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REMARKS ON THE ORIGIN OF PALSA FROST MOUNDS

Abstract

Frost mounds known by the name of "palsas" can be found in subarctic regions, in zones of discontinuous permafrost. This fact is proof of the general dependence of these forms on the climate. The local, environmental conditions – that is, the presence of an isolating permafrost layer (peat, snow) are precise determinants of the places in which they occur.

Palsas are thus surface forms of permafrost and are dependent on the physical conditions of this surface. In this they differ from pingo mounds which originate and develop in dependence on the conditions prevailing inside the permafrost layer or even below it (subpermafrost water).

Palsas are subject to cyclical aggradation and degradation, their outward appearance being thus dependent on the particular phase they undergo at a given moment. Palsa-like mounds to be found in the arctic region as well as in the zone of continuous permafrost are also surface forms, not internal permafrost ones, but their actual genesis remains hitherto unknown.

Two articles have recently shed new light on the problem of palsa frost mounds. In the first of them (SEPPÄLÄ, 1982) the genesis of palsas is restricted to local factors with snow cover playing a vital role in their formation. The author writes: "The formation of palsas begins when the snow cover is locally so thin that the frost penetrates so deeply during the winter that the summer heat cannot thaw it completely". The author assumes a critical attitude towards my thesis (in fact not only to mine) which associates the occurrence of palsas with the general climatic conditions as well as the climatic changes of the zone (JAHN, 1976). SEPPÄLÄ writes: "The observations support the conclusion that changes in climate are not necessarily the reason for the collapse of palsas". The author forgets that the climatic conditions in which palsas may occur, i.e. discontinuous permafrost, have long been determined rather precisely (LUNDQVIST, 1962). In his important paper on the palsas of Norway, R. ÅHMAN (1977) writes: "The palsa area in northern Norway is bounded by a mean annual air temperature between 0° and –1°C, a winter temperature of –10°C for 120 days, a mean annual precipitation below 400 mm/year and less than 100 mm during the winter (December – March)".

If this is the case, it follows that a change of these conditions in one or the other direction should lead to the decay of palsas. This statement is the basis of my concept published in Polish (with a brief English abstract; JAHN, 1976). The misinterpretation of this concept, presented in the above mentioned paper by the

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Finnish author, resulted most probably from a lack of comprehension of the actual arguments which were not included in the English abstract.

The other important paper on the subject of palsas was presented at the Scandinavian symposium on problems of frost morphology, held in Lund in September 1982. Its author, H. J. ÅKERMAN (1982), found palsas or rather palsa-like mounds high up in the arctic zone, on Spitsbergen, and also in areas of continuous permafrost in Siberia. ÅKERMAN'S discoveries were not the only ones of their kind. Mounds resembling palsas in form and structure had much earlier been reported to occur in zones of continuous permafrost. It would then follow that palsas are forms not only of the subarctic zone, as has been believed hitherto, but may also be found in the arctic region. ÅKERMAN states that the Spitsbergen and even more so the Siberian palsas "are almost identical with the "classical" palsas and palsa localities in northern Scandinavia". Thus the matter seems to remain open and we have returned almost to starting point, i.e. the turn of the 19th century when mainly botanists (vide KIHLMAN, 1890–92; SUKAČEV, 1911) described certain mysterious mounds they had found on the peatbogs of northern Scandinavia or Siberia.

What are palsas? Does the resemblance between their subarctic and arctic forms or even that of their structures justify the search for a homogeneous theory of their origin? There can be no doubt that the essential factor in their genesis is the presence of peat that is, peatbogs within the reach of which palsas can be found (the imputation put forward by SEPPÄLÄ, 1982, that I had ruled out the presence of peat among palsas is untrue). Is the palsa formation due to a bulging or upheaving caused by ice segregation and aggradation or are there also palsas developed from peatbog due to the erosional processes (PYAVČENKO, 1955) or thermokarst processes, e.g. SCHUNKE'S (1973) "thermokarst mounds"? In this case not aggradation but degradation would be the principal formative factor. The question is whether palsas can be restricted to segregated ice as opposed to pingo mounds which are connected with massive, injection (intrusive) ice. But here again we have those "ice cored mounds" of the periglacial zone, mounds that resemble palsas in form but are also very similar to pingos on account of their ice core (Pl. 1). Or does the solution to the problem lie in the concept put forward by WASHBURN (1979) who writes: "The present writer agrees with SVENSSON (1976) that palsas and pingos [...], are related through transitional forms but where best developed occur in different environments".

So we have three kinds of peat mounds occurring on peatbogs in groups (not separately), which could all be given the name of palsas:

– mounds made of peat only and containing thin layers of segregated ice,
– mounds with ice cores,
– mounds with mineral cores (minerogenic palsas).

This diversity of forms was known even to GRIGORIEV (1925) who divided peat mounds ("bugor" in Russian) into a European and a Siberian type. The first type should equal our classic peat palsas, whereas the palsas of the second type often contain ice or mineral cores. This Siberian type – as can be inferred from GRIGORIEV'S description – would also include Siberian pingos, i.e. bulguniakhs.

What criteria then might be applied to distinguish palsas? The most important seem to be their size (maximum height 7–10 m) and their occurrence on the peatbog in complexes. This distinguishes them from pingos which are usually single and much larger. The difference is caused by the fact that the pingos are rooted in the permafrost itself and are connected with its development throughout its whole thickness and even with the sub-permafrost water (MACKAY, 1979), whereas palsas are surface forms dependent on processes taking place on the soil surface. In this case palsas should be more closely related to the climate than pingos, since climate and its variations, including snow cover, determine the nature of the soil surface processes. Where palsas are concerned peat is only an auxiliary element, a regulator of heat transfer.

The palsa structure, especially the type of ice inside the mound, whether segregated or intrusive ice, depends on the way of the water inflow. If the water gets into the peat by suction, segregated ice is developed. If the water reaches the mound in a full stream (free, gravitational water) a palsa ice core is formed. "Ice-cored" mounds or "ice hydrolaccoliths" occur most often at the foot of a slope in places where gravitational pressure makes the slope streams seep through under the peat. Although the shape of such a mound resembles a palsa, its genesis is – as suggested by MAARLEVELD (1965) – more similar to an open type pingo.

Much like most natural phenomena, palsas undergo cycles of growth and decay, and that is why we speak of their aggradation and degradation. This division remains valid no matter what factors cause the growth or decay of a form. These may be climatic factors such as a change in climate, a change in the heat balance of the soil (JAHN, 1976) – or a change in other, even local conditions of the environment. It has been a common notion that degradation is an inherent element in the development stages of a palsa. The beginnings of this theory may be found in the opinions of botanists who explored the tundras of northern Europe seventy years ago. It was later developed by Russian investigators of Siberia of whom S. P. KAČURIN (1961) deserves special attention. He included the thermokarst theory in the development and decay cycle of bugors-palsas. When a frost heaving (bulging) hillock has reached a certain, limited size, its desiccated top covers with cracks and so permits the penetration of heat. A. P. TYRTIKOV (1969) is of the opinion that palsa degradation begins with the wearing away of the thin layer of light-coloured lichen on the peat top of the mound. This top becomes the object of eolian erosion while the sides also undergo erosive processes. The natural consequence is decay, and so no greater climatic changes are needed for the hillock to degrade to the initial level of the peatbog. If we accept the theory of the development and decay cycle of palsas, the genetic division of these mounds into bulging (upheaving) and erosion forms becomes pointless, for they are forms of homogeneous origin and belong to the aggradation or degradation stages of the same cycle. The palsas of the central part of Iceland should be included in this class of degradable palsas of which SCHUNKE (1973) wrote: "The development of many palsas in central Iceland is not a matter of ground bulging due to ice segregation but of phenomena related to cryokarst". But even earlier (FRIEDMAN, *et al.*, 1971) a simultaneous occurrence of aggrading and degrading palsas had been recorded on Iceland.

If we assume palsas to be forms related to processes acting on the ground surface and originating from it, we shall find many instances of relationship between these mounds and forms that are dependent on the development degree of vegetation. It is sometimes difficult to distinguish high mounds with upwards growing sphagnum, which have not yet developed a frozen core (Pl. 2) from typical palsas with a permafrost lens inside. On the Varanger peninsula, in northern Norway, both forms are quite common, and their apparent similarity is such that only a detailed examination of their structure will show their difference (JAHN, SIEDLECKI, 1982). Thus the very origin and source of palsa formation is not easily perceptible, especially if we realize that palsas develop gradually from a seasonal (one-year) form to the actual, many-years form. Seasonal permafrost holds on in many mounds (Pl. 3) and vanishes sometimes as late as towards the end of summer.

There also exist palsa mounds related to such typically vegetative forms as the ridges (ramparts) on string-bog surfaces. Formations of this kind were observed by the present author in the Schefferville region, on the Labrador peninsula (Quebec), Canada [1]. Here is an example.

One of the valleys in the SW direction from an iron mine has a flat bottom with a very unusual palsa arrangement (Fig. 1). All the palsas there are short and flat (up to 0.5 m high) and have distinctly marked edges strengthened with *Betula* and *Salix* bushes (Pl. 4). The permafrost surface was at a depth of 50 cm (September 1975), and a peat sample taken from the depth of 70 cm was dated – according to analysis ^{14}C – as 3230 ± 120 years [2].

The palsas are arranged in two directions. The larger patches keep the direction of the valley, parallel to the shores of the lakes and the marshy (stream) axis of the peatbog. The smaller patches lie diagonally in relation to the course of the valley. The reason for this direction is difficult to explain. It might be the crack system of the bedrock. The cracks are visible on the valley slope and run in the same direction.

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[1]The author is indebted to Dr. FRANK NICHOLSON, that time (1975) Director of McGill University, Sub-Arctic Laboratory in Schefferville, Quebec, for his friendly aid in the field researches.

[2] The dating was carried out at the Institute of Physics of the Silesian Technical University in Gliwice, Poland. Laboratory ^{14}C. Nr. of sample: Gd-473 (M. F. PAZDUR).

Photo by the author, July 1973

Pl. 1. Frost mound with ice core in Siberian tajga. Chandyga region, Aldan river basin

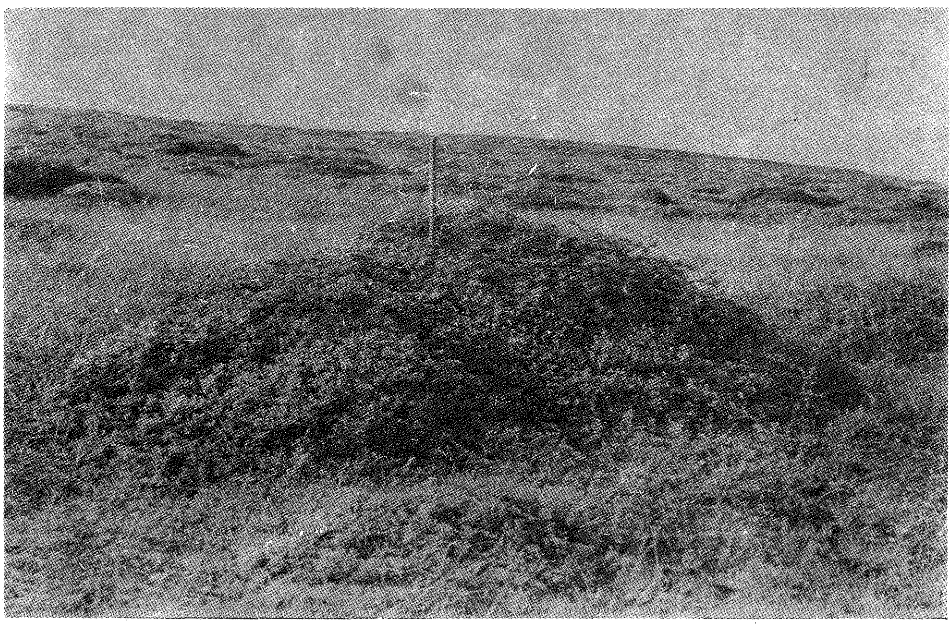

Photo by the author, July 1974

Pl. 2. One of the largest peat-turf mounds of "thufur" type (1.5 m high) in the Gaednialakka valley, Varanger Peninsula, Norway. Although resembling a palsa in shape and height, this form cannot be included in this type of phenomena

Photo by the author, June 1979

Pl. 3. Seasonal permafrost (light-coloured) in peat mounds on the Kåf fiord (route to Nordkapp) in northern Norway

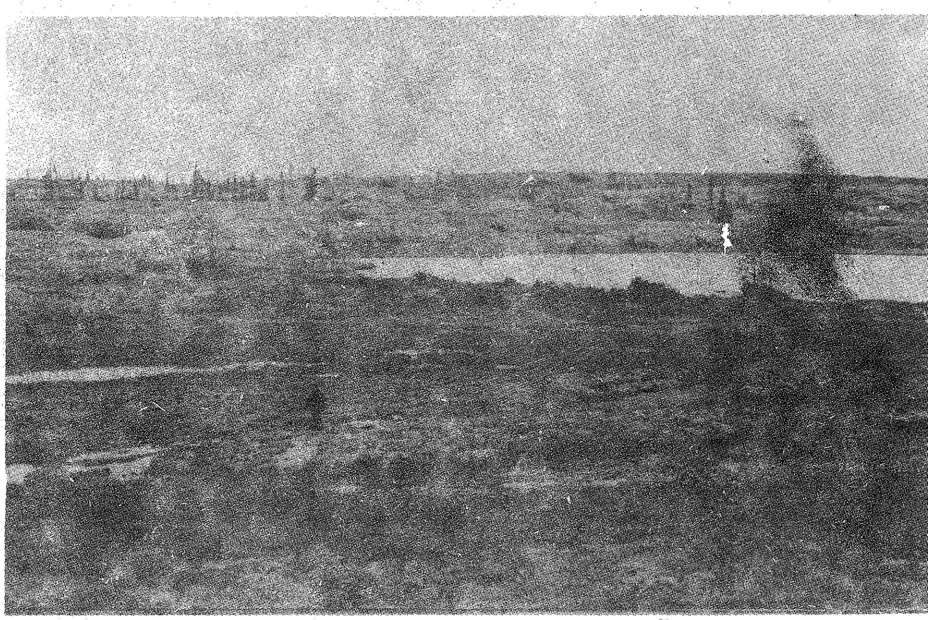

Photo by the author, August 1975

Pl. 4. Plateau-like palsas and string-bogs on marshy valley bottom. Schefferville region, Quebec, Canada

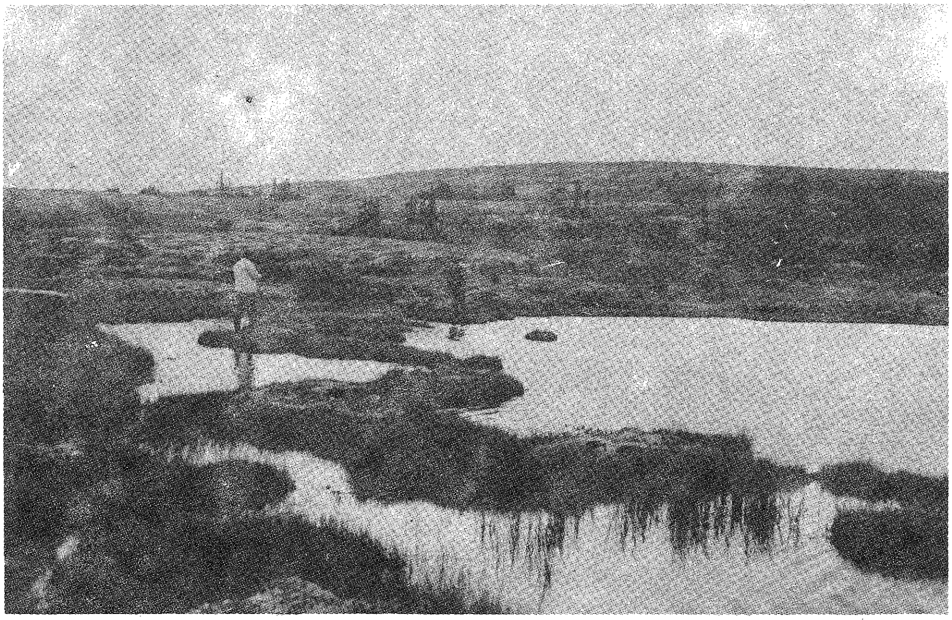

Photo by the author, August 1975

Pl. 5. Palsas turning into string-bog ridges. Palsas are the light-coloured mounds both on the opposite side of the lake and near the ridge, closing the lake. Schefferville region, Quebec, Canada

Photo by the author, July 1973

Pl. 6. Frost mounds on the bottom of the Oymyakon valley. Siberia

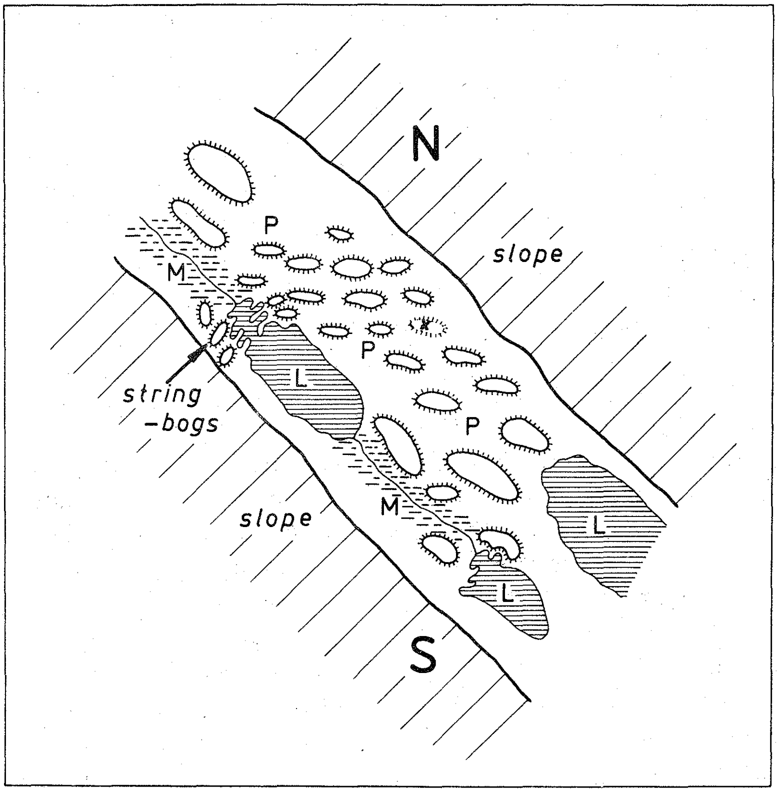

Fig. 1. Palsas located on valley bottom in the Schefferville region
X – place of sampling for analysis ^{14}C; L – lakes; P – palsas; M – marshy area

The transitional zone between the peatbog and the lake is characterized by string-bog formation. The palsas there pass into the peat ridges of the string-bogs (Pl. 5). These are parallel running ridges separated by shallow lake waters and showing the typical vegetative phenomenon, sedge, on the surface. In some places they are interspersed with palsa mounds. The surface of the mounds is dry, and the thickness of the unfrozen soil is here from 0.5 – 0.8 m. The thawed layer between the mounds amounts to 1.5 m, and in flooded places a 1.5 m long drill did not hit permafrost at all.

Having presented these facts I shall now return to the principal problems mentioned at the beginning and refering to the doubts expressed by ÅKERMAN (1982). It is beyond question that using the term palsas we are dealing with a phenomenon of convergence. This fact, I wish to repeat, was first pointed out by GRIGORIEV who perceived the similarity as well as the difference between the mounds of northern Europe and Siberia. It is a difference between the mounds of regions with discontinuous and continuous permafrost. In the first case the peat mound is an island in itself or rather a permafrost patch (on the principle of a close linkage of both phenomena), in the second case the mound rises above the homogeneous, many meters thick permafrost layer. Both types of mounds can thus be regarded as phenomena of internal permafrost (continuous) and peripheric permafrost (discontinuous). The two types of mounds differ from each other. The "classical" palsas of the peripheric permafrost area are always peat-covered and of convex, shield- or bell-like shape, often also flat (palsa plateau). They occur as complex forms on the whole peatbog. They are, in fact, a surface formation of peatbogs.

The frost mounds described by SALVIGSEN (1977) and ÅKERMAN (1982) – the latter ones are known to me, too, from personal inspection (JAHN, 1975) – are smaller than the typical palsas and develop separately. Though their structure (segregated ice) resembles that of typical palsas, they can hardly be identified with the forms to be found in the subpolar zone of Scandinavia.

The greatest controversy, however, has arisen over the small frost mounds of the continuous permafrost zone- that is, Siberia and also Alaska. Being known as "bugor" in Russian literature, they have not been compared to the "classical" Scandinavian palsas. The copious literature dealing with "bugors" does not contain any attempts at drawing comparisons. The division between two worlds, languages and cultures reaches even those phenomena of nature. Not much attention is usually paid to the fact that the Russian "bugor" or even "torfiannyi bugor" means a whole range of forms different in size, structure and the environment in which they develop. There are typical forms of peatbog surfaces, peat mounds occurring in complexes rather small ones, such as those investigated by ÅKERMAN (1982) in the Viluy river basin or such as the ones observed by the participants of the Second International Congress on Permafrost in the very center of continental Siberia, in the Oymyakon basin (Pl. 6). There are typical pingos, the Russian "bulguniakhs", large, single hillocks in the tundra or tajga plains. Finally, there are "bugors" such as were described by Mrs. ROZENBAUM (1965) who observed these 8 m high mounds devoid of peat cover, with segregated instead of intrusion ice in the Jana river basin. The authoress was right in linking the development of those mounds with the presence of talik in the depth of permafrost. This talik developed once during permafrost aggradation in an abandoned oxbow. The freezing of the talik produced tension which manifested itself on the soil surface in the form of a mound. The genesis of this form is therefore closer to a pingo than to a palsa.

In view of this diversity of forms the most reasonable seems to be the division of frost mound forms presented above.

Thus the genesis of some forms is connected with the development of permafrost, its aggradation and degradation as well as its hydrology (cracks, taliks). Such forms are produced by processes taking place in the depth, through the whole or the larger part of the permafrost layer. Pingo-bulguniakhs belong to them. Injection (intrusive) ice can often but not always be found in them. In the cross-section of some pingos there is a predominance of segregated ice (MACKAY, 1979; JAHN, 1975) as a possibly secondary pehnomenon, as seen in the example of the "bugors" of the Yana delta (ROZENBAUM, 1965). The development of the form by internal thrust (hydrostatic pressure) took place earlier than the formation of segregated ice in the already elevated mound mass.

The second type of frost mounds is produced by external processes directly connected with climatic factors. Freezing and thawing controlled by the presence of an isolator (peat, snow), the effect of warm surface water (thermoerosion, thermokarst) – all these being determined by the prevailing climatic conditions. This type of palsa is the "classical" one which may also be called the Scandinavian type, although it may be found in other subpolar regions. The thermal conditions of this zone are not precisely determined, e.g. the palsas of the Schefferville region belong to an area where the annual mean temperature is close to – 5°C (BROWN, 1979). Similar conditions have been noted (DIONNE, 1978) for the occurrence of palsas in the James Bay region in Quebec (annual temperature – 4°C to – 4.5°C). Where then is the place of Siberian frost mounds in this system? Can they be determined according to climatic conditions? If the term "palsas" refers to forms of Scandinavian type, i.e. to frost mounds of the peripheral permafrost zone with all the specific influence of this environment on the relief forms, it cannot be applied to Siberian mounds much less so to Spitsbergen ones.

There can be agreement, however, on the fact that these mounds are surface formations unrelated to the deeper processes of the whole permafrost (including talik), which makes them different from pingos. They are forms being placed on the permafrost and possibly affected by the changes having occurred in its active layer and so also by climatic changes.

Note: A. L. WASHBRUN'S important discussion "What is a Palsa?" (*in:* "Mesoformen des Reliefs im heutigen Periglazialraum", *Abhandl. d. Akad. d. Wiss. in Göttingen*, Math.-Phys. Kl., III Folge, Nr 35. Göttingen, 1983; p. 34–47) and A. PISSART'S article "Pingos and Palsas: Un essai de synthese des connaissances actuelles" (in the same edition, p. 48–69) were received after submission of the present article.

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References

ÅHMAN, R., 1977 – Palsar i Nordnorge. *Medd. Lunds Univ., Geogr. Inst.*, 78; 165 p.

ÅKERMAN, H. J., 1982 – Observations of palsas within the continuous permafrost zone in eastern Siberia and in Svalbard. *Geogr. Tidsskrift*, 82; p. 45–51.

BROWN, R. J. E., 1979 – Permafrost distribution in the southern part of the discontinuous zone in Quebec and Labrador. *Geogr. phys. Quat.*, 33; p. 279–289.

Dionne, J. C., 1978 – Formes et pénomènes périglaciaires en Jamésie, Québec subarctique. *Géogr. Phys. Quat.*, 32; p. 187–247.

Grigoriev, A. A., 1925 – Die Typen des Tundren Mikroreliefs von Polar-Eurasien, ihre geographische Verbreitung und Genesis. *Geogr. Zeitschr.*, 31; p. 345–359.

Jahn, A., 1975 – Problems of the periglacial zone. Warszawa; 223 p.

Jahn, A., 1976 – Pagórki mrozowe typu palsa (summary: Palsa-type frost mounds). *Studia Soc. Sci. Torunensis*, 8, sec. C; p. 123–139.

Jahn, A., Siedlecki, S., 1982 – Periglacial phenomena on the Varanger Peninsula (Norway). *Biul. Peryglacjalny*, 29; p. 25–52.

Kačurin, S. P., 1961 – Termokarst na territorii SSSR (Thermokarst on the territory of the USSR). Moscow; 291 p.

Kihlman, O., 1890–1892 – Pflanzenbiologische Studien aus Russisch-Lappland. *Acta Soc. pro Fauna et Flora Fennica*, 6.

Lundqvist, J., 1962 – Patterned ground and related frost phenomena in Sweden. *Sver. Geol. Unders.*, 55, ser. C 583; 101 p.

Maarleveld, G. C., 1965 – Frost mounds, a summary of the literature of the past decade. *Meded. Geol. Stichting*, N.S., 17; 16 p.

Mackay, J. R., 1979 – Pingos of the Tuktoyaktak Peninsula Area, Northwest Territories. *Geogr. phys. Quat.*, 33; p. 3–61.

Pyavčenko, N. I., 1955 – Bugristie torfianiki (Bugor moors). Moscow.

Rozenbaum, G. E., 1965 – Mekhanism obrazovanya bugrov pučeniya s maloldistom yadrom (Mechanism of formation of upheaval bugors with fine ice core). *in*: Podzemnyi led (Underground ice), vol. II; p. 112–119.

Schunke, E., 1973 – Palsen und Kryokarst in Zentral Island. *Akad. Wis. Göttingen Nachr., Math.-Phys. Kl.*; p. 65–102.

Salvigsen, O., 1977 – An observation of palsa-like forms in Nordauslandet, Svalbard. *Norsk Polarinst. Arbok*; p. 364–367.

Seppälä, M., 1982 – An experimental study of the formation of palsas. *in*: The Roger Brown Memorial Volume. *Proc. Fourth Canadian Permafrost Conf., Calgary, Alberta*; p. 36–42.

Sukačev, V. N., 1911 – K voprosu o vliyaniii merzloty na počvu (On the influence of permafrost on soil formation). *Izv. Akad. Nauk SSSR*, 65; p. 51–60.

Tyrtikov, A. P., 1969 – Vliyane rastitelnogo pokrova na premerzaniye i protaivaniye gruntov (Influence of vegetation cover on ground freezing and thawing). Moscow.

Washburn, A. L., 1979 – Geocryology. A survey of periglacial processes and environments. London; 406 p.