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Iciness of the Russian Plain Loess Deposits at the Cryogene Stage of Late Pleistocene

Nasycenie lodem utworów lessowych Równiny Rosyjskiej podczas kriogenicznego etapu młodszego plejstocenu

Льдистость лёссовых пород Русской равнины в криогенный этап позднего плейстоцена

ABSTRACT

Current data on paleocryogenic study of loess sections in the Russian Plain allows to start quantitive evaluation of the former development of the ground and, first of all, reformed ice wedges. The loess horizons of the cryogenic stage of Late Pleistocene (from 35 to 10 ka BP) in the Russian Plain almost everywhere to the north of 49—50° NL are characterized by the presence of pseudomorphs of vein ice. Proceeding from the available data we determined volumetrical macro-iciness of former frozen loess deposits containing polygonal veine ice. From covering loess-like loams northern regions towards southern loess regions it changed from 15—10% to 5% and to minimum values in 48—49° NL.

In contrast to studies on definition of volumes and mass of ancient ice sheets and iciness of modern cryolithic zone the works on reconstruction and assessment of the underground ice within Pleistocene periglacial areas is still in an embryonal state. Since this issue refers to ancient periglacial areas we must discuss it first of all in the light of loess problem — the most important phenomenon of periglacial situations of the past. Regions most favourable for such reconstruction are those where loess rocks are widely distributed and the knowledge of their paleocryogenic features is rather high. In this way the territory of the Russian Plain is of obvious interest. The collected by to-day material on paleocryogenic analysis of loess sections allows to approach preliminary quantitative estimations of the former development of the underground, including evident ice and in the first turn ice wedges.

As it is known the maximum phase of their development reconstructed by numerous findings of pseudomorphs of ice wedges falls on the cryogenic stage of Pleistocene at the time interval from 35—30 to 10 ka BP (A. A. Velichko 1973a). The author has carried out a detailed paleocryogenic analysis of about one hundred sections in the west of the Russian Plain (Volyn'-Podolsk and Dnieper uplands). Loess horizons of the studied region stratigraphically located between the Holocene soil and fossil Dubna (an analogue of the Bryansk) soil, whose age according to radiocarbon dating is 23—29 ka, contain large wedge-shaped structures everywhere northward of 48—49°NL. Such structures were revealed to be clearly delineated not only in the lower narrow part but to be closed above by specific gleying layers up to 1.0—1.2 m thick. The structure of the latter allows to define them as a buried active layer of ancient perennial frost. Following combination of indicative features defines large wedge-shaped structures of the studied region as pseudomorphs of ice wedges (V. P. Nechaev 1980):

1. Contact zones of wedge-shaped structures are filled in with the material of the buried layer and are subvertical blocks of displacement downward. Consecutive block caving causes the step-like nature of the contact zone.

2. Central parts of structures are filled in with loess overlapping the active layer. Filling is compact with no evident traces of stratification.

3. Significant subvertical cracking of enclosing loesses at contacts with structural, plastic bending of crossed horizons of buried soils.

4. Vertical sizes of structures (below the foot of the active layer) amount from 4.0—5.0 m to 2.0—2.5 m, horizontal sizes — near the foot of the active layer — amount from 0.5—0.8 to 1.5—2.0 m (across the strike).

5. Dimensions of pattern grounds (polygons) reach 20—25 m on the mean.

Such a pseudomorph of ice wedges in one of the loess sections in Podolsk area is given on Fig. 1. Geomorphological conditions of their formation — watershed areas, peculiarities of enclosing rocks — silt deposits with small content of organic matter as well as the likely depth of the active layer not more than 1.0—1.2 m — allow to assume the ice veins to be formed under conditions close to those which exist at present only in the northern half of the zone of continuous permafrost. The conclusion on severe climate conditions of this time interval is confirmed by Ye. Ye. Gurtovaya data. At the Korshev section (Volyn' Upland) in

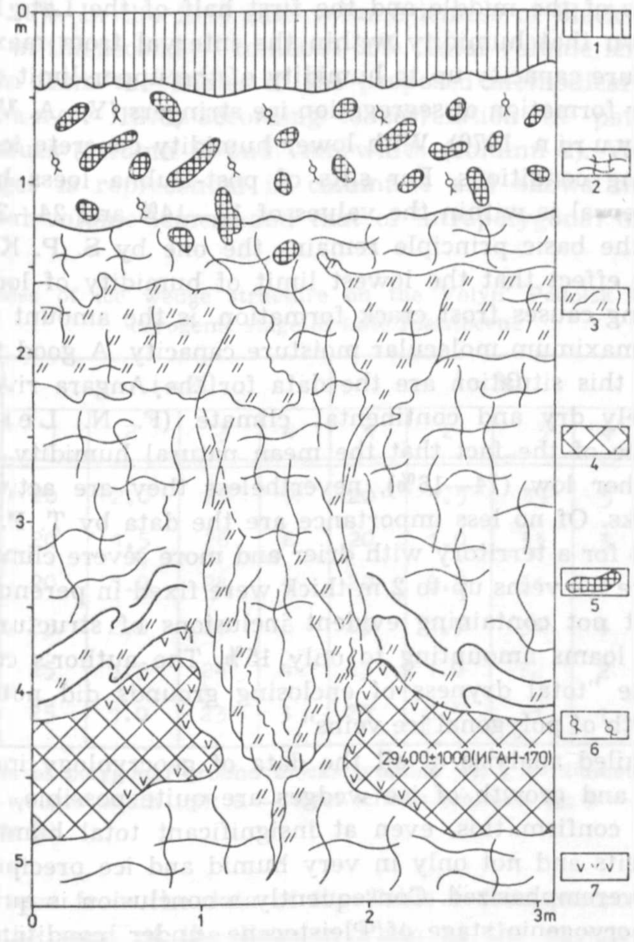

Fig. 1. Pseudomorph of ice wedge in the Krasnoselka section (Podolsk Upland)
1 — humus horizon of modern soil; 2 — loess; 3 — gleying loess-buried active layer; 4 — poorly humic loam-buried soil; 5 — krotovinas; 6 — carbonates; 7 — ferrugination

post-Dubna (post-Bryansk) loesses she obtained glacial flora containing such microterms as *Betula nana, Alnaster fruticosus*.

This loess horizon is characterized by high general porosity reaching 42—45% on the average. A large part of general porosity in post-Bryansk loesses is represented as it is known by vesicular pores whose origin is associated with processes of thawing of fine concrete ice crystals (A.

A. V e l i c h k o and A. K. M a r k o v a 1971). Our studies have stated that this loess horizon is almost totally deprived of specific fracturing of post-cryogenic structures associated with the existence in the past of segregation ice stringers which are quite typical, for instance, for loess horizons of the middle and the first half of the Late Pleistocene.

It is known that humidity within the interval from maximum molecular moisture capacity up to humidity of the upper limit of plasticity is optimal for formation of segregation ice stringers (Ye. A. V t y u r i n a and B. I. V t y u r i n 1970). With lower humidity concrete ice is formed under freezing conditions. For silts of post-Dubna loess horizon this humidity interval is within the values of 12—14% and 24—26%. On the other hand the basic principle remains the one by S. P. K a c h u r i n (1959) to the effect that the lowest limit of humidity of loose deposits whose freezing causes frost crack formation, is the amount of moisture close to the maximum molecular moisture capacity. A good factual confirmation of this situation are the data for the Angara river territory with relatively dry and continental climate (F. N. L e s h c h i k o v 1978). In spite of the fact that the mean natural humidity of silts and loams is rather low (14—16%), nevertheless they are actively subject to frost cracks. Of no less importance are the data by T. P. K u z n e t s o v a (1973) for a territory with drier and more severe climate—central Yakutia. Here ice veins up to 2 m thick were fixed in perennially frozen loams almost not containing evident inclusions of structure ice, total humidity of loams amounting to only 15%. The author's conclusion is quite definite "total dryness of enclosing grounds did not hinder intensive growth of polygonal ice veins".

Thus detailed analysis of all the data of geocryology indicates that frost cracks and growth of ice wedges are quite possible, and natural observations confirm this, even at insignificant total humidity of enclosing deposits and not only in very humid and ice precipitation as is sometimes overemphasized. Consequently a conclusion is quite probable that during cryogenic stage of Pleistocene under conditions of very severe and dry climate growth of ice wedges occurred at insignificant humidity as well (close or somewhat higher than maximum molecular moisture capacity) of enclosing frozen deposits loess-like sandy loams and loams. Their total humidity could not exceed 13—15% essentially, while the main structure forming ice was concrete ice. As for the main type of evident ices it was ice wedges whose quantitative characteristics we must dwell upon.

One of the most important quantitative characteristics used in geocryology are volume iciness of ice wedges and its parameters. If for the first two there are numerous natural observations (column 1 and 2,

Table 1), for the iciness of ground blocks index the values were calculated by known formulae (N. A. Tsytovich 1973). While calculating the formulae he assumed the total humidity of silts (Volyn' and Dnieper uplands) to be 15% and that of more finely dispersed silts (Podolsk Upland) — 20%. In the first case volume iciness of block amounted to nearly 20%, in the second — to about 30%. Total volume iciness (column 3) was taken from the Tables of the proposed methodical work (V. P. Marakhtanov 1978) according to correlation of pattern ground diameter values (column 1) and vein width (column 2). Volume iciness of ice wedges is represented in column 4 and shows the difference between total volume iciness and that of intrapolygonal blocks.

Table 1. Iciness of ice wedge structure on the Volyn' Podolsk Upland at the cryogenic stage of Late Pleistocene

i ≈ 20				i ≈ 30			
1	2	3	4	1	2	3	4
20	2.0	27	7	20	1.5	35	5
20	1.5	26	6	20	1.0	33	3
20	1.0	24	4	20	0.5	31	1
25	2.0	26	6	25	1.5	34	4
25	1.5	24	4	25	1.0	32	2
25	1.0	23	3	25	0.5	31	1

i — iciness of polygonal ground blocks (volume %); 1 — diameter of polygons (m); 2 — ice wedges width (m); 3 — total iciness (volume %); 4 — iciness of ice wedges (volume %).

As it is seen from the data of the Table 1 total macroiciness of ice wedges in the west of the Russian Plain at the cryogenic stage of Pleistocene changed at the transition from more northern to more southern regions from 6—7% to minimum values. For the plots with the development of the largest wedge-shaped structures (about 5 m along the vertical and 2 m wide above) it could approach 10% which being recalculated by the ice "crust" equivalent was about half a metre for each square metre of the surface of such a plot. The total thickness of ice "layer" enclosed within the thickness of perennial frost up to the level of zero annual temperature variations could reach 2—3 m.

Selective paleocryogenic study of loess deposits of the similar age in the interfluve of the Desna and Sudost rivers as well as in the Oka river basin showed the mean value of macroiciness of the upper part of former perennial frost to amount to 3—5% on the mean inspite of a trend towards eastward reduction of pseudomorph dimensions and diameter of their pattern ground. Thus this value is comparable to those of macroiciness of growing ice veins in the northern zone of modern permafrost (B. I. Vtyurin 1975). The author's material proper and numerous data from literature (A. A. Velichko 1961, 1973b, V. V. Berdnikov 1976, V. P. Udartsev 1980, G. P. Butakov and A. G. Illarionov 1982) allowed to compile the first preliminary map of volume macroiciness of ice wedges of the Russian Plain at the cryogenic stage of Late Pleistocene. Comparison of these values with distribution of different types of covering loess deposits in the east of Europe is very important (Fig. 2). Boundaries of zones of development of different types of covering deposits (by B. S. Bykova data) are taken from E. M. Sergeev (1978). Isolines of volume iciness fix the southern limit of maximal possible iciness of ice wedges for typical conditions of watershed areas. Wedge shaped structures of a given age may certainly occur southward of the zero isoline as well but in more favourable for formation of ice wedges conditions (deposits of river terraces, closed moistened depressions and so on).

For the northernmost zone of the development of non-subsiding covering loess like loams the most studied in paleocryogenic way is the region of Yaroslavskoe Povolzhe (on the Volga) area. Thus at the Shestikhino section in the covering Valdaian deposits pseudomorphs of ice wedges of 6—7 m along the vertical and 2—3 m wide with the diameter of pattern grounds of 15—20 m occur (V. V. Berdnikov 1976). Peculiarities of the structure of pseudomorphs allow to assume the syngenetic type of their formation. Calculations by these parameters show the volume iciness of ice wedges to have been able to reach 20—25% and the total evident iciness (with the account of probable syngenetic type of freezing) 40—50% and over. Thus deposits of this zone could approach by their parameters filled with ice silty deposits of the north-east of Asia. These considerations agree well with conclusions of T. N. Zhestkova et al. (1982) on covering loams as "dwarf yedoma". Degradation of such filled with ice formations at climate warming at the boundary of Late Pleistocene and Holocene could not but tell on the nature of enclosing deposits. And indeed covering deposits of this region are characterized by low carbonate content (the $CaCO_3$ content not more than 3—5%), rather low porosity (often less than 42%), manifestation of stratification of facial inhomogeneity (G. N. Sudakova and L. I. Bazilevskaya 1976).

We have already spoken about iciness of more southern regions. Let

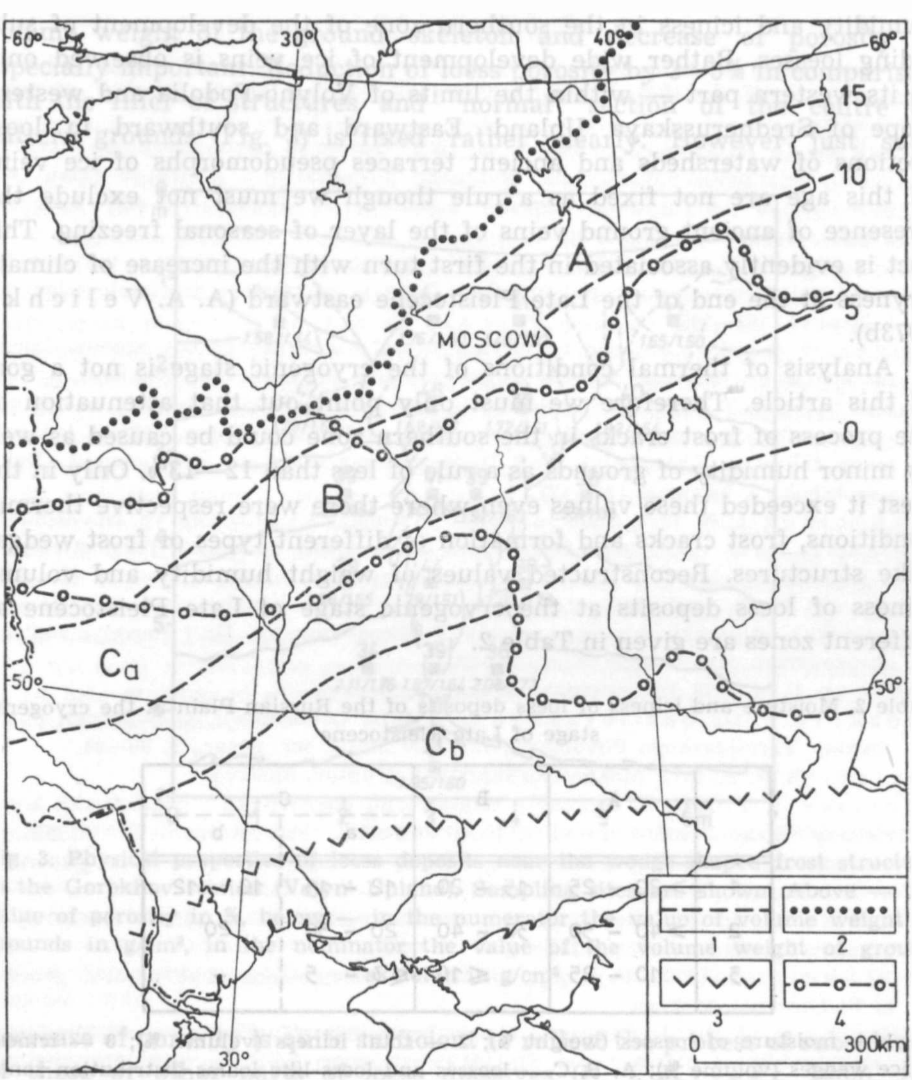

Fig. 2. A Map-Scheme of volume macroiciness of ice wedges on the Russian Plain at the cryogenic stage of Late Pleistocene

1 — isolines of volume macroiciness; 2 — late Valdai ice sheet extent; 3 — boundary of permafrost in late Valdai; 4 — boundaries of zones of loess-like and loess deposits: A — the zone of prevalent development of not subsiding covering loams; B — the zone of prevalent development of poorly subsiding loess deposits; C — the zone of prevalent development of subsiding loess deposits with: a — western province and b — the remaining part of the zone

us only emphasize that for the central zone of the development of poorly subsiding loess rocks it changed by 10% and less on the whole. The most important in paleogeographic way is the analysis of former humidity and iciness in the southern zone of the development of subsiding loesses. Rather wide development of ice veins is observed only in its western part — within the limits of Volyno-Podolia and western slope of Srednerusskaya Upland. Eastward and southward in loess sections of watersheds and ancient terraces pseudomorphs of ice veins of this age are not fixed as a rule though we must not exclude the presence of ancient ground veins of the layer of seasonal freezing. This fact is evidently associated in the first turn with the increase of climate dryness at the end of the Late Pleistocene eastward (A. A. Velichko 1973b).

Analysis of thermal conditions of the cryogenic stage is not a goal of this article. Therefore we must only point out that attenuation of the process of frost cracks in the southern zone could be caused as well by minor humidity of grounds as a rule of less than 12—13%. Only in the west it exceeded these values even where there were respective thermal conditions, frost cracks and formation of different types of frost wedge-like structures. Reconstructed values of weight humidity and volume iciness of loess deposits at the cryogenic stage of Late Pleistocene at different zones are given in Table 2.

Table 2. Moisture and iciness of loess deposits of the Russian Plain at the cryogenic stage of Late Pleistocene

	A	B	C	
			a	b
1	>20 - 25	15 - 20	12 - 15	10 - 12
2	>40 - 50	30 - 40	20 - 30	20
3	10 - 25	⩽10	⩽3 - 5	-

1 — moisture of loesses (weight %); 2 — total iciness (volume %); 3 — iciness of ice wedges (volume %); A, B, C — loesses and loess-like loams distribution zones according to Fig. 2.

In spite of the fact that the Table 2 gives the data on paleo-humidity and paleo-iciness the traces of their former effect on deposits are rather clearly manifested even now. They can be discovered in particular when studying in detail physical parameters of grounds in the cross-sections with large wedge-shaped structures. Such research carried out by the author on a number of cross-sections of Volyn'-Podolsk area showed that some properties of loesses at their contacts with large frost structures differ both from the filler of structures and from the section of the central part of the pattern grounds. To our mind increase of the volume weight of the ground skeleton and decrease of porosity is especially important. Reduction of loess porosity by 3—5% in comparison with the filler of structures and "normal" section of the centre of pattern grounds (Fig. 3) is fixed rather clearly. However just such

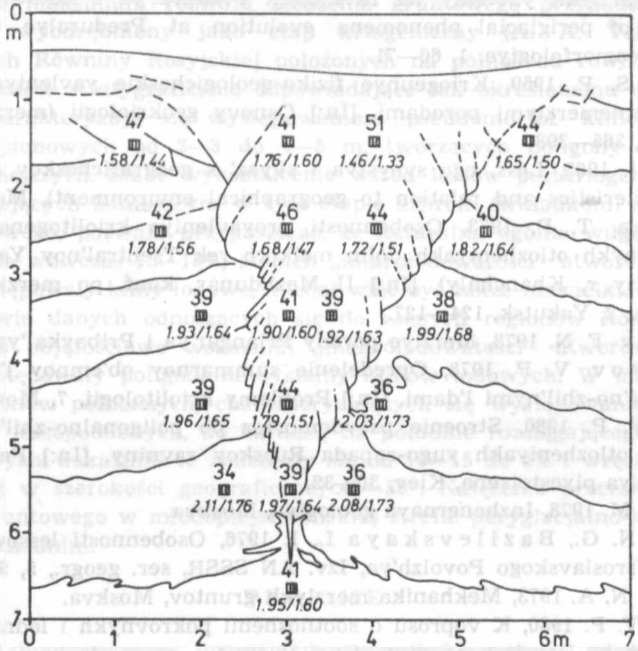

Fig. 3. Physical properties of loess deposits near the wedge-shaped frost structure in the Gorokhov section (Volyn' Upland). Sampling sites are shown. Above — the value of porosity in %, below — in the numerator the value of volume weight of grounds in g/cm³, in the nominator the value of the volume weight of ground skeleton in g/cm³

decrease of porosity is quite sufficient to reflect the process of subsidence of these or other parts of loess massives (N. I. Kriger 1965). All these locally moistened in the past linear zones within the limits of loess massives by ancient polygonal network find their explanation in the mechanism of thawing of concentrations of ice wedges in relatively poor with ice loess rocks at general climate warming at the transition from the cryogenic stage of Late Pleistocene to Holocene.

The given example indicates that problems of reconstruction of ancient humidity and iciness of loess deposits apart from paleogeographic one have certainly an applied engineering-geological aspect. Regularities of the development of ancient cryolithozone — "underground glaciation" — are necessary not only to predict the development of natural environment but to successfully develop economic activity at present.

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STRESZCZENIE

Fakty dotychczas nagromadzone w trakcie paleokriologicznych badań utworów lessowych Równiny Rosyjskiej pozwalają podjąć próbę ilościowej oceny pierwotnie związanego z nimi lodu gruntowego, a przede wszystkim jego odmiany występującej w postaci klinów lodowych. Na podstawie badań pseudomorfoz takich klinów stwierdzono, że maksimum rozwoju zlodzenia gruntowego przypadało na okres 35—10 ka BP, wyodrębniony jako etap kriogeniczny (A. A. Velichko 1973).

W obszarach Równiny Rosyjskiej położonych na północ od równoleżnika 49—50° warstwy lessów stratygraficznie odpowiadające tak określonemu etapowi kriogenicznemu charakteryzują się występowaniem pseudomorfoz klinów lodowych o wymiarach pionowych od 2—3 do 4—5 m, tworzących poligony o średnicach 20—25 m i mniejszych. Słabe wykształcenie wśród lessów postkriogenicznych tekstur, odpowiadających istniejącym w tym etapie szlirom (wkładkom) segregacyjnego lodu gruntowego, pozwala przypuszczać, że naturalna ogólna wilgotność lessów nie przekraczała wówczas 13—15%; stopień „mikrolodowatości" utworów lessowych, w których występowały kliny lodowe, musiał więc być także niewielki.

Na podstawie danych odnoszących się do różnych regionów Równiny Rosyjskiej określono objętościowe wskaźniki „makrolodowatości" utworów lessowych, w których występowały poligonalne systemy klinów lodowych. W miarę przechodzenia od regionów północnych, charakteryzujących się występowaniem pokrywowych utworów lessopodobnych, do bardziej na południe rozciągającego się obszaru lessów właściwych wskaźniki te zmieniały się od 10—15 do 5% i wręcz do ułamkowych wielkości w szerokości geograficznej 49—50°. Natężenie procesu kształtowania się lodu gruntowego w młodoplejstoceńskiej strefie peryglacjalno-lessowej rosło w kierunku zachodnim.

РЕЗЮМЕ

Известный к настоящему времени фактический материал по палеокриогенному изучению лёссовых разрезов на Русской равнине позволяет приступить к количественным оценкам развития подземного, и в первую очередь, повторно-жильного льда. Как известно, максимальная фаза его развития, согласно многочисленным находкам псевдоморфоз по ледяным жилам, приходится на криогенный этап плейстоцена в интервале времени от 35 до 10 тыс. лет назад (А. А. Величко 1973).

Лёссовые горизонты Русской равнины, стратиграфически соответствующие криогенному этапу, почти повсеместно к северу от 49—50° с. ш. характеризуются наличием псевдоморфоз по жильным льдам, размером по вертикали от 4—5 до 2—3 м, с диаметром полигонов 20—25 м и менее. Слабое развитие в лёссах посткриогенных текстур, связанных с существованием в прошлом шлиров сегрегационного льда, позволяет предполагать, что естественная влажность лёссовых пород при промерзании не превышала 13—15%, а микрольдистость вмещающих жилы льда пылеватых пород также была небольшой.

Исходя из имеющихся данных по разным районам Русской равнины определялась объемная макрольдистость мерзлых лёссовых пород, содержавших полигонально-жильные льды. При переходе от более северных районов развития покровных суглинков к более южным лёссовым районам она изменялась от 10—15% до 5% и вплоть до минимальных значений на 49—50° с. ш. Отмечается усиление процессов формирования льдов в пределах древней лёссово-перигляциальной зоны в западном направлении.