X МЕЖДУНАРОДНЫЙ КОНГРЕСС ПОЧВОВЕДОВ
X INTERNATIONAL CONGRESS OF SOIL SCIENCE
МОСКВА 1974 MOSCOW

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MORPHOLOGICAL INVESTIGATION

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This book presents a short review of the literature concerning genesis of soils with textural differentiation and a bleached horizon in the profile and formulates the main tasks of genetic investigations of sod-podzolic soils derived from loamy deposits on the Russian plain. According to these tasks thorough morphological studies of the soil mass arrangement have been carried out in a profile of sod-pale-podzolic soil. The studies are based on the idea of hierarchical macro-,meso-and microorganization of the solid phase of the soil and on the idea of the necessity of continuous and combined investigations of all the levels of arrangement.

Editors: M.A.Glazovskaya
I.P.Gerasimov

PREFACE

This essay gives a thorough morphological description of sod-pale-podzolic soil (profile 2-7I). The soil is formed from mantle loams in the central part of the Klin-Dmitrov Ridge. A short description of this profile is contained in the essay "Southern taiga of the Russian plain. Soil of the Klin-Dmitrov Ridge". Chemical characteristics for profile 2-7I will be given in an additional essay.

This booklet was prepared by V.O.Targulian., A.G.Birina, A.V.Kulikov, L.K.Tselishcheva, staff members of the Department of Soil Geography and Geochemistry of Landscapes, the Institute of Geography of the USSR Academy of Sciences, and by T.A.Sokolova, staff member of the Soil Science Faculty, Moscow State University. Scientific editing was made by V.O.Targulian.

A.D.Armand, V.P.Belobrov, I.V.Vishnevskaya, M.I.Gerasimova, R.G.Gracheva, G.G.Malinovskaya and I.G.Pobedintseva helped in carrying out field investigations.

Editing and technical work in preparing this manuscript for publication were made with the assistance of A.L.Alexsandrovskiy, M.I. Gerasimova, B.F.Ilyichev.

BRIEF REVIEW OF PROBLEM OF GENESIS OF TEXTURALLY-DIFFERENTIATED LOAMY SOILS WITH BLEACHED HORIZON

Sod-podzolic loamy soils are widely spread in the USSR, especially in its European part. More or less similar soils occur frequently in the temperate humid forest areas of northern hemisphere plains (Central and Western Europe, North America).

Nevertheless, up till now there are serious divergencies in the nomenclature, classification and genetic interpretation of such soils. That is why it seems desirable to very precisely outline the range of problems for discussion.

Morphology. The soils under consideration are developed on a homogeneous loamy material and display the following diagnostic morphological characteristics:

I. Shallow horizons of a mixed grass-needle-leafy fall-off and forest litter (O1,O2).

2. The humus horizon (A1) is not deep and consists of disperse dark brown humus (mull type).

3. The light-coloured A2 horizon is more light in texture than the underlying brown horizons, it has a platy structure and features of seasonal reductive phenomena in the form of bluish-rusty mottles (moist) and rounded ferruginous concretions. The upper part of this horizon is frequently light brown pale ($A2_1$), the lower part ($A2_2$) is more bleached and has the highest amount of concretions.

4. Transitional A2B1 (B1A2) horizons are mottled in colour (brown and whitish) with peculiar wedge-like glosses penetrating in the lower brown part of the profile along fissures.

5. A set of brown heavy textured Bt horizons. Ped faces, walls of pores and fissures are covered with silicate mainly illuvial cutans. In the lowest part of this solum beginning with I50-200 cm gley features appear in the form of stripes and mottles, bluish and greenish in colour. They are not associated with ground waters (the ground water table is deep) and result from hindered filtration and relative stagnation of atmospheric water in the soil.

Nomenclature. The existing nomenclature of soils with the described properties varies both in the Soviet literature and in the works of pedologists of the northern hemisphere.

The most traditional and widely accepted term for such soils in the USSR is "sod-podzolic soils" and its derivatives: sod-pale-podzolic, sod-podzolic with a surface gley, etc. For the western regions of our country other terms have been suggested and used, these are: brown-pseudopodzolic, paragley soils, podzolozems and others. It should be emphasized that these names designate only partially the soils with the described profile structure and are applied to soils with a somewhat another combination of features.

The nomenclature of soils under discussion used in Europe and North America is still more diverse and suffered numerous alterations. The "oldest" terms that were widely used in the past, but are now becoming rare are those with the word "podzolic": grey-brown podzolic soils (USA), sols podzoliques (Belgium, France), etc. There are many names where the term "podzolic" is combined with other terms indicative of clay migration (without dissolution) and surface gley, such as: "sols podzoliques lessivés à pseudogley", "sols lessivés dègradés", "soluri podzolic argilo-illuviale pseudogleice", "illimerized soils", "podzoluvisols", etc. Some of these terms emphasize the existence of surface excessive moistening and gleyzation - Pseudogley-parabraunerde, Pseudogley. Finally, there is a group of names where terms characterizing substance migration and gleyzation are omitted, and some salient features of soil morphology are reflected in the soil name. Glossisols (FAO), glossic groups or subgroups in the alfisol and ultisol orders (USA), Fahlerde may serve as examples.

The terminology being diverse, two quite different main trends may be noted. The first approach consists in naming the soil in accordance with the concept of main soil forming processes, i.e. in accordance with the genetic conception of soil formation. According to the second approach, the soil is named not on the basis of the genetic interpretation of the profile, but on a definite combination of stable diagnostic properties (combination of horizons, development of glosses or concretions, etc.). In this case, genetic interpretation is not completely left out, but simply is not involved in the choice of the name for a certain type of the profile. In our opinion, the second approach may be interpreted as a choice of codes-symbols and is more reasonable and preferable since it provides a correct definition of the term, its stability and independence of inevitably changing genetic conceptions.

In the present work we use the combination "sod-pale-podzolic soil" as the most traditional term in Soviet pedology which indicates a complex of certain properties (mull humus horizon, bleached eluvial horizon with a pale yellow colour in its upper part; profile textural differentiation, etc.), rather than a profile formation process. The word "podzol" or "podzolic" is known to have been introduced by V.V.Dokuchaev as a folk name. It had no definite soil-genetic meaning and was only indicative of the presence of a bleached horizon ash-like in appearance.

Genesis. Perhaps the greatest number of works in the soil-genetic literature since 1880's deals with the problems of genesis of soils with a texturally differentiated profile and a light-coloured upper horizon in the humid temperate regions of the northern hemisphere. It was at the onset of soil science that the two main concepts were suggested almost simultaneously and independently by Dokuchaev (1887) and Müller (1887). Working in different regions of Europe, Dokuchaev and Müller came to similar conclusions: the typical profile of loamy soils with a light-coloured upper mineral horizon is always formed due to the surface gley process combined with one of two main eluvial processes: a) removal in solutions; b) removal in suspensions. Dokuchaev held that both processes could occur in loamy soils, whereas Müller associated removal in solutions with sandy soils, and that in suspensions with loamy soils. In fact, the main genetic problems of the more than 90-year long discussions and searches was briefly formulated at the very beginning of the development of soil science.

Since we cannot discuss here the instructive results of the evolution of the doctrine on the genesis of soils with a bleached upper horizon and textural differentiation, we shall restrict ourselves to briefly outlining the main stages of this evolution.

I - 1880's-1890's. Genesis of these soils is explained by surface gleyzation, removal of substances both in solutions and suspensions without taking into account site conditions (Dokuchaev, Müller).

II - 1890's-1910's. Formation of the soils under consideration is explained mainly by surface gleyzation, predominant dissolution of silicate minerals and leaching of soluble Si, Al and Fe (Sibirtsev, Glinka, Stremme). It is interesting to note that because of insufficient knowledge of loamy podzolic soils the conclusion on the predominant form of leaching in solution was wrongly extrapolated on these soils from sandy and skeletal podzolic soils investigated mainly in Fennoscandia (Aarnio, Frosterus and others).

III - 1920's. Glinka rejects for the loamy soils the concept of Si, Al, Fe leaching in solutions and suggests the idea of clay suspension removal. In the USSR and in many other countries this concept is not supported, whereas the idea of leaching in solutions becomes very popular.

IV - 1930's-1940's. The concept of chemical dissolution of minerals in the A2 horizon followed by the removal of its products in solutions alongside with surface anaerobiosis and gley is rapidly being developed in the USSR (Gedroitz, Williams, Rode and others). On the contrary, in Western Europe and in America the concept of clay suspension leaching (Baldwin, Cline, Aubert and others) is being revived, but without taking into account the initial ideas of Dokuchaev, Müller and Glinka.

V -1940's-1950's. The concept of chemical decomposition and substance removal together with surface gley predominates in the USSR

(Rode, Zavalishin, Yarkov). In Western and Central Europe the pseudogley and lessivage concepts are developed and expanded (Kubiena, Aubert, Duchaufour, Dudal, Mückenhausen and others).

VI-I960's. The concept of the combined effect of surface gley and clay illuviation is actively revived in the USSR. The following notions are suggested: illimerization (Fridland) - synonymous for lessivage and pseudopodzolization (Gerasimov) - to denote the complex of surface gley (pseudogley) and clay migration in suspensions (lessivage). The concept of pseudopodzolization according to Gerasimov comprised the combination of modern lessivage and surface gley processes with features of paleoprocesses: cryogenic dislocations, permafrost degradation, carbonate leaching and decolmatation. Thus the genesis of pseudopodzolic soils was explained not only by the combination of modern soil forming processes, but also by many-phase contrasting alterations of the site conditions during the upper Pleistocene and Holocene. The concept suggested that loamy pseudopodzolic soils occur in the temperate regions of the Central Europe as well as in the west and south of the forest zone of the USSR, whereas loamy podzolic soils (those formed by way of mineral dissolution in the A2 horizon and leaching of soluble Si, Al and Fe) are confined to the cold boreal taiga of northern and north-eastern regions of the USSR.

In Western and Central Europe, the USA and Canada genetic concepts of pseudogley and clay illuviation without dissolution are developed and detailed.

The present status of the problem of the genesis of loamy soils with a bleached horizon and textural profile differentiation may be described in the following way.

It is accepted by the majority of foreign investigators that the idea of chemical (acid humus) decomposition of silicate minerals in the upper light-coloured A2 horizons with subsequent leaching of soluble products in the form of organomineral compounds into the B horizons is mainly applicable to soils on sandy or stony parent material (Bloomfield, Duchaufour, Stobbe, Wright, the reviews of Muir and Dudal). Practically in all the foreign soil classifications, both regional and global, soils formed on such rocks and having a light-coloured upper horizon and B horizon enriched with amorphous Fe and Al compounds and fulvic humus are referred to podzols (spodosols).

In foreign literature the origin of loamy and clayey soils with a light-coloured horizon and textural profile differentiation is interpreted mainly using two concepts: surface gley (pseudogley) and clay illuviation in suspensions (lessivage, illimerization, argilluviation) from the A2 into the B horizons. Only for soils with deep glosses of the light-coloured material penetrating into the brown textural B horizons is the stage replacement of illuviation of clay suspensions by the subsequent chemical decomposition of silicates along fissures and removal of soluble products in solutions considered possible. The name suggested for such soils is "podzoluvisols" (Dudal). The modern status of the problem under discussion in the USSR is more complicated. As to podzols or podzolic Al-Fe-humus soils on sands and stony rocks, the genetic conceptions in the USSR and abroad are similar. There are no serious divergencies in opinions on the genesis of these soils. The main profile-forming process is considered to be illuviation of the Al-Fe-humus compounds without or with a very weak surface gley (Ponomareva). This main process is accompanied by the intrasoil stage transformation of layered silicates, most intensive in the A2 horizon, which results in the accumulation of swelling clay minerals in this horizon (Gradusov, Targulian, Sokolova). Besides, it has been ascertained that in the B horizons processes of desilication, ferrugination and aluminization in situ occur (leaching of SiO_2, RO, RO_2 with relative accumulation of Fe_2O_3 and Al_2O_3). The lower part of the profile features the migration of sandy-silty-clay suspensions (Targulian, Belousova).

The situation with texturally differentiated soils having a light-coloured horizon on loams and clays which were formerly called "podzolic" in all the humid areas of our country is quite different. The generally accepted abroad viewpoint on these soils as being formed due to surface gleyzation and clay illuviation, was not so popular in the USSR. Now in this country there is a broad discussion of two concepts, alternative genetically, but localized geographically. Rather similar to the foreign concepts of pseudogley and lessivage (argilluviation) are the ideas of pseudopodzolization (Zonn, Reintam, and others), or podbel-formation (Kornblyum, Liverovsky). Most important in the profile differentiation according to this concepts are:
a) processes of surface gleyzation, Fe segregation and gley migration of ferrous compounds accounting for bleaching of the A2 horizon, formation of concretions and profile distribution of amorphous Fe_2O_3;
b) processes of clay illuviation which are responsible for profile textural differentiation: clay accumulation in the form of argillans in the B horizon and profile distribution of the total Al_2O_3.

According to this concept, such genesis is typical of soils in humid temperate regions of the forest zone of the USSR under mixed (coniferous-broad-leaved) forests or broad-leaved forests with an intensive biological cycle. These are pseudopodzolic or brown-pseudopodzolic soils with a weakly acid or acid reaction, with a litter rich in bases, with mull-type humus and impeded internal drainage, sometimes with weak superficial drainage of large areas (plains, flat slopes and interstream areas). However, as contrary to foreign concepts generally applicable to soils with texturally differentiated profiles, the Soviet authors of this concept do not extrapolate it on soils developed in the cold humid regions of East-European and Siberian taiga. Formation of loamy soils with differentiated profiles due to decomposition of minerals and chemical translocation of substances in solutions (podzolic soils) is supposed to be possible here.

In the USSR, alongside with this genetic-geographical conception there is another one formulated by A.A.Rode in 1937 and amended recently (Rode, Kaurichev, Ponomareva). Similar to most conceptions, it attaches much importance to the surface eluvial gley leading to bleaching of the A2 horizon, formation of concretions and iron migration in the profile. However, the main factor of profile textural differentiation is considered to be chemical decomposition of primary and secondary silicates in the bleached eluvial A2 horizon and removal of decomposition products in the form of solutions out of the horizon. Thus, the fate of clay silicates in the A2 horizon and the way of substance leaching are entirely different from the lessivage-pseudopodzolization concepts.

Depending on further fate of mineral decomposition products leached from the A2 horizon the following three possible modifications of the concept under discussion are admitted (Rode):

1. Eluvial : the whole profile is involved in the processes of mineral decomposition and eluviation of Fe and Al compounds, the latter are leached out of the solum without being retained in any genetic horizon; profile differentiation is due to surface gley and different intensity of decomposition and eluviation (maximum in A2 and gradually decreasing in the B horizons); there are no horizons of clay and R_2O_3 accumulation in comparison with the parent rock.

2. Eluvial-metamorphic : alongside with leaching of the products of mineral decomposition from the A2 horizon beyond the soil profile, processes of soil metamorphism (argillification) proceed in the B horizons, they cause here clay accumulation in comparison with the parent rock; a clay accumulation horizon may be distinguished in the profile while there is no accumulation of mobile or total Fe_2O_3 and Al_2O_3, the sesquioxides being completely leached out of the soil.

3. Eluvial-illuvial : substances leached from the A2 are accumulated in the B horizons, where soil metamorphic argillification may proceed; B horizons illuvial for clay, Fe_2O_3 and Al_2O_3 as compared both to the A2 and to the parent rock are definitely distinguished in the profile.

In the first two modifications the decisive processes alongside with surface gley are considered to be mineral dissolution and the removal of soluble products out of the solum. The importance of clay suspension illuviation in profile differentiation is regarded as quite insignificant. The third modification holds that profile differentiation may be due both to chemical and suspensional eluvial-illuvial processes.

The second concept with all its three modifications is more universal in the geographical aspect and is usually extrapolated on the major part of humid areas with texturally differentiated soils having a bleached horizon. This concept is well known in the USSR as that of podzolization on loamy deposits. All soils in humid areas having light-coloured horizons (the soil reaction being acid) are classified as podzolic according to this concept; they are further subdivided into lower taxonomic units - subtypes: gley-podzolic, podsolic proper, sod-podzolic, etc.

Apart from the two alternative concepts described, so-called "combined" concepts are being elaborated recently in the USSR. These concepts take into account all the three main groups of processes causing profile differentiation in loamy soils of humid areas (surface gley, dissolution of silicate minerals and removal of soluble products, clay translocation in suspensions). M.A.Glázovskaya thinks that in the majority of acid loamy soils with a bleached horizon all the three groups of processes are combined; various degrees of surface gley allow to refer these soils either to the family of "eluvizemic-podzolic" soils ("podzolozems"), or to that of acid surface-gley eluvial soils. F.R.Zaidelman suggests that these soils be called "podzolic", but believes that their genesis is dominated by gley processes. I.P.Gerasimov considers the sod-podzolic soils of the southern taiga in the USSR to be transitional between the pseudopodzolic soils of Western and Central Europe and purely podzolic soils of boreal taiga in the northern part of Eastern Europe. The combination of podzolic and pseudopodzolic features (according to I.P.Gerasimov) in the group of sod-podzolic soils is related both to the present bioclimatic situation and to the complicated history of these soils which underwent several changes of podzolic and pseudopodzolic soil formation phases during the Holocene.

The existence in the USSR of several viewpoints on the genesis of loamy soils with a bleached horizon has given rise to a long dispute in Soviet soil literature (Gerasimov, Zonn, Rode, Zaidelman and others).

This discussion in the Soviet Union made obvious a number of facts which rendered classification of loamy soils with a bleached horizon more difficult both genetically and geographically. It was found that seasonal surface gley (pseudogley) characteristics are inherent in almost all the soils under discussion (seasonal or stable gley mottling, Fe_2O_3 segregation in concretions, etc.) from the northern taiga to broad-leaved forests. Features indicating clay migration in suspensions as well as such characteristics as the stability of clay composition (less than 0.00I mm) throughout the profile, even or accumulative profile distribution of non-silicate iron and others have been found typical of the majority of loamy soils with a bleached horizon both in "warm" eutrophic site conditions (soils with supposedly pseudopodzolic genesis), and in "cold" oligotrophic ones (soils with supposedly purely podzolic genesis).

In this way, a situation arose in which two alternative genetic concepts are not always confirmed by really different diagnostic properties of the soil profile. At the same time it became clear that neither of these concepts alone can comprehensively explain an actual combination of properties observed in the investigated soil profiles. Thus, for instance, the concept of chemical dissolution of minerals and substance removal in solutions does not explain a frequent occurrence of illuvial-suspensional phenomena in soils (clay and silty cutans in fissures, pores on ped faces). The concept of lessivage, on the contrary, does not explain the absence of illuvial maxima of clay and total Al_2O_3 in the B as compared to the rock (in the case of soil formation on homogeneous parent material).

The discussion in the USSR made it clear that an alternative approach to the problem of texturally differentiated loamy soils with a bleached horizon is not always able to provide a comprehensive explanation of an actual combination of features in such soils. Genetic models embodying such alternative concepts do not completely correspond to the real objects. Besides, it became evident that the diagnostic characteristics chosen to serve as criteria for solving the problem of genesis of loamy texturally differentiated profiles are too insufficient and far from being always non-ambiguous genetically. A possible way out of the existing situation is to increase the number of indices involved in the genetic analysis of the profile, through a more detailed macro-, meso-and micromorphological description together with differential analytical treatment.

Further investigations of loamy texturally differentiated soils with a bleached horizon should be aimed at developing a synthetic concept which would use all the positive ideas of the existing hypotheses. Such a concept must be based on a most comprehensive investigation of soil properties, including their hierarchical organization in the soil profile, on studying elementary soil-forming processes and their combinations, on an analysis of geographical soil patterns and soil evolution resulting from paleogeographical changes in the environment.

In accordance with this main target, the following tasks were formulated for the investigation of the sod-pale-podzolic soil :
a) a detailed investigation and description of the morphogenetic properties of the soil profile; b) separation of morphologic components of the soil mass and their analytical study; c) recognition, analysis

and genetic interpretation of elementary (particular) phenomena and processes accounting for the formation of various features in the soil profile; d) general estimation of the nature and combination of elementary soil-forming processes and their role in the profile formation as a whole, i.e. general interpretation of soil genesis.

MORPHOLOGICAL STUDY OF SOD-PALE*-PODZOLIC SOIL (Profile 2-7I)

General arrangement and methods for morphological investigation of soil profile

Profile 2-7I is differentiated into the following groups of horizons.

I. Organogenic horizons of litter-fall and litter (O1,O2).

2. Organo-accumulative and eluvial horizons (A1,A2) formed in the upper part of the mantle loam layer, distinguished by the absence of a network of large vertical fissures.

3. Mottled and brown deep eluvial-illuvial horizons (A2B1, B1A2, B1, B2, B3) also formed in the of mantle loams.

The heterogeneity of the soil mass within these horizons is peculiar due to a network of large and deep vertical fissures dissecting the majority of horizons. The fissures are filled with a heterogeneous mass (fissure infillings-FI) differing from the soil mass between fissures (interfissure mass-IFM). The density of the fissure network as well as the width of individual fissures decrease gradually with depth. There are several kinds of fissures. The main fissures are largest and deepest; they traverse the whole depth of soil horizons and penetrate deeper. These fissures begin as wide glosses in the A2B1 horizon and dissect the brown-coloured loam into vertical "columns" or large prisms which are subdivided into genetic soil horizons (B1A2, B1, B2, etc.). Besides main fissures, intrahorizon and interhorizon fissures may be distinguished, the former, limited by soil horizons, being larger than exped voids.

4. Reddish brown lower soil horizons (IIB3_3D, IIB3_4D, IIIDI, IIID2) representing the gradual transition of mantle loam to the underlying rock and the rock itself - moraine sandy loam. A fissure

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* The term "pale" in the name of this and similar soils of the USSR literary denotes a Russian colour designation "palevaya" corresponding to the following colours in "Munsell soil colour charts": very pale-brown (IO YR 7/3,7/4), pale brown (IO YR 6/3), light yellowish brown (IO YR 6/4, 2.5 Y 6/4), pale-yellow (2.5 Y 7/4) and yellow (2.5 Y 7/6).

network is extremely sparse here, the fissures being the continuation of the main and intrahorizon fissures of the above layer.

The main principles underlying morphological investigation were concepts of hierarchical macro-, meso-and microarrangement and differentiation of the solid phase of the soil mass, and the need to study the chemical and mineralogical composition of the soil and soil texture in an intimate relation with soil arrangement.

This approach to soil investigation is based on the ideas of Zakharov, Gemmerling, Tyulin, Kubiena and especially of Brewer who elaborated the main concepts and nomenclature for the analysis of soil profile arrangement (fabric analysis). We have somewhat modified this approach and adapted it for the description of intricately organized fissured profiles of sod-podzolic soils on mantle loams. Our main requirement was continuity and interrelation of all the levels of morphological investigation of soil mass arrangement, beginning with a visual macromorphological description of the soil horizon up to the micromorphological description of the intrapedal mass and its components (the skeleton, plasma, pores, new formations).

Following such an approach, we have given a morphological and analytical description of the soil mass components.

At a visual macromorphological level we, first of all, described the total mass (TM) of the horizons; bulk TM samples taken for analytical characterization were repeatedly averaged. For those parts of the soil profile where deep vertical fissures are distinctly developed (from A2B1 to IIID horizon), the TM of each horizon was separated into interfissure mass-IFM and fissure infillings-FI. Both components were described separately not only on the vertical walls of the soil pit, but in the volume on the horizontal cross sections made for each horizon. Individual IFM and FI samples in each horizon were taken for the analysis.

Within the TM or IFM of each horizon peds (aggregates) of various levels of complexity, composing the IFM were distinguished and described: macro-, meso-and micromorphologically*. Special attention was paid to the description of simple primary (minimal) peds and to the type of their arrangement into more complicated secondary and tertiary peds.

In the primary peds of the IFM the following components were described mesomorphologically: intrapedal mass (IPM) and the ped surface

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* A macromorphological soil description is a visual field description; a mesomorphological description is made in the field under a binocular and includes description of natural intact surfaces of soil mass and its sections (vertical and horizontal); a micromorphological description involves soil mass thin sections.

together with cutans (films, crusts, coatings) of different origin and composition. Cutans on the surfaces of composite peds were investigated as well. IPM and cutans on different ped faces were separated in the field with the help of a binocular and collected for the analytical treatment.

We have investigated in thin sections : a) IPM – the skeleton and plasma, organic remains, pores, new formations, cutans on skeleton grains and pore walls; b) surfaces of primary (simple) peds and the composition of cutans on them; c) apedal material; d) surfaces of composite peds and cutans on them.

In fissure infillings (FI) with the help of macro-, meso-and micro-morphology we have described the character of prevailing soil mass and its arrangement (apedal, pedal, cutanic vertically stratified, etc.) as well as the type of cutan interstratification in fissures, etc. Samples of FI were collected in the field visually and with the help of a binocular both in the whole mass and separate cutans (sandy-silty skeletans, argillans, ferric-manganic cutans). Details of the FI fabric such as composition and fabric of various cutans, orientation pattern of their ingredients, kind of contacts between stratified cutans, contacts between FI and IPM, were investigated in thin sections.

Soil environment and macromorphological description

The most elevated and dissected central part of the Klin-Dmitrov Ridge. The Moscow-Yaroslavl highway, 107 km north-east of Moscow. The absolute height is about 220 m.

An undulating hilly area dissected by deep valleys of small rivers and streams; slopes of variable gradients. The upper parts of hills are either convex-round-shaped (well drained) or level (poorly drained), usually gently sloping; middle and lower parts of slopes are dissected by young (active) or overgrown gullies of variable depth. The microrelief on watersheds is weakly pronounced and mainly consists of gentle overgrown hollows of erosional origin, knolls around tree stems and shallow microdepressions.

The profile is located on the level upper part of a hill gently sloping (gradient about 2^{o}) east-south-eastward. The hill-top and hillsides are overlain by a mantle of brown and reddish-brown heavy loams (so-called mantle or loess-like loams).

This loamy material is dissected into columnar structural units by a net of vertical and inclined fissures. The origin of these fissures is often attributed to the periglacial conditions of the formation of mantle loams. This is consistent with the occurrence of a net of relic cryogenic wedges and large blocks forming a polygonal pattern within the area of extensive distribution of mantle loams. In addition to these large structural elements, however, the loams are dissected into smaller structural units by a dense net of cracks which are deep and relatively thin (I-IO cm). The genesis of these fissures is not clear, but they are thought to have been formed during the later period of time as they commonly superimpose the polygonal network of large wedges and blocks. The fissures are probably polygenetic in nature and formed partly under periglacial conditions and partly during the whole Holocene due to the processes of leaching, shrinkage, desiccation or freezing. In addition to fissures inherited from the parent material, there are some contemporary fissures in the profile; this process seems to be active nowadays.

The thickness of mantle loams in the profile and near the sampling site ranges from 2 to 3 m.

Mantle loams are underlain by red brown bouldery moraine deposits. Near the upper boundary these deposits are partly rewashed and mixed with mantle loams. There are some features of cryoturbations at the contact between moraine deposits and mantle loams. A fine texture of the loams results in imperfect drainage and hence in the appearance of some gley features in the lower part of the solum (deeper than I.5-2 m). Ground water on the watersheds is found at a great depth (IO-20 m) and does not affect the hydrological regime of the profile studied.

The vegetation is birch-spruce forest with asp and maple; the ground cover is represented by oxalis and some herbaceous plants. Dominant tree species in the first storey are Picea exelsa and Betula pendula which make up about 55% and 45% of stems, respectively, with sparse trees of Populus tremula. The main height of the first storey is 20-25 m; the age of the oldest spruce and birch trees is about 70-90 years. The second storey consists of Acer platanoides, Alnus incana, Sorbus aucuparia and sparse Quercus robur. Under the tree stand there is a storey formed by Corylus avellana, 2-3 m high. Shrubs are represented by rare specimens of Rubus idaeus. The total density of canopy is about 0.8. The herbaceous soil-covering which makes 65% includes the dominant grasses: Asperula odorata, Galeobdolon luteum and Oxalis acetosella. Other species are also common: Pulmonaria obscura, Majanthemum bifolium, Asarum europaeum, Aegopodium podagraria, Stellaria holostea, Convallaria majalis, Ajuga reptens. Gramineous plants are represented by Milium effusum and Calimagrostis aruodinacea. Mosses cover about 0.I% of the soil surface and consist of Dicranum polycetum, Mnium affine and Hylocomium proliferum.

O1 O-I cm* Very dark brown (IO YR 2/2) moist litter-fall consisting of weakly to moderately decomposed leaves, needles and small branches of trees, leaves and stalks of grasses which have conserved their original form, but changed their colour; loose, finely stratified. Coprolites may be occasionally found between layers of leaves. They consist of brown (IO YR 4/3) moist mineral fine earth; locally fungal mycelium can be found, roots are absent; abrupt, smooth or wavy boundary.

O2 I-2 cm Dark brown (IO YR 3/2, 3/3) moist forest litter consisting of moderately decomposed scraps of leaves, needles and grass stalks, rather large amount of weakly decomposed raw plant remains (small branches); cinnamonic decomposed amorphous organic mass binding the plant remains. Structureless, friable; the organic mass contains crumby coprolites as well as almost apedal soil material, very dark gray or very dark grayish brown (IO YR 3/I, 2/2) with occasional bleached quartz and feldspar grains. The whole mass of the horizon is densely interlaced by coarse, medium and fine roots. Clear, wavy boundary.

A1 2-II cm Very dark gray (IO YR 3/I, 3/2) moist, with numerous medium mottles of a yellowish brown colour (IO YR 5/4) with clear boundaries; sandy loam, weak fine crumby, friable; numerous pores; occasional soft fine spherical concretions, black red in colour; abundant roots; pierced by earthworm holes with brown and black coprolites, locally numerous charcoals occur; abrupt wavy boundary.

$A2_1$ II-27 cm Brown (IO YR 5/3), moist, with fine rounded very dark grayish brown (IO YR 3/2) mottles with a clear boundary; sandy loam; weak to moderate thin platy; friable; many fine crevice-like pores; few spherical soft and hard brown to almost black concretions; common fine and medium roots; many earthworm holes with dark brown coprolites; abrupt wavy boundary.

$A2_1n$ 27-33 cm. Pale brown (IO YR 6/3, 5/3), moist, many small and medium yellowish brown (IO YR 5/4, 4/4) mottles with clear boundaries. In texture, structure and porosity similar to the above-lying horizon; many rounded hard concretions (I-3 mm in diameter), brown, red and black; abrupt wavy boundary, locally irregular; sometimes the horizon becomes very thin and almost disappears.

$A2_2$ 33-42 cm The horizon is discontinuous and may not be traced on all the walls of the profile. Light brownish gray (10YR 6/2), moist, many coarse and medium faint mottles of grayish brown

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* Here and further the horizon depth has been determined as a mean of IOO-I50 measurements made on the walls of a large soil profile (the perimeter of the profile is about I5-25 m).

(IO YR 5/2) colour with diffuse boundaries; fine and medium brown (7.5 YR 5/6, 4/4) mottles with sharp boundaries are few. Sandy loam to loamy sand, moderate-strong, medium-platy, soft when crushed in the hand and rather compact in its natural state. Many fine and medium pores, horizontal exped crevice-like and bead-like predominate, tubular pores occur. Soft rounded concretions (0.2-I.5 mm in diameter), brown, reddish brown and black; roots are scarce, mainly fine roots may be found; rare earthworm holes with coprolites; abrupt wavy, locally-irregular boundary.

A2B1 42-5I cm Mottled transitional moist horizon with alternation of light brownish gray, pale brown or brown (IO YR 6/2, 6/3, 5/3) mottles occupying 60-80 per cent of the section and of reddish brown or brown (5 YR 4/4, 4/6; 7.5 YR 4/4) mottles occupying larger areas in the lower part of the horizon. Light-coloured zones are sandy loamy, moderate, fine-medium platy, friable or firm. Brown zones are loamy or heavy loamy, strong fine-medium subangular blocky (nuciform), more compact. Many exped pores of different size and shape; inped pores are more numerous in light-coloured zones; the amount of concretions decreases rapidly as compared to the previous horizon, concretions are small (less than I mm in diameter), hard, dark brown or black rounded. Rare earthworm holes with coprolites, few roots with predominance of fine ones; few gravel and small boulders. Clear locally wavy boundary.

B1A2 5I-60 cm Mottled in colour, discontinuous, locally replaced by A2B1 horizon and even by A2 horizon. Differs from A2B1 by the predominance of brown mottles over light-coloured ones. Against a brown (7.5 YR 4/4) background making up 60-80 per cent of the area, light-coloured mottles (IO YR 7/2, 7/3) moist, in the form of vertical cracks or wedges (glosses) are distinguished. Light-coloured fissure infillings are sandy loamy or loamy sandy, structureless or platy, friable. Brown mass is loamy, moderate fine and medium blocky, friable or compact; many exped pores varying in size and shape, crevice-like vertical and horizontal ones predominating; inped pores are less numerous. Concretions are rare, they are small, rounded, black and dark red; few fine earthworm holes with brown or light gray coprolites; few fine and medium roots, single thick roots; few gravel and small boulders. Gradual irregular, locally wavy boundary.

B1 60-87 cm Reddish brown to dark brown (5 YR 4/4; 7.5 YR 4/4), moist, with light gray (2.5 Y 7/2; IO YR 7/2, 7/3) vertical and oblique fissures crossing the horizon. FI is sandy silty, usually structureless, with single brown peds-"outliers". Brown IFM is loamy, moderate to strong fine - medium subangular blocky (peds are slightly firm, the total mass is friable); many exped crevice-like pores and tubular inped pores. Few fine hard and soft concretions in clusters; they are rounded and irregular, black to dark brown. Very few fine and medium roots; very few gravel and small boulders; gradual wavy boundary.

$B2_1t$ 87-I40 cm Brown (IO YR 4/4; 4/3; 7.5 YR 5/4; 4/4) moist, with vertical light gray, very pale brown (2.5 Y 7/2; IO YR 8/3) and pale brown (IO YR 6/3; 7.5 YR 6/2) stripes (fissures). FI is represented by vertical stratification of light-coloured sandy, greenish blue silty-loamy and dark brown argillaceous cutans. Brown IFM is loamy, strong angular blocky prismatic; peds are weakly firm, the total mass is friable; many fine crevice-like exped and tubular inped pores; few hard and soft dark concretions of irregular shape forming clusters; very few fine roots, more numerous in fissures; occasional rock fragments and small boulders occur; gradual wavy boundary.

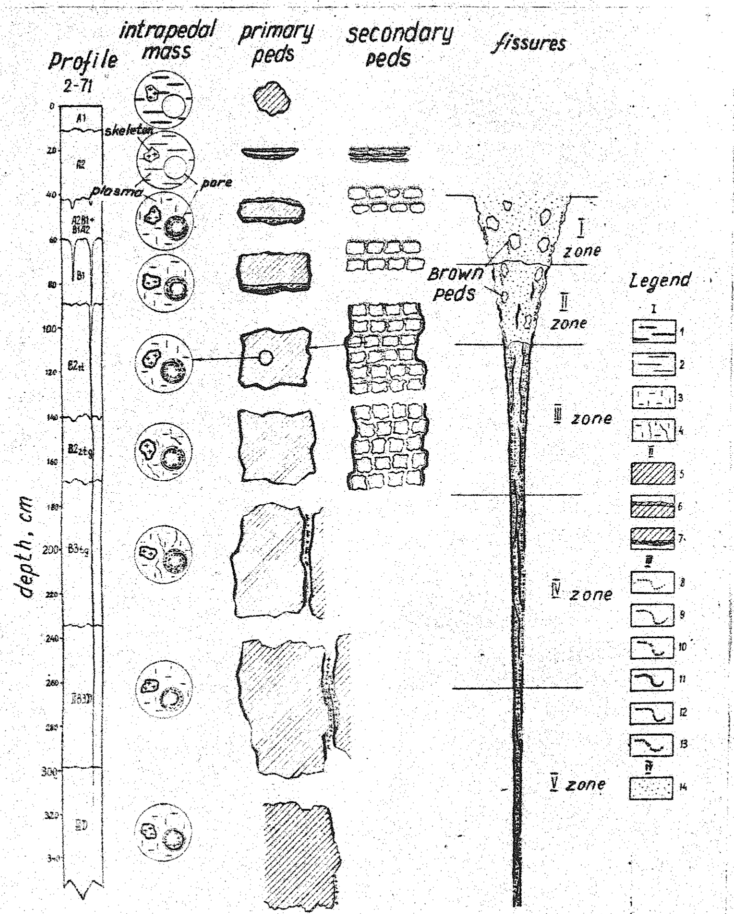
$B2_2tg$ I40-I67 cm Brown (7.5 YR 5/4, 5/6), moist, locally with a reddish hue (5 YR 4/4) and some small greenish grey and pale green (5GY 6/I, 5/I; 5G 7/2) rounded or oval gleyed mottles and light gray (IO YR 7/I; 7/2), olive gray, greenish gray (5 Y 6/2; 5 GY 4/I) and yellowish brown stripes along vertical fissures. The texture of stripes varies from loamy sandy to loamy. Brown IFM is loamy, moderate medium to coarse, angular blocky, prismatic, rarely coarse platy, slightly sticky and slightly plastic; few small black and black brown soft and hard concretions of rounded and irregular shape. Roots are rare within peds and common in fissures, fine roots prevail; very few gravel and small boulders; gradual wavy boundary.

$B3_1tg$ I67-207 cm Yellowish brown (IO YR 5/4; 5/6; 5/8), moist, fine and medium, rounded or elongated greenish gray (5 GY 5/I), grayish brown (IO YR 5/2) and brown (7.5 YR 4/4 ; IO YR 4/4) mottles are common. Their boundaries are diffuse or clear. Heavy loamy, weak to moderate medium and coarse prismatic, sticky, slightly plastic, hardly breaks down into peds. Rare exped crevice-like pores, many fine and medium tubular inped pores. Few small soft and hard irregular concretions, black and dark brown, in the form of clusters. Very few fine inped roots, in fissures fine and medium roots are common. Single gravel and small boulders. Clear wavy boundary, may be traced by an increase in the content of rock fragments, gravel and boulders.

$IIB3_2tg$ 207-234 cm Strong brown (7.5 YR 5/6), moist, locally with a reddish hue (5 YR 4/4), with medium rounded grayish brown (IO YR 5/2), gleyed greenish gray (2.5 Y 5/2; 5 GY 5/I) and fine rusty (7.5 YR 5/8) mottles. heavy loamy; weak to moderate, coarse prismatic; weakly plastic, with rare exped crevice-like pores. Insignificant or medium amount of black, soft and hard, irregular in shape small concretions. Few fine roots; rock fragments, gravel and small boulders are more numerous than in the previous horizon but their amount is less than 5 per cent of the section area. They are weakly weathered, rounded and subangular, with the prevailing size of I-3 mm. Clear, locally gradual boundary, irregular or discontinuous. The horizon is discontinuous and may be interrupted with wedges of $B3_1$tg or $IIB3_3$D.

$IIB3_3$D 234-273 cm Reddish brown with large yellowish red (5 YR 4/6) and brown (7.5 YR 4/4; 5/6) mottles, loamy, with rock fragments, gravel and small boulders (larger than in the $IIB3_2$tg horizon), weak indistinct coarse prismatic or angular blocky structure; weakly sticky, nonplastic, firm; medium (small) number of fine tubular inped pores, few crevice-like exped pores; clusters of few fine, usually soft, black and black brown irregular concretions. Fine roots are sparse in tubular pores and more numerous in fissures. Stony inclusions of various rocks, angular and rounded, slightly weathered, composing 5 per cent of soil volume. Abrupt to clear boundary, discontinuous and irregular; the horizon is not traced on all sides of the pit.

$IIB3_4$D 273-298 cm Heterogeneous in composition and colour. Yellowish red (5 YR 4/6) moist loamy material with a considerable admixture of red moraine loam enriched with rock fragments and gravel prevails. On this background large brown (7.5 YR 4/4) loamy stoneless zones (mantle loam) alternate with red (5 YR 4/8; 2.5 YR 4/6) stony sandy loamy zones of the underlying red IIID layer; compact, weakly coarse, angular blocky, weakly sticky and weakly plastic; with rare narrow exped crevice-like and fine tubular inped pores. Horizontal and inclined striated red brown domains weakly cemented by iron oxides with a dark brown clay band in the centre occur in this horizon. In close proximity to them there are large rounded segregations (relic lithogenic concretions?) with red yellow and yellow concentric rings (such segregations are extremely rare in horizon $IIB3_3$D). Pedogenic concretions are scarce, they are small, soft black, irregular in shape and form clusters; fine inped roots are very few, but in fissures they form locally a dense network; gravel and fragments of hard rocks occur; they are weakly weathered and poorly rounded. Near the lower boundary of the $IIB3_4$D horizontal lens-like mottles, 5-I5 cm long and I-5 cm thick, can be observed. They are loamy, bluish gray (5 B 5/I; 5 Y 5/I) in the



F i g. 1. Schematic drawing of the soil mass arrangement in the sod-pale-podzolic soil profile by macro- and micromorphological data. Legend is given on the reverse side of the page

Legent to fig.1. I.Plasma: 1 - isotropic,containing humus;2 - bleached isotropic; 3 - brown scaly; 4 - brown scaly-fibrous. II. Intrapedal mass (IPM): 5 - the least changed part; 6 - zone of bleaching and eluviation; 7 - zone of impregnation by iron-humus compounds. III. Cutans on sceleton grains, on ped faces, in pores and fissures: 8 - bleached whitish and light-gray sandy; 9 - bleached light-gray and light-brown sandy-silty; 10 - gleyed bluish-greenish sandy-silty and silty-clayey; 11 - brown and dark-brown humus and humus-clayey; 12 - yellow and red-brown iron-humus; 13 - yellow-red and black-red iron-manganese. IV. 14 - bleached sandy-silty apedal mass.

periphery and argillaceous dark brown (7.5 YR 3/2; IO YR 4/2; 4/3) in the centre of the lenses. The amount of stones and sand in these lenses is much lower than in the enclosing mass; we have called them in the field "clay traps", because it is possible that they accumulate clay arriving in suspensions along fissures at the lithological contact. The boundary of the IIB3$_4$D horizon with the lower IIID horizon varies: it is usually abrupt, rarely gradual and occasionaly broken.

The whole zone of the contact of mantle loams with the underlying red sandy moraine loam is extremely heterogeneous, the boundaries are irregular. The IIB3$_3$D and IIB3$_4$D horizons are morphologically interpreted as a gradual transition from the "pure" mantle loam to the moraine loam (appearance of red hue and rock debris). At the same time direct invasion of the brown mantle loam in the form of wedges into red moraine loam is observed. These wedges (about I m thick) break the IIB3$_3$D, IIB3$_4$D and IIID1 horizons and reach the IIID2 horizon; they have abrupt boundaries, dark brown clay cutanic fringes and are usually non-gleyed. Where the boundary is wavy, the transition is more gradual and some large detached plots of the underlying material are included in the above mass (paleocryogenic swelling). Lens-like gleyed mottles are usually restricted to the mantle loam, to even and wavy boundaries and do not penetrate into red moraine loam.

The entire transitional zone has many indices of mixing, disruption of horizons, wedge-like structures and may be probably regarded as a zone of paleocryogenic phenomena which accompanied the process of deposition of brown mantle loams on the surface of red moraine loams.

IIID1 298-400 cm. Red (2.5 YR 4/6; 3/6) moist, gravelly sandy moraine loam with vertical and horizontal strong brown (7.5 YR 5/6; 5/8) sandy and loamy-sandy interstratification; in the upper part weakly angular blocky indistinct peds, friable; in the lower part, structureless loamy sand. Very few pores, mainly fine tubular ones, crevice-like pores are rare. Fine roots are rare in the horizon but they form a dense network in the fissures; few fragments and gravel of various hard rocks, more or less weathered and rounded. Abrupt wavy boundary to the underlying IIID2.

Meso-and micromorphology* (Fig.1)

A1 2-II cm. A network of large fissures is absent, the horizon

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* The colour of soil mass components is given for moist samples and was determined in the field.

consists only of primary peds and apedal soil mass.

P r i m a r y   p e d s - fine rounded subangular crumbs.

I) IPM - very dark gray (IO YR 3/I; 3/2), yellowish brown in coprolites (IO YR 5/4). Skeleton - quartz and feldspar grains, sandy-silty, weakly to moderately rounded, bleached; plasma is isotropic, ferruginous-humus-argillaceous, its colour varies from almost black (dispersed humus prevails) to yellowish brown (ferruginous-clay plasma); rare fine concretions, mainly black-red in colour, humus-ferruginous with included skeleton grains; organic residues are represented by numerous charred particles and plant residues with a various degree of decomposition; pores are absent or very rare; cutans are absent.

2) Ped faces are similar to IPM, cutans are absent; sometimes plasma adjacent to the ped faces is humus-enriched and forms rounded clots.

S e c o n d a r y   p e d s - absent.

A p e d a l   m a t e r i a l - similar to IPM; skeleton grains of the apedal material are in many cases lighter in colour.

$A2_1$ II-27 cm. A network of large fissures is absent, the horizon consists of primary and secondary platy peds.

P r i m a r y   p e d s - fine lens-like plates.

I) IPM - brown (IO YR 5/3); quartz-feldspar skeleton grains, fine sandy-silty, weakly to moderately rounded, grains touch one another; plasma is isotropic, fine silty-argillaceous with an admixture of dispersed organic material and iron hydroxides; brown and black rounded concretions with indistinct limits, mineral grains are not visible in them because of the dark colour; organic residues occur in the form of numerous fine charred particles and rare plant remains, displaying various degrees of decomposition; pores are absent, only very rare fine rounded pores occur; cutans are absent both on pore walls and skeleton grains, the latter have bleached surfaces.

2) Ped surfaces: the upper surface is weakly concave, light-coloured (IO YR 6/3; 5/3), IPM is depleted of clay plasma and also colouring humus and iron hydroxides as compared to the central part of the ped; the lower surface is darker (7.5 YR 5/4; 4/4). IPM near the lower ped surface is coloured with humus-ferruginous compounds; besides them dark surfaces of concretions protrude here, attributing a darker colour to this ped surface.

S e c o n d a r y   p e d s - medium or fine plates composed of several primary plates.

The upper surfaces of secondary plates are covered with fine discontinuous (IO YR 6/3) light-coloured skeletans. Their grains are similar to those of IPM in composition, but are lighter in colour and more densely packed. Skeletans superimpose frequently the contacts between primary peds and penetrate into the vertical pores between them. In such cases the skeletans are the thickest, their grains are most densely packed and perfectly sorted. The lower surfaces of secondary plates lack cutans and are composed of the mosaic of primary peds surfaces.

$A2_1n$ 27-33 cm The total horizon arrangement is close to that of the $A2_I$ horizon.

P r i m a r y p e d s - mainly fine plates, few fine isometric (nuciform) peds.

I) IPM of platy peds - brown, pale brown (IO YR 5/3; 6/3); IPM of isometric peds - yellowish brown (IO YR 5/4; 4/4); skeleton is similar to that of the $A2_1$ horizon; plasma is fine silty-argillaceous with fine mottles; light gray plots are leached of iron hydroxides, are isotropic, contain gray dispersed humus, brown plots are enriched with iron hydroxides, are locally weakly anisotropic; many dark red, almost black and brown concretions of various size and shape, they consist of skeleton grains cemented with humus-iron compounds and iron hydroxides; very dark compact concretions with an abrupt boundary with IPM were described as well as less compact ones, the latter display a weaker degree of segregation and have diffuse transition to IPM; organic residues are represented by fine charred particles; rounded fine pores, usually cutan-free; locally discontinuous weakly anisotropic argillans with an admixture of humus-ferruginous substances occur.

2) Primary and secondary ped surfaces are similar to those described in the $A2_1$ horizon.

$A2_2$ 33-42 cm A network of large fissures is absent, the horizon arrangement repeats that of $A2_1$ and $A2_1n$ horizons; the light-coloured mass with a distinct platy structure predominates, separate "outliers" of brown mass with a rounded-subangular and isometric (nuciform) structure are distinguished.

P r i m a r y p e d s i n l i g h t-c o l o u r e d m a s s - fine and medium plates.

I) IPM - light brownish gray, grayish brown (IO YR 6/2; 5/2) sandy loamy; quartz-feldspar skeleton grains, weakly to moderately rounded, distinctly predominate over plasma; plasma is fine silty-argillaceous, isotropic with a minimum content of iron hydroxides and clay in the whole profile; subangular separations of anisotropic clay plasma not related to voids occur. Plasma of central parts of the peds may have a dark grayish hue due to fine dark humus clots. Concretions : fine, rounded, sometimes irregular, less frequent than in the $A2_In$ horizon, similar to the above described in fabric, but with a more abrupt boundary with IPM; organic residues - fine subangular charred particles; few rounded pores; no cutans.

2) Ped faces : IPM adjacent to the upper ped surface is light-coloured (IO YR 7/2) as compared with the central part of the ped; the lower ped surface is brown or dark brown (IO YR 5/3; 4/3) due to impregnation with humus-ferruginous substances and outcroping clusters of concretions.

S e c o n d a r y   p e d s   i n   l i g h t-c o l o u r e d   m a s s - platy, consisting of primary plates. Their upper surface is covered with a light gray (IO YR 7/2) continuous or broken skeletan, superimposing contacts between primary peds. It consists of fine sandy-silty, quartz-feldspar densely packed grains which have no cutans and are light-coloured or even bleached. The lower surface has no cutans and is composed of the mosaic of primary plate surfaces.

P r i m a r y   p e d s   i n   b r o w n   m a s s - fine, platy and isometric, rounded and subangular, having an abrupt to diffuse boundary with the light-coloured mass.

I) IPM - brown (7.5 YR 5/6; 4/4) loamy, skeleton has the same composition as that of light-coloured mass; plasma - brown argillaceous, anisotropic, of indistinct scaly fabric, enriched with iron hydroxides. The total plasma content is greater than in the light-coloured peds; few fine concretions similar to those of the light-coloured mass; organic residues - fine angular charred particles; rounded and irregular pores; cutans on pore walls are almost black, argillaceous, humus-enriched isotropic and red brown ferruginous-argillaceous, anisotropic, falcate.

2) Ped surfaces; near the upper surfaces of some brown peds IPM is light-coloured and forms a diffuse transition to the bleached enclosing mass; the lower surfaces are red brown due to impregnation with iron hydroxides.

S e c o n d a r y   p e d s   i n   b r o w n   m a s s - are either absent(in small brown plots)or are medium to thick platy (in large brown plots).

Ped surfaces resemble the surfaces of secondary peds of the light-coloured mass, but the upper surfaces bear less bleached skeletans containing fine clots of anisotropic clay and dispersed dark gray humus.

A p e d a l   m a t e r i a l - is morphologically analogous to the IPM of light-coloured platy peds.

A2B1 42-5I cm. A network of large fissures is well developed, the whole mass is easily separated into IFM and FI. Two types of IFM may be distinguished according to its structural organization : light-coloured and brown ones with a lot of transitional varieties.

P r i m a r y p e d s o f l i g h t-c o l o u r e d I F M - fine and medium plates with a concave upper surface and a convex lower surface.

S e c o n d a r y p e d s o f l i g h t-c o l o u r e d I F M - medium plates composed of primary ones.

Primary and secondary peds with their surfaces are similar in morphology and fabric to the light coloured platy mass of the $A2_2$ horizon.

P r i m a r y p e d s o f b r o w n I F M - medium and fine isometric nuciform, with weakly rounded faces.

I) IPM - reddish brown (5 YR 4/4; 4/6) heavy loamy; skeleton is similar to that of the A2 horizons; plasma is reddish brown and brown, argillaceous, anisotropic, scaly with an admixture of iron hydroxides; concretions: rare, fine, black, irregular in shape; many pores, rounded and irregular ones prevail; grain cutans are argillaceous or ferri-argillaceous; pore walls are enriched with clay, iron hydroxides and humus in the form of anisotropic falcate cutans.

2) Ped surfaces : the IPM adjacent to the upper ped surface is depleted of plasma and is lighter in colour as compared with the central part, while near the lower ped surface it is intensely coloured (5 YR 4/3; 3/2; 7.5 YR 4/2) by iron-humus substances; lateral ped faces (and sometimes the upper ones) are covered with dark brown anisotropic scaly-fibrous argillans.

S e c o n d a r y p e d s o f b r o w n I F M - thick and medium plates composed of isometric primary peds.

Ped surfaces : on the upper ped surface very pale brown (IO YR 7/3) fine sandy-silty, broken or continuous skeletans occur, they consist of densely packed quartz-feldspar grains with a low amount of clay plasma, usually in the form of grain cutans, they are also enriched with fine clots of dark gray dispersed humus.

The lower ped surfaces lack cutans.

A p e d a l m a t e r i a l between brown peds is similar in composition to IPM, but depleted of clay plasma.

Skeleton grains are coated with broken grain argillans, plasma is light-coloured, argillaceous, with a scaly fabric.

B1A2 5I-60 cm A network of large vertical fissures distinctly divides the horizon into brown IFM and bleached FI.

P r i m a r y p e d s o f b r o w n I F M - fine and medium isometric nuciform peds with a flat upper surface and a slightly convex lower one. Primary peds near fissures are weakly platy and have rounded faces.

I) IPM - dark brown (7.5 YR 4/4) heavy loamy with very fine colour mottling consisting of more brown (plasma-enriched) and light-coloured (depleted of plasma) microzones; the skeleton is similar in shape and composition to that of the A2 horizon, but all the grains are brown; plasma is brown fine silty-argillaceous, anisotropic with a scaly fabric and abundant clay separations; few concretions with the predominance of fine dark opaque ones; organic residues occur in the form of fine charred particles; few pores, mainly rounded; anisotropic falcate argillans, dark or black red surround the concretions or fill fine pores; larger pores contain isotropic fine silty cutans rich in humus.

2) Ped surfaces : the upper ped surfaces are coated with very fine dark brown (IO YR 5/3; 4/3; 7.5 YR 4/3) broken or continuous argillans which are anisotropic, falcate and are enriched with fine silt and humus; on many peds these argillans are replaced by more dark clay-humus-ferruginous cutans. IPM adjacent to the upper ped surface (under the argillans) is frequently light-coloured and depleted of clay plasma as compared to the central part of the ped interior. The lower ped surfaces are coated with reddish brown (5 YR 4/3; 4/4) clay-humus-ferruginous cutans. The lateral ped faces in the central part of IFM (far from large fissures) either have no cutans or are coated with fine dark brown clay cutans.

In IFM zones adjacent to large fissures primary peds are smaller and have diffuse limits; instead of dark clay and humus-ferruginous cutans the upper, lower and lateral ped faces are covered with light-coloured quartz-feldspar skeletans lacking clay plasma or with grayish brown silty-argillaceous thick anisotropic cutans (on lateral faces).

S e c o n d a r y p e d s o f b r o w n I F M - medium and thick unstable plates; the upper surfaces of secondary peds carry white and pale brown (IO YR 8/2; 8/3; 7/2;7/3) thick broken or continuous skeletans consisting of densely packed quartz and feldspar grains with bleached surfaces lacking any grain cutans. These skeletans superimpose the surfaces of primary peds and contacts between them and penetrate into vertical

exped pores. The thickness of light-coloured skeletans on secondary peds of brown IPM increases considerably near fissures and becomes almost equal to the thickness of the peds.
The lower faces of secondary peds lack their own cutans and are composed of the mosaic of primary ped lower surfaces and outcrops of sceletans along exped crevice-like pores.
A p e d a l m a t e r i a l is represented by brownish gray sandy loamy mass similar to the light-coloured IPM of the A2 horizons; skeleton predominates over the plasma, the grains being light-coloured and densely packed; plasma is isotropic enriched in fine silt; few dark red concretions; fine charred particles.

B1 60-87 cm. The horizon is distinctly differentiated into IPM and FI.

P r i m a r y p e d s of IPM - fine and medium, angular, isometric (nuciform), sometimes thick platy with distinct lateral faces.

I) IPM-reddish brown (5 YR 4/4; 7.5 YR 4/4), loamy: skeleton consists of quartz and feldspar grains, is fine sandy to silty; plasma is brown, argillaceous anisotropic with a scaly fabric; few concretions are weakly segregated, black and dark brown, irregular, with indistinct limits; organic matter - fine charred particles; pores - fine, rounded and oval, irregular; cutans - fine brown grain argillans and brown falcate void argillans locally enriched with iron hydroxides and/or fine humus particles.

2) Ped surfaces : primary peds are completely enveloped in fine broken or continuous reddish brown (5 YR 4/4; 4/3) falcate argillans, their colour is sometimes darker on a lower ped surface (5 YR 3/4) due to an admixture of humus-ferruginous compounds.

S e c o n d a r y p e d s of medium and thick plates composed of isometric primary peds.
Ped surfaces : on the upper ped surface there is a patchy or broken quartz-feldspar skeletan with an admixture of fine humus particles, it is light gray (IO YR 7/2) or very pale brown (IO YR 7/3; 7/4) skeleton grains are bleached and light-coloured, only few of them have fine clay films; this skeletan superimposes the contacts between primary peds composing the secondary plate and is lying either on the argillans of primary peds or directly on their IPM. The lower and lateral surfaces are covered by patchy light-coloured skeletans.
T e r t i a r y p e d s - medium prisms with slightly rounded upper surfaces.

Ped surfaces : the upper and lower surfaces are composed of secondary ped surfaces; the vertical faces of the prisms in the central parts of the IFM are coated with fine continuous reddish brown (5 YR 4/4; 4/3) argillans,nearer to fissures very pale brown (IO YR 7/4) and light gray (IO YR 7/2; 2.5 Y 7/2) skeletans show up. They superimpose the contacts between the vertical faces of primary and secondary peds which compose the prisms.

$B2_1t$ 87-I40 cm. The horizon is distinctly differentiated into IFM and FI. The IFM is homogeneous in colour,composition and arrangement.

P r i m a r y p e d s o f IFM are fine,medium and coarse isometric (nuciform) with sharp faces.

I) IPM - brown (IO YR 4/4; 4/3; 7.5 YR 4/4; 5/4) moist,heavy loamy; skeleton is the same as above; plasma is brown,argillaceous,anisotropic with a scaly fabric; rare concretions - soft with diffuse boundaries; many pores which are mainly rounded and irregular; cutans : light brown,very fine anisotropic grain argillans; on fine pore walls - reddish brown or dark brown anisotropic falcate argillans,on large pore walls - anisotropic argillans with an admixture of fine silty material and fine humus particles; in the largest pores the described clay cutans are interstratified with light-coloured skeletans consisting of coarse silty densely packed mineral grains without any coatings. Sometimes there are narrow zones in argillans which are enriched with iron hydroxides (ferri-argillans).

2) Ped surface - the upper,lower and lateral ped surfaces are covered with very fine reddish brown and brown (5 YR 4/4; 3/4; 7.5 YR 4/4) continuous anisotropic argillans with a falcate fabric. Below them a narrow light-coloured IPM band poor in plasma can be seen. Argillans on the upper ped surfaces near large fissures are sometimes superimposed by light-coloured broken skeletans.

S e c o n d a r y p e d s - fine and medium,rarely coarse prisms, sometimes - thick plates.

I) Ped surfaces : the upper and lower surfaces of secondary peds in the central part of the IFM do not have their own cutans and are composed of corresponding surfaces of primary peds There are broken light-coloured cutans over argillans on the lateral surfaces. They are loamy and light brownish or pinkish gray (IO YR 6/2; 5 YR 6/2) in the central part of the IFM and consist of skeleton grains and of the light brown clay-fine silty anisotropic plasma. Nearer to large fissures,these cutans are replaced by sandy-silty very pale brown (IO YR 8/3) skeletans with an olive or light-gray hue (5 Y 6/2; 2.5 Y 7/2) of weak gleyzation.

$B2_2$tg I40-I67 cm. The horizon is dinstinctly differentiated into brown-mottled IFM and light-coloured FI.

P r i m a r y p e d s o f I F M - coarse angular isometric (nuciform); medium and coarse prismatic, rarely - thick platy.

I) IPM - mottled: against the background of brown (5 YR 4/4; 7.5 YR 5/4; 5/6) loamy mass there are rounded greenish gray (5 GY 6/I; 5/I; 5 Y 6/I;7/2) gleyed mottles around tubular pores; skeleton is the same as in the A2, BI and B2 horizons; plasma in brown IPM is light brown argillaceous, anisotropic with a scaly fabric; gleyed IPM mottles around pores are poor in plasma; the remaining plasma is light-coloured, with a fibrous and flow-fibrous fabric; rounded and irregular opaque concretions occur in the form of clusters, among them fine black concretions prevail, larger ones, reddish brown in colour, are rare. Many fine rounded and oval pores. Grain argillans are fine light brown anisotropic, continuous in brown IPM and broken in gleyed mottles. Several types of cutans are intricately interstratified on pore walls: a) dark brown or dark reddish brown (7.5 YR 3/2; 5 YR 3/2) anisotropic falcate argillans; b) brown or pale brown fine silty-clay anisotropic cutans; c) grayish greenish fine sandy-silty cutans without plasma and with rare clay films on skeleton grains. Occasionally cutans completely fill the pore.

2) Ped surfaces: the upper and lower ped surfaces in the central part of IFM carry very fine patchy brown (7.5 YR 5/6; 5/4) argillans restricted to depressions, outcrops of tubular pores and horizontal root holes. The vertical surfaces are covered with continuous dark brown argillans.

On vertical ped surfaces in IFM zones adjacent to large fissures the following types of cutans are interstratified:

a) light gray (IO YR 7/I; 7/2) skeletans; b) light greenish grey (5 GY 5/I) loamy cutans; c) light yellowish brown (IO YR 6/4) fine silty cutans; d) dark brown argillans.

$B3_1$tg I67-207 cm. The horizon is differentiated into finely mottled yellow brown IFM and light-coloured FI.

P r i m a r y p e d s of IFM: medium and coarse prisms.

I) IPM-yellowish brown (IO YR 5/4;5/8; 4/4) and brown (7.5 YR 4/4) loamy with numerous fine olive gray (5 Y 5/I;5/2) gleyed mottles around tubular pores. Between gley mottles and dark brown IPM a compact grayish brown (IO YR 5/2) ring-like zone is frequently distinguished; skeleton is rather similar to that of the above horizons, but contains some rare larger non-rounded quartz grains; plasma in brown IFM is light brown fine silty argillaceous anisotropic, scaly in fabric, becoming flow-fibrous near pores and planes; gley mottles are depleted of plasma; few fine irregular black and dark brown concretions, both soft and hard occurring in clusters. Numerous pores with the predominance of rounded tubular ones. Fine yellowish brown anisotropic grain argillans, continuous in brown IFM and broken in gley mottles. Three types of cutans on pore walls: a) brown falcate anisotropic argillans and ferri-argillans with an admixture of humus particles and fine silt; b) greenish gray silty cutans; c) black red ferri-manganic cutans.

2) Ped surfaces : the upper and lower surfaces are cutan - free. On the vertical faces of prisms in the central part of IFM there are dark reddish, grey and reddish brown (5 YR 4/2; 4/3) anisotropic argillans or gleyed continuous gray and olive gray loamy cutans (5 Y 5/I; 5 Y 5/2). In the vicinity of fissures these cutans are superimposed by patchy or broken light-coloured (IO YR 7/2; 7/3) skeletans.

$IIB3_2tg$ 207-234 cm. The horizon is distinctly differentiated into yellowish brown mottled IFM and light-coloured FI.

P r i m a r y p e d s o f I F M: coarse prisms with indistinct horizontal surfaces and clear vertical walls.

I) IPM - mottled: against the yellow- or reddish brown (7.5 YR 5/6; 5 YR 4/4) background rounded or oval greenish gray gleyed mottles (5 GY 5/I) occur. The bulk of the skeleton is the same as above, but an admixture of rock fragments represented by non-rounded grains of quartz, feldspars, dark basic rocks, quartzite, sandstones, etc. appears. Plasma in brown IFM is light brown argillaceous anisotropic with a scaly fabric, becoming large scaly and fibrous near coarse mineral grains. Bleached gleyed zones are depleted of clay plasma; plasma in these zones is light-coloured and scaly in fabric. Fine black brown and black concretions form clusters. Many fine and medium rounded and irregular pores. Cutans : on the skeleton grains of brown IFM and in gley mottles - fine yellow continuous anisotropic argillans; on fine pore walls - red brown falcate argillans with an admixture of fine silty material; in large pores - interstratification of brown argillaceous and dark red opaque ferri-manganic cutans.

2) Ped surfaces. The horizontal ped surfaces lack cutans.

The vertical walls are covered with a continuous reddish brown (5 YR 3/4; 4/3);7.5 YR 5/4) argillan,or more rarely with a dusky red or strong brown (2.5 YR 3/0; 3/2; 7.5 YR 5/8) ferri-manganic broken cutan with a dull fine scaly surface.

$IIB3_3D$ 234-273 cm. The horizon is differentiated into reddish brown IFM and light-coloured FI. A fissure network is rare.

P r i m a r y p e d s o f I F M are indistinct coarse prismatic or angular blocky.

I) IPM is yellowish red or brown (5 YR 4/6; 7.5 YR 4/4; 5/6) with rare light-coloured gley mottles around pores,skeleton is the same as in the $IIB3_2$ horizon; plasma is light brown argillaceous,with a scaly fabric and fine clots; fine black concretions occur in clusters; many pores,fine and medium,rounded and irregular ones prevail; cutans : continuous anisotropic grain argillans or ferri-argillans; brown anisotropic void argillans, black-red void ferri-argillans. Clay with a fibrous fabric occurs subcutanically near some fine pores.

2) Ped surfaces. The horizontal surfaces lack cutans.The lateral surfaces are covered with reddish brown (5 YR 4/3) anisotropic argillans with silty laminae; broken or continuous yellowish red and dark reddish brown (5 YR 5/6; 3/4; 2.5 YR 2/4) ferri-manganic cutans with dull scaly surfaces are rare.

$IIB3_4D$ 273-298 cm. The horizon is heterogeneous in colour and texture.

P r i m a r y p e d s - very coarse angular blocky.

I) IPM is heterogeneous : against the main yellowish red (5 YR 4/6) gravelly loamy background there are red (5 YR 4/8; 2.5 YR 4/6) mottles of gravelly sandy loam,brown mottles of silty loam and bluish gley mottles around tubular pores. In brown zones of IPM the skeleton is the same as in the $IIB3_2$ and $IIB3_3D$ horizons; plasma is brown fine silty-argillaceous,anisotropic,with a scaly or short-fibrous fabric; many pores with the predominance of coarse irregular ones; very few fine red brown concretions with diffuse boundaries; cutans : brown anisotropic grain argillans and reddish brown falcate anisotropic void argillans. In red and red brown zones of IPM the skeleton consists of sandy weakly to moderately rounded grains of quartz and feldspar; plasma is red brown argillaceous,anisotropic scaly and collected in clots; no concretions; few mainly rounded pores; cutans : thick reddish brown anisotropic grain argillans and rare fine anisotropic void argillans.

In gleyed zones of IPM near the contact with the moraine loam the skeleton is the same as in brown zones,but mineral grains are bleached; plasma is light brown argillaceous,anisotropic,fine scaly,almost "dotted"; no concretions; organic remains: fine charred particles; few pores (rounded); cutans: whitish brown broken grain argillans,light brown anisotropic void argillans.

2) Ped surfaces: cutans occur only on lateral surfaces; thick and medium brown (7.5 YR 5/4; 4/4) argillans are common for brown zones of the horizon,more rarely - black (5 YR 2/I; IO YR 2/I) or. dark red ferri-manganic cutans with dull surfaces; stratification of dark reddish brown (5 YR 3/2) argillans and lighter (5 YR 4/4; 4/6) clay cutans with sand and silt admixture is observed within dark and dark-brown zones of the horizon.

IIID1 298-400 cm. The horizon is differentiated into bright brown IFM and rare fine fissures with red brown FI.

P r i m a r y p e d s o f I F M: weakly developed coarse angular blocks.

I) IPM-IFM: homogeneous red sandy loamy; skeleton consists of coarse sandy angular grains of quartz and feldspar,cracks on their surfaces contain amorphous substance or fine disperse clay; plasma is red brown,anisotropic,argillaceous,with a scaly fabric and fine clots; no concretions; few pores with rounded ones prevailing. Cutans: continuous fine and medium anisotropic grain and void argillans.

2)Ped surfaces.Cutans occur only on the lateral surfaces. Three types of cutans are distinguished: a) dark brown argillans; b) almost black manganic and humus argillans; c)patchy black red or yellow red ferri-manganic cutans.

MAIN RESULTS OF MESO-AND MICROMORPHOLOGICAL STUDIES OF SOD-PALE-PODZOLIC SOIL

Interfissure mass (IFM)

The general pedal arrangement of the IFM,including peds of various orders, has been found to regularly change throughout the profile.

Organic horizons (01, 02) are structureless or weakly layered (leaf fall and compaction of the forest litter). The humus horizon (A1) is weakly aggregated; only primary peds - fine crumbs bound by humus are formed in A1.

A group of eluvial horizons ($A2_1$, $A2_2$ and bleached zones of the A2BI) are characterized by two levels of platy structure: primary fine platy peds compose secondary medium platy peds. The size (thickness) of individual plates increases downward the profile from the $A2_1$ and $A2_2$ to the A2BI.

Brown-coloured horizons in the middle part of the solum (B1A2,B1, $B2_1t$) have the most complicated arrangement of soil material; primary peds are represented by isometric subangular blocks (polyhedrons,nu-ciform aggregates). Primary peds compose secondary platy or prisma-tic peds which sometimes make up coarse prismatic tertiary peds.

In the bottom of the solum ($B3_1tg$ - IIB3D) the structural arrange-ment becomes less complicated: only primary coarse or medium prisma-tic peds are usually pronounced. In some places blocks composing pris-matic peds are visible. The degree of aggregation decreases and the size of peds increases down the profile,prismatic peds being replaced with coarse blocky ones. In the IIID horizon soil material is essen-tially structureless and the soil is separated into supercoarse blocks by sparse fine fissures.

Intrapedal mass (IPM)

Proportion of skeleton and plasma. The IPM in the A1,A2 and in bleached zones of the A2B1 and B1A2 is essentially devoid of plasma, hence skeleton grains touch one another with their faces and corners.

There is a considerable increase in plasma in the BIA2, B1, B2, B3, IIB3D and IIID horizons, skeleton grains are embedded in plasma and isolated.

The skeleton. In the major part of the solum,from the surface up to the IIB3D,the skeleton in IPM and in apedal material is repre-sented by fine-sandy and silty weakly and moderately rounded grains of quartz,feldspars and quartz-feldspar metamorphic rocks. Flakes of muscovite and biotite and grains of amphibole,epidote,garnet,ilme-nite,etc. can be found in negligible amounts. A considerable simila-rity in size,composition and degree of rounding of skeleton grains throughout the profile indicates that the soil studied has been de-rived from the homogeneous parent mantle loam.

The $IIB3_2$ and $IIB3_3D$ horizons display some features of lithologi-cal discontinuity: angular coarse-sandy (>0.25 mm and $>I$ mm) quartz and feldspar grains and fragments of basic igneous rocks,quartzite and sandstone appear in these horizons. There is an increase in these grains and decrease in the plasma content in the IIID horizon, the skeleton being represented by a mixture of non-rounded grains of various rocks and minerals which are specific for moraine loams.

Surface of skeleton grains. In the A1, A2 and in the bleached zones of the A2BI and BIA2 horizons the surface of skeleton grains is cutan-free and in some places bleached and corroded. In the pale brown $A2_1$ horizon part of skeleton grains are light-brown,but there are no cutans on their surfaces.

In brown-coloured horizons (starting from the brown zones in the A2B1 to IIID) skeleton grains in brown IPM are coated with brown and yellow-brown fine anisotropic argillans and ferri-argillans.

Such a micromorphological differentiation of the surfaces of skeleton grains testifies to the eluviation of the IPM in the A1-A2B1 horizons. Grain argillans in these horizons have been subjected to dispersion, washing out and probably to partial dissolution; suspensions and solutions are leached from the IPM of the eluvial horizons.

Plasma. The major components of plasma in all the horizons are clay minerals and fine particles of quartz and feldspars; dispersed gray organic substances and iron hydroxides are present almost everywhere in variable amounts.

The quantity of plasma in the IPM is distinctly differentiated throughout the profile : the lowest amount of plasma is found in the A1-A2B1; it increases downward from the B1A2 to IIB3D and decreases again in the IIID horizon.

The proportion of plasma components varies regularly within the profile. In the upper eluvial horizons (A1-A2B1) slightly coloured isotropic fine silty argillaceous plasma predominates with an admixture of gray disperse humus and iron hydroxides.

The microscopically observed isotropy of the plasma in these horizons is associated with the loss of the finest silicate clay minerals and with the dispersion of their individual particles,i.e. with the total eluviation from these horizons. The silicate phase of the optically isotropic plasma is characterized by random orientation of individual particles and does not form domains with a mutual orientation of particles.

In the A1 this fine-silty-argillaceous isotropic plasma is enriched with dispersed humus accumulated in situ and attributing the dark-gray and gray colours to the plasma. In the $A2_1$ and $A2_1n$ horizons isotropic plasma is poorer in humus,but it is light-brown coloured due to the presence of iron hydroxides. The most pronounced loss of silicate clays,iron hydroxides and disperse humus is typical of the A2 and the bleached zones of the A2B1.

Brown-coloured horizons (B1A2, B1, B2, B3 and deeper) contain mainly brown anisotropic plasma,morphologically uniform. It has a higher content of silicate clays and iron hydroxides and is poorer in fine-silty particles of quartz and feldspars. The plasma is mainly scaly in fabric. Plasma scales are microaggregates of individual mutually oriented clay particles; at the same time the scales themselves display random orientation. Such a fabric is also typical of the plasma of the parent mantle loams which suggests that the major part of IPM brown plasma in the B has been inherited from the parent material and has not been essentially rearranged in the course of pedogenesis.

In reddish-brown zones of the IIB3D and IIID plasma is red-coloured, scaly and enriched in iron hydroxides.

Inped voids (IPM of S-matrix adjacent to pores and pore infilling) Inped voids in the A1, A2 and in bleached zones of the A2B1 are sparse; usually they are fine and rounded. There are no cutans within voids and on their walls. The IPM adjacent to voids does not essentially differ from that of the rest of the primary ped IPM which is evidence of the total frontal eluviation from these horizons. The processes of leaching are operative in the entire IPM of eluvial horizons (A1,A2,A2B1), including both voids and areas proximate to voids.

The IPM of the brown zones of the A2B1, B1A2, B1 is much more porous than that of the A1, A2. There are numerous voids, vertical tubular ones predominate. IPM in the proximity of voids is not changed. Brown peds in the A2B1 and B1A2 contain many black and red-black isotropic cutans which have the largest amount of organic matter and iron hydroxides; brown and red-brown anisotropic falcate argillans with an admixture of humus and iron oxides and a continuous orientation pattern are not so common. Larger voids contain sometimes fine-silty isotropic cutans enriched in humus.

In the B1 the amount of organic matter and iron hydroxides in void cutans decreases. In this horizon predominate reddish-brown anisotrpic argillans which are only locally enriched in humus and iron.

In the $B2_1$ IPM becomes still more porous, large tubular voids appear. The IPM around voids is hardly altered. Infilling of voids with cutans in this horizon is still more complicated. Fine pore walls are coated with reddish-brown argillans similar to those in the B1. In coarser pores brown argillans contain fine-silty particles of quartz, feldspars and small charred particles. In the largest pores brown argillans are interstratified with bleached skeletans of illuvial-suspensional origin. Thin isotropic dark-red iron-humus cutans may sometimes occur in such interstratifications.

The amount of inped tubular vertical pores in the $B2_2$tg and $B3_1$tg does not decrease and may even increase locally. As distinct from the overlying B1 and $B2_1$t there are greenish-gray bluish and light-brown light-coloured round-shaped tubular zones of gleyed and eluviated IPM around voids in the $B2_2$tg and $B3_1$tg horizons. They pierce primary peds and are especially pronounced by contrast with the brown IPM so that specific bluish-brown mottling is produced on the cross-section. Skeleton grains in gleyed zones are light-coloured and usually lack argillans, the IPM is low in argillaceous plasma.

The remaining plasma is characterized by gley (greenish-gray) colours and fibrous or scaly-fibrous fabric which indicates that it has been reoriented as compared with the scaly plasma of the brown zones of the IPM. In the $B2_2tg$ and $B3_1tg$ different kinds of cutans are repeatedly interstratified within voids : a) dark-brown or red-brown anisotropic falcate argillans with an admixture of dark dispersed humus; b) grayish-greenish fine-sandy-silty skeletans without any grain argillans; c) brown or light-brown fine-silty-argillaceous cutans; d) black or black-red manganic-iron isotropic cutans. Bleached gleyed silty skeletans and brown argillans are usually the thickest in such interstratifications.

In the $IIB3_1tg$, $IIB3_3D$, $IIB3_4D$ and IIID the number of inped voids gradually decreases, gleying and eluviation of the IPM become less pronounced; interstratification of dark-red-brown anisotropic falcate argillans and red-black isotropic manganic-iron cutans predominates within voids in these horizons.

Thus inped voids manifest a complicated picture of migration and accumulation of substances which is not entirely consistent with macrodifferentiation of substances in horizons and with microdifferentiation of skeleton grains and plasma in the IPM. In the A1-A2B1 voids serve only an channels through which substances are eluviated. Inped voids in the A2B1 (brown zones), B1A2 and B1 accumulate clay, humus, iron hydroxides and their compounds; in the $B2_1t$ and especially in the $B2_2tg$ and $B3_1tg$ accumulation of sandy-silty material high in SiO_2 and low in Fe_2O_3 and Al_2O_3 takes place which is comparable with the accumulation of clay, humus and iron hydroxides. Some eluviation of argillaceous plasma and reduced iron compounds occurs along voids in the $B2_2tg$ - $IIB3_2tg$. In the $IIB3_3D$ -IIID clay, humus, iron and manganese hydroxides are found to accumulate in the inped voids.

Concretions. The A1 contains sparse rounded iron-humus black-red concretions which points to predominantly oxidizing conditions in this horizon. The A2 and bleached zones in the A2B1 contain the maximum amount of concretions. In these horizons round hard black, dark-red and dark-brown concretions predominate. They are high in iron hydroxides, organic matter and manganese. The main part of concretions however, consists of silicate material enriched with cementing humus-manganic-ferruginous compounds. The abundance of concretions in the A2-A2B1 suggests the idea of regular alternation of periods when waterlogging produces reductive conditions with periods of dessication accompanied by oxidation. Surface reduction and seasonal gleyification take place in spring during the snow melting, in this period ferrous compounds are subjected to the localization into concretions within the horizon. Respectively bluish and rusty-bluish mottles indicating seasonal gleyification appear in the soil mass of these horizons in spring and disappear in summer.

In brown zones of the A2B1, B1A2 and B1 the amount of concretions sharply decreases; in these zones irregular black concretions are found which are softer than rounded ones.

The lower horizons $B2_1t$, B3tg, IIB3D contain many soft irregular black manganic concretions occurring in clusters. The clusters are distinctly visible against the background of the brown IPM. Such clusters are permanent centres of within-horizon localization of Mn and Fe hydroxides; they are especially evident in horizons with tubular and striated gleyification along voids and fissures ($B2_2tg$, B3tg).

In the IIB3D apart from concretions described above, there are also macro-and microzones cemented with iron and manganic compounds. These zones are associated with gleyification and oxidation at the lithological contact of different sediments. Neither segregation nor cementation have been found in the IIID horizon.

Thus segregation and cementation are markers of two zones of excessive superficial moistening - reduction -gleyification: the upper zone (A2 horizon) associated with regular snow melting in spring and the lower zone ($B2_2tg$ - IIB3D horizons) characterized by impeded intrasoil percolation of atmospheric moisture and stagnation of moisture above the lithological contact.

Primary ped surfaces

Ped faces (walls of exped voids) as well as inped voids are most sensitive indicators of substance migration within the profile. It is these surfaces that are washed with gravitational moisture transporting soluble and suspended substances. Therefore, the study of differences between ped surfaces and IPM and also their changes within the solum are of prime importance for understanding the regularities of migration and accumulation of substances in the profile.

In the A1 the surfaces of crumby peds do not differ from the IPM, the former may be only slightly higher in humus. As to the $A2_1$-B1A2, here eluviation is more vigorous along the upper faces of platy peds as compared with ped interiors; therefore these surfaces are still more bleached and form microzones poorer in humus, iron hydroxides, clayey plasma and relatively higher in strongly bleached skeleton grains. On the contrary, the lower surfaces of platy peds exhibit dark-gray, dark-brown or dark-red IPM microzones enriched in dispersed humus, iron hydroxides and sometimes in brown argillaceous plasma.

Thus primary peds - plates in the A2 - BIA2 manifest a microprofile in their vertical cross-section: the upper side is an eluviated microzone, the central part is least changed and the lower side is of illuvial character.

In the B1, $B2_1t$ and $B2_2tg$ brown primary peds - blocks are coated with continuous dark-brown falcate anisotropic argillans which seem to be of illuvial origin. In the BIA2 and BI these argillans on the upper ped faces usually contain fine-silty quartz grains and organic particles,whereas lower ped surfaces are enriched in humic-iron reddish-coloured compounds.

The most uniform fine continuous falcate argillans coating peds - bloks are typical of the $B2_1tg$. In the $B2_2tg$ horizon continuous argillans remain only on vertical ped surfaces; on horizontal ped faces they occur only in the proximity of the outlets of tubular inped voids. Below the $B2_2tg$ within $B3_1tg$ - IIID, there are no cutans on horizontal ped faces; only vertical ped faces are coated with humus-argillaceous dark-brown and black red humus-manganic-iron cutans interstratified with rare olive-gray gleyed silty argillaceous cutans. The area of ped faces coated with iron-manganic cutans increases with depth.

Thus the morphology of primary ped surfaces allows to obtain a more precise picture of migration and differentiation of substances through exped voids.

In the A2 and A2B1 some indications of additional microeluviation from the upper parts of the peds and microilluviation of humus and iron into their lower parts are manifested against the general eluviation background.

The processes of illuvial accumulation of clay material on all ped faces predominate within the B1A2, B1, $B2_1t$ and $B2_2tg$, clay accumulation on horizontal ped faces becoming weaker with depth.

In the B3tg, IIB3D and IIID no illuvial accumulation of clay material on horizontal ped faces has been observed. As translocation of moisture, suspensions and solutions takes place mainly along vertical ped faces,it is on these faces that illuvial accumulation of clay and fine silt is pronounced as well as precipitation of humus, iron and manganese hydroxides from solutions.

Secondary ped surfaces

In horizons from $A2_1$ up to $B2_1t$ where secondary peds are represented by plates,horizontal surfaces of secondary peds are of prime interest. Vertical ped surfaces in these horizons are weakly pronounced.

The upper faces of secondary peds are usually coated with bleached skeletans superimposed on primary ped surfaces and junctions and penetrating into short vertical pores between primary plates. Such skeletans usually consist of fine sandy-silty bleached grains of quartz and feldspars with an admixture of gray humus and fine charred particles. The location and morphological features of these skeletans point to their allochtonous origin with respect to the

IPM of primary peds. It is obvious that they are illuvial skeletans consisting of material which has been translocated as suspensions from upper horizons.

These bleached skeletans are most markedly pronounced on the upper surfaces of secondary plates in brown parts of the A2B1, B1A2 and B1 where they are superimposed on dark-brown argillans coating primary peds-blocks. Such a combination of cutans shows that illuvial accumulation of substances proceeded in two stages: in the first stage clayey material accumulated on the surfaces of primary peds; in the second, sandy-silty material built up on secondary ped surfaces.

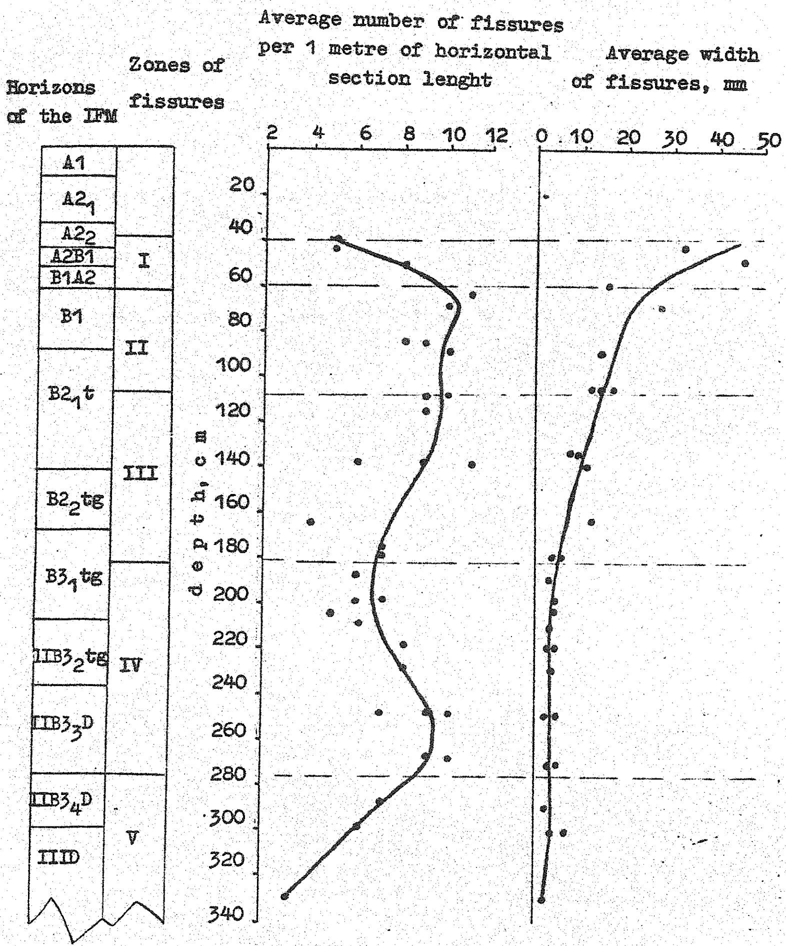
Up from these horizons towards $A2_2$, $A2_1$ and down to $B2_I$t bleached skeletans become less obvious: they decrease in area and thickness and in the degree of skeleton grain bleaching. In the A2 this phenomenon is related to the superficial location of these horizons which enables translocation of sandy and silty suspensions within the horizon only. The $B2_1$t is located too deep and therefore sandy and silty suspensions hardly penetrate here through horizontal exped voids.

Below the $B2_1$t there are no cutans on the horizontal faces of secondary peds. Cutans on the vertical faces of secondary and tertiary peds are well pronounced only within the B1, $B2_1$t, $B2_2$tg where these peds are represented by prisms. In the BI bleached skeletans predominate, whereas in the $B2_1$t they are interstratified with grayish-brown and greenish silty-clayey cutans; brown argillans appear only in the $B2_2$tg. In the lower horizons the soil mass is not arranged into secondary peds.

Fissures and fissure infilling (FI)

The majority of vertical fissures appears below the A2 horizon. The average number of fissures and their average width on vertical and horizontal cross-sections of the solum are shown in Fig.2. Horizontal cross-sections display a distinct general polygonal pattern.

Fissuring of sod-podzolic soils on mantle loams is a widely spread phenomenon, but its genesis is not yet quite clear. Many investigators are of the opinion that fissures develop syngenetically with mantle loam formation (contraction - drying of the loams) or are the epigenetic result of paleocryogenic fissuring after the deposition of mantle loams but before the beginning of the proper Holocenic humid-forest soil formation. The largest and deepest fissures in soil profiles are probably inherited from the parent material. But at the same time one can hardly deny the possibility of appearance of new fissures during recent (Holocenic) soil formation, i.e. fissures of pedologic origin.



F i g. 2. Average number and average width of fissures in the sod-pale-podzolic soil, profile 2-71. (Countings and measurement were made both on vertical and horizontal sections)

The properties of fissure infilling (FI) do not change down the soil profile with the same regularity and distinctness, as the IFM; nevertheless investigation of a great number of fissures reveales a quite definite FI differentiation with depth. It does not completely coincide with the IFM horizon differentiation for which reason it seems more convenient to describe it as one consistent system of zones (from the upper horizons down the solum) differing both in the nature of FI and the number and width of fissures.

Fissure zone I, embracing A2B1 and B1A2. Wide, frequently wedge-like fissures form a rounded-polygonal pattern on a horizontal cross-section. They are filled mainly with apedal or weakly platy whitish gray sandy material (FI) enclosing separate brown "outliers" - isometric or platy peds similar to the peds of the surrounding brown IFM. There is no cutanic orientation of the bleached mass along fissure walls.

The bleached FI consists of densely packed, cutan-free skeleton grains represented by quartz and feldspars. There are many charred plant residues in the FI; zones of enrichment in gray dispersed humus and light brown indistinctly scaly plasma occur. Brown peds-IFM outliers occurring in the centres of fissures of FI have indistinct light-coloured limits and their peripheral parts are poor in plasma, so they are gradually eluviated and transformed into sandy FI. Near fissure limits transition to the brown IFM is diffuse; some brown peds of the IFM are destroyed and transformed into light-coloured apedal FI. Along fissure walls groups of brown peds are "cut" from the fissure walls and included into the FI. Such peds are usually subangular and weakly eluviated. Fissure walls are locally covered with isotropic humus-ferruginous cutans.

The morphology of FI and its contact with IFM in the A2BI and B1A2 suggest that in the first fissure zone fissure infilling is of complex origin involving the following processes : a) eluviation (removal of argillaceous plasma, accumulation of the bleached skeleton); b) sinking and filling up of the bleached mass of the upper horizons; c) migration and accumulation of suspensions of bleached sandy-silty material and raw humus arriving from A1-A2; d) transit migration and, to a smaller extent, accumulation of clay suspensions and humus-ferruginous compounds.

Fissures in this zone are aggressive towards the brown IFM: they are enlarged at the expense of eluviation of IFM zones adjacent to fissures and of the brown outliers - peds enclosed in the FI.

Fissure zone II, embracing B1 and upper part of $B2_1t$. This zone is in many respects similar to the one previously described. Fissures are numerous, but they are narrower and their shape changes: instead of wedge-like fissures crevice-like ones begin to dominate. Similar to zone I, FI consists mainly of apedal material and /or indistinct vertical plates. The soil material is weakly porous, whitish gray with frequent inclusion of brown IFM "outliers".

The composition of the light-coloured FI is the same as above: quartz-feldspar cutan-free skeleton grains predominate. The number of zones enriched in light or reddish brown fibrous scaly clay-fine silty plasma, dark gray organic matter and charred particles is greater. There is no distinct cutanic orientation along fissure walls except for the local occurrence of red brown isotropic humus-ferruginous and weakly anisotropic humus-argillaceous cutans in FI pores and on the boundary between FI and IFM.

Brown outliers within light-coloured FI are more subangular and have more distinct limits than the outliers of zone I which points to weaker eluviation and bleaching in zone II. The same features are characteristic of the contact between the light-coloured FI and brown IFM along fissure walls. The "aggression" of a fissure wall into brown IFM is mainly realized by illuviation of the light-coloured sandy-silty mass from the fissure into exped crevice-like pores of the IFM. The light-coloured material from a fissure penetrates into the brown IFM forming deep "sprouts" growing from the fissure wall and merging gradually into the light-coloured skeletans on IFM ped faces. Some brown peds adjacent to fissures are "cut" of the IFM and included into the fissure. Direct eluviation along fissure walls is of secondary importance.

The light-coloured FI of fissure zone II is apparently of an illuvial-suspensional origin. It is mainly the skeletal material of the upper horizons A2, A2B1 which are eluviated, poor in plasma and grain argillans and lack a water-stable structure. This material is translocated in the state of suspensions and forms light-coloured FI in fissure zone II. Very important are brown material eluviation processes occurring along and within fissures directly in this zone resulting in residual bleached or light-coloured material. Another possibility of origination of light-coloured material - simple sinking from above is not entirely ruled out, although it seems to be weak.

As a whole, fissure zone II is characterized by the predominance of illuvial accumulation of suspensions which bring sandy-silty material already eluviated, rich in SiO_2 (quartz) and poor in R_2O_3, from the A2 and A2B1 horizons. Accumulation of the material from clay suspensions and humus-iron solutions is more vigorous than in the first zone, but is still of secondary importance in the formation of FI.

Fissure zone III embracing lower part of $B2_1t$, whole $B2_2tg$ and upper part of $B3_1tg$. Here, fissures become still narrower and form an angular polygonal pattern on the horizontal cross-section.

Fissure infilling features a distinct cutanic orientation along fissure walls and consists of several types of vertical interstratified cutans; "cutting" of brown IFM peds from fissure walls and their inclusion into FI is rare. Fissure infilling is composed mainly of greenish-gray gleyed and light brown silty loamy cutans consisting mainly of silty light-coloured quartz-feldspar grains with an admixture of bleached light gray coarse scaly argillaceous plasma. The whitish gray sandy-coarse silty material characteristic of the FI of the first two zones is less abundant here and forms rather rare and most bleached skeletans. Quartz and feldspar grains are leached weaker than in the above lying fissure zones, falcate argillaceous light yellow cutans occur on the skeleton grains.

The number and thickness of argillaceous dark brown and red brown anisotropic cutans of fluidal and falcate shape with a distinct continuous orientation pattern increase in this zone. Argillans are repeatedly interstratified with gleyed silty and light-coloured sandy cutans. Dark brown argillans usually cover the fissure wall proper at the contact with the IFM. A grayish pale brown or bluish-greenish transitional zone with elements of pedal fabric is formed in the fissure zone adjacent to the brown IFM of the B2 and B3 horizons. This zone, changed because of its proximity to the fissure, is light-coloured, depleted in iron hydroxides and rather enriched in pale brown clay. Such transitional zones between IFM and FI are apparently formed from the material of brown IFM in situ (unlike FI cutans) due to iron reduction, gleyification and removal and to illuviation of clay brought along the fissures into the contact pale brown zone.

The morphology and genesis of FI in this zone are radically different from those of zones I and II. The "aggression" of fissure walls into the IFM with cutting and subsequent eluviation and destruction of brown peds within fissures almost ceases here, being replaced by coating of the fissure walls with illuvial-suspensional argillans and near-fissure IFM gleyification with iron leaching and accumulation of the illuviated clay penetrating in the fissure walls.

Fissure infilling proper is formed through processes of clay and silt migration in suspensions and their illuvial accumulation in the form of distinct vertical interstratified cutans within fissures. Migration and accumulation of sandy-coarse silty suspensions are much weaker. In this way, the illuviated material is heterogeneous; 1) clay enriched in R_2O_3, 2) sandy-silty, mainly quartz-feldspar material, rich in SiO_2, eluviated and removed in suspensions. This zone is also noted for the appearance of distinct within-fissure gleyfication of cutans which contributes to iron reduction and its removal along fissures and thus establishes a within-fissure eluvial-gley regime.

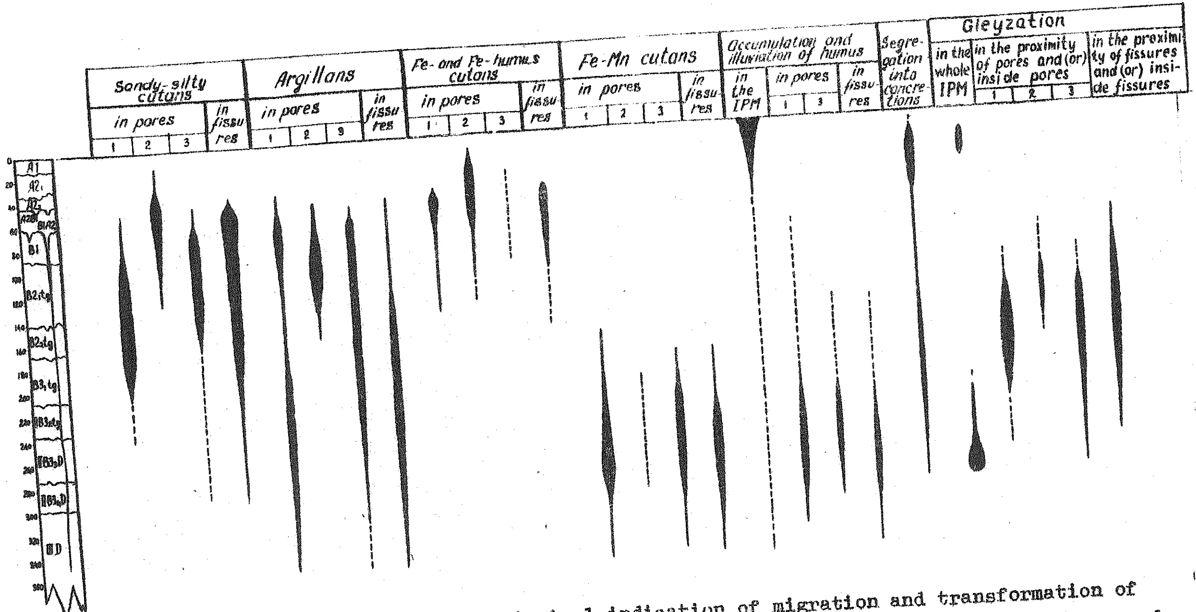
Fissure zone IV embracing lower part of $B3_1$tg,$IIB3_2$tg and $IIB3_3$D. Fissures become narrower,their number is smaller in the upper part of the zone as compared with the lower one. FI is composed mainly of interstratified bluish-greenish gleyed loamy and dark brown argillaceous and clay-humus cutans. The clay substance of these cutans is fine dispersed,has a distinct stream-like (fluidal) fabric and high birefringence. In gleyed cutans,clay is light-coloured or gray-greenish,in dark brown cutans it is enriched in humus and iron. Black red and red yellow patchy isotropic ferruginous-manganic cutans appear among mainly silicate cutans of this zone. In the central part of fissures very few fine sandy-silty light-coloured cutans occur with a scaly argillaceous plasma and clay films on skeleton grains. Brown IFM outliers are absent within fissures,while the IFM adjacent to fissures is locally light-coloured and gleyed,depleted in iron and enriched in clay.

There is a considerable accumulation of fine dispersed loamy-argillaceous suspension material in this fissure zone as well as gleyification along some of the cutans accompanied by eluvial-gley iron leaching. At the same time oxidized iron and manganese accumulation from solutions proceeds simulteneously here.

Fissure zone V embracing $IIB3_4$D and IIID. Fissures here are the narrowest,they are filled with mainly dark brown,sometimes black brown humus-argillaceous cutans,consisting of the finest dispersed clay material and dark dispersed humus. Bluish-greenish gley loamy cutans are very rare,but the proportion of isotropic manganic ferruginous cutans,black red or bright yellow in colour,increases. Fissure limits are distinct,the red brown IFM adjacent to fissures is not gleyed.

The FI of this zone is formed due to : a) illuvial accumulation of the finest silicate argillaceous material brought in suspensions; b) accumulation of humus brought in solutions and probably in suspensions in combinations with clay minerals; c) oxidized iron and manganese accumulation probably related to contact phenomena in the zone of lithological discontinuity.

Summing up the description of fissures in the investigated profile,a rather complicated but a distinct differentiation of substances filling the fissures should be emphasized. The IFM horizons do not coincide with the zones of FI, so that the "FI profile" proves to be replaced far downwards as compared with the IFM profile : the FI zo-



F i g. 3. Macro-, meso- and micromorpological indication of migration and transformation of substance in the sod-pale-podsolic soil, profile 2-71. 1 - inped pores; 2 - horizontal exped pores; 3 - vertical exped pores nes enriched in light-coloured, SiO_2 and quartz-containing sibstances, occur in those IFM horizons, where bleaching and eluviation decrease or stop whatsoever, being replaced by clay illuviation along ped faces (BI, $B2_1t$, $B2_2tg$). FI zones accumulating clay, iron, manganese and humus are situated in the IFM horizons with a decrease or even absence of illuvial accumulation of these soil components ($IIB3_2tg$, IIB3D, IIID). Comparing the average width of fissures within the profile and their average number (Fig.2) it may be concluded that the maximal "capacity" of observed nowadays fissures acting as accumulators of the illuviated suspension material is characteristic of fissure zones II and III, i.e. of depth 60-140(180) cm. It is here that the relation between the average number and mean width of fissures is optimal. The "capacity" of fissures falls considerably with depth because of the decrease of their mean width.

C O N C L U S I O N

This work is devoted to macro,-meso-and micromorphological study of sod-pale-podzolic soil which has revealed a complex combination of various elementary processes forming individual profile horizons and the entire profile. It has been found that all (or almost all) horizons in the profile studied consist of meso-and microlocal regions (meso-and microzones) which exhibit features of different processes which at first sight may appear even incompatible. The combination of the morphological features of migration and transformation of substances in various meso-and microzones of horizons and their profile distribution are given in the general diagram of Fig.3.

A detailed morphological investigation seems to us to appreciably increase the number of features and corresponding elementary processes which should be used for constructing a genetic model of formation of sod-podzolic soils on mantle loams.

Contents

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Заказ 1136. Тираж 800 экз. Цена 30 коп.