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PARAGENESIS OF A CRYOGENIC (PERIGLACIAL) ZONE

Considerations of the relationship between the so-called periglacial phenomena and other, climatical and physico-geographical, leading Pleistocene agents require an elucidation of the notion of *periglacial zone*, *periglacial phenomena*, etc.

Initially, when the new, very fruitful branch of science arose, the definition of the subject investigated introduced by Łozinski and Dylik, the Polish scientists, did not raise any particular controversy. The complex of geological and geomorphological formations originated as a result of the frost and eolian processes, synchronous with glaciation and occurring in the temperate zone of Europe outside of the reach of ice-sheets, was considered to be strongly influenced by continental glaciers.

Later on, however, the validity of the term *periglacial* began to be called in question. Scientists, and first of all the Soviet scientists, pointed out that the notion of *periglacial phenomena* and even more the *periglacial zone* was much wider. Such a comprehension embraces the entire natural environment with the whole range of elements of the area outside of the glaciations, but remaining under the climatical influence of the ice-sheet. In the literature, however, the term *periglacial* has persisted in its initial meaning, i. e. it is applied to the fossil frost soil—structures even though the creators of the *periglacial* branch of science realize that the term itself has a much wider meaning. In the present author's opinion the term *periglacial* to be strict should be replaced by: of *fossil frost* or by *paleocryogenic*, which will be used in this paper. The new branch of science that had originated in Poland, appeared to be so productive and its development so vigorous that the term *periglacial* in its narrow sense entered into literature and scientific vocabulary. Apart from the conventional character of application of this term, recognized by the majority of scientists, there is no good arguing its rightness. It should be emphasized, however, that this term is to define the complex of physico-geographical processes, first of all the frost and eolian processes, i. e. those operating in severe continental climate of the Pleistocene, similar to the present-day climate in the arctic areas.

Although the term *periglacial* implies information on the causal dependence of periglacial phenomena upon glaciation, the problem itself is neither simple nor univocal.

The existence of „periglacial conditions in the forefield of ice-sheets has been evidenced in the areas adjoning the present-day ice-sheets in Greenland and Antarctic (MARKOV, *et al.*, 1967), where exist „oases" with very severe continental climate; they are polar deserts, whose surface is diversified by polygonal relief with a great deal of forms of the eolian deflation and accumulation.

Such a bordering of „periglacial areas on the glacier can be logically explained. It results from the presence of the cold and dry air which arises above the ice-sheet surface and descends down the glacier edge into the farther foreland. But this explanation does not fully elucidate the problem. It has not been known so far at what distance from the glacier front depending on its shape should be stretched the area influenced by such masses of the air. Solution of this problem is the more sifficult that the present-day extensive ice-sheets invade the cryogenic areas (cryosphere after BARANOV) of the polar regions of the Earth and thereby the ice-sheets can influence as a catalytic agent on the „periglacial" phenomena. The doubts about the exclusiveness of the paragenetic interrelations of periglacial phenomena and ice-sheets arise when adapted to the Pleistocene events.

The present state of knowledge of the Pleistocene ice-sheets, especially of the Upper-Pleistocene, is fairly satisfactory. The investigations of the paleocryogenic (*periglacial*) phenomena have also brought some achievements. These phenomena are not only the geological structure but they also form a whole morphological complex. Preiglacial structures of various age have been examined in variuos regions. There are, however, some gaps in the views on genetical types of these structures. But none the less we can speak about the basic characteristics of the development in time and space of periglacial processes in the main regions. One of them is Eastern Europe.

Periglacial phenomena have been investigated in the plains of Eastern Europe by MARKOV (1956), MOSKVITIN (1947), GRIŠČENKO (1956), KAPLINA and ROMANOVSKIJ (1961) and by other scientific workers, the present author included (*cf.* the references cited in NOVOSELSKAYA, 1961). The data obtained permit to recognize the causal relation between periglacial phenomena and glaciation in time and space. The dependence of periglacial phenomena upon the ice-sheets being assumed, there should be also accepted interrelations between the limit of glaciations and that of the fossil cryogenic phenomena.

As generally known, in the western Eauropean part of the USSR, till Orša, the maximum limit of the Valdai (Wurm) glaciation runs almost W—E with some northwards deflection. Farther, however, it clearly runs northwards and becomes almost meridional.

Considering the distribution of the Valdai paleocryogenic phenomena (VELIČKO, 1965), one can readily notice that there is no coincidence between the limits of the Valdai ice-sheet and the area of permafrost (Fig. 1). The maximum limit of the Valdai permafrost and of the main types of cryogenic land-forms runs almost W—E and therefore crosses the limit of glaciation. The maximum range of the Valdai glaciation as well as stadials of its recession form more or less concen-

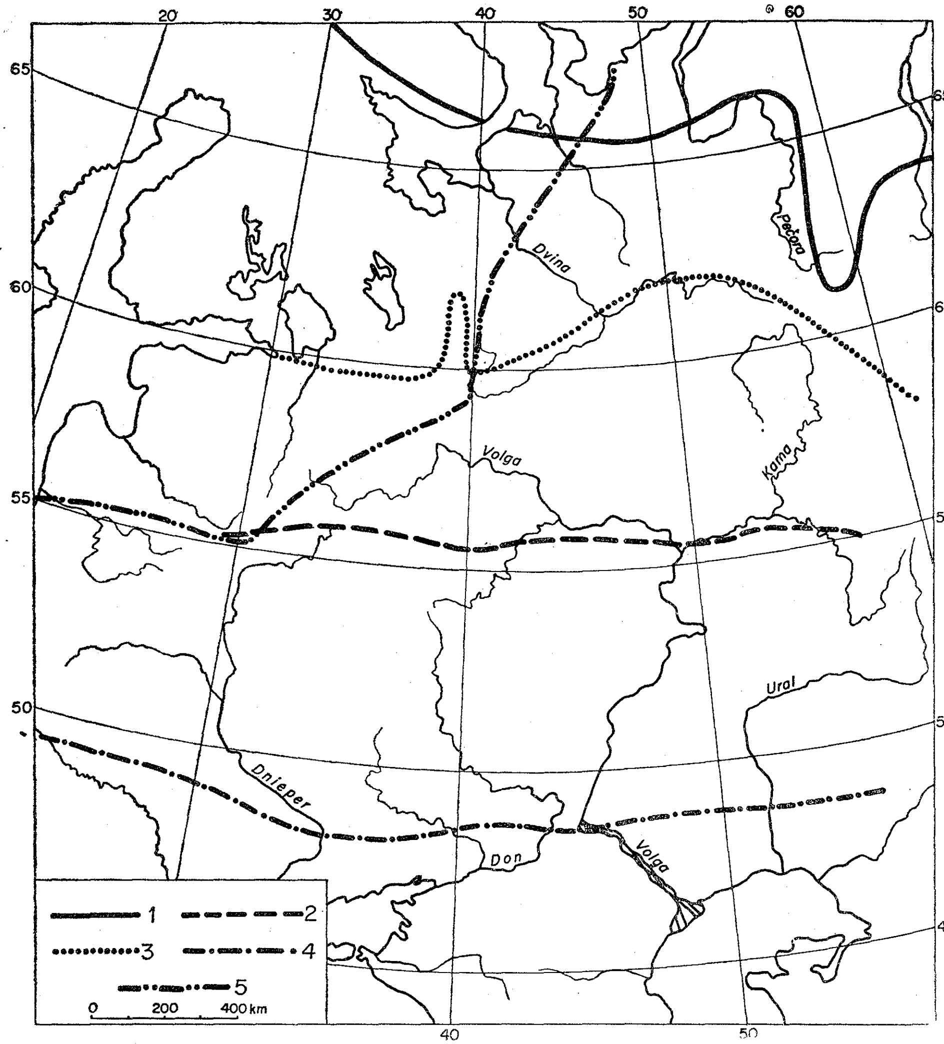


Fig. 1. Limits of glaciation and permafrost in the Upper Pleistocene and at present time in the European part of the USSR (after the author)

1. southern limit of the present-day permafrost area; 2. southern limit of the occurrence of relict thermokarst forms according to KAČURIN; 3. southern limit of distinct land-forms of the Upper Pleistocene cryogenic relief (polygonal, hummocky-and-depressional thermokarst land-forms); 4. southern limit of permafrost in the Upper Pleistocene; 5. limit of the maximum range of the Valdai glaciation

trical lines inside the oval, whose longitudinal axis runs almost meridionally, while the limits of the maximum extent of permafrost of the same age (Valdai) and the limits of cryogenic land-forms reflecting to some degree the stages of permafrost degradation, are probably subjected to other rules because of their parallel or almost parallel course.

The relation between the sizes of ice-sheets and areas of permafrost of the same age is striking. The stratigraphical investigations concerning the origin of the so-called periglacial areas carried out by the present author in Eastern Europe have revealed a seemingly paradoxal discordance in proportions of the both phenomena. In the area invaded by the Dnieper glaciation in its maximum — the Moscow stage, the croygenic disturbances occur within the glaciated territory, mainly in the marginal zone (MOSKVITIN, 1964; VELIČKO, 1958).

Behind the maximum of the Dnieper glaciation, where the present author examined a full series of the loess profiles there were not formed any disturbances synchronous with the loess of Dnieper age. Such deformations should be visible due to the presence of the fossil soil horizons in the loess. However, in the first pre-Dnieprian soil underlying the Dnieper loess as well as in the older horizons there are barely some traces of shallow and narrow desiccation fissures, but no frost disturbances.

Consequently, it may be assumed that during the greatest — Dnieper glaciation covering almost one half of the area of the Russian Plain (2 667 000 km^2 according to MARKOV and others) the permafrost did not exist at all or it was insignificant and the development of frost processes was confined to the marginal zone of the ice-sheet. Thus, it becomes obvious that in such a case there is no direct interdependence between the dimensions of the ice-sheet and of the permafrost area. A purely logical assumption, which still requires theoretical argumentation, about the direct interdependence mentioned above, can lead to serious errors. In particular when some scientists (POPOV, 1959; KOSTYAEV) present the maps worked out not on the basis of the analysis of concrete data but — as it seems — on the *a priori* assumption that the periglacial—cryogenic area of the Dnieper age occurred in the European part of the USSR, far south of the glacier front; it comes clearly by itself from the logical presupposition. However, the concrete stratigraphical and geochronological investigations indicate that everything took another course in nature: the cryogenic processes had the maximum range during the Valdai glaciation. Just when the glacier covered only 828 000 km^2 i. e. an area three times smaller than that under the Dnieper glaciation, the cryogenic processes were the most extensive and their limit stretched farthermost to the south. The southern limit of the permafrost and of deep seasonal freezing was over 1000 km from the maximum range of glaciation.

Comparing the area of the occurrence of cryogenic processes with the size of ice-sheets of the same age, one comes to the conclusion that in the Pleistocene the directly proportional interdependence between the sizes of ice-sheets and cryogenic (*periglacial*) area could not exist. Such comparisons may lead to the contrary conclusions about the inversely proportional interdependence. But it would be a basically false hypothesis because under similar conditions a smaller glacier cannot produce greater masses of cold and dry air than a larger one does, neither it can produce a *periglacial* zone of a larger extent.

The alike important conclusions can be drawn from the analysis of the course of cryogenic processes within one cold (glacial) cycle. However, some cycles, the Dnieper glaciation included, could not be investigated, which, in the present author's opinion is due not only to the insufficient knowledge but also to the poor development of cryogenic processes during these periods.

Only the last cold (Valdai) period displays the indispensable set of data which is not casual, as it will be further discussed. The problem can be more readily solved because the stratigraphy and chronology (including the absolute dating) of the deposits have been best worked out for the last Valdai (Würm) glaciation, within and behind the glaciated area[1] as these deposits show a great number of cryogenic structures. Some observations of the limits of permafrost in this period and qualitative changes of frost processes in time, can be presented already (VELIČKO, 1965, 1969; VELIČKO, BERDNIKOV, 1969).

Data concerning the distribution of cryogenic phenomena of the last cold period point to very specific dynamics of the processes. The limit of permafrost took the most northern position during the early Valdai period (beginning of the Valdai loess I accumulation), when the soil of the Mikulino interglacial was undergoing deformations. The limit was not likely to overstep 52—54° of northern latitude (Fig. 2). Unfortunately, the extent of the permafrost zone of that time cannot be determined because the position of the early-Valdai glacier front is unknown.

The next, younger extension of permafrost is fairly conspicuous due to disturbances of the Bryansk fossil soil. This stage was marked directly after the Bryansk warm period (interval?) 29—25 000 years ago. The limit of permafrost kept moving southwards reaching up to 49—48° of northern latitude in Central Ukraine. It should be born in mind that at the post-Bryansk period the Valdai ice-sheet reached its largest extent (over 1.5 thousand km from the Scandinavian centre). Its maximum took place in the Bologovsk stage, 19,000 and more years ago (ČEBOTAREVA, VIGDORČIK, GRIČUK, FAUSTOVA, 1965).

In the next, last part of the Valdai glaciation the ice-sheet was shrinking which produced a series of the recessional stadials. The last larger stadials were: the Salpausselka (11—10,000 years B. P.) and the Pereslav stadial (about 9,000 years B. P.).

It is remarkable that just at the end of the glacial epoch when the Valdai ice--sheet was rapidly retreating, on its foreland the maximum expansion of permafrost took place, it stretched from the north to south on over 2,000 km. Then, the limit of permafrost had the most southern position (46—47° N. lat.). The whole east-European plain was under the permafrost conditions.

Let us set together all the available data concerning the distribution of the Valdai ice-sheet and permafrost area. During the initial stage of the glaciation, in the

[1] The comprehensive data on these problematics can be found in „Četvertičnyj period" (vol. 1—3, 1965—1967; K. K. MARKOV *et al.*), "The last European glaciations" (1965), "Loess — periglacial — Paleolith of Eastern and Central Europe" (1969), "Stratigraphy and chronology of the Upper Pleistocene" (1965).

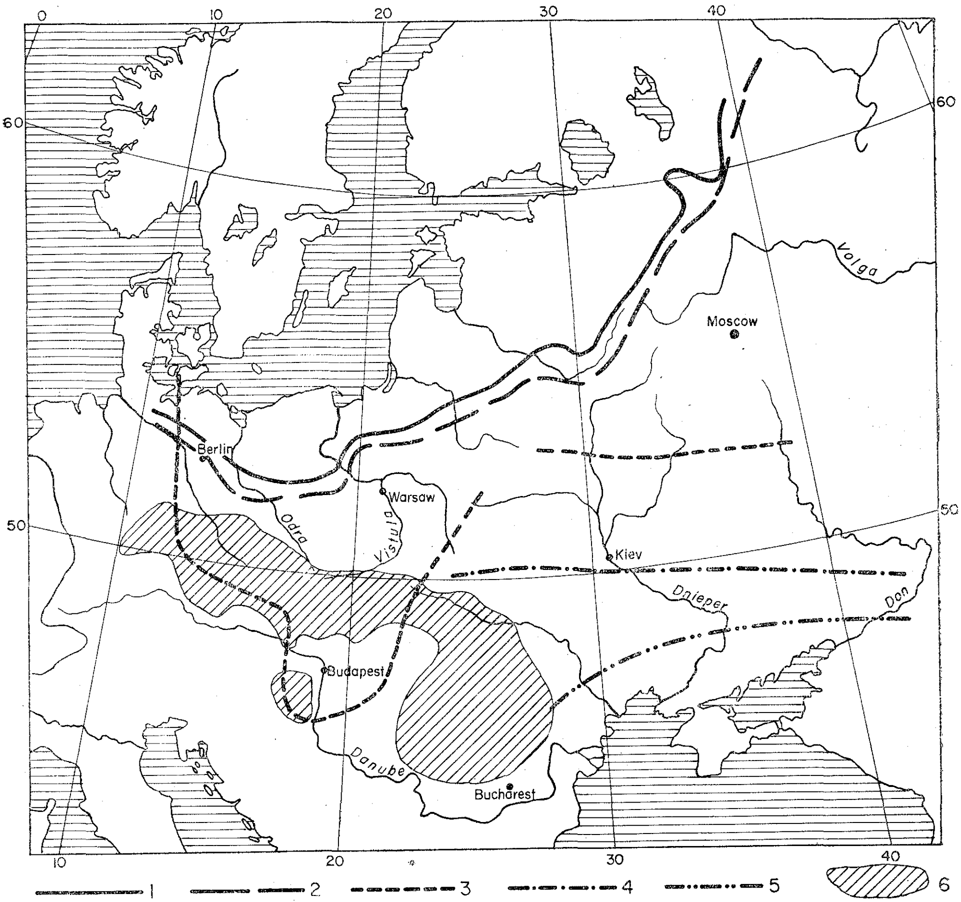


Fig. 2. Main stages of the development of Upper Pleistocene permafrost in Eastern Europe (according to VELIČKO and BERDNIKOV, 1969).

1. limit of the Bologovsk stade of the Valdai glaciation; 2. maximum range of the Valdai glaciation; 3. limit of permafrost at the beginning of the Valdai epoch; 4. limit of permafrost in the post-Bryansk period; 5. limit of permafrost at the end of glacial period; 6. range of the cryogenic processes in mountainous areas

course of the ice-sheet advancement, the limit of permafrost had the utmost northern position. The glacier was at its maximum extent in the post-Bryansk period, about 19—21,000 years B. P. (maybe, the glacier extent was the same also in the pre-Bryansk period — 44—32,000 years B. P.: SEREBRYANNYJ, 1965). Between these two periods the permafrost area increased but its limit was still in an intermediate position. Not sooner than at the end of the Valdai glaciation, when the ice-sheet almost disappeared, the limit of permafrosts shifted to its utmost southern position.

Evidently, the curves of changes of the glacier- and permafrost limits show a different course (Fig. 3) and what is more, the permafrost was still at its maximum

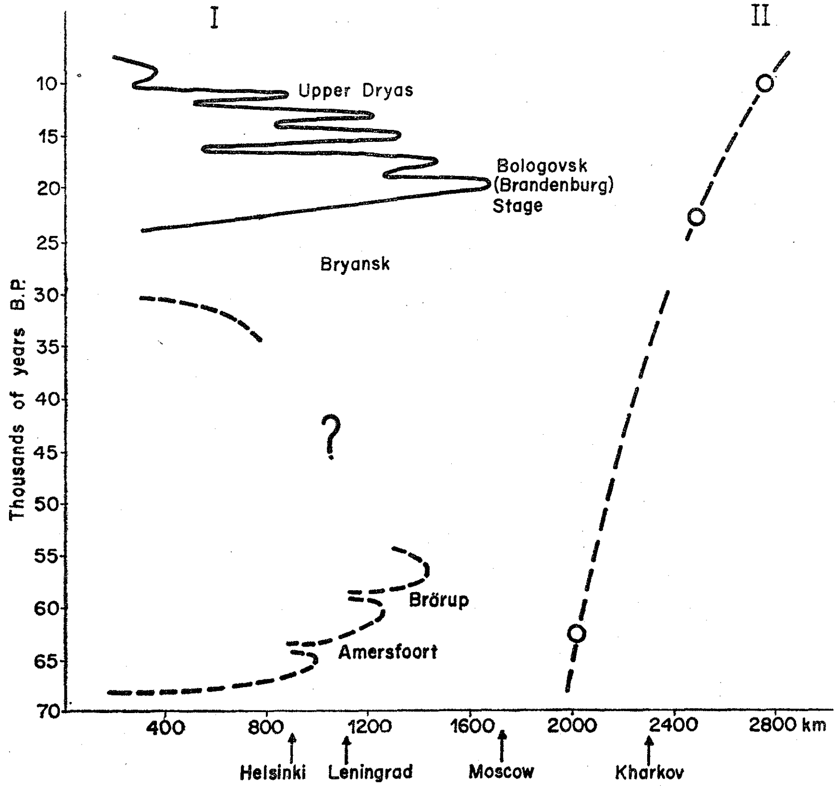


Fig. 3. Dynamics of the development of glaciation and permafrost in the Upper Pleistocene (according to the author)

I — glaciation, II — permafrost

when the glacier had retreated to Scandinavia. The curve of the development of glaciation resembles rather a parabola, whereas that of permafrost — a hyperbola.

There should be mentioned a general trait characteristic of the relation of the permafrost to glaciation of the same age and to phases of the development within one glaciation: the permafrost was best developed during the smallest (the last, Valdai) glaciation, the permafrost attained its maximum extent at the end of this glaciation, after the ice-sheet had undergone a complete shrinkage.

Taking into consideration all the arguments mentioned above it seems improbable that the formation of permafrost could be provoked by climatical influence of the ice-sheet (descent of the air masses formed above the continental glacier). However this conception has not been proved by the qualitative changes of the cryogenic processes which operated during the last glaciation.

The research of the loess deposits formed in *periglacial* zone of the Valdai glaciation permits to determine direction of the changes in character of the permafrost structures according to their age. A lot of structures have been examined in order to avoid any possibility of a false interpretation: various characteristics of structures result from facial differences caused by lithological and geomorphological conditions. Only those structures have been taken into consideration which developed under similar facial conditions (VELIČKO, 1961, 1965, 1969). From the geomorphological point of view, all the structures are distributed on the flat, slightly sloping interfluves between the Dnieper, Ostr, Desna, Sura and the Psla. Lithologically, they are all associated with the well stratigraphically defined loess horizons. Besides, it is worth while mentioning that there were quite often found some structures of different types and ages in horizons of various ages within one profile, i.e. under almost similar facial conditions (Bryansk, Arapovici, Mezin). Despite of the facial similarity, the properties and features of the frost structures change according to their age.

The oldest frost disturbances of Upper-Pleistocene age were associated, as mentioned before, with the early-Valdai because the fossil soil of the Mikulino interglacial (Mikulino complex) underwent some deformations. The most characteristic disturbances of that age are solifluctional (in the northern part of periglacial zone, till the latitude of Bryansk or so) as well as deformations and injections of cryoturbation- and involution types. Such disturbances occur in the upper, 0.5—0.7 m horizon of ground (Fig. 4). They were probably formed in the moist, active layer during the autumn freezing, when the moistened ground closed between the underlying permafrost and freezing layer growing downwards is subjected to squeezing. Besides, some narrow (10—20 cm) veins distributed at 2.5—3.5 m intervals occur to the depth of 1—1.5 m. In horizontal plan they form a micro-polygonal net. In all probability, they belong to the elementary ground veins which are often associated with cryoturbations also in the present-day zone of permafrost. The narrow fissures originated when the ground was fully frozen in winter. Such fissuring must have been connected not with the higher gradients of temperature but with severe desiccation of surface — the process described by POPOV (1967) for the present-day permafrost zone.

In general, there were plastic deformations characteristic of the beginning of the Valdai epoch; the polygonal-fissure forms were in their initial stages of development, and the formation of polygonal vein ice was not typical. Even though it was sufficiently cold, the climatical conditions of that time were characterized by considerable humidity, hence, they were not strongly continental.

In the epoch of the chronologically second denudation which occurred soon after the Bryansk period (maximum extent of the Valdai ice-sheet) the nature of deformations changed. The deformations disturbing the Bryansk soil display very regular systems of wedge-like structures 1.5—2 m deep, funnel-like in the top (0.5—0.8 m in width). On the surface they form small polygons (2—3 m), which occur with amazing persistancy all over the area of permafrost of that time. These forms resemble in structure nonsorted polygons (pyatna medalions) occurring in the present-day permafrost area (KUDRYAVCEV, DOSTOVALOV, 1967).

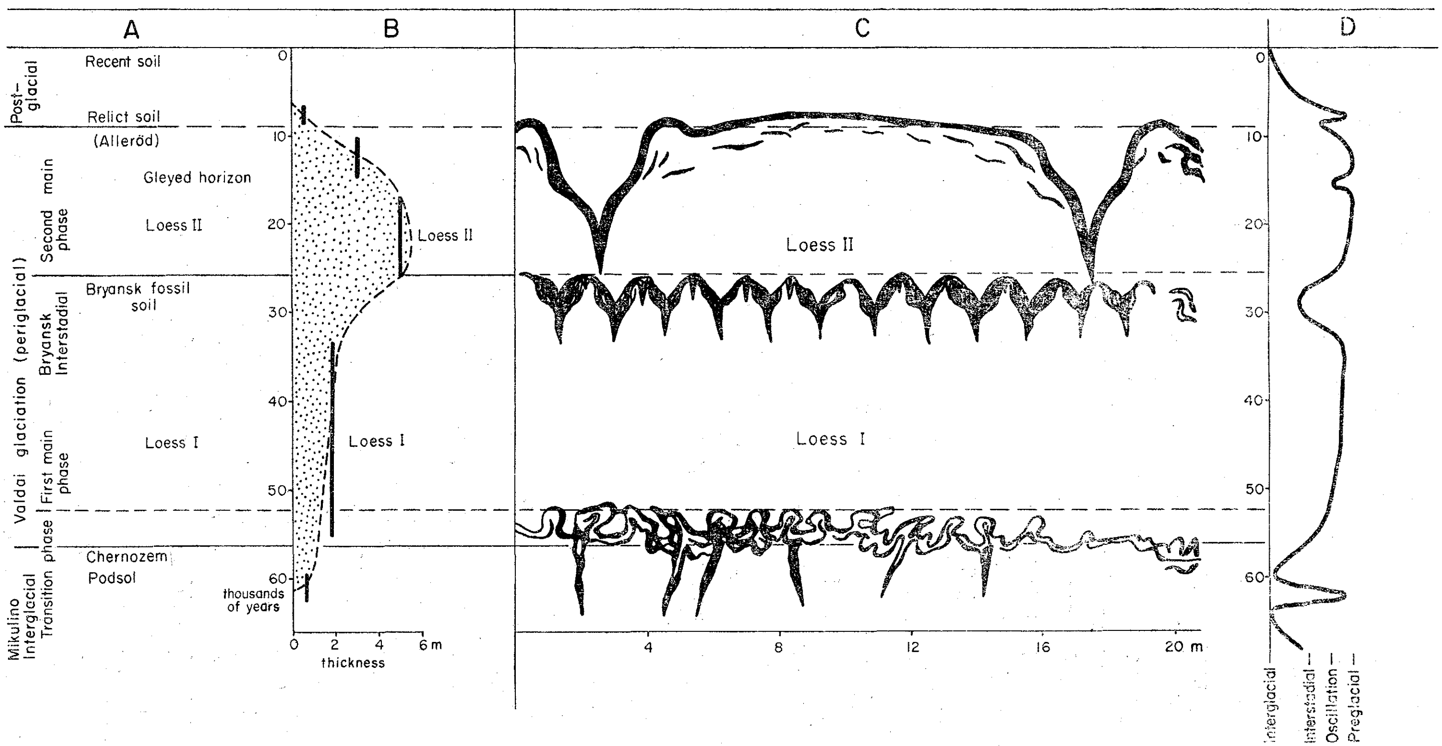


Fig. 4. Change of predominant type of frost structures in various periods of the Upper Pleistocene (according to the author)

A — chronological division; B — intensity of loess deposition; C — predominant type of frost structures; D — climatic curve

Nonsorted polygons are common in the whole present-day permafrost area. However, in the central and northern regions they are associated with „normal" polygons. The common occurrence of nonsorted polygons only cannot bear witness to extremely severe conditions because they are also found behind the limit of permafrost: in the region of deep seasonal freezing. Their formation is conditioned not so much by high temperature gradients as by the winter desiccation of the ground whose structure proves that it was strongly moistened in summer.

It may be admitted that despite of more severe permafrost conditions in the post-Bryansk period than at the very beginning of the Valdai epoch — because the micro-fissure nonsorted polygons had already been common — the gradients were not high yet. The approximate climatic conditions are similar in the southern zone of the present permafrost area.

The nature of the permafrost processes strongly changes at the end of the Valdai epoch. This horizon of deformations corresponds to the youngest Valdai horizon of loess III. Unlike in the earlier stages, the European part of the USSR was at that time the arena of the formation of a very composite complex of cryogenic forms whose features have much in common with the present permafrost area. In this complex the main part played the „normal" frost-fissure polygons with fissure ice, and ground wedges. The polygons were ca 20—30 m in size with the mean depth of fissures — some 4—5 m. In the present permafrost area the frost-fissure polygons with ice-wedges develop actively in regions of the most severe climatical conditions, mainly in Northern and North-Eastern Siberia. The frequent occurrence of polygons and polygonal relief not only in the north but also in central regions of the Russian Plain testifies that in the waning phase of the Valdai glaciation till the Older Dryas the continental conditions were here extremely severe as compared with the whole Valdai epoch (let us add that also in comparison with the whole Pleistocene). It should be also emphasized that the ice-sheet was so reduced at that time that it practically disappeared from the Russian Plain.

Thus, the change of the nature of permafrost processes in the Upper-Pleistocene cannot be explained by the climatic influence of the ice-sheet. And what is more, the cryogenic relief also happens within the area of the Valdai glaciation (Kačurin, 1961; Veličko, 1965). It means that the advancing glacier did not produce the cryogenic area in its foreland but soon after the retreating glacier the abandoned area was invaded by permafrost; it was gradually progressing and finally joined the permafrost in the northern regions which has not been glaciated up till now.

The possibility of existence of the „periglacial" area independently of the ice--sheet is sufficiently evident in the present-day environment. And sure enough, in Northern Eurasia there is a vast area of permafrost that stretches N—S for more than 3,000 km. It is also significant that almost one half of the USSR territory is occupied by permafrost, despite of the lack of glaciers (and ice-sheets) which could have exerted climatic influence upon such a vast area. This situation cannot be explained by the activity of the small glaciers on the North Land, Franz Josef

Land or cirque glaciers of the Northern Ural. From this point of view, the present-day situation prevailing in Siberia resembles that in Eastern Europe at the end of the Valdai glaciation.

So, the attempts to demonstrate the dependence of the old cryogenic („periglacial") phenomena upon the ice-sheet were without results. This connection could not be confirmed by the complex investigations because:

(a) there do not exist any interrelations between the lacation of limits of Pleistocene glaciations and those of permafrost;

(b) there is no proportional dependence between the increase of the ice-sheet and expansion of the old cryogenic („periglacial") zone. It must have taken an inverse course: in the epoch of maximum glaciation the cryogenic zone was either small or did not exist at all, whereas during the minimum Valdai glaciation the old area of permafrost displayed the most intensive growth, attaining its greatest extent during the retreat of the ice-sheet;

(c) analysis of the qualitative development of the Pleistocene cryogenic phenomena shows that the most vigorous development of frost processes characteristic of the coldest and more severe climatical conditions was marked not in the period of the glacier advancement or of its maximum extent but inversely — in the final phases of glaciation, when the glacier body was already considerably reduced;

(d) position of the present-day permafrost area indicates that the processes analogous to the old cryogenic processes operating in the so-called „periglacial" zones of the Pleistocene, develop without any contribution or distinct influence of the ice-sheets.

On the basis of the above reasoning, the conception of „paragenesis" of continental glaciation and old cryogenic („periglacial") areas should be renounced and a new scheme of the „paragenesis" of „periglacial" (fossil cryogenic) phenomena taken into consideration.

The present author holds that the right view on paragenetic connection further discussed must result from the analysis of a general course of nature in the Pleistocene. The main features of this scheme, based on Markov's opinion (Markov, *et al.*, 1965, 1967) on the Pleistocene changes of nature have been already presented in one of the author's papers (Veličko, 1968), in which the problem of glaciation and permafrost of different ages is also discussed. So, let us take into consideration the possible dependence of the present-day and former cryogenic areas (Fig. 5) upon the climatological factors.

The present permafrost area, especially in Europe, has a peculiar distribution. In western Eurasia permafrost occurs on the Kola Peninsula, runs across the polar Ural, reaches the middle Yenisey and farther stretches through the Sayan Mts. and Mongolia. Thus, its limit running from the north-west towards south-east shifted southwards more than 3000 km (about 20°).

Although the permafrost area is often called a zone, its limit has an almost meridional orientation and as such it does not fulfil the conditions of zonality con-

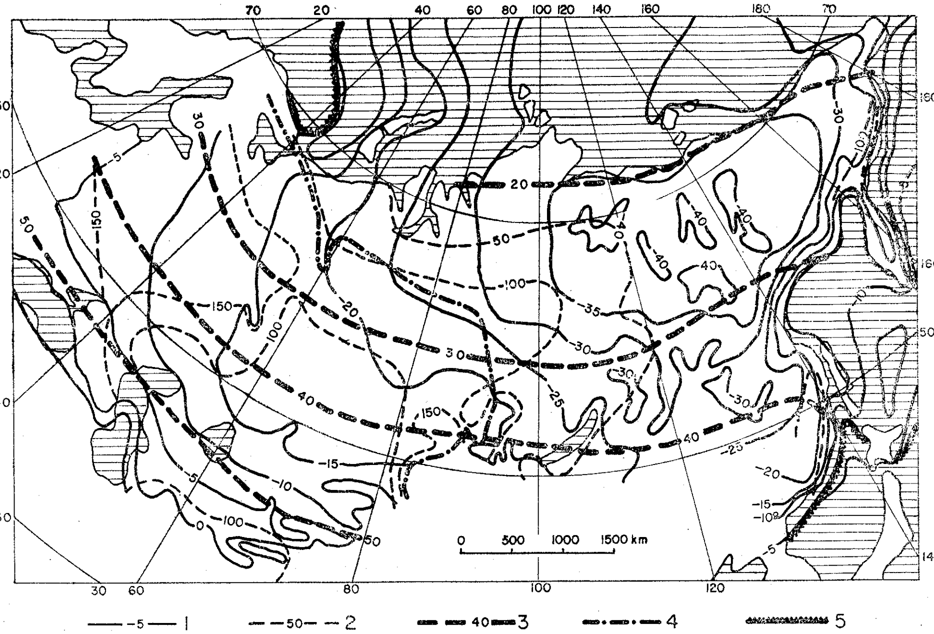


Fig. 5. Interrelation of permafrost and sea-ice limits, and the more important climatic indices

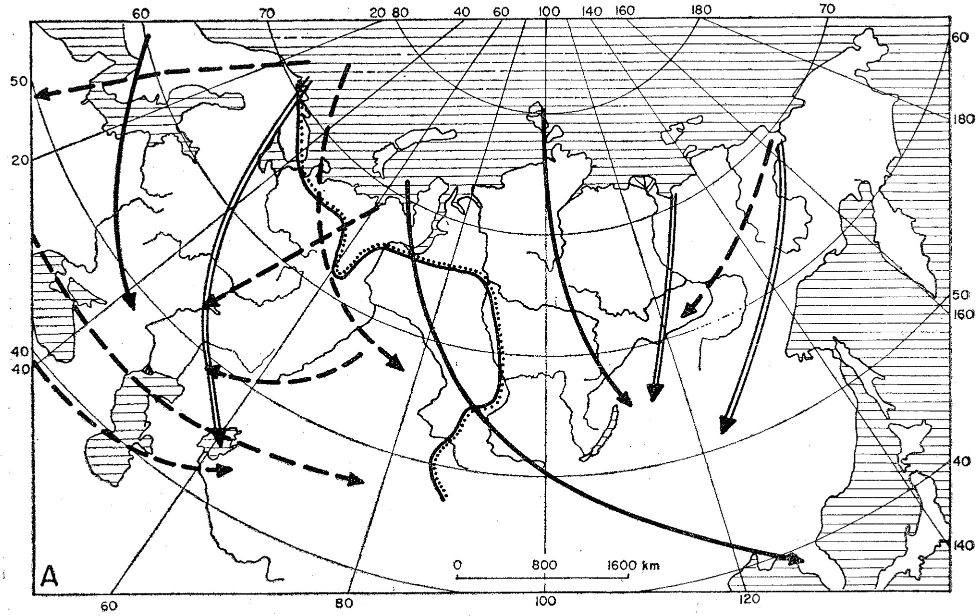
1. January temperatures; 2. precipitation of the cold half of the year (in mm); 3. annual radiation balance (in kkal/cm²): 4. limit of permafrost; 5. range of sea ice in winter

nected with the latitudinal orientation. It neither corresponds with the course of izolines of such important climatical indices connected with the zonality as the global solar radiation and mean annual balance of radiation.

The limit of permafrost is controlled by some climatical agents, especially by their group that characterizes the air masses over a given area. Within the permafrost area the frost-days persist for three fours of the year, and the temperature below -10^{0}C prevails during about a half of days in the year, while the mean diurnal air temperature over $+20^{0}$C does not occur at all or very rarely in limited areas only. The permafrost area is characterized by very scant summer as well as winter precipitation: usually below 300 mm in summer and 100 mm in winter. All that testifies to the cold, strongly continental climate prevailing in the permafrost area, with cold and arid air masses during the greatest part of the year. In Asia, where the permafrost mainly exists, the conformity of climatical areas presented above with the southern limit of permafrost is extremely well marked.

The limit of permafrost, however, does not enclose only land but it also encroaches on the oceans, in the north-west on the Arctic Ocean and in the south-east on the Pacific Ocean. It can be readily proved that limit of sea ice marks in the ocean a continuation of the permafrost limit. The comparison of the both limits on the coasts of Europe, Asia and North America reveals their direct relation throughout the Northern Hemisphere. Some deflections of the limits on the contact lines are caused by the sea currents. It is also significant that there is a conformity between the limits and climatical indices such as the air temperatures, especially in winter. The isotherms -10^0, -15^0, and sometimes -5^0 mark the limits of sea ice. It is generally known that surfaces covered with sea ice produce cold, and arid air masses. As it has been pertinently expressed by WIZE, such oceanic surfaces have climatical conditions typical of continents. It is assumed that during the greater part of the year climatic conditions of lands with permafrost are under a direct influence of the areas on which continental conditions prevail, i.e. vast areas covered with ice. The ocean, which is the main supplier of humidity for continent is covered with ice. The ice cover can only produce the cooled, almost dry air. Thus, in this part of Eurasia where the permafrost occurs, the oceanic air masses create a severe and continental climate. Advection is the main factor in this process. In the present--day permafrost area of Eurasia the air masses from the „climatical land", i.e. from the ice-covered Northern Polar basin, are shifted due to anticyclones in summer and in winter as well. It can be inferred from the maps of main directions of the anticyclones' displacements (Fig. 6; BORISOV, 1967). They show that anticyclonal activity predominates in this territory. For instance, in the region of Yakutsk, the days with anticyclones (136) are twice as numerous as those with cyclones (69 days). Even more striking is the dominant role of air masses over the whole USSR area (Fig. 7; BORISOV, 1967). The map shows clearly that the permafrost area is invided by air masses from the North Arctic Ocean (the Kara Sea, the Leptev Sea), from the Pacific Ocean (the Bering Sea) as well as from the mountainous regions of Central Asia. It is, therefore, an area invaded by the arid, usually cold, arctic air, which, under conditions prevailing in North-Eastern Asia, especially in winter, is additionally cooled by effective radiation.

The experimentally obtained calculations and reconstructions recently published by POGOSYAN (1969) show how strong influence exerts the ocean surface on the climate of permafrost area. POGOSYAN gives a prognosis of conditions which could start if the polar sea ice disappeared. The results obtained agree with the above comment on the climatical indices, decisive for the permafrost. Decay of sea ice might cause very significant changes of weather in winter (it is worth calling to mind that in the present paper the decisive meaning of winter indices has been already discussed). The most remarkable would be the changes of the air humidity. In the arctic regions, the air-layer near the water-table would be twice as humid as it is today (5—6 g/kg instead of 2—3 g/kg). The permafrost area in the European part and in Western Siberia would receive more precipitation, mainly in form of snow. Also Northern Asia would undergo remarkable changes of the air humidity. Due to advection the humid air would flow in both from the Atlantic and from the Arctic Oceans. The humidity would increase from 0.3—0.5 g/kg to 2—3 g/kg, which means that it would be almost ten times greater. Generally speaking, POGOSYAN



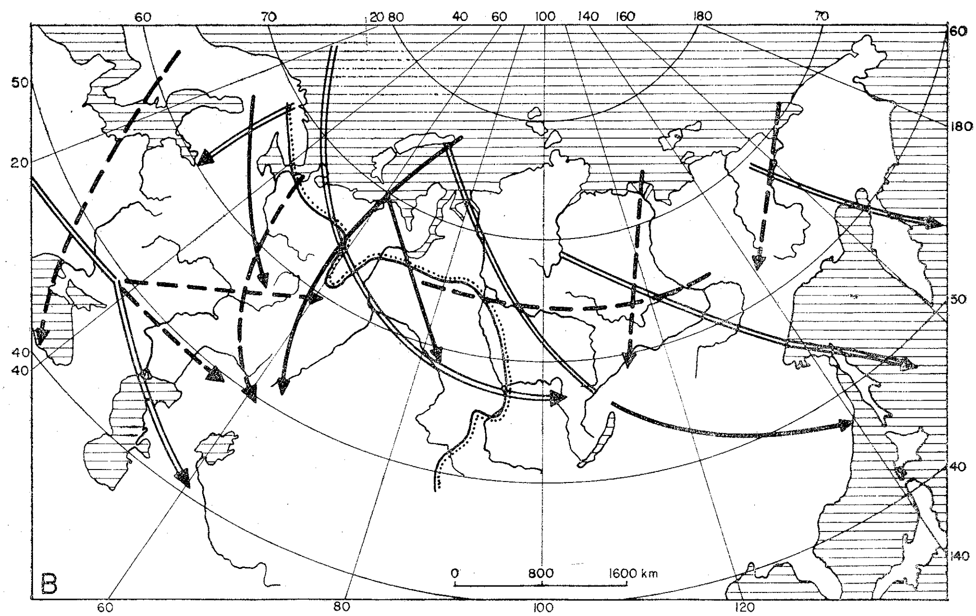


Fig. 6. Main directions of movement of anticyclones in January (A) and July (B), according to Borisov, 1967

Frequency of the passage of anticyclones during the month: 1. up to 1; 2. from 1 to 2; 3. from 2 to 3; 4. limit of permafrost

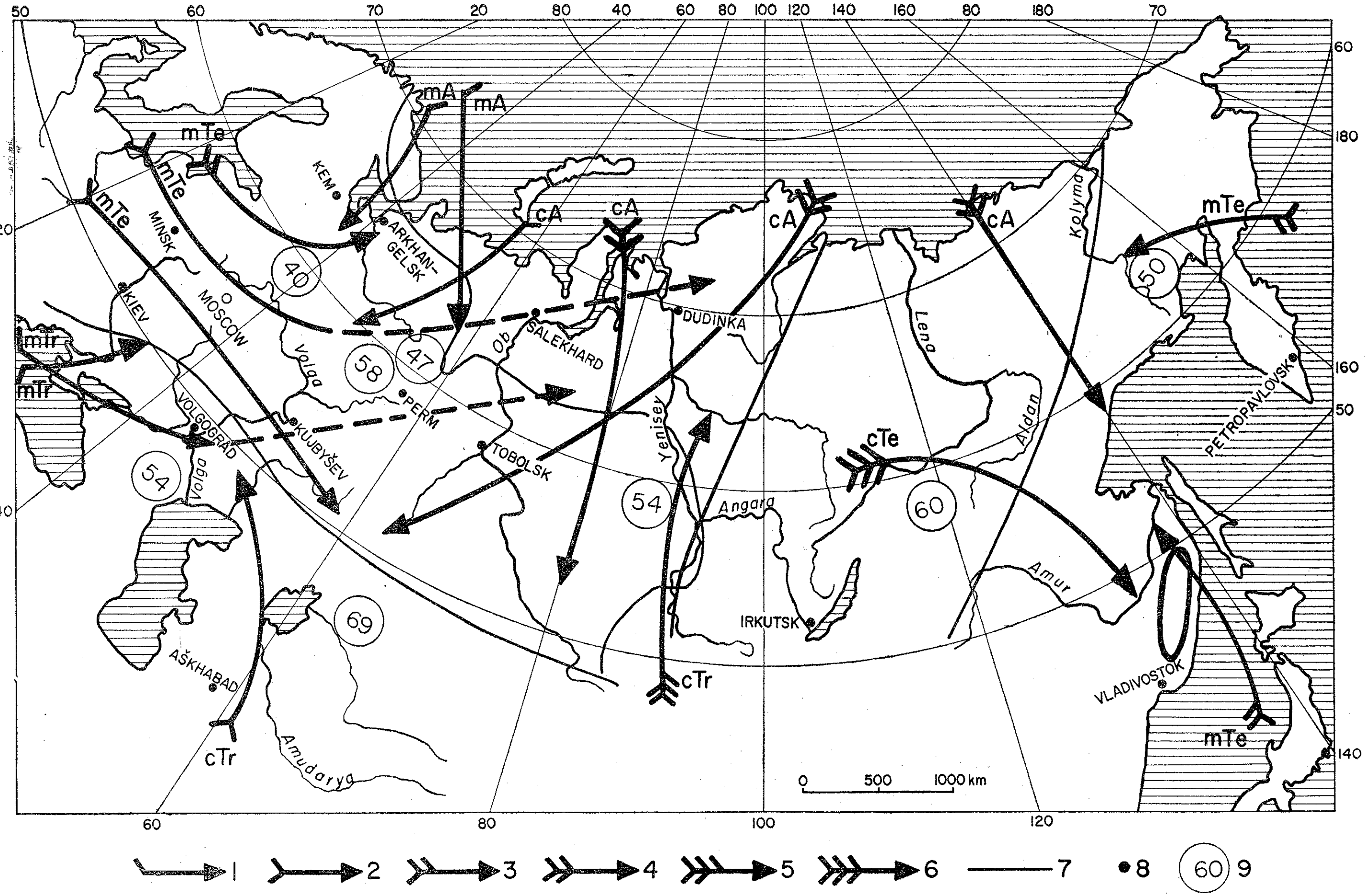


Fig. 7. Circulation of the main air masses in the territory of the USSR, according to Borisov, 1967

Direction of movement of air masses and frequency of days with different air masses (%): (1) 10-14; (2) 15-19; (3) 25-29; (4) 35-39; (5) 50-54; (6) 60-64; 7. boundaries of climatic regions; 8. meteorological stations; 9. frequency of days with continental Temperate air masses showed that the masses of relatively warm and humid air from the Arctic would penetrate into inland parts of the continent.

From the data presented by POGOSYAN results that these properaties of the air masses which determine the presence of permafrost depend strictly upon the rate of the ocean ice (after vanishing of sea ice the continental, specific climate prevailing in the permafrost area would change, the temperature and air humidity would increase).

In the present author's opinion, the above data and considerations perm it to assume that in the present time there exists a paragenetic relation between the permafrost area and ice-covered ocean.

It is justifiable to presume that the similar paragenetic relation was characteristic of the Pleistocene cryogenic area too. The similarity of the nature of cryogenic phenomena suggests itself the possibility of the relation supposed. However, as it has been presented with respect to today: sea glaciation—permafrost, the paragenesis is manifested here not only by the submission of processes but also by interrelation of parameters characteristic of the both areas.

It has been long ago stated that the most severe cryogenic conditions prevailed in the Late Pleistocene and the maximum extent of cryogenic areas greatly surpassed that of the present-day. The data testyfying to the presence of old permafrost in the southern part of Western Siberia and even in a part of Kazakhstan are discussed in many papers (BAULIN, 1965; SEVELEVA, 1964; FEDOROVIČ, 1962). In Eastern Europe the permafrost reached the very southern part of the east-European plain and farther it stretched over the greater part of Central and Western Europe. The results of field as well as data found in the literature show that the southern limit of the Late-Pleistocene permafrost ran along the line of 45—47° to 50° of northern latitude. From Mongolia it ran towards central Kazakhstan and farther to the west to the Caspian steppes and to the Stavropol Upland and Central Ukraine. In Central and Western Europe the southern boundary of permafrost probably had a more complicated course because of the mountainous system of the Carpathians and Alps. In Hungary, Poland, Roumania, Czechoslovakia, Austria and France (DYLIK, 1964; DEMEK, 1969; JAHN, 1969; TRICART, 1956, and others) the permafrost limit reached up to 45° of north latitude (Fig. 8).

According to the map made by LISICYN (1962) and on the basis of the data concerning the absolute age cited above, in the Late Pleistocene the area occupied by sea ice was at its maximum extent on the whole northern and probably also on the southern hemisphere. Such a great dimension of sea ice still persisted about 11,000 years B.P., i.e. when the permafrost area was at its maximum. In the Pacific Ocean the ice limit ran at 40° of N. lat. near the eastern coasts of Asia, and at the western coasts of North America almost reached up 30°. It stretched even more southwards in the Atlantic Ocean: in the middle part of the Ocean the limit was at 20°. There was a narrow ice-free belt along the north-west coasts of Africa

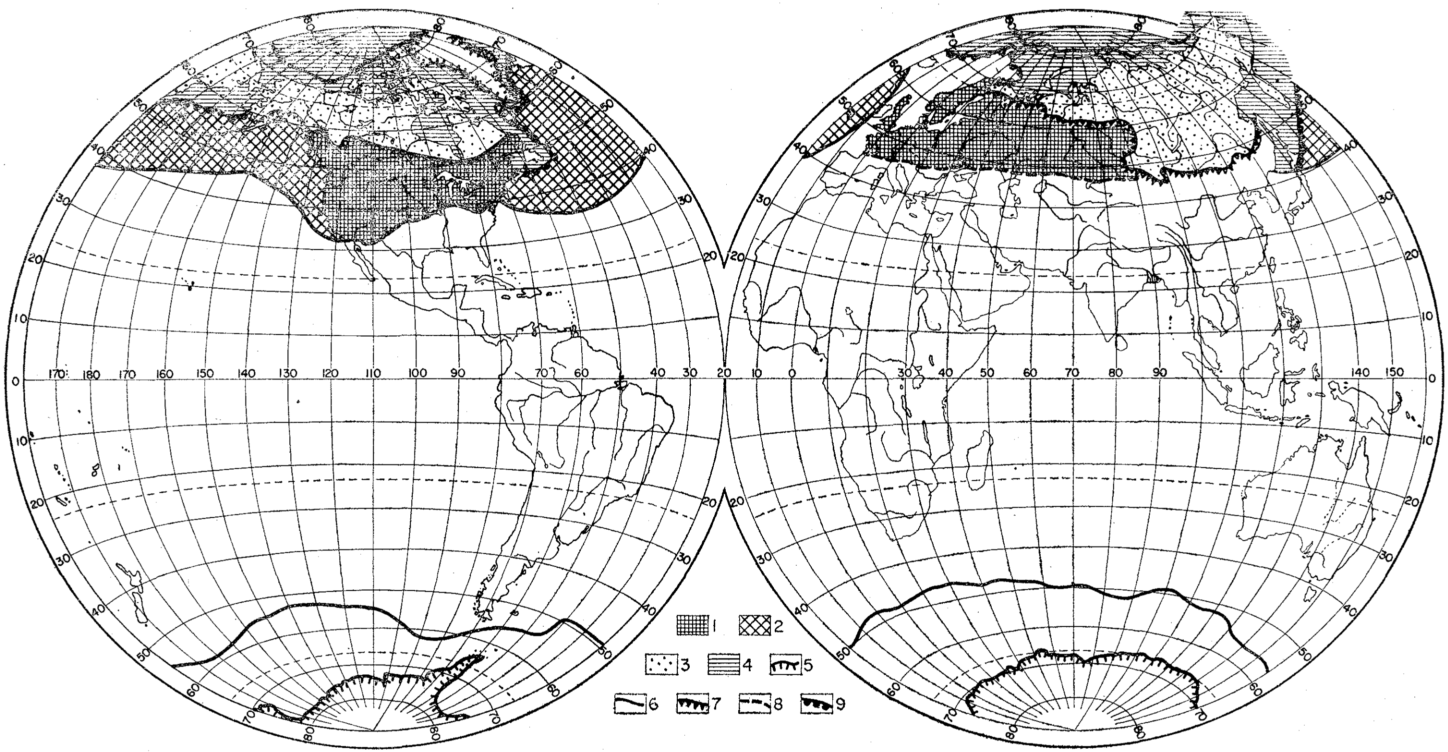


Fig. 8. More important areas of permafrost and sea ice in the Pleistocene and at present time (according to the author)

1. zone of permafrost degradation; 2. zone of sea-ice degradation; 3. zone of present-day permafrost; 4. zone of present-day sea ice; 5. limit of ice-cap; 6. limit of pack-ice; 7. limit of permafrost; 8. limit of ancient permafrost; 9. limit of sea ice

and Europe. Thereby, in the Late Pleistocene there was a vast, circumpolar area covered by sea ice.

This shows that the maximum ranges of sea ice and old permafrost extent were convergent in time. And what is more, it is clearly seen on the map that the limit of sea ice approaches the continent both on the west and east of Eurasia (on the west even farther to the south) at the same latitudes as the permafrost limit running from the inside of continent reaches the coasts. The convergence of the limits of sea ice and of permafrost can be also observed in space[2].

According to the author's scheme, while climatic deterioration was progressing on the northern hemisphere in the third stage of the Pleistocene, there arose a vast, circumpolar cap of sea ice (VELIČKO, 1968, 1969). The climatical land (continents and the surface of sea ice) occupied the larger part of the northern hemisphere. It expanded over 15,175 thousand km^2, which makes 65% of the whole northern hemisphere while in the present time its area is 54% only.

North of the 45—47^0 of N. lat. almost the entire Earth surface constitutes the climatical land.

Having in mind that at present the area of sea ice situated on the Eurasian coasts supplies dry and cold air only for the north-eastern part of the continent, it should be stressed that in the third stage almost the whole continent up to the subtropical latitudes was surrounded with the sea ice areas not only from the North Arctic Ocean and the Pacific Ocean but also from the Atlantic Ocean. The Atlantic Ocean, being in the present time the main source of humid and relatively warm air masses, during the Upper Pleistocene supplied the air of lower humidity and temperature. Such properties of the air masses had a decisive significance. In the first place, they led to the expansion of severe continental climate in vast European areas (except for the southern parts), and in consequence to the development of cryogenic phenomena under conditions similar to the present-day's in North-Eastern Europe. Secondly, the role of the Atlantic air masses being probably reduced to minimun in Eastern Europe and especially in Western and Eastern Siberia, the climate in these regions should have been extremely continental, much more so than it is even in Eastern Siberia now. This opinion is fully confirmed by the paleogeographical data from Northern Eurasia, where in the Upper Pleistocene a strong continentality was rapidly marked (LEROI-GOUTHAN, 1959; ANDERSEN, 1961; GRIČUK, 1965; BOYARSKAYA, MALAEVA, 1965; GITERMAN, *et. al.*, 1968).

It is striking that the distribution of continental climatic conditions in the past and present time display very similar properties. Therefore, continentality should have increased from west to east due to the woodless zone stretching near the western

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[2] Because of the lack of data concerning the course of the limit of cryogenic area in North America, the author tried to reconstruct this limit on the basis of the well-known rule of interdependence between the area of sea ice and permafrost with regard to sea currents and relief of the area in question.

coasts of Europe. This opinion is supported both by paleobotanical and paleofaunistical data as well as by the nature of distribution of fossil cryogenic structures.

In Siberia, during the Late Pleistocene the most dominant were the processes giving rise to the formation of great polygonal forms: ice and ground wedges. n Western Europe these forms were also very common but in the west and south-west regions of Europe an important role was played by thermokarst processes, as can be easily inferred from the investigations of cryogenic relief. Numerous items in the literature, some cited in this paper, as well as the results of a series of field works permit to assume that in Central, and especially in Western Europe, although some ground- and ice pseudomorphoses of Upper Pleistocene age can be met, none the less the cryoturbation- and solifluction structures are predominant, which testifies to milder climatic conditions. In the Atlantic regions (France) also appear slope deposits rhythmically bedded — *grèzes-litées* and *éboulis ordonnées* — bearing witness to rhythmical seasonal changes of humidity under frost conditions.

There may be attempted a general scheme to define the following climatological provinces from the east to west: (1) Siberian province — extremely continental with predominant large fissure polygons; (2) east-European — strongly continental, fissure polygons, the solifluction and thermokarst forms are very important;

(3) mid-European — continental, the thermokarst and solifluction processes are essential, fissure-polygonal forms are of minor importance; (4) west-European — relatively the least continental, dominant solifluction processes and slope sedimentation under conditions of variable humidity.

It should be born in mind that the processes occurring in each province are very simplified, they are referred to the flat areas disregarding the processes of sedimentation and denudation.

In this paper there have been presented counterarguments denying the possible existence of paragenesis: ice-sheet and cryogenic (periglacial) areas. To end with, there should be emphasized the main arguments that confirm undoubtedly the existence of paragenetic relationship: sea glaciation — cryogenic (periglacial) area:

(1) the present-day climatical interdependence between the permafrost area and areas of sea ice occurrence, which is confirmed by the present climatical dependences;

(2) contemporaneity (the Late Pleistocene) of the maximum extent of sea ice and of permafrost;

(3) conformability of the courses of sea ice and permafrost limits in the present time and in the Upper Pleistocene.

The main conclusion is as follows: in the past and present time the formation and development of cryogenic (periglacial) area have been associated not with the existence of a continental glaciation but with the development of sea-ice cap. In other words, in nature the ocean phenomena control the permafrost.

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