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TRAVAUX DE LA SOCIÉTÉ DES SCIENCES ET DES LETTRES DE WROCŁAW
SERIA B. Nr 99

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SOIL-FORMING AND TYPOLOGICAL SOIL PROCESSES

PART I

SOIL-FORMING PROCESSES

On the assumption that soil is a dynamic system, we have been carrying out, since 1910, research on soil dynamics in various soil-climatic zones. Our main interest has been in the dynamics of the processes connected with the formation, development and evolution of soils.

In the literature on soil science the term "soil-forming process" is mostly used, while the appropriate term "soil process" is rare. In all cases where there occurs the phenomenon of soil metamorphosis, due to the variability of natural factors, or under the influence of agricultural cultivation, the majority of European soil-scientists connect the phenomenon of soil-metamorphosis with the gradual development of the soil-forming process. The well-known Russian agrobiologist WILIAMS [19] * has gone so far in his theoretical speculations as to create a "theory of unity of the soil-forming process". The theory became an impediment to the development of pedological concepts and soil-science in general, especially in the field of soil dynamics. WILIAM'S theory discouraged numerous pedologists from investigating the processes occurring in the soil. The author of the theory himself distinguished tundra, podsol, turf, steppe, and swamp soils, but took no pains to examine the dynamics of the processes bringing about the formation of various soil types.

It must be admitted that the overwhelming majority of soil scientists investigate soil statics; that is, they conceive the soil statically, and develop various conjectures and hypotheses concerning

* The numbers in brackets refer to the literature at the end of the paper (p. 49).

the processes occurring in soils. It should not be surprising, then, that both in text-books and scientific papers the term "soil-forming process" is inappropriate, not rendering the actual meaning. Logically, the soil-forming process is one which forms the soil, transforms and prepares the dead rock to "accept life", or accept and colonize microorganisms. As we understand it, soil is animated, enlivened rock.

When water, and with it microorganisms, enter a crushed rock, the dead rock soon becomes animated; that is, it becomes raw soil, where the action of physical, chemical and biological processes has already been started.

This is why the processes which we have been investigating for a long period of time should be divided into two categories:

I. *soil-forming processes*, bringing about the formation and accumulation of soil mass (*substratum*),

II. *soil processes*, acting in soil already formed.

Both the soil-forming and the soil processes may run parallel, with various intensities. For example, during the spring inundation of a river valley with river water and the formation of deposits, the predominant process will be the soil-forming alluvial process, while soil processes will be restrained to a large extent during that period. But when the flood water flows away, the soil processes will prevail.

In this paper we are going to present briefly a characterization of the soil-forming processes, including:

1. rock-weathering,
2. alluvial,
3. deluvial,
4. aeolian,
5. organic matter accumulation.

1. THE ROCK-WEATHERING PROCESS

The whole of the processes causing division and transformation of rocks and rock-forming minerals under the influence of water, air, insolation, and other factors, is called rock weathering. The weathering processes occur in the surface layer of the rock, to the depth to which water, air, and temperature fluctuations can penetrate. Weathering rocks, especially when massive, change their external appearance, consistency, colour and properties. The volume of the weathered rock is very considerably increased compared with that of the original rock. Neglecting the little-studied biological factors, we distinguish two kinds of rock weathering: *physical* and *chemical*.

Physical weathering is brought about by the action of external factors, chiefly meteorological, e. g. temperature fluctuations, the freezing of water in rock crevices, the effects of winds, sea waves, and migrating water. Due to the action of the factors mentioned, cracks and crevices are formed in the rocks, followed by a disintegration of the rock into pieces of various sizes, which undergo further disintegration and division to the consistency of clay. A more important factor causing physical weathering of rocks is insolation, with the temperature fluctuations connected with this. The degree of warming up and cooling down of the rocks depends on several factors, viz., the colour, composition and structure of the rock, heat conductivity, and geographical position and exposure.

The greatest temperature amplitudes between day and night and between summer and winter occur in the continental climate. In the semi-desert zone the rock surface is warmed in summer during the afternoon hours up to about 75°C, while in the night the temperature falls as low as 12°C. Insolation is stronger in the mountains than on the plains, in view of the fact that in the mountains the rays of sunshine pass through a thinner layer of air, containing less water vapour.

Dark-coloured rocks (e. g. basalts and andesites) are comparatively more strongly warmed than rocks of light colouring. The composition and texture of rocks also influence the rate of physical weathering. Coarse grain granites, diabases, and diorites undergo weathering more readily than fine grain rocks.

Water filling up the cracks and crevices in rocks increases in volume on freezing, thus exerting a high pressure and causing enlargement of the crevices and the destruction of the rocks.

Chemical weathering. Simultaneously with the physical disintegration of the rock, chemical changes occur, which are referred to as chemical weathering. The chief factors of chemical weathering are water, oxygen, and carbon dioxide (CO_2).

During the chemical weathering of the rock the following simple processes are acting: dissolution, hydration, hydrolysis, oxidation, de-oxidation (reduction), decarbonization, sorption, etc. (Polynow [3]).

The primary processes of chemical weathering yield products in the form of oxides (K_2O, Na_2O, CaO, MgO, FeO, Fe_2O_3, Al_2O_3, etc.), while in combination with water hydroxides are formed (KOH, $Ca(OH)_2$, $Fe(OH)_2$, $Fe(OH)_3$, $Al(OH)_3$), the colloidal ferrum and aluminium hydroxides being stable and not subject to decomposition and leaching. These primary weathering products react with one another to form various salts, mostly carbonates.

The course of the decomposition of silicates is the following:

$$4(Mg \cdot Fe)_2SiO_4 + 5CO_2 + 2H_2O = MgCO_3 + 4FeCO_3 + H_2Mg_3Si_2O_8 \cdot H_2O + 2SiO_2.$$

Olivine Serpentine

At a further weathering stage the serpentine decomposes, yielding $MgCO_3$ and silica:

$$2H_2Mg_3Si_2O_8 \cdot H_2O = 6MgCO_3 + 4SiO_2 \cdot H_2O.$$

By the weathering of alumino-silicates, etc., secondary clayey minerals are formed, e. g.:

$$Na_2Al_2Si_6O_{16} + 2H_2O + CO_2 = H_2Al_2Si_2O_8 \cdot H_2O + Na_2CO_3 + 4SiO_2.$$

Albite Kaolinite

The clayey minerals are divided into 3 groups:

(a) the kaolinite group,
(b) the montmorylonite group,
(c) the muscovite group.

Their properties are briefly as follows:

(1) The clayey minerals consist of very fine crystals in the form of laminae smaller than 0.002 mm.

(2) A very important property of these minerals is their sorption ability, the montmorylonite group possessing the highest sorption ability and the kaolinite group the lowest.

(3) These minerals are of a colloidal character, and the crystals have a very large surface area.

(4) Among their components chemically bound water is found, which evaporates at the temperature of 400°C.

The character of chemical weathering and the composition and properties of the products of rock weathering depend to a large extent on the climatic and ecological conditions. Both physical weathering and chemical weathering occur simultaneously in rocks, chemical weathering bringing about changes in the chemical composition, colour and consistency of the rock undergoing this process.

The phenomena and processes presented above bear witness to the fact that the weathering process transforms the dead rock into a divided mass (weathered rock) capable of accepting and growing live organisms and starting the physical and chemical processes of a newly formed primary soil.

Weathering acts as a soil-forming process in the primary stage of soil formation, but then the developing soil processes take the upper hand, while the action of the weathering process becomes weaker.

2. THE ALLUVIAL PROCESS

During inundation of a valley by river water the alluvial process takes place. This causes humification of the valley and the deposition on its surface of the suspended matter and precipitated colloidal matter contained in the water. In the opinion of geologists and the majority of pedologists, this is a geological process, consisting in the mechanical deposition on the surface of the valley of the suspended matter contained in running river water and the formation of stratified alluvial deposits.

The studies and experiments carried out by us during a period of 9 years in the valley of the Cna river in Polesie (BSSR) have enabled us to elucidate, in some measure, the nature of the alluvial process, and to learn the general outlines of its dynamics (TOMASZEWSKI [16]).

While studying profiles of steep river banks, as well as those of alluvial soils, we have found an enormous variety in the mechanical and chemical composition and in the thickness of the individual layers of alluvial deposits. We have found a certain regularity in the structure of these profiles, in so far as at the bottom we have always found coarse-sized deposits in the form of gravel and well-rounded pebbles, or gravel with coarse sand. In the central portion of the profiles, sand and silt layers predominate, while clayey and humus strata are rarely encountered. In the upper part, besides sand and silt strata, clay and humus layers are more frequently found.

We have often considered the problem of sedimentation in a valley of clayey or humus material, carried by the flowing river waters. Under the conditions in which the alluvial process in river valleys occurs, mechanical sedimentation of the clayey and humus material, containing a considerable amount of the colloidal fraction, cannot take place. Only the processes of physical or physico-chemical coagulation can bring about the formation of the clayey and humus layers in the valleys. But in the isolated basins in the valley, where the river water is motionless, thin layers of clayey and humus material can be formed.

The alluvial process is complex, consisting of several secondary processes, viz.

(A) mechanical sedimentation,
(B) physical coagulation,
(C) physico-chemical coagulation,
(D) penetration of river water into soil,
(E) physical and exchangeable sorptions.

Processes (A)-(D) have been studied on the section of the river Cna in the vicinity of Hancewicze, Polesie, while process (E) was examined experimentally in the laboratory. The Cna river valley in this locality is on the average 240 m wide, and the river bed 14 m wide.

The mechanical sedimentation process consists in the mechanical falling of the suspended matter contained in the running river water on to the surface of the valley. In this way the sandy and silt alluvial sediments which constitute the majority of alluvial sediments are formed.

Experiments on the physical coagulation of the clayey and colloidal suspensions were carried out in the above-mentioned section of the Cna river valley in the period of 16th to 23rd July, 1933, during the great summer inundation. Due to strong sun insolation, the water on the peripheries of the valley was warmed up to 26°C. while at night the temperature of the water fell as low as 12°C. Due to the large temperature amplitudes and strong water evaporation, the physical coagulation of the fine humus and mineral suspended matter took place. On sheet iron immersed in the shallow water a grey-brown sediment perceptible to the eye was formed. The withdrawal of the flood waters was found to be much obstructed by the slime of the meadow vegetation, mostly with brown ferric hydroxide $Fe(OH)_3$. This marked obstruction of the valley surface was favoured by the circumstance that the experimental section of the valley is divided by a small-gauge railway track, with a culvert for the railway bridge which is relatively narrow compared with the amount of the flood waters. During the spring floods that occur at the end of March or early in April, however, so strong an obstruction of the valley surface has never been recorded during these 9 years.

Experiments with the physico-chemical coagulation process of the clayey and colloidal suspensions were carried out in the spring of 1935, in the same section of the valley, at the mouth of a stream constituting a right bank tributary of the river Cna. The experiments were organized on the basis of the views of HALVORSON and STARKEY [2], who studied the changes undergone by iron compounds in soils, and expressed the opinion that iron compounds can migrate only in solutions and pseudosolutions with an acid reaction, but when the reaction is changed to weakly acid or neutral, the coagulation of ferrum hydroxides occurs. The above-mentioned stream flows out of a sphagnum peat-bog "Piata" at a distance of 5 km from the valley, and carries water with an acid reaction, pH = 5.8, containing 0.0490 g organic matter, 0.0474 g mineral matter, with 0.0058 g FeO and 0.0073 g Fe_2O_3 per 1 litre water. Where the stream entered the Cna river valley, the meadow surface of the valley was sprinkled over an area of 0.5 ha with 1000 kgs. powdered quick lime, CaO. At the beginning of the inundation period the water of the stream was directed on to the limed surface, and a couple of days later on, the river water also reached this surface. After 3 weeks when the flood was over, and the surface of the valley had dried a little, we made an inspection of our experiment. From a distance of 30 m we noticed small rusty-brown on the meadow flora, due to obstruction with coagulated ferric hydroxide $Fe(OH)_3$. In the southern part of the limed area, as well as beyond it, in the direction of the inclination of the surface, brown patches were to be seen, coloured by ferric hydroxide $Fe(OH)_3$. Among the brown patches the obstruction was weakly marked, small dark-grey spots of humus obstructions being discovered there. These results of the experiments confirmed our opinion that the coagulation processes of fine clayey and colloidal suspensions actually occur during the spring and, to a greater degree, during the summer inundations. Were the coagulation processes not active in the river water in the valley, the fine mineral and humus suspended matter would be carried out to the sea by the water, and there would be no clayey and humus alluvial sediments.

The process of percolation of the river water into the valley soil during the spring inundations was systematically studied in connection with the phenomenon of anaerobiosis, appearing in the water-saturated soil horizons.

Early in the spring before the floods, the upper horizons of the valley soil are not normally water-saturated, except for the damp sections of the valley with shallow stagnant ground water. The flood water percolates into the soil, brings about the water saturation of this, and feeds the ground water, the table of which is raised. The river water percolating into the soil causes the phenomenon of relative anaerobiosis, since the river water is strongly oxidized and does not inhibit the action of microorganisms. A periodical relative anaerobiosis is a desirable phenomenon, as it intensifies the processes of hydrolysis, contributes to the building up of a good soil structure, and improves the physical and chemical properties of the soil.

The exchangeable sorption processes were examined experimentally in the laboratory. Six cylinders of soil, each of 250 c. c. capacity, were put in an oval tin bath tub with an outlet. The tub was supplied at one end with water from the water-supply in such quantities that the cylinders of soil were immersed in the water. At the other end was an outlet pipe. The inflow and outflow of water were controlled so as to keep the water flowing like river water. For the experiments humus soil containing absorbed $Ca^{\bullet\bullet}$ cations was used in the cylinders. By the side of the tub a tin tank was placed, containing 0.5 n KCl solution, with a rubber outlet pipe, through which the KCl solution flowed slowly into the tub with the cylinders and the running water from the water supply. While the KCl solution was being let into the tub through the outlet, the inflow of top-water was withheld. During the exchangeable sorption process the humus soil sorbed the $K^{\bullet}$ cation from the solution, and gave back the $Ca^{\bullet\bullet}$ cation.

At the end of the experiment a certain amount of absorbed $K^{\bullet}$ cation was found in the upper humus stratum of the soil, using a flame photometer.

Interpreting the results of this experiment, it may be said that under natural conditions exchangeable sorption occurs between river water flowing in a valley and the valley soil. It may be assumed that exchangeable sorption of gases also occurs, viz., the soil sorbs a certain amount of oxygen from the river water, and gives back a certain amount of the CO_2 and CH_4 produced in the soil.

It is clear that the conditions of the laboratory experiments, as well as the course and intensity of the sorption processes in these experiments, deviate from the natural conditions, nevertheless they corroborate our concept of the action of the exchangeable sorption processes between the alluvial soil and the flowing river water in river valleys.

The results of the experiments and studies on the nature and dynamics of the alluvial process permit the expression of a justifiable opinion that the alluvial process is neither a simple nor a geological process, consisting in the more mechanical deposition of the river water suspensions on to the valley surface. It is a complex process, or a complex of processes occurring in the specific environment of a river valley, during the periodical inundations of the surface of the valley by the river water. As a result of the action of the alluvial process, alluvial sediments are formed in the valley, and these constitute the material (mass) of the soil. The alluvial process should thus be regarded above all as a soil-forming process. Since some of the above-described processes occur also in the formed alluvial soil, the alluvial process is at the same a soil process. It is, therefore, a difficult problem to separate both the sphere and the mechanism of action of the soil-forming and the soil processes.

3. *THE DELUVIAL PROCESS*

The deluvial process, like the alluvial process, takes place under the influence of flowing water. The fundamental difference between these two processes is that the alluvial process occurs in furrowed longitudinal valleys, the water having its range of action limited by the edges, and the alluvial sediments gradually fill up the valleys.

The deluvial process is due to the action of water flowing down a flat slope in the form of a dense network of minute rivulets; the deluvial sediments fill up the lower-situated plains as well as the lowlands and the depressions of the ground. As the deluvial process consists in washing down material from higher-situated to lower-situated places, the dynamics of this process depends on the amount of the water flowing down, the degree of slope inclination, and the properties of the material washed down.

Larger areas of deluvial formations are found in zones adjacent to mountainous regions. In Poland, vast areas of deluvial formations occur in the form of a wide belt bordering the foot hills of the Carpathian and Sudetic mountains. Round the Świętokrzyskie hills, in the Kielce district, large stretches of deluvial formations are found.

Deluvial formations also predominate spatially in the Alpine valleys. Cultivated land, formed on loess, is also covered by the deluvial process, so that on a strongly undulating loess area, mostly lowland, large stretches of deluvial formation are found.

The deluvial formation areas adjacent to mountainous regions exhibit a clay-silt mechanical composition and are, according to our terminology, fine sand loams of aqueous origin, with the following mechanical composition:

Components	Thickness (in mm)	Percentages
sand	>0.1	22 - 34
fine sand	0.1 - 0.02	29 - 52
silt	0.02 - 0.002	12 - 24
colloidal clay	<0.002	11 - 21

In the scientific literature (geology, geography, soil science, geobotany), the authors ascribe these fine sandy loams to loesses of aeolic origin.

On geological and pedological maps, both Polish and German, areas of deluvial fine sandy loams are marked as loess regions.

The results of our studies in the field and in the laboratory have shown them to be fine sandy "loess-like loams" of aqueous origin for the following reasons:

1° they contain in their mechanical composition on the average 18% colloidal clay of particle diameter <0.002 mm, while loesses of aeolic origin are distinguished by far less consolidation and contain about 9% colloidal clay;

2° they contain on the average about 36% of the 0.1 to 0.02 mm fine sand fraction, while loesses proper contain above 56% of this fraction;

3° they do not contain $CaCO_3$, except for a few localities situated in the vicinity of weathering carbonate rocks;

4° they often contain a considerable admixture of gravel, so they cannot be attributed to formations of aeolic origin.

Seams of fine sandy loams have a relatively small thickness — 1.5 to 2.5 m on the average. In some localities (the environs of Jarosław and Przemyśl in the Carpathian region, Biały Kościół and Księginice in the Sudetic region), their thickness attains 6 to 8 metres. The fine sandy clays were formed as deluvial formations by the washing out of the fine material from the weathered hard rocks and its transportation by water falling from the mountainous region to the lower lying localities.

The dynamism of the deluvial process does not consist only of the transportation of the fine material from the hilly regions to the lower-situated areas, and the formation of seams of deluvial sediments.

This process becomes at the same time also an erosion process, bringing about the destruction of the surface rock material by the mechanical, and partly also by the chemical, leaching of the fraction of fine particled chemical compounds dissolved in the water.

The deluvial process occurs and acts also in localities of strongly undulating relief on lowland ground. The degree of intensity of this process is lower here, however, than in hilly regions. While determining the degree of intensity of the deluvial process, not only the kinetic energy of the water falling down the inclines and slopes, but also the properties of the eroded rock should be taken into consideration. In strongly undulating loess regions, subject to mechanical cultivation, the intensity of the deluvial process is high. As an example we shall briefly consider the results of the action of the deluvial process in the experimental field "Motycz" near Lublin. (TOMASZEWSKI [14]).

Fig. 1 (p. 45) represents the soil cover profile of the hill slopes and the flowless dale in the experimental field "Motycz". The broken line represents the original profile of the dale and the slopes, prior to the development of the deluvial process.

A metamorphosis of the relief, the soil cover, and the bio-ecological conditions occurred here. On the top of the hill, the thickness of the humus horizon lessened, owing to the effect of the deluvial process. On the slopes, the brown horizons of the soil profile were laid bare, still subject to the destructive action of the deluvial process; and in the flowless dale, in the bottom part of the soil profile, a layer of washed-down humus about 30 cm thick was formed, which was then covered with a 60 cm layer of the washed-down delimed loess material containing a small admix of humus.

On the slopes of the loess hill and in the flowless dale there are now other parent rocks, on which soils different from those preceding have been formed. On the slopes of the hill the two upper horizons A and B_1 of the loess soil have been washed down, and the brown deluvial horizon B_2 has been laid bare, resulting in the formation of a loess soil profile without humus. In the dale, loess soil with an underlying layer of washed humus has been formed.

This amorphous humus layer, with an acid reaction, $pH = 5.8$, exhibited strong humification-swelling properties (experimentally checked in the laboratory), and in the spring season took in water and became an impermeable layer, on which a seasonal ground water table was formed, at a depth of about 50 cm below the soil surface.

With such an arrangement of the water relations, a fundamental change in the bio-ecological conditions occurred and a soil metamorphosis took place. A shallow loess soil was formed, with an underlying stratum of transformed humus. In the spring the ground water table in the dale was maintained for 1.5 to 2 months, from the middle of April till the beginning of June.

In the given case, the deluvial process has produced in the dale a soil mass about 90 cm thick, with various properties, and has brought about a fundamental change in the ecological conditions. A damp loess soil has been formed here, defective from the view-point of agricultural utility.

The facts, observations and experiments presented above lead to the conclusion that the deluvial process is very widespread on the globe.

With a high intensity of this process, when strata of deluvial sediments are built up on which a soil profile is formed, the deluvial process becomes a soil-forming process.

4. THE AEOLIAN PROCESS

The effect of winds on the soil in Poland is insignificant in our days. The soil-forming action of the winds can be observed only on the Baltic coast. Here, in the narrow coast belt, devoid of vegetation, aeolian accumulations are formed in the shape of dunes, and the entire sandy surface of the sea-coast is subject to the action of wind.

The soil-forming effect of the winds is clearly seen in the zones of dry steppes and semi-deserts, in the neighbourhood of the northern coast of the Caspian Sea and in Turkestan (Central Asia).

For 11 years (1911-1922) we carried out systematic soil-hydrological studies at the experimental station "Choszeuty", including research on the nature and mechanism of action of the aeolian processes.

The results of analytic examination of the grey-brown saline semi-desert soil found on the plain round the Choszeuty station, 120 km north of the Caspian Sea have revealed a very strong effect of aeolian silting on the composition and properties of the soil examined. The morphological features of this soil are as follows:

A_1 0 to 4 cm. Grey fine sand coloured by humus of stratified mass composition. Strongly fermenting with HCl.

A_2 5 to 17 cm. Light-grey fine sand, slightly coloured by humus, porous. Not fermenting with HCl.

B_1 18 to 51 cm. Brown fine sand, compact and prismatic. Here there occurred an accumulation of the ferrum hydroxides. Not fermenting with HCl.

B_2 52 to 150 cm. Strongly cemented fine sand, light-grey in colour, with a large quantity of fine white spots of calcium carbonate $CaCO_3$, washed down from the upper horizons. Strongly fermenting with HCl in the upper portion to the depth of 78 cm; the fermentation becomes weaker in the lower portions. In the horizon 85 to 120 cm concentrations of white gypsum, washed down from the higher-situated horizons, are visible against the light-grey background. The transition to the next horizon is gentle.

B_3 151 to 180 cm. Grey-yellow fine sand, also saline. Weak fermentation with HCl.

C 181 to 250 cm. Light-yellow sand, loose, not fermenting with HCl.