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Micromorphology, chemical and mineralogical composition of hydromorphous soils in the taiga zone

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Mineral hydromorphous soils (soddy-podzolic soils with different gleyzation rate and soddy-gley soils) are widely spread in the taiga zone. The attention, paid to the study of genesis of hydromorphous soils, is explained not only by their wide distribution, but also by peculiarities of soil processes, occurring under excessive moistening.

Many scientists have discovered peculiarities of swamping at their investigations [1, 2, 5], but these peculiarities mainly refer to soils in the state of an intensive gleyzation. Variations in the microstructure and properties of soils subjected to a gradual swamping have not yet been properly studied. Various forms of gley process manifestation under surface and ground water moistening are not sufficiently investigated.

The present paper is aimed to make a detailed investigation of the peculiarities of microstructure, composition and properties of mineral hydromorphous soils at different swamping rate and to discover possible objective characteristics of the rate and the type of moistening.

The studied soils are developed in temperate-continental climate characterized by the following features: mean annual temperature is about +4°C, mean annual precipitation ranges within 550-720 mm with its maximum in the warm period (June—October). Soils refer to areas with a poor drainage capacity (flat plains, shallow depressions), characterized by a regular stagnation of surface water or relatively high ground water table. The prevailing vegetation comprises coniferous forests (fir, pine) with a small percentage of deciduous species (birch, maple, aspen). At present mineral hydromorphous soils are mainly occupied by different meadows, some areas are cultivated.

The investigation of waterlogged soils was undertaken according to soil-geomorphological series, providing to follow the transition from the earlier stages of swamping to soils of permanent excessive moistening. These series were selected under the conditions of surface moistening and under moistening by hard ground waters on varve clays and carbonate boulder loams of Ilmen Lowland and Valdai Hills (Novgorod region).

Regular or permanent moistening is essential for development of waterlogged soils with the critical moisture content of all the soil horizons.

Surface over-moistening covers biologically active upper horizons with the major portion of plant roots, which causes a rapid occurrence and intensive development of reduction processes.

The formation of soils at the initial stage of superficial gley occurs at a sharp alternation of periods of excessive moistening and moisture deficit. The contrast of the expression of oxidation and reduction features results in the accumulation of the most active and free forms of the organic matter. The humus mainly comprises brown humic acids and aggressive I-a, I fractions of fulvic acids. As surface swamping proceeds, the total humus content tends to increase in the upper horizons. Humus accumulation mainly occurs due to humic acids, in this connection the ratio $C_h : C_f$ exceeds 1. The over-moistening and anaerobiosis of soils, however, prevent condensation and formation of humic acids of a complex structure: humic acids are characterized by low value of optical density and a wide ratio $E_4 : E_6$.

In waterlogged soils humus accumulation is indicated through a microscope by the change of the colour of humus horizon from dark grey appropriate to soils of short over-moistening up to dark brown, almost black — in strongly gleyed soils. Micromorphological investigations of sections from horizon A_1 of soddy-podzolic-gleyed soil showed, that humus is evenly diffused in the form of small point accumulation. In large pores plant residues of different rate of decay occur. The organic matter is slightly mixed with the mineral mass. It may, probably, explain a poor aggregation of the humus horizon. As swamping proceeds, humification of plant residues tends to increase; the organic matter is more closely connected with argillaceous plasma of the horizon and serves as a connecting agent at the formation of small aggregates. In severely waterlogged soil (soddy-gley soils) humus has a mull structure, which stipulates a proper aggregation of horizon A_1.

The development of surface over-moistening causes considerable variations not only in the organic part of soil, but also in the composition of their mineral mass.

By fostering the formation of water-soluble compounds of low molecular weight [3] and free organic acids, the superficial gley causes an acidic reaction of the upper horizons. Acidification and intensive development of reduction processes increase the chemical activity of mineral soil components. The experiments of Siuta [4] showed, that under such conditions the compounds of iron, magnesium and other elements are transformed into more soluble forms and are washed away very effectively. At the inital stages of superficial swamping an intensive eluviation of

Table 1. Some analytical data for excessive soil moistening by surface water

Rock	Soils	Genetic horizon	Depth cm	pH salt KCl	Absorbed bases $Ca^{++}+Mg^{++}$ m-equiv/100 g	% Saturation	Total amount C, %	$\frac{C_h}{C_f}$	% Content of particles $<1\ \mu$	Total content, % SiO$_2$	Total content, % Al_2O_3	Total content, % Fe_2O_3	Total content, % CaO	Total content, % MgO	Free forms, mg/100g H_2SO_4 extract FeO	Free forms, mg/100g H_2SO_4 extract Fe_2O_3
Varve clay	Soddy-podzolic gleyed	A_1g	0-10	4.23	11.50	48.7	2.90	1.04	19.6	74.65	16.95	3.85	1.25	1.70	28	711
		A_2g	19-27	4.25	6.96	55.0	0.53	0.56	16.4	72.41	14.73	6.09	1.19	1.74	14	526
		A_2B_1g	30-40	4.50	12.15	70.8	0.39	0.50	37.2	67.42	19.19	6.51	1.21	2.42	6	798
		B_1	50-60	5.75	18.90	86.7	0.033	0.31	41.4	66.72	18.54	6.98	1.28	2.62	4	797
		C	110-120	6.80	24.56	88.2	—	—	35.1	64.91	19.66	6.94	1.63	2.82	4	567
	Soddy-podzolic gley	A_1g	0-10	4.14	14.10	40.5	8.28	1.51	20.6	70.84	22.02	2.57	1.24	1.72	162	810
		A_2g	21-31	4.22	7.52	50.6	0.97	0.37	18.8	71.81	18.01	4.87	1.26	1.75	17	530
		B_1g	50-60	4.60	23.50	83.6	0.25	0.20	40.8	65.66	20.69	7.16	1.21	2.53	12	740
		Cg	110-120	6.40	25.38	87.2	—	—	36.6	64.95	22.12	6.37	1.74	2.69	5	545
	Soddy-gley	A_1G	0-10	3.99	10.71	24.4	10.47	1.88	26.9	69.04	23.09	3.27	1.05	1.48	193	950
		B_1G	20-30	4.04	11.70	69.0	0.48	0.31	28.8	69.77	20.52	4.12	1.26	2.00	45	535
		B_1G	30-40	4.23	19.80	83.1	0.10	0.19	36.4	66.59	20.26	7.55	1.19	2.08	40	770
		B_2G	50-60	4.84	22.50	92.8	—	—	37.9	66.75	21.15	7.51	1.20	2.40	—	—
		CG	110-120	5.47	22.50	95.7	—	—	36.1	66.72	19.86	6.61	1.56	2.22	—	—

iron, manganese, calcium and magnesium occurs. It should be noted, that a maximum content of free iron is observed in the upper horizon though total iron is low in such soils (Table 1). As oxidation occurs, the elements of alternating valency are deposited and fixed as concretions. At the superficial gleyzation segregations and concretions of these elements are observed from the very surface. In the humus horizon the concretions are small and loose. The maximum concretions occur at the bottom of the eluvial horizon. They are compact, orbicular, with definite edges and are isolated from the soil. As the rate of moistening proceeds, the decrease of concretions number is quite evident, their shape changes: it is less definite and loose.

The analysis of the chemical composition of concretions showed their considerable enrichment by humus (up to 2%), by manganese, phosphorus, iron; and about 70% of iron in concretions is in a free form. It testifies once again a high migration capacity of mineral and organic compounds at surface moistening.

A considerable acidity and reduction conditions serve as an important factor of chemical variations of silicate minerals. At initial stages of superficial swamping a peptization of argillaceous matter and its differentiated eluviation occur. This process is displayed in the formation of red-brown tongues of optically oriented clay in pores and fissures of illuvial horizons. Narrow fissures and thin pores are often completely filled with homogeneous collomorphic argillaceous matter (Fig. 1).

X-ray investigations prove heterogeneity of soil horizons in respect of argillaceous minerals. In the eluvial horizon at the intensive migration of elements and a high aggression of the medium there takes place a partial transformation of hydrous mica into non-swelling hydrous-mica-

Fig. 1. Filling of clefts by homogeneous collomorphic clay in the illuvial horizon of soddy-podzolic gleyed soil of surface moistening. Magnif. ×130, Ni X.

vermiculite minerals (11.4 Å, 12.6 Å) and into vermiculite (14 Å). The transport of argillaceous minerals, however, with the percolating water leads to a relative accumulation of kaolinite and finely-dispersed quartz in this horizon, as well as a decrease of hydrous mica minerals. Hydrous mica, mixed-layer minerals, being the most hydrophilous ones, are transported into the illuvial horizon and here they are accumulated in the form of optically oriented separations.

Ground swamping is characterized by specific peculiarities, which make it different from gleyzation occurring in the upper part of the profile. Soils of ground over-moistening are formed under the influence of rising fluxes from more or less permanent aquifer. In these soils the gleyzation starts from the lower part of the profile where microbiological processes are hindered, and it is rather stable.

Swamping by ground water is accompanied by neutralization of upper horizons of the soil profile. Soils are characterized by a high rate of base saturation.

As the role of excessive moistening of these soils proceeds, as in case of superficial swamping, the accumulation of organic matters tends to increase. Organic acids connected with calcium prevail in the humus composition. The amount of mobile fractions of humic and fulvic acids is not great.

The fractional composition of humus is reflected in its microstructure and in the microcomposition of the humus horizon. The microstructure of the humus horizon in soils of ground water swamping is characterized by a certain ferrugination of plant residues and products of their decay. Humus micro-tissue becomes brownish under the influence of ferric oxides. Humus is less mobile, in some places it has the features of micro-coagulation. With the increase of ground water table a gradual transformation of humus forms from moder to mull occurs, the aggregation of the humus horizon is improved. (Fig. 2).

Ferric accumulation in the upper horizons and its eluviation from lower gleyed ones is a peculiar feature of ground water swamping. Besides iron, the accumulation of calcium, aluminium and manganese (Table 2) occurs in the upper horizons, it is caused by the inwash by ground water and by the accumulating capacity of plants.

Ferric new formations in given soils are found mainly in the horizon of ground water fluctuations and create blurred flocculent formations (Fig. 3).

At ground water swamping the argillaceous matter is less dispersed than in soils of surface moistening. Differentiated transference of argillaceous mass is not considerable: separation of collomorphic material is isolated. The transference of argillaceous mass with descending fluxes of water prevails, this mass is not differentiated by the size and is marked

Table 2. Some analytical data for excessive soil moistening by ground water

Rock	Soils	Genetic horizon	Depth, cm	$\frac{PH}{KCl}$	Absorbed bases Ca^{++} + Mg^{++} m-equiv /100 g	% Saturation	Total amount C, %	$\frac{C_h}{C_f}$	% Content of particles < 1 μ	Total content, %					Free forms, mg/100 g H_2SO_4 extract	
										SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	FeO	Fe_2O_3
Carbonate boulder loam	Soddy-podzolic gleyed	A_1	0-10	5.76	21.40	76.2	2.94	1.08	12.63	81.69	11.10	2.44	1.73	1.45	23	424
		A_2	26-35	6.59	13.64	68.4	1.24	0.91	9.30	82.54	10.82	3.15	1.54	1.56	9	351
		B_1	60-70	6.74	17.05	72.2	0.12	0.11	24.83	77.54	14.13	3.84	1.36	1.88	14	306
		Ckg	90-100	7.35	—	—	—	—	21.61	76.00	12.30	3.82	4.57	1.62	16	274
	Soddy podzolic gley	A_1	0-10	5.90	35.30	87.4	8.35	1.74	19.55	76.16	14.11	4.33	2.22	1.21	49	783
		A_2	26-35	6.47	15.50	92.6	1.86	1.01	14.77	77.12	12.85	5.53	1.54	1.60	15	414
		B_1g	50-60	6.57	20-86	95.4	0.16	0.21	25.16	76.63	13.72	3.65	2.10	1.72	25	371
		CG	90-100	7.11	—	—	—	—	22.50	76.43	12.54	3.27	4.43	1.70	27	335
	Soddy-humic-gley	A	0-10	5.63	71.60	92.6	17.42	1.88	21.46	74.75	15.16	4.69	9.21	1.65	105	815
		A_1B_1G	40-50	6.17	13.05	87.3	0.26	0.84	21.78	78.63	13.51	3.09	1.37	1.34	65	413
		B_1G	50-60	7.00	16.70	88.7	0.14	0.17	22.45	78.55	13.80	2.30	2.11	1.71	42	397
		Ckg	90-100	7.33	—	—	—	—	22.32	78.64	12.68	2.98	3.77	1.99	20	331

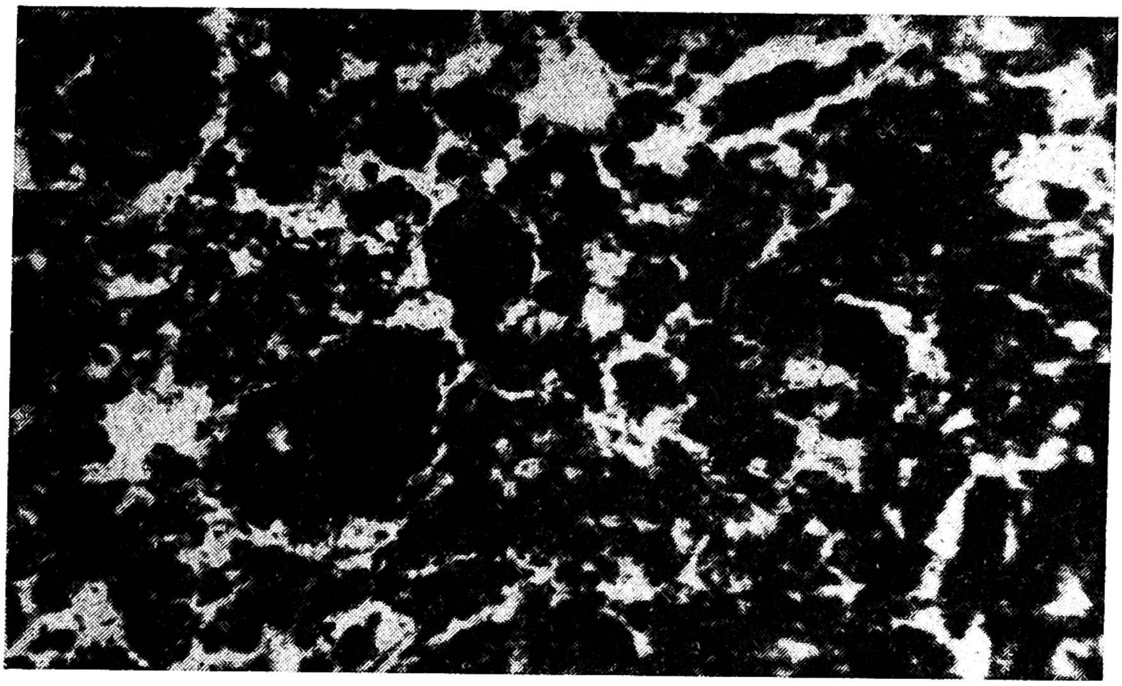

Fig. 2. General view of humus horizon of soddy-podzolic gley soil of ground water moistening. Magnif. × 50, Ni II.

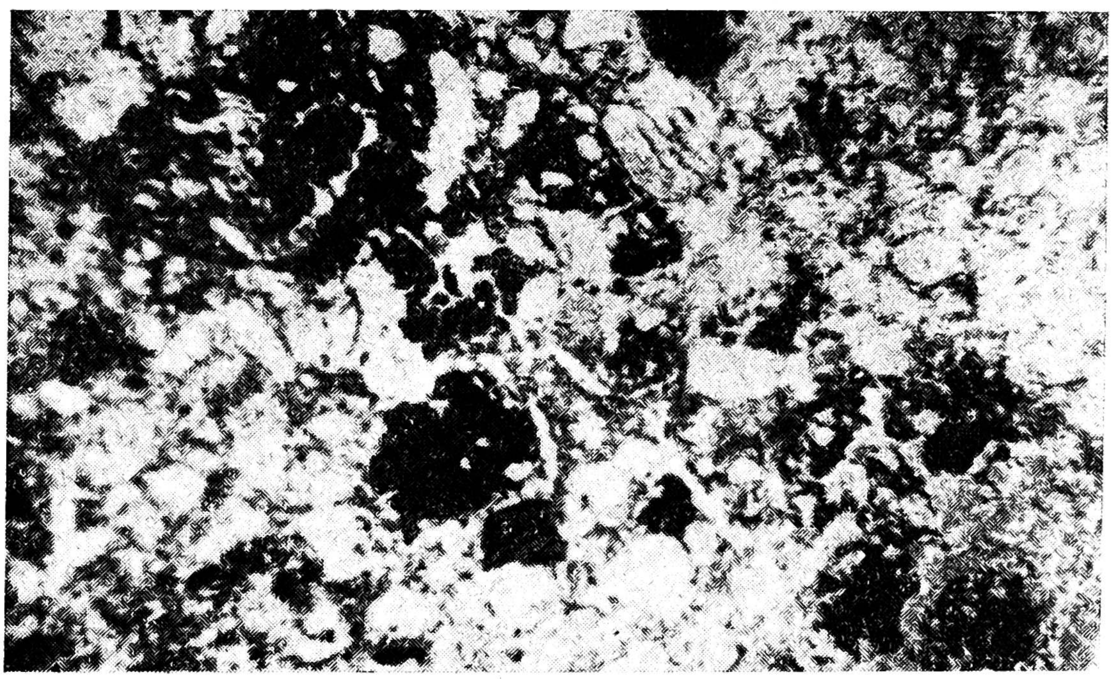

Fig. 3. Separation of ferric oxides in the form of clots in horizon A_2g of soddy-podzolic gley soil. Magnif. ×50, Ni II.

in the form of tongues over the surface of primary minerals and in the pores of the illuvial horizon (Fig. 6). The orientation of particles in these tongues is less perfect, it testifies heterogeneous blackening and bleaching of individual microzones. The argillaceous fraction comprises hydrous mica, hydrous-mica-vermiculite minerals, kaolinite.

In soddy-podzolic gleyed and gley soils of ground water swamping the distinctions between genetic horizons according to the nature of associations of argillaceous minerals are less evident, in comparison with corresponding soils of superficial gleyzation.

At the intensive swamping of soils by surface and ground water at the stage of formation of soddy-gley, soddy-humic-gley soils the migration of chemical elements does not occur.

In the given soils concretions are not formed. The separation of ferric oxides is concentrated near the pores, channels of roots, fissures in the form of brown-red stains (in the reflected light), diffusion rings (Fig. 4). In gleyed microzones ferric protoxide causes the greenish colour of the argillaceous plasma.

At the intense gleyzation the removal of finely dispersed mass from upper horizons does not occur. Gley soil is characterized by an even distribution of argillaceous fractions over the profile. In the given soils the optically oriented accumulations of clay in the form of tongues are not

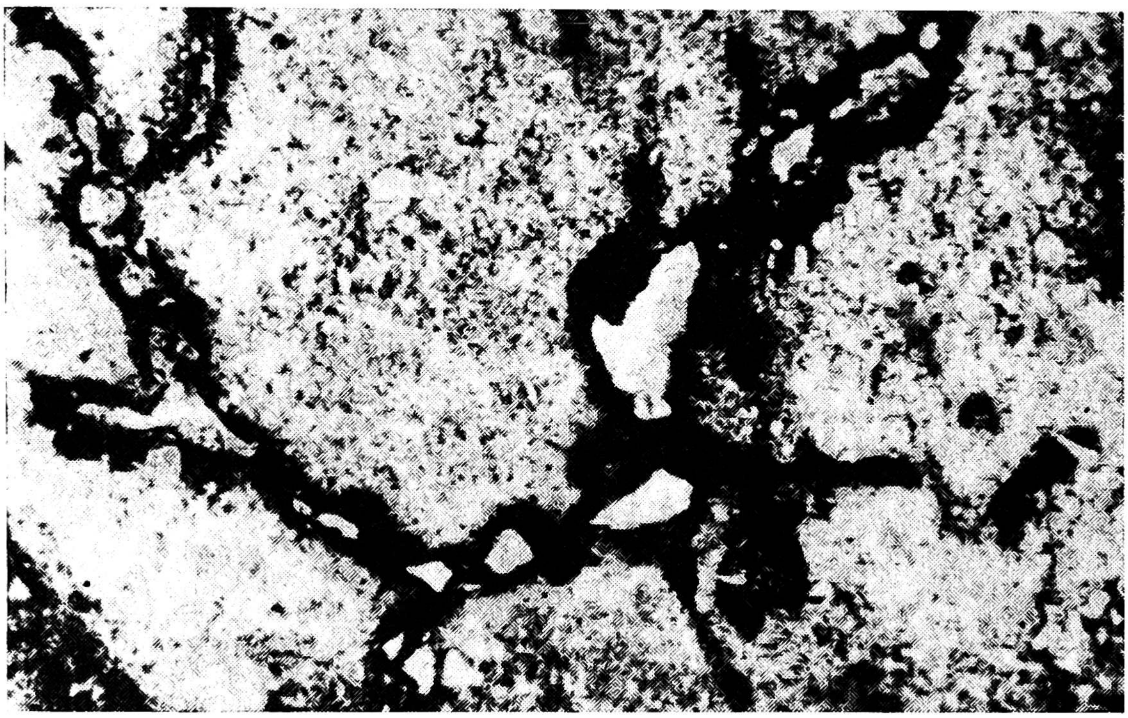

Fig. 4. Separation of ferric oxides along the root passages and pores of soddy-gley soil of surface moistening. Magnif. ×50, Ni II.

observed. The coatings of oriented clay over the sides of fissures are not thick (0.02-0.01 mm). The bulk of the argillaceous mass of soil polarizes in the form of fine scales and fibers (Fig. 5).

Fluid location of the oriented clay probably results in the slow local motion inside microzones. Brewer [6] states, however, that a similar orientation of argillaceous particles may occur at weathering with a subsequent swelling (at moistening) and compression (at drying). The oriented clays differ by the colour as well: they are transparent or stained into light yellow with a greenish tint. The lack of dislocation of the argillaceous mass along the profile of strongly swamped soil stipulates a homogeneity of mineralogical composition of argillaceous fractions in all the genetic horizons. In the given soils mixed-layer formations of hydro-mica-montmorillonite type prevail. The appearance of montmorillonite is observed sometimes. Hydrous mica and kaolinite content is not considerable.

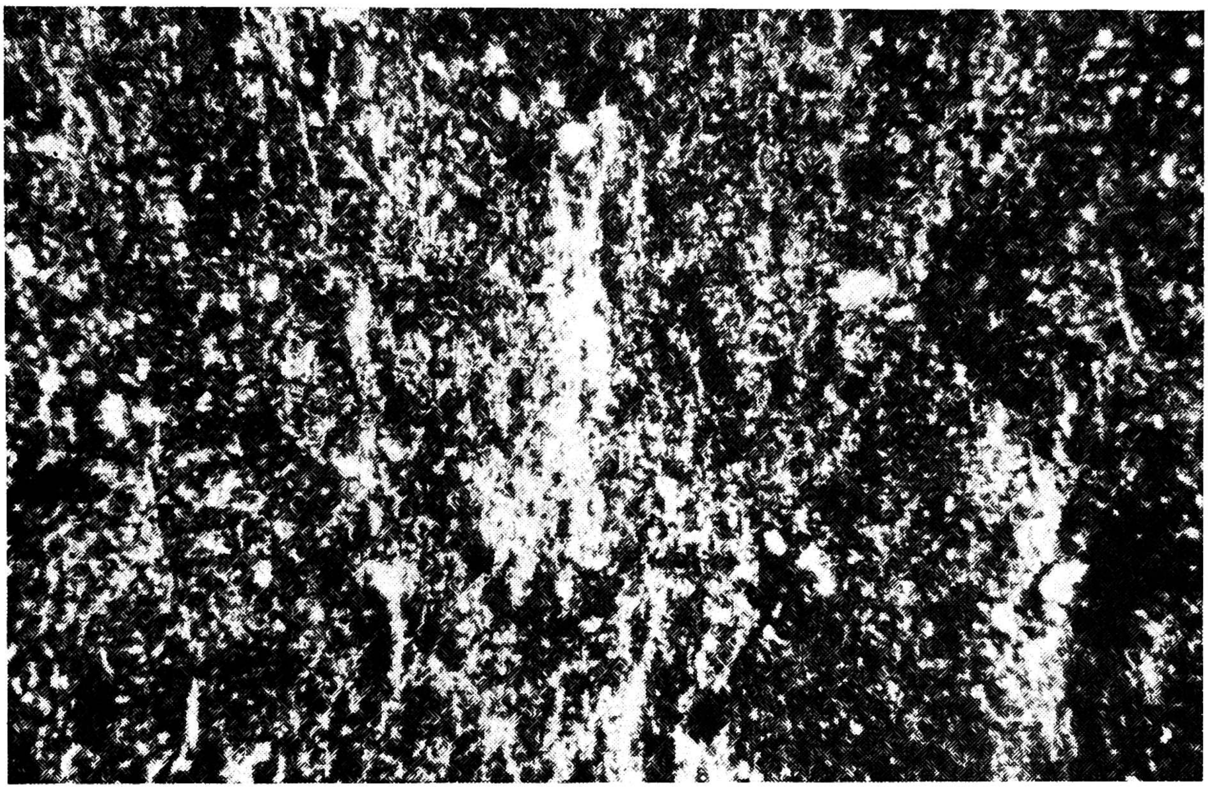

Fig. 5. Fluid orientation of argillaceous particles in horizon B_1G of soddy-gley soil. Magnif. ×130, Ni X.

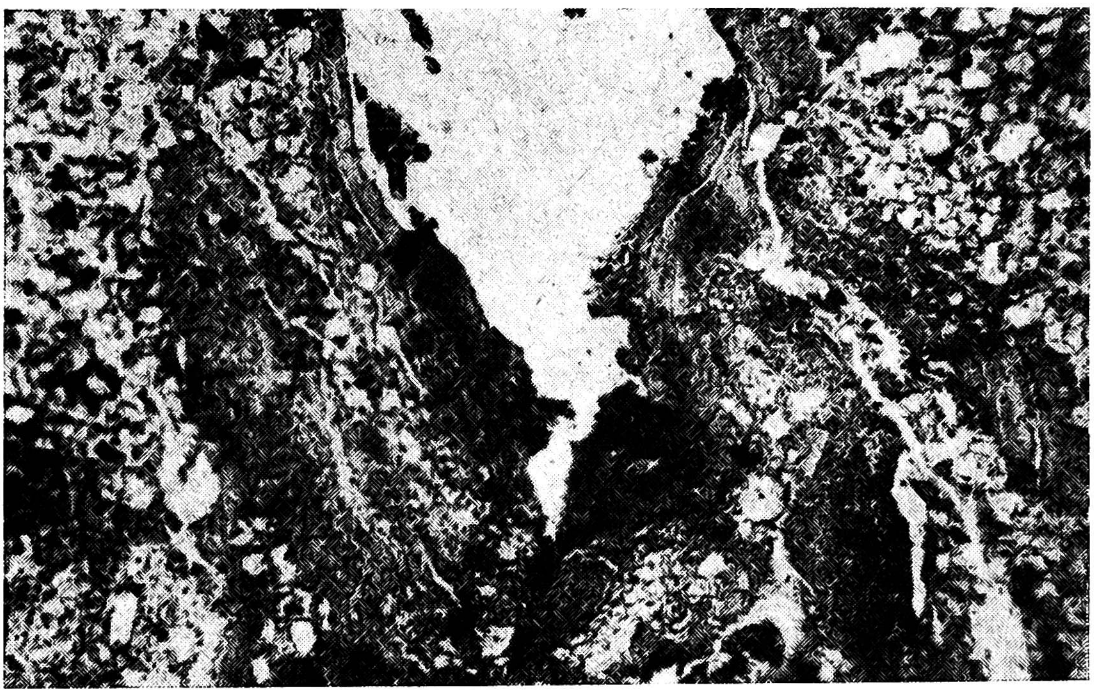

Fig. 6. Separation of weakly differentiated argillaceous matter in the pore of the illuvial horizon of soddy-podzolic gleyed soil of ground water moistening. Magnif. ×150, Ni II.

The formation of montmorillonite and mixed-layer minerals of montmorillonite type in gley soil is caused by the stagnant regime, by low velocity of removal of decay products from the reaction sphere, by concentration of magnesium and calcium, by a high ratio of silica and aluminium.

Finally, a general peculiarity of microstructure of hydromorphous soils should be mentioned — combination of microzones of an intensive reduction and oxidation and smooth transition between them. Zones of intense oxidation of compounds of sesquioxides are observed mainly in pores, fissures and at the plant roots. The compounds R_2O_3 are amorphous, red-brown, in the periphery part of formations they are light green. It testifies a different oxidation rate of ferric compounds. Reduction zones have a transparent plasma and solid microstructure.

The combination of bluish and rusty stains and their location in the profile serves as a diagnostic feature of hydromorphous soils of different moistening. In soils of surface moistening a sharp change of excessive moistening and drainage stipulates a heterogeneous staining of soil horizons A_2g, B_1g. In soils of ground water moistening stains are observed in the lower part of the profile.

CONCLUSION

The performed investigations showed, that every soil type has a corresponding micromorphological structure. The increase of moistening is accompanied by a transformation of humus forms, by an increase of aggregation rate of the humus horizon, by the change of content, by forms of separation and by the colour of the oriented argillaceous matter.

Under the influence of the intensive swamping the form and the number of new formations are changed, the size of reduced microzones is increased.

According to general regularities of the variations of soils microstructure at the occurrence of swamping the nature of manifestation of individual micromorphological features depends on the type of moistening.

The mentioned micromorphological characteristics in combination with analytical data may be applied for diagnosing of the swamping rate and its development.

The comparison of given analytical data shows that soils of superficial gleyzation and soils of ground water swamping are quite different, though they have some feature in common.

These common features of soils, increased as the gleyzation rate proceeds, should be considered as follows: organic matters accumulation in the upper horizon, the presence of humic acids in its composition; the presence of a considerable amount of ferric protoxides in all the horizons; a considerable concentration of free iron in the humus horizon.

Distinctions in waterlogged soils, stipulated by the type of moistening and peculiarities of local features, are revealed by the changing of such chemical indices as reaction of the medium, qualitative composition of organic matters, distribution of chemical elements over horizons.

The transformation of argillaceous minerals in hydromorphous soils is stipulated by the conditions of the hydrological regime.

SUMMARY

Series of mineral hydromorphous soils formed under surface and ground water swamping have been studied.

Definite micromorphological variations of soils, stipulated by the increase of moistening rate, have been discovered. The development of swamping is accompanied by the variation of content, structure and colour of the oriented clay, the amount and forms of ferruginous separations, transformation of humus forms and improvement of the structure of the humus horizon.

Certain interrelations of micromorphology and chemistry of soils and mineralogical composition of their argillaceous fractions have been followed.

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