, breadth, and depth.

Every soil has a profile—a succession of layers in a vertical section down into loose weathered rock. The nature of the soil profile has a lot to do with the growth of roots, the storage of moisture, and the supplies of plant nutrients. The profile also is basic to scientific studies of soil. The profile carries within itself a record of its history for those who learn to read it.

THE PLANET EARTH

Let us “begin at the beginning” and describe briefly the planet on which we live. Omitting for the moment the living things and their products, the earth consists of many different materials—rocks, minerals, ores, sand, water, ice, air. These materials are constantly moving and changing. Rain and snow, waves and currents, streams, glaciers, volcanoes, and earthquakes all bring about changes in the crust of the earth. These changes went on for millions of years before life arose on the earth and before soil formation started. We may describe the lifeless earth as a ball of rock known technically as the lithosphere, three fourths of which is covered by water and much of the remaining fourth of which is saturated with water (the hydrosphere) and all of which is surrounded by a gaseous envelope (the atmosphere). The
outer layers of the lithosphere, from which soil is derived, are made up of rocks of a great variety of chemical composition, hardness, density, and color. The hydrosphere includes not only the oceans, lakes, and rivers, but also the ground water which occupies underground cavities and pore spaces in the rock. The atmosphere consists mostly of nitrogen and oxygen, but also includes water vapor, carbon dioxide, dust, and various rare gases. It seems extremely light, and by comparison with rock and water it is, but its total weight is such that it exerts a pressure of about 14.7 pounds per square inch of the earth's surface.

Before life developed on the earth and extended its mantle of green over the length and breadth of the land, the earth would, no doubt, have seemed a rather dismal place. We can imagine how it may have looked—perhaps like a desert without even the sparsest of vegetation, perhaps like the surface of the moon as seen through a high-power telescope, perhaps like the fantastically eroded surface of the Bad Lands.

**THE BIOSPHERE**

The earth on which we live is not lifeless, however. In addition to the lithosphere, hydrosphere, and atmosphere, it also has a biosphere or sphere of life. This consists of the plant and animal life that occupies almost every available bit of space on the earth. The forests, prairies, fields, and gardens with their wild and cultivated plants as well as the birds, insects and other animals living in and on the plants—these are familiar to us. In Kansas we are not so aware of seaweed, sponges, corals, oysters, lobsters, sharks, and whales; if we lived in Florida or California these oceanic creatures, too, would be familiar to us. Even Kansas is not all dry land, however; its thousands of artificial bodies of water, ranging from tiny farm ponds of less than an acre to the great Federal dams such as Kanopolis and Fall River, are alive with algae, bacteria, and other microscopic organisms, pondweeds, insects, crustaceans, clams, fishes—these and many more.

The soil teems with bacteria, fungi, worms, insect larvae, and a variety of digging and burrowing animals, all working in and about a complex and constantly changing network of plant roots. In the air are not only the flying birds and insects, but pollen, spores, dandelion seeds, and many other tiny bits of...
living matter light enough to be carried about by the wind. Nearly all of these myriads of living things depend directly or indirectly on the soil. Animals eat the plants, or they eat animals that eat the plants.

**MINERAL BASIS OF SOIL**

How did soil come to be? No human observers were on hand to see how the first soil was formed, but since the process is going on all the time we can see how it takes place now and guess that it probably worked about the same way in the past. Let us consider a bare rock surface, such as the rocks and boulders left after a glacier has receded, the lava that has just come from a volcano, or a limestone ledge in Kansas that has just been exposed in making a highway cut.

Geologists often classify rocks into three main groups as follows:

<table>
<thead>
<tr>
<th>IGNEOUS</th>
<th>SEDIMENTARY</th>
<th>METAMORPHIC</th>
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<tbody>
<tr>
<td>First to form on the earth; solidified directly from molten condition.</td>
<td>Deposited by wind or water; also known as stratified rocks.</td>
<td>Changed by heat, pressure, volcanic action.</td>
</tr>
<tr>
<td>Granite, basalt</td>
<td>Conglomerate, sandstone, limestone, shale</td>
<td>Slate (from shale), marble (from limestone)</td>
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At first the only things that would change this rock surface are sun, wind, rain, snow, and other non-living factors. Falling rain absorbs carbon dioxide from the air and thus becomes dilute carbonic acid, which may slowly dissolve some kinds of rock. A rock may be heated to a high temperature during a sunny winter day if the sun shines directly on it and then cool down to well below freezing during the night. Such temperature changes may cause cracks; water from falling rain or melting snow may collect in the cracks, freeze and expand and thus further split the rock. Particles that have split off may be carried by wind or water and wear down rock surfaces while the particles themselves are also worn down to finer and finer sizes.

Rocks consist of minerals. What are minerals? In technical language, they are chemical elements or compounds that occur in nature and result from non-living or inorganic processes; or if you like, they are things that are neither animal nor vegetable. There are thousands of different kinds of minerals. Rocks are grouped and named according to the minerals in them, their hardness, specific gravity, color, texture, and other properties. In Kansas the most common rocks are limestones, sandstones, and shales.

Limestones are highly variable in hardness, texture, and color. They all consist mainly of the mineral calcium carbonate \( \text{CaCO}_3 \), a compound which in turn is made up of the elements calcium (Ca), carbon (C), and oxygen (O). Many limestones contain magnesium (Mg); these are known as dolomites. Some contain clay or sand. Certain kinds of plants and animals, such as algae and corals, contribute to the formation of limestones; in fact some limestones are almost like masses of shells cemented together.
Sandstones consist mainly of grains of quartz cemented together by compounds of silica, calcium, or iron. Quartz is silicon dioxide ($\text{SiO}_2$), and a common cementing material in Kansas sandstones is lime. Sandstones grade into conglomerates, which consist of sand and pebbles cemented together. Concrete is an artificial conglomerate. Many well preserved plant fossils, especially leaf impressions, have been found in the Dakota sandstone in Kansas.

Shales or "mudstones" are essentially clays which have hardened into rock. They are rich in feldspar and contain aluminum silicate ($\text{Al}_2\text{Si}_2\text{O}_8$) combined with one or more metals other than aluminum. For example, potash feldspar contains potassium (K) and albite contains sodium (Na). Some shales are extremely fine-grained and may form layers that are almost water-tight.

Much of the phosphorus in rocks comes from a mineral, apatite, which consists of phosphorus, calcium, oxygen and fluorine.

PLANTS AND SOIL

Exposed rock surfaces do not long remain uncovered. Spores and seeds soon arrive, carried by the wind or by animals. Especially important in the early stages of soil building are the lichens—combinations of algae and fungi. Each lichen is composed of fungus fibers among which live cells of algae. The algae manufacture food for themselves and the fungi. Lichens may be seen at work on exposed cliffs, boulders, old concrete pavements and sidewalks, stone buildings, monuments and tombstones. As the lichens cling stubbornly to the rock surfaces, they tend to hold water and bits of dust or tiny particles of rock that are blown about. By alternate swelling and contracting in wet and dry weather, the lichens may loosen tiny particles from the rock to which they cling. They also secrete chemicals which dissolve the cementing materials from among the rock particles, thus freeing these particles to be blown about or carried away by water.

Lichens are sometimes called pioneer plants. They are tough, can survive severe environmental conditions, and are largely self-sufficient. They can stand long periods of severe conditions and take advantage of any favorable times that come along. As they continue to grow and reproduce, covering more and more of the rock surface on which they live, they hold more water and collect more dust and rock particles. When a mixture of water and solid particles accumulates in a rock crevice, we have a pocket of "soil" in which spores or seeds can lodge and grow. This soil will soon be invaded by bacteria, fungi, plant roots, and tiny animals. The waste products of the invaders, as well as their remains after their death, add organic matter to the soil. Each growing season adds its installment of organic matter. As more soil accumulates, and especially as the percentage of organic matter increases, the soil can hold more water. After a while, soil
and moisture conditions become less severe and other plants, not so tough as the pioneer lichens, can survive. These, too, make their contribution to the soil. In time a succession occurs in which each stage produces conditions in which new types of plants can survive. For example, mosses may follow lichens, to be followed in turn by goldenrods, milkweeds, sunflowers, grasses, and small shrubs. The new invaders may crowd out the plants of the earlier stages, mosses crowding out lichens, and so on.

Throughout their lives, the plants and animals take in water, minerals, and various other substances which they convert into complex organic substances. When the plants and animals die, their organic remains are added to the soil. Much enrichment of the soil results from the bacterial breakdown (decay) of plant and animal remains. Decayed and decaying organic matter is mixed in with rock particles in varying percentages in various kinds of soil.

One of the important elements needed by plants is nitrogen. There is an abundance of nitrogen in the atmosphere, almost eighty percent of the air consisting of this gas. However, plants cannot use nitrogen in the gaseous form. It must first be chemically combined with oxygen and other elements to form nitrates. Certain microorganisms in the soil can bring about this chemical combination—the nitrogen-fixing bacteria. Some of these bacteria

The lighter plants are lichens, the darker plants are mosses, growing on limestone in Lyon County (left) and on sandstone in Woodson County (right).
live free in the soil, but most of them live in the roots of legumes (clover, alfalfa, beans, lespedeza, leadplant).

As the larger plants invade an area, the soil-building process is speeded up. Plant roots penetrate into cracks in rocks and widen them. Eventually, what was bare rock becomes covered with a mantle of material thick enough to support certain types of annual grasses and animals associated with the grasses. These add to the soil and are replaced by perennial grasses and associated animals. At all stages the bacteria and fungi convert the remains of dead organisms to simple compounds and finally into nutrients which are used over to support new plant growth. Earthworms, insect larvae, and larger burrowing animals mix soil elements, bring soil to the surface and carry surface materials into the soil, add to the soil their own waste products and in due time their own dead bodies. Eventually we have the complex mixture of mineral and organic matter that makes up a mature soil.

At all stages of soil formation the mutual influence of soil and plants is important. Plants depend upon the soil for their needs, and in turn they determine to a large extent, the characteristics of the soil. A plant needs a place to gain a foothold. It uses water, which it gets from the soil. Its roots use oxygen, which comes from the soil. If the soil is too wet, as during or immediately after a flood, there may not be enough oxygen in the soil and plants may die. Most of the nutrients come from the soil. Only hydrogen, oxygen, and carbon commonly come from the air; all the others—nitrogen, phosphorus, potassium, magnesium, sulphur, iron, manganese, copper, zinc, boron, sodium, chlorine, cobalt, and still others—come entirely or mostly from the soil.

Nitrogen-fixing bacteria live in nodules on the roots of legumes, as shown in the upper figure. Each nodule (lower left) contains many bacteria, shown greatly enlarged (lower right).
The Hydrologic Cycle

It has been estimated that almost 100,000 cubic miles of water evaporate each year from the oceans and continents. Total evaporation equals total precipitation; about 25,000 cubic miles falls annually on the land surface of the earth. Sketch by courtesy of United States Department of Agriculture.

THE WATER CYCLE

Of primary importance in soil formation and the maintenance of the fertility of the soil is the water cycle, known technically as the hydrologic cycle. Let us look briefly at this unending circulation of water from the sea to the atmosphere, from the atmosphere to the land, and from the land back to the sea. Since the sea covers about three fourths of the earth's surface most of the water vapor in the air comes from the sea, only a small amount from the land and fresh water.

Whenever air, especially warm the amount that could be present at the temperature involved. The water vapor capacity of the air goes up and down with the temperature. For example, at ordinary atmospheric pressure a cubic meter of air at 10 degrees Centigrade can hold 9.33 grams of water, at 15°C, 12.71 grams, at 20°C, 17.12 grams and at 25°C, 22.80 grams.

When the air warms up and the actual water content stays the same, the relative humidity falls. Thus, a cubic meter of air which contains all the water possible at 10°C (9.33 grams) has a relative humidity of 100 per cent. If this cubic meter of...
air, blows over a water surface, some water evaporates into the air, unless the air already contains as much water vapor as possible, that is, unless the relative humidity is already 100 per cent. The relative humidity is the percentage of water vapor in the air, as compared with air is warmed to 15°C, its capacity is 12.71 grams, but it still contains only 9.33 grams. The relative humidity is now 9.33/12.71 or 73 per cent.

When the air cools, the relative humidity rises; if it reaches 100 per cent of the water vapor capacity the air is said to be saturated. The temperature at which the air is saturated is often referred to as the dew point. If the temperature fall below the dew point some of the water vapor condenses as fog, mist, rain, snow, or sleet. Thus a cubic meter of air contains 17.12 grams of water at 20°C is saturated, and the dew point is 20°C. If this air is cooled to 10°C, the water capacity is only 9.33 grams. The difference between 17.12 and 9.33, or 7.79 grams, is condensed as some form of precipitation. The portion of the precipitation that falls on the land is of special concern to agriculture, horticulture, forestry, and all other activities that depend on the soil.

When rain and other forms of precipitation fall on the land, all or part of the water enters the soil by infiltration; the water that does not infiltrate flows away and is called runoff. Of that water which enters the soil, most goes down by percolation. Some goes down and down until it reaches a level known as the water table. This may be near the surface or several hundred feet down. It is the highest level at which the ground is saturated with water. This is the level at which water stands in a well. Or water may percolate down until it reaches a water-tight layer of rock and flows along the surface of this layer, to emerge as a spring or in a "seepy" area. Of the water that remains near the surface of the soil, some returns to the air by evaporation, and some passes through growing plants to be returned to the air by transpiration. Thus water that falls on the soil may leave the soil in four ways—runoff, springs or seepage, evaporation, transpiration. Under ideal conditions, some water should leave in each of the four ways, and not too much or too little in any one way.

SOIL PROFILE

If you see the soil only on the surface, you will miss its layered arrangement. A good way to see this is in a cross section, as in a ditch or roadside cut. Such a section is called a soil profile. The profile of a mature soil which was developed directly from the underlying rock usually shows three fairly distinct layers. The lowest layer consists of the parent material, weathered and partly broken down. Then comes the subsoil, which consists largely of mineral matter, but with some organic matter, plant roots, and some soluble materials that have diffused down from the topsoil, the top layer. The topsoil is the living, active, part of the soil, the part that is more important both for native plants and for cultivated crops.
A typical soil profile has three main layers.

These three layers are not always clearly defined. In young soils in early stages of development, the thin topsoil may rest directly on the nearly unchanged parent rock, with little or no subsoil between. Where much erosion has taken place all of the topsoil may have been removed, leaving only the parent rock and the subsoil.

Furthermore, most soils were not developed entirely in place from underlying rock, but were transported wholly or partly from somewhere else. Most soils were formed at least in part from materials carried by glacial ice, running water, or wind.

In the northeastern part of Kansas, roughly north of the Wakarusa River and east of the Blue River much of the soil is of glacial origin, carried hundreds of miles from the north and deposited as the glacier melted, in the form of glacial drift. Also in the northeastern part of Kansas, much soil was built up from windblown material known as loess. Here some of the highway cuts show deep layers of loess.

In central and western Kansas one may see good examples of sand dunes; here the rock has been ground down to fine sand particles which blow about so that the dunes shift to and fro, different in position.
and form each season. While some plants grow in the dunes, not many can survive the severe conditions. In the flood plains of the streams of Kansas we see a great deal of alluvial soil, carried down by the streams during high water and deposited on the flood plains as the water recedes. In all of these examples, glacial drift, loess, sand dunes, alluvial deposits, the boundary between subsoil and topsoil may be quite indistinct.

A prairie soil profile has a topsoil in the form of turf, with a dense network of tangled roots of grasses, legumes and other plants. Some of these roots extend through the topsoil far down into the subsoil. Among the roots are the burrows of animals. In the woods, the topsoil is usually thin, with a layer of leaf mold on top. In this leaf mold live a large number of bacteria and fungi, worms, insects, centipedes and millipedes, snails, and other animals; one result of their activities is the return to the soil of organic matter of the fallen leaves.

Sand dunes in Stafford County; upper, mostly drifting sand; lower, fairly well stabilized by vegetation.

A prairie soil profile in Butler County; deep soil, good type for agriculture; photo U.S.D.A.

An example of severe erosion; photo U.S.D.A.
"THINGS TO DO"

1. Rub together two pieces of limestone, sandstone, or shale over a sheet of paper. Examine the material with a magnifying glass or a microscope. Try rubbing together two pieces of granite or marble. How do these differ from the other types of rock?

2. Put small pieces of different kinds of rock in a shallow dish. Set the dish in the sunlight during the day and in the freezing compartment of the refrigerator during the night. After several days, see whether any particles of rock have come loose. Repeat, but before putting the rocks in the freezing compartment, soak them in water. Note which kinds of rock absorb most water.

3. Fill a pint or quart fruit jar about three fourths full of garden soil. Add water until the jar is almost full, seal, and shake vigorously. Set aside and examine after a few minutes, after an hour, after several hours, and the next day. How many layers of soil are formed during settling? How do these layers differ?

Try the same experiment with soils of different textures, and from different localities. Try the same experiment with a sample of topsoil and a sample of subsoil from the same soil profile.

4. Mark off an area one foot square, and remove the soil from the top four inches of this area. Bring this soil indoors and spread it out on newspapers or wrapping paper. Inspect it carefully to find as many kinds of living things as you can. You may find small worms, insect larvae, mites, red spiders, snails, millipedes. Examine some of the soil with a magnifying glass or you may miss some of the smaller insects and mites. You may find seeds and plant roots; examine these carefully because small animals may live in or on them. How many animals did you find? At this rate, how many would there be per square yard? Per acre? (An acre equals 43,560 square feet.)

5. With a screwdriver, chisel, or other metal instrument, scrape a bit of lichen from the surface of a rock. Note the tiny particles on the underside of the lichen and the rough or pitted surface of the rock. Find a place where both mosses and lichens are growing and see the difference in the amount of "soil" where the mosses grow.

6. Obtain two shallow pans of the same size, about 8 x 12 inches or so. Fill one with bare soil and the other with sod. Set both at a slight slope, one end about one fourth to one half inch higher than the other. Be sure the
slope is the same for both pans. With a sprinkler nozzle on a garden hose, or with a clothes sprinkler, give the same amount of "rain" to each pan over the same length of time. In a bucket or other container, catch the water that runs off each surface. What is the effect of the grass? Allow both surfaces to dry. Which dries first? Then cover the bare earth with grass clippings, peat moss, finely cut straw, or some other vegetable mulch. Repeat the sprinkling. What is the effect of the mulch?

Different kinds of soil permit water to percolate through at different rates; they also retain different amounts of water. Sketch by courtesy of South Dakota Association of Soil Conservation Districts.

7. Take four equal sized tin cans and punch several holes in the bottom of each, or tie muslin over the ends of four lamp chimneys. Fill one with rich topsoil, another with sand, another with a mixture of equal parts of topsoil and sand, and the fourth with equal parts of gravel, topsoil, and sand. Place the cans or chimneys in a rack or other support so that water passing through the soil can be caught in separate containers. Pour an equal measured amount of water into each can, taking care to see that all the water goes into the soil and none spills out over the edge of the can or chimney. See how long it takes for water to begin dripping out of the bottom. Through which soil did the water pass most rapidly? How much water came through the sand, the topsoil, and the mixture? Keep a record of the amount of water added to each soil and subtract the amount that came through. The difference is the amount retained. If

8. Immediately after a heavy rain, collect in glass jars water samples from the runoff from different soil surfaces, such as a bare plowed field, a pasture, a wheat field, a plum thicket. Set aside until the soil in each jar has settled and the liquid looks clear. How deep is the settled soil in each jar? Pour off the water and allow the soil to dry. Weigh the soil and calculate the amount of soil per gallon of runoff water. At this rate, how much soil would be carried off per thousand gallons? How much per acre-inch? (An acre-inch is the amount of water that would cover one acre to a depth of one inch; this amount of water weighs 113 tons.)
1962 Workshop in Conservation

First Section, June 4 to 22
Credit: 3 semester hours; fees: $25.35 for Kansas residents; undergraduate or undergraduate; for non-resident undergraduates, $50.10; graduates, $45.30

Outline of Program
   June 4-12: soil and water, grasslands, field trips
   June 15-19: wildlife, conservation education
   June 20-22: individual projects, completion of reports

This section is open to any student interested in conservation or conservation education.

Second Section, June 25 to July 13
Credit: 1, 2, or 3 hours for 1, 2, or 3 weeks; fees: $8.45 per hour for Kansas residents; for non-resident undergraduates, $16.70; graduates $15.10

To be admitted to this section a student must have completed a course in conservation or been a participant in the first section, and have demonstrated ability to write clearly. There will be no formal program, the objectives and procedures being determined by the group. This section will be devoted largely to the production and revision of projects and activities useful in the teaching of conservation.

Anyone interested in further information should write the director, Thomas A. Eddy, Department of Biology, Kansas State Teachers College, Emporia, Kansas.

The cover picture shows an effective soil-building practice, brome grass and alfalfa being plowed up on Class III land in Lyon County. This photograph and those marked U.S.D.A. are by courtesy of the United States Department of Agriculture and were supplied by Roy M. Davis, Area Conservationist, Emporia. The Bad Lands photograph is by Cane­dy’s Camera Shop, Rapid City, South Dakota; all other photographs are by the author.