FUNDAMENTAL FORMULA OF SOIL FORMATION.

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ABSTRACT. A mature soil represents the steady state of the dynamic system comprising the soil and its environment, the latter including the climate and the organic world. The steady state depends upon the cyclicity of the pedogenic processes. Such a cyclicity is due to the coexistence and precise coördination of the contrasting processes of synthesis and decomposition. Presumably nothing is synthesized in the soil which does not decompose and nothing decomposes which is not synthesized. Therefore, neither accumulation nor depletion proceeds endlessly without coming to a certain equilibrium between the losses and gains.

Assuming that the rate of synthesis is constant and independent of decomposition, whereas the rate of decomposition is constant but the absolute value of decomposition varies as a function of accumulation, the steady state of the soil system might be expressed by an equation the limiting value of which is as follows:

$$S_n = \frac{A}{r}$$

in which S_n is the amount of any variable substance at the moment when a steady state is reached and constant for as long as such a state is maintained. A is the amount of this substance synthesized each year (constant), r is the rate of decomposition as a decimal portion of the amount present, and n is the number of years required for reaching the equilibrium.

Obviously, n is infinity. The difference between the gain due to synthesis and the loss due to decomposition, however, is approaching zero and at a certain moment becomes negligible, thus giving n a definite value.

The steady state of a mature soil is not absolute, being subject to continuous adjustment to the concurrent geological processes and to general evolution of the soil which depends upon the broader biochemical cycles on the surface of the earth.

SOIL science is a young but rapidly growing discipline. In spite of the relatively short time which has elapsed since it emerged as an independent branch of science, it already has outgrown some of the original underlying concepts. The concepts change, but the words remain the same until the disparity between their meaning and the concepts makes their further usage misleading.

The fundamental concept of soil science is the concept of soil. Dokuchaev and his followers, especially Sibirtzev and Glinka, have defined the soil as an independent natural body which develops from a given parent material under the influ-

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ence of climate and organisms acting upon such a material for a certain period of time. Climate, organisms, parent material, and time are regarded as the factors of soil formation, although some authors prefer to call them agents, agencies, forces, causes, elements or conditions of the soil formation.

Marbut[3] emphasized that the soils, being independent natural bodies, must be defined by their own characteristics and not by forces or factors which have produced these bodies. Thus, Marbut tends to separate the soil as a physical entity from its environment. The contraposition, soil versus environment, however, is open to criticism. It is generally accepted that the soil first of all is not a static body but is a dynamic system. Deprived of its dynamics the system ceases to be a soil and becomes an inert assemblage of the soil materials. Its dynamics are a direct function of the environment outside of which they cease to operate. Therefore, a dynamic soil is no more independent from the environment than, for example, a living organism is independent from oxygen or water. As an organism in a vacuum is nothing more than a corpse, the soil outside of its environment is just a pile of the soil material. It follows that what is usually designated a factor of the soil formation is in reality an integral part of the dynamic system. A steam engine is just an assemblage of metal parts, whereas the same engine at work is a system in which fuel, water, and steam are no less vital than the cylinders, pistons, and levers.

Some controversy exists about the relative importance of the factors of soil formation. The older representatives of the Dokuchaev's school in Russia and Hilgard's school in the United States have placed a rather strong emphasis on climate. The former school has coined the principle that the general trend of soil formation or the genetic type of soil does not depend upon the parent material. This school established that fundamentally different soils, such as podzol and chernozem, develop from the same parent material in different climatic regions, whereas essentially the same soil, such as either a podzol or chernozem, develops from different parent materials if the latter are affected by the same climatic conditions. This principle refers to the acquired soil characteristics only, indeed, and does not refer to the inherited features. No one ever maintained that the podzol derived from granite is or ever will be precisely the same as the podzol formed on limestone, or that the chernozems developed from the glacial till and loess are identical in every respect. It was sufficient to establish that both soils are podzols in the former case and both are chernozems in the latter.

Neustruev[5] argues against an overestimation of the rôle of climate. He states that "parent rocks are far from being just a white sheet of paper on which climate may write whatsoever it desires." Thus he made an attempt to revive, although in a modified form, the views of the older school which made an accent on geological factor.

The most recent tendency is to ascribe the leading rôle in soil formation to the biotic factor. It must be borne in mind, however, that all attempts to evaluate the relative importance of different factors in the process of soil formation are purely academic. One may argue as to whether the wheel or axle is the most important part of the vehicle, but the driver knows that he cannot make any progress without either one or the other.

The group of principal factors of soil formation includes the time factor, although time stands quite aside from the other factors. According to Jenny,[1] time belongs neither to the soil nor to the environment and one may wonder whether any good reason exists for ascribing to time the status of a factor of soil formation, similar to that of either climate or vegetation. The time factor acquired particular prominence whenever the so-called age of the soil is considered. Several attempts were made to classify soils according to the stages of their development and the terms such as young, immature, mature and old soil came into common usage, although the underlying concepts of the soil maturity and of various stages through which the soil approaches maturity never were satisfactorily defined.

Prassolov[6] warns against the tendency to introduce an historical approach in dealing with the soil classification. He points out that individual characteristics of different soils develop because of the uneven local conditions rather than of different ages of these soils. Therefore, the tendency to substitute an abstract idea about the stages of formation for observable facts in dealing with the soil taxonomy is rather dangerous.

Soil maturity itself is one of the most controversial concepts in soil science. It has been more or less generally assumed that a mature soil is characterized by a distinctly developed profile, and that its maturity can be defined by certain morphological characteristics the absence of which indicates a relative youthfulness of the soil.

Contrary to this interpretation, we assume that the soil maturity indicates the steady state of the soil system which is obtained by a precise adjustment of the parent material to the environment and coördination of all factors comprising the soil system. Such an adjustment is not necessarily accompanied by a striking development of the profile or any particular morphological characteristic. Any soil, no matter how dull and inconspicuous its profile, can be adjusted to its particular environment and thus be just as mature as any other soil. It follows that morphological characteristics alone cannot serve as the criterion of the soil maturity.

The steady state of the soil system is not the state of static rest. The soil maturity may indicate the cessation of progressive change of the original material but it does not indicate the suspension of the process which brought about such a change. This process keeps going as long as the soil exists. If it stops then the soil becomes an inert relic. To put it another way, the difference between the original material and the soil gradually increases until the soil reaches maturity. When maturity is reached this difference becomes stabilized and is maintained as long as the given soil continues to function. Such a state may persist indefinitely provided that the environment does not change. It follows that the time factor has no significance after the soil has reached maturity and that the difference in the age of mature soil does not necessarily indicate any appreciable difference in the systems themselves. A hundred-year-old system and another 10,000 years old may be quite alike if both systems are mature and exist in identical conditions.

Theoretically, the time factor might have some importance before the steady state of the system is established, i.e., during the period beginning with the initial state of the soil system and ending with its maturity. We do not know how long this period might be because we do not know the velocity of soil development.

Perhaps it would be possible to determine the velocity of modification of the parent material experimentally by exposing such a material to the influence of certain constant climatic and biotic conditions. Such a condition, however, hardly exists in nature. The steady state of the soil system is approached by a mutual adjustment of the substratum to the environment and of the environment to the substratum. The principal elements of the environment are climate and organisms. The climate of the atmosphere, perhaps, is not affected by the character of the soil. The climate of the soil which is instrumental in soil formation, however, is to a large extent the function of the soil itself. Under essentially the same air climate, the soil climate of the loose sandy soil may be markedly different from that of the dense clayey soil. Since the texture and density of the original material may change due to the development of the soil profile, it is possible that the character of the soil climate also changes even if the climate of the air remains constant. The same is true as regards organisms. Certain species of plants which may flourish on the original material perhaps will not survive on the modified material and will be replaced by different species. Thus, the general character of both soil climate and vegetation will not be constant and truly independent from the changes taking place in the substratum.

The changes in character of the biotic factor continue until the climax vegetation is established and this apparently coincides with the stabilization of the steady state of the entire soil system, i.e., its maturity.

Now, what does such a steady state or dynamic equilibrium mean as regards the soil?

We assume that the fundamental characteristic of the soil-forming processes is their cyclicity which presupposes that each progressive process is accompanied by corresponding regressive counterprocess. Synthesis must be accompanied by decomposition; accumulation by leaching; any kind of gains by losses, and vice versa. If it were otherwise, then the earth would be wrapped by a mantle composed of certain unreactive materials and its dynamics would come to a standstill.

If the rate of loss is equal to or greater than the rate of synthesis, then obviously no accumulation can take place. Accumulation is possible only if the rate of production is greater than that of the losses. Such an accumulation, however, does not continue unchecked. The rate of accumulation gradually decreases approaching zero as the soil system develops toward maturity. No further accumulation takes place after maturity is reached and an equilibrium is established. Beginning from this moment, production equals the losses and the content of accumulated material remains constant until some change in the environment disturbs the equilibrium. A continuous replacement of the lost material by an equal amount of the formed anew indicates that the accumulated substances are not fixed but undergo continuous renovation.

The general formula of this process is as follows:

$$S_n = A\left\{\frac{(1-r)\ .[1-(1-r)^n]}{r}\right\} + A \text{..........Eq. 1.}$$

in which

S_n is the amount of any substance present at the end of n years.
A is the amount of this substance synthesized during one year.
r is the rate of decomposition expressed as decimal portion of the amount present.
n is number of years.

It is assumed that the amount A is the same each year throughout the period characterized by the stable condition of the environment and that r is constant as regards its relative value although its absolute value increases as a function of S_n until it becomes equal to the amount A.

The limiting value of equation 1 is as follows:

$$S_n = A\left(\frac{1-r}{r}\right) + A = \frac{A}{r} \text{..............Eq. 2}$$

Obviously n is infinity. At certain moment, however, the value $(1-r)^n$ becomes negligible as approaching zero, thus giving n a definite significance. It follows that the time factor of accumulation is significant when the age of soil is less than n years and has no significance or becomes negligible after this age is passed. The $(n+1)^{th}$ year is the first year of the soil maturity.

The mechanism of the chemical and physical processes which take place in the soil is not yet precisely known. Very little is known about various phases of the cycles. Therefore, the formula given above may be analyzed by conjectures only. We know that appreciable and measurable amounts of humus are formed annually, that certain amounts of free carbonates are deposited in certain soil horizons and certain mineral colloids are produced in others; we know that in certain geologically mature regions these processes continue for millenniums at a presumably constant rate and, nevertheless, none of these substances accumulates in the normal soil above some rather limited quantity. Consider, for example, that the amount of the new humus produced during one year would form a layer one centimeter thick. If this humus were stable, then after 1,000 years this soil would be covered by a layer of pure humus 10 meters thick. No such accumulations actually are taking place in the soil. From this we must conjecture that the pedogenic production of these materials is accompanied by their decomposition. If this is not true, then we have a fundamentally different straight-line geological process which leads to the indefinite accumulation of a stable material such as, for example, peat.

By way of illustration, let us consider in some detail a few most common examples of pedogenic accumulation. Suppose that A (Eq. 2) representing the amount of new humus formed from the organic residue in the course of one year is one ton per acre. Certain parts of this humus undergo mineralization, i.e., break down into carbon dioxide, water, and mineral salts. Suppose that the rate of decomposition is such that during one year one per cent of the total humus disappears from the soil. Then S_n which represents the amount of humus that will accumulate in the soil during n years will be equal to 100A or 100 tons per acre. This soil will contain so much humus when it reaches its humus maturity. After this stage is reached, the annual production of a new humus becomes equal to the annual loss of it due to the mineralization, and the content of humus (S_n) in the soil remains constant for as long as the controlling factors remain unchanged.

Now let us consider an accumulation of the free carbonates. The carbonates, presumably, are formed by combining carbon dioxide released by decomposition of organic matter with the bases liberated by decomposition of various mineral and organic compounds. Synthesis of carbonates apparently is accompanied by their decomposition followed by leaching of bases and dissemination of the carbon dioxide. If the rate of production is higher than the rate of the breakdown, then the carbonates begin to accumulate in the soil and such an accumulation continues until the stage of maturity as regards carbonates is reached. Again, if A is the amount of new carbonates formed during one year and r is the rate of decomposition expressed in per cent of the total amount of carbonates, then S_n will give the content of carbonates in the soil at the state of maturity.

Presumably, the carbonates could be formed wherever the chemical and biological weathering of rocks is taking place, although their synthesis and retention in the soil take place only if the rate of their solution and leaching is lower than the rate of production. The ratio between these rates is not the same under different climatic conditions. In humid regions, the rate of leaching is higher than that of production, thus no accumulation is possible in these regions. On the other hand, in arid and semiarid regions the rate of removal is lower than that of production and the accumulation is taking place.

The ratio between the rates of production and leaching controls not only the mere presence or absence of carbonates in the soil but also the distribution of accumulated material throughout the soil profile. Carbonates may be formed in any horizon but they accumulate only in some particular horizons. The rate of leaching in the A horizon is usually greater than that in the B. Therefore, even if the rate of production is the same in both horizons, there might be no accumulation in the A (except for the Solonchaks), whereas it will occur in the B horizon. Farther down, i.e., in the C horizon, the rate of leaching may be less or the same as in the B. Here, however, the rate of production must be lower than in either of the upper horizons because of the decrease in content of free carbon dioxide and free bases. Therefore, the content of carbonates which can be maintained in the C of a mature soil drops below that in the B, thus forming a conspicuous zone enriched in carbonates, usually designated a horizon of the carbonates accumulation.

Accumulation of the carbonates, like the accumulation of humus, does not proceed endlessly. The rate of accumulation decreases approaching zero as the soil reached maturity. After this stage is reached, the content and distribution of carbonates remain constant, although not static. Some part of carbonates continuously is decomposed, leached and replaced by an equal amount of newly synthesized.

What is said about the dynamics of carbonates may be repeated about the dynamics of various other salts and compounds, i.e., about any other pedogenic process, although many important aspects of these processes are not as yet known. Let us consider, for example, the accumulation of colloidal clay in the B horizon of various soils. One may assume that this accumulation of colloid is governed by the same law which regulates accumulation of humus and carbonates. Presumably, colloids are formed continuously, but the horizons of their accumulation do not grow beyond certain limits. This indicates that their formation is followed by the reverse processes about which practically nothing is known. Perhaps, they consist in part of a complete breakdown of the clay mineral into the free oxides and in part of recrystallization of the secondary minerals.

Needless to say, the formulas given above represent only the general trend of pedogenic processes which undoubtedly are much more complicated than those outlined in this paper. The soil humus, for example, is a mixture of many different substances which decompose at widely different rates. Numerous intermediate products are formed before a complete breakdown occurs. Therefore, the general rate of decomposition of humus is nothing more than a rather rough approximation of the mass effect of numerous reactions which take place in the soil. The steady state as regards some particular constituents of humus should be reached sooner than that of the others. The steady state of the whole humus complex, however, must depend largely upon the stabilization of the last constituent.

The quantity A (Eq. 2) of the fresh humus formed during one year has been assumed as constant. It has been pointed out, however, that this is hardly true. The amount of new humus which may be produced depends upon the amount of fresh residue, its source material, and its composition. This in its turn depends upon the character of vegetation, kind of plants, their density, and so forth. It has been pointed out already that the character of vegetation may change according to the changes taking place in the soil, thus shifting the value of A in one or another direction. Therefore, in assuming a constant quantity A we consider only an average for the entire period of the soil prematurity.

The same is true as regards mineral constituents of the soil. It is very likely that dynamics of individual oxides such as alumina, silica, iron oxide, lime, and magnesia are more or less independent from one another. Some of them may reach an equilibrium earlier than the others and such an equilibrium in one soil horizon may be fundamentally different from that in another horizon of the same soil profile. The steady states of the constituents which reach the equilibrium sooner than the others, however, may not be wholly independent from the others and more likely are subject to shifting in one or another direction and adjustment to the changes caused by the stabilization of the constituents which come to equilibrium later.

Therefore, in order to evaluate the whole process of a gradual stabilization of the equilibrium between the soil proper and its environment, i.e., of the soil maturity, this process must be resolved into a number of individual components and each of these must be analyzed separately before the final synthesis is attempted.

A discussion of the dynamics of mineral constituents leads to the consideration of another aspect of the process of soil formation. So far we were dealing with various types of accumulation such as that of humus, carbonates, or colloids. In all these instances the rate of production is obviously higher than the rate of their destruction. Now we must consider certain processes in which the rate of leaching is higher than that of production, for example, podzolization, the fundamental feature of which presumably is liberation and leaching of the sesquioxides and bases.

Some soils, such as podzols, are subject to the measurable leaching. Many podzolic soils are affected by this process continuously during the scores of millennia, for example, the soils developed from the earlier glacial tills. Nevertheless, none of them is thoroughly deprived of the leachable constituents and a vast majority are rather weakly podzolized. Even in the strongest podzols translocation of the sesquioxides is not as drastic as one would expect it to be. These facts indicate that the processes of leaching apparently are governed by the same law which controls accumulation. Depletion of the mobile substance does not increase unchecked beyond certain limit. The rate of depletion decreases approaching zero as the soil system approaches maturity and after this state is reached the content of mobile constituents in the soil is maintained at a consant level. Leaching does not cease indeed, but its effect is balanced by that of replacement. Obviously, this is possible only if the processes of leaching are accompanied by the reverse processes of replacement.

Following the same logic, we assume that the rate of replacement is on the average constant so that the same amount of substance is returned to the soil each year. The rate of leaching in per cent of the total amount of this substance in the soil is also constant under a given set of conditions. During the prematurity stage of the soil system, the quantity of material removed by leaching is greater than that returned to the soil. The difference between the two, however, gradually decreases and becomes zero as soon as the soil reaches maturity. After this moment the loss through leaching remains equal to replacement and no further depletion takes place as long as the environment remains the same. Because of this, the soil which was subject to a continuous and appreciable leaching during several millenniums, still may remain rather weakly podzolized. This suggests that the degree of podzolization depends not so much upon the duration of leaching as upon the ratio between the rate of depletion due to the decomposition and the rate of replacement due to synthesis. This ratio is not the same throughout the soil profile; it varies in different horizons and may be reversed entirely which leads to the formation of the accumulative horizon beneath the leached.

This process may be expressed by a slight modification of Equation 1, as follows:

$$S_n = S_1(1-r)^n + A\left[\frac{1-(1-r)^n}{r}\right] \quad \text{................Eq. 3}$$

in which

S_n is the amount of a given substance at the end of n years.
A is the amount of the same substance synthesized during one year.
r is the rate of decomposition expressed as decimal portion of the amount present lost during one year.
S_1 is the amount of substance present at the beginning of process.
n is number of years.

We assume again that A is constant and r is a function of S. Thus, the limiting value of equation 2 is the same as that of equation 1, namely,

$$S_n = \frac{A}{r}$$

which arrives after sufficient time (n years) that we can neglect the $(1-r)^n$ as approaching zero.

It follows that the amount S_n present in a mature soil does not depend upon the amount S_1 which was present at the beginning of the process but depends entirely upon the ratio between the rates of synthesis and decomposition. For example, if the steady state of the degraded chernozem is characterized by the presence of three per cent of humus, then it has no significance whether the original chernozem contained five or fifteen per cent of humus, or if a mature podzol can retain two per cent of iron oxide, then it will contain two per cent of this oxide regardless of whether the content of it in the parent material was ten or two and one-half per cent.

It must be borne in mind, however, that a difference in the value of S_1 might have a strong effect on morphology of the soil. For example, if the two mature podzols each containing two per cent of iron oxide are developed from the different parent materials one of which contained eight per cent of iron oxide and another only two and one-half per cent, then the former material would lose about 75 per cent of its iron oxide whereas the latter only about 20 per cent. This might lead to the development of different accumulative horizons underlying the leached layer as well as to a different degree of modification of the original material in the leached zone itself.

Investigations of accumulation were concerned chiefly with the aspect of production. Relatively little attention was given to the reverse processes. On the other hand, investigations of leaching were dealing especially with the processes of decomposition and migration with little attention being given to the concurrent synthetic processes. Therefore, very little is known about this aspect of the soil formation.

One may conjecture that one of the principal factors stabilizing leaching is vegetation. Organic residue continually returns to the soil a certain amount of the mobile constituents in the form of the ash material of humus. In this way the equilibrium of various bases as well as phosphorus, sulfur, and other elements might be maintained. It is very doubtful, however, that the biotic factor alone is sufficient for maintaining the steady state of a mature soil, especially as regards the dynamics of the sesquioxides and silica. What the other factors may be, we still do not know. Perhaps some reversible reactions or cyclic transformations of various clay minerals and colloids are significant.

Here, again, we see that the time factor has no significance or at least becomes negligible after the soil reaches maturity.

The steady state of the soil system obviously depends upon the stability of the environment, especially of climate and biological pressure. Any changes of these factors shift correspondingly the equilibrium of the entire system. If such a shift continues in one particular direction long enough, then it may lead to a drastic altering of the original soil which is said to be an evolutional process. There is a difference in connotations between "the soil development" and "the evolution of the soil." The former means a formation of any particular soil from a given and presumably virgin parent material, whereas the latter indicates a chain of transformations of one soil into another. The first process represents the case of the soil ontogeny, whereas the second is only a phase of continuous soil phylogeny.

If we consider a formation of the podzol from glacial till or of the chernozem from a virgin loess, then we deal with the soil development, whereas if we consider the degradation of a chernozem caused by the invasion of the grassland by forest and its remaking into a secondary podzol, then we are dealing with an evolutional process. Another example of the evolutional process is the remaking of the hydromorphic soil into a "normal" one caused by the improvement (either natural or artificial) of the drainage of the poorly drained land.

The newest school of thought (mainly in Russia) assumes that the soil evolution in itself is a continuous, endless, and universal process and that all varieties of the existing soils are nothing more than temporary stages of such a process which presumably is a part of the general geochemical and geophysical cycles. One stage might be relatively shorter than another; at one stage the progress of evolution may be faster than at the other, but there is no such thing as alternation of the periods of stagnation and the periods of motion. The steady states of the existing systems are only apparent, not real. They appear as steady only because of the slowness of the evolution.

The type of soil depends upon the character of vegetation no more than the type of vegetation depends upon the character of the soil. Both are only parts of one system and are mutually interdependent. Adjustment of the soil to one particular biotic complex already prepares the ground for the changes in composition of the plant community, whereas these changes may lead to the further readjustment of the soil system to the new community.

According to this philosophy the ecological climax is nothing more than a relatively longer occupation of the area by the more stubborn and persistent transient plants.

Whatsoever the merits or shortcomings of this theory may be, it is still only a philosophical postulate. For all practical as well as immediate scientific purposes we may assume that our mature soils are relatively stable systems, at least to the extent corresponding to the stability of the regional types of climate and climax vegetation. The general evolution should not be confused with certain particular phenomena and the concept of universal evolution cannot be based safely on some particular cases of regeneration of the soil.

These particular cases refer especially to the changes of the grassland soil occupied by the forest. Recent shifting of the boundary between the open grassland and forests is more or less firmly established. In some instances the prairie has been invaded by forest, whereas in others the forest retreated under the impact of grasses. The battle between trees and grasses continues and the shift of the forest front in certain regions takes place under our own eyes.

The remaking of the grassland soil such as chernozem into a podzolized soil attracted considerable attention of the soil students, especially because this process is accompanied by easily observable changes of the most conspicuous soil characteristics. Numerous other, less spectacular evolutional processes escape our attention simply because of crudeness of our criteria and our technique. We judge the changes in soil system on the basis of observable changes of certain morphological characteristics and our methods still are very primitive, rather amateurish and fully inadequate for a precise investigation of such a delicate problem.

The replacement of the coniferous forest by the broadleaf or of any grass community by another must be accompanied by the corresponding disturbance of the equilibrium in the soil system, which may not be immediately reflected by the morphological face of the soil. Even our methods of chemical analysis of the soil are not yet satisfactory for revealing these disturbances. Therefore, our investigations of the evolutional processes deal chiefly with a few and the most obvious cases such as either degradation or regeneration of the chernozem which accompany the shifts of the boundary between the forest and the prairie.

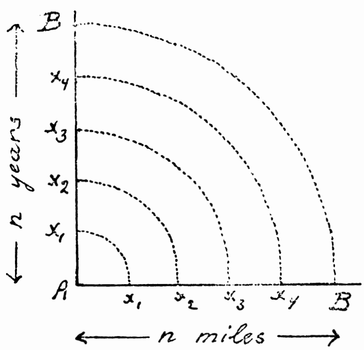
Readjustment of the soil system to the new conditions takes certain time. Stabilization of these new conditions itself proceeds gradually, indeed. We do not know yet whether changes in the soil lag behind the changes in the composition of the plant community or vice versa. Perhaps, these changes take place simultaneously. In any event the general condition of the soil system at any given time between the beginning of the evolutionary process and its culmination represents the unstable temporary state of this system. At each of these states the soil acquires characteristics somewhat different from those of the other states. None of these characteristics is permanent. If the temporary stage-profiles of the soil undergoing regeneration are arranged into a consecutive series, then this series would reveal a gradual fading and an ultimate obliteration of the features characteristic of the initial state of the system and a simultaneous enforcement of the features pertinent to the final state. For example, during the degradation of the chernozem the reaction of the soil changes from neutral to increasingly more acid; the content of humus decreases; the soil loses its dark color and granular structure; the content of free carbonates decreases until they vanish from the profile; exchangeable bases replace each other; sesquioxides begin to migrate downward and so forth.

It follows that a complete remaking of soil A into soil B proceeds through a continuous series of intermediate stages. Each stage replaces the preceding one and grades into the following. The entire process takes place at the same given point. A complete change of any soil into a different one, however, has never been actually observed or followed from the initial to the final stage at the same place. Various presumably intermediate stages usually are examined at different points and the assumption is made that at certain particular places the process has advanced farther than in other places. This, however, is not necessarily the case.

The important thing to be remembered is that there are no abrupt boundaries between the areas occupied by the different soils. If we have the soil A at one point and soil B at another, then between these two points there will be a continuous series of intermediate geographical phases of the soil. A continuous transect extending from one point to another would demonstrate a gradual fading of certain soil characteristics and their replacement by others. Now, if both soils A and B are mature and stable, then each intermediate phase between them might be equally mature and stable, being just as well adjusted to the specific conditions of the respective geographical points as the end members of the series are adjusted to theirs.

One may postulate that the transformation of the soil A into soil B proceeds through a continuous series of intermediate stages in which the soil acquires temporary characteristics similar to the permanent characteristics of the geographically intermediate soil phases comprising a continuous geographical series between the two points, one of which is occupied by the soil A and the other by soil B. To put it another way, the changes of the soil in time are similar to the changes in space, provided that the initial and final states of the soil system are identical in both instances.

This postulate may be expressed graphically as follows:



Changes due to the evolution (i.e., changes in time) are projected on the ordinate. They are taking place in the soil at one particular point characterized by a definite kind of parent material and a definite position as regards the relief of the land surface. These conditions are constant for the entire series represented by the ordinate. Since our postulate is based on the assumption of identity of the soils in both pairs, initial and final, it should be obvious that the soil in the point **B** of the geographical series represented on the abscissa (as identical with the soil at the stage **B** of the evolutional series) and all intermediate phases between the points **A** and **B** must be developed from essentially the same parent material and in essentially the same topographic conditions. It would be entirely erroneous to apply the principle of this postulate to the interpretation of the series, the end members of which are not identical as regards the parent material or location. Unfortunately, this very important condition is not always given a proper consideration, which leads to the unwarranted conclusions.

It follows that the soils classified on the basis of their morphological characteristics as intermediate might represent either mature and stable geographical phases or only temporary transitory stages. Whether they are the first or the second can be determined only after a thorough exploration of all the factors involved.

Another conclusion from the discussion of our postulate is that there is a certain functional difference between the various factors of the soil formation such as parent material, location, climate, and organisms. Two of them including the parent material and location (relief) are relatively "passive" or static, whereas the other two i.e., climate and organisms are active or dynamic. According to Joffe,[2] the former represent the material, whereas the latter supply the energy. As regards evolution of the soil, the former are constant, whereas the latter are conditionally independent variables. We emphasize the conditionality of their independence because their variability may be stimulated and influenced by the changes taking place in the "passive" component of the system, as has been pointed out already.

The relationship between weathering of the earth's crust and soil formation is another highly controversial subject of soil science. A number of soil students are inclined to identify these two phenomena and to consider the soil formation as nothing more than weathering of the bedrocks. The others make a step further and "consider weathering as one of the many processes of soil formation" (Jenny[1]), whereas the third school of thought maintains that soil formation represents a group of phenomena comprising only a certain phase of the general weathering. To be sure the whole of this question is purely academic. It deals with a formalistic division of the two closely related scientific disciplines rather than with their underlying concepts. It will be discussed here in some detail not for the sake of argument but in order to illuminate from a different angle the essence of soil formation. It is immaterial whether such a formation is nothing more than a detail of weathering (which is undoubtedly true) or something else that includes the weathering as one of its tools.

Soil science, indeed, is an offspring of the branch of geology dealing with the dynamics of the surface formations that is generally referred to as weathering. According to Merrill,[4] "the term weathering . . . . is applied only to those superficial changes in a rock mass brought about through atmospheric agencies, and resulting in a more or less complete destruction of the rock as a geological body" . . . "It is a change which began with the beginning of matter; which will end only with the blotting out of matter itself. There are no traces of a beginning; there is no prospect of an end." The endless changes on the surface of earth are due to the permanent lack of a perfect harmony between certain natural objects such as rocks and their surroundings in which the summer's heat and winter's cold, the chemical action of atmosphere, acidulated rains, and wind combine their forces. Merrill states that "what is commonly known as soil is but disintegrated and more or less decomposed rock material, intermingled, perhaps, with organic matter from plant decay. Such being the case, a study of the processes of rock weathering and the transportation, deposition, and physical properties of the resultant debris, is but a study of the origin of soils on the broadest and most comprehensive basis. Their study belongs as legitimately to the realm of geology as does that of any subject relating to rock formation or other phases of the earth's history."

Living substance as a geochemical formation representing organic world itself is, perhaps, nothing more than one of the most elaborated products of weathering. Therefore, the subject of biological sciences may also belong to the realm of geology, although its rooting in this realm has not been clearly conceived yet, and perhaps will be disputed by many biologists for many years to come. Soil science follows the trail of biological sciences: it took up one chapter from the great history of the earth and is developing it into an independent discipline without breaking the ties with the mother science and strengthening the ties with the other physical and biological disciplines.

It is impossible to draw an exact line of demarcation between weathering and soil formation, indeed. Nevertheless, the underlying concepts of weathering and soil formation are different and their identification is confusing.

The initial state of the system from which the soil formation begins is that of the unmodified parent material such as glacial drift, loess, alluvium, or any residual loose debris which are already more or less finished products of weathering. On the other hand, the initial state of the system subject to weathering is a rock. Weathering is a straight-line process; it begins from a certain state of the system and leads to another static state of this system. For example, weathering of a granite may lead to the formation of kaolin or quartz sand which may represent the stable end products. Theoretically, weathering would come to a standstill after sufficient accumulation of such unreactive and stable end products on the surface of land. In reality, however, it never ends because the process of production of such a material is accompanied by the other straight-line processes, such as deflation or erosion.

Transportation of the loose material by wind, water, or ice, assorting and redeposition are all important phases of weathering and factors in the formation of parent materials, whereas soil formation is a process which is tied to a given point and develops normally in the relatively anchored material. If the parent material is not stabilized, if either its deflation or sedimentation continues, then the normal development of the soil is encumbered or, in some instances, brought to a standstill.

Since weathering is endless, the soils regardless of their maturity are subject to it just as much as the fresh rocks. Therefore, the changes of the parent material brought about by soil formation are subject to a continuous readjustment to the shift of condition of such a material caused by its weathering. As regards the steadily anchored materials, this shift is much too slow in comparison with the velocity of the soil formation and the condition of such a material may be regarded constant insofar as the development and functions of the soil are concerned.

This brings us again to the fundamental concept about the state of maturity of the soil. It has been defined as the steady state of the dynamic soil system. Now, the question may be raised as to how can we conceive such a steady state if we know that the system is subject to continuous readjustment and beside this undergoes evolutional changes. Obviously, this steady state is not absolute. Its stability refers to the precise coördination of functions of various parts of the system which is maintained continuously in spite of the general shift of the system through various stages of evolution. This coördination of functions of the entire system including its mineral framework, its own climate and life, is the essence of harmony which characterizes a mature soil. It is not a "harmony" a lack of which, presumably, stimulates the endless process of weathering. Such a "harmony," if it existed, would lead to a standstill. We are speaking about harmony of the motion. The steam engine works not because of the lack of harmony between its parts. It works because of a perfect harmony between the cylinders, pistons, levers, fuel, and steam. Similarly, the dynamic system of the soil functions because of the complete harmony between various factors comprising the system. There are no traces of the beginning of function; there is no prospect of its end until the planet is dead; nothing is gained and nothing is lost. Thus, we conclude that this motion consists of the cycles like rotation of the wheels on which the steam engine rolls and whose motion depends upon a coördinated work of levers, pistons, steam, and fuel.

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