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LATE PLEISTOCENE PERMAFROST PHENOMENA IN THE EUROPEAN PART OF THE USSR AND THEIR SIGNIFICANCE FOR PALEOCLIMATIC RECONSTRUCTIONS

The last 10 years, starting with the year 1971, have given new data on the distribution and the development of Pleistocene frost processes in the European part of the USSR. The total number of cross-sections in which the relic permafrost structures have been recorded exeeds 100 at present, including the sites formerly investigated. In the area of the European part of the USSR, they are irregularly distributed, with the greater part of cross-sections situated to the north of the line approximately running across the towns (from the east to the west): Orenburg—Saratov—Voronež—Černikov. A considerable number of cross-sections with the cryogenic structures is situated to the south of this line, within the Volhynia—Podolia Upland and the surrounding terrains.

Relatively few data have been gathered for the area of Belorussian SSR and for north-eastern terrains lying to the north of Jaroslavl, Kostroma, Kirov. It should be stressed, however, that northern and south-western terrains of the European USSR were covered then with the Valday ice-sheet.

In the discussed area it is possible to distinguish several regions with great amount of permafrost structures, which results from the fact that most of all investigations have been carried out here. A. A. Veličko has collected the basic materials during the investigations carried out in the vicinity of Smolensk, Briansk, and further to the south (Veličko, 1965, 1973).

Next, the fossil structures have been subjected to detailed investigations in the areas lying in the north (the region of the upper Volga) and in the west (the vicinities of Kaluga and Smolensk), and also in the north-east, (the vicinities of Kirov and Udmurt) where the author carried out his investigations in the years 1966—1979 (Berdnikov, 1970, 1976; Veličko, Berdnikov, 1970; Butakov *et al.*, 1978). The basic data attained in the Volhynia—Podolia area (Bogucki *et al.*, 1975) derive from this period as well as the single pieces of information about the fossil permafrost structures in the district of: Kirov, Penzan, Saratov.

Very important thing was the elaboration of the map of permafrost phenomena of the Late Pleistocene which is included in paleogeographical atlas of the

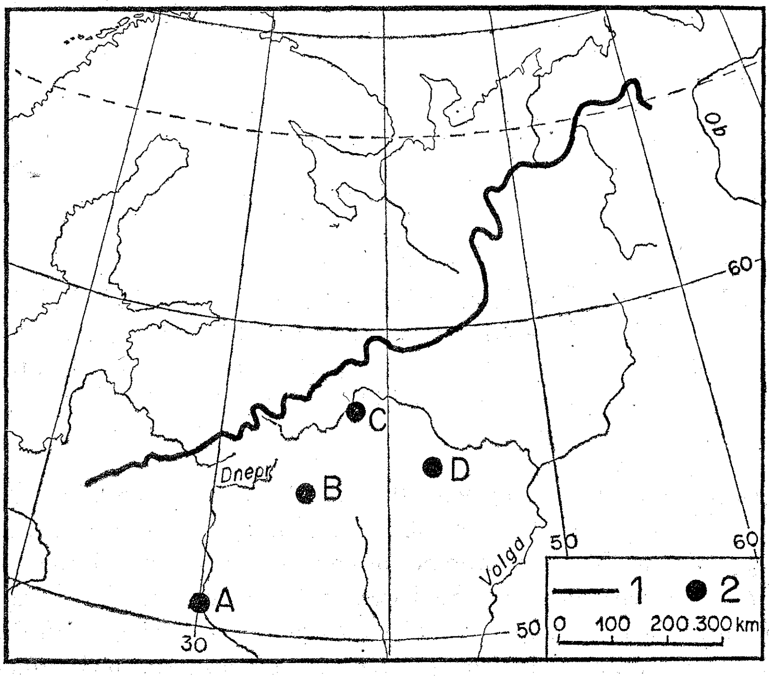

Fig. 1 Distribution of the sites with permafrost forms depicted in the paper
A — Cistogaylov; B — Gorokhovka; C — Kirianovo; D — Levino; 1. the boundary of maximum extent of the Valday ice-sheet, 2. cross-sections described in the paper

USSR (Gerasimov, Veličko, Spasskaya, 1980). Thus, in the domain discussed, the apparent growth in information concerning permafrost phenomena has followed and the increased knowledge about the investigation methods of the fossil permafrost has been gained. Simultaneously, and even in certain advance, the domain of applications of the new data in paleogeographical and paleoclimatic reconstructions has been growing.

The materials collected from the sites in which the fossil permafrost structures have been observed, differ in detail and do not cover the complex of the possible analyses. In connection with it, as early as during the marking of the data on the provisional collecting map, the division into several groups have been made, which has been reflected in the legend of the map. A group of sites has been distinguished in which the fragments of polygonal network, at least two wedge structures distributed one after the other are visible and their full characteristics is given. Within this group the wedge forms have been distinguished: a) from over 2.0—2.5 m to 4—5 m, b) the wedges of the size of 1.0—1.5 m. Such a division has turned out to be purposeful, for the vertical sizes of the wedges depend on the variation under permafrost and climatological conditions.

The sites in which well developed single wedge structures occur and are apparently connected with defined stratigraphical horizons, have been included in the seperate group. A large group is made by such places in which the occurrence of wedge-like structures has been recorded, but their stratigraphical position is not absolutely clear. The cross-sections showing the wedge forms either indistinctly fashioned or of the similar origin but different appearance have also been distinguished. The places in which the occurrence of polygonal networks have not been geologically investigated in the field but discovered by using the air photos make the group completely separated.

It should be added that in the set of sites, besides the ascertainment of the occurrence of fossil wedge forms or irrespectively of it, the texture properties of the ground have been investigated which also evidence the existence of fossil permafrost. However, the employment of the analysis of textural properties of the ground as a separate method of reconstructions of permafrost is limited and has not a detailed elaboration.

From the groups distinguished above, the first group is of greatest importance, because the profiles gathered in it make it possible, on the one hand, to attain the information about past permafrost and paleothermic conditions and on the other hand, they are the leading profiles for the vast areas adjoining to their places of occurrence. As our investigations in the river basin of the upper Volga have shown, the occurrence of full fragment of polygonal network in the cross-section not only defines the whole polygonal network of a given place, but, to some extent, characterizes all the province, including its lithological and geomorphological features. The extent of such provinces may be considerable, and the occur-

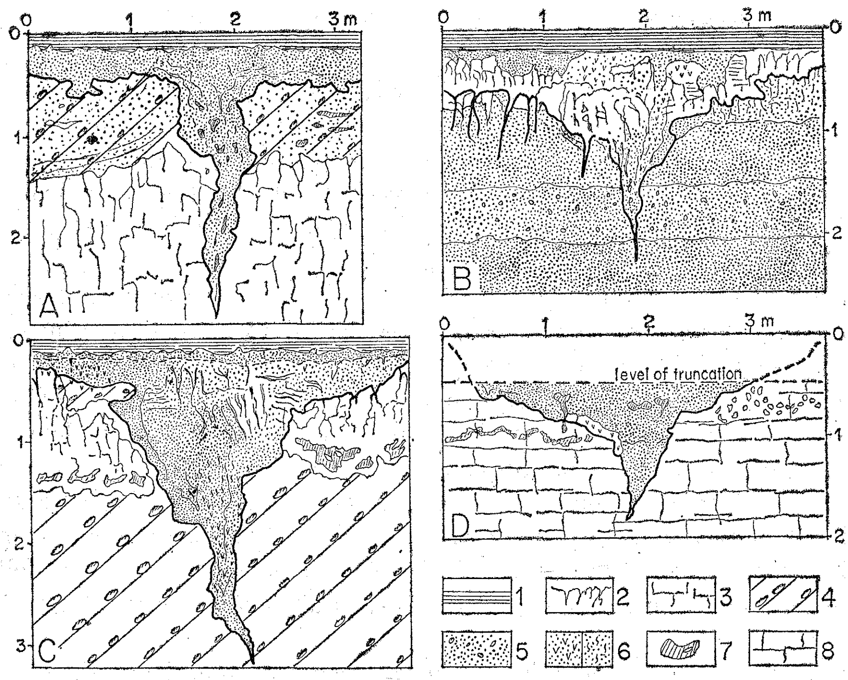

Fig. 2. The shapes of wedge structures from the four sites

A — Cistogaylov; B — Gorokhovka; C — Kirianovo; D — Levino; 1. gray sand with humus — the cultivated horizon; 2. light brown till; 3. light brown heavy till; 4. red brown till with gravel — moraine; 5. varied-grained sand; 6. varied-grained sand: a. with hard pan, b. with gley; 7. dark brown till with humus; 8. red heavy till

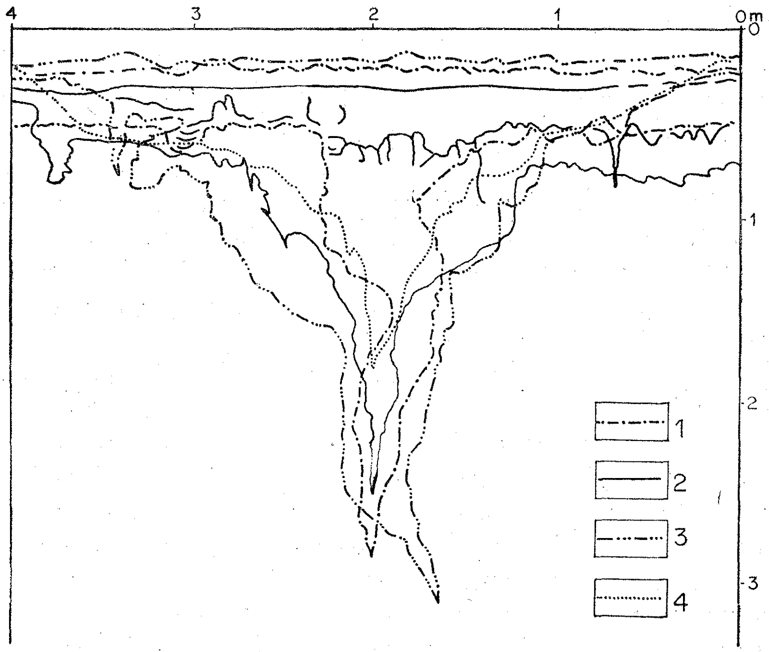

Fig. 3. The comparison of cross sections with the wedge structures
1. Cistogaylov (A); 2. Gorokhovka (B); 3. Kirianovo (C); 4. Levino (D)

rence of permafrost and the conditions corresponding to it in the past may be interpolated throughout 100 and more kilometers of the investigation places.

We do not present here the juxtaposition of all the data concerning the group discussed. The comparison of polygonal network fragments from the four sites from which the utmost lie over 1000 km away from each other gives a certain idea on its variation (Fig. 1).

In all the four cases the polygonal network of great dimensions was developed within the heavy moraine sediments. The first profile is situated near the Cistogaylov village which is about 100 km to NW of Kiev (the materials collected by V. P. Nečaev), where on the very top of the crest of the moraine of the Dnieper ice-sheet the wedge structure developed reaching almost 3.0 m in depth and having 1.0 in width in the upper part (Fig. 2A).

The second cross-section is situated near the Gorokhovka village, 15 km to SW of Yukhnov. Within the tripartite series consisting of silts sands and moraine silts the polygonal network developed, the dimensions of which are as follow: the wedges depth from 2.5 to 0.9 m, the polygon diameter amounts to 10—16 m (Fig. 2B).

The third profile lies near the Kirianovo village (2 km to the north of Uglič). The polygonal network cuts here the supra — and moraine silts down to the depth of 3.1 m; the polygon diameter: 12—17 m.

The fourth cross-section is from the neighbourhood of the Levino village in the district of Kirov. The polygonal network has been discovered where the wedges are of 1.2 m and 5.0—1.5 m in depth and occur at the distances of 4—6 m. They cut the thin alluvial layer with not too numerous gravel grains and heavy red tills belonging to the Tatar formation (Fig. 2C).

First, the analysis presented above is a proof that such comparisons are plausible i.e. that the traces of permafrost formerly existing have been revealed in all the cases, and moreover the forms preserved are absolutely comparable in such a vast area. Secondly, the undoubtful homogeneity of the origin of the structures and the great similarity in morphology of the investigated forms is apparent which once more forces the author to draw the conclusion about the similarity of natural conditions in the period of existence of permafrost (Fig. 3.) The conclusion is not new but illustrates well, to the author's mind, the thesis, formerly expressed by VELIČKO, of the existence of vast Late Pleistocene zone of permafrost (VELIČKO, 1965, 1973).

The examples mentioned above consitute only a portion of great number of cross-sections in which the polygonal patterns have been investigated in the area of the Russian Plain; they are characteristic because the polygonal structures excavated in them were developing in the heaviest sediments of moraine silts. It proves that just in such sediments the significant features of fossil permafrost polygons have been best preserved, which makes it possible to investigate them thoroughly. It is actually possible to distinguish in these cases such features as two-storeyed construction and asymmetry of polygonal structures, dimensions of particular wedge parts close to the original ones, i. e. vertical sizes and even the width of the top part of the structure. These are the features of permafrost polygonnals relief, which are of great importance for the reconstruction of polygonal patterns and the conditions of their formation.

The relic polygonal patterns evolved for a long time starting with the formation of permafrost and the polygons in accordance with contraction theory (DOSTOVALOV, 1952; DOSTOVALOV, KUDRYAVCEV, 1967; ROMANOVSKI, 1970; BERDNIKOV, 1972) through the period of degradation of permafrost up to the present state of their preservation. VELIČKO (1973) distinguishes three basic stages of production of relic cryogenic relief (Late Pleistocene polygonal patterns): I — the stage of the existence of permafrost; II — the stage of the degradation of permafrost; III — the stage of the complete decay of permafrost and the transformation of structures into the fossil state.

During each of the stages the relic permafrost structures were affected by various forces and processes. The effects survived most often in the sediments within which the structures developed as well as in the material filling them up. The whole complex of morphological features of the relic forms, from the moment of the formation of the polygons to the last stage of their existence may be observed in them. In general, however, in the cross-sections known to the author only few of the morphological elements survived and the succesion of their formation is not always absolutely clear. At present the following scheme may be accepted:

I stage — permafrost, establishment and development of polygonal networks, essential transformation of the host material (turning of the layers down in contact zones, the traces of uppushing, upfreezing, segregation of debris);

II stage — development of permafrost physical-geographical processes and thermocarst but without succesive degradation of permafrost, development of solifluction and cryoturbations;

III stage — degradation of permafrost, essential transformation of the surface (most active within the limits of 3—5 m layer);

IV stage — complete degradation of permafrost within the top tens of metres and appearance of water action (development of gley processes, the movement of snail shells downwards, fashioning of contact zones and secondary boundaries);

V stage — the cooling of the climate and increasing continentality, formation of small network of polygonal fissures (formation of soil fissures and ground veins);

VI stage — activation of soil processes, increase in thickness of humus and podsolic horizons;

VII stage — slopewash and segregation of the material, erosion of the top parts of soil profiles, infilling of the cracks;

VIII stage — final planation of the surface, fossilisation of the cracks (polygon furrows), eolian movement of local material (the end of geological history);

IX stage — man's activity in the areas (mechanical disturbances of the top parts of the cracks, changes in the base of erosion and in hydrological regime).

Even the above scheme shows that the significant changes in polygonal patterns, expressed in the morphology of the relic forms, should be reflected, to a varying degree, in the basic parameters. It is absolutely plausible to claim that the first of parameters — a distance between the wedges — is preserved, in fact, without changes in all conditions and left the same as it was at the beginning of development of polygons. Relatively rare cases constitute the exception where the structures developed in the ground underwent such a heavy transformation that they lost their morphological distinctness in the cross-section. The cases like these have been observed by the author in loose sediments i. e. in silts and fine sands, where only the secondary features like the inclusions of foreign material and snail shells etc. evidence the existence of permafrost structures.

Polygonal structures were undergoing the relatively intensive and frequent changes. It is possible to say that according to sediment lithology all the structures were transformed to a varying degree. The top parts of the structures developed in the heaviest sediments i.e. in moraine silts, underwent most intense changes, whereas the structures produced in loose sediments were transformed in the aggregate. In the vertical profile all the relic polygonal patterns were transformed and the determination of the degree of the changes constitutes our purpose. The length of the structures must have decreased, and the adhesion of the sediments must have grown together with the increase in ice contents in them when the polygons were formed and developed. The data should be evaluated and taken into account during the reconstructions of past permafrost.

The two-storeyed form of the wedges (Popov, 1957) is according to the author of great importance, because it reflects the difference between the conditions prevailing in the active layer and in frozen ground (tjäle), but the difference is not directly distinguished in cross-section details. Such a conclusion opposite to that drawn earlier has been made by the author as a result of the observation and the comparison of structure features excavated in the Russian Plain. During the thorough works in the basin of the upper Volga, the morphology of polygonal structures occurring in the cross-sections in different geomorphological position and in different sediments has been compared. The occurrence of the same size of the top storey of the wedge has been recorded — — its order of magnitude amounts to 1.4—1.6 m (Berdnikov, 1976). Comparing the data from the excavations situated closer to the south with those situated in the north, similar values have been achieved; sometimes, hovever, the author failed in determination of the boundary between the upper and the lower storeys of a wedge.

The observations mentioned above are commonly known; the author, however, claims that it should be stressed that the following things are important in the investigation of Pleistocene permafrost: (1) the analysis of details of the texture of the wedge structures and infilling material indicating the main stages of development of polygonal patterns. Moreover the discovering and the comparison of succesion of their development may constitute the basis for chronological comparisons of polygonal patterns, (2) the consideration of polygonal patterns (with taking into account all the analyses existing) in connection with other aspects of the existence of permafrost. In the investigations of the relic cryogenic relief of the polygonal forms make the base on which it is possible to distinguish the different investigations between the paleocryogenic elements (Berdnikov, 1976).

The reconstructions of conditions of the existence of Pleistocene permafrost have been caried out, with taking into account the mentioned remarks, for the vast regions, from the time when first generalizations of collected materials were made in the area of Russian Plain. Using the papers concerning the distribution of the relic cryogenic relief, the juxtapositions of events referred to Late Pleistocene permafrost have been made (Veličko, 1965, 1973; Aseev, Veličko *et al.*, 1973; Veličko, Berdnikov, 1969, 1978).

The approximate evaluation of temperature in the frozen sediments has been made at the level of the amplitudes of 0 °C and of permafrost thickness (Veličko, Berdnikov *et al.*, 1978).

In all the juxtapositions mentioned above the comparison of polygonal structures has not taken into account the division into groups or categories based on lithological features, and the characteristics of their development and occurrence has not been considered in all the places. In the end the wedge structures developed in the heavy moraine sediments have been compared with the collapse structures in the loess-like silts and in the loess.

Now, already possessing the elaborated and generalized data, attained during the works on the collecting of the maps included in paleogeographical atlas of the USSR, we try to take into account lithological and geomorphological properties of the sediments in which paleocryogenic structures occur. It has been said at the begining of the article where the author paid the attention to the fact, that all the mentioned cross-sections have been connected with the heavy moraine sediments or with the ones similar to them.

At present there is a real possiblility of the attainment of characteristics of the past permafrost conditions i. e.: temperature of the ground at the level of annual amplitide of 0°C, thickness of permafrost calculated on the basis of the average thermic gradient, approximate ice contents, and in the series of cases fabric of sediments. Such a characteristics is usually supplemented by the estimation of epi- or syngenetic type of the structures with reference to the sediments in which the structures occur.

Such a characteristics is, according to the author, sufficiently complete and allows to determine the conditions in which the polygonal patterns were formed and existed. The processes of production of the polygons including lapse rate in the top layers of permafrost have already been mathematically estimated (ROMANOVSKI, 1977). It has been emphasized that polygonal structures are of basic importance in the estimation of past permafrost conditions and not in the whole paleoclimate (ROMANOVSKI, 1977, p. 196).

It seems that such a characteristics of past permafrost conditions should not be carried out separately as the one referred only to the polygonal-vein patterns. It should be remembered that both during the investigation of most distinct and complete aspects of past permafrost ex. during the investigations of the fossil permafrost forms in the basin of the upper Volga, and in other cases the polygonal forms constitute the base of the whole complex of fossil phenomena (the phenomena of former periods).

In all the cases it is assumed the existence of severe climatic regimes with small precipitation, violent wind, faster than now changes of air masses, and the strong cooling. It is undoubtful that during the investigations of the one of most interesting Quaternary phenomena — the permafrost, we will gain more complete characteristics of natural and climatic conditions prevailing in the past, because the forms discussed responded fast to them and registered not only winter and summer oscillations, but also the local climatic changes.

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