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CRYOGENIC PROCESSES AS REFLECTED IN GROUND MICROSTRUCTURE

During the last stages of the geological history of the Earth, the formation of continental deposits over vast areas proceeded under conditions of perennial and seasonal freezing. Various physical and physico-chemical processes related to crystallization of water were active at the stages of the supergene transformation and sediment diagenesis.

The degrees of effect and the forms of manifestation of the permafrost processes in the Quaternary deposits were rather diverse. From a lithogeneous view-point, the permafrost processes are now divided into two types (Popov, 1967).

The first type is associated with repeated alternate freezing and thawing of rocks and sediments, and is regarded as a factor of weathering (cryoeluviogenesis) and slope denudation. The operations of these processes were restricted to the seasonally freezing—thawing layer.

Processes of the second type are related to unicursal freezing of deposits and to underground ice formation. The cryogenesis of both the types was accompanied by intricate changes in the structure and texture of the deposits. A voluminous literature is devoted to the study of these processes, yet many aspects of the mechanism of cryolithogenesis are not yet quite clearly understood. The introduction of more diversified methods to the study of these processes would obviously facilitate a more comprehensive knowledge.

The present paper deals with the possibilities of the microscopical method of studying cryogenic phenomena. The authors' observations concerning the microstructure of clay rock subjected to repeated freezing and thawing are presented with particular reference to the loess-like cover formations of the Bolšezemelskaya Tundra together with the results of experimental studies, and a description of certain features of the microstructure of glacial deposits which – the authors believe – are of a cryogenic nature.

The cover formations in the eastern part of the Bolšezemelskaya Tundra are usually represented by rocks composed of loam, occasionally of sandy--loam; these are generally ordinary silty loam, less frequently heavy or light clay loam and sandy loam. As a rule, a small number (5% to 7%) of pebbles, gravels and sometimes boulder inclusions, are present in the cover loam. A high content of silt fraction, up to 90% and commonly 60% to 80%, is a distinctive feature of the grain-size composition of the cover formations, with coarse silt fraction (0.06 mm to 0.01 mm) predominating, amounting usually to 40–60%.

Cover formations are embedded, as thin mantles 0.2–0.5 m to 3–3,5 m thick (average thickness 1.5 m to 1.8 m), at various geomorphic levels differing in age and origin. They are underlain by Quaternary and basic loose rocks of various age, lithologic-facies and genesis. Cover formations have the most characteristic appearance in watershed divides, on hills and ridges built up of marine-glacial boulder loam. Cover formations are absent from the first terraces and floodplains of river valleys, from swampy watershed depressions and basins covered with peat, and occasionally from slopes.

The contact between the cover formations and the underlying rocks is, in most cases, rather obliterated; legible contacts are found on steep slopes of river valleys, of ravines and brooks, where traces of displacement of material are clearly seen. Cover formations over large areas and under different geological and geomorphic conditions are highly similar in consistency in composition, morphological aspect, structure and texture, and also in their relation to the underlying rocks and polygonal relief. At the same time, the peculiarities of their structure depend on the underlying rocks. The character of substratum shows first of all in the thickness, morphological structure and mechanical composition of the cover formations (Koniščev, 1962, 1965).

There exist different views as regards the question of the genesis of cover formations (Izrailev, 1963; Kostyaev, 1963; Lavrov, 1962; Mazurov, 1948; Pisarev and Datsky, 1934; Sofronov, 1944). On the basis of detailed studies carried out by the Cryolithology and Glaciology Department, Faculty of Geography, Moscow State University, to ascertain the conditions of distribution and bedding, as well as the composition and structure of cover formations, the authors believe these formations to be of eluvial origin. The eluvial process took place under conditions of cold climate and with permafrost factors actively participating (Popov, 1958; Koniščev, 1962, 1965).

A microscopical study of loess-like cover formations that are the most typical grounds of the seasonal thawing layer in the eastern part of the Bolšezemelskaya Tundra revealed a number of special features of their microstructure, such as are not peculiar to other types of deposits, and are associated with the cryogenesis of these rocks.

Study of the microstructural features of the cover formations and of the underlying deposits was carried out in three sections typical of the area, with a primary non-redeposed loam cover underlain by boulder marine-glacial loam and clay.

The character of the ground microstructure was discovered to change within the profile. A change was observd firstly in the microstructure of the clay oriented optically in the profile, and, secondly, in the character of distribution of fine clastic material.

An uneven distribution of the sandy-silty particles and of fine-dispersed clay material was noted in the upper, pale-yellow, loam horizon (up to 0.8 m) characterized by a massive permafrost texture in winter and by considerable moisture variations throughout the year. The following types of differentiation of fine clastic material were observed here: (1) aggregations of mineral components of an irregular, oval or elongated shape; (2) micropolygons in the form of rings constituted by fragments of the primary minerals, of 0.03 mm to 0.07 mm in size (inside the rings aleurite-clayey material was embeded with grains of 0.007 mm to 0.01 mm in diameter); (3) concentration of sand and coarse-aleurite grains in pores and along fissures (Pls. 1, 2).

These forms disappeared with depth. The lower horizon was characterized by a rather even distribution of the sand-aleurite grains amidst the clay material.

Down the section the clay material changed likewise in microstructure. The change manifested itself by variations in dimensions of the scales of clay aggregates, in their mutual disposition, the degree of orientation of the clay material, and the degree of its dispersion. Rapid upfreezing and the intensive migration of moisture hindered the aggregate-scales to be clearly oriented in the uppermost horizons of the cover formations. A fine-scale microstructure with a random distribution of scales was found in the upper horizons of the loam cover at a depth of 0.3 m (Pl. 3), and deeper downward the arrangement of the scales became reciprocally perpendicular resulting in a sort of reticular pattern. The dimensions of the individual aggregate-scales increase with depth, reaching their maximum in the underlying boulder loam.

A „ring" microstructure of the optically oriented clay was noted to appear down the section, being best-expressed at a depth of 1.2 m to 1.6–1,7 m, i.e., in the lower horizon of the cover formations and in the upper horizon of the underlying boulder loam, within both the layer of seasonal freezing and thawing (Pl. 5). Such microstructure seldom occurs in the pale-yellow horizon of the cover formations at depths of 0.5 m to 0.6 m. At depths of

0.3 m to 0.4 m, the "ring" microstructure disappears almost completely.

Thus the persistence of a legible coarse-scale microstructure of the optically oriented clay with a reciprocally perpendicular disposition of the scales, as well as of a ring microstructure, was observed in the lower part of the profile corresponding to the lower icy horizon of the active layer with increased moisture and a stratified permafrost structure. This is due to a high content of particles which have here, less than 0.001 mm, to a specific hydrothermal regime, and to freezing conditions; high moisture content during the whole year, its insignificant variations, and slower freezing as compared with the upper horizons. And *vice versa*, the rapid alternation of freeze and thaw and the intensive moisture migration with freezing of the upper horizon of the cover formations are unfavourable to the preservation of clay material of the aforesaid types, and induce a peculiar sorting of the sand and clay material, described above. Microstructure of the types characterized above was observed in slides prepared both of thawed and of frozen samples.

To verify this assumption, an experiment was set up that was intended to answer the question as to what kind of structural changes originate in clay grounds as a result of recurrent freezing and thawing. Boulder loam from the region of the town of Vorkuta was used as an experimental sample. Triturated and sieved through a 1 mm-mesh screen, the loam (Table I) was

Table I

Grain-size composition of the experimental ground

Particle diameter (mm)	Content (percentage)
1 to 0.5	1.60
0.5 to 0.25	7.35
0.25 to 0.1	16.40
0.1 to 0.05	20.35
0.05 to 0.01	24.50
0.01 to 0.005	8.20
0.005 to 0.001	9.40
<0.001	12.20

exposed to one-way (from above) freezing and thawing. Before the test, the loam had been wetted up to 30% and that moisture was maintained throughout the whole experiment. The freezing was carried out at a temperature of −10°C, and the thawing at +20°C. The sample was held for 12 hours at a negative temperature and for 12 hours at a positive temperature. Altogether 28 freezing–thawing cycles were repeated. After that, slides of the loam were prepared on two planes, perpendicular to and parallel with the freezing front. Slides of the control loam sample of a similar composition were also prepared but frozen only once under the same conditions. The slides were prepared of the frozen grounds according to the methods devised by P. A. Šumsky (1954), and were examined under a MIN-8 polarization microscope.

Special features of microstructure related to the uneven distribution of sand particles in the slide field, and similar to those found in the upper horizon of the cover formations in the Bolšezemelskaya Tundra were discovered in the slides prepared of the ground that had been exposed to repeated freezing. Portions were marked out with aggregations of sand-aleurite particles, and also portions where fine sand and aleurite particles formed ring-like micropolygons 0.1 to 0.3 mm in diameter. The constituent particles of the rings had to 0.02–0.05 mm (Pl. 6). Inside the rings contained either a homogenous clayey mass or particles representing fragments of the primary mineral. The sand-aleurite rings were not noted over the entire field of the slide. The rings occur either isolated or grouped but set apart.

The sand-aleurite rings were found in both the vertically and the horizontally oriented slides, hence these formations should be regarded as volumetric.

Such forms were not discovered in the slides made of the control sample. The coarse sand and aleurite particles were aranged rather evenly and did not form such a pattern. The rings of the sand-aleurite particles observed in the repeatedly frozen ground were nearly similar in shape and size to the rings built of the fragmental grains which were noted when studying the slides derived from the cover loam of the Vorkuta region. Thus there may be hardly any doubt that the above noted peculiarities of the microstructure of both the cover loam and the experimental sample, associated with segregation of sand and coarse aleurite particles, originated as a result of reiterated freezing and thawing of the ground. Scale microstructure of the optically oriented clay with a chaotic disposition of scales was characteristic of repeatedly frozen ground. Concentration of the clay mineral scales around a coarse sand particle was observed only as an isolated phenomenon. Evidently a different type of microstructure of optically oriented clay (ring, coarse scale, and other structures) may originate and persist under different conditions of ground freezing.

As compared with the control ground the sand and coarse silt particles in the repeatedly frozen ground were distinguished by a high degree of fracturing.

The above data indicate that the micropolygonal type of ground microstructure is related to such a type of processes as are characterized by rapid alternation of freeze and thaw.

Apparently this type of microstructure might be regarded as one of common occurrence, for it is found not only in cover formations, but also in soils (Koševeva, 1958) and in glacial deposits. In the microstructure of the latter, cryogenic processes are reflected originally, which seem to be related to the conditions of the periglacial zone. In the oriented slides of moraine loam from the area of the recent glaciation (the Pskov province and the north-western part of the Smolensk province), the authors observed several types of clastic material concentration that might be explained, like those mentioned above, by the effect of permafrost processes upon moraine grounds. Most often micropolygonization occurs in the form of rings or half-rings constituted by fragmental grains of 0.2 mm to 0.4–0.5 mm in size (Pl. 7). The inner part of such polygons is represented by finer clastic and pelitic material. The polygons vary in diameters, for example, from 0.8–1.5 mm to 2–3 mm in the two upper horizons of the Valdai moraine in one of the regions of the Lovatsk lowland. Micropolygonization may be expressed not only in the form of legible rings, but also in that of smaller polygons of an irregular but mostly oval shape. Out of other types of differentiation of clastic material observed in the moraine loam of the recent glaciation and most likely related to be permafrost processes, worth noting are the "coverings" of fine sand fragments and coarse aleurite particles around coarser fragments (Pl. 8). Since the coarse mineral grains enclosed inside such "coverings" are "recent" as a rule and do not bear any traces of deformation due to pressure processes at the time of moraine deposition, such features of moraine microstructure of the recent glaciation are likely to be of a cryogenic nature. Oval aggregations or concentrations of mineral grains found on individual microportions of the slide may likewise be partly associated with cryogenic processes (Pl. 9).

Cryogenic phenomena are not so fully manifested in microstructure of the moraine loam of the recent glaciation as in the above mentioned active layer of cover loam in the Bolšezemelskaya Tundra. In the moraine ground, for example, the authors did not observe any phenomenon of squeezing-out of the coarse grains onto the walls of the pores or joints, and the micropolygonization and concentration in the form of grain segregation in some slides from the moraine horizons of the recent glaciation were displayed only for the relatively fine grains (fine sand and coarse aleurite). Nevertheless, it should be taken into account that a change in microstructure due to cryogenesis can substantially disturb the orientation of the elongated coarse sand particles in the direction of ice movement (such orientation is observed in ground moraines).

The results of the above studies show that certain specific features of microstructure can originate in grounds subjected to reiterated freezing and thawing, which process should be taken into consideration in any genetic interpretion of the results of microscopic studies of the formations occurring in the periglacial zone.

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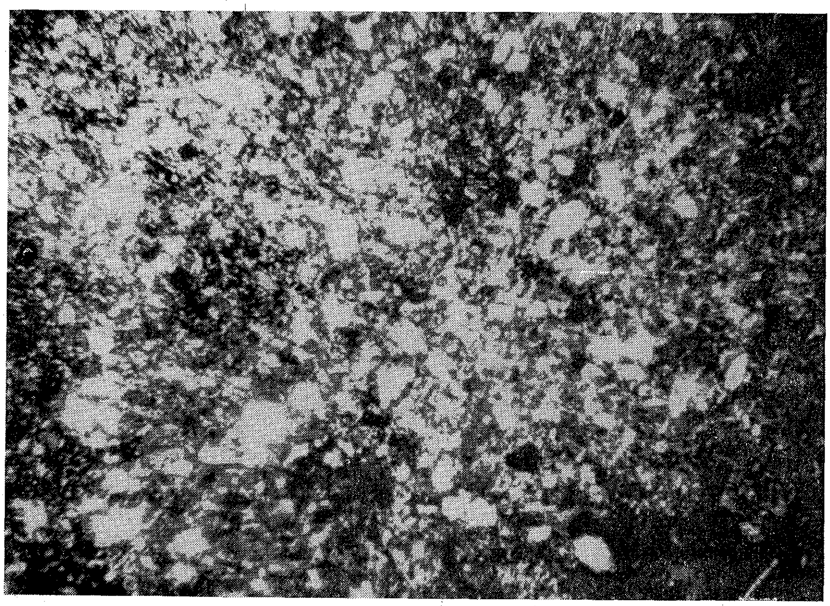
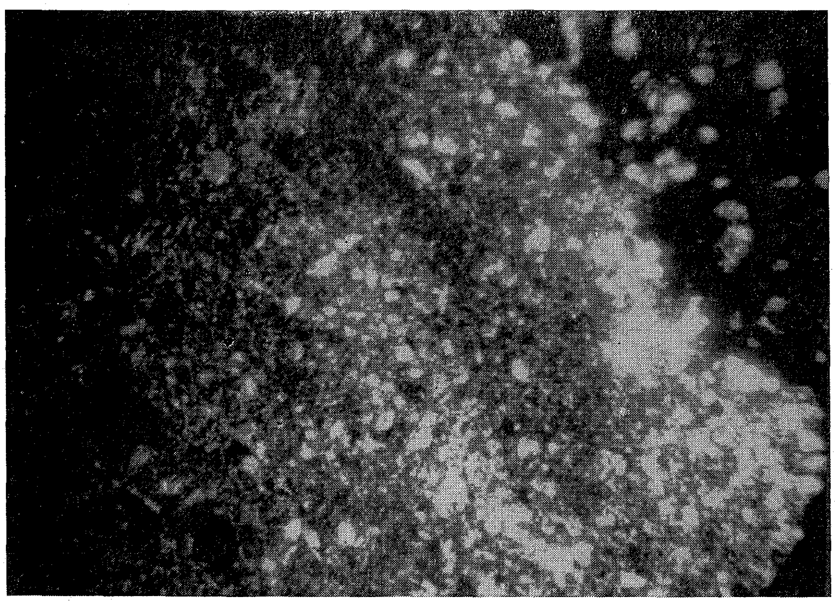


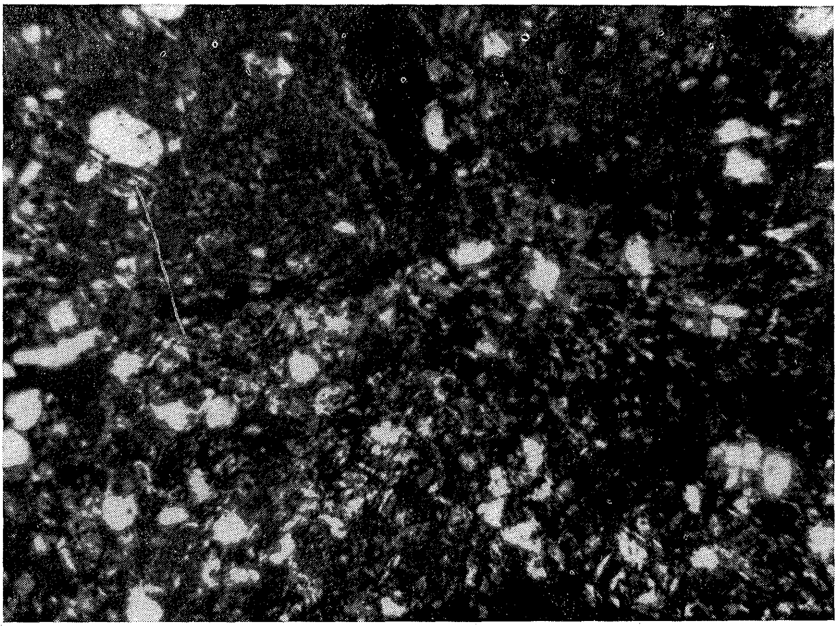
Pl. 1. Rings of sand-aleurite grains in the upper horizon of the cover loam. The town of Vorkuta region

depth 0.3 m, mignified 9 × 8, nicols X



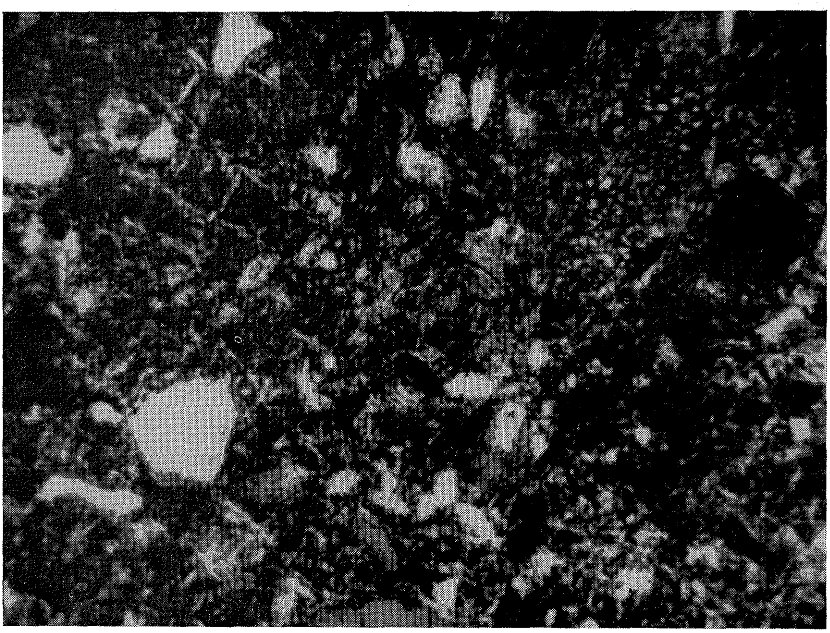
Pl. 2. Type of cryogenic sorting of material in the upper horizon of the cover loam Vorkuta region

depth 0.3 m, magnified 9 × 20, nicols X



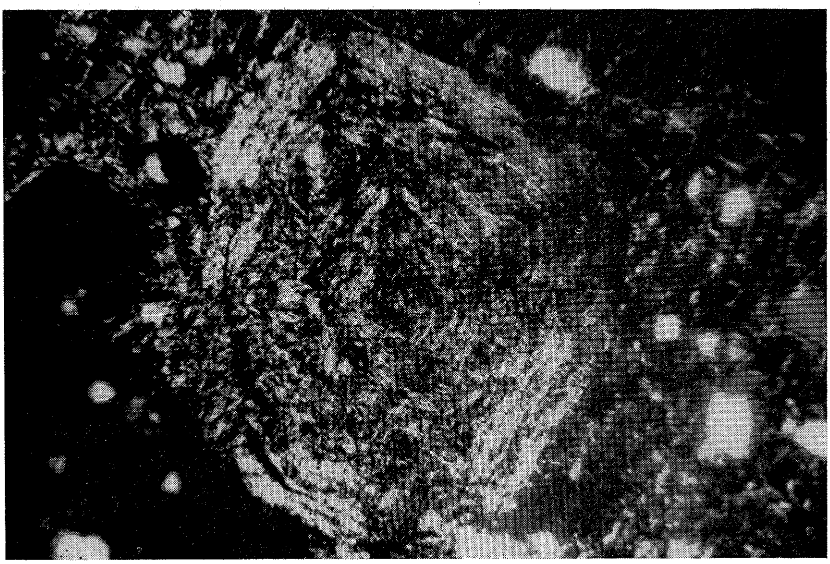
Pl. 3. Fine-scale structure of the optically oriented clay in the upper horizon of the cover loam. Vorkuta region

depth 0.3 m, magnified 8 × 20, nicols X



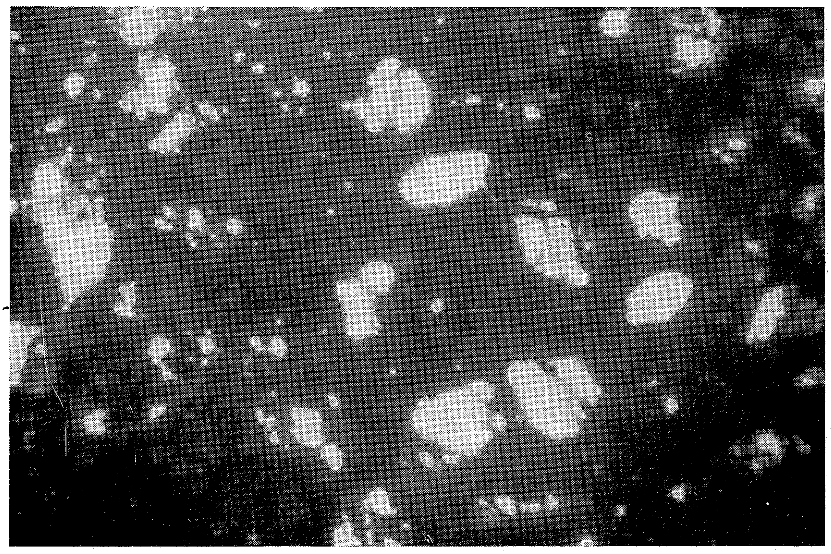
Pl. 4. Coarse-scale structure of the optically oriented clay in the lower horizon of the cover loam. Vorkuta region

depth 0.8 m, magnified 8 × 20, nicols X



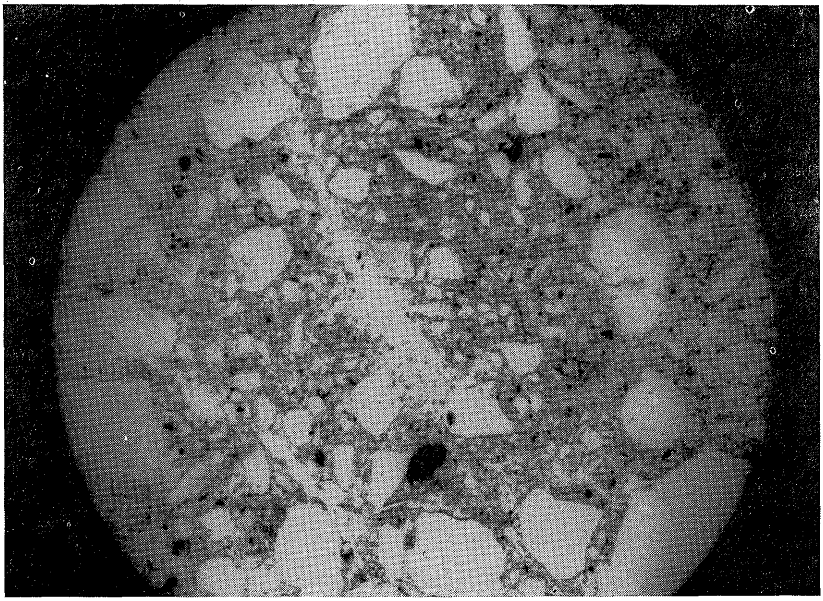
Pl. 5. Rings of the optically oriented clay in the lower horizon of the cover loam. Vorkuta region

depth 1.6 m, magnified 8 × 20, nicols X



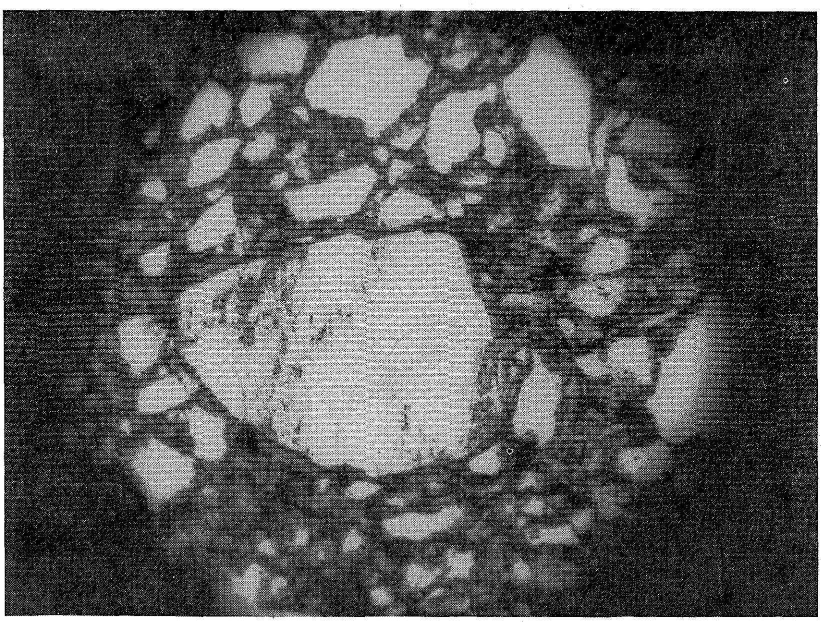
Pl. 6. Micropolygons of sand-aleurite particles in the ground subjected to repeated freezing and thawing under laboratory conditions

magnified 100, nicols X



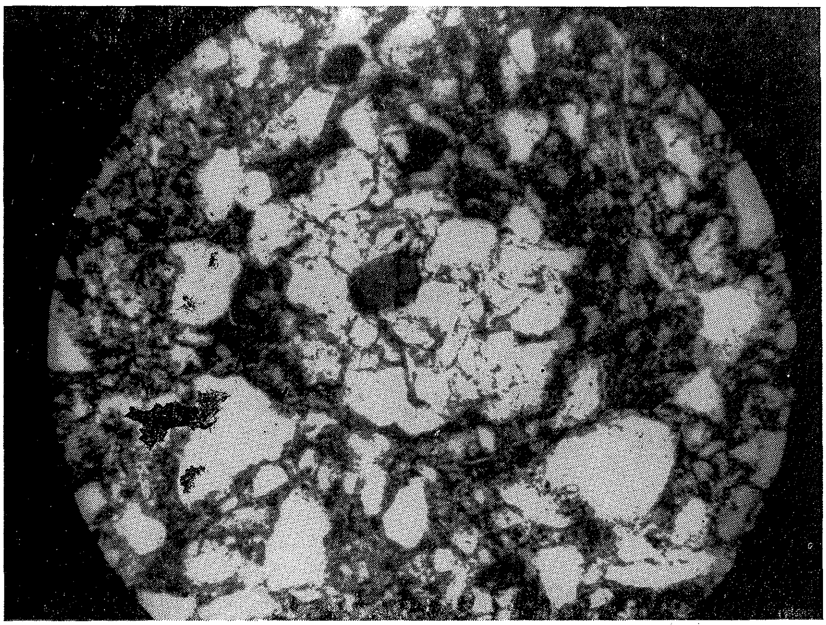
Pl. 7. Ring disposition of fragmental grains in the upper moraine horizon. The river Oka village of Polibino

magnified 90, nicols parallel



Pl. 8. "Covering" of fine grains around coarser grains. The river Kunya

magnified 90, nicols parallel



Pl. 9. Aggregate of fragmental grains. The river Oka, village of Polibino, upper moraine horizon

magnified 90, nicols parallel