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THE PERIGLACIAL ZONE OF WESTERN EURASIAN PLAINS

Substantial corrections are required in our concept of the terms *periglacial* and *periglacial zone* due to present knowledge and interpretation of the multitude of wedge- and fold-type disturbances occurring in the loose Pleistocene sediments, especially the periglacial deposits, as well as because of the necessity to take into account the phenomenon of glacio-isostasy in areas previously invaded by ice-sheets.

From the moment of its appearance until the present time the term *periglacial* had a clearly definite climatic meaning. Periglacial zone (previously only in the foreland of old glaciers) was regarded as an area characterised by widespread permafrost and strong freezing of the ground that resulted in a large number of various cryogenic disturbances in loose sediments (ice veins, fold-like contortions of cryoturbation and involution type, frost-heaving mounds, etc.) and by intensive mechanical weathering resulting finally in the formation of dusty (loess-like) waste. Slope processes (mainly solifluction) and wind action under dry continental climatic conditions were particularly intensive in this zone.

The occurrence of many such structures or other similar phenomena (e. g. ice and ground wedge polygons, etc.) in areas that are at present under severe climatic conditions, i. e. in the North and North-east parts of Eurasia and North America, and to some extent also in the periglacial zones of existing glaciers gave support to a broad concept of the term of *periglacial* which came to be identified in the first place with climatic morpho-lithogenesis and, spatially, with cold climate, even though without any larger glaciers present. Many authors attached to this term an exceptionally great morphogenetic importance. Such an approach would obliterate the extremely important differences between the western part of North Eurasia, covered by ice-sheets and characterized by a set of very specific conditions due to the presence of the glaciers, and the eastern part where the principal Pleistocene phenomena had different, though in many cases similar origins. But even today the relative differences are clearly visible.

Even if the problem is thus climatically approached, the geological aspect of the phenomena remains clearly evident. Relative evidence is supplied by the disturbances which represent a particular geological phenomenon in ground with peculiar grain-size composition. Climate is only a general background that does not differ very much within large areas. Only sediments that are, even over small areas, strongly varied vertically and horizontally can be responsible for the great variety of ground disturbances. The same can be said about rocks of which the origin is related to the climate.

Therefore a group of processes can be distinguished in which the climate has a limited or even indirect influence. These are: sedimentation in ice-dammed lakes; erosion and accumulation of glacial rivers; the processes similar to the above occur in cold climate without any relation to proglacial environment. They include also diagenetic deformations in the bottom sediments (both of deep-water and littoral facies).

Geological and geophysical investigations of the last ten years have made it necessary to be more precise, or even to change views on many questions in geology and paleogeography of the Pleistocene. This relates especially to the problem of interpretation of the so-called periglacial phenomena (i. e. deformations in the Pleistocene loose formations) and also to changing views on the environment characteristics and conditions that gave rise to the principal ground disturbances within the zone interpreted formerly as related to the continental ice-sheets, which is now considered as glacio-periglacial. These changes make it necessary to adopt a different attitude towards the role of the geological factors in relation to periglacial morphology and lithology.

Extensive glacial and periglacial plains are considered at present as the areas of the development of continental facies. This is primarily reflected in the approach to such formation as boulder clays, generally regarded as moraines, and also to loesses unanimously regarded as subaerial formations (eolian, over great areas). With this approach, the proglacial water-laid deposits, usually regarded as fluvioglacial sediments, appear to be an entirely local phenomenon associated with depressions in the interfluves and with valleys. It was assumed that the Pleistocene glaciers activity was limited to erosion of the bedrock during ice advance and to accumulation during its recession (to some extent also during advance). Thus relative heights of the glaciated areas did not change. It was only the absolute height which increased due to general glacio-eustatic depression of the World Ocean. In other words, remarkable changes in altitude and relative heights within the glacial- and periglacial plains caused by the weight of thick ice-sheet, as well as the resulting geological and paleogeographical conclusions escape in fact from our considerations.

Recent investigations of Artyuškov (1967) indicate that it is necessary to recognize glacio-isostasy as one of the main factors in solving the basic geological and paleogeographical question of the Pleistocene glacial and proglacial areas. This author proved that a layer of low density at the depth of 80 to 200 km (referred to as asthenosphere) allows for isostatic bending of earth's crust not only under the 2—3 km thick ice sheet but also on the periphery of the glaciers.The bending is sometimes as much as 100 km in the vertical and 100 km in the horizontal direction. The extent of the depressed areas which were then flooded by meltwaters could be considerably enlarged by adjoining low-lying terrains and due to accumulation of water against mountains and hills. From the above it can be seen that in the ice-sheet foreland, in the maximum phase and during the stagnation, there is an area of inland accumulation in fresh-water basins both in close vicinity of the ice front and in remote portions of the depression.

Close to the ice sheet, where the water is deepest, the detaching and floating icebergs transport the debris. As the ice melts, the material is accumulated; it consists of poorly sorted silts and clayey sands containing boulders. Southwards, due to gradual decrease in the reservoir's depth the mineral material is finer and moraine horizons wedge out. It is reasonable to expect a lesser admixture of clays and better segregation within the fine-grained sediments. Thus, the area of the occurrence of boulder moraine is more extensive than the areas directly invaded by the ice sheet.

In the southern, shallow part of the reservoir, there are the best conditions for sedimentation. This is the zone of accumulation of fine-grained clay and dusty deposits which are parent material for the periglacial loess. That is why the grains of the loess become coarser and the thickness of the loess layer becomes thinner towards the glacier's front.

The question of expansion of periglacial water reservoirs southwards remains open. However, it is quite reasonable to suppose that supply of meltwaters into the closed and half-closed southern seas — the Black and the Caspian Sea — could cause their transgression at that time. Thus, the vast areas were unavoidably flooded.

As the area raised during the recession of the ice sheet the ingression—transgression facies (usually „boulder" silts and loamy sands) were replaced by the regression facies, represented by sands and covers of aleurite clays. These deposits built diversified accumulational land-forms — flat plains, hill complexes, ridges and depressions. The aleurite clays are not, however, as thick and well sorted in the central and northern parts of the plains as they are in the southern regions as a result of dynamics of the accumulational environment.

Pauses in the accumulation are instantly marked by soils which develop on dusty loess and sometimes also on other deposits corresponding to the climatic zones and to the local geomorphological properties of definite periglacial regions.

During recession of the ice sheet the area, where glacial drift was deposited as a thin ground moraine, was flooded by the waters of the proglacial lake, and the moraine was now washed and included into fresh sediments. Therefore, the moraines in their typical form may be not manifested in sections exposing various silty sediments formed in these reservoirs, and the whole series of deposits and also the area of their occurrence should be called glacio—periglacial. In the North, where the ocean waters penetrated to the reservoirs, similar glacio—periglacial sediments were formed already in the marine environment.

The above concept becomes even more established when the main geological facts are considered. It is well known that southwards the morainal horizons occurring within the stratified loess- and sandy-silty deposits became thinner and contain fine-grained material. Such cross-sections are especially well-defined in the Dneper and Don lowlands and in the valleys of Irtyš and Yenisej. On the contrary, northwards the loess becomes thinner and poorly sorted, and coarser particles content increases, sometimes single pebbles or boulders can be encountered.

Silts and clayey sands contain very small amount of debris but they contain, however, fresh-water mollusca and ostracods, very similar in its composition and degree of preservation to the fauna appearing in loess, including the lower, stratified aqueous loess varieties. Both the silts and the loess are indentical in their mineralogical composition and are characterized in some places by an imperceptible transition of one of these deposits into the other, both vertically and horizontally. The glacial sediments do not anywhere built accumulational land-forms of a terminal moraine type. There are no true erratic blocks in this area. Very characteristic is a lobate boundary of the sediments deposited directly by ice, which avoids even small elevations of ground relief.

The drift silts of the central region of the glacio-periglacial zone are also similar in character. The common features are: reddish-brown or grey colour, similar segregation of material, which is in some places stratified, distribution of debris, the occurrence of manganese-, mangano-ferruginous, limonite- and siderite--limonite concretions. The identity of the lithological characteristics of various moraine horizons together with the presence of drift facies in the profile gives good reasons to suppose that the ground moraine became assimilated by the sediments deposited in the proglacial water basin, and that at the beginning they were rather thin.

Dark-grey and brown glacial deposits in the North are characterized by greater thickness, remarkable homogeneity in vertical profile, fine grain-sizes — especially in the horizons containing small amount of debris — distinct stratification in some series, by the fauna of marine mollusca and foraminifera, by autogenous formations (pyrite, manganous and limonite concretions), etc. Besides, the sediments contain in some places great blocks derived from the bedrock. Here, just like in the central regions, the glacigenic deposits differing essentially from main sediments formed in the aqueous environment (perhaps with the exception of those formed in the base of the profiles and of those formed in deep burried valleys) are absent.

Just like in the regions lying more southwards, glacio-marine silts are covered by sands and boulders of the regressional series, giving a diversified landscape of accumulational origin, characteristic of the littoral zone. They are also overlain by a thin and discontinuous mantle of lagoon aleurite clays, i. e. loess-like loamy sands and silts.

The fossil soils (these sensitive indicators of natural conditions that existed in the past) which developed on loess-like and other formations in different glacio-periglacial areas, reveal distinct hydromorphous characteristics which coincide very well with the conditions of the origin of the sediments described above.

Thus discussed, the paragenetic complex of sedimentary formations constitutes a single geological unity as far as the regularity in structure and occurrence in the whole glacio-periglacial zone. In the last few years this problem was very often discussed as one of the fundamental questions of the Pleistocene of the northern part of Western Siberia. In relation to the areas situated more to the west, in spite of many divergent opinions nobody has ever pointed to the fact that the stratigraphic horizons are homogeneous in the northern, central and southern regions.

A very great, remarkably greater than normal, rate of the Pleistocene tectonic movements and of accumulation in the regions of NW-Eurasia points to the glacio-isostatic character of these movements and to the accumulation of deposits in the proglacial zone. Therefore, the regions which during the Pleistocene were flooded with sea water are the most essential proof in favour of the hypothesis of continental glaciations.

The interpretation of the genesis of numerous wedge- and fold-like deformations in Pleistocene sediments is another important problem. In the course of investigation and discussions in which the author took part himself, new processes and mechanisms have been ascertained as involved in the development of similar deformations in loose sediments which were previously regarded as entirely permafrost phenomena. These are: mainly convection instability of ground, and syneresis and dilatation processes. The convection instability and dilatation may be, however, interdependent. A critical analysis of the data introduced a great degree of uncertainty about the frequent occurrence of ice veins in former glacio-periglacial areas, without denying the importance of frost-cracking forms in the active zone.

On the basis of the new criteria it was concluded that a majority of deformations originate due to the diagenetic, and partly to the seasonal freezing processes. This approach is free of the intrinsic discrepancies, since the diagenetic processes can occur, because of their aclimatic character, in any circumstances, as for example under subaqual and subaerial conditions and also in mild or cold climates; the freezing processes, however, were undoubtedly very active in cold phases of the Pleistocene in the upper zone of land surfaces.

And indeed, a majority of the wedge-like structures occurring in glacio-periglacial and other areas show similar features of which the most important are: (1) the disturbances occur on the boundary of different material, (2) „flowing" transitions of these border-lines from horizontal to vertical (in veins), (3) clear contacts (increasing downwards), (4) different sloping of structure walls, etc. These features which find a satisfactory explanation in the convection hypothesis, can be observed in the unquestionable subaqueous sediments, and in probably subaqueous sediments and in those formations of which the genesis is not yet fully explained.

The former phenomena are exemplified by the wedge-like structure of the dark-grey silts, containing maritime macro- and micro-fauna, which penetrate into the underlying sands (the river Šapkina in the water basin of the lower Pečora, pl. 1). Another example is provided by a large diapir-like form in the middle part of the Likhvin profile (the river Oka). The diapir developed in the boundary between the middle horizon of stratified silts and the lower horizon composed of unstratified, typically glacigenic silts. The latter were described already in 1939 by K. K. Markov as water sediments formed in proglacial lakes (pl. 2). Examples of the second type are the well known disturbances in the form of wedges, depressions, tongues, etc. Their occurrence is associated with inter-polygonal depressions,but there may be no such relation. These structures often terminate as narrow cracks wedging into the cover formations spreading over larger glacio-periglacial areas. Fissures and other structures occur often side by side (pl. 3).

The second case is of course more difficult for interpretation, as climatic factors are fundamental in frost-cracking, freezing and thawing which take place either during or after the „universal" process of convection. In the earlier papers, the present writer gives attention primarily to the diagenetic processes, which had some influence not only on his approach to the general problems of periglacial zone but also on his one-sided understanding of the mechanism of the origin of convection and convection—dilatational disturbances. However, observations made by the present writer, during the last two years, in the north part of Western Siberia led to recognition of the occurrence of analogous — mainly in morphological form — present-day polygonal forms which develop under subaerial conditions in the active zone of present permafrost. That is why similar cases would acquire substantial importance.

Pl. 4 illustrates a ground vein in an inter-polygonal depression on a narrow flattening surface in the middle part of the slope of the third terrace of the river Taz (near the village Tazovskoye). This surface lying ca 5 m from the upper edge of the terrace, is formed due to a change in the material: on this level the upper series of loose fine sands passes into a layer of silts (thickness 1—2 m) underlain by interbedded sands and silts. This narrow flattening has everywhere the same height and occurs in valley and gullies (pl. 4). This flattening, in an initial stage, can be observed in steep-sided gullies where it is found exactly along the outcrops of the silts.

The upper part of the ground wedge is pocket-shaped and is filled with the overlying sand which belongs to the lowest series, displaced in places by solifluction. The second, lower part of this structure is a fissure running downward from the pocket base and is filled with the same sand. An analysis shows that the main part of the wedge-structure i. e. the pocket, developed due to convection processes between the sand and the silt, while the fissure is the result of frost-cracking.

The penetration due to convection of sand into the silt was possible owing to the fact that the specific gravity of sand (1.59 g/ccm) is greater than that of silt (1.52 g/ccm). Moreover, due to intensive water-saturation in spring-time the specific gravity of sand, in relation to silt, is further increased owing to its higher water absorbtion. Unlike sand, silt has lower moisture content, and in the case of rapid thawing the shortage of water content in silt, in relation to its laboratory calculated potential hygroscopicity, can be as much as 8 per cent. Thus, in spring-time the inversion of the material weight is up to 0.05 g/ccm, which, together with low limit of fluidity of the ground (< 0.025 g/ccm), very uneven line dividing the sediments, and 10°—15° slope of the surface provides the required conditions for the development of convection instability.

The narrow end of the structure is a frost fissure filled with material from the upper horizon. However, the fissures in this area, similarly as in many other areas of the present sub-arctic, only sporadically attain the base of the active zone (the depth is here no more than 1.2—1.3 m), their width does not exceed a few millimeters, and they play a clearly secondary part in the formation of disturbances. They are chiefly a sort of van-guard for the convection processes which start in the zone in which the fissures occur. This is evidenced by embrional narrow sand-veins (particularly in places of shallow thawing), changing downwards into hair-thin ice veins. The general tendency in the development of a wedge-like structure is to expand downward. Such a situation can be observed in many places of a polygonal system (pl. 5).

It is interesting that none of the convection structures nor any of the sand-filled frost fissures penetrate to very base of the active zone. This is attributed to the fact that the upper horizon is almost completely saturated with moisture and, therefore, has a maximum density (specific gravity is about 2.00 g/ccm). This condition prevents both further progress of convection (for the sand in the veins will have already lost part of the moisture down to a little over 1.90 g/ccm) and fixation in the profiles of the hair-thin winding veins. This, and the facts described above are indicative of complete analogy between the discussed structures and all the peculiarities of the present active zone. It means, therefore, that from their very beginning these structures have been ground structures of climatic origin (i. e. they bear no relation to the melting of vein ice) and that they are quite young (dating back to a few hundred years ago, similarly as the valley edge itself). Admittedly, deeper cracking of the permafrost would promote formation of ice veins. Their melting would cause subsidence of the upper horizon and, consequently would result in the formation of genetically and morphologically mixed forms (under favourable conditions the process of convection may take place even during the formation of pseudomorphoses alone). It is hardly probable that ice veins of any considerable width could form under geological-geomorphological and permafrost conditions as described.

There is little doubt that if the similar forms had been found in fossil state or near the surface, following serious climatic changes (e. g. disappearance of permafrost), the majority of investigators would have regarded them as relicts of some ancient ice veins, i. e. pseudomorphoses, and the upper sand layer in the polygons as the active zone with underlying permafrost. This example shows how misleading such a view-point would be. At the same time this example disproves the conviction that the structure in vertical profile has to bend in the base part of the active zone, although it does not exclude the possibility of such cases (see below).

One of the numerous varieties of the wedge-like structures is presented in pl. 6. The ground veins exposed in the 1st supra-inundation terrace occur below the polygonal grooves and are spaced 10—20 m apart. Unlike in the previous case, these veins were formed as a result of penetration of a material highly changed by soil processes. Specific gravity of the material exceeds that of the underlying parent sediments by a few hundredths of a gramme. These veins were also formed owing to frost cracking. The formation of so well developed podsol soil must have taken place in the Holocene Climatic Optimum since at the time of its formation (probably very late Pleistocene: Sartanian Period) the terrace surface was overgrown, as it is at present, only with tundra vegetation. It was at that time that structures 2.5—3.0 m deep were formed, which would indicate that hypothetical depth of the active zone in sands is 2.5—3.5 m during the optimum period and 1.5—0.8 m in the later period. The gradual cooling of the climate led to a decrease in the depth of the active zone down to the values observed today. In many cases the upper convection depression-shaped structures occur very near the permafrost top, they even seem to rest on it. The lower parts of the structures were the first to be fossilized. They escaped the processes of convection and preserved their frost-fissure character. The tips of the largest veins, beneath the base of the maximum Holocene thawing resemble, as it were, fine ice veins (partly ground-ice veins) i. e. an older element of the polygonal system. The fine ice veins intersecting the system of ramified ground veins in the lower sections of some structures are a completely present-day phenomenon. Even today disturbances may deevlop along the terrace edge in a zone of deep thawing and exposed by the action of river. A similar process took place in the past.

On the grounds of what has been said above it is possible to conclude that there are many morphologically similar phenomena that are genetically different: from purely diagenetic, aclimatic—convection—dilatational and syneretic structures originated under aqueous conditions to purely climatic—convection and fissure—convection structures and structures wholy associated with frost-cracking within the active zone in a cold climate. (The series does not include pseudomorphoses after typical ice veins and notably differing from the above described structures both with regard to their morphology and vertical and horizontal distribution. Here belong also intermediate processes, such as melting of ice veins, which were discussed against the above particular phenomena.)

It is to be stressed that the similarities between the described forms are due, in the first place, to the universal process of gravitational convection (associated with solifluction on sloping surfaces). The process predominates under all natural conditions and determines the similarities of resulting structures. The similarity of dilatation, syneretic and frost fissures is also very great; they all are similar in morphology (isomorphism or convergence) due to homogeneity of the ground.

The mentioned circumstances impede good insight into the genesis of the fossil wedge-like disturbances. Here are the most important criteria and methods which used jointly, may help to solve the problem:

(1) interrelation between the size of recent and fossil polygons and their distribution, both in N—S and W—E directions;

(2) the interrelations between the depth of structures and the diameters of polygons (lack of interdependence would exclude convection as the primary process and would confirm the initiating role of frost cracking);

(3) thorough investigation of the morphology of disturbances;

(4) pedological and chemical examinations in order to find traces of soil processes that would be indicative of subaerial conditions of the deformations;

(5) understanding of the physical and mechanical properties of ground and its microstructure both in relation to solifluction, dilatation and syneresis and processes leading to frost cracking;

(6) mechanism of the essential diagenetic and frost processes and their interrelationships;

(7) consideration of the general problems in interpretation of the particular profiles and reconstruction of the paleogeographical conditions prevailing over large glacio—periglacial areas and especially while using mathematical methods for the determination of limits of permafrost occurrence and depth of the active zone.

Most of the criteria and methods are used in studies of the so-called cryoturbations and involutions, i. e. fold-type convection disturbances originated under subaerial and subaqueous conditions, and also of their present-day related structures — stone polygons and earth-circles associated directly with dilatation forms and desiccation cracking or showing no such relations (pls. 7, 8).

Many problems remain still unsolved. The data which would make it possible to determine the interrelation between the size of the veins and the polygon diameters are still only fragmentary (as related to Eurasia). The differences between the syneretic or dilatation (i. e. diagenetic) and frost fissures and the fact that the fissures belonging to the first group seem to imitate those belonging to the other group are not clearly explained. In fact, no investigations aimed at full explanation of the mechanical and physical properties of ground from the point of view of the wide variety of combinations found in nature have been carried out.

The origin of pseudomorphoses after ice- and ground-veins (which are of basic, and for some territories even of paleogeographic importance) remains still unsolved. In most careful and detailed analysing of fossil wedge-like structures it is necessary to regard a possibly great number of doubtless contemporary forms and to pay attention to the fact that these structures are formed by melting of vein ice under various conditions.

From the new data and as a result of critical re-examination of his previous views the present author is convinced that there is an interrelation between the dimensions of the structures and their intervals, in accordance with the convection hypothesis. This is a characteristic phenomenon of the interfluves and of the lower surfaces within the glacio-periglacial zone: Privalovo, Odincovo—Otradnoye, Zagorsk—Bolševo, Bryansk—Smolensk, Kiryanovo (presented at the Symposium), in many areas of the Pečora lowland, in the northern part of Western Siberia, etc. In each of those sites the structures betray all characteristics of convection structures, often without fissures below.

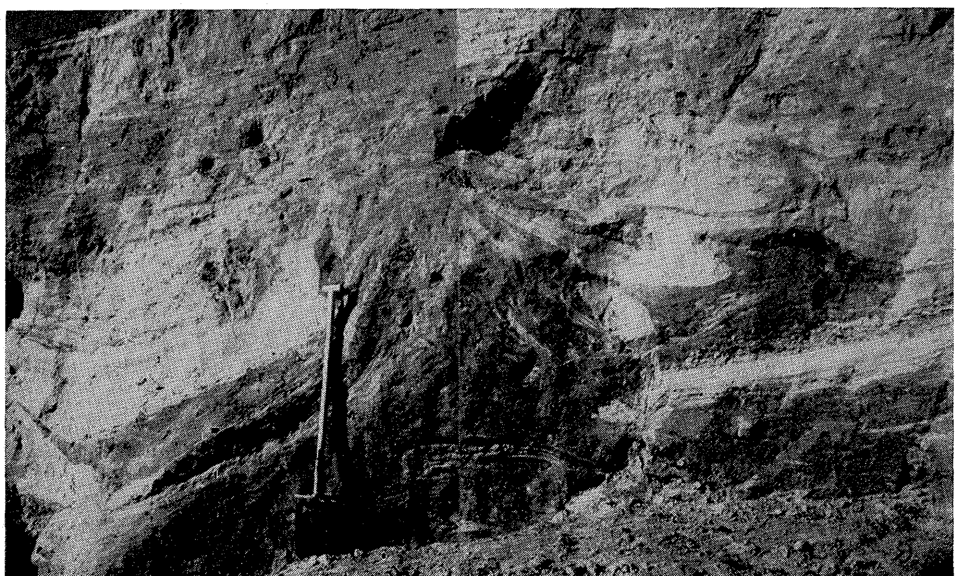
In considering these facts (compared with the above discussion of the genera characteristics of the vast areas lying south of the ice-sheet front) the author has no choice but to uphold the subaerial—subaqueous and subaqueous—subaerial hypotheses, adding the following very general variants: the polygonal relief and structures on the interfluves were formed as convection and convection—dilatation forms, more rarely as syneretic forms in subaqueous environment and during transition of the area to subaerial regime and were, therefore, subjected to frost-cracking (but not everywhere); the disturbances on the terraces were developed mainly under subaerial conditions and hence their genesis is of crack—convection nature (some of the fissures are frost cracks). It is not yet clear whether in the glacial—periglacial plains there was forming a layer of active zone of permafrost resembling the active layer of the present—day subarctics with active processes of gravitational plastic transportation of material and, in the higher latitudes and in north-eastern Siberia, with frost-cracking of the ground. If that was the case, the questions arise what are the interrelations between the structures formed in this layer and the preceding purely diagenetic disturbances; where was the south border-line of the climatically conditioned polygonal relief forms; what part was played here by permafrost and what was its most probable extent in the particular periods of the Pleistocene. Answers are required for the above and for many more questions. Progress in the periglacial studies will mainly depend on a quick consistent implementation of the principle: structure (morphology)—material (considered in all aspects of its various properties)—paleogeography, instead of the outdated principle: structure—paleogeography.

There is, however, a concept that enables a direct approach to the discussed problems. According to this concept, the polygonal relief of the main glacial—periglacial zone has never had anything in common with ice veins. The concept is strongly borne out by the described structures. These will have to be further corroborated by the following statements:

Pl. 1. A wedge-shaped intrusion of the dark-grey glacial silt, containing a sea molusca and foraminifera, into the underlying fine-grain sands (convection subsidence of the second phase of instability)

The asymmetry of the form can be clearly seen. To the left of the middle part of the structure and to the right in the upper part we can see intrusion of silt into sand and sand into silt, characteristic of the compensatory penetration of the sediments, so -called ear-type forms, so characteristic of the ground veins in Pleistocene formations. Below the tip of the ground vein there is a wedge-shaped form built of the underlying sediments. Section in low coastal watershed surface (30 m above sea level) in the Šapkin valley (lower Pečora basin), 4.5 m from the surface

Photo by the author



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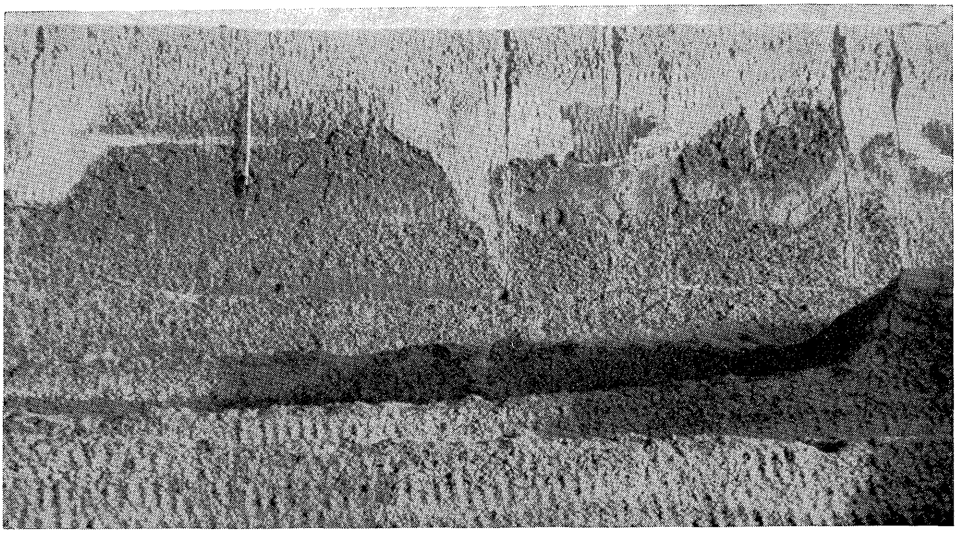
Pl. 2. Convection structure of the central type (second phase of instability): a large diapir composed of the lower moraine constisting of unstratified and stratified glacial silts and loamy sands

On the diapir wings there are numerous horizontal folds resulting from subaqueous plastic down-creeping of the material. Likhvin profile on the left bank of the Oka, 150 m above sea level, 15 m from the surface



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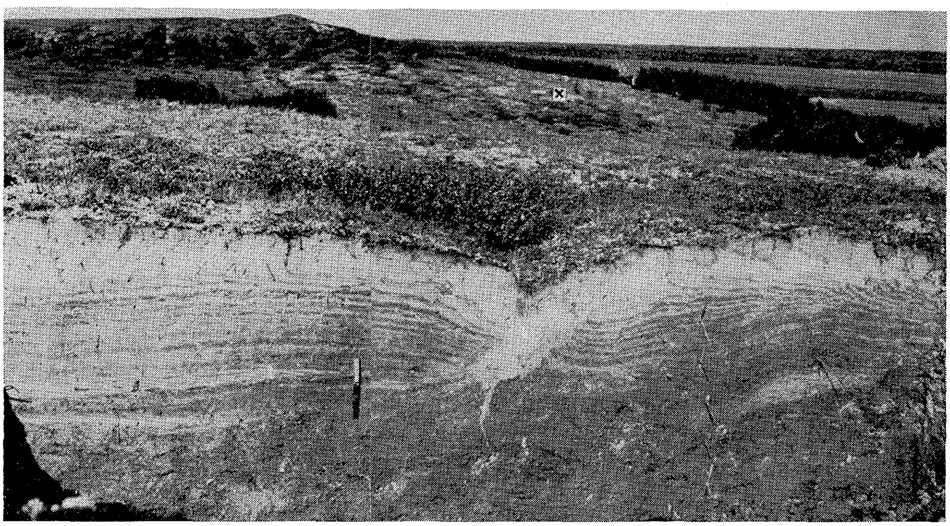
Pl. 3. Ground-wedge structures of the convection and convection-fissure origin

Loess (80-90% of 0.1-0.005 mm particles) is lighter in colour; sand-dusty coarser silt is darker and towards the base it passes gradually into the glacigenic silt. The 0.2-0.3 m thick upper layer has been removed by a bulldozer. Sidorovsk brick-yard near the station of Privalovo (SSW of Moscow). Watershed, 175-180 m above sea level



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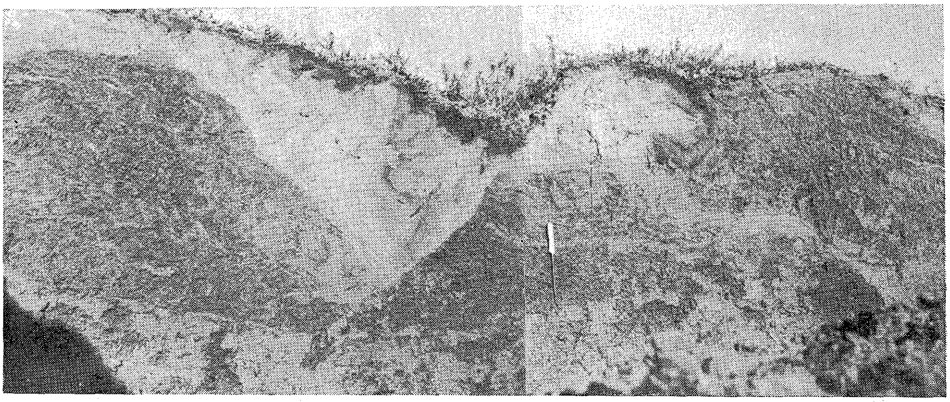
Pl. 4. Cross-section through a ground vein in the depression of the present-day polygons on a slightly sloped (2—4°) segment of the middle part of III terrace of the river Taz (neighbourhood of the hamlet of Tazovskoye)

At the base of the vertical face, to the right, the permafrost, developed in mid August 1968. In the background — III terrace surface and the sloping segment, with polygons, descending toward the valley of a small stream; X — the point of the section of the ground vein shown in pl. 5



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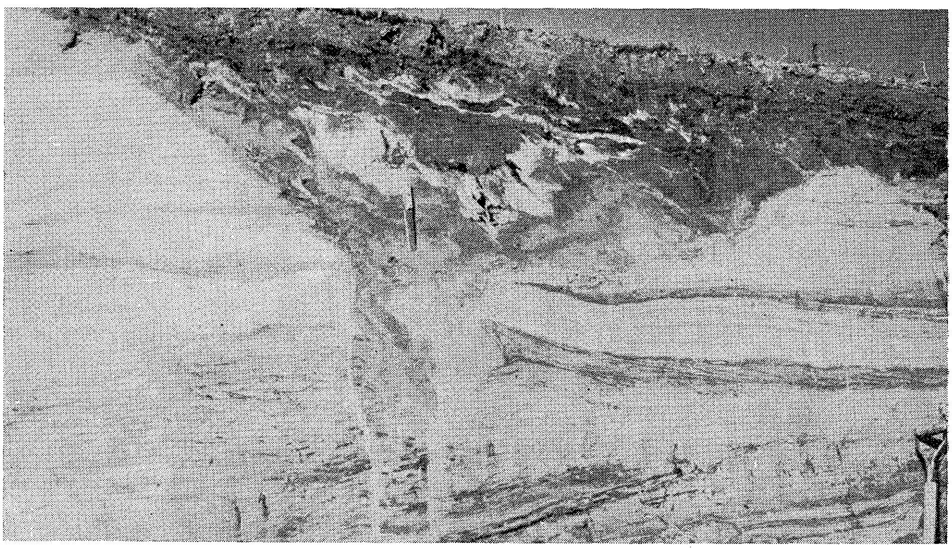
Pl. 5. Cross-section through the ground vein in the depression of the polygons on an 8—12° surface, shown in the background on pl. 4

Interpolygonal trough is oriented down the surface sloping to the right. The intense displacement of the ground within the well-developed structure has been completely stopped by frost fissures (new fissures are not evident in the section); owing to lateral migration of the material on the sloping surface the vein became asymmetrical, as a result of intrusion of sand which pushed the silts in the opposite direction to the slope; sand from the upper part of the right-hand polygon migrated into the depressions surrounding the polygonal blocks; a "hanging", wing of the structure with clear traces of sand and soil intrusions into the silt is well seen to the right of the trough; to the left of the vein are the „ear-shaped" forms due to turbulent-compensation movement in the contact zone; right-hand side — a distinct line of slide; at the bottom — sufficiently water saturated horizon



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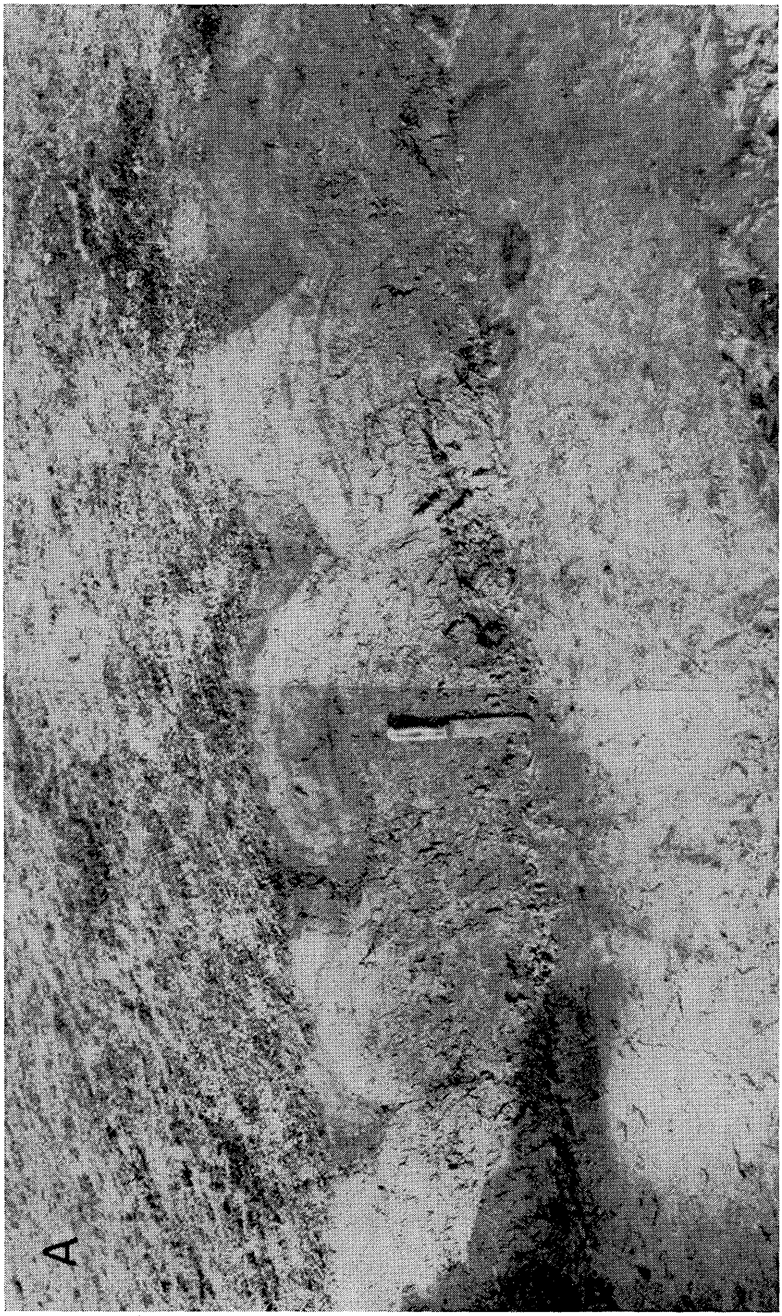
Pl. 6. Ground vein in the I terrace of the river Vesako-Yakha (tributary of the river Taz, south of the hamlet of Tazovskoye)

Well bedded structure — upper convection hole and lower fissure, partly affected by convection processes. The section is 45° to the vertical axis of the structure. In the top — the layer of wind-blown sand wedging out completely ca. 20 m from the section



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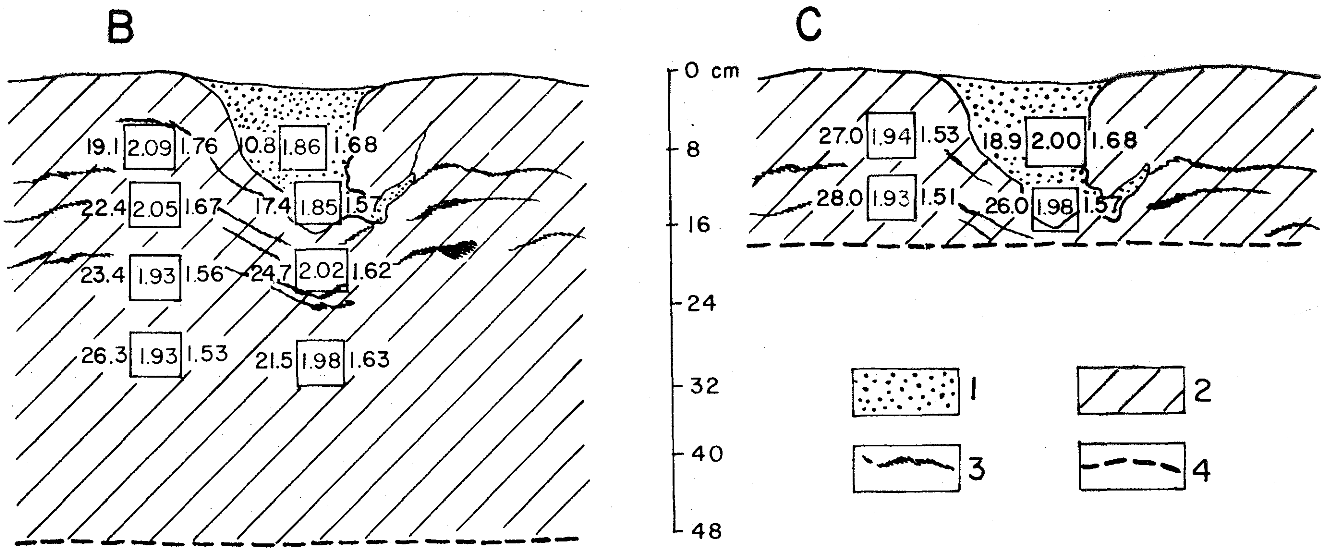

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Pl. 7. Typical non-sorted circles in the Subarctic (III terrace in the region of the gulf of the Ob, SW of the hamlet of Nyda)

A — convection structure of the border-type, in II and III stage of instability, adjoining the desiccation cracks filled with ice (visible on the horizontal surface of the permafrost top) at the bottom, on the left.

Under the furrows, below the pockets of wind-blown sand — also over the convex polygons — there appear patches of ferruginous material which clearly continue as thin horizons in the polygon centres; this points to the compensational (i.e. convection) character of the movement, and is also evidenced by the ratio of the depth of the disturbance zone to polygon size which is typical of convection — approximately 1:2; taking as an example the left-hand furrow it can be seen that, as a result of cracking, the pocket assumes a wedge-like shape

B — a scheme of interrelation between the weight by volume and the moisture of the ground under the polygonal furrow and in the center of the polygon. The true density on 26th June, 1969, is given inside the squares, the density of the skeleton material is given at their right-hand sides, and the moisture content of the ground at the left. There is a distinct inversion of the compaction of ground in the polygon, due to the downward heaving of the silt, towards the top of permafrost. Within furrow zone the silt has a higher density, which is probably the result of the pressure exerted by the sandy pocket; the sediments of the most upper part in the profile (especially sand) are already remarkably dried.

C — probable relation between the weight by volume and moisture of the ground at the beginning of thawing (weigh by volume is given inside the squares, values of the density of skeleton material are placed right of the squares). The silts in the state of heaving (weight by volume of the lower sample was calculated at moisture content approaching the complete water-saturation and corresponding to the skeleton; the upper sample at moisture content 1 per cent less and correspondingly higher skeleton density); sand — in the state in which the pores were almost completely filled with water (the lower sample calculated at the maximum moisture content and the upper at moisture content lower by 3 per cent). There are inversional relations in the density of the sediment, characterized by unusually low compactness, which leads unavoitdably to the development of the convection instability

1. brown-grey fine-grained sand; 2. bluish-grey silt; 3. ferruginous horizons in the silt; 4. top of permafrost

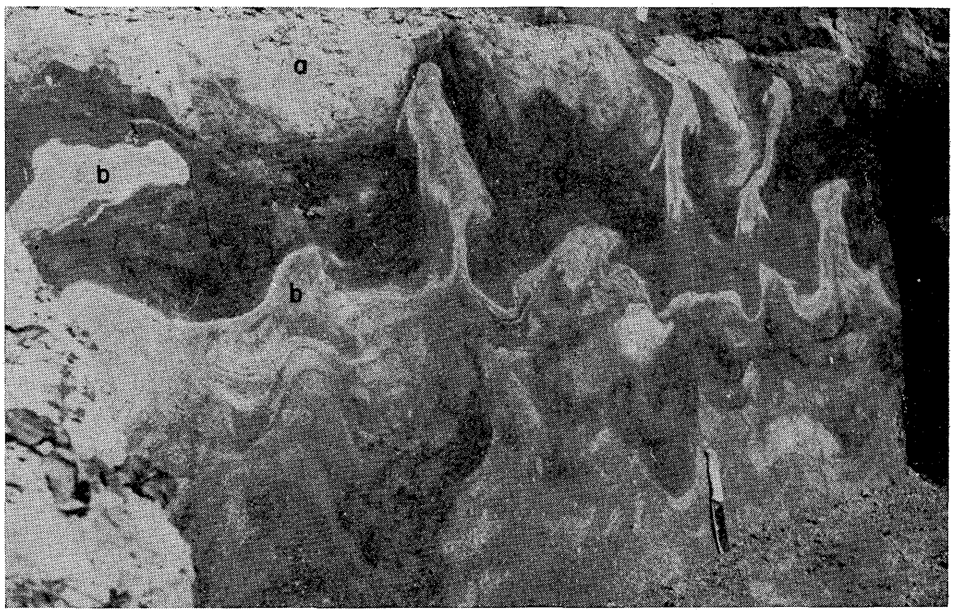

Photo by the author

Pl. 8. Example of fossil complex fold-like deformations in subaerial-subaqueous sediments

At the top — central subsidence in II and III phase of convection instability on the boundary line of the upper part of the yellow loess-like silt (loess "a") and the black, strongly organic silt (muddy-humus horizon of the Dneper-Valdai (?) "b" — soil). Between the „drops", as well as within the silts below there are the diapirs of whitish podzolic horizon — "c" (developed III stage); in some places the "drops" are detached from the parent layer and become "floating" (IV stage). At the base of the soil profile the movement ceases. Likhvin profile, 5 m from the surface

1. The ground veins are clearly related to the boundary between different material.

2. The upper sections of wedge—like structures are remarkably close to the surface (only 0.3—0.5 m), which would indicate an improbably small depth of the supposed freeze—thaw layer in areas lying at relatively low latitudes which, in the Pleistocene would have undoubtedly had a high degree of solar radiation and high continentality. On the other hand, accepting this depth of the active zone (similar depth is observed in the northern parts of the Yana—Indigirka plain) one has to admit that the air mean annual temperatures are uncommonly low — at least —12°C, —13°C, in the latitudes of Bryansk—Smolensk (even without allowing for a considerably lower organic content of the ground and higher seasonal amplitudes of the temperature) and, therefore, if the mean annual temperature were lower by 16—17°C the permafrost limit would have run through central parts of the Middle East and northern regions of the Mediterranean.

3. The geological and morphological as well as permafrost—facial conditions of development of the ground veins are clearly unrelated to a majority of the ice wedges, whether fossil or still in progress.

Thus, for all possible conditions the conclusion presents itself clearly enough: the structures, esp. their lower portions, are primarily ground forms as was observed by A. I. Popov already long ago. Now, it is necessary only to choose between the different modern variants of the hypothesis and select those which do not contradict one another.

Accordingly, the term *periglacial* has a very broad meaning, both spatially and morphologically. This is a paragenetic complex of different phenomena accompanying near-glacial areas. They include the climate and weathering processes, vegetation, fauna, but first of all morpho-lithogenesis which according to the old idea of „periglacial" constitutes one of the most specific elements of the complex and determines the other elements. The modern periglacial areas have many characteristics in common with non-periglacial areas.

Distinct differences in the natural environment of the past periglacial zone of western Eurasia and of the present periglacial areas of high latitudes (Greenland, Antarctica and others) depend on climate and tectonics. Due to small changes in the size of the ice-cap of Antarctica and Greenland during the Pleistocene the adjacent aresa were tectonically stable. But in western Eurasia Pleistocene glacial isostasy caused great tectonic movements, mainly depression, leading to the overflooding of the glacial—periglacial plains and therefore to the formation of a thick cover of aqueous sediments containing boulders. These sediments underwent diagenesis. The climatic conditions of the old periglacial zone were milder than those observed at present over the ice-free areas of Antarctica and Greenland because it was situated farther south and remained under modifying influence of the great water-basins adjacent to southern borders of the Pleistocene ice-sheets.

Though the contemporary periglacial zone can be referred to as cryogenic zone, there is no sufficient reason for the ancient (fossil) zone, and, in consequence, for the whole term *periglacial,* to be referred to in that way.

In relation to the old periglacial plains, because of their lithogenesis, the term „ice-glacier-reservoir" plains would be more proper, and the structure formation could be described as diagenetic and permafrost—diagenetic.

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References

ARTYUŠKOV, E. V., 1965 — Obrazovanie konvektivnykh deformacii v slabolitificirovannykh osadočnykh porodakh (Formation of convexion deformations in feebly lithified sedimentary rocks). *Izv. Akad. Nauk, ser. geol.*, no. 12.

ARTYUŠKOV, E. V., 1969 — Četvertičnye oledeneniya i transgressii v Zapadnoj Sibiri (Quaternary glaciations and transgressions of Western Siberia). *Izv. Akad. Nauk SSSR*, ser. geol., no. 7.

BERG, L. S., 1947 — Less kak produkt vyvetrivaniya i počvoobrazovaniya (Loess as the product of weathering and soil formation). *In*: Klimat i žizn; Moscow.

BONDARČUK, V. G., 1965 — Zakonomernosti rasprostraneniya lessovoj formacii i principy ee stratigrafičeskogo podrazdeleniya (Distribution of loesses and the principles of their classification). *In*: Materialy po četvert. periodu Ukrainy; Kiev.

BUTRYM, J., CEGŁA, J., DŻUŁYŃSKI, S., NAKONIECZNY, S., 1964 — New interpretation of "periglacial strucıures". *Folia Quaternaria*, 17; Cracow.

DEMEK, J., 1969 — Plejstocenovye kriogennye obrazovaniya (résumé: Formations cryogènes de pléistocène). *In*: Less—periglacial—paleolit na territorii srednej i vostočnoj Evropy; Moscow.

DOROFEEV, L. I., 1961 — Mineralogičeskij sostav i usloviya formirovaniya moreny maksimalnogo oledeneniya v srednem Pridneprove (Mineralogical composition and origin of the moraines of the maximum glaciation within the area of the middle course of the Dnepr). *Četvertičnyj period*, vyp. 13, 14, 15; Kiev.

DOSTOVALOV, B. N., KUDRYAVCEV, V. A., 1967 — Obščee merzlotovedenie (General cryology). Moscow.

DYLIK, J., 1964 — Elements essentiels de la notion de "périglaciaire". *Biuletyn Peryglacjalny*, No. 14.

DYLIK, J., 1965 — Right and wrong in sceptical views on the problem of periglacial phenomena revealed in Pleistocene deposits. *Bull. Soc. Sci. Lettr. Łódź*, vol. 16, no. 8.

DŻUŁYŃSKI, S., WALTON, E. K., 1963 — Experimental production of soil markings. *Trans. Edinburgh Geol. Soc.*, vol. 19.

FEDOROVIČ, B. A., 1962 — Merzlotnye obrazovaniya v stepyakh i pustynyakh Evrazii (Periglacial phenomena of Eurasiatic steppes and deserts). *Trudy Kom. po izuč. četvert. perioda*, Akad. Nauk SSSR, t. 19.

GERASIMOV, I. P., 1939 — Relief i poverkhnostnye otloženiya Evropejskoj časti SSSR (Land—relief and surficial deposits of the European USSR). *In*: Počvy SSSR, t. I; Moscow.

GORECKIJ, G. I., 1961 — Genetičeskie tipy i raznovidnosti otloženij periglacjalnoj formacii (Genetic types and varieties of periglacial deposits). *In*: Materialy po genezisu i litologii četvert. otloženij; Minsk.

JAHN, A., 1969 — Structures périglaciaires dans les loess de la Pologne. *Biuletyn Peryglacjalny*, No. 20.

JAHN, A., CZERWIŃSKI, J., 1965 — The role of impulses in the process of periglacial soil structure formation. *Acta Univ. Vratislaviensis*, 44.

KATASONOV, E. M., 1962 — Kriogennye tekstury, ledyanye i zemlyanye žily kak genetičeskie priznaki mnogoletnemerzlykh četvertičnykh otloženij (Cryogenic textures, ice- and ground-veins as genetic features of Quaternary permafrost). *In*: Voprosy kriologii pri izučenii četvert. otloženij; Moscow.

KOSTYAEV, A. G., 1965 — O yužnoj granice podzemnogo oledeneniya i periglacialnoj zone v četvertičnyj period (On the southern boundary of underground glaciation and on the periglacial zone in the Quaternary period). *Podzemnyj led*, vyp. 2.

KOSTYAEV, A. G., 1968 — Nekotorye problemy četvertičnoj geologii severa Evropejskoj časti SSSR i Zapadnoj Sibiri (Some problems of Quaternary geology of the European USSR and of Western Siberia). *In*: Kajnozojskaya istoriya Polarnogo bassejna i ee vliyanie na formirovanie landšaftov prilegayuščikh territorij; Leningrad.

KOVDA, V. A., SAMOJLOVA, E. I., 1966 — O vozmožnosti novogo ponimaniya istorii počv Russkoj ravniny (On the possibility of a new interpretation of the history of soils of the Russian plain). *Počvovedenie*, no. 9.

KVASOV, D. D., 1963 — Vliyanie oledeneniya na razvitie gidrografičeskoj seti Russkoj ravniny (Influence of glaciation on the development of drainage system of the Russian plain). *Trudy Labor. Ozerovedeniya Akad. Nauk SSSR*, t. 15.

LAZUKOV, G. I., 1965 — O svyazi meždu četvertičnymi oledeneniyami i transgressiyami na severe Evrazii (On the interrelation of Quaternary glaciations and marine transgressions in northern Eurasia). *Trudy NIIGA*, t. 143; ed. Nedra.

LUKAŠOV, K. I., DOBROVOLSKAYA, I. A., LUKAŠOV, K. V., 1966 — Obrazovanie lessovykh porod na territorii Belorussii (The development of loess deposits within the territory of Belorussia). *In*: Sovremennyj i četvert. kontinentalnyj litogenez; Moscow.

MARKOV, K. K., VELIČKO, A. A., 1967 — Četvertičnyj period (The Quaternary Era). T. 3; Moscow.

MARKOV, K. K., LAZUKOV, G. I., NIKOLAEV, V. A., 1965 — Četvertičnyj period (lednikovyj period — antropogenovyj period) (The Quaternary period). T. 1, 2; Moscow.

PÉCSI, M., 1969 — Periglacialnye obrazovaniya (résumé: Les formations périglaciaires). *In*: Less — periglacial — paleolit na territorii srednej i vostočnoj Evropy; Moscow.

PÉWÉ, T. L., 1959 — Sand-wedge polygons (tesselations) in the McMurdo Sound region, Antarctica. *Am. Jour. Sci.*, vol. 257.

POPOV, A. I., 1962 — O psevdomerzlotnykh obrazovaniyakh (On pseudoperiglacial phenomena). *Vestnik Moskovskogo Univ.*, ser. geogr., No. 3.

POPOV, A. I., 1967 — Merzlotnye yavleniya v zemnoj kore — kriolitologiya (Cryogenic phenomena in the earth's crust — cryolithology). Moscow.

ROMANOVSKIJ, N. N., BOYARSKIJ, O. G., 1966 — Poligonalno-žilnye ldy i gruntovye žily v severo-vostočnoj časti Vitimo—Patomskogo nagorya (Polygonal-vein ice and ground veins in the north-eastern part of the Vitim—Patom upland). *Merzlotnye issledovaniya*, vyp. 6.

ŠANCER, E. V., 1966 — Očerki učeniya o genetičeskikh tipakh kontinentalnykh osadočnykh obrazovanij (An outline of the study of genetic types of inland accumulational formations). *Trudy Geol. Inst. Akad. Nauk SSSR.*, vyp. 161.

ŠČUKIN, I. S., 1963 — O tak nazyvaemykh „periglacialnykh yavleniyakh" (On the so-called "periglacial phenomena"). *Vestnik Moskovskogo Univ.*, ser. geogr., vyp. 5.

SPIRIDONOV, A. I., 1957 — O proiskhoždenii pokrovnykh suglinkov (On the origin of covering silts). *Zemlevedenie*, nov. ser., t. 4 (44).

STRELKOV, S. A., SAKS, V. N.. ARKHIPOV, S. A., VOLKOVA, V., 1965 — Problemy četvertičnykh oledenenij Sibiri (Some problems of the Quaternary glaciations in Siberia). *In*: Osnovnye problemy izučeniya četvert. perioda; Moscow.

SUKHODROVSKIJ, V. L., 1967 — Reliefoobrazovanie v periglacialnykh usloviyakh (Landscape development under periglacial conditions). Moscow.

SVENSSON, H., 1962 — Ice-wedges in fossil tundra polygons on the Varanger peninsula. *Svensk Geogr. Årsbok*, 38.

WASHBURN, A. L., 1956 — Classification of patterned ground and review of suggested origins. *Bull. Geol. Soc. America*, vol. 67.

VELIČKO, A. A., BERDNIKOV, V. V., 1969 — Kriogennye obrazovaniya (Les formations cryogènes). *In*: Less — periglacial — paleolit na territorii srednej i vostočnoj Evropy; Moscow.

ZARRINA, E. P., KAPLYANSKAYA, F. A., KRASNOV, I. I., MIKHANKOV, Y. M., TARNOGRADSKIJ V. D., 1961 — Periglacialnaya formaciya Zapadno-Sibirskoj nizmennosti (Periglacial formations of the West-Siberian Lowland). *Trudy VSEGEI*, nov. ser., vyp. 4.

ZUBAKOV, V. A., 1968 — Šelfovo-lednikovaya formaciya Zapadnoj Sibiri (Glacial shelf formations in Western Siberia). *Biul. Kom. po izučeniyu četvert. perioda*, Akad. Nauk SSSR, No. 34, 35.