THIRD INTERNATIONAL WORKING-MEETING ON SOIL MICROMORPHOLOGY
WROCŁAW, 1969

ZESZYTY PROBLEMOWE POSTĘPÓW NAUK ROLNICZYCH 1972 z. 123

Comparative characteristic of fabric components in some chernozems of the U.S.S.R.

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After Kubiëna's detailed [11] studies of certain chernozems fabrics only few micromorphological characteristics of different representatives of this extensive soil type appeared in the literature. We have obtained some data on micromorphology of chernozems from different regions of the U.S.S.R., and from one and the same region but under different parent rock, topography, vegetation and so on. Here we shall consider only a part of our study of those fabric components which are under most strong effect of the soil forming process.

SOILS INVESTIGATED

1. Typical thick medium-humic heavy loam chernozem of the Central Russian highland forest-steppe developed on a loess loam. Variants with normal, heightened and lowered effervescence under natural grassy-heteroherbaceous vegetation, lightened oak-woods (central chernozem state reservation) and under crops (Kursk regional state agricultural experimental station).

2. Deeply leached chernozem on the lower part of a northern slope in the field of the same experimental station.

3. Podzolized meadow-steppe medium thick medium humic heavy loam chernozem on a loess-like loam (Moscow region). Plough-land and under coniferous and desiduous forests.

4. Ordinary heavy-loam steppe chernozem on a loess-like loam (Zaporozhye, Ukrainian S.S.R.). Plough-land.

5. Ordinary medium thick, medium humic loamy chernozem under rich heteroherbaceous steppe vegetation on loess-like loam (Altai province, Ob river plateau). Virgin land.

6. Southern heavy loam chernozem on a loess-like loam (Zaporozhye, Ukrainian S.S.R.). Plough-land.

7. Southern chernozems of the dry-steppe zone of Transvolga Syrt,

loamy on triassic rocks eluvium, clayey on a brown syrt clay (watershed) and on an ancient alluvial loam (terrace). Plough-land.

8. Southern medium loam and clayey, slightly solonetzic, calcareous on loess-like deposits (Kazakhstan, Kustanai region). Virgin and plough-land.

9. Southern solonetzic chernozem on clayey eluvium of Jurassic rocks (Transvolga Syrt). Plough-land.

10. Compacted chernozems on tertiary clays (Stavropol province). Plough-land.

Field descriptions of these soils and their analytical results can be found in papers listed in the references.

MICROSTRUCTURAL CHARACTERISTICS

They depend upon the kind of parent rock and bioclimatical conditions. Chernozems developed on the loess-like loams have a coherent spongy fabric described by Kubiëna [11]. It is best of all expressed in typical thick chernozems under natural vegetation (Fig. 1). The coalesced earthworm droppings forming it preserve to a greater or smaller degree their roundish form. The sponginess of the soil mass is formed by numerous biogenic pores as well as by smaller pores between the simple microaggregates composing the compound ones.

The biogenic pores are for the most part filled with destroyed earthworm casts and excrements of *Enchytraeidae* more or less aggregated. Those microaggregates consist predominantly of humus or of the material of the surrounding soil as it was found by Zachariae [20] and Babel [4]. According to Ghilarov's [7] determinations *Enchytraeidae* prevail over the *Lumbricidae* in chernozems of Kursk region.

The transition horizon (after humus) is characterized by an uneven distribution of the dark humus in the light coloured parent material which gradually becomes predominating. This results in an unequal aggregation degree in different parts of it. There are also many biogenic pores with soil mesofauna excrements. In the less altered calcareous material of the parent rock clay nodules (ooides) characteristic of loess-like loams are distinguished, their size is for the most part 0.1-0.3 mm. Due to an intensive and deep burrowing of the chernozem there are found dark coloured excrements in its lower part and casts consisting of the parent material in the upper.

Other chernozems on loess-like loams show generally the same microfabric. In strongly leached and podzolized chernozems biogenic aggregates are more runned into greater (up to 5 mm) angular clods poor in pores separated by biopores and fissures. Smooth protrusions at the surface of some of them show that they are formed of a coalesced excreta. In the lower part of the humus horizon the walls of some biopores interspersing the dense soil mass are impoverished in plasma and built up mainly of skeleton grains forming the so-called "siliceous powder". In this horizon numerous argillans appear, which enlarge in the transitionary horizon.

In ordinary and southern chernozems the roundish aggregates forming the spongy soil mass and the biogenic pores are of lesser sizes in the upper horizon than in the typical chernozem (for the most part 0.5-0.7 mm) and are rather looser. This is especially expressed in the chernozem of the Altai province where the aggregates are composed of roundish and irregular microaggregates (0.02-0.2 mm) separated by a network of fine pores; the smallest of them are humus-clayey clots or mineral grains covered by organo-argillans.

Fig. 1. Spongy biogenic microfabric of the humus horizon of typical thick heavy-loam chernozem, Kursk region (×100).

In the lower part of the humus and transitional horizons the earthworm burrows reach 2 mm in diameter. There are many areas of spongy fabric composed of enchytraeid excrements partly joined with each other.

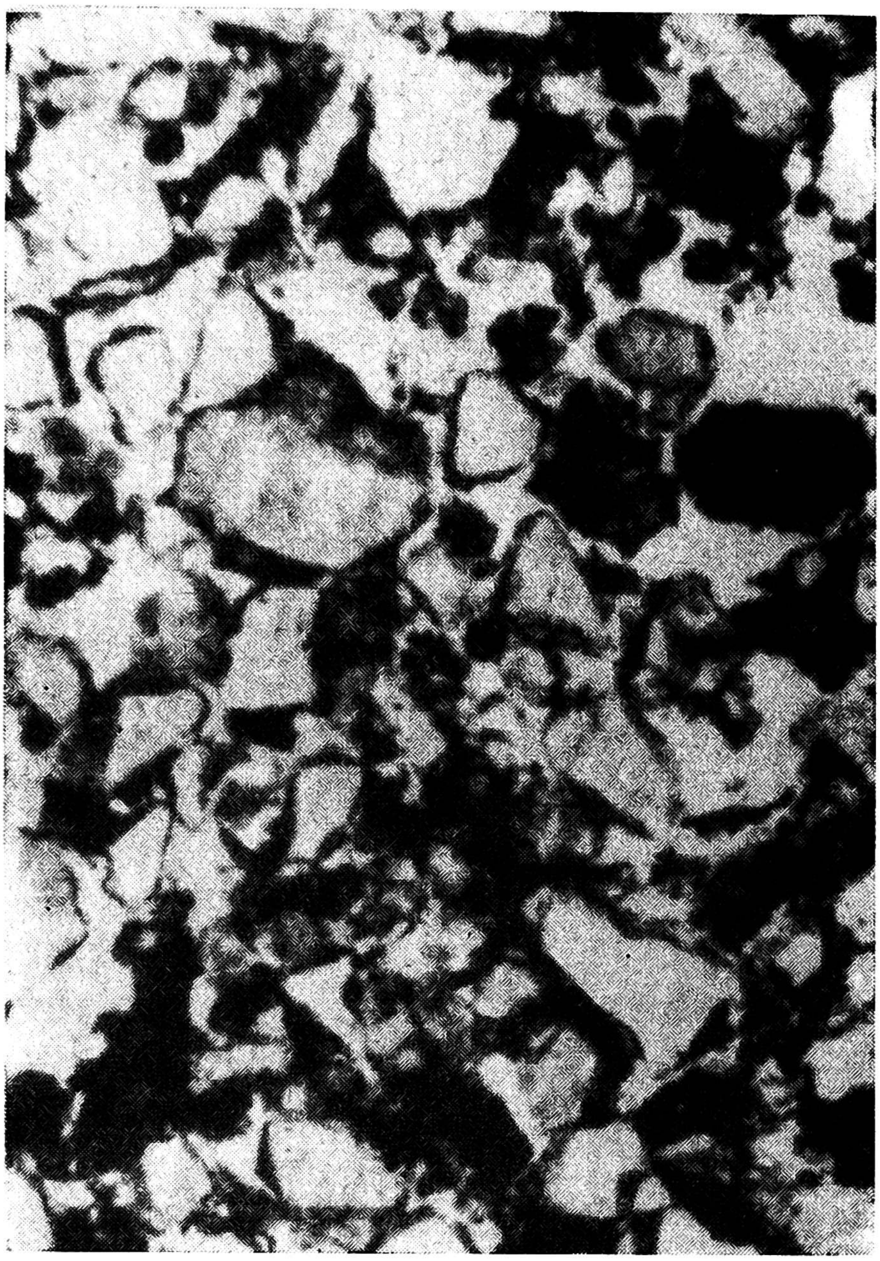

Fig. 2. Agglomeratic microfabric of the humus horizon of a southern sandy-loam chernozem, Kustanai region (×100).

The fabric of calcareous southern chernozems is less coherent, the aggregates being more separated as the result of splitting effect of microgranular calcite efforescences. In the case of low humus content in these soils and its uneven distribution (for example in southern clayey chernozem) compact angular cleavage blocks are formed in addition to roundish microaggregates in places poor in organic matter.

A sharp alteration of microfabric is observed in southern chernozems of the Kustanai and Transvolga Syrt regions with a considerable content of sandy particles (50% and more), where it becomes agglomeratic. Here the small humus-clayey microaggregates (for the most part less than 0.1 mm) are situated in interspaces, between the grains of primary minerals, often exceeding them in size, which are covered by cutans of clay-humus material (Fig. 2). Such a fabric is characterized by small voids (no more than 0.2 mm). The mineral grains and aggregates are loosely bound together and this explains the erodibility of such chernozems.

A compact cracky fabric is the most peculiar to compacted clayey chernozems in which labile 2:1 clay minerals predominate. Under the influence of biogenic factors the compactness of the soil becomes weaker in the topsoil, the biogenic aggregates nevertheless remain unstable and easily coalesce into a structureless mass becoming fissured on drying.

HUMUS

A detailed characteristic of humus substances of chernozems was given by Kubiëna [11]. Using high magnifications two humus microforms can be distinguished under the microscope: (1) dark-coloured mostly roundish grains (2-6 μ) and (2) brown-coloured colloidal, bound with the clay in the form of a rather homogeneous flocculated mass. The first one represents humic acids with most condensed aromatic rings combined with calcium; their predominance lends to the humus of chernozems an "inert appearance" (expression of Kononova [10]. The brown coloured humus microform consists of humic acids of simpler construction, easier peptized and more mobile. Both humus microforms are found in all chernozems, but their quantitative relations, status and distribution differ depending on bioclimatic conditions.

In the typical chernozem the well outlined granular particles of dark-coloured humus are found in microaggregates mostly as numerous small accumulations 0.04-0.08 mm in diameter in the colloidal humus-clayey plasma. The same material composes excrements of enchytraeid occurring in biogenic pores of the humus horizon. In earthworms casts especially enriched in dark-coloured humus its small particles are coalesced into dense clots.

In the lower part of the humus horizon and the upper part of the transitory horizon of the leached and podzolized chernozems peptization of dark-coloured humus particles is observed in some places, which gain a brownish tint (Ponomareva and Nikolaeva [14], suggest a possibility of depolimerization of the black humic acids).

In the upper part of the humus horizon of the ordinary chernozems the dark-coloured humus particles are collected into small accumulations like in thick chernozem but they show already some tendency of more even distribution, observed in the lower part of this horizon. These chernozems have a smaller content of brown-coloured flocculated humus, this correlates with its fractional composition. The latter shows a higher percentage of humic acids bound with calcium and respectively a lower content of these acids free and bound with mobile sesquioxydes. The humic acids in ordinary chernozem have a somewhat higher optical density.

In southern chernozems the dark-coloured humus particles are rather evenly distributed already in the humus horizon. The flocculated light coloured colloidal substance of the plasma is more distinctly outlined.

Humic acids content combined with calcium and their optical density are still higher. In the southern chernozem of Kustanai region, developed under highly continental climate with a long period of freezing and deep drying, the humus particles have a particularly dark, nearly black colour and a well outlined granularity. This correlates with a very high humic acid optical density of these soils found by Nikolaeva.

In the compacted chernozem of the Stavropol region the roundish dark-coloured humus particles are mostly disseminated in the clay plasma forming loose accumulations in some places.

The differences between chernozems in respect to other humus forms — raw humus and moder — are determined by their vegetative cover. In the root channels of virgin and arable chernozems only fresh plant tissue occurs and in the soil mass a small quantity of it strongly decomposed and humified fibrous fragments are seen. This shows a rapid destroying of the residues of cereals and grasses in these soils. Quite a different picture is observed with the chernozems under arboreal vegetation: they contain numerous brown-coloured plant tissue fragments in various decomposition and humification stages. There are more microfungi and excrements of enchytraeids, mites and other small soil animals decomposing plant residues. A considerable content of carbonified plant debris falling to small pieces, scattering in the soil mass are characteristic of the southern chernozems of the Kustanai region.

PLASMA FABRICS AND CLAY NEW-FORMATIONS

Of chernozems in which calcium is the prevailing exchangeable cation coagulated plasma is characteristic. The plasma of the S-matrix in the humus and calcareous horizons show asepic fabrics. In the transitionary (after humus) horizon where the plasma includes only a small amount of humus and carbonates (in chernozems with lowered effervescence) in some places a tendency to masepic and vosepic orientation pattern of domains called forth by clay mineral shrinkage and contraction is evident. The same plasmic fabric is observed in the earthworm casts consisting of the lower soil horizons material translocated by these animals into the humus horizon. It is remarkable that in the case of predominance of exchangeable magnesium over calcium in the soil absorbing complex throughout the profile or in some horizons (southern chernozems of the Kustanai region and compacted chernozems of the Stavropol province) the striated plasmic fabric is stronger expressed (but the cutanic forms of clay are absent). Thus it follows that magnesium ion exerts a weaker coagulation action upon the clay as compared with calcium ion.

The fixed plasma status is most peculiar to ordinary and southern chernozems of the steppe and dry steppe regions. In the typical thick chernozem of the meadow-steppe the most fine part of the plasma shows symptoms of mobility hereby becoming a new-formation [5]. These are small (0.03-0.06 mm) rather uniform browncoloured plasma separations with wavy extinction appearing mainly around decomposed plant residues. In the virgin chernozem single pores of the humus horizon have thin organo-argillans (probable as a result of formation of organic substances provoking plasma peptization in the course of steppe mat decomposition). In the lower part of this profile single pores are filled with yellow collophormic clay showing a high degree of orientation.

Fig. 3. Humus-clayey cutans in the transition horizon of a deeply leached chernozem, Kursk region (×250).

The peptization and mobility of plasma is favoured by a more prolonged wet state of the chernozem, leaching out of coagulators and the decrease of glueing organic matter contents. In the deeply leached and podzolized chernozems numerous pores in the medium and lower part of the profile have argillans or are filled with clay often including punctual dark-coloured humus sometimes in such a large quantity that they loose their transparence (Fig. 3). Clay new-formations are not found in the calcareous horizon. In the podzolized chernozem some pores are filled with a more coarse clayey material which has partly lost its colloids. In the solonetzic chernozem containing exchangeable sodium thin argillans are observed [3].

CARBONATES

Carbonates, mainly calcite, are the mobile constituents of chernozems their forms readily reflecting the environment. Depending on changes in moisture, temperature, concentration of the soil solution and its carbon dioxyde content, evaporation and transpiration rates, mesofauna activity and other factors carbonates undergo dissolution, redeposition and dislocation within the soil profile.

The principal forms of soil calcite have been described by Kubiëna [11]. At present his observations may be only a little completed.

The typical thick meadow-steppe chernozem is characterized by the greatest variety of calcite forms. The predominating micro-granular calcite (irregular rounded or petal-shaped grains chiefly 0.5-1.5 μ in size)

Fig. 4. Small-grained calcite in a pore-chamber of typical thick chernozem, Kursk region (×150).

is distributed in the clayey plasma and forms calcitans in some biogenic pores more often found in chernozems with sunk calcareous horizon. In the lower part of the profile single pores are sometimes densely filled with such calcite. Coarser carbonate grains of different origin and shapes being decomposed pass into this calcite form.

The small-grained (0.01-0.1 mm) calcite new-formations occur in two forms. The first one presents irregularly shaped more or less isometric grains loosely or densely filling the pores-chambers (Fig. 4) and rarely disseminated in the soil mass. Their sizes vary in narrow limits (0.04-0.08 mm). Often they show symptoms of corrosion and transition into micro-granular calcite. Among such calcite grains fan-shaped particles

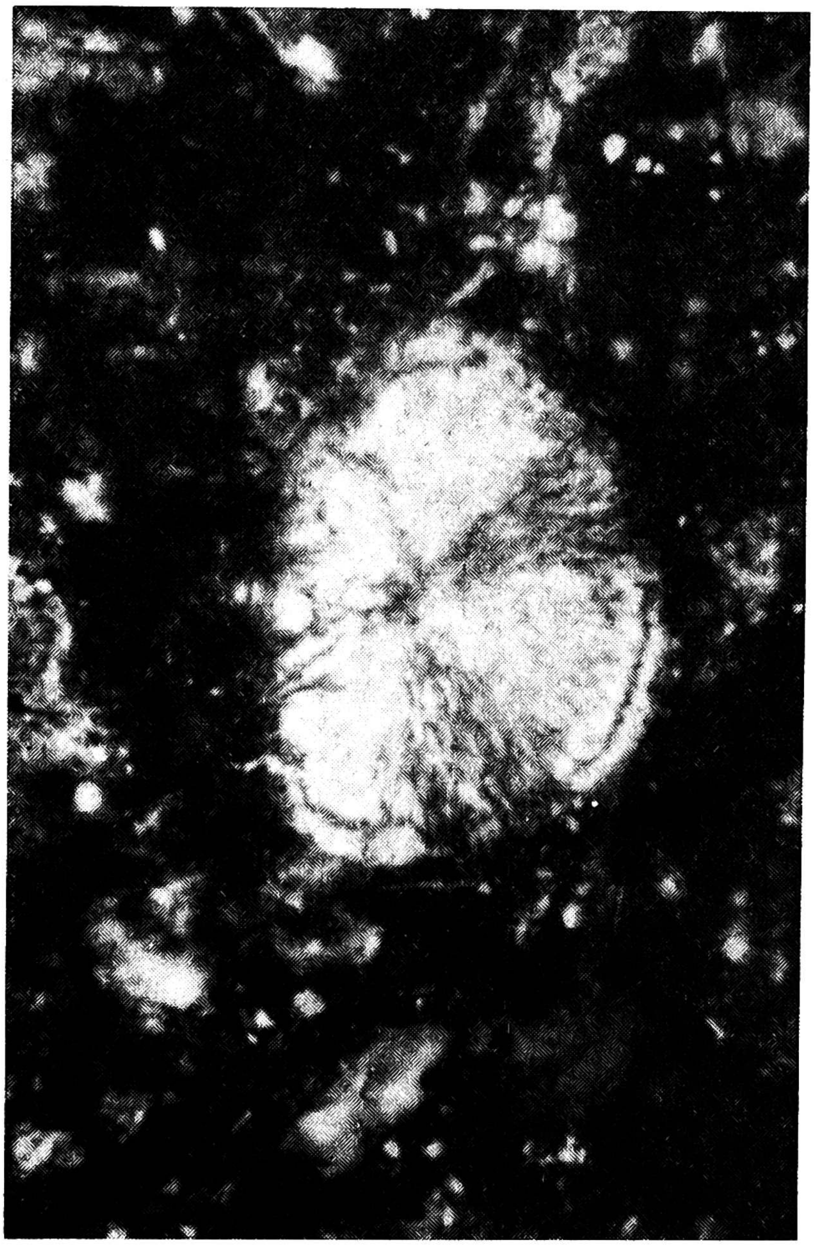

Fig. 5. A carbonate grain of radial-fibrous construction in the same chernozem (×800).

of radial-fibrous construction (Fig. 5) and sometimes spherulites are seen. Often a partial transition of monolythic calcite crystals into the fibrous form is noticed.

Some authors [9, 15] found that a definite orientation of crystalline individuals building up coarser grains is peculiar to biogenic carbonates.

Feofarova [6] came to the conclusion that such grains are, at least partially, aragonite, but this needs verification. Fibrous grains are more numerous in pores of the leached and, especially, podzolized chernozem where the small-grained calcite is being intensely destroyed. It is of interest to mention that radial calcite spherocrystals were found by Altemüller [2] in a soil which received calcium-bearing fertilizers. In this case they presented a new-formation that appeared as a result of biochemical transformations of the fertilizer material.

The second form of small-grained calcite presents more or less elongated crystals in pore-channels (Fig. 6). They are arranged in several

Fig. 6. Fossil calcareous algae relics in the same chernozem (×150).

adjoining rows their long sides being oriented in direction of the pore axis. These crystalline tubes correspond to the description of fossil calcareous algae found by Masslov and Rentgarten [12] in some loesses. Between crossed nicols calcite grains conduct themselves like a monocrystal or fall into differently extinguishing polygons. Some of these grains have radial-fibrous or fibrous entangled construction. In the authors opinion this is due to the biological deposition of lime from the cell juice.

In many biogenic pores and irregularly outliner inter-aggregate pores needle-shaped calcite (lublinite) is seen. In some cases fibre-like needles grow from a very fine "colloid-granular" calcite material.

In addition to the described carbonate new-formations the parent loess loam and chernozem contain small amounts of calcareous rocks and mollusc shell fragments and dolomite rhombohedrons.

Afanassieva [1] discovered seasonal and annual carbonate migrations in the typical thick chernozem. They result in the formation of micro-granular and needle-shaped calcite depending on the migrating soil solution concentrations. Earthworms transfer all previously mentioned forms of carbonates into the humus horizon of chernozems with a high effervescence. Besides they themselves produce calcite in the form of aggregates of irregularly shaped grains [13].

In the calcarous-illuvial horizon of the podzolized chernozem carbonate forms are similar to those of the typical thick chernozem (except algae relics). The microgranular calcite is mainly concentrated around the pores. The small-grained calcite in pore-chambers is strongly corroded and to a great extent aquire micro-granular and fibrous forms loosing transparence and gaining a brownish colour. The amount of calcite needles diminishes here.

In the ordinary chernozem of Zaporozhye and in southern chernozems nearly all calcite is micro-granular presenting a plasma constituent. Small-grained calcite is found only as sparse fragmentary grains and debris of mollusc shells, a part of which has been transformed into micro-granular calcite. Sometimes its pseudomorphs after roots are encountered.

In the lower horizons of the clayey southern chernozem (Kazakhstan) some pores are filled with compact microgranular calcite accumulations including iron oxides representing relics of the hydromorphic stage in the development of this soil. Similar carbonate forms are observed in the compacted chernozems of the Stavropol province.

In addition to the above given characteristics of carbonates in chernozems some more data may be presented on Moldavia obtained by our postgraduate student V. E. Alexeiev. These chernozems are characterized by a wide distribution of needle-shaped calcite. It forms the upper part (migration zone) of the carbonate profile of the calcareous and ordinary chernozems. The needles are the longest (up to 100 μ) in the typical and the shortest (less than 30 μ) in the podzolized chernozem. The micro-granular calcite is for the most part concentrated around the pores and its amount increases from the south to the north. Pore-chambers with small-grained calcite are absent. Radial-fibrous and other forms of carbonates are found in insignificant quantities.

FERRUGINOUS-MANGANESE NEW-FORMATIONS

In chernozems developed on drained watersheds iron and manganese posess a very low migration capacity and their new-formation are therefore almost completely absent.

In southern chernozems sometimes single clayey micronodules enriched in iron and manganese oxides are found. Transvolga chernozem on ancient alluvial loam contains concretions consisting of concentrically oriented clay and iron oxides up to 0.5 mm in size representing relics of the previous hydromorphism of the soils. Such concretions are rather numerous in the meadow-chernozemic soil of the same region.

In the humus horizon of the typical thick chernozem of Kursk region single roundish nodules consisting of iron oxides and humus (0.15 mm) occur, this being an evidence of a slight quite local iron mobility apparently depending on the formation of organic-mineral compounds. In the superficial meadow-chernozemic soil (without symptoms of gleyization) in a shallow depression among chernozems nodules are present also in a small amount but they are rather greater in size and contain more iron oxides. In the ground water meadow-chernozem soil whose fabric is similar to that of the typical chernozem in addition to such nodules in the transitory horizon compact irregularly shaped iron oxide nodules of greater size have been formed.

In the podzolized chernozem at the depth 50-60 cm single clayey-ferruginous concretions rather loose in their central part up to 0.4 mm in diameter are observed. At the depth of 100-130 cm this soil contains rare compact ferruginous nodules and manganese oxide new-formations.

In the compacted chernozem of Stavropol province already in the upper part of the humus horizon organic-ferruginous concretions are present becoming looser with depth.

In all iron-manganese new-formations described under high magnifications accumulations of unidimensial slightly elongated bodies (a little smaller than 1 μ) partially arranged in chains can be distinguished. It appears that they are bacterial cells.

CONCLUSION

The presented material may be used for the purpose of micromorphological diagnostics of chernozem. This diagnostics will, no doubt, be improved when other varieties of chernozem soils are subjected to a detailed study.

SUMMARY

This paper deals with microstructural characteristics, humus microforms, plasmic fabrics, forms of carbonates and ferruginous-manganese

new-formation in chernozems from different regions of U.S.S.R. under different parent rocks, topography, vegetation and so on. The presented material may be used for purpose of micromorphological diagnostics of chernozems.

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