MODERN CONCEPTS OF SOIL GENESIS—A SYMPOSIUM

Outline of a Generalized Theory of Soil Genesis[1]

Roy W. Simonson[2]

ABSTRACT

Processes of soil formation have been related to prominent great soil groups by means of names such as podzolization, laterization, and solonization. A change from this point of view seems necessary when soils of the world are considered as a continuum with a number of properties in common. It is therefore proposed that soil genesis be considered as two overlapping steps; viz, the accumulation of parent materials and the differentiation of horizons in the profile. Of these two steps, the second is of more immediate concern to soil scientists.

Horizon differentiation is ascribed to additions, removals, transfers, and transformations within the soil system. Examples of important changes that contribute to development of horizons are additions of organic matter, removals of soluble salts and carbonates, transfers of humus and sesquioxides, and transformations of primary minerals into secondary minerals. It is postulated that these kinds of changes, as well as others, proceed simultaneously in all soils. It is further suggested that the balance within the combination of changes governs the ultimate nature of the soil profile. If this point of view is valid, the same kinds of changes occur in horizon differentiation in soils as unlike as Chernozems and Latosols, but the balance among the processes is not the same.

Theories of soil genesis reflect the state of knowledge in the soil science of their day. This state of knowledge includes the extent to which soil properties are known and understood. It includes the relative prominence given to various soils in the classification system in use. It includes the very concept of soil itself. As knowledge of soils has grown over the years, there have been a number of changes in concept of soil. These have been followed in turn by changes in theories of genesis. Review of a few theories widely held in the past will bear out these observations. Furthermore, changes in theories of genesis are part of a continuing process which will not stop in our time. Concepts in soil genesis need continuing scrutiny and modification. This paper is an effort to sketch the outlines of a theory of soil genesis consistent with a concept of soil widely held at the present time.

Past Concepts of Soil

Most scientists concerned with soil a century ago, and even a half century ago, thought of it as disintegrated rock mixed with some decaying organic matter. This is evident from published reports (4, 10). If soil is considered to be disintegrated rock, weathering alone provides an adequate explanation for its formation. Nothing further is necessary to provide a satisfactory theory of soil genesis.

This early concept was replaced first in Russia (5) and later in other countries by the idea that soils were more than weathered rock and that they had profiles consisting of genetically related horizons. After this concept was developed, weathering alone was no longer an adequate theory of soil formation. A modified theory was required to explain the evolution of the profile with its related horizons. As a consequence, soil genesis was considered to be a combination of weathering and certain additional changes due to interactions between living organisms and weathered rock. In the early Russian studies (5, 11), much stress was placed on climate and vegetation as factors of soil formation though parent materials, relief, and time were also considered. Functional relationships between soils and their environment were recognized in these studies.

The studies of Dokuchaeiv and his colleagues were centered on soils with marked horizonation, such as the Chernozems and Podzols (11). These and parallel groups have continued to receive much attention in soil science. In this country, processes of soil formation have been related directly to prominent great soil groups by names such as podzolization, laterization, and solonization (7). These processes have been thought to differ from one another in a number of essentials. In fact, some pairs of processes such as podzolization and laterization have been considered to be opposites in large measure.

A number of shifts in theories of soil genesis have occurred since attention was first focused on the profile and on multiple factors of soil formation in Russia some 75 years ago. One point of view developed in that country holds soil evolution to be a continuous process (11, 12). According to this view, all kinds of soils existing on the earth at any given time are temporary stages. Each kind represents one stage which may disappear, recur, disappear, and recur again. Each stage is succeeded by some other stage in the process of continuing evolution. Thus, the patterns of distribution of soils can change over the face of the earth even though, collectively, the kinds of soils remain the same.

Present Concept of Soil

A concept of soil widely held in this country at the present time is a further modification of earlier ones. According to this concept, soils are natural bodies formed on the land surface, occupying space, and having unique morphology. The character of the soil profile remains important though it must share place with other features of the soil. Looking upon soils as geographic bodies entails certain consequences which do not follow as long as attention is focused exclusively on the profile.

First of all, each body of soil occupies volume or space. It is an entity with three dimensions; namely, length, breadth, and depth. Each soil body has a distinct upper boundary where it meets the atmosphere. Each has a less distinct perimeter where it meets other soils. Each has an indefinite lower boundary where it grades into weathered rock. This idea is illustrated diagramatically in figure 1, which also shows the relationship of the soil profile to the soil body (17).

Individual bodies of soils are seldom set apart from their neighbors by sharp boundaries. Adjacent bodies commonly grade into one another. The normal gradation between adjacent soil bodies is well known to every man who has helped make a soil survey. Thus, the soils of the world form a continuum or a continuous mantle over most of the land surface.

Every soil type comprises a number of separate geo-

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[2]Director, Soil Classification and Correlation.

graphic bodies or segments of the soil continuum. For the most part, the individual bodies are small so that several occur within a limited area, such as 10 acres. For example, bodies of Fullerton, Dewey, and Emory soils occur in a single small field in east Tennessee. Comparable illustrations can be drawn from any other section of the country. The pattern of small individual soil bodies thus introduces local differences into the soil continuum.

Every soil type has a characteristic region of occurrence. It occurs as a number of separate bodies or segments of the continuum within a certain geographic region or regions. Most soil types commonly occupy characteristic positions in a given landscape. The occurrence of specific soil types in definite geographic regions is reflected in regional differences in the soil mantle of the earth. Thus, there are differences of importance between soils of central Maine and soils of central Arizona, normally greater than local differences in either place.

Although the soil continuum varies both locally and regionally, all soils are alike in some ways. All are three-phase systems; i.e., solid, liquid, and gas. All or nearly all consist of the same major components; i.e., mineral matter, organic matter, water, and air. The proportions of these major components vary widely. All soils have profiles of some kind, and all occupy space. In other words, all form small segments of the surface mantle of the earth. Common to all soils, these features are of consequence to theories of genesis.

To be adequate, a theory of soil genesis must be consistent with the similarities and differences known to exist among the soils of the world. This seems almost too obvious to be worthy of mention but it does deserve emphasis. A theory of soil genesis should be consistent with the existence of soils of the world as a continuum, of features common to all soils, of the normal gradations from one soil to its neighbors, and of differences expressed to various degrees among soils.

Steps and Processes in Soil Genesis

Soil genesis can be viewed as consisting of two steps; viz, (*a*) the accumulation of parent materials, and (*b*) the differentiation of horizons in the profile. It is not suggested that these steps are clear-cut and distinct or that they lead only in one direction. The two merge and overlap so that it is impossible to tell where one begins and the other ends. For purposes of discussion, however, it is convenient to subdivide the broad and complex topic of soil genesis, as has been done in many earlier discussions. Examples are (*a*) the reference to combined effects of weathering and of living organisms by Dokuchaeiv (11); (*b*) the outlining of destructional activities of weathering and of constructional biological activities by Kellogg (7); (*c*) the distinctions between weathering and soil evolution made by Nikiforoff (13); and (*d*) the subdivision of soil formation into soil wasting, the organic cycle, and the inorganic cycle by Taylor and Cox (19).

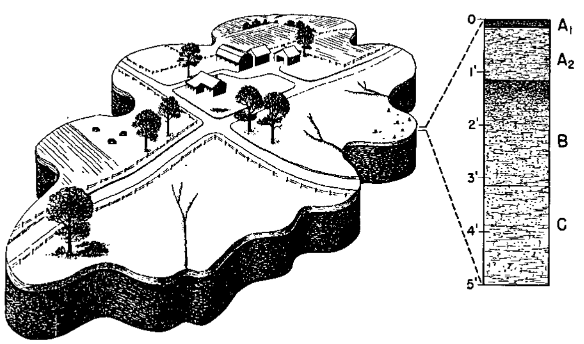

Figure 1—Sketch to illustrate a single body of soil as it occurs together with a diagrammatic soil profile. This body would be shown as one delineation on a detailed soil map.

Subsequent discussions in this paper are focused on horizon differentiation. This is not intended to imply that the accumulation of parent material is unimportant. The nature of the regolith in which horizon differentiation proceeds does affect the rate and direction of changes immensely. Lack of space, however, precludes full discussion of either of the two steps. Furthermore, the theory of soil genesis outlined in this paper is more directly concerned with the second step.

Horizon differentiation in soils is considered due to four basic kinds of changes. These are additions, removals, transfers, and transformations in the soil system. These four kinds of changes cover a wide range of processes. In his lectures 30 years ago, Marbut (9) observed that processes of soil development did a "good many things" in making soils from parent materials. His examples included decomposition of minerals, accumulation and assimilation of organic matter, removal of substances, translocations of substances, and development of structure.

Each of the four kinds of changes affects many substances comprising soil. For example, there may be additions, removals, transfers, or transformations of organic matter, soluble salts, carbonates, sesquioxides, or silicate clay minerals. Organic matter is added to the soil in the form of fresh residues. It is transformed and lost through decay. It may be transferred from one horizon to another. Rapid and continuing changes thus affect the organic matter in soils, accompanied by much slower alterations of the mineral fraction. Soluble salts may be lost from the profile or moved from one part to another. Silicate clay minerals may be formed by the transformation of primary minerals, or they may be lost by weathering. They may also be moved from the upper to the lower horizons. Transfers of substances from one horizon to another operate in many soils. Transformations of substances from one form to another proceed in all horizons. Considering the soil as a whole, all of these changes, and others, may contribute to differentiation of horizons.

The additions, removals, transfers, and transformations in soils do not necessarily promote horizon differentiation. Some tend to offset or retard it. For example, the materials transferred from one horizon to another by animal activity (20) or by the cracking and churning of certain clays (16) may retard or offset the differentiation of horizons. Similarly, the mixing of soil by windthrow in the northeastern United States (3) also retards the evolution of horizons in a profile. The uptake of nutrient elements from the deeper profile by growing plants is another example of transfer which does not necessarily contribute to horizon differentiation. Thus, the additions, removals, transfers, and transformations may act to promote or retard the development of horizons. Some changes operate in one direction and some in the other. The various processes operating at the same time in the same profile may be in conflict to some degree.

Role of Organic Matter

Additions, removals, transfers, and transformations in organic matter during horizon differentiation are discussed briefly in this section of the paper. The purpose is to illustrate the kinds of changes that do occur. Organic matter has been chosen for the discussion as one example of a major constituent, not necessarily the most important. Parallel discussions would be possible for silicate clays, sesquioxides, silica, or soluble salts and carbonates. It should, therefore, be stressed that the discussion of organic matter is simply meant to illustrate what can happen through gains, losses, transfers, and transformations. Lack of space precludes discussion of other substances rather than any lack of importance in soil genesis. The discussion in this section is focused mainly on mineral soils. Organic matter regimes in soils have been considered at length by Jenny (6) in his discussion of the functions of living organisms in soil formation.

Additions of organic matter are an early step in horizon differentiation in most soils. The additions of organic matter to the upper part of the regolith commonly exceed the rate of decay for a time after soil development begins. For example, a borrow pit used in the construction of a railroad in North Dakota about 50 years ago is now marked by a darkened A_1 horizon approximately 6 inches thick. Crocker and Dickson (2) found appreciable accumulation of organic matter in soils being formed from fresh glacial drift in Alaska within a matter of decades. After a period estimated to be 150 years, soils on this glacial drift were as high in organic matter as are most of those in the eastern part of the United States. Thus, gains in organic matter seem to be greater than losses for a time after horizon differentiation begins.

For most soils, the balance between gains and losses in organic matter seems to shift as horizon differentiation moves out of the earliest stages. The rates of loss through decay and transfer increase until they equal those of gain from plant and animal residues. Under a given set of conditions, the gains and losses tend to become equal after a time. Thus, the quantity of organic matter in a soil stabilizes and remains fairly constant even though additions continue.

The nature and amount of organic matter in each horizon of a soil depends upon the additions, transformations, and transfers in the past and present. These are in turn governed by climate, the nature of flora and fauna, the age of the soil, and the like. For example, the additions of organic matter are small in Desert soils. So are losses. The rates of additions and decay are both higher in Chernozems. They are still higher in many Latosols. The points of balance between additions and losses differ among these three groups of soils. Quantities of organic matter are low in Desert soils and relatively high in Chernozems and many Latosols.

Gains in organic matter have been of special importance in the differentiation of horizons in the soils of grasslands in temperate zones. The prominent A_1 horizons of Chernozems, Brunizems, Chestnut soils, and Humic-Gley soils[3] are due largely to additions of organic matter in the past. Other changes have also occurred but the additions of organic matter have been of special importance in setting apart the prominent A_1 horizons.

Relatively rapid turnover in organic matter is the rule in most soils. The soil is simply a way-station for organic matter moving in a larger cycle. Additions of fresh residues are made periodically. Transformations of organic matter through decay proceed all the while. Losses through decay and transfers also continue. The bulk of the organic matter added as fresh residues during a single growing season decays and disappears before the next arrives. Some indication of the rate of change is given by radiocarbon data for A horizons of certain soils formed under grass in the Midwest. Samples were obtained from the deeper part of the A horizon in uncultivated areas, except in the one instance. The data (1) for these samples are as follows:

Barnes	350 years ± 120
Clarion	440 years ± 120
Cresco-Kenyon intergrade	210 years ± 120
Cresco-Kenyon intergrade (plowed)	< 100 years
Webster	270 years ± 120

The above data indicate that a small part of the organic matter added to the soils in grasslands persists for a long while. At the same time, the implications of the data are consistent with other observations, which indicate that the bulk of the organic matter added to soils decomposes and disappears rapidly.

Transfers of organic matter within the profile contribute to horizon differentiation in many soils. Such transfers may be due to downward moving water, as in Podzols and solodized-Solonetz, or they may be due to the activities of animals.

Evidence of downward transfer of organic matter by water seems clear in Podzols. Narrow moving fronts which appear to be humus can sometimes be observed as water moves downward through the A_2 horizons of Podzol profiles. The marked accumulation of humus in the B_2 horizons of many Podzols is almost certainly due to downward transfer. This is indicated by position of the humus B horizon in relation to the water table in Ground-Water Podzols in Florida and Holland. The depth at which the humus B horizon occurs may vary widely, depending upon the position of the water table. Downward movement is also indicated by the nature of organic matter in certain Podzol profiles in Michigan. According to data of Norman and Bartholomew (14), approximately twice as much of the organic carbon is in the form of uronides in the B horizon as in the A horizon. Downward transfer of organic matter high in uronides seems essential to explain this difference in composition.

Downward movement of humus by water is also indicated in the profiles of solodized-Solonetz and Planosols. The faces of prisms or columns in B_2 horizons of many solodized-Solonetz profiles have dark coatings. These have been found to be higher in organic matter than the interiors or caps of the prisms or columns (15). The distribution of the coatings on the vertical faces of the peds and their association with clay films indicate that the humus was transferred downward into the B horizon.

The transfer of organic matter from the A to the B horizon also seems to have occurred in a number of Planosols. For example, the distribution curve for organic matter against depth has two maxima in a profile of Edina silt loam from Lucas County, Iowa. The first and most important is in the A_1 horizon (4.41%) and the second smaller one is in the B_2 horizon (1.47%). The A_2 horizon has the first minimum of 0.90% and the C horizon the second minimum of 0.32%. These differences in amounts of organic matter are not large, but they suggest transfers of organic matter.

Losses of organic matter are apparent in the deeper A horizons of Brunizems which have been occupied by forest and are gradually being changed to Gray-Brown Podzolic soils. The appearance and gradual expansion of light-colored A_2 horizons in the profile are accompanied by parallel decreases in organic matter (22). Dark coatings on the peds in the underlying B horizons also suggest that organic matter is being transferred downward from the A horizons.

Organic matter is transferred by animals from one horizon to another in many soils. Burrowing animals move soil materials low in organic matter from the deeper horizons to the surface and vice versa in many places (20). For example, the author has observed as many as four crotovinas per square foot of horizontal cross-section in the upper C horizon of Webster profiles in north central Iowa. That number is unusual but 1 per square foot is common. Earthworms mix organic matter with the mineral fraction and move it in many soils. In soils such as Oak Lake silt loam in Brookings County, South Dakota, earthworms have

[3]Concepts of these great soil groups and others referred to later are those given by Thorp and Smith (21), except for Brunizems, defined by Simonson et al. (18), and Latosols, defined by Kellogg (8).

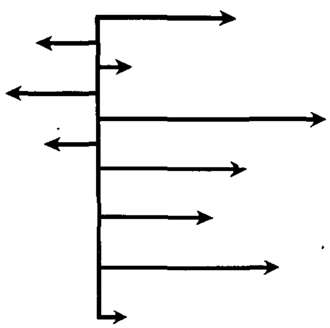

Figure 2—Diagram illustrating a combination of processes of differing importance in horizon differentiation.

completely mixed upper horizons to a depth of 2 feet or more, transferring organic matter down in the process. Earthworms transfer organic matter downward and mix it with the mineral fraction in profiles of Brown Forest soils in New York. These are a few examples which indicate transfers of organic matter by animals from one horizon to another. Collectively, for all soils, the magnitude of such transfer is substantial.

For the most part, the evidence of transfer of organic matter is not clear cut. It seems probable, nevertheless, that there is some transfer of organic matter from upper horizons to deeper ones in most soils, if not in all of them. The relative importance in horizon differentiation of such transfers may be either large or small.

The preceding discussion of organic matter is meant to illustrate the kinds of changes which affect one major soil constituent as horizons are developed. As emphasized in the first part of this section, parallel discussions could be prepared for other substances. Other illustrations could also be drawn of additions, removals, transfers, and transformations. Though not complete, the discussion still suggests the variety and complexity of changes that affect a single major constituent. The discussion also suggests differences in relative importance among the several basic kinds of processes from one soil to another.

Combinations of Processes

It is postulated that additions, removals, transfers, and transformations of the same constituents proceed in horizon differentiation in most if not all soils. Thus, the processes in horizon differentiation in Podzols would be the same as those in Latosols, Chernozems, or Desert soils. Following this line of thought, there would be some solution and transfer of sesquioxides in all of these soils, though not necessarily the same amounts. There would also be additions of organic matter, transfers of humus within the profile, and losses through decay in all of the soils. There would be one or more of additions, removals, transfers, or transformations of silicate clay minerals. The same combinations of processes would be operating in horizon differentiation in all of these soils.

It is further postulated that the relative importance of each process operating in horizon differentiation is not uniform for all soils. The relative importance of the several processes differs from one soil to another. The relative importance may also change with time in a single profile. For example, the solution and transfer of sesquioxides is far more important in the differentiation of horizons in Podzols than in Chernozems. Additions of organic matter are important in the development of A horizons in Humic-Gley soils and much less important in Red-Yellow Podzolic soils. Differences in relative importance of any process in the full combination are small when two similar soils are compared. The differences are much larger between soils that are themselves unlike in many ways.

The combination of processes operating in horizon differentiation and the balance among them may be illustrated by a diagram consisting of arrows of different lengths, as in figure 2. The length of each arrow indicates the importance of a single process. The balance among the several processes is suggested by the relative lengths of the arrows. This balance can be altered by changes in the length of any one arrow or by changing the lengths of several simultaneously. Similarly, the relative importance among the processes may be altered by changes in one or more of those processes. It should further be recognized that in certain combinations some processes may be of little importance. By and large, however, the full variety of processes seems to leave its imprint on soil character.

Further examples as applied to a few specimen groups of soils may be helpful. In Desert soils, there are small losses of soluble salts and carbonates from the profile, downward transfers of salts and carbonates into deeper horizons, small additions of organic matter, limited transfers and transformations of clay minerals, and limited transfers of sesquioxides. In Podzols, there is much greater removal of salts and carbonates, appreciable gains in organic matter, marked transfers of sesquioxides and organic matter, limited losses of sesquioxides and clay minerals, and some loss of silica. In Latosols, there are marked removals of salts and carbonates, appreciable additions of organic matter, some losses of sesquioxides, marked losses of silica, and transformations and losses of clay minerals.

The balance among individual processes in a given combination thus becomes the key to the nature of a soil. The relative importance of each process in the combination is reflected in the ultimate character of the soil itself. Additions of organic matter are of little importance in the combination of processes that differentiate horizons in Desert soils. Removals and transfers of sesquioxides are also of little importance. On the other hand, these same processes are of great importance in horizon differentiation in Latosols. This further illustrates the importance of the balance among processes in any given combination.

The variety of changes proceeding during the differentiation of horizons in a profile depend themselves upon a host of simpler processes such as hydration, oxidation, solution, leaching, precipitation, and mixing. These simpler and more basic reactions proceed in all soils. They are controlled in their turn by factors such as climate, living organisms, parent materials, and topography.

Thus, the theory of soil genesis outlined in the preceding discussions requires a shift in emphasis from theories of soil formation held in the past. The theory does not so much discard ideas held earlier as modify them and place them in a different setting. Primary emphasis is placed upon the operation of processes in combinations, with some processes promoting and others offsetting or retarding horizon differentiation. Major emphasis is also placed upon the balance among processes in any combination. It is further suggested that shifts in balance among combinations of processes are responsible for soil differences rather than the operation of markedly different genetic processes. The emphasis on widespread operation of the same kinds of changes in horizon differentiation seems consistent with the existence of the soils of the world as a continuum over the land surface. It is also consistent with the common lack of sharp boundaries between one soil and the next. It can accommodate the existence of both local and regional differences among soils. Finally, it is consistent with the sharing of some properties by all soils.

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