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GENESIS OF SOILS

By S. S. NEUSTRUEV

Chapter I

SOIL AND CONDITIONS OF SOIL FORMATION *

1. GENERAL CONCEPTION OF SOIL

CONTRARY to many definitions accepted in Western Europe, most of the Russian investigators regard soil as a product of modification of surface formations, due to the combined effect of atmospheric agents (climate) and vegetable and animal organisms. Besides those factors, Dokuchaiev, who had outlined the above definition, also took into consideration the age of soil and that of the country. However, both he and his followers excluded from the scope of soil science the so called loose sediments which are not subjected to the effect of the above mentioned agents, though both Dokuchaiev and Sibirtsev consider „aeolian" loess soils to be such products as are carried by the action of the wind, and both these authors include the so called alluvial soils, i. e. soils of river flood-plains and of sea-coastal marshes into their soil systems. It is doubtless that Dokuchaiev was fully aware of the complexity of the problem, for he admitted a comparison between soils „of one and the same genetic series" only, i. e. the normal „dry land soils".** „From this view-point",— he says,—„no comparison can be drawn between Russian chernozem, Turkestan loess, and Nile silt", though the best German agro-chemists, such as Knoop and others have repeatedly attempted to do so, and, we may add, such attempts are still being made at present by naturalists of various countries. It is doubtless, how-

* „Elements of soil formation", according to N. M. Sibirtsev („Pedology", 1899, Ist edition).

** Contributions to the question of land valuation in the Europea Russia, with a classification of soils, Moscow, 1898, pp. 31—82.

ever, that from their view-point, those formations were soils only inasmuch as they had been subjected to weathering processes *in situ.* From this point of view soil presents an unremoved and unremovable * weathering product, and, as far as such transportation takes place, it inevitably alters the character of the process of soil formation, or, at any rate, impedes the progress of the latter. A similar definition places beyond the scope of scientific pedology many of the loose surface formations which often represent redeposited weathering products, and sometimes have the rôle of cultural „soil", i. e. of a medium for the cultivation of plants. Inasmuch, however, as soil science studies the physico-chemical properties of powder-like finely textured masses, to which true „soils" in Dokuchaiev's understanding of the term also belong, it can largely contribute to the study of loose sediments, just as it can often throw a light on the ancient continental formations in the series of ancient country rocks, i. e. such formations as had in their time undergone the effect of soil forming agents, by closely studying the weathering processes occurring in the superficial parts of the earth's crust.

The physico-geographical („natural") bodies, ** which are formed in the process of weathering *in situ,* possess, according to Dokuchaiev, a definite *construction,* or *profile*—a term now used by many scientists (apparently, beginnng with Ramann)—that reflects the results of soil forming processes in the succession of separate horizons, and in their morphology, i. e. in their texture, colour, structure, mechanical intrusions, and new growths of chemical origin. As will be further seen, those processes not only vary throughout the whole of the globe, but can also be differentiated within inconsiderable areas as dependent on external conditions.

This regularity in the correlation of soil horizons possessing definite physico-chemical properties, which results in the formation of a definite profile, led Polynov [92] to regard soil as *„a paragenetic series of weathering rocks represented on the earth's surface by a definite humus horizon".*

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* Penk similarly does not connect the weathering process with the transportation of material (see Polynov. Soils and their formation, 1925).

** Concerning soil as a „natural" body — see next chapter.

Polynov's definiton, however, has met with many objections which we shall not discuss here, though we consider it necessary to mention that Glinka[36] had even earlier *identified soil formation with weathering*, in Van Hise's understanding of the term, i. e. he regarded as soil all such surface masses of the earth's crust as lie within the zone of weathering as far as the level of ground-water, where, according to Van Hise, the zone of cementation begins.

This identification of soil formation and weathering was, however, far from being generally accepted. Dokuchaiev restricted his conception of soil to the idea that soil formation is due to the combined effect of weathering and of „*animal and vegetable organisms, lower organisms in particular*". It is known that the quantity of the latter markedly decreases towards the bottom of the soil profile, and the soil therefore is restricted to a comparatively thin layer that swarms in bacterial life, i. e. to that „edaphon" of Francé or that soil of Williams and Perotti, which is wholly within the sphere of biological or „biotical" (after Williams) processes. As it has been proved by Vinogradski's recent work, the number of micro-organisms which live in the upper soil horizons amounts to milliards in 1 cm^3. Vinogradski's method enables one to procure from soil, with comparatively great accuracy, separate groups of bacteria for the purpose of studying their activity. It should be mentioned here, for the benefit of those following the „biological" tendency, that in this case desert soils, as well as to a certain extent tundra soils, might scarcely be regarded as soils; on the other hand, the products of the life-activity of organisms in soils, which are rich in them, may extend their influence to a far greater depth than that of layers, where their life and activity are concentrated, and therefore it might be difficult to determine the lower limit of soil. Moreover, the weathering processes in the „abiotical" layers of the earth's crust may scarcely be separated from the soil forming processes in that part of it, where organisms chiefly live. At any rate, soil science has no right to decline studying such processes as occur in the „abiotical" layers without the risk of being converted into a purely biological discipline. In this case, as well as in the case of other sciences, no distinct line may be drawn for separating soil science from cognate disciplines. In borrowing from them, soil science provides them in exchange with such results as could not have been otherwise obtained.

Physical and chemical weathering, and biological as well, depend on external conditions. These conditions are represented by the geographical landscape, and a certain effect is produced on the processes of weathering and soil formation not only by the natural, but also by the cultivated landscape (Dokuchaiev). Soil is *an element of landscape* that is mostly not directly visible, but that nevertheless entirely reflects all the effects due to which this given landscape had been created. Indeed, soil is more conservative than vegetation, and preserves for a longer period of time the characteristics of former stages, though the so called relics may also be found in vegetation. But, when vegetation has been thoroughly changed by cultivation, soil may still give us a rather true idea of the former landscape, provided this soil itself has not been considerably changed by essential meliorations. We shall here touch but very slightly on the effect produced by cultivation on soil. The separate elements of the geographical landscape are linked in a single chain, and it is impossible to gain an understanding of any one of them without studying, at any rate, the most important of others. Therefore, in order to attain an understanding of soil, it is indispensable to give one's consideration to the so called conditions of soil formation. The regularity existing in the relation between the soil and the external conditions was fully grasped by Dokuchaiev, who outlined a vivid picture of the landscapes of Russia in close connection with their soils.

2. THE FACTORS OF SOIL FORMATION

Climate.

In discussing the factors of soil formation, it should be noted that though Dokuchaiev had established such factors of soil formation as climate, parent rock, relief, vegetation, and age of the country, he still in the first place emphasised the idea, that it is their interaction * which leads to definite conditions of soil formation. However, it is Sibirtsev who carried out the analysis

* Dokuchaiev even gave the following formula: $P = f(K, O, G, V)$, where P stands for soil, K for climate, O for organisms, G for subsoils, V for age of the soil (see V. V. Dokuchaiev. On the theory of natural zones, St. Petersburg, 1899).

of the effect of different factors of soil formation, and in the first place established the predominant rôle of climate (1896); it was also he who was the first to introduce into science the idea of the zonality of soils, and of the zonal types of soil formation. To be sure Dokuchaiev also had emphasised the dominating rôle of climate (see „*Russian chernozem*"), but the theoretical differentiation of the relative importance of various factors of soil formation belongs to Sibirtsev.* The latter, having advanced the idea of the soil type and the genesis of soils, classifies the zonal soils as follows: a) according to the extent and intensity of the dynamic processes (chernozem formation, podzolisation, etc.), which determine the general character of the soil type, and b) according to the composition and structure of soils, in connection with the composition and structure of the parent material. Besides establishing the division of soils belonging to the zonal type, he also distinguishes a division of *intrazonal* soils; the local geophysical conditions are of prevalent importance in the formation of these latter as compared with the general zonal conditions; the division of „intrazonal soils" includes such soils as the alkali-, the moor-soils, the rendzina, etc.

It has been lately established that „intrazonal soils" also bear an impress of the zone, and are far from being universal; but already Sibirtsev applied the term *semi-zonal* to them, i. e. he acknowledged their being dependent on climate; thus, the character of moor-soils varies in different zones, the alkali-soils and salines are adapted to definite zones, beyond which they are found but rarely, and that in peculiar conditions.

Without discussing in detail the *rôle of climate in the process of soil formation*, we shall, however, mention that soil zonality is but a sequence of climatic zonality; and since the latter is highly modified owing to the effect of local factors, such as distribution of elevations, proximity or remoteness of the sea, sea currents, etc., the *theory of climatic soil zonality* was necessarily followed by the *idea of soil climatic provinces* (Prasolov[97]). Thus, it has been recently pointed out in literature that chernozems of the south-east and south-west of Russia, and those of Precaucasia

* Having accepted that *soil moistening* is chiefly due to the effect of climatic factors, such as water and heat, Glinka also succeeded in largely contributing to the solution of problems connected with soil formation.

and of Siberia possess certain peculiar properties as connected with the peculiarities of climate. Similarly Glinka [37] had established the „inversion" of climate, and attributed to the effect of the latter the formation of alkali-soils and salines, i. e. soils characterised by a steppe vegetation found in high latitudes, owing to a highly continental climate (Yakutsk region). The climatic maps we have at our disposal (Supan's, de Martonne's, even Köppen's and Berg's) by far do not correspond to soil maps. However, the maps of the latter two authors may best serve as basis for a soil scientist, and this is quite natural as they are more detailed. Moreover, it is necessary to take into consideration the fact that the climate of soil is not entirely identical to the atmospheric climate, and that soil is but an irregular reflection of the latter. Repeated attempts have been made to establish the chief climatic factor. The fact that the rôle of precipitation was exaggerated, and that of temperature not sufficiently accounted for, prevented the finding of an explanation of the peculiarities of soils of certain subtropical, and of torrid regions in general.*

The rôle of separate climatic factors has been but slightly analysed in literature. This fact has already been noted with regard to temperature; an independent rôle was attributed to the latter only so far as it increased evaporation, and helped the formation of low hydrates of iron oxydes in the tropical zone. Later, Zakharov** has advanced the idea that temperature played a part in the formation of mountain meadow soils, and particularly so in their transformation into peat, and their „pseudo-granular structure". The effect of a high degree of heating of rocks in conditions of arid climate was also pointed out to [25, 69]. The rôle of the mean annual quantity of *precipitation* is usually pointed out to by all the authors,

* On the ground of Glinka's idea (1908) that the effect of precipitation is neutralised by that of temperature, Lang established his „rain factor" (Regenfactor), which, owing to erroneous calculation, gave a false picture of the effect of climate on soils, even after this method had been improved by Hirth. The factor established by A. Meyer, which is the quotient of the division of the annual quantity of precipitation by the coefficient of undersaturation, approaches the solution of the problem more closely. For the purpose of establishing the soil zones of Russia A. A. Kaminski successfully applied the values of the relative and of the least relative humidity of the air both at 1 o'clock p. m.

** See further.

whereas some of them emphasise the importance of their seasonal distribution (for instance, snowless winters, in conditions of continental climate, lead to the freezing of subsoil), the character of precipitation (rain, snow, dew, etc). Owing to lack of data on the rate of evaporation or the evaporation capacity for the greater part of this country, these latter factors unfortunately cannot be used by soil scientists. Kaminski has particularly appreciated the value of relative humidity as of a factor available instead of evaporation[49].

The *importance of wind* in dry countries is a matter of general knowledge, and therefore needs not being dwelt upon. We shall only mention that already Dokuchaiev pointed out the importance of „black" storms in the chernozem zone, and that the investigators of the Ekaterinoslav gvt. had stated the gradual accumulation of dark soils in ravines due to afflation. Finally, the rôle of permanently frozen subsoil in the process of soil formation was described by Sukachev[115], Dranitsyn[20] (polar countries), Prokhorov[102] (Amur region), etc. This latter phenomenon is chiefly manifested in the swamping of soil taking place owing to its frozen lower portion and subsoil acting as water tight layer, and impeding the percolation of water. This explains the predominance of bog-soils, which is observed in tundras. By preventing the penetration of solutions into the deeper portion of soil, the permanently frozen layer leads to the deposition of humic and iron hydrates in that portion of soil which lies above the permanently frozen layer (in the so called „talik"). An irregularly coloured (with streaks and wedges) profile is peculiar to soils with a permanently frozen layer. The freezing of water in polar subsoils produces various effects on *the transportation of soil masses*, which have been particularly well described by the Scandinavian scientists; therefore we shall not discuss this question here, but shall only mention the fact that similar phenomena have been also described for Russian tundras (Gorodkov, Dranitsyn).

Thus at present, a closer knowledge of the effect of climate on soils has been attained, and this will doubtlessly contribute to the solution of problems connected with the genesis of soils. Besides, it should be mentioned that recently the effect of *micro-climate*, or the climate of the smaller elements of landscape, has also been taken into consideration, though so far chiefly in connection with the study of the ecology of plants. It is possible that the inverse effect of soil on the micro-climate may be observed here, for the climate of soil, or rather its hydrothermical régime, is a complex phenomenon not only due to the atmospheric climate, but to the properties of the soil itself as well. Until now we possess no direct data with regard to the rôle of micro-climate in soil formation. The interrelation observed recently by Skvortsov[112] between the climate and soils of irrigated oases in Turkestan as compared with the climate and soils of adjoining deserts, might be considered as belonging to this class of phenomena; however, the effect of climate on soils is interwoven here with that of irrigation water, and therefore cannot be entirely isolated.

Nevertheless, however great the rôle of climate might be, there are other factors of soil formation which, too, are of importance. The „zonal" and „climatic" types of soils develop more or less completely only in certain conditions, and among these we shall in the first place discuss the effect of parent rocks.

The rôle of parent rocks.

In the great majority of cases, parent rocks exert their influence on soil through vegetation.* This *indirect* effect is for instance seen from the fact that forests spread more readily on sandy and stony rocks[114] than on clayey rocks (owing to the peculiarities of the water régime of those rocks); hence the extension of podzolised soils on sandy subsoils far into the steppe zones (the Buzuluk pine forest, the Tambov tongue-shaped district of podzolised soils, etc.). On the other hand, the *direct influence* of rocks on soil formation consists in their water régime (as connected with their texture), and in their chemical composition. The effect of parent rocks is frequently so marked, that it makes it difficult to compare the climatical types of soils of neighbouring zones. The classification of chernozem arose in those localities of central and southern Russia, where they develop on homogeneous covering of loess-like loams (Voronezh, Saratov, Poltava, Ekaterinoslav gvts, the Don region, and the Transvolgian south-east part of USSR).

Such loess-like loams and loesses belong to rocks, characterised by a half-permeability and half-water capacity,** and therefore

* In most cases, it is the soil that is expressed by vegetation, not *vice versa*; that is why one says: „forest", „steppe" soil.

** i. e. possessing the capacity for retaining water.

it is on them that the soil profile develops most completely, whereas it displays various peculiarities on the outcrops of ancient country rocks. Thus, carbonaceous rocks (limestones, marls, carbonate containing moraines), delay the podzolisation process, as in this case, owing to the nature of the rock, the soil solution contains calcium salts which favour a coagulation of organic and mineral colloids taking place *in situ.* In such soils, an accumulation of humus occurs, whereas the process of leaching develops at a much lower rate. However, in the course of time such humus soils containing carbonates, or „rendzina" (a Polish term introduced by Sibirtsev), evolve into podzolised soils, in conditions of a forest climate. The indirect influence of the carbonaceous rocks exerted through the ground-waters favours the formation of dark-coloured half-bog-soils [27, 58]. Further, attention was given to the *low weathering capacity* of certain rocks, such as the red Permian clays, serpentines (south Ural [70]), quartzites, and others. In some cases, this is manifested by the soils retaining the tint of the rock (brown soils of the Perm gvt., which probably belong to the feebly developed podzolised soils), as described by Rizpolozhenski [104,105]; in other cases — by the grittiness and the inconsiderable depth of the finely textured layer. The rôle of saliferous rocks in the formation of salines has been repeatedly pointed out to, though it has not been always confirmed by facts. Thus, the vast spreading of alkali-soils over the Caspian plain is mainly due to the effect of climate, not always to that of subsoils which prove to possess a low salt content [71]. Likewise, the cause of the salinity of soils in the forest-steppe and steppe portions of Western Siberia may scarcely be wholly attributed to the underlying Tertiary clays containing salt; for the latter are here mostly separated from the soil by a mass of loess-like clays [14, 69, 81, 84].

The dryer the climate, the less pronounced the process of soil formation, and the stronger the effect of parent rock. Thus, soils on hard country rocks become less developed as the climate grows more arid, but at the same time they acquire more markedly features of alkaline soils and of salines: profiles of gypsiferous alkaline sierozem, and even stony gypsiferous desert soils (gammadas) * may be observed in Turkestan, on coarsely textured sub-

* This last circumstance is particularly emphasised in the works of K. N. Gorshenin: „The soils of Kalachinski district", and S. S. Neustruev: „Contributions

soils, together with the normal profile of sierozem developing on loess.

Thus, parent rocks are far from being a white sheet of paper on which climate may write anything it desires. In some cases, the effect of parent material so far diverts soil from the climatic type, that it becomes necessary to apply to this soil the term „*intrazonal*".

The effect of the relief.

Relief is almost a stronger factor of soil formation than parent rock. At present we do not associate the soil type either with the type of the relief, or with parent rock, but the modification of climatic types is closely connected with the nature of the relief. Zakharov[72, 73, 136] most thoroughly analysed the influence of the relief, and summarised to a considerable extent the work carried out in this direction by Dokuchaiev, Vysotski, Tumin, and others[119, 128, 129]. Similarly to Zakharov, we differentiate the *direct* and the *indirect* rôle of the relief. The first consists in the manifestation of the power of gravity on the slopes of undulating and mountainous localities. Leaving aside the talus and landslides on mountainous slopes, and steep slopes in general, every declivity contributes to the removal of soil particles, and thereby paralyses the intensity of soil formation; that is the reason why less developed (more or less immature) soils are peculiar to slopes. Moreover, the steeper the slope, the less developed the soils, the more marked the effect of parent rock. Therefore, a classification of slopes according to the angle of their inclination acquired considerable importance. Nabokikh[68] even introduced the term „eroded" chernozem — for chernozem with a low humus content found on the slopes of the Ukraina. The more dissected the country, the smaller the amount of normally developed soils that occur in it, and the greater the number of immature soils. Already Sibirtsev[110] noted the fact that an even country proves to be the most favourable for a complete development of the process of soil formation.

The *indirect* effect of the relief on soils is exerted by means of two factors: the climate, and the distribution of water which pre-

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to the study of the Post-Tertiary sediments of Western Siberia", 1925, though the subject has been previously mentioned in the works of authors, who had investigated the soils of Western Siberia (Khainski, Dranitsyn).

cipitates on the soil surface. The relief proves to be a powerful distributor of climatic elements. This latter rôle of the relief is principally manifested *in the vertical soil zonality* [17, 18] which was first established by Dokuchaiev for the Caucasus, and by Krasnov [60] for the Tian-Shan. Glinka [36]* states that the succession of zones depends on the foot of the mountain being situated in this or that climatic zone. Nevertheless there is, apparently, a certain zonality appropriate to every different climate: the Tian-Shan and the Altai are practically lacking in forest zones (with podzolised soils); in the northern Caucasus — zonality is different in character to that of the Transcaucasia or along the coast of the Black sea. The phenomena of vertical zonality are still more peculiar in the tropics. Vertical zonality may also occur in localities with comparatively small differences in altitude (Vysotski [128]). Recently, this form of zonality has been established by Prasolov and Makhov [66] for the Donets ridge. Further, the importance of the so called *relative position* should be noted; this comprises the separating effect of ridges, the exposition of slopes, and the peculiarities appropriate to the climate and the soils of areas more or less isolated by elevations. The fact that large ridges sometimes separate extensive climatic and, consequently, soil regions, does not require to be discussed in detail. It should be, however, mentioned that there are certain vastly spread highlands possessing a peculiar climate, such as the Transcaucasian steppe areas, which are spread over the forest zones of the northern and western Caucasus („false inversion of zones").** With regard to exposition, it should be stated that its rôle in dissected localities is frequently of tremendous importance. Leaving aside the northern and southern slopes of the Caucasian ridge, it must be said that even smaller elevations show marked soil contrasts between their northern and southern slopes. The southern slopes which are more exposed to heating are covered with soils of a more southern type than those found on the northern slopes (the „sivera" and the „solnopioki"*** of the Siberian elevations [28]). Even the asymmetry frequently observed in the

* Literary works dealing with characteristics of vertical zones of the Turkestan highlands and the Caucasus are so numerous that they cannot be quoted for want of space.

** See S. Zakharov and P. Akimtsev, in „Pedology", 1926, No. 2.

*** local idiomatic termes for northern and southern slopes.

slopes of longitudinally extending valleys was attributed to the climatic conditions of those slopes. Due to descending air-currents, the valleys enclosed by mountains have a drier climate, and are covered with soils of a more arid type than exposed areas lying below these valleys (local fens, according to Hann [79]).

The *distribution of waters* deposited on the earth's surface by rain and snow is due to the effect of the macro- and the micro-relief. In reference to this, we may first of all distinguish elements of the relief, *without or with an outlet.* Flat countries, in general, have an insufficient outlet, and therefore are relatively richer (as compared to dissected localities) in soils of an excessive moistening (moor-soils, salines). This results in such contrasts, as for example are observed between the plains of the western Turkestan and Kashgaria, lacking in outlet, and the surrounding mountains, and in other instances. All the concave parts of the relief are more exposed to moistening than the convex ones. A rapid and even impetuous outlet is observed on the steeper slopes and on narrow summits, which results in a feeble development of soil formation. Contrary to this, those elements of the relief, along which the water carried from the higher portions flows, are covered with soils possessing a higher or even an excessive degree of moistening.

It is not the macro-relief alone, but the micro-relief as well, wich plays a very *marked part* in the distribution of humidity [7, 10, 16, 72, 73]. By „micro-relief" should be understood only those variations of the surface, where the exposition of the slopes is of no great importance, owing to their being either comparatively small or very flat. A great variety in the kind of the micro-relief may be observed. According to its form, it may be differentiated as follows: micro-relief with hammocks, with knobs, with either flat or steep small sized depressions, with minute depressions or wider depressions, etc. The micro-relief may also be of different origin. That form of the micro-relief where hammocks are observed is due to vegetation; that with knobs is due to aeolian accumulation, to rodents' heaps [10, 48], to the overflow of the „talik" subsequent to the freezing of soil in the forest tundra and tundra zones, etc. Small depressions (in sandy relief) are the result of deflation, or of the so called „suffosion", * when the leaching of salts occurs in the pro-

* Term introduced by A. P. Pavlov, Member of the Academy of Science.

cess of transformation of salines into alkali-soils, which increases the dispersion of soil, i. e. the content of fine particles and, consequently, the compactness of soil in a dry state; further, they may also be due to deep „suffosion“, when fissures occur in the deeply lying rocks (Sarmatian limestones under the „pody“ in the south of the USSR), and when the process may be regarded as true Karst phenomenon, etc. The contrast between the small depressions *without* outlet and the areas *possessing* an outlet („placore“ * areas, according to Vysotski), produces the diversity of the soil covering or its *complexity*. The soil complexes of the podzol zone comprise different kinds of podzolised and moor-soils (Zakharov[137], Prokhorov[103], with his collaborators, Kasatkin[50], etc.); in the chernozem zone they comprise the more or less leached chernozem[120], the alkaline and the alkali-soils (Tumin, Popov, and others[96]). The complexes of soils characterised to various degrees by features of alkali-soils, and differing in their humus content, which are found in arid steppes, were the first to be described (Kostychev senior, Bogdan, Neustruev, Bezsonov, Dimo).

The soil transitions occurring in the micro-relief, according to Afanasiev's[1,2] terminology form *micro-zones* resembling in certain instances the climatic zones or macro-zones. The study of the soil complex from the geobotanical view-point gives excellent results both in the steppes (Bogdan[10], Keller[16], Popov[96] Larin[63]), and in the forest zones (meadow exploitation). Here the soil surveyor and the botanist were taught a lesson of solidarity, and learned to keep step basing their work on geomorphology.

It has been found that in arid steppes the complexity occurring in the micro-relief is not only due to the distribution of surface-water, but to the different relation of small depressions and protrusions to sun heat; the latter, owing to stronger insolation may have a higher salt content („the insolation complex“). ** Owing to the fact that absolutely even, horizontal, or sloping areas are but rarely met with, the existence of micro-relief is not a matter of exception, but a general rule, and it is scarcely possible that anywhere soil complexity should be altogether absent. Sufficiently thorough study will always enable us to observe the com-

* i. e. a relief with an outlet which is not affected by ground-waters.

** Observations of E. N. Ivanova (not yet published).

plexity (motley character) of the *soil covering, chiefly due to the micro-relief,* leaving aside other causes to which this complexity may be due. Therefore, our maps showing continuous areas of some definite soil are in reality conventional: in this case, the complex is not revealed owing either to an insufficiently thorough investigation, or to the inconsiderable diversity observed in the essential soil variety, or lastly, to it being understood though not expressed on the map. These complexes are particularly marked in cases when the moisture is at its minimum, for then the contrasts between places possessing an outlet and those devoid of it are exceedingly pronounced; on the other hand, these complexes are also very marked in conditions of abundant moisture, to which permanent swamping of enclosed depressions is due. The more markedly manifested the contrasts of micro-relief and macro-relief, the more striking the soil contrasts in the complex.

Mezo-relief.

The introduction of the term „mezo-relief“ for certain physico-geographical regions proved to be necessary. Contrary to the conditions of micro-relief, here the variation in altitude is more considerable, and the exposition of the slopes should not be entirely neglected in a detailed investigation. However, here we still have to deal with a minute relief characterised by frequently occurring enclosed depressions, separated from each other by convex or slightly convex smooth surfaces. The soil contrasts are here still more marked than in conditions of micro-relief. To these latter belong certain areas of the relief of suffosion* (Cheliabinsk district, along the margin of Tertiary sediments), certain moraine and kames-landscapes with a recurrence of knobs and basins devoid of outlet (the „knob and basin relief“ of American geologists). However, owing to obvious reasons, the category of the mezo-relief is evidently far from being as distinctly delimited as that of the micro-relief.

Owing to the fact that the soils of every zone vary in connection with relief and micro-relief, soil analogues are naturally found in every zone on corresponding elements of the relief and the micro-relief. Afanasiev has constructed a system of analogous

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* See p. 12.

formations (comprising even such soils as have not yet been encountered, but were only postulated [2]), without in the first place considering the effect of parent rocks.

Evolution of the relief (soils and cycles of erosion).

Omitting some of the less important features of the effect of relief on soils, we shall pass on to the discussion of the effect produced by *the evolution of the relief on soils.* This problem has been advanced but recently, though it had been previously touched upon mainly from the geobotanical point of view (Popov [96]), with reference to the evolution of soils of small depressions. The smoothing of small depressions, and the way soils were affected by it, has also been discussed; the destruction of soils, and sometimes even of the whole of the soil covering, due to the development of ravines, has also been pointed out to, etc. * Dokuchaiev introduced into soil science the idea of the *youth of soils*, as dependent on the youth of the country. This idea has not been systematically applied in soil investigations, though in certain cases it was used for the determination of the character of soils in certain districts.

The idea of the „youth" of soils is very complicated, and cannot be wholly and directly associated with the history of the relief. However, attempts have been made to solve the problem concerning the connection existing between the evolution of soils and the evolution of the relief [74]. In studying the most common instance of such evolution, namely the dissection of the „primary" plain in the course of the erosion cycle (the latter is understood in Davis' meaning of the term), a series of soil formation stages may be observed. The soil complexes in the plains are essentially dependent upon the micro-relief, and are very markedly manifested; they are characterised by the presence of either moor-soils or salt containing soils in the depressions. In connection with the variation of atmospheric precipitation, this soil covering is not constant, but easily varies [41, 42], being affected by the evolution of small depressions, in dependence on whether they are filled up by the deluvial process or become deeper owing to suffosion. With the development of the erosion, in conditions when either a rising of the country or a sinking of the erosion basis occurs, the country loses its relief characterised by the absence of an outlet, it is

* Dokuchaiev and Sibirtsev.

drained, and slopes directed towards river valleys extend over considerable areas; consequently, the soil covering acquires a more normal character, the effect of the stagnant surface-water and of ground-water is less pronounced. A similar contrast has been described by Gorshenin[43] for Western Siberia, where the chernozem of a granular structure, i. e. the normal variety of chernozem is developed either in localities adjoining rivers (for instance, along the Irtysh river), or in conditions of the „grivy" relief (crest's relief), * and is replaced with the variety of a cloddy structure on the plains situated at a great distance from the rivers. These cloddy chernozem, with a relatively thin humus horizon, may in certain cases be derived from salt containing (slightly alkaline) soils (transformation into solodee). A similar evolution of soils in Western Siberia is very probable.

A further dissection of the country results in the growth of deep valleys and of areas occupied by slopes, and at the same time in an increase in the amount of immature, undeveloped, and coarse soils on the steeper slopes. In instances of an early maturity, the remaining plains characterised by the micro-relief are found in the central parts of the country. Such are the areas of the central chernozem regions of the European part of the USSR (Tambov, Voronezh gvts), where extensive plateaus with „bliudtsa" („dishes") — shallow basins with „solodee" — are still to be found, notwithstanding the fact that on the periphery of central divides an undulating dissected relief characterised by a predominance of slopes over watershed areas („plateaus") is already prevalent. In the stage of an advanced maturity of relief development, no traces of the primary plain or plateau are left, the landscape is often of dissected character, the normal soil covering is limited in space for further extension, and therefore feebly developed, and half-washed off soils of the slopes become predominant, whereas when hard country rocks are present, barren outcrops of cliffs and gravelly immature soils are not unfrequently met with.

It is possible to form a conception of a still further stage—the old age of the relief, when it once more develops a tendency to smoothing. The erosion proves to be incapable of removing the

* „grivy"—not high elevations of elongated form on the Siberian plain, composed of loess-like and silty loams.

products of weathering, and an accumulation of sediments is observed. Conditions are again more favourable for the formation of fully developed soils which are in correspondence to the climatic type. Island-mountains („ostantsy“ monadnocks) will in this case form a contrast with the smoothly undulating plains at their foot (such as parts of the „Kirgiz silty country“—„melkosopochnik“, according to L. S. Berg).

The evolution of the relief does not, however, necessarily begin with the plains. The uplifted peneplain may also undergo the process of evolution, and passes through approximately similar stages of development as those of the plain. The uplifting will modify the „climatic“ type of the soil complex; this modification is characterised by an increase in moisture and a decrease in temperature, and consequently, a corresponding modification is observed in the soil complex. Thus, the evolution of the soil complex in connection with the evolution of the relief is dependent throughout the erosion cycle upon the character of the original stage, i. e. on whether the dissection of the country is accompanied with a rising of the country or with a sinking of the erosion basis, upon the rate at which the process of dissection develops, and on the form it acquires; while this in its turn depends upon the climate and the rocks of which the country is composed. It is natural that certain (central) parts of the country will evolve less rapidly as compared to others which are on the periphery of erosion valleys, where the process of dissection sooner results in mature forms of the relief, and in predominance of slopes covered with incompletely developed soils. In investigating some given territory with respect to soil, it is very important to know the *history* of this soil in order to understand its present aspect, for it often happens, particularly in conditions of an arid climate, that the present „climatic“ soil formation cannot entirely obliterate the features of previous conditions, and therefore it is most important to establish the stage of the erosion (or any other) cycle, to which the relief of the country under investigation and that of its different districts belong to; it is also necessary to establish what was the first stage, with which the continental period of the relief's evolution began; it is indispensable to find out at what rate this evolution formerly proceeded and now proceeds, and to establish its factors (climatical, geological, biological, and cultural). As an instance of this, we may point out the strongly dissected areas of dislocated hard rocks in conditions of arid climate — the so called „bad-lands" where *almost no soils whatever are present;* we also may mention the smoothly undulating sandy steppes, which are a result of the evolution occurring in *hillocky sands* * (Dubianski[23]), when they are covered with vegetation, and many other instances contributing to the understanding of the genesis of the present soil complex in the process of geographical cycle. ** Such instances have been frequently dealt with in literature, but no distinct geographical formulation of the problem has as yet been attained.

The dependence of soil combinations and complexes on geomorphology has always been evident to the Russian soil scientist. We have seen above how the general properties of the soil covering of plains, the conditions of soil formation in mountains, etc., were determined. Unfortunately, the data obtained have not as yet been summarised; however, as far as we may judge from literature, the following picture might be outlined:

A differentiation of the following orographical groups is of importance in soil formation: slightly dissected plains, dissected non-mountainous, and mountainous forms (according to Penk), which have been subdivided by Zakharov into the forms of medium and high mountains.

The chief soil peculiarities of plains (the effect of the micro-relief on soils) have been already discussed. Dissected non-mountainous forms are a result of the erosion of table-land plateaus, where the slopes and valleys provide sufficient drainage, and where the soil formation is most markedly manifested in areas with no exceedingly rapid drainage („placore" depressions). The irregularly dissected localities comprise the glacial forms (moraine and kames-landscapes) characterised by an alternation of more or less enclosed basins, without outlet, and separate hills (knobs) — „griady", *** and others. The mountainous forms may be subdivided as follows: the mountains of high regions, where soil formation is influenced by low temperature and air-transparence (see above), and the forms

* „*barkhans*" slightly covered with vegetation.

** The author of this report does not believe it possible to apply the term „cycle" to all the forms of evolution, and suggests it to be replaced by the terms „development" or „evolution".

*** elongated hills.

of medium mountains, with more gentle outlines. The original character of soil formation in mountains, due to the peculiarity of climate and relief, led Zakharov to advance the idea of *orogenic soil formation.*

As it is impossible to consider here all the mountainous and generally dissected forms of the relief and their effect on soil, we shall limit ourselves to mentioning the soils of river valleys. Several river terraces may be differentiated, of which a separate position is occupied by the flood-plain as being subjected to the effect of overflows (temporary excessive moistening), and therefore composed of alluvial material, and partly to the effect of a high ground-waters stand. A description of flood-plain soils of the podzol zone (chiefly of its southern part) was reported by Williams[135], but it has not always proved to be entirely uniform. In the last work of Prasolov[98], the soils of the flood-plain of the Volkhov river and the Ilmen lake are recorded. On the flood-plains of rivers of the southern part of the steppe zone, alkali-soils and salines become of main importance instead of the moor, meadow, and podzolised soils of the northern parts of the flood-plain.

The higher terraces hardly bear any traces of overflow, and of the effect of ground-waters. Such traces may be observed in them only in the shape of relict features (continuous or indurated carbonate horizons, etc.).

The evolution of valleys accompanied with the sinking of the erosion basis and the drying of terraces, has been described by Krasheninnikov[56]. The salines and moor-soils of the flood-plains of steppe rivers are substituted on higher terraces by alkaline soils. The older the terrace, the nearer its soils approach the normal climatic type.

The rôle of organisms.

Owing to the fact that Dokuchaiev's determination of soil, which has been accepted by the whole of the Russian school, acknowledges the rôle of vegetable and animal organisms, we are obliged to touch, in our report, upon the *biological factors of soil formation.* In this respect the rôle of lower organisms, such as fungi, algae, and particularly bacteria, is very important. However, the problems connected with their rôle in soil formation have by far not been sufficiently studied by our soil scientists. Investigations carried out by bacteriologists left the essential problems of soil science untouched. Indeed, in the works of the latter, particularly in the recently published papers of Kostychev, and of his collaborators, an attempt has been made to establish the rôle of bacteria in various soil (climatic) types[53]. However, this rôle has only been touched upon in reference to the conditions of Crimean and the northern (podzolised) soils, in relation to nitrogen. In that respect, the microbiology and the conditions of cultural soils in general, had even earlier been subjected to numerous investigations, as well as the genesis of soils, chiefly in connection with cultivation, cultures, etc., but without any reference to the types of soil formation. Only very few facts had been obtained with regard to the importance of ferro- and sulphur-bacteria, i. e. bacteria capable of decomposing the cellular tissue, but no explanation of processes producing the transformation into humus and the decomposition of mineral compounds, was found in the activity of bacteria; therefore, the microbiological literature, unfortunately, proved to be of small value in the study of the genesis of soils. The new tendency represented by Omelianski and Kostychev is only undertaking the first steps in this direction, and it may be hoped that with the help of soil scientists, morphologists, geographers, and chemists, the work carried out along this line will reveal many features of the soil forming processes. Provided even Francé's views on soil as on a biological formation, in which all reactions are due to the activity of organisms, shall be denied, the determination of the rôle of bacteria in different soil processes must be considered as one of the most important problems of the present day.

With regard to algae and fungi, it must be said that investigations carried out by moor-experimental stations have elucidated the rôle of the former in the formation of sapropels, whereas the investigators of forest soils have repeatedly noted a vast spreading of fungi in the forest bedding of podzolised soils. A closer determination of the rôle of fungi has not, however, as yet been obtained, though the character of the humus of podzolised soils has been considered as being connected with their activity (Williams, Kossovich). The lack of experimental work in this field does not allow us to further discuss this problem.

The rôle of higher plants has by no means been underestimated by Russian soil scientists. In connection with the problem, we should in the first place mention Dokuchaiev, who established a correlation between all the types of soil formation and vegetation. The rôle of steppe vegetation in the genesis of the chernozem proved to be particularly evident according to his view-point. Forests never produced, and never could produce chernozem, and soils covered with forest growth always are of a podzolised character. Previously to Dokuchaiev, the botanist Ruprecht had clearly shown (and even exaggerated) the rôle of steppe vegetation in the formation of chernozem, and that of grassy vegetation, in general, in the formation of „soddy" soils (of the north).

The great importance Russian soil scientists generally attributed to the rôle of vegetation in the genesis of soil is evidenced by their close union with geobotanists, and the fact that many of the latter were engaged in a scientific study of pedology. It should also be mentioned that Sabanin [109] even adopted for his soil classification a nomenclature of soil types, which corresponded to the types of vegetation, such as: soils of ever-green vegetation, steppe-soils, etc.

Williams' views in this respect stand quite apart; he not only acknowledges the important rôle of vegetation in soil formation, but explains the entire soil evolution exclusively by the independent evolution of vegetation. This evolution of vegetation and soil is acknowledged to be so unlimited that it by far extends beyond the reach of climate and other landscape forming factors. The basis of all these transformations is the so called „soddy" process, * in which the primary forest vegetation is subsequently replaced by various stages of meadow vegetation; finally, the process is terminated with the reign of the high-moor. The forest is substituted by the meadow as a result of the formation of indurated ortsteins in soils creating unfavourable conditions for forest growth — by affecting the water and air régimes: the forms of meadows characterised by a predominance of plants with rhizomes, or by that of plants growing in loose or in compact bunches, are the subsequent stages (phases) of the unfavourable changes occurring in the air régime, due to the accumulation of organic material,

* term introduced by Williams, which means the process of the evolution of soil under herbaceous growth (V. Williams. Soil Science, 1926, 2nd edition).

characterised by a slow rate of decomposition; such a gradual modification results in the settling of *Sphagnum*. *According to Williams, the steppe vegetation and soils are subjected to a similar evolution. The followers of Williams (Bushinski) are inclined to see traces of former forest vegetation in steppes as evidenced by the alkali-soils, where the illuvial indurated horizon B, as they believe, is a remnant of the ortstein horizon of podzolised soils which existed there in former times. ** However, if the „soddy" process has been described by Williams more or less comprehensively, then the evolution of steppe and desert soils is only partially elucidated, so that it is entirely impossible to subject it to any critical judgement. The „soddy" process was in its time studied by Sukachev[116], who found that the different stages of the process are not concretely manifested in Nature, that the facts obtained contradict certain statements with regard to the succession of various stages of the meadow evolution, and that at any rate the universality of the „soddy" process can by no means be affirmed, though some particular instances of the phenomenon may, of course, be observed in Nature. We consider it necessary to mention besides that the description of processes occurring in soil is not illustrated by experimental data based on observations, but is dogmatically stated in a way which impedes critical judgement, and presents no possibility of either accepting the principles there advanced or entirely rejecting them. Only such principles as obviously contradict the facts established by other investigators might have been of value in this respect, but the majority of Williams' statements deal with phenomena that have not been touched upon in the investigations of other soil scientists, either morphologists or experimentalists. These considerations compel us to evade a detailed discussion and estimation of the evolutionary system advanced by Williams and his pupils.

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* We find a reflection of these ideas on the soil evolution in the works of Hemmerling, though he accepts as chief factor not the evolution of growth, but that of natural soil leaching. (Quoted from the article of L. J. Yozefovich. Distribution of humus and nitrogen in soils of dry regions as dependent on the relief, p. 6a).

** These views professed by soil scientists belonging to Dokuchaiev's school are not accepted by any others as there is no foundation for them; there are, moreover, proofs of the contrary.

In passing on to the data concerning the rôle of vegetation found in other Russian works, we shall first of all mention that vegetation plays an important part both as a living organism, and as a dead organic substance.

In reference to the first instance, a difference in the effect of forest and steppe vegetation on soils has been noted. First of all, forest produces under its foliage a climatic régime which is very different to that produced by herbaceous growth, though opinions differ as regards the extent of the effect produced by forest growth. Vysotski's opinion is that the climate of areas exposed to air currents coming from forests becomes milder, but this view-point is not entirely approved by meteorologists (Kaminski). At any rate, the hydrothermical régime of soil under forest is quite different from that under herbaceous growth in general, and steppe vegetation, in particular. It has been established by the works of Ototski [90], Vysotski [130], and Morosov, that owing to strong transpiration of forest vegetation, subsoil under forest is far more dry than that of adjoining districts covered with herbaceous growth; this is evidenced by a lower level of ground-waters under forests, and by lower degree of moistening of the deep layers of parent material. The upper soil horizon is, however, subjected under forests to greater moistening both owing to a better preservation of the snow covering, and to a considerably lower degree of evaporation under the shade of leaves and forest bedding. Thus, more leached soils develop *ceteris paribus* under forest. Moreover, the character of the micro-flora found under forests is different from that found under grassy-meadow, and particularly under steppe vegetation; this leads to the formation of peculiar forms of humus possessing a higher degree of dispersion. The immense mass of tree roots is of a ligneous character, which also causes the humus formed under forest to be different from that formed under meadows and steppes. Contrary to this, the roots of herbaceous growth are usually distributed in the upper portion of soils; they remove the ashy elements from the deeper layers, and raise them to the soil surface, enriching the upper portion of soil with ashy elements, and thereby paralysing the decrease in bases effected by hydrolysis in the mineral portion of soil; this results in soils under meadow vegetation being much more saturated with bases than those under forest vegetation. The meadow vegetation, which does not provide as great a protection against evaporation as the forest-crown, favours a higher intensity of capillary processes in dry seasons enabling soil solutions to rise to the surface and evaporate, thus neutralising to a certain extent the results of water percolation occurring in humid seasons. This has a similar effect resulting in a decrease in the degree of unsaturation of soil, and in the degree of acidity of the soil solution.

It is necessary to note that every vegetative formation produces peculiar „micro-climate" over the area it covers, which is at present being thoroughly studied by both geobotanists and meadow-investigators (for instance Keller, and others [51]). It is doubtless that these peculiarities of the climatic régime produced by plants are of a certain importance in the soil genesis, though their rôle has not as yet been finally determined.

A substitution of herbaceous growth by the forest vegetation causes an inverse modification of the process of soil formation. Russian soil science is indebted to Korzhinski, who was the first to attempt establishing this dependence [52]. While studying the northern part of the chernozem zone in the Ural and the Transvolgian region, he suggested the idea that the dark-coloured soils of nutty structure, characteristic of the chernozem steppe oak-woods, which are known by the term of grey forest soils or degraded chernozem, are in reality chernozem modified by forest vegetation during the period of forest spreading over steppe territories. Korzhinski believed, that forest being a more vigorous formation was supplanting the steppe vegetation, and by thus spreading over steppe areas, modified, leached, and *degraded* the soils. Korzhinski did not attempt determining how far south the forest was able to spread thus replacing steppes, and, according to his point of view, the phenomenon was entirely due to a biological evolution. The negative results obtained by the attempts of an artificial afforestation of arid steppes, and the observations carried out over steppe forests, have enabled Vysotski to establish the existence of certain limits of the spreading of forest over the steppes; these limits are due to climate, as there is a certain degree of moisture which is absolutely necessary for forest growth. The fact that forests are spreading over steppe areas which had been previously free of forests shows that in the climatic conditions of the Post-Tertiary preceding the recent era, the limit of steppes was situated further north as compared to the present limit, and that its digression accompanying the moistening of climate is followed by a further spreading of forest over steppe areas. The existence of a similar era is also postulated by other paleographical investigations. In short, the degradation of chernozem under forests is one of the arguments in favour of the opinion that a change of climate is taking place during the last periods of the geological history. Successful attempts to prove experimentally the phenomena of degradation have been made by Kostychev [38,54,55]. Some data with regard to the degradation processes were obtained during field observations carried out over artificial forest plantations in steppes. Tumin's observations in the Kamennaia Steppe, and Gorshenin's [44] in Omsk (as well as those previously carried out by Tkachenko), have shown a decrease in the humus content and a leaching of bases and of R_2O_3 under forest plantations as compared to virgin chernozem. We shall discuss below the nature of degradation regarded as a podzolisation process; but we shall mention here that Dranitsyn attributed to degradation the existence of a humus intercalation below the eluvial (podzolised) horizon in podzolised soils of the Narym region (Vasiuganie)—the so called horizon A_z [21]; according to his view-point, degradation had taken place in the thick humus horizon of the flood-plain meadow-moor-soils which had previously existed here, and had developed during the intrusion of forests. Similar phenomena occurring on meadow soils have been observed by Tomashevski on the Zeia—Bureia watershed [118]. The degradation of soils develops rapidly—a period of 20—30 years is sufficient, as has been shown by observations over forest plantations, to make the physico-chemical and morphological effects entirely evident.

Krylov [61] is one of the botanists-geographers, who rejects the hypothesis of the spreading of forests over steppes, and declares that in Western Siberia the forests *were formerly extended further south*, and that their restriction to the present limits is only due to their destruction by man. He is inclined to regard the podzolised chernozem (degraded) as a result of regradation, i. e. the restoration of the chernozem profile after the cessation of the podzolisation process. However, he does not explain this process of regradation either from the morphological or from the physico-chemical view-point, in particular. Moreover, the adherents of the hypothesis of the settlement of forests in steppe regions in the recent era, regard the extension of steppes further north as having taken place in pre-historical times, but they do not deny the variation of the limit of forests occurring in the *historical* era.

Thus, a certain vegetation carries with it its own régime, and determines the direction of the soil process as one of the elements of landscape and soil formation; allthough the presumption that a plant requires a definite soil is to a certain extent true, it nevertheless may be accepted only with the following limitation: plants are sensible to texture, to salt content, and to other properties of the parent material, but it is mostly plants which direct the soil process in accordance with the conditions they create both in the living and the dead state. It is definitely established at present that the undulating and uneven character of the boundaries of podzol and chernozem soil zones is partly due to the effect of soil texture. Sandy (fluvio-glacial, etc.) areas intrude into the steppe region, and mostly spread over some depressed spaces; they favour the growth of forests, which podzolise the areas occupied by them (Tambov tongue-shaped region of podzolised soils, etc.). The forests together with podzolised soils have similarly advanced far to the south of the steppe zone on *sandy country rocks* of the Cretaceous and Tertiary systems, and may even have occupied them during the precedent drier period, as have shown investigations carried out in the Penza, Ulianovsk (formerly Simbirsk), Samara gvts, as well as in the Kharkov gvt., and others. Pine forests growing on coarse sands (i. e. feebly and averagely podzolised sandy soils), advance particularly far, as it is seen in the Buzuluk „bor" (pine forest), and other places.

Areas occupied with chalk, limestones, granites, and other hard rocks, also serve as favourable ground for the growth of the forest, where, according to Vysotski, the latter is placed in conditions similar to those of a flower pot, as water is distributed here only along the fissures, not throughout the mass of such rocks, and thus moistens comparatively small quantities of loose earth. Here also, the development of podzolised soils is observed.

Such is the connection between soils and vegetation. If it be mentioned besides that, according to bacteriologists and botanists, the life of higher plants is closely connected with bacteria, and that the processes of assimilation of mineral and organic substances by plants, as well as those of decomposition of organic tissues take place owing to the activity of those lower organisms, it will be understood that we are but approaching this side of the problem connected with soil genesis. It is possible that in many instances it will be necessary to substitute simple equations of chemical processes by a series of chemico-biological transformations.

The rôle of animals in soil formation.

Here we must again begin with by mentioning Dokuchaiev, who was the first to determine the rôle of rodents in chernozem and other soils.

Superior animals first affect the soil surface. This is particularly true in reference to the wild and cultural animals of the steppes, whose grazing has a thinning effect on the herbaceous stand, and alters the composition of the vegetation. This phenomenon of „pastural digression" has been thoroughly described by Vysotski[131]. The effect of grazing on slightly sandy soils is in this respect undoubted, and leads to their dispersion. Extensive grazing modifies the water properties of the soil surface, decreasing the permeability of loamy soils, affecting the humus content, etc. The observations carried out by Tumin over the „zapoviedniky",* in the Kamennaia Steppe, where some districts were not used as pastures, have shown that shrubs were apt to appear amidst the thick herbaceous growth of these latter districts, the soil acquired a vegetable felt on the surface, and displayed a tendency towards degradation. It is possible that in conditions of the Kamennaia Steppe a further absence of grazing might have led to afforestation. It is evident that in natural conditions a moderate pasture always existed in steppes, and that the soil and vegetative covering were formed with the help of a certain amount of herbivorous animals.

The effect of burrowing animals is, however, far more evident. Among those — the moles, the mice, etc., are characteristic of the podzol forest meadow zone, though their effect on the soils of these localities has not been sufficiently described and appreciated. The steppe-rodents, such as the marmot (*Arctomys bobac*), the so called „souslik" (species of *Spermophilus*), the blind rat (*Spolax*), the jumping hare (*Alactaga*), etc., were very numerous in steppes,

* prohibited regions.

previous to their cultivation. The marmot is at present almost extinguished, but the Siberian marmot is until now disastrous to the farmer. These two species of rodents are of prevalent importance in steppes. Burrowing their holes three and more meters deep, they cast, near the openings of their burrows, heaps of the deeper lying rock, and thus destroy the surface. These hillocks are sometimes as much as 0.5—0.7*m* high, and in case of several openings joining together, may be several meters in diameter. It is interesting to note that often they do not only consist of soft loess-like loams, but of fragments of chalk, of silicic clays, and of other fairly hard rocks as well. These passages and holes having been subsequently filled up with soft material, present in section the aspect of small circles, tubes, and sausages from 3 to 10 *cm* in diameter, called „krotoviny" (burrows).

The passages of the *Spermophilus* are smaller in diameter than those of marmots. In the humus horizon they are filled with a lighter coloured material from the deeper layers, in the underlying humusless horizon — with the darker material from the upper soil horizons. Sometimes the number of heaps formed by the *Spermophilus* and the *Arctomys bobac* is so great that the steppe seems to be covered with hillocks, and the soil in this case is burrowed to such an extent that its normal profile is deteriorated. Similar burrowed chernozem, and even loesses, have been pointed out for European Russia by Pankov [91], in the Voronezh gvt., and by Nabokikh [67]* and his collaborators, in Ukraina, where they have even been mapped by Nabokikh. The burrowed chernozem on loesses and loess-like loams possess, according to Pankov, the following properties: 1) a humus horizon of increased thickness; 2) a fairly streaked constitution of the latter due to the fragments of parent rock; 3) an abnormally loose coarse-granular structure; 4) a high effervescence level (sometimes reaching close to the surface).

Dokuchaiev has stated that burrows („krotoviny") are an obvious indication of *steppe soils*. Subsequent attempts (Taliev, and others) to prove that the burrows („krotoviny") are traces of tree-roots were not successful, and the searching of burrows is a method of no small importance for establishing the former existence of steppes

* See Contributions to the Investigation of Soils and Subsoils of the Kherson gvt., 1915, № 1, and also other works on the soils and subsoils of Ukraina, and on „krotoviny-loess" (mole burrowed loess).

within the forest zone. Sometimes even the steppe animals themselves remain as a relic, for instance, the *Spermophilus eversmanni* in the Yakutsk region, where among areas covered with „taiga“ (coniferous forests of northern zones), steppe districts with alkaline and slightly saline soils are even at present to be found (Glinka, Dolenko, and others). Of course, this indication must be made use of with precaution.

Various *Arthropoda*, insects included, play a great part in the burrowing of soil, and produce the porosity of the latter. Dimo and Rudzki have pointed out the rôle of ants in the Saratov arid steppes. A constant presence of burrows and large beetle chambers up to 3 *cm* and more in diameter, in Turkestan sierozem, has been repeatedly reported [75] from the Golodnaia Steppe (Turkestan). Dimo has pointed out the important rôle of the termites which excavate their small holes of 2—3 *cm* long and 0.2—0.5 *cm* high in great number [13]. Such a quantity of hollow interstices in soil, on areas inhabited by termites, has a fatal effect in instances when they are subjected to irrigation, producing subsidence and downfalls. Moreover, numerous passages of the *Crustacea* have been observed in the „tugay“ and the „takyr“ (grey) soils of lower Turkestan.

Finally, the great importance of the activity of worms should be pointed out to. Dokuchaiev, believing the rôle of worms in the formation of the humus layer to be such as described by Darwin [19], nevertheless did not attribute to this rôle any exceptional importance, and justly considered that in chernozem soils, notwithstanding the established fact of their containing a great quantity of worms (chiefly larvae of *Agrostis segetum*, *Agr. exclamationis*, and earth worms), the formation of humus is mainly due to plants. This firmly established inference does not, however, prevent us from estimating the activity of worms in various soils. Earth worms are not unfrequent in podzolised soils; according to Vysotski, the huge *Dendrobena mariupoliensis* grind the soils of the Mariupol steppes [132]; Precaucasian chernozem of the Terski region is being burrowed by them at the considerable depth of 50—70 *cm*, which may be the cause of their abnormally high effervescence level [83].

Finally, the typical sierozem of the Turkestan forelands is mostly burrowed [75] by larvae and worms to such an extent that it displays a grate-like cavernous structure at a depth between 10 and 50—70 *cm*. According to Sibirtsev[110], the activity of worms consists in the following: 1) in their carrying vegetative remnants into their holes, which leads to the formation of coprogenous humus, thus resulting in an increase in the content of humous substances in soil; 2) in their mingling the humus with mineral particles, and thereby contributing to the weathering of the latter; 3) in their perforating soil with pores, and thus increasing soil aeration; 4) in their loosening the soil; 5) in their modifying its structure (by forming grains, curved columns, etc).

Among these latter properties, the porosity of the soil and its granular structure prove to be of particular significance, causing a high permeability (penetrablity) of soil for water and air. In cases when similar soils are subjected to abundant irrigation, both their porosity and their structure disappear, and thus the soil loses its important properties with regard to fertility. It is possible that the fact of sierozem being devoid of features appropriate to alkaline soils is due to their higher permeability, and to their insufficient capillarity caused by the activity of worms[83].

Age of the soil and time, as a factor of soil formation.

The age of the soil and of the country is the last *soil forming agent*. Dokuchaiev distinguished these two notions, though they cannot always be considered separately. „Soils, as well as other organisms, should only be compared on condition of their being *of the same age*: youth, maturity, or old age". This just consideration led to the differentiation of *normal* and *abnormal* soils (f. i. soils subjected to the effect of deluvium processes and of erosion).

The same consideration led Sibirtsev to introduce the idea of *fully developed soils*. However, the problem of the age of soils has been so far but little studied. Single investigators have attempted to establish a connection between the character of soils and the youth of the country, such as for instance between the salt content of soils and the recent retreating of marine waters. It is doubtless that owing to the relative rapidity of the processes of soil formation, it is difficult to connect the age of soils with that of the country. We may speak of young, undeveloped soils only in instances of drying flood-plains, terraces, and lake bottoms. In other cases, the origin of feebly developed soils is due to the climate, or to a high resistance of parent rocks against the weathering process. As in the scheme of geographical cycles of Davis, besides time, the consideration of climate, rocks, and other factors, must be introduced as a correction. Likewise, in soil formation, time plays only a relative part. It has been already shown above, in what way it is possible to connect the evolution of soil complexes with that of the geomorphology of the country.

The problem of the rôle of time in soil formation has been considered by Dokuchaiev from the stand-point of the development of the soil forming process, as for instance with regard to the rapidity of humus formation. Subsequently, the idea of the soil forming process being developed within time has been applied by Hemmerling[45] to the podzolisation process. The latter author believes that no soil type whatever should be considered as something permanent and stable. Every soil must change its aspect, provided even that the combination of soil forming factors is permanent. It has its initial phase of development, and a series of subsequent stages of metamorphosis. From this point of view, such soils as show a greater intensity of soil forming processes, will be subjected to changes, and evolve more rapidly. The initial phase for the podzol zone is the so called „soddy" (turfy) soil, which in its morphology and properties is a complete *analogue* of the steppe chernozem. Subsequently, it is *gradually transformed* into a soil of a podzolised type, whereas the podzolised soil, having developed a sufficiently thick and highly water tight illuvial horizon B, shows a tendency to further evolve in the direction of the bog-type. As the process of leaching is also peculiar to other types of soils, these latter must, too, have a tendency towards podzolisation. It should be noted that the more southern a soil variety is being dealt with, the smaller the chances of a similar evolution to occur. No definite limit of this evolution can as yet be established. The bog-process may likewise delay the podzol formation, and cause an inverse enriching of soil.

Hemmerling's point of view has been developed by Filatov[29] into the theory of „evolving" and „metamorphic" soils. The „soddy", the chernozem, chestnut, brown soils, the sierozem and laterite as well, are the first stage of the metamorphosis which leads to the formation of other soils — the podzolised soils, leached and degraded chernozem, adjacent and degraded chestnut brown soils, and leached sierozem. It is doubtless that climatic peculiarities may not only interrupt the process of evolution called forth by leaching, but may also produce reverse phenomena. (An increase of the salt content in desert soils is also a process of evolution).

We also see that the idea of an evolution within time is applied to the phenomena of soil degradation, *podzol* being the ultimate stage of the podzolisation process. Similarly to German soil scientists, Williams and Hemmerling believe that with the development of an indurated (ortstein) horizon the podzolised soil will be subjected to bog-soil formation. Such instances may occur in the podzol zone, but whether the same may be stated with regard to all degraded soils, is still a question.

The alkali-soils degrade into the so called „solodee", by a similar process. During the process of leaching, which the salt containing subsoil is subjected to, the following series is established: saline (solonchak)—alkali-soil (solonets) — solod. In this series, the saline is the young soil, the solod — a stage of old age. Perhaps in this instance, the alkali-soil or solonets should be considered as the stage of maturity. But there is a further stage which is still possible for the solod, namely that of podzol. Both the solod and the podzol in particular, may be considered as final stages, in which soil consists of an uniform layer of silicic acid, reaching to a considerable depth, i. e. soil which has lost its heterogeneity. Having turned absolutely sterile, it is necessarily deprived of its vegetation, and becomes a prey to the wind. However, these ultimate stages are but very rarely observed in Nature. Soil is capable of restoring its heterogeneity in various ways, which we shall not discuss here, and the struggle between those mutually opposed tendencies is present in every soil. At all events the various categories of soil age may be of importance in separate instances, but similarly to the stages of the development of the relief included in Davis' geographical cycle, which bear no indication of the actual time, the notion of time in soil evolution is of a very conditional nature.

Chapter II

THE PROCESSES OF SOIL FORMATION AND THE GENESIS OF SOILS

The processes of soil formation.

Due to the effect of various external factors, the rôle of which has been briefly outlined in the preceding chapter, the parent rock is subjected to changes; certain processes develop within it, and as they lead to the formation of soils, we call them, following the example of Dokuchaiev and Sibirtsev, „soil forming" processes. As every soil needs be characterised by definite soil forming processes, the above mentioned pioneers of Russian soil science have established the *types of soil formation.* Without discussing the achievements made in the classification of Russian soils, we shall only mention that the *essential zonal or climatic types of soil formation* resulting in *definite types of soil* have on the whole remained very approximate to those established by Dokuchaiev and Sibirtsev. These soil forming processes are complex in themselves, and are composed of more elementary processes, such as: dissolution, sedimentation, humus formation, transformation into peat, one or another stage of decomposition of alumo-silicates, or of mineral portion of parent rocks [76] in general, etc. Further, when discussing the genesis of zonal (climatic) soil types, we shall mention these elementary processes. Likewise there are certain processes which are not of an entirely zonal (climatic) character, and but correspond to certain conditions within the limits of general climatic zones. This chiefly refers to soils with excessive moisture, which are differentiated into a class of intrazonal or hydromorphous [76] soils.

The soil forming processes result in the soil acquiring a definite „construction" (Sibirtsev) or *profile* manifested in a succession of horizons characterised by certain morphological properties, such as: colour, texture, structure, chemical composition, constitution, consistency, formation of various new growths, etc. The majority of soils, not subjected to ground-moistening, with the exception of those of a very dry (extra-arid) climate, and perhaps partly those of the tropical climate, are characterised by the formation of a more leached or eluvial horizon A, in their upper portion; this latter is subdivided into horizon A_1, i. e. the accumulation horizon with a maximum deposition of humus, and horizon A_2, in which this deposition plays a secondary part. Below this eluvial horizon, a sedimentation of substances removed from the latter, and the formation of the so called illuvial horizon B, is observed. The illuvial horizon is succeded by more or less *unaltered* parent rock C. The letters used by various authors for the definition of these horizons are not, however, as yet always the same.* The eluvial and illuvial horizons are not due (in different soil types) to the displacement of the same substances.

It is possible, however, to regard such soil forming processes as enabling to distinguish the above mentioned horizons, as various *stages of the same soil process,* and references on the subject may be found in Russian literature[45]. This process must lead to a maximum leaching of eluvial horisons, and to a maximum deposition of substances in illuvial horizons; in certain soil types, the rate of development of soil forming processes is high, in others it is lower, and there are some soil types where this rate is hardly perceivable. This theoretical scheme is, however, only partly confirmed by experience and cannot be applied to a whole series of soil forming processes.

Passing on to the discussion of the genesis of soils from the view-point of soil forming processes, we are obliged to state that there is no unanimity of opinion as regards the *number* of the latter. Glinka[39] distinguishes five types of soil formation: 1) the *laterite* type; 2) the *podzol* type, including primary and secondary podzolised soils; 3) the *steppe* type, comprising the steppe soils from chernozem to sierozem, on the one hand, and to the red soils of desert steppes, on the other; 4) the *alkaline* type (solonets), and 5) the *bog*-type, including both the true bog-soils, and the salines as well. Zakharov[138] seems inclined to distinguish the *mountain meadow* type; the *meadow* and *mountain meadow* types are also differentiated by Afanasiev[2]. However, the geographical classification of the latter author, as well as Vilenski's[125] classification, cannot be accepted as a basis for our description of soil forming processes owing to their complexity. ** Gedroiz's[33] classification of soil forming processes comprises only four types: the *chernozem* type, the *alkaline* type, the *podzol* and the *laterite* types; it thus closely approaches Glinka's classification, with the

* The quoted nomenclature belongs to Glinka (Soil Science, 1915); Zakharov (see Bibliography, № 138) uses another nomenclature: A — humus-accumulative horizon; B — intermediary or eluvial horizon; C — illuvial horizon, and D — parent rock. The Ukrainian soil scientists also suggest their own nomenclature.

** In order to avoid introducing into our discussion anything pertaining to hypotheses, we shall withhold from applying here S. S. Neustruev's scheme which he advances in his „Essay on a classification of soil forming processes", 1926.

only difference that it does not distinguish the bog-type, and sometimes interprets differently separate processes. As far as space will permit, we shall further attempt to consider all the principal theories of soil formation.

The laterite type.

No true recent laterites are, of course, to be found within the boundaries of the USSR. Only specimens of the laterite type known as red soils, have been subjected to direct study by Russian scientists (chiefly in the Caucasus). It should be first of all mentioned that, according to Glinka[39], the genesis of true laterite characterised by an accumulation of hydroxides of Al and Fe, in its upper horizons, and by removal of silicic acid in the form of a pseudo-solution into deep horizons, is due to the presence of a weakly alkaline reaction of the soil medium in conditions of an intense decomposition of alumo-silicates. Gedroiz[33] on the ground of his analyses sees a similarity of the subtropical and tropical soils with the podzolised soils as to unsaturation*, or low saturation of their absorbing complex. He sees the difference between them „firstly in the intensity of this process, and in connection with this, in the degree of decomposition of the alumo-silicate portion of the complex; secondly, in the amount of the organic portion of the absorbing complex"; thirdly, in the fact that the vegetative remnants are subjected to more rapid decomposition, and „that the decomposition process of the alumosilicate portion of the complex penetrated more deeply in soils of the laterite type", and lastly,—contrary to the podzol process, „there are in the laterite process factors coagulating the sols of colloidally dissolved aluminium and iron hydroxides, and transforming the precipitated gels into a half-reversible state". Gedroiz believes that the concentration of coagulators—the calcium and magnesium cations—is considerably higher in the soil solution of laterite than in that of podzolised soils, owing to a more intense expelling action of the hydrogen ion, as well as to a more rapid mineralisation of enormous quantities of organic remains. High temperature causes the gels of aluminium and iron-hydroxides which have been formed to be changed into an insoluble (irreversible) state.

* in other words, the presence of the hydrogen ion in the absorptive soil complex.

As compared to podzolised soils, the rapidity of dispersion of the non-colloidal portion of the soil due to external factors in laterite is also very great. However, Gedroiz considers the difference between podzol formation and laterite formation to be only quantitative.

The *red soils* along the Black sea coast, near Batum, have been described by Krasnov, Dokuchaiev, Kalinin, Gedevanov, Zemiatchenski, Boch, Glinka, Ostriakov, and others. Similarly to other authors, Ostriakov[89], who gave the latest summarised description of these soils, and investigated their character, states that in most cases the red-coloured and yellow (motley-coloured) horizons of the Batum „laterite" are overlain by a humus horizon of a brownish colour about 40 *cm* thick or even more. Glinka, who has subjected these soils and rocks to a mineralogical analysis, proved the presence of clays belonging to the types of halloisite, zeolite (hydrothomsonite), but had not considered it possible to accept the presence of free hydrates of Al_2O_3 as being established. Glinka regards the iron hydroxide, to which the red colouring of the Chakva red soils is due, as belonging to turgite; he also established another variety of iron hydroxide. Zemiatchenski's and Ostriakov's[89] analyses have confirmed the presence of a certain amount of free hydrates of alumina in the Batum soils, and therefore the latter author regarded them as belonging to the laterite type. Ostriakov had also established the high capacity of absorption peculiar to red soils, and their high hygroscopicity (after Mitscherlich), which is an evidence of a considerable content of mineral colloids in soils. The water extracts of soils exhibited in this case an acid reaction (according to Gedroiz). However, it must be taken into consideration that the data obtained by investigations of the humus horizons of the Batum soils, or in general of horizons which are at present subjected to weathering, somewhat differ from those obtained by the study of red and yellow „subsoils", or „veins", or fragments of the weathering parent rock (andesite). The presence of free hydrates of alumina is appropriate just to the crusts covering the fragments of rock, and to veins of apparently ancient weathering. Therefore, we may scarcely agree with Ostriakov that the soils along the Batum sea coast, which he had investigated, belong to Fermor's „laterite" loams. Glinka's[37] opinion is that the red-coloured and motley-coloured horizons of the Batum and Chakva soils, judging from their clayey composition and the absence of a marked accumulation of Al_2O_3 in them, are relict red soils dating back to the Tertiary era. The overlying more or less humus-coloured horizons may belong to the incompletely developed and slightly podzolised soils. Whether any brown (according to Ramann) or yellow soils are to be found here above products of ancient weathering, is a question that has not yet been solved [62].* The probability of the relict character of west Caucasian red soils has been confirmed by the finding of similar relics in the Far East [36], in eastern Ural region [57, 77], in the Kirgiz-steppe, ** and even in the central region of the European part of the USSR [40]. These relict soils partly belong to subtropical red soils, partly to kaoline-laterite, kaoline-bauxite, and to bauxite-laterite. Subtropical fossil flora has been found in the neighbourhood of kaoline-laterite deposits of the Ural region (Krasheninnikov), and a series of relics in modern flora correspond to red and yellow-coloured soils of the Far East (Glinka). There are in general a series of deposits of kaoline-bauxite and kaoline-laterite in this country which may be regarded as belonging to an ancient weathering crust [35, 76, 77] of the Tertiary, and even more ancient era, or to an ancient soil forming process.

The red soils of subtropical and tropical deserts and semi-deserts have also to a certain extent been studied by Russian investigators; they will be treated in the part of our report dealing with deserts and semi-desert soils, as the laterite character is only manifested in them by a preservation of small quantities of red-coloured hydrates of iron oxyde in the upper horizon, and as there are no direct indications as to their containing any free hydrates of alumina [32]. ***

Dranitsyn [22] has given a short outline of red soils found along the subtropical Mediterranean coast. He describes them as soils of reddish tint with a weakly manifested profile, mostly deprived of carbonates, sometimes filled up with shells of mollusca, the latter being the cause of effervescence. The humus horizon is manifested by an obvious browning and darkening. This description

* On the brown soils of Ramann, see further, p. 38.

** See Bibliography, №№ 57, 77.

*** Hilgard, however, affirms that the free hydrate of alumina accumulates in soils of arid countries. But whether it accumulates precisely in the red-coloured soils has not yet been established.

is in accordance with other descriptions. Whatever the view-point on the relict character of many laterite, bauxite, kaoline, and simply red-coloured formations (soils), might be, the question as to whether the process of humification in the upper soil horizons may occur simultaneously with a precipitation of free hydrates of iron (red-coloured) and aluminium oxides, and an accumulation of clays (of the character of kaoline) in the deeper horizons, cannot as yet be considered as solved.

Yellow soils and brown soils (Ramann).

The yellow soils and the brown soils of Ramann * are the intermediary link between red soils and podzolised soils. Recently, there have been found in Georgia, in the Caucasus (by Zakharov[139]), along the southern coast of the Crimea (by Prasolov), and on the Talysh ridge (by Akimtsev[5]), soils which according to their morphological description may be regarded as belonging to Ramann's brown soils and to yellow soils. ** Glinka believes that Ramann's brown soils (not to be mistaken for brown soils of arid steppes) are the intermediary link between podzolised soils, on the one side, and the yellow and red soils of Western Europe, on the other, whereas some of them definitely belong to the podzol type. *** However, the prevalency of somewhat dull brownish and yellowish tints in their colouring, and the absence of any traces of the podzolised horizon in clayey soils of the Caucasus, lead us to regard them as true intermediary links between the forest podzolised soils (in high altitudes, as for instance in the Caucasus, these brown soils are actually transformed into the latter), and the forest red soils characterised by an accumulation of free hydrates of Al and Fe sesquioxides. As yet, however, literature does not contain sufficient analytical data for a detailed description of the soil forming processes occurring in these soils. Judging from morphological data, an accumulation of clays, and, together with yellowish-coloured hydrates of iron oxide, seems to be characteristic of Caucasian yellow soils and brown soils of Ramann.

* Contrary to brown soils of arid steppes, in Dokuchaiev's understanding of the term.

** In Russian literature the yellow soils were first described by N. A. Bogoslovski, in his paper: „Some records on the soils of Western Europe". „Pedology", 1902.

*** This idea has been already advanced by Bogoslovski, in 1902, and subsequently developed by Lang and Afanasiev.

It should also be mentioned that Afanasiev[3], while observing the podzolised soils of Belorussia, perceived in the whitish tint of the podzolised horizon, i. e. in the fixation of hydrates of iron oxide in the latter, an indication of their being a transitional stage to Ramann's brown soils. Afanasiev attributes this transitory character of the podzolised soils of Belorussia to the similar character of the climate, which also affects vegetation (the presence of elm and beach trees in forest formations).

The podzol type of soil formation.

The *podzol type* is generally regarded as peculiar to forest vegetation, though there are cases when it is found under meadow and meadow-moor vegetation (Glinka, Prasolov).*

It is generally accepted, that there are two indispensable conditions for the formation of podzolised soils: moistening of the upper soil horizons sufficient to ensure the percolation of water into deeper horizons, and moderate evaporation so that it might draw upwards the percolating solutions. These conditions are realised in forests which impede the evaporation, and ensure a sufficient moistening of the soil. Thus, climatic conditions admitting forest growth are at the same time favourable to podzol formation. The morphology ot the podzol soil type is considered to be characterised by a division of its profile into two horizons: the upper, comparatively decolorated and leached portion, with an increased content of sandy particles, the eluvial horizon A, and the underlying illuvial horizon B — of a more intense colouring, with an increased content of clayey particles, and chemically enriched with bases, with hydrates of sesquioxides, R_2O_3, and partly with humus. The upper horizon A of a completely developed soil is subdivided into: A_0 — a bedding of undecomposed organic matter frequently containing (under forest) the hyphi of fungi; A_1 — a horizon coloured by humus into a greyish tint, and A_2 — a whitish horizon, nearly or wholly deprived of humus tinting, and enriched with silicic acid. The horizon B is also subdivided: an upper coffee-coloured subhorizon B_1, with precipitated humous substances, and a subhorizon B_2 of a more yellow, rusty tint, with an evident precipita-

* Podzolised soils under herbaceous growth are termed by V. R. Williams as „dernovy" (soddy) owing to the development of a considerable thick humus layer over the podzolised one.

tion of iron hydroxide, are clearly distinguishable. Ferro-humic concretions in the form of small-sized „shots", „beans", „peas", etc., are frequently though not regularly observed in the sub-horizons A_2 and B of podzolised soils. Sometimes horizon B consists of a compact indurated ferro-humus layer, known as the ortstein (ortsand). This or that development of the above mentioned sub-horizon serves as basis for the classification of podzolised soils. The process of leaching, which horizon A is subjected to, as compared to horizon B, is called *podzolisation*; it may affect a greater or smaller thickness of soil, and may be more or less pronounced beginning with scarcely perceivable spots, and ending with a compact whitish streak of clearly schistose structure, affecting accordingly the degree of development of horizon B.

The development of the podzolisation process may advance more or less rapidly owing to various conditions: the general — climatical, and the local — geological and geomorphological conditions. From three to five *varieties* are usually distinguished according to the intensity of the podzolisation process manifested in one or another development of the eluvial horizon A_2.

The term „concealed podzolised" (slightly podzolised), is then applied to soils, in which the horizons A_2 and B are not manifested, but the position of the soil and other indications show that it must necessarily evolve into a podzolised one. Probably most of the „soddy" (turfy) soils, according to which the zone itself was being termed the „soddy-podzolised zone",* should be regarded as belonging to the concealed podzolised soils. Hemmerling understands by the term „soddy" soil slightly humus coloured soils, with no distinct development of podzolisation features [29].** When horizon A_2 is expressed in the form of indistinct pale-whitish spots, the soil is called slightly podzolised; the appearance of a continuous whitish layer leads us to term the soils as ***„podzolised"***, and when this whitish layer becomes strikingly pronounced (A_2), we call such a soil *strongly podzolised.* By ***„podzol"*** we understand that stage of development ot the podzolised soil, in which

* N. M. Sibirtsev, Moscow soil scientists.

** The „dernovy" (soddy) soil is regarded by Filatov as the fundamental type of soils, evolving into the podzolised ones, which in their turn are considered by Filatov as belonging to „metamorphic" soils.

the whitish horizon begins near the surface and attains a considerable thickness, whereas the humus horizon A_1 is hardly developed. On the whole the development of the B horizon in these varieties follows the development of the podzolised horizon, but may vary in connection with the parent rock, its permeability, the level of ground-waters, and other conditions.

The fact of horizon A being poor in sesquioxides as compared to horizon B was formerly attributed to a process similar to *swamping*. Namely, it was supposed that the upper soil horizons under forest were temporarily subjected to excessive moistening, resulting in an anaerobic condition owing to which the iron compounds were transformed into protoxides, and were removed in solution to deeper layers. Dokuchaiev advanced the idea of „acid" humus as an explanation of the leaching of horizon A. The soil formation and soil destruction — progress and regress — proceed simultaneously in these soils to a considerable extent under the influence of „acid" moisture, which is, according to Sibirtsev, rich in paler, lighter, and more mobile humus substances, the crenic and apocrenic acids. Owing to these acids, the alumo-silicates are subjected to more complete destruction than when the soil solution contains the carbonic acid alone. The processes of leaching and decoloration have been also long ago observed and explained by the effect of „acid" humous substances (Sprengel, Miller).

Single investigators did not always draw a marked distinction between the effects of the podzolised and bog-processes, for in nature they frequently mingle or partly replace one another, and therefore these authors in describing podzolised soils point out to characteristic features of bog-soils, as for instance to the presence of protoxides of iron, etc.* However, this refers to particulars, but in general the explanation of the origin of podzolised soils as due to the active effect of mobile humous acids on their mineral portion was subsequently advanced by Dokuchaiev, Sibirtsev, Glinka

* See Bibliography, № 110, p. 251, and № 122, pp. 96—97. Tumin does not consider the ortsteins and concretions to be connected with the podzolisation process, although they are often present in podzolised soils, and according to his view-point are the results of processes of deoxidation and oxidation connected with excessive moistening. It seems that the majority of investigators are of the same opinion (see Glinka).

(in the Ist edition of his „*Soil Science*"), Kossovich, Tumin, Williams, and others.

Tumin[121] suggested to distinguish in the podzolisation process two different features: the degree of podzolisation, and that of leaching; the latter may be also characteristic of other soil processes. According to Tumin, the degree of podzolisation depends on the ratio existing between the amount of whitish-coloured humous substances and that of dark-coloured ones; it is the relative prevalency of the former over the latter which is of importance in podzolised soils. According to Tumin, the fact of the soil being leached of bases and sesquioxides may not result in its podzolisation in the above stated understanding of the word, i. e. in an accumulation of light-coloured humus. The degree of podzolisation depends on the variation in the composition and distribution of mineral substances in the different soil horizons; it is possible to judge of the degree of podzolisation by indications of a morphological character, whereas of that of leaching from data obtained by chemical analysis. These views of Tumin's were opposed by Hemmerling[46], who does not consider either the dependence of the colouring of the podzolised horizon on crenic acid, or the absence of a concurrence between the degree of podzolisation and that of leaching as being established. His experiments showed that the various methods of removing the organic substances (such as the „crenic acid" and its salts), from the podzolised horizon did not change the whitish colouring of the horizon, and even increased it. However, the fact of highly mobile humic acids being present in podzolised soils, and their important part in the soil forming processes, can scarcely be doubted even at present.

The ascertainment of the colloidal nature of humous substances, and at any rate of some of the weathering products as well, and the establishment and explanation of the exchange absorption of bases by soil, was a great step forward in the study of the genesis of podzolised soils. There exist at present two explanations of the podzolisation process.

The first one, suggested by Glinka, consists in the following: owing to considerable moistening, a separation of bases, and chiefly of calcium from the organic portion of the soil, occurs, i. e. from the humus, which thus becomes mobile, being transformed into the condition of a sol, and acquires the capacity of protecting mineral sols and suspensions against precipitation; hence the latter are removed together with the humus into deeper horizons, where they precipitate either when capillary water is transformed into pellicular water, or when they come into contact with electrolytes. Iron oxide, which, in general, separates easily from ferro- and other silicates passes into the pseudo-solution together with calcium which played, previous to leaching, the part of a preserver with regard to humus: the sol of iron hydroxide is also stabilised by humus and, according to Aarnio's experimental data, may, in conditions of a certain concentration, undergo inverse coagulation. This phenomenon is observed in the horizon B. Thus, the horizon A, being deprived of bases (chiefly such as calcium and hydrate of iron oxide), is at the same time deprived of fine colloidal clay and suspensions. Glinka[39] considers it scarcely probable that the alumo-silicates should decompose in podzol formation to a state of free hydrates of alumina, owing to the absence of the latter substances in the ortstein or the soil horizon B. The silicic acid of the parent rock deprived of its clayey particles being removed by water, remains in the horizon A_2 in the form of fine quartz powder.

According to Glinka, the so called „amorphous silicic acid" being a product of decomposition of alumo-silicates is not accumulated in horizon A_2. Many authors (Gedroiz, Sokolovski, and others) point out to the important rôle of calcium in the organic part of soil, as well as to the protecting rôle of humic colloids. Thus, the old theory of the „acid" humus being a podzol-forming agent has modified to a considerable extent, and has evolved into the theory of mobile colloidal humus unsaturated with bases, whereas the ideas of disintegration and dissolution were replaced by that of the „protecting" effect of the colloids of humus on mineral suspensions and sols.

The genesis of podzolised soils is somewhat differently treated by Gedroiz.* The essence of his ideas consists in the following. In conditions of a sufficient water supply, the absorbing organic (humate) and mineral alumo-silicic complexes which are a characteristic feature of soils, exchange the bases (such as Ca, Mg, etc.), absorbed by them, for hydrogen. In this case, the salt-like com-

* See Bibliography, № 33, pp. 18—24.

pounds, under the influence of the hydrogen of the dissociated water molecule, are as though transformed into acids without it being necessary that the reaction should take place in a true solution. The absorbing complex is a finely textured part of the soil (particles smaller than 0.00025 *mm* in size), which is therefore of a colloidal nature; the reaction proceeds only with molecules at the surface of soil particles, though it is subjected to stechiometrical relations. There is, therefore, no reason to believe that we have here a phenomenon of hydrolysis of the mineral portion with its transformation into a soluble condition. The bases separated from the absorbing complex in the form of oxides and carbonates are removed from the soil. Though an absorbing complex which is wholly or partly saturated with hydrogen possesses the property of once more replacing the hydrogen by bases, i. e. possesses the properties of acids (on the ground of other investigations, Gedroiz has proved this process to be entirely reversible), it may not be possible to reveal this acidity by the usual method applied for the determination of acid reaction.* Gedroiz has proved that the humusless soils and rocks may also possess the capacity of absorption, and contain hydrogen among other absorbed bases. Such soils unsaturated with bases exhibit number of peculiarities, namely, their absorbing complex saturated with hydrogen does not possess the same degree of stability as a complex saturated with Ca and Mg. The absorbing complex wholly, or at least partly saturated with sodium possesses the highest degree of instability (see below, on alkali-soils), but hydrogen does also not afford the same protection against decomposition as calcium and magnesium, as thed ispersive pulverescent effect of H ions, even when non-abundant, is not resisted by a ion of higher valency.

The replacement of absorbed calcium and magnesium in soils by hydrogen ion not only calls forth an intense removal of the alumo-silicate absorbing complex itself (caused by the dispersive effect of hydrogen ion), but also increases the decomposition of its alumo-silicate nucleus into the constituent oxides. Thus, not only bases are removed from horizon A, but also hydrates of iron and aluminium oxides, and silicic acid as well. No accumulations of the

* The degree of precision, with which the unsaturation with bases may be determined by the definition of pH is not yet wholly established.

so called amorphous (free) silicic acid in the decolorated horizon A_2 is observed. In the course of the podzolisation process the humate portion of the absorbing complex is intensely destructed and renewed, whereas the mineral portion displays a tendency towards decreasing with the progress of the podzolisation process. The unsaturation of the absorbing complex with bases (resp. its hydrogen content) varies in the different horizons of podzolised soil. In horizon A, the absorptive capacity is highest owing to the content of organic substances, and that of hydrogen ion as well. In horizon A_2, the absorptive capacity is the lowest; here the absorbing complex is the most decomposed, the organic substances have been removed, the absolute and relative content of H is considerably lower. In horizon B, the absorptive capacity increases (mostly owing to an increase of the content of clayey particles in the mineral portion), whereas the absolute and relative content of H ions decreases[47].

According to Gedroiz, the absorbing complex of podzolised soil, besides containing H, Ca, and Mg, also contains Al, which is probably liberated from the alumo-silicate nucleus, and NH_4 as well — a result of the ammonification of the organic substances in soil; owing to their being present in soil solution in considerable quantities, they are absorbed by the soil.

Thus, contrary to Glinka, Gedroiz admits the possibility of a decomposition of the alumo-silicate absorptive complex resulting in the formation of free SiO_2, and hydrates of Fe_2O_3 and Al_2O_3. He also believes that the free hydrate of Al_2O_3 together with silicic acid may produce an alumo-silicic compound of „zeolite-like" character (by means of an inter-coagulation of these two substances), possessing a capacity for exchange reactions. A similar neo-formation may also be observed in the B horizon of podzolised soil.

The deposition of substances removed from the eluvial horizon A may proceed in podzolised soils in different ways. A peculiar more or less continuous illuvial horizon B may develop, which differs from the overlying horizon A by its more clayey character, its more intense colouring, and its comparative hardness (though a strongly leached subhorizon A_2 may also prove to be very hard); it also may differ in structure (prismatic or nutty). However, in clayey soils, it is frequently scattered with whitish spots on a brownish ground, or rusty-brownish tints cover, in streaks, the grey ground of the parent rock (morainic loams, and others). In certain cases, the horizon B may not be differentiated by its aspect in spite of a clearly developed horizon A_2, as for instance on red morainic clay (Pskov gvt.), etc. In other cases, we observe a distinct differentiation of horizon B into two subhorizons: the upper, coffee-brown, dark-coloured subhorizon, and the underlying, rusty brown horizon. This is in accordance with the respective high humus and iron contents of the two subhorizons. In separate instances, either a clearly humus or a clearly ferric colouring of the entire horizon B is generally observed, which led Frosterus to subdivide the podzol into humus and iron containing varieties. The illuvial or „ortsteinogenous" horizons of sandy podzolised soils have been investigated by Polynov, who discovered new growths in them in the form of minerals belonging to the type of palygorskite, which he determined both chemically and mineralogically. It is this magnesium alumo-silicate which is apparently the cause of the concentration of magnesium so frequently observed in the B horizon of podzolised soils. It possesses a high *stability*, but at the same time does not prevent the exchange of bases, when subjected to the effect of salt solutions [93].

The ferric illuvial horizon of sandy and sandy-loamy soils sometimes assumes the character of a hard ferric (dark-brownish) sandstone (a conglomerate in cases when the soil is of a gritty-gravelly texture), which is not unfrequently of a considerable thickness, i. e. the so called „ortstein" * (ortsand) in the direct meaning of the word. The ortsteins are sometimes observed in a soil section in the form of narrow undulating rusty-brownish streaks which give the profile of sandy, for the most part slightly podzolised soils, a zebra-like aspect; these „pseudo-fibres" (Vysotski [133]) are sometimes found at a considerable depth. Finally, hard grains and peas („small shots", „beans") are frequently formed in horizon A_2, and in the upper portion of horizon B; these have also been sometimes called ortsteins, but Tumin quite justly suggested to use for them the term „concretions" [122].

They also contain humus and the hydrate of iron oxide; it has been proved by Tumin that the amount of humus contained varies

* This formation exposes to light some of the ferruginous sandstones and conglomerates of ancient geological formation.

in different horizons; the concretions of the subhorizons A_2 and B have the maximum content; black concretions and spots chiefly consisting of manganese are also occasionally to be found (Hemmerling, Nabokikh). The evolution of this element in the soil has not yet been sufficiently studied.

Glinka, Tumin, and other authors do not regard either the ortsands or the concretions as a characteristic feature of the podzolisation process; moreover, Tumin definitely states that the presence of deoxidation and oxidation of iron compounds is indispensable for these formations, i. e. the presence of a bog-formation process in soil, or, according to the term used by Russian scientists, the superposition of the bog-formation process over the podzolisation process, which is manifested as follows: there are moments of excessive moistening in the life of a given soil, when its horizons are in an anaerobic condition favouring the deoxidation of iron oxides, and their transformation into soluble forms. The re-precipitation of these compounds takes place together with the drying of such a soil, when the formation of unsoluble hydrate of iron oxide becomes possible. The pseudo-solution also contains, in this case, humous substances which precipitate together with the iron compounds. Hemmerling succeeded in finding free hydrate of alumina in these ortsteins, which confirms Gedroiz's hypothesis with regard to the decomposition of a portion of the alumo-silicate nucleus taking place in podzolised soils.

Filatov[30] attempted to establish experimentally the origin of ferric intercalations („ortsands" and „pseudo-fibres"), by precipitating the hydrate of iron oxide at the limit of silty interlayers in sand.

According to Tiurin's[117] observations, a certain quantity, up to 7 p. c., of clayey material (silt—smaller than 0,001 *mm* in diameter) is accumulated in the pseudo-fibres, and 10 p. c. of hydrochloric acid dissolves up to 30 p. c., and 10 p. c. of Na_2CO_3—up to 36 p. c. of the claeye portion. Tiurin is therefore inclined to consider these pseudo-fibres to be not of a „bog-gley", but of an alluvial origin. It is obvious that in permeable sandy material, the solution containing sols of sesquioxides and humus hydrates (and probably of silicic acid and clays as well), may penetrate to a considerable depth. The precipitation of iron and humus in the form of separate streaks may obviously be explained by a change in texture; this way the layered structure of the parent rock, which is imperceptible to the eye, is manifested. Thus, Afanasiev succeeded in discovering the layered structure of loess-like deposits in Belorussia. On the other hand, a sedimentation in the form of streaks can likewise occur in a homogeneous medium, according to the colloidal principle of „zones".*

In singular cases, the presence of white spots and streaks under horizon B is observed. These have been found in the soils of the Smolensk gvt. by Tumin, who regarded them as accumulations of lightly coloured humus, but it is more probable that this phenomenon should be attributed to decoloration which occurs in the process of „gley" formation, i. e. to the removal of iron in a state of deoxidation.** Similar whitish intercalations are the most frequently found at the limit of the less permeable underlying rocks, which impede further percolation. In the so called „yellow-podzolised" soils of the northern part of the USSR described by Krasiuk[59], a comparatively thin yellow horizon B is observed below the whitish horizon A_2, followed by a whitish horizon, which the author suggests to call A_3. The genesis of this formation has been explained in various ways: either the lower whitish horizon should be regarded as a relic of a priorly thicker podzolised horizon, which consequently (through the rising of ground-waters preventing deep percolation) became the place where the humus and iron leached from horizon A_1 were being deposited; or one may consider that the lower whitish horizon is the result of the removal of ferro-salts due to the accumulation of ground-waters. The latter explanation is confirmed by the bulk composition of this horizon which is comparatively rich both in bases and sesquioxides, and by its position below the more water-tight layers.

In general, the rôle of parent rock in the genesis of podzols is most important. The morphology of clayey, sandy-loamy, and sandy podzolised soils, as already has been seen, differs considerably. The podzolised soils developed on two or three beds of inconsiderable thickness (the two- or three-phased combination) were studied with particular thoroughness by Afanasiev[4].

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* Slightly podzolised soils on sands under pine forests to which the precipitation of pseudo-fibres is peculiar, bear the name of „borovyie peski" (sands under pine forests in dune-landscapes).

** See below: the bog-formation process.

Owing to the high degree of moistening peculiar to the podzolised zone, the soils often undergo the process of swamping, and, as has been above indicated, produce certain peculiarities in the soil profile. The high degree of moistening favouring the swamping of soils prevents the further development of the podzol formation; thus, the podzolisation process in the north of European and Asiatic parts of the USSR is gradually replaced by the bog-formation process which becomes prevalent here. Moreover, the temperature in the northern part of the podzol zone is not sufficiently high to favour intense soil formation, and the strongly podzolised soils are replaced by slightly podzolised and concealed podzolised soils. Likewise, a decrease in the intensity of the podzol formation process is observed further south from the maximum development of podzolisation, i. e. from the central part of the podzol zone, in this case, due to a lack of water. Strongly and medium-podzolised soils extend further north along sandy permeable rocks, as the process of swamping develops earlier on clays [122].

According to Gorodkov [82], in the southern part of the podzol zone, in Western Siberia, the podzolisation of soils is more markedly manifested on clayey subsoils, whereas in the northern part — on sandy subsoils. As we already know from the paragraph dealing with the effect of rocks on soil formation, the podzolised soils on sands advance far to the south of steppe-zones owing to peculiarities of the moistening of sands. In the steppe zone, podzolised soils are frequently observed in small depressions of the relief, but here these soils must had gone through the stages of a high salt content and alkalinity, and therefore there are certain peculiarities in their leaching (i. e. degradation), which will be further considered.

The conditions of the relief leave an impress on the development of podzolised soils. In the Moscow gvt. [88] (other conditions being similar), slightly developed podzolised soils were observed on the uppermost parts of slopes, where the water flowed down without having had time to percolate into the subsoil, and even partly destroyed by erosion the „soddy“ (turfy) soils which had already been formed. In these places, the slightly and concealed podzolised soils were formed. Further down the slope, medium - podzolised soils appeared, and still further, towards the bottom of the slope, strongly podzolised soils were located.

Below the slope, in the Moscow gvt., either the dark-coloured (meadow half-bog) or the meadow-bog („gley") soils are developed.

A similar succession is described by Kasatkin[50] for the sandy-moor districts of the Minsk Polésie, where he has observed the transformation of concealed podzolised soils of pine forests with a lichenous covering on the tops of elongated sandy hills into peat bog-soils of „mshary" passing through different stages of podzolisation.

The „soddy" soils often prove to be of sandy-loamy or gritty texture. Williams[135] advanced the theory of the origin of soils possessing different degrees of podzolisation in different parts of the slope as being connected with „ground-water supply" and „eluvial" phenomena.

The modification of soils of the podzolised zone, in connection with the different conditions of the micro-relief, was first studied by Zakharov in the neighbourhood of Leningrad (1910), and later in the Moscow gvt., and in many other places. In the neighbourhood of Leningrad, in conditions of a micro-relief[137] characterised by hammocks composed either of *Polytrichum* or of dead pine trunks, or of species of *Gramineae* and *Carex*, he observed sandy-loamy peaty-podzolised soils over the slopes of the micro-relief, sandy-loamy, peaty-ortstein soils deprived of the podzolised horizon over knobs, and peaty-sandy podzol in the central parts of small depressions. The knobs of the given relief, according to Zakharov, are more accessible to air, and more exposed to the coagulating effect of the frost, both of these conditions necessarily leading to the oxidation of soluble humates of iron, and to the formation of an ortstein horizon directly underlying the peaty soil horizon. Orlov observed in the Moscow gvt. an increase in thickness of the podzolised horizon in the direction of depressions, and the formation of numerous ferric concretions (ore-grains). It is quite evident that there can be no uniformity in the development of soils in dependence on the difference in the character and the origin of the micro-relief, on that of the rocks and on various zonal conditions.

The steppe type of soil formation.

The steppe type of soil formation is characterised by saturation of the absorptive complex with Ca and Mg, and by an absence of the removal of sols of sesquioxides and clay; therefore, the soils of this type are devoid of the two-story profile, peculiar to podzolised soils. The above quoted general determination of the steppe type of soil formation should as yet be regarded as conditional, as soil formation in arid steppes has not been so far completely explained. But even in this form, it excludes a series of soils under herbaceous growth—the so called meadow and mountain meadow soils, which will be further discussed. The steppe type of soil formation is naturally subdivided into the *formation of chernozem*, and that of *arid steppe soils*, but as there is no marked limit between meadow steppes with varied herbaceous growth and steppes with a pure growth of *Gramineae*, it is likewise impossible to draw a distinct line between the chernozem and the chestnut soils, peculiar to arid steppes.

Chernozem formation.

The Russian word „chernozem" similarly to the German „Schwarzerde", the English „black soil" (black earth), and the French „sol noir", had originally no precise meaning, and was generally applied to dark-coloured soils, whereas in the spoken language it was a synonym of decomposed organic remains and humus. But Russian soil science has long abandoned the word with so an indefinite meaning, and attributed to it a strict sense, understanding by the term chernozem *the humus soils of steppe soil formation;* this was quite natural owing to the great expansion of these soils, commonly known as chernozem in this country. Owing to this, „chernozem" was introduced into other languages as a precise scientific term.

There is no necessity to discuss here the history of the various view-points on the origin of Russian chernozem, as it has been already described in detail by Dokuchaiev [19], the founder of Russian scientific pedology, and subsequently has been introduced into text-books. It will be sufficient to mention here that the theory of the marine origin of chernozem advanced by Murchisson, was of a very short duration, whilst the moor-formation theory was able to struggle for its acknowledgment longer than any other theory. The idea of the moor origin of chernozem was based on the West European view-point on the formation of soils rich in organic substances (humus) under humid meadow and moor vegetation. But the geological data have refuted the existence of moors and forests in the chernozem zone of Russia during the precedent epochs of the Post-Tertiary period; moreover it has been proved that neither the moss nor the humid-meadow vegetation ever produce chernozem. Dokuchaiev's „*Russian chernozem*" is precisely an argumentation in favour of the theory that the chernozem is of dry land vegetative origin, and that its formation is chiefly due to the effect of steppe vegetation.

In the course of time, when the idea of soil was so far extended as to comprise the whole thickness of the parent rock subjected to soil formation, it became necessary to add to the features characteristic of chernozem, as of a humus soil formed under steppe vegetation, the presence of efflorescences of calcium and magnesium carbonates at this or that depth of the soil horizon. Sibirtsev[110] was the first to mention the effervescence of the steppe chernozem with acid ($CaCO_3$) as being of permanent character. Since then it is already possible to speak of the profile of the chernozem soil as consisting of: 1) the humus horizon, and 2) the horizon of carbonate accumulation. The presence of sulphates beneath the chernozem has been proved in the southern varieties. The humus horizon is gradually, and in some instances even rather rapidly replaced by a humusless horizon which may or may not be regarded as pertaining to chernozem in dependence on the amount of the products of chernozem soil formation it contains. However, when the thickness of the chernozem is spoken of, it is generally the thickness of the humus horizon that is tacitly understood; this latter is subdivided into the horizon A (A_1), which seems as being uniformly coloured, and horizon B(A_2), in which the colouring gradually decreases, and finally vanishes. The uniform colouring of horizon A is not, however, a proof of uniform humus content, and therefore all data obtained with regard to the thickness of this horizon are far from being credible; indeed, in arable chernozem an uniformly mingled horizon may be created artificially. The limit of horizon B is sometimes also hardly distinguishable, both owing to its containing humus wedges, spots and veins, and to a slightly humus coloured parent rock, far below the level of the well expressed colouring. Traces of the eluvial process are still distinguishable at a greater or smaller depth below the humus horizon; these not only consist of a structure different from that of the unmodified parent rock, but also in traces left by the activity of animals. The gradual or rapid change from horizon B to horizon C (humusless horizon of chernozem) is a classificational feature.

The genesis of the described profile is at present explained as follows. Owing to a comparatively small amount of precipitation, and to considerable evaporation, the washing and leaching of the soil in the chernozem climatic zone is not great. The decomposition of the organic and mineral portions does not proceed rapidly, and does not result in products of intense hydrolysis. Owing to a comparatively small moistening of the soil, the soil solution contains of electrolytes for the most part Ca and Mg carbonates, whilst salts possessing a higher degree of solubility are either washed down to such a depth as not to exert any influence on the soil profile, or are entirely removed beyond its limits. The particularly important rôle of calcium in this process has been pointed out to by Gedroiz and Sokolovski[113].

Therefore, according to Tanfiliev, chernozem can generally not be formed on rocks containing no calcium. Owing to the soil solution containing magnesium and calcium salts, both the organic and mineral soil colloids are in a *coagulated state.* The humous substances saturated with calcium are lacking in mobility (only $^1/_{200}$—$^1/_{250}$ of the entire humus content in the horizon A passes into the water extract), and therefore, being fixed in the soil, undergo a comparatively slow process of decomposition *in situ,* and are supplied with more or less equivalent amount of humus at the expense of newportions of vegetation being subjected to decomposition. The mineral colloids are similarly coagulated, and the sols which are newly formed coagulate *in situ.* According to Gedroiz, the absorbing mineral complex saturated with Ca and Mg possesses stability, and is but slightly subjected to decomposition. The absence of humus sols, which are the protective colloids with regard to mineral sols, also does not favour the mobility of soil colloids in pseudo-solutions.

The water supply is only sufficient to remove the easily soluble salts, and to carry to a certain depth the calcium and magnesium carbonates which possess a low degree of solubility.

Thus, an equilibrium in the alumo-silicate portion of chernozem may be observed; the contents of SiO_2, Al_2O_3, Fe_2O_3 varie but little throughout the soil profile; the bases are not removed from the level reached by roots; an inconsiderable penetration of the latter somewhat below this level in the form of sols may also be sometimes noticed. However, this equilibrium is instantly destroyed if the water supply on the surface of chernozem increases, or if the evaporation of this water decreases, so that this superfluous quantity of water may produce a more intense leaching of bases from the alumo-silicate and organic (humate) portions of the soil. This will first of all result in the salts being carried down to a greater depth, in the solution becoming poorer in electrolytes, in the passing of the absorbed bases into the solution, and their replacement by hydrogen; the humus will become mobile, the mineral colloids less stable, and partly subject to decomposition (Gedroiz), causing the separation of iron oxides, silicic acid, and perhaps even aluminium hydroxide. This will be followed by the removal of humus from the soil, by the displacing of sesquioxides and colloidal clay[39] * from the upper horizons down to the deeper ones, or in short, a process known by the term of *degradation* will ensue, and will finally lead to podzolisation. A similar superposition of the podzolisation process on chernozem may occur in case of a change in the hydrothermic régime of the soil caused either by a change of climate or of the water régime, in general. In discussing the evolution of vegetation and its rôle in soil formation, we have already mentioned that during the last period of geological history the greater part of the chernozem zone was occupied by forest, and that „forests have degraded chernozem".

Morphologically the degradation of the chernozem is first of all manifested by the colouring becoming somewhat paler; this lighter colouring usually begins somewhat below the maximum level reached by plant-root-systems: simultaneously the structure of the clayey varieties of chernozem becomes coarser, while the loose granular structure is replaced by a hard pea-shaped-nutty structure. Futher, a progressive paling of the humus horizon occurs, as well as a sinking of the horizon of effervescence; then, a dark, somewhat brownish humus-coloured horizon of prismatic structure is formed beneath the paler streak of humus horizon, the brownish tint

* „Suspensions" according to Glinka. Glinka considers that the mobility of humus after the removal of absorbed calcium is the main cause of degradation.

covering the faces of structural fragments; finally, another horizon of similar structure, and of a somewhat brownish colouring, but containing no humus, appears, while the carbonate horizon sinks still further down. A similar scheme of degradation was established for the Ukrainian chernozem by Florov[31]; this investigator and other Ukrainian soil scientists have studied the whole series of degraded soils beginning with the typical chernozem of the south-west soil provinces with a high level of effervescence, and ending with the light grey forest (podzolised) soil. According to Nabokikh[68], all the parts of the Ukrainian territory were not simultaneously covered with forests, and therefore some soils attained a further stage of development in their evolution towards podzolised soils; meanwhile, other soils reached only the earlier stages, and this explains the completeness of the entire series which may be observed the more easily as all those soils are developed on one and the same parent material, i. e. the loess.

When explaining from the chemico-analytical point of view the degradation of the Ukrainian chernozem, Florov calls attention to the fact that the brownish somewhat compact horizon of a prismatic structure, which seems to be analogous to horizon B of podzolised soils, proves to be less rich in sesquioxides (particularly in Fe_2O_3) as compared to the underlying horizon of carbonate accumulation, where they apparently are subjected to more intense coagulating. This phenomenon has not yet been sufficiently studied, and its constancy is not yet proved. It should be taken into consideration that in Florov's* scheme, the initial form of the degrading chernozem is not finally established — it being possible that in different subzones or regions of the Ukraina the process of degradation did not begin with one and the same variety, and if so the harmony of the authors scheme suffers considerably. We do not even mention the variations produced by a difference in the texture of the parent rocks. Glinka has lately studied the processes[38] of degradation occurring on the Voronezh loamy sands. Degradation

* Following Nabokikh's example, Florov admits another possibility of explaining the formation of red-brownish horizons, i. e. of the removal and precipitation of R_2O_3, namely by attributing it to the reduction of Al compounds, due to temporary water stagnation, and to the subsequent oxidation during the period when oxygen penetrates into the soil.

produces here a dividing of the humus horizon into a series of streaks, which are then washed down to the deeper horizons, and finally these thin humus streaks undergo a transformation into ferric streaks („pseudo-fibres").

The loesses, loess-like loams, and loess-like clays, besides various ancient hard rocks, have a great spreading among the parent rocks of the chernozem, as the chernozem was being developed in European Russia in that belt of glacial complex, where the moraine is mostly covered with the above mentioned deposits, or is entirely absent. Still there are cases, when chernozem develops on the moraine (boulder loam) or on sandy mantle rocks. The frequent development of chernozem on loess even led us to regard loess as a condition *sine qua non* for the formation of chernozem (Karpinski); West European geologists (and sometimes also soil scientists) until now believe the chernozem to be a humus-coloured loess, without taking into account the fact that the loess is also subjected to modifications by the chernozem forming process. At present, however (since the time of Dokuchaiev and Sibirtsev), it has been proved that the chernozem may develop on various rocks; there are cases known of chernozem being formed on crystalline rocks (granites, andesites, and others), as well as on chalk, on Permian, Jurassic, and other limestones, on marls of the Upper Perm, on Tertiary siliceous clays, and even on sands and sandstones, provided the latter are not very poor in complex minerals. Sandy-loamy and sandy chernozem *ceteris paribus* has a lower humus content. It clearly follows from the above stated that Tanfiliev's opinion as to the impossibility of chernozem being formed on rocks containing no calcium, has sufficient grounding. In cases of small quantities of calcium containing minerals in the soil, it is more easily subjected to leaching and degrading, and sooner yields to the invasion of forest growth, as for instance on more or less pure sands.

The chernozem developed on loess-like loams and loesses was the most thoroughly investigated owing both to a more complete development of these deposits within the steppe zone, and also because of the fact that in this case chernozem of different climatic subzones may be better compared. It is possible to estimate the modifications caused in the morphology of the chernozem by its passing from one subzone to another only in comparing soils in similar conditions of relief and parent rock. However, the study of chernozem on loess-like rocks may present some difficulties, as on the one hand, these rocks being similar to finely-textured soil-like masses may contain products of ancient weathering and soil formation in their finely-granular part, and therefore do not permit to draw a definite distinction between the newly formed colloidal portion and that originated from the parent rock; on the other hand, loess-like clays and loams contain salts which may have partly been peculiar to them before the recent soil formation processes began developing, and therefore, it is hardly possible to distinguish them from those which have been and are being formed in the course of the present soil process. Many problems both of the genesis of the chernozem and the formation of these loess-like rocks are, therefore, as yet unsolved.*

The effect of climate on the chernozem formation is evidenced by the existence of climatic varieties („subtypes") of chernozem. The chernozem zone in a virgin state is characterised by a steppe with a varied herbaceous growth, which changes at its southern boundaries into a *Steppa Stipacea* (*Stipa Ioannis*), by a gradual decrease in the variety of forms and in the thickness and tallness of the stand; contrary to this, at its northern limit the steppe becomes richer in the variety of herbaceous growth, and is known under the term „meadow-steppe". By analogy with vegetation forms, the varieties and „subtypes" of chernozem gradually succeed each other from the limit of the forest podzol zone to the extreme limit of arid steppes. Thus, the change of climate in the chernozem zone simultaneously affects both vegetation and soils. The „subtypes" were first mapped by Dokuchaiev[19], in the form of *isohumus belts*, [the first, second, and third belts, with a respective humus content of: 1) from 10 to 13 p. c., 2) from 7 to 10 p. c., and 3) from 4 to 7 p. c.], concentrically encircling the patch of central-eastern chernozem with a humus content of more than 13 p. c.** in the upper horizon A, or more precisely in its upper portion. Sibirtsev[110], however, very justly pointed out that these isohumus belts afford evidence of both the effects of climate, and of

* These problems will be partly referred to below.

** By the quantity of humus was understood the value of CO_2 content after the oxidation of the organic matter of the soil, multiplied by the coefficient 0.481.

parent rock as well. The latter author's classification comprised the „brown chernozem of the forest-steppe region", the „chernozem rich in humus" (with a humus content above 10 p. c.), the „medium chernozem" (5—10 p. c. of humus), the „chocolate-coloured chernozem" (termed now as „southern"), and the chernozem which is a transitional form to chestnut soils. Besides we now differentiate *degraded* and *swamped* chernozem. The investigations carried out by Dokuchaiev's expedition in Poltava gvt. were based on the „humus" stand-point for the classification of chernozem; the modifications in the humus content coincided with the alterations observed in vegetation and climate, thereby confirming the opinion that the southern part of the government (the „placore" localities or even plateaus) was devoid of leached and degraded soils. The chernozem of Samara (Transvolgian) region was also subdivided according to humus content, and this subdivision coincided with that based on the thickness of the soil and other features. The following subtypes were here established: 1) „chernozem rich in humus" (with more than 10 p. c. of humus in the clayey varieties); 2) „ordinary chernozem" (with 7—10 p. c.), and 3) „chernozem poor in humus" (5—7 p. c.). Freiberg and Rumnitski[108] have established several varieties of degraded and leached chernozem, and have suggested the term „*crumbly*" for the non-leached chernozem. The most complete classification of chernozem belongs to Tumin[123], who investigated their modification as connected with climate on the area occupied by central Russia.

Tumin's morphological scheme is based on genetical principles. It comprises the podzolised soils, the chernozem, and the soils of arid steppes, presenting them in an evolutive series, and solving in a definite way the problem of their classification.

The soil process not only results in the formation and the decomposition of humus, but also in leaching, which leads to a partial decomposition of „zeolite-like" substances; this latter process produces a separation of silicic acid remaining on the spot of its separation. The chief difference between podzolised and chernozem soils consists in the form, in which the *precipitation* of silicic acid occurs; in podzolised soils the silicic acid accumulates in nests, and the so called „powdering" is exhibited in a pellicular form, whereas in chernozem, the structural fragments are powdered with silicic acid. Podzolised soils are classified according to the forms of these whitish nests (the accumulations of silicic acid); in slightly podzolised soils, the whitish cluster-like accumulations are scattered throughout the brownish horizon B; in the podzolised soil, the horizon A_2 is already formed in the shape of a whitish intercalation, whereas horizon B has the same aspect as in the slightly podzolised soils. Finally, the podzol differs from podzolised soil by a strikingly marked whitish horizon A, and by the brownish tint peculiar to horizon C which underlies the humus containing horizon.

Tumin subdivides the chernozem chiefly according to the thickness, while the powdering with silicic acid, as well as the amount of humus, and the structure of different textural varieties are entirely in accordance with these subdivisions. A change in the degree of leaching causes a change in the content and the degree of coagulation of organic and mineral colloids; the „amorphous" nature of the soil, as well as its „stickiness", and consequently its granular, powder-like, or cloddy structure is due to this latter phenomenon. The properties of chernozem on the ground of data obtained by Tumin, are summarised in the following table (see p. 61).

In other classifications, the northern chernozem is defined by the term grey and brown forest soils (forest earths); the leached chernozem is sometimes called degraded, and sometimes leached. The thick chernozem is occasionally determined as „chernozem rich in humus", though Tumin believes that owing to the effect of texture the humus content cannot serve as a trustworthy indication for classificational purposes. In the belt, where the chernozem on clays contains above 10 p. c. of humus, its humus content on loams varies from 6 to 8 p. c., and on sandy-loams from 3 to 5 p. c.

Thus, the essential idea of Tumin's generalising morphological characteristics is based on the thickness, and partly on the colouring of the soil, and on the distribution of the silicic powdering („prisypka"). It should be stated that no one but Tumin has ever studied this powdering („prisypka"), and even he never published any paper specially treating the subject. However, the very cause of its formation in soil, even in the course of the podzolisation process, is denied both by Glinka and Gedroiz, who assert that no amorphous silicic acid ever accumulates in soils of the podzolised type, and still less in those of the chernozem type, and consider this powdering to consist of quartz which has remained in the corresponding horizon after the removal of other constituents — namely, of clay. The idea itself of free silicic acid being formed in almost any type of soil formation is by no means contradictory to facts. In every instance of an incomplete decomposition of alumo-silicates — even in its initial stage, a certain part of the silicic acid is separated. What becomes of this separated silicic acid is another question. Gedroiz believes that it is immobilised only in alkali-soils (solonets) and „solodee“. Thus, in this respect Tumin's ideas are contradictory to the view-point which has been lately established, and therefore, need to be experimentally verified. It may, of course, be that this „powdering“ („prisypka“) is the „residual“ quartz, but then it should be necessary to assume that the mobility of the humus, and the removal of clays begin at the stage of the ordinary chernozem, or, at any rate, of the thick chernozem.

Tumin considers that the increase in thickness from the southern chernozem to the thick chernozem is due, on plough-lands, to an increase in the underground portions of vegetation, whereas in virgin steppes both to that of the under- and overground portions. An increased degree of leaching in soil (causing a lack of nutritive substances, and the appearance of certain other physico-chemical conditions unfavourable to vegetation) results in the thickness of the soil decreasing to north of the central region of the „thick“ chernozem. The modification progresses similarly on virgin soils; however, the quantity of humus is higher, and a vegetative felt („dernina“ — sod or turf) develops in the upper 3—5 *cm* of the virgin soils.

In his large work which is here being quoted, Tumin declares that „the varieties that were formerly known as southern chernozem and chestnut soils are now comprised under one term: „the southern chernozem“. Thus, Tumin extends the chernozem zone in both directions — to the north-west, and the south-east of the thick chernozem, and includes thereby into the limits of this zone the so called grey forest soils, on the one side, and the chestnut soils, on the other. In outlining his scheme, the author does not touch upon the question of soil degradation, and does not regard either the northern or the leached chernozem as degraded typical chernozem, contrary to Glinka, who considers that degraded chernozem belong to podzolised soils, as these soils are in the power of the pro-

Varieties	Thickness of horizon		Depth of effervescence (horizon)	Humus (p. c.)	Siliceous powdering covers	Structure of clayey varieties *
	A	$\frac{A + B(B_1)}{A + B_1 + B_2}$				
1. Grey chernozem	45—25 grey, dark-grey	100— 70 *cm*	C		The whole of the soil and very markedly (whitish and pellicular spots)	Granular, passing in lower horizons into nutty and nutty-cloddy
2. Leached chernozem	55—45 dark-grey	$\frac{65\text{— }75\ cm}{100\text{— }90\ cm}$	C or the limit B — C		The whole of the soil (whitish powdering pellicular in B_2)	Granular granular-cloddy (nutty)
3. Thick chernozem	34—54 dark	100—120 *cm*	B or the limit B — C	10	Horizon A, part of B	Granular, passing in lower horizons into cloddy granular
4. Ordinary chernozem	20—35 dark	$\frac{40\text{— }55\ cm}{65\text{— }85\ cm}$		7—10	5—10 *cm*	Cloddy-granular, passing in lower horizons into cloddy
5. Southern chernozem	10—25 greyish-coloured	40— 70 *cm*	B or the surface of C	5—6	absent	Cloddy structure (not varying with texture)

* Structure varies according to change in texture

cess of podzolisation, but at the same time distinguishes them from initially, i. e. primary podzolised soils, and calls them *secondary podzolised* soils. Other investigators (the Moscow soil scientists) are inclined to consider the degraded chernozem and grey forest soils (according to Tumin's terminology, the northern and partly the leached chernozem), as belonging to a particular type, the so called „*chernozem forest*" type. The soils of this type are not necessarily at present covered with forests, as the latter may have been hewn, but their degradation must have had taken place under forests. We have seen above the scheme of degradation of the Ukrainian chernozem advanced by Nabokikh and Florov; a generally similar picture may also be observed in other regions of the forest steppe zone, so far as they have been studied.

All that has been said on chernozem leads us to the following conclusions. The study of chernozem on the territory of the USSR has helped us to establish its dry land vegetative (steppe) origin. The climatic conditions over the area of the chernozem zone (in the European part of the USSR) are modified in the direction from the north (north-west) to the south (south-east), and produce modifications of the chernozem in the same direction. On the other hand, this series (in the southern and south-western parts) is complicated by chernozem formed in conditions of a warmer and less markedly continental climate (Ukraina, Caucasus). The chernozem of the Ural and the Transural region, contrary to this, bear an imprint of a more continental climate. Each of these climates has its own peculiar series of chernozem, which are in accordance with the variations of temperature and of the amount of precipitation, and are partly parallel to the series of central Russian chernozem. The difference between them consists in the thickness of the humus horizons, the quantity of humus contained, the depth of the effervescence level, and the form in which carbonates are manifested in them, as well as in the structure of the humus and humusless horizons, and in the activity of burrowing animals. Besides differentiating climatic varieties, we may also distinguish same according to parent rock, and to the preceding evolution of the soil. This somewhat complicates the problem of the classification of chernozem, and makes it more difficult to distinguish the purely climatic „provinces". The same difficulties are, of course, to be met with in classifying other soils, particularly those of arid steppes.

Soils of arid steppes.

The systematical composition and the diversity of vegetation, and the thickness of the stand gradually change together with the change of climate towards a greater dryness; the steppe characterised by a varied herbaceous growth and a tall stand is succeeded by a pure *Gramineae* steppe with a less tall stand of *Stipa*, which is further followed by steppes covered with a pure growth of *Artemisiae*, and those covered with both *Artemisiae* and *Salcolaceae*, where the soil surface is already devoid of a densely stalked turf. Therefore, we may first observe in these soils a decrease in their humus content and in the thickness of the humus containing horizon, a rising of the level of effervescence and of the precipitation of calcium carbonates, and the presence of a horizon containing sulphates (gypsum). All these features characterising the soils of arid steppes have been long ago described, and the above mentioned properties owing to their being zonally distributed were naturally in the first place accepted for the purpose of classifying soils of the arid steppes; the chernozem was directly succeded both to the south and the south-east by *chestnut soils* (subdivided according to their humus content into dark and light chestnut soils), containing from 5 to 3 p. c. of humus, and characterised by an accumulation of calcium carbonate in the form of „glazki" (eyes) and spots at a depth of 50—60 *cm*; the chestnut soils were followed by brown soils with a lower humus content [8, 78, 99, 110], and an accumulation of gypsum in the form of spots and streaks (rarely of „glazki"), at a depth of 30—40 *cm*. However, besides these properties, certain morphological features have been concurrently established in soils of arid steppes, which distinguish them from the typical chernozem, as for instance [1e, 65, 111] the differentiation of the humus containing portion of the profile, its subdivision into a more friable subhorizon, schistose in its lower part, and a more compact, cloddy one; a similar differentiation in light-chestnut and brown soils is moreover accompanied with certain variations in the colouring of the subhorizons; the upper subhorizon acquires a greyer tint (to the level of 10—15 *cm*), whereas the lower one — a markedly browner shade. Besides, the grey horizon in brown soils acquires the character of a more or less compact, porous crust, with a squamose-schistose layer under it. In cases when the cloddy subhorizon was not evidently compact, it was impossible to speak of its alkalinity, as even water-extracts usually did not help to discover it in these horizons, and the differentiation of the humus horizon had to be attributed to other causes. A partial explanation of these phenomena was suggested by Gedroiz, but as yet, however, there is no unanimity of opinion as regards the origin of the differentiation of the profile of arid steppe soils. Nevertheless, it should be mentioned that the compactness of the humus subhorizon of cloddy structure is in many cases very marked, and that the farther the arid steppe soils are situated from the chernozem zone, the greater number of *alkaline varieties* they may display, which often prevent these soils from being correctly identified. The *alkaline varieties of dark chestnut soils* have been described in the Turgay table-land by Orlov, Lebedev[64], Levchenko[65], Skalov[111], Tumin, Stasevich, and Abutkov, and later, in the southern Transuralia, by Rozhanets[106, 107], who called them grey-chestnut soils. The light chestnut alkaline soils have been described by Dimo under the term of *typical semi-desert soils;* as to morphology and to distribution of R_2O_3 along the profile of such soils this author established an analogy with podzolised soils (increased content of R_2O_3 in the somewhat compact horizon B as compared with horizon A).* As no systematic summary of water extracts for different horizons of arid steppe soils, with the determination of both their general alkalinity and that of normal carbonates of alkalies and alkaline earths, has ever been published, and as, on the other hand, no determinations of absorbed bases ** have ever been carried out, it is difficult to distinguish in separate instances the alkaline from the non-alkaline soils, the more so as the described soils of arid steppes are developing on different rock. The drier the climate, the greater the effect of parent rock on the aspect of the soil. The least alkaline soil profile, or the chernozem character is preserved on light loess-like parent material; on clays and slightly permeable rock alkaline soils develop more readily[106, 107]. Alkalinity may also be the result of a coarse, stony composition of the soil, probably due to a warmer climatic régime. Thus, an alkaline profile is peculiar to stony, gritty, and

* See Bibliography, № 16, p. 132.

** This method having only been but lately introduced into analytical soil investigation.

coarsely sandy soils of the deserts of Bed-Pak-Dala, Ust-Urt, of the „ostantsy" (the monadnocks — residual hills), and of small elevations in the low plains of Turkestan: the marked differentiation of the profile into a light-grey coarsely-cellular crust, squamose-schistose in its lower part, and a brown somewhat compact horizon below it containing spots of carbonates, which is succeeded by a horizon rich in gypsum (acumulated in the form of icicles and crusts on the surface of stones, and even in the form of intercalations of fine elongated prismatic crystals). These soils are characterised by an insignificant humus content — only about 1 p. c. (the vegetation covering them chiefly consists of *Salsolaceae*, *Artemisia maritima*, f., *terrae albae* Krasch.), carbonates of calcium accumulating in the very upper horizon and gradually decreasing along the profile. All these features have led us to consider such soils as belonging to alkaline or structural „sierozem", and „bielozem" as well. *

Nikitin, and previously Prasolov[100], preferred, however, to continue calling these soils by the term of (light) brown soils, which is quite possible, if no *grey zone* be distinguished. The soils on hard parent rocks of the low elevations in Turkestan sometimes prove to be so weakly developed that they are represented but by a grey loamy crust with large pores covered with grit and gravel, and directly underlain by weathered fragments of the parent rock, sometimes containing in great quantities fine elongated prismatic crystals of gypsum (the gammada). Such soils as the above described alkaline sierozem, are also peculiar to the highland desert of Pamir[79].

Contrary to hard rocks and clays, the loess-like loams and loesses of Turkestan are covered with soils characterised by a normal steppe profile, with a whitish-yellow or dull-whitish-yellow tint in its upper part and an inconsiderable differentiation of the humus horizon into an upper schistose and a cloddy (non-compact) lower subhorizon, with efflorescences of carbonates at a depth of 30—35 *cm*, and accumulations of gypsum at a rather great depth (100 *cm* below the surface, and even more). These soils generally have a low humus content (less than 2 p. c.),

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* Previously the term of „grey-brown" soils was applied to them (see Bibliography, №№ 14, 24, 69, 81, 84, 85, 87).

and always effervesce from the surface. With their approach towards the mountains, they become both darker and thicker on loess hills, and though retaining the above indicated properties show traces of an intense activity of worms, evidenced by their being markedly burrowed and porous, as well as by their peculiarly granular structure. These soils have been termed „sierozem“,* the lighter coloured varieties having been distinguished into the variety of *light sierozem* (*„svietlozem“*, according to Dimo), the darker varieties covering foot hills — into that of *typical sierozem*. The soils of the ancient alluvial plains, in Turkestan, are less developed — separating into single plates, with a schistose-crumbly subhorizon beneath it; this *primitive sierozem* [15, 94, 85] mostly rich in salts is already closely allied to salines.

Thus, in the series of arid steppe soils on loess-like loams, the soil types succeed each other in the following order: chestnut soils, brown soils, light sierozem. The typical and the dark (thick) sierozem should be considered as members of the vertical series of mountainous soils, i. e. analogues of the brown and the light chestnut soils developed in conditions ot higher temperature and greater quantity of precipitation as compared to the corresponding members of the horizontal series; these soils are thus more closely allied to chestnut soils of the Precaucasia.** They rarely possess alkaline humus horizons.

Gedroiz attributes the cause of the differentiation of the humus horizon in arid steppe soils into a schistose and cloddy subhorizons to the previous weak alkalinity ot the soil, the latter having passed through a stage of transformation into solodee in the presence of $CaCo_3$, i. e. not only the stage of leaching of the Na ion from the soil, but of its replacement by Ca as well. In this case, the soil seems to restore its normal non-alkaline character, though its former alkalinity might be proved by a precise chemical analysis. Other investigators were inclined to explain the morphology of upper horizons of arid steppe soils by the water régime of these horizons. However, Gedroiz's explanation seems to be the most credible, and is confirmed by facts which will be mentioned further; at any rate, the majority of arid soils have derived from alkaline [80] soils.

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* See Bibliography, №№ 9, 15, 75, 86, 101, 124.

** On chernozem of the Precaucasia, see above.

The chestnut and brown soils on parent rocks characterised by a half-permeable and half-water capacity possess *always* horizon containing accumulations of gypsum underlying a horizon with accumulations of carbonates, which in its turn is frequently alkaline owing to the presence of Na. Thus, the alkalinity of the carbonate horizon and the salinity of the sub-carbonate horizon, in the humusless portion of the profile, is in this instance still more marked than in the case of the southern chernozem. The question may arise, whether this alkalinity of the horizon overlying the accumulation of gypsum should not be attributed to a previous presence of sodium above the gypsum horizon, reaching the same level at which the alkalinity is now distinguishable, i. e. whether the salt content of the soil was not higher in a preceding stage of development.

In any case, the rôle of salts in soil formation becomes more and more marked with an increase in dryness of the climate, first *alkalinity* appearing in zonal soils, subsequently followed by *salinity;* it should be understood that the increased alkalinity is due to carbonates of alkalies, and the salinity — to the presence of soluble salts in the upper part of the profile. Glinka is, therefore, inclined to call the brown zone (and, probably, the southern part of the chestnut soil zone as well) — the *alkaline* soil zone, and the grey soil zone — *saline* zone.

Within the boundaries of the USSR, *desert soils* either belong to gritty gypsum containing soils (and partly also to alkaline salines or alkaline sierozem), or to the above mentioned primitive sierozem. On the sands of Turkestan, a superficial layer cemented with calcium carbonate and gypsum is frequently observed. Besides, concretions of calcium carbonate (in the form of roots and stems), consisting of rather hard fragments of rock and of sandy or clayey fine textured admixture, are also very characteristic of these sands, and have often been described by tourists and investigators. These concretions are apparently due to the transpiration of the soil moisture through vegetable organs, which become enriched with salts in the course of this process.

Silicic crusts have not been observed in Turkestan in ordinary conditions. In cases when they were found by Fersman [26], their origin should be attributed to the effect of free sulphuric acid appearing in sulphur deposits and decomposing alumo-silicates. It is altogether doubtful that silicic crusts may be formed during the process of displacement of alkaline solutions. These solutions are prevalent in the „alkaline“ (brown) zone, where free silicic acid accumulates in the form of „gel“.*

Besides the above described zonal varieties of arid steppes, certain local provincial varieties may be distinguished. Thus, chestnut soils of Precaucasia (the region of the foot hills), resemble more closely the dark sierozem of Turkestan than the chestnut soils of Western Siberia, and of the south-eastern part of European part of the USSR. The peculiarity of the chestnut soils of Transbaikalia, and of the brown soils of Mongolia, was also pointed out to by Prasolov, and recently by Polynov.

The soils of dry subtropical countries have also been described as closely resembling the brown soils and sierozem of the Turkestan deserts and semi-deserts. Thus, the soils in the vicinity of Madrid, described by Glinka[36], only differ in their reddish tint, but in all other respects have the same features of the profile as the brown soils of Western Siberia, and are characterised by a differentiation of the humus horizon into an upper, schistose, and a lower, cloddy, subhorizons. According to Dranitsyn[22], the red soils of subtropical deserts are also characterised by similar features, whereas those of tropical deserts were less considerable in thickness, and had a high salt content. Thus, their genesis is similar to that of the arid steppe soils and the deserts of central Asia, but with an addition of a new property due to climate — the red tint of the upper horizons, i. e. the presence of red hydrates of iron oxide, the latter phenomenon being usually regarded as a witness of lateritisation. However, in this instance we have not sufficient ground to consider it as such until the presence of free hydrates of Al_2O_3 in these soils should be finally established. Iron oxides in a free state are almost permanently present in soils. It is only the form of the hydrate (due to this or that water content), i. e. its colour, which is caused by high temperature of the subtropics. We have, however, already mentioned that Hilgard succeeded in establishing the presence of free hydrates of sesquioxides in soils of arid countries, i. e. the process of lateritisation. The question

* See further, the paragraph on alkali-soils and solodee.

as to the origin of the red tint appropriate to these soils can only be solved after a special study of the latter.

A review of the type of steppe soil formation shows a gradual modification of the process; the chernozem type of soil formation seems to be the centre, while the soils of a higher or lower moistening spreading from this centre lose the uniformity of the R_2O_3 content throughout the soil profile, and thus become respective transitional stages towards the podzol or alkaline types of soil formation. The two latter types of soil formation seem to impose with always increasing intensity on the chernozem profile, modifying it accordingly. This superposition is partly due to a change of the present climatic conditions in the direction of the north, and partly to the modification of one or another soil forming conditions within time: their degradation caused by the spreading of forest, on the one hand, and the leaching of soil with a higher salt content, on the other. Both these phenomena are an indication of the digression of zones towards the south, which is taking place during the last period of geological history[6].

The alkaline type of soil formation.

The soils of the alkaline type of soil formation are closely connected with the steppes, as has already been shown. However, it is not possible to understand their genesis without first studying such soils as bear traces of either a past or present effect of ground moistening.

Salines („solonchak"). Though almost every soil solution contains electrolytes in conditions of comparatively dry climate, their quantity may increase to such an extent as to affect different soil properties. Similar soils, rich in salts, are called salines („solonchak"), and their formation is chiefly due to the capillary rising of water and its evaporation either at the surface or at a certain depth (Glinka); in the first case, when the maximum of salts is accumulated near the surface, — it will be the „surface salines"; in the second case — the „interior salines" (Vysotski). The condition of an excessive moistening near the surface, even if occurring but periodically, is the chief cause of salines formation.* Glinka, therefore, considers salines as belonging to the group of soils

* From this view-point salines are related with moor-soils, the presence of salts, however, adding a particular character to the soil.

temporarily characterised by excessive moistening; with the transition from more humid into drier (steppe) zones, the salines gradually replace the bog-soils. Morphologically salines are not characterised by any independent profile, as even the efflorescences of salts at the surface, and their appearance along the soil section do not always evidence such a content of salts as might affect the nature of growth, etc. Thus, in certain cases, podzolised soils enriched with salts may be observed in the West Siberian plain. In some cases, however, salines are characterised by certain morphological peculiarities. When a considerable accumulation of salts occurs, crusts composed of an earthy material are formed near the surface; these are cemented with salts, and covered with salt efflorescences of a snow-white colour (of sulphates and chlorides). Frequently a similar or less hard crust is underlain by a soft, friable, „puffed-like“ layer containing a great quantity of separate salt crystals, to which its puffed-like nature is due.* Similar salines are known by the term of „puffed“ salines[75, 81]; their salt content decreases from the surface downwards. Dimo and Nikitin[84] believe it possible to attribute the lowering in the salt content of such salines to the action of the wind (Turkestan). The irrigation and tillage favour a more uniform distribution of salts along the profile. The Turkestan „tugai“ (flood-plains) owing to ploughing evolve through the stage of „puffed“ salines into a further stage of salines with a maximum salt content in deeper horizons, while the „puffed“ surfaces are changed into „takyr“-like, i. e. into hard grey, porous, usually loamy crusts. The sinking of the ground-water level is the cause of this evolution, while the removal of salts to a greater depth by deep washing, and their deflation, is its outward manifestation. It will be further seen that in the chestnut and the chernozem zones salines having been leached evolve into the so called alkali-soils („solonets“).

Salines were usually subdivided, according to the kind of salts, into salines containing 1) carbonates, 2) sulphates, and 3) chlorides. The first were differentiated by Glinka, who understood by salines containing carbonates, soils with an abnormally high effervescence due to the effect of ground-waters; to those belong the carbonate

* Strong coagulation of suspensions and colloids due to a high content of salts is partly manifested in this phenomenon.

containing salines of mountain slopes, as well as those of river valleys and plains in Western Siberia, observed by this author. These salines often not only contain carbonates of alkaline earths, but easily soluble salts as well; purely carbonate containing salines are peculiar to the northern parts of the steppe zone. A certain content of carbonates (manifested by means of effervescence with acid) is generally peculiar to chloride and sulphate containing salines, though in some cases, the phenomenon of effervescence is absent in these soils.

Purely sulphate and chloride containing salines are not frequently observed; usually various anions are prevalent in different horizons. Among chloride containing salines, those rich in calcium chloride are distinguished by their hygroscopicity; therefore, the soil surface proves to be constantly wet.

Alkali-soils („solonets“). Gedroiz suggested to distinguish salines not according to the anions, but to the cations of the salts they contain, i. e. to differentiate calcium, magnesium, sodium, etc., containing salines, as the prevalency of this or that cation in soil markedly modifies its properties. Before going in search of sufficient grounding for such a suggestion, it should be mentioned that until 1910 the terms „saline“ („solonchak“) and alkali-soils („solonets“), were indifferently used in Russian soil scientific literature, the latter being even more frequently used. The alkali-soils („solonets“) were differentiated into wet or non-structural alkali-soils, applying this term to such soils as have been already treated above, and into dry structural (true) alkali-soils. The latter were first described by Zemiatchenski[141], for the Saratov gvt., and by Pegeev, for Western Siberia, but finally differentiated by Bogdanov[10], and subsequently by Dimo and Keller[16], the latter authors having described them for different localities of European Russia and Siberia. In short, their morphology is characterised by a *two-story* profile. The upper paler horizon (of a greyish tint) is more or less markedly distinguished from the darker (blackish, brownish) indurated horizon which in dry state separates into blocks, prisms, or columns with rounded heads. Analogously to podzolised soils, the upper loose horizon was called A, and the somewhat compact horizon — B. An analogy may also be seen in the morphology of horizon A — its upper, humus containing part A_1 is darker; the lower, schistose or foliated part A_2 is of a lighter colour (to a whitish-grey). The somewhat compact and comparatively dark horizon B sometimes contains, in its lower parts, not only efflorescences of carbonates, but more soluble salts as well, and the latter are occasionally discovered even by analysis in minute quantities. In spite of this, no one ever denied the connection existing between these „dry“ or „structural“ alkali-soils and the process causing the increase in the salt content. Simultaneously to the increase of data referring to the morphology of these soils, information with regard to their chemical composition was also accumulating. The subsequent differentiation of alkaline soils from true alkali-soils („solonets“) was based on morphological features, namely, the degree of distinctness of the limit between horizons A and B. Further, strongly and weakly alkaline soils were established, and even the idea of alkaline chernozem and alkaline chestnut soils was advanced; the compactness of these latter soils within the limits of the humus horizon, which is not usual for their normal varieties, is considered to be the main feature of alkalinity. A definite distinction was also drawn between the so called wet salines and the structural salines, and the special term of salines „solonchak“ was now applied to the first variety, while the term „alkali-soil“ („solonets“) was now only used for determining soils of the above described structure, which also necessarily have a different genesis. It was quite evident that in alkali-soils the processes causing the removal of salts into their lower portion were prevalent to those resulting in the raise of salts to upper horizons, which is observed in salines. The first attempt to explain the genesis of alkali-soils was based on their analogy with podzol. D i m o even affirmed [16] * that the upper horizons of the alkali-soil were characterised by an acid reaction; the frequent occurrence of alkali-soils in small depressions without outlet (exposed to temporary excessive moistening) confirmed the possibility of another analogy. It was, however, soon established that alkali-soils are, on the contrary, characterised by an alkaline reaction, and that their soil solution contains carbonate of sodium. G l i n k a considered the alkali-soils to be analogous to the sodium soils of Hungary; he advanced the theory of the genesis of alkali-soils, according to which the bicarbonate of sodium,

* The analogy between salines and podzolised soils was already stated by P. A. Z e m i a t c h e n s k i, in 1894 (see Bibliography, № 160).

obtained by means of Hilgard's[36] reaction, rises capillarly from the deeper parts of the soil to the upper ones; here, in the dry season, it is transformed into the neutral sodium carbonate, dissolves humus, converts into a soluble condition certain mineral substances, at the same time decomposing, with comparative intensity, the alumo-silicates; the products of this decomposition are then removed by the alkaline solution to the lower horizons, partly precipitating in horizon B which is, therefore, comparatively rich both in organic substances and clayey particles. The origin of the carbonate of sodium, or rather of the alkalinity of soil in general, due to the presence of normal and acid carbonates of alkalies, was, however, explained by Gedroiz from quite a different point of view.* Gedroiz bases his explanation on the phenomena of absorption, and first of all draws a marked distinction between soils containing salts of different cations. These salt cations found in the soil solution are absorbed by the organic and mineral soil complexes („humate" and „zeolite", according to Gedroiz), i. e. by the minutest fractions of the soil, the suspensions, and the colloids. The presence of Na in the absorbing complex, due to increased content of sodium salts in the soil, communicates to the latter certain peculiar properties, as this cation has a dispersive effect on both mineral and organic soil particles. The high solubility of humus in alkali-soils was established long ago. However, in order that the alkalinity of the soil solution might become somewhat markedly manifest, it would be necessary that a removal of the former excessive quantities of salts should previously take place. Only then, owing to the absence of sodium salts in the solution, does the sodium of the absorbing complex pass into the solution (this phenomenon is usually determined as: „carbonate of sodium in the soil", „alkalinity due to normal carbonates"), and begins intesely affecting the organic and mineral portions of the soil. The absorbing complex saturated with sodium not only possesses solubility, but a capacity for comparatively easy decomposition as well; its alumo-silicate portion is therefore disintegrated with a sub-

* See many of Gedroiz's works since 1912: „Colloidal chemistry applied to problems of soil science"; „Absorbing capacity of the soil and soil zeolite bases", and others. Especially the quoted above: „The absorptive soil complex and the absorbed soil cations as basis for a genetic classification of soils", 1925; „Transformation of soils into „solodee", 1926.

sequent immobilisation of a part of silicic acid it contains in horizon A (chiefly in subhorizon A_2 directly above the somewhat compact horizon B, where solutions are retained), while the hydrates of sesquioxides (in pseudo-solution) penetrate together with the humus still further down, and are immobilised after coming into contact with the electrolytes, in horizon B, which is, therefore, comparatively enriched with R_2O_3, P_2O_5, and has the aspect of a more intensely coloured and somewhat compact horizon. The horizon B thus formed, enriched with clayey particles and somewhat in humus, separates in dry seasons into prisms (prismatic „solonets" alkali-soil). Owing to its water-tightness [12], * water accumulates on it, thus causing a more intense leaching of the directly overlying part of horizon A as compared to the upper portion of the latter; this results in horizon A separating into two horizons — the more intensely coloured by humus and less leached horizon A_1, and the decolorated, schistose horizon A_2. In the process of further leaching, the apexes of the prisms become eroded, and acquire the form of tops powdered with a whitish (siliceous) flour („solonets"-alkali-soil of columnar structure, the most typical specimen of alkali-soils). The process may go on until a marked corrosion of horizon B takes place. This theory leads to the conclusion that the alkali-soil originates *from sodium containing salines;* or more precisely, the alkalinity of a given horizon is an evidence of its former considerable content of sodium salts. It should also be accepted, that the leaching of these salts from the given soil is another necessary condition of alkalinity. The more the soil was formerly enriched with NaCl and Na_2So_4, the stronger will be manifested the features of alkalinity during its leaching. The treatment of soils saturated vith sodium, by means of sodium salts, with water, has confirmed these considerations. The presence of other salts, carbonates of calcium, gypsum, even in the absence of sodium salts, prevents the separating of sodium from the absorbing complex (the formation of carbonate of sodium, of NaOH), and the formation of alkali-soils, though in some cases there are alkali- and alkaline soils containing rather considerable quantities of calcium carbonate [84, 85]. Their genesis,

* The water properties of alkali-soils have been investigated by S. K. Chaianov.

however, is not yet studied in detail. There is in all probability a limit of concentration of calcium carbonate in the soil solution, up to which the formation of alkali-soils is possible. Recently, Glinka has accepted the explanation of the origin of alkali-soils advanced by Gedroiz, though he is still of different opinion with regard to the destruction of the alumo-silicate portion, and thinks that similarly to the podzolisation process, the transfer of suspensions (clays) takes place here in the alkaline solution. The decomposition of silicates seems, however, to be confirmed by a marked accumulation (up to 6 p. c., and even more) of „free" silicic acid (soluble in 5 p. c. KOH) in the alkali-soils (Gedroiz[34]). Analogously to that, free alumina may be expected in the deeper horizons of the alkali-soils, and the increase in its total content in horizon B seems to confirm this presumption.

The evolution of soils with high salt content.

Thus, alkali-soils are a stage in the process of decreasing of salt content in saline soils. Therefore, the presence of alkaline horizons deep below the humus horizon may be presumed, provided the salt content of similar soils had decreased for some reason. Indications as to the correctness of this presumption are not only found in the alkaline (southern Don) chernozem (Nikiforov), where the so called illuvial, somewhat compact horizon attains the depth of 100—150 *cm*, but also by the chernozem of the northern Precaucasia[83], where the humus containing horizons are devoid of alkali-soil features, the latter being noticeable only at a depth of 100 *cm* in the horizon of increased alkalinity due to the presence of normal carbonates; this horizon directly overlies the gypsum containing horizon, where precipitation of carbonates of calcium is observed. These phenomena either seem to evidence that the upper limits of salt containing horizons lay formerly higher (gypsum is at present observed at a depth of 150—200 *cm*), or that there exists an alternation of the periods of increasing and decreasing salt content in the present life of the soil. The first presumption seems to be the more correct, as it is in accordance with the greater dryness of the climate of the precedent epoch. The presence of easily soluble salts in the subsoils of the steppes, found at a certain depth below the soil, has been often noticed beginning with the normal chernozem and further south; a gypsum „belt" beneath the carbonate „belt" of soil is always observed in parent rocks characterised by a half-permeability and halfwater capacity, such as the loess and loess-like loams. Unfortunately, chemical investigations of such steppe subsoils are as yet very scarce (some papers of Vysotski and of other investigators).

Solodee. When the process of leaching is going on, and the alkali-soil has lost considerable quantities of absorbed sodium, the latter is replaced by *hydrogen*, and the *podzolisation* process arises. A similar „degradation" of the alkali-soil was particularly well described by Popov for the small depressions of the chernozem steppes in the Voronezh gvt., which are covered with the so called „aspen shrubs"[96]. The morphology of these soils is characterised by a strikingly whitish leached horizon A_2; the horizon B frequently retains some of its former properties — its prismatic structure, etc., notwithstanding the fact of its being considerably corroded. In Western Siberia, such degraded alkali-soils or „solodee" (as Kossovich and Gedroiz suggested to design them), are found under separate birch-groves („kolky"). According to Gedroiz, the „solodee" markedly differ from podzolised soils in their content of „free" silicic acid (soluble in 5 p. c. KOH): Ivanova has established that the „solod" found in small depressions of Western Siberia contains more than 12 p. c. of free silicic acid, while in podzolised soils the free silicic acid is either completely absent, or its content is not above 0.26 p. c. (Moscow Experimental Station). Gedroiz thinks that such an amount of free silicic acid indicates the fact that the absorbing complex, which is saturated with sodium, shows a greater capacity for destruction than that saturated with hydrogen. The presence of free silicic acid in soil, provided even that there are no indications of its being at present rich in salts or possessing features of alkali-soils, points out to a former presence of Na in the absorbing complex. Gedroiz's ideas on the genesis of alkali-soils and salines have proved to be of great importance in paleogeography, as may be seen from the following example: Krasheninnikov and Polynov[56] have established that soils of river terraces, in case of their gradual drying (due to a lowering of the erosion basis), undergo a process of evolution. The flood-plains, and in general the abundantly irrigated lower river terraces of steppe rivers, are rich in salines, while alkali-soils alone or in complexes with other steppe soils appear over the middle terraces[94].

Later, Vilenski advanced an interesting scheme of the history of steppes based on the assumption that all alkali-soils were salines in the geological epoch preceding the Post-Glacial period, i. e. soils exposed to temporary excessive moistening [126, 127]. The fact that alkali-soils („solonets") are spread in valleys, and chiefly on parent rock of an alluvial habitus, seems to furnish sufficient ground for a similar conclusion. However, as alkali-soils are also found over divides composed of ancient rocks (such as Permian, Jurassic, Cretaceous clays, sandstones, and others), Vilenski's conclusions should be restricted, or, at any rate, somewhat modified.

On the ground of the above stated with regard to the evolution of alkali-soils, we would be ill-founded in denying the importance of the latter in the explanation of certain paleogeographical problems.

The bog-process of soil formation.

Bog-soils. The excessive moistening of the soil, i. e. the filling of its pores with water during a more or less lasting period produces different effects. In countries characterised by a small degree of evaporation, and particularly in those with considerable amount of atmospheric precipitation, the *organic portion of soil*, owing to a lack of oxygen, is not subject to decomposition, and does not produce intermediary products of decomposition in the form of humus, which is usually accumulated in meadow and steppe soils, but instead is enriched with carbon, and *transformed into peat.* In the course of this process, a certain part of vegetable substances is evaporated in the form of gaseous hydrogen compounds, such as CH_4, H_2, PH_3. Apparently the activity of micro-organisms plays an important part in this process of transformation into peat and of carbonisation. In any case, when the moistening of the soil attains the uppermost horizons, the formation of peat bog-soils takes place, due to the transformation into peat of the remains of paludinous herbaceous growth (*Carex*, etc.), as well as of paludinous mossy vegetation (*Sphagnum*, and other mosses), and partly even of remains of forest growth (alder, dwarf-birch, and others), resulting in accumulation of thick masses of peat. Certain instances have been observed, when deeper soil horizons were not as excessively moistened as the upper ones; in this case, *superficial swamping**

* Such cases are described for the Amur region, the northern region of the European part of the USSR, the and other localities.

was the result. Here, the peat-forming process was being developed simultaneously with the „gley“ and podzolisation processes proceeding in the deeper, mineral parts of the soil (see below). The transformation into peat of the upper soil horizons may extend to different depths, and in cases when the lower portions of the peaty horizon are accessible to moisture rich in oxygen, this latter horizon is underlain by a humus horizon.

The lack of oxygen in the mineral portion of the soil due to excessive moistening may also produce the deoxidation of iron compounds (by means of solutions containing slightly oxidated organic substances), which are therefore present in such soils in the form of salts of protoxides (as vivianite, phosphoric salt of iron protoxide, ferro-sulphide, and others). Horizons containing compounds of iron protoxides are of grey, black, and blue colour. The character of the decomposition of the mineral mass under the bog has not yet been finally established, but apparently different forms of decomposition may be expected in accordance with the variations of temperature, beginning with very slight decomposition and ending with the formation of clays and even of kaoline, in dependence upon the climatic zone. The mobility of iron in the form of compounds of iron protoxide seems to be universal. It should be noted that the presence of iron compounds of protoxide in most cases may be noticed only on freshly excavated soil,* as iron is subject to rapid oxidation. The traces of subsequent oxidation caused by drying are usually observed in swamped soils in the form of rusty spots, and even concretions. The occurrence of hard ortstein layers, and other accumulations of concretion in soils, is due to the presence of iron in solutions, and to the precipitation of the latter in the form of hydroxide. As a result of the evaporation on the surface of the swamped soil, iron precipitates in the upper soil horizon (directly beneath the peaty horizon) in the form of nodules of *bog-ore*, the formation of the latter being consequently analogous to the genesis of salines.** As stated by Vysotski, soil horizons that had been exposed to deoxidation processes, and consequently to the removal of iron in the form of protoxides, have been found by this author in the subsoils of forest steppe soils, near to the ground-

* Test by potassium ferrocyanide.

** Salines were therefore related to the bog-type soil formation (Glinka).

water level. These horizons proved to have a lower iron content, and were characterised by a greyish tint and a clayey texture. Vysotski attributed to them the popular name of *„gley“*[134]. This term was further accepted in Russian literature for the determination of deoxidated horizons of moor-and bog-soils. The „gley“ horizons generally develop beneath the more or less peaty horizons, occasionally also beneath the podzolised horizons of podzolised soils, and sometimes beneath the humus horizons of the so called meadow-soils. Therefore, the following „gley“ soils are distinguished: the peaty „gley“, the podzolised „gley“, the meadow „gley“ soils, etc. Different forms of podzolised „gley“ soils and peaty-podzolised „gley“ soils are a transitional stage between the podzolised and bog-soils, and are therefore sometimes called half-bog-soils, although a term precisely determining the genesis of the soil should be preferably used. „Gley“ horizons are often so poor in iron as to become decolorated, and resembling podzolised horizons (bleaching process). „Gley“ horizons are observed at different depths of the ground-water level under soils of different types. The process of the formation of bog-soils should therefore be distinguished from „gley“ process, which, like the transformation into peat, carbonisation, and ore formation, is but a part of the bog- formation process. These processes are elementary processes differently combined for the formation of this or that kind of bog-soil.

Soils of tundra.

The climatic conditions of tundra are favourable to excessive moistening, and its soils are therefore allied to bog-soils. The podzolisation process was observed by Krasiuk, in the tundra of the southern part of the Kanin peninsula, and by Gorodkov, in the Obdorsk tundra. A typical tundra, however, is the domain of the bog-process. Its swamping is not only due to a low degree of evaporation, but also to the presence of permanently frozen subsoil at a comparatively small depth impeding the outlet of waters. The excessively moistened horizon above the permanently frozen subsoil, slightly thawing in summer, is called „talik“. Its colouring is due to ferric rusty spots, and wedges of humus. When drying this „gley“ horizon of tundra soils retains its motley colouring; judging from samples collected by Ratmanov, similar soils are found in Novaia Zemlia. The mass of vegetative remains of mosses, lichens, and dwarf forms of shrubs, has a tendency to transform into peat. The so called hillocky tundra is a result of a peculiar overgrowth of mosses and lichens in the form of knobs; these hillocks or knobs contain, according to some authors, a kernel of frozen material, while others even believe them to contain an icy block, which is caused by the freezing of the water flowing through them. The decomposition of vegetation produced by freezing causes denudation and cracking of the surface of the knobs, which undergo the stage of destruction. Soils of the „medallion“ [20] and „spotty“ tundra landscapes are also very remarkable. Sukachev [115] attributes similar landscapes to an overflow of the „talik“, i. e. the humid horizon overlying the permanently frozen subsoil, owing to the freezing of the soil from the surface, when the „talik“ is exposed to high pressure. The semi-liquid mass of outpoured soil flowing over the surface forms spots deprived of vegetation. Prokhorov explains the formation of knobs on swampy (bog) „mary“ in the Amur region in a similar way. Gorodkov attributes the formation of spotty tundra to the activity of the wind which carries away the dead parts of plants from the soil surface. In summer the air of the tundra is relatively dry owing to the continuity of sunshine, and thus favourable conditions are created for the manifestation of the aeolian process. Apparently, the formation of similar landscapes is due to different causes in different conditions. The presence of permanently frozen subsoil, and the phenomena of mechanical transfer of masses due to the freezing of water, which have been described by many polar travellers, produce certain peculiar features in the soil formation in tundra. The former assumption that the soil formation in the tundra is interrupted owing to low temperature, has not been fully confirmed by facts, although the rôle of the physical factors of soil formation is markedly prevalent here over that of chemical processes. At any rate, traces of the processes of „gley“ and peat formation are observed at the highest latitudes of the Arctic regions, wherever there is no continuous ice or snow covering, and wherever some traces of growth still remain.

The meadow type of soil formation.

Meadow soils are closely connected with bog-soils. The conception of a „meadow“ is associated with meadow herbaceous growth which requires a much greater amount of moisture than steppe vegetation. Meadows are therefore more frequently found in the podzol zone than in steppes, where they occur near river valleys, and in general in localities with an increased moistening. In the forest (podzol) zone, they are observed in localities where the forest, due to different causes, did either not settle on the territory (over flood-plains, declivities) or was destroyed by man. Thus, the meadow is often a temporary unstable formation. This seems to indicate that the conditions of soil formation over meadows are not identical. The only feature which is characteristic of all meadow soils is the herbaceous growth, which, contrary to forest growth, leads to the accumulation of humus, and contrary to bog-vegetation is not transformed into peat. The imprint of the zone is, however, more or less markedly manifested in these formations; the meadow soils of the podzol zone are often podzolised and still more frequently swamped, whereas in steppe zones an increase in their salt content is observed. The process of transformation into „gley“ often develops in the lower part of the profile of meadow soils. Glinka, therefore denies, in his works, the independence of the type of meadow soils. Afanasiev[2], however, considers it necessary to differentiate at least a *series of meadow soils,* i. e. soils formed in the forest zone under herbaceous growth. The author himself, however, regards this series more as a „logical theory“ than as a „tangible fact“.

Mountain meadow soils.

Mountain meadow soils are more easily differentiated. These soils were first described by Bogoslovski[11] for the Crimean Yayla, and the mountain Pilatus near Lucerne. The presence of the belt of herbaceous, and even xerophytic growth in mountains above the forest belt, is due to the fact that the zone of maximum nebulosity, and consequently of maximum moistening, corresponds in a given mountainous country to certain definite altitudes, above which precipitation already begins decreasing, while insolation, and consequently evaporation, increases owing to a greater transparence of the rarefied air. The transparency of the air favours strong radiation of the soil, and its cooling during the night, which leads to noticeable variations of temperature. All these peculiarities of the mountainous climate increase with altitude.

Mountain meadow soils are therefore subdivided at least into two groups, with transitions between them and deviations towards other types of soil formation (the podzol and the bog-type).

First, chernozem-like meadow soils of subalpine meadows characterised by a high humus content are distinguished (described by Bogoslovski, Prasolov, Neustruev,* and Zakharov [140]). Investigations carried out by the above named authors have proved that these soils differ from chernozem in the absence of horizons of carbonate accumulations, and sometimes even in an acid reaction (Prasolov, Zakharov), though no noticeable features of their podzolisation are usually observed. According to Zakharov, in the Caucasus mountains their humus content increases to a certain altitude, as they replace the forest soils; in the mountains of Turkestan, where the forest podzol zone is mostly absent, chernozem-like mountain meadow soils are a nearer approach to chernozem, and differ from the latter only in the character of their humus horizon, whereas the presence of carbonates in mountainous soils is observed here even at great altitudes.

The second group of *mountain meadow soils* developing on the highest altitudes is connected in certain features with the bog-soils. These are soils of high regions pertaining to the Alpine zone, with a kind of peaty horizon formed owing to the decay of short growth, and with a distinctly brownish-coloured underlying horizon. Low temperature does not favour the formation of a thick humus horizon, and the mass of growth is being transformed into peat. The podzolisation process does not develop, probably owing to the same cause, though according to Zakharov, the soil is characterised by an acid reaction. The transitional stage between chernozem-like mountain meadow and mountain tundra soils is represented by mountain meadow soils with a thin humus horizon (4—5 *cm* thick) of a slightly peaty character, and a prevalency of a brownish colouring in the underlying horizons, which also show a rather high content of humus (up to 9 p. c.[75]). Zakharov points out the granular structure of the profile of humus containing mountain meadow soils; this granular structure, however, differs in its origin from that of chernozem, and therefore, he calls it „pseudo-granular". Zakharov believes that the frequent and marked variations of temperature in high mountainous regions, and consequently the alternating freezing and thawing of the soil are the cause of this „pseudo-granular" structure. Water extracts from

* In a series of works on Turkestan.

mountain meadow soils, as might be expected, show a high solubility of organic matter (an acid reaction, and consequently the formation of dispersed sols), and a small quantity of electrolytes. The humid meadow, the humus, and the peaty soils showing a tendency to deviate in the direction of the bog-type of soil formation, and the meadow bog-soils, all of which have been differentiated by Zakharov, should be added to the above mentioned groups of mountain meadow soils. Thus, it is evident that the climatic conditions of highlands create certain peculiarities of the soil covering, and therefore, according to Zakharov, it is possible to consider the *type of mountain meadow soils* as a peculiar combination and manifestation of different soil forming processes. It should, however, be noted that the extreme varieties of mountain meadow soils greatly differ from each other in their properties, and that these soils are far from being uniformly represented in different mountainous regions; in the mountains of Turkestan, and partly in those of the Caucasus, a subzone of chernozem-like mountain meadow soils is observed; swamped mountain meadow soils are prevalent in the Ural mountains, whereas in Siberian highlands the mountain bog-tundra soils are developed, and finally, in the tropical zone the chernozem-like and mountain meadow belt is sometimes entirely absent, and the upper part of the forest zone is succeeded by desert xerophytes.

In discussing above the genesis of different soil types, no preconceived classification of soil forming processes had been in view. However, both the soils and the processes of soil formation have already been united in a series of more or less harmonious, more or less hypothetical schemes, which are discussed in a special report. We consider it necessary but to emphasise here the difference existing between those soil forming processes which take place in conditions of excessive moistening, when the soil pores are filled up with water during a period of time sufficiently long to give rise to anaerobic conditions of the soil mass, and those soil forming processes, in which this phenomenon is not observed. The bog and the tundra types of soil formation at least partly belong to the former. Further, we may distinguish soils which are formed in conditions of a prevalent water supply from the surface downwards, and those characterised by the rising of soil solutions from the ground-waters. The first are mainly zonal soils, whereas the second together with soils of an excessive moistening belong to the division of intrazonal or „semizonal" soils, as after all they, too, are affected by the climate. It is hardly possible to include all the soil forming phenomena in a general scheme of classification. The works of Vilenski[125] and Afanasiev should be pointed out to as the most successful attempts in this direction. The elementary processes are combined in such exceendingly varied forms as to render the identification of some of the soils observed in Nature very difficult[76]. However, this does not prevent us from differentiating the main *typical soil forms*[76, 95]* which correspond to definite types of soil formation. The purpose of the present report was to throw some light on the latter.

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* „Form of soil", term advanced by B. B. Polynov.

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