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DOMED-HUMMOCKY PEATBOGS OF THE NORTHERN TAIGA IN WESTERN SIBERIA

Development of the so-called domed-hummocky (large-sized hummock) peatbogs within the northern taiga of Western Siberia is commonly known to all explorers of Western Siberia. Problems related to the genesis of these formations, the time of their development and their present state have frequently been discussed in the literature, with most contradictory views that have been described in detail in the works by Popov (1953, 1967), Kačurin (1961) and Tyrtikov (1969). The present paper is devoted to an analysis of the observations made by the authors during the summer of 1969 in the area of the Pravaya Khetta (a right-bank tributary of the Nadym river), which permits to advance certain hypotheses concerning these problems.

The region under study is situated in the northernmost part of the taiga zone. It is a slightly dissected plain with absolute heights of up to 100 metres, built, of marine and marino-glacial sediments of either Lower or Middle Quaternary age. On the surface, of common occurrence are large relict-lake closed basins filled with bog-lacustrine deposits and occupied by bogs with small relict lakes in which peat accumulation continues even now.

Three zones can be distinguished within these basins. The first zone is along the very border of the basin. It is usually characterized by a dry surface, thixotropic ground, small-hillock microrelief with peat hummocks 0.2 m to 0.3 m in height, and dwarf-shrub vegetation mixed with tree species. Mean annual tempearture of the ground is 0°C (Fig. 2A) and the depth of the annual oscillations reaches 3.5 to 4 m. The second zone, several hundreds of metres wide, is distinguished by high moisture content, a hillocky-sinky relief with peat hummocks 0.5 m to 0.8 m high, and swampy intervening depressions. Large peat fields commonly occurring in this zone are broken into 30 × 40 m polygons with hillocks, and elevated ca. 1 m above the inter-polygon surfaces. The intervening depressions are elongated, with dimensions of about 5 m by 15 m, and occupied by sedge and cotton-grass swamp. The permafrost is frequently disrupted, the temperature approximates 0°. The third zone occupies the central, usually largest area of the basin. It represents a recent sedge-sphagnum bog with small lakes dispersed over its surface. Portions of ancient drained peatbogs occur here very seldom. Permafrost is absent from the surface (at least down to 7 m).

In the overwhelming majority of cases, the hummocky peatbogs under consideration are confined to the fringing strip between the first and the second zones. They are practically absent in the second zone, and do not occur at all in the third.

Hummocks are developed in both large and small basins, and occur as single, individual forms though they may be grouped and even form ridges 1 to 2 km long and up to 200 m wide. As a rule, isolated hummocks have the smallest heights of 2 to 2.5 m, grouped hummocks are higher, 3 to 5 m, and ridge hummocks reach maximum heights of 8 to 10 m (Pl. 1).

All the hummocks have a number of morphological features in common: they are usually rather large-sized and domed forms with diameters at the base of 30 to 80 m, and steep (10° to 20°) slopes, steeper at the side facing the centre of the basin and gentler, often step-like on the opposite side. The inter-hummocks depressions, mostly elongate, are occupied by cottongrass--sedge bogs with small lakes in their central parts. The largest hummocks are frequently broken by fissures up to 0.2–0.3 m deep.

Field observations show that the southern forest-tundra constitutes the northern boundary of hummocky peatbog occurrence (in this area are the heads of the Nižnaya, the Srednaya and the Verkhnaya Pody rivers, left-bank tributaries of the Nyda). Near this boundary, hummocks are predominantly small and isolated, even in large basins. Southwards, in the northern taiga, the hummocks have larger dimensions and are much more widespread. Grouped hummocks are more frequent, and finally the largest hummocks appear in ridges.

The hummocks are built of the same material as the lake basins. There are peat hummocks in which peat 0.5—2.5 m thick (Fig. 1, Borings 20-PA and 9-PA) overlies bog-lacustrine deposits, and others consisting of purely mineral material.

The frozen cores of the hummocks are extremely icy. Our observations confirm Pčelincev's calculations (Popov, 1958), according to which the height of a hummock corresponds to the total thickness of the ice layers. These data are shown in Table I.

The usually clear dependance of ice content on the lithological composition of frozen ground is quenched in these hummocks by a more pronounced relation between ice content and the height of a hummock. The lesser the height of a hummock the lower the ice content, and *vice versa*. For example, in peatbog of the second zone (that did not undergo frost heaving) the total

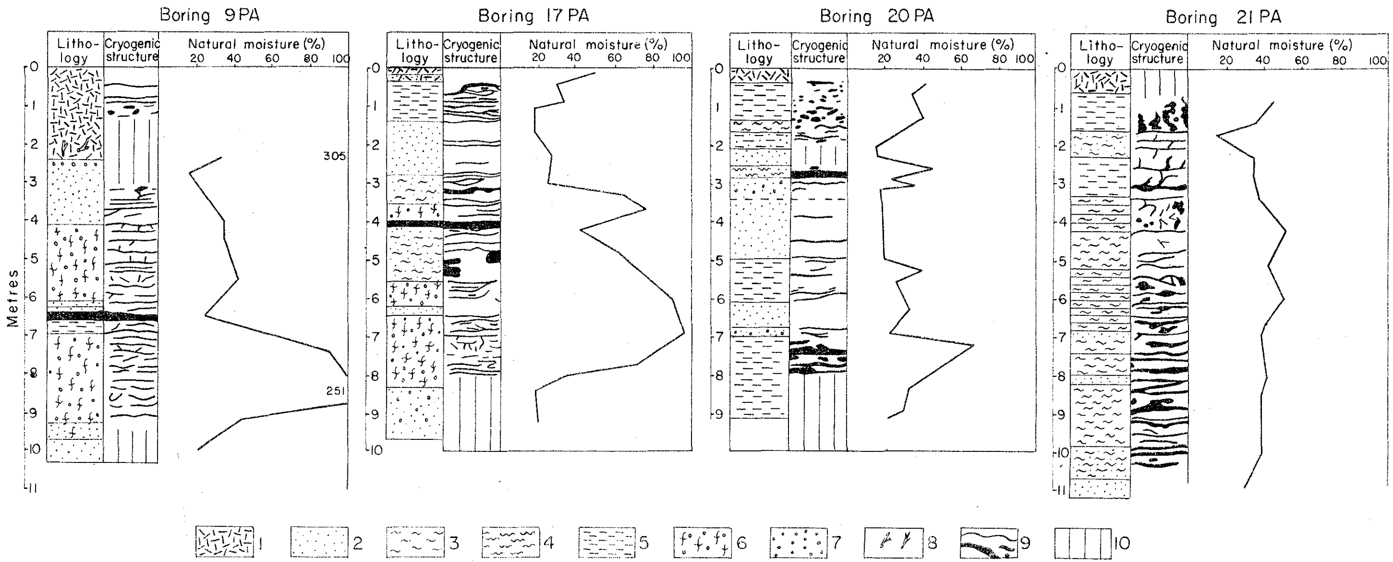


Fig. 1. Cryogenic structure and natural moisture in mounds (Borings 9-PA, 17-PA, 20-PA) and on the surface of peatbog (Boring 21-PA)

1. peat; 2. sand; 3. aleurite; 4. clay aleurite; 5. loam; 6. clay; 7. gravel; 8. tree remnants; 9. ice seams; 10. massive structure

Table I

Distribution of thickness of ice interlayers in frost heaving hummocks (in centimetres)

Depth interval (in metres)	Height of hummock (in metres)		
	2.0 Boring 9.PA	2.5–3.0 Boring 27.PA	2.0 Boring 20.PA
0 to 1	22	7.6	13.2
1 to 2	10	9.6	21.6
2 to 3	–	22.6	17.2
3 to 4	13	39.1	5.2
4 to 5	13	49.7	–
5 to 6	15	47.9	8.5
6 to 7	37	25.4	1.6
7 to 8	37.5	14.0 (to 7.9 m)	24.9
8 to 9	10.2	–	–
9 to 10	10	–	–
10 to 11	–	–	–
Total thickness	167.7*	215.9*	100.3

* The boring has not cut the entire permafrost through, so the amount of ice is incomplete.

moisture content of the aleurite in Boring 21-PA (Fig. 1) averages 30–40%, the highest moisture content of the sand in the 3 to 3.5 metre hummock (Fig. 1, Boring 17-PA) is 60–96%, and the lowest moisture content of the sandy loam in the 8–10 m high hummocks (Boring 24-PA) is 115–156% (it is practically an ice-mineral core).

The cryogenic structure of the hummocky peatbogs is most pronounced in the section of a hummock near Boring 6-E (Pl. 2). The basal structure in 0.8 m thick peat passes in the underlying peaty aleurite (0.5 m thick) into a reticulate structure with vertical schlieren (1–2 cm thick) set up some 20 cm apart, and to horizontally distributed 1 cm thick interlayers spaced 2–3 cm. The underlying pure aleurite (0.4 m thick) has a reticulate structure with 15–20 cm cells, and 3–5 cm schlieren. Further downward, in the same aleurite, basal structure is traced in the 1 m to 1.2 m thick layer: the 10–15 cm schlieren have an oval shape, and the mineral interlayers are broken by ice into regular plates up to 5 cm by 20 cm in size. Below, horizontally stratified schlieren are 2–3 cm thick, spaced 10–20 cm. Downwards, the schlieren gradually become less widely spaced and decrease in thickness.

The cross-section of this hummock shows that cryogenic structure does not either depend directly upon the lithology of the ground.

Distribution of temperatures in hummocky peatbogs is most specific. The grounds of the inter-hummock spaces have either a positive temperature or temperature approximating 0° whereas the grounds in the hummocks have rather low temperatures varying from −1° to −6° (Fig. 2). There is a close interrelation between the height of a hummock and its temperature: the higher the hummock the lower its temperature. At the same time temperature fall is noted in the ground of the hummocks arranged in groups as well as its rise in the isolated forms (Fig. 2E and 2B).

With depth, temperature of the ground in the hummocks rises rather fast and reaches 0°. Thus the hummocks described have a frozen core of small size, "floating" amidst the thawed or plastically frozen ground. The thickness of a frozen core increases with falling ground temperature, and with increasing height of the hummock and consequently with growth of its base.

Analysis of the material obtained supports the correctness of Popov's opinion (1953, 1960, 1967), who regards hummocky peatbogs as a result of water migration and of frost heaving in a previous colder period (the time following the thermal maximum), and holds that they are now actually inactive.

The fact that the swelling-up hummocks of the northern taiga in Western Siberia are relict hummocks is confirmed by quite a number of facts given below.

As results from the description of the hummocky peatbogs, the major number of swelling-up hummocks is concentrated in the marginal parts of he ancient lake-and-bog basins surround ng them in nearly closed rings. Such distribution may be explained in the following manner.

After the thermal maximum during the period of temperature fall freezing up of grounds started in such portions of the bogs as were previously drained out. These were the marginal parts of the bogs (the present-day first zone) composed of peaty and purely mineral material. Both had undergone swelling. Hummock formation seems to have proceeded in the way described by Popov (1953). At the initial stage of freezing snow was distributed unevenly on the hummocky surface of a flat peatbog, and consequently the different parts of the surface cooled unevenly. This was the time of initial differentiation into hummocks and intervening depressions due to moisture migration from aside towards the growing hummocks. An additional factor activating this mechanism was in the proximity of the freezing strip with localities differing from it by their higher superficial insulation: a waterlogged swamp on one side (the present second and third zones), and an afforested (hence evenly snow covered in winter) watershed divide on the other. Such location is apt to induce intensive and lasting processes of migration and heaving. As a matter of fact, according to Baženova's (1953) and Orlov's (1962) the vicinity of localities with a pronounced heterogeneity of freezing conditions, the presence particularly in the adjacent locality of a heat-insulation layer (a snow

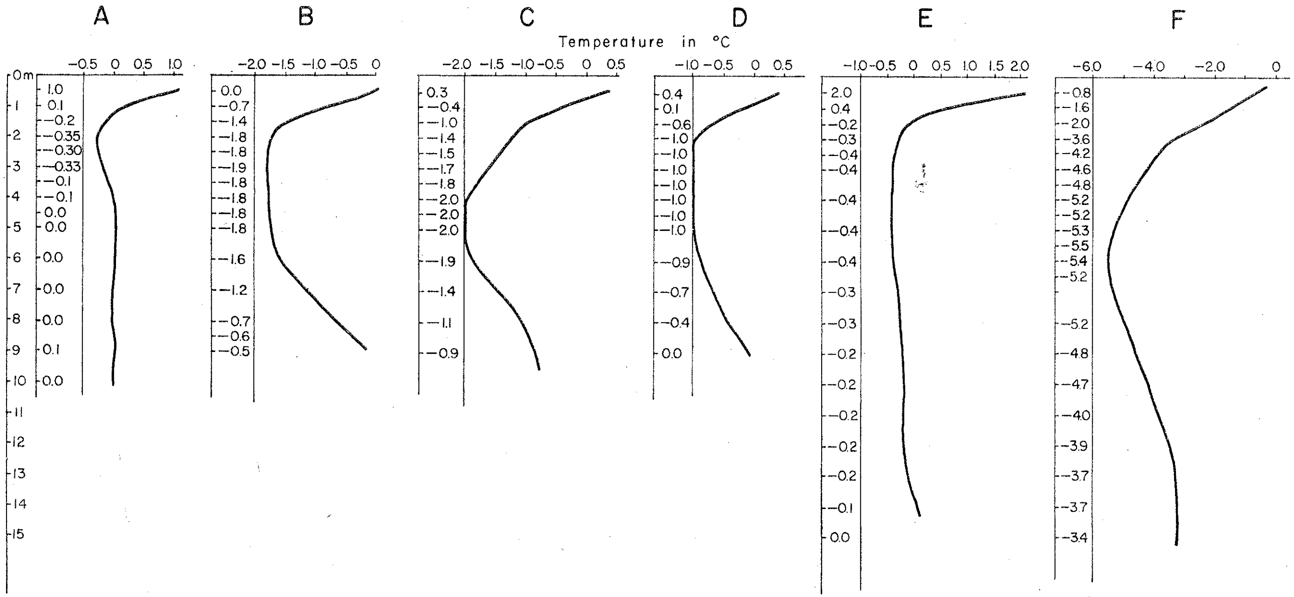


Fig. 2. Temperature section of frost-heaving hummocks

A – Boring 8-PA; B – Boring 9-PA; C – Boring 17-PA; D – Boring 20-PA; E – Boring 10 (Kunicyn, 1958); F – Boring 24-PA cover, or else), causes horizontal temperature gradient to be originated in the ground, which favours the horizontal transition of moisture from the thawed layers underlying thermal insulation towards the freezing up sites. The result of this is that the intensity of heaving is, as a rule, 1.5 to 2 times higher in the bordering localities than in the parts that freeze up under uniform conditions. Just because of this the overwhelming majority of mounds in this region are confined to the marginal parts of the bog-lacustrine basins and in particular to the boundary between the two zones.

The process of hummock formation, prolonged in time, involved also the newly drained innermost areas of the bogs with thicker peat. Here the largest hummocks were formed, because the considerable thickness of peat hindered summer thawing of the ground, and under such conditions according to Orlov's experiments (1962), heaving operates through the whole year.

Further drainage of bogs continued also in the way described by Tyrtikov (1969), in particular, due to the dynamics of the vegetation cover, but oving to the gradual warming-up of the climate hummock development ceased in the newly drained peatbogs. As a result, swelling-up hummocks are absent now from the vast area of the second zone. The evidence of Boring 21-PA (Pl. 2) plainly shows that heaving never occurs in such sites. Reticulate cryogenic structure, rarefying with depth, is traced in aleurite overlain by peat 0.6–0.8 m thick – a typical result of epigenetic freezing. At the same time, association with the lithologic changes is clearly observable in the section: clayey aleurites have a denser ice network and thicker schlieren than the alternating sandy aleurites. There is no degree of increased iciness that might provide evidence of extra moisture migration towards this site. Since the cryogenic structure is always an indication of freezing rather than of thawing (Popov, 1967) conditions, the conjecture that the present-day flat peatbogs of the second zone might have been hummocky in the past but now are thawed out may be safely ruled out. According to the authors' observations, permafrost disapears on the surface in the site of thawed-out hummocks.

No origination of domed-hummocky peatbogs is taking place at the present time. This is confirmed by the complete absence of such formations from the third zone where peat accumulation continues and partial drainage of the surface takes place due both to recent tectonic uplifting and to the succession of plant associations.

In summing up, it may be reasonably assumed that the conformity of hummocks due to heaving to the peripheral parts of the ancient bog-lacustrine basins, the combination of peat and mineral hummocks of heaving on the exterior side and the absence of mineral hummocks in the interior of the hummocky zone as well as the absence of hummocky peatbogs from the existing third zone and at the boundary between the third and the second zone, all seem to indicate that domed-hummocky peatbogs are relict formations that originated in a past, colder epoch.

The authors' investigations in 1969 permit therefore of an approximate estimation of the upper time limit of the development of hummocky peatbogs in the northern taiga of Western Siberia. Thus for example, thickness of peat in the peat hummocks situated on the inner side of the humlmocky zone (i.e., in the "youngest" hummocks) is 2.2 m to 2.4 m (Fig. 1, Boring 9-PA and 24-PA), whereas the thickness of peat in the adjacent waterogged part of the bog is 3.6–3.8 m. Similar correlations were observed in the farther northern regions. For example, the thickness of peat in the hummock near Boring 6-E is 0.8 m, and in the adjoining waterlogged fen (third zone) is 1.8–2.0 m. The difference in peat thickness is 1 m to 1.4 m in both the first and the latter case. The life-time of a hummock may thus be taken to correspond to the period of peat accumulation. According to Neištadt's data (1965), one centimetre of peat in the Leningrad region takes 16 to 40 years to develop. Proceeding from these figures, the formation of hummocky peatbogs might be assumed to have taken place some 3,000 years ago.

The temperature field of the majority of hummocks reflects likewise a state of degradation. In spite of the fact that the prevailing temperature of frozen grounds in the northern taiga is 0°C, hummocks have rather low temperatures. This is due to the fact that snow is blown off from the domed surface of hummocks, grounds cool off without hindrance in winter, and warm up slightly in summer because of the high ice-content and low heat conductivity of peat. And higher hummocks ought to have a lower ground temperature. However, as shown by the present observations and those of other workers (Fig. 2) the temperature rises rapidly with depth and equals the temperature of the surrounding ground. A noticeable increase in the vertical gradient in the lower part of the temperature section is a characteristic feature. This fact appears to be a result of insufficient elimination into the atmosphere of the heat penetrating from below towards the lower boundary of the frozen core, and this is just the cause of rising temperature in the lower parts of the core. Such a phenomenon is impossible in the ground freezing that would have taken place in case of an upward development of hummocks, for in that case the vertical temperature gradient in the lower part of the section would decrease. This is clearly shown in the appropriate diagrams by Orlov (1962).

Another evidence of the present degradation of hummocky peatbogs is in the morphology of the hummocks and, in particular, in the presence of a peaty-undershrub slightly elevated 0.5 m wide edge that encircles a hummock at some distance (0.5—2.0 m) from its base. Such an edge appears to be fixing the initial position of the now partly thawed out hummock base.

Depending on the stage of degradation edges vary from a small arch to a closed ring.

As results from all these factual data the domed-hummocky peatbogs of the northern taiga in Western Siberia are relict formations. The mechanism of degradation of these peatbogs may be likewise inferred from the same factual material. This mechanism is usually attributed in the literature to such factors as: thawing-out of hummocks from above, their disintegration into separate thawing polygons, the increasing depth of seasonal thawing, etc.

Observations showed that in the majority of cases all these factors were absent as the surface of hummocks is not broken up by fissures (except for some larger hummocks in ridges), the depth of seasonal thawing is in complete conformity with the temperature and lithology (it is 0.4–0.6 m in peat hummocks, and 1–1.5 m in mineral hummocks), and hummocks are seldom broken into polygons. Cryogenic structure, undisturbed down from the uppermost horizons, also substantiates the inference that hummocks of heaving do not thaw out from above. Nevertheless degradation of hummocky peatbogs is obvious, being chiefly revealed by the heights of hummocks and the presence of peat-undershrub edges.

A group of three hummocks was studied in the Pravaya Khetta area. The hummocks were built up of similar fine sands and aleurites and represented successive stages of degradation.

The first, mineral, swelling-up hummock (Fig. 1, Boring 17-PA and Fig. 2-C), situated on the exterior side of the hummocky zone, had 3 m in height and up to 40–50 m of diameter at the base. On the southeast side of the hummock, a small arched edge was separated at a distance of 2 to 3 m from the hummock base. The ground temperature was $-2°$ at 5 m depth (Fig. 2-B), ice-content reached 95% (Fig. 1, Boring 17-PA). The second hummock stood some 100–150 m from the first towards the centre of the basin. It was a peat hummock (peat thickness – 0.5 m) 1–1.5 m high with a base diameter of 30 m. Its degree of degradation was considerable, as manifested by both its height and the developed edge that encircled this hummock completely forming a regular ring, at 1.5–2.0 m distance from its base. The ground temperature in this case was $-1.4°$, and ice-content averaged 35 to 40% never exceeding 65% (Boring 20-PA). The third formation was a closed ring of peaty-undershrub edge (Pl. 3) with flat swampy inner surface. The peat thickness inside the ring varied from 0.9 to 0.25 m at the centre and at the edges respectively. Permafrost from the surface (at least down to 6 m) was absent. This was the next stage of degradation, when the mound had thawed out completely.

Such phenomena can be explained only by the frozen core of the hummock

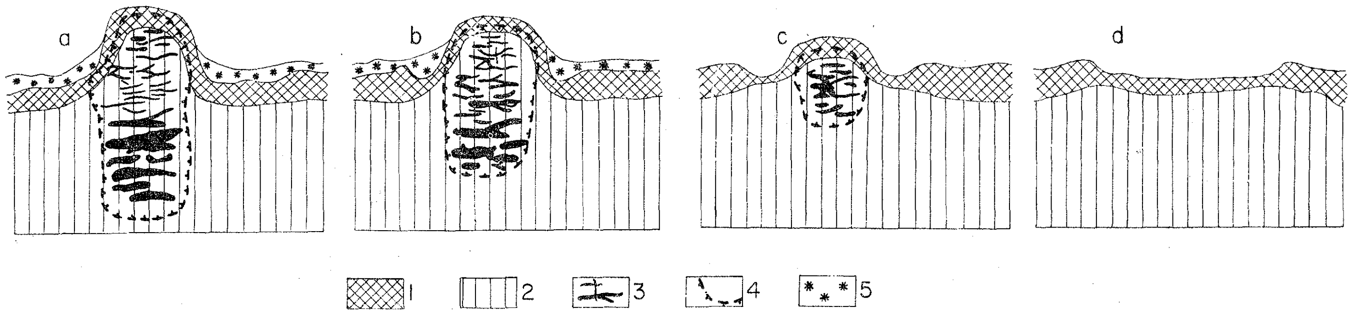


Fig. 3. Successive stages of degradation of frost-heaving hummocks

1. peat; 2. mineral ground; 3. ice schlieren; 4. boundary of frozen core; 5. snow

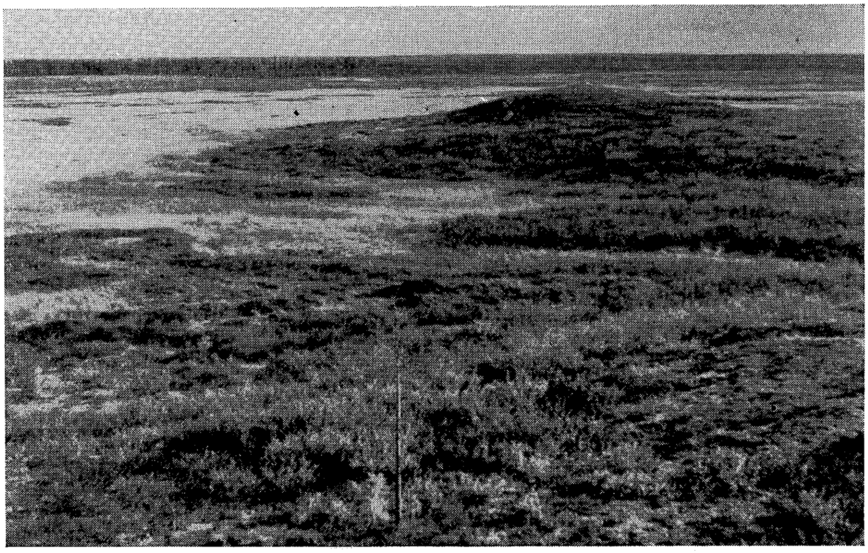
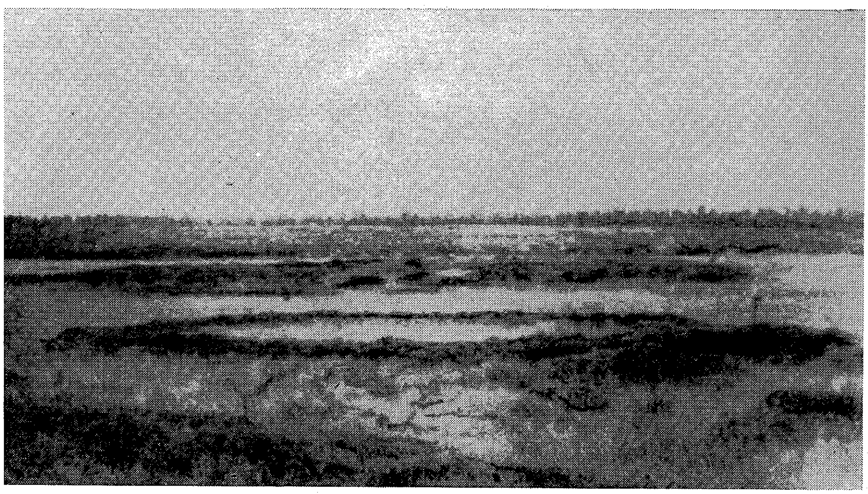


Photo by Evseyev

Pl. 1. General view of a frost-heaving hummock



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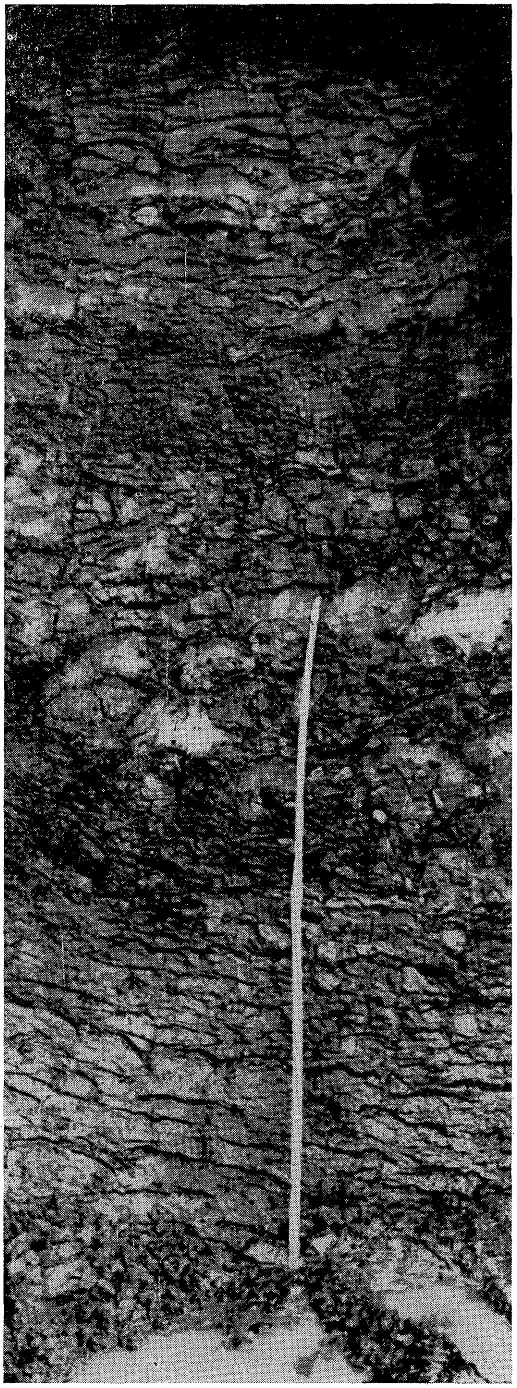
Pl. 2. Cryogenic structure of a frost-heaving hummock (near Boring 6-E)



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Pl. 3. Final stage of degradation of a frost-heaving hummock thawing out from below. The authors believe that this mechanism is prevailing in the northern taiga of Western Siberia. The frozen core of a pillar-like hummock (Fig. 3 a), is as if floating amidst thawed and plastically frozen rocks, while thawing from below gradually submerges into the surrounding rock. Since the upper ground horizons in the hummock are still in a frozen state, the cryogenic structure of the upper part of the hummock remains unaltered until complete thawing out. Another related fact is that ice-content of a hummock decreases with its diminishing height as a result of core submersion. Hummock sections show (Fig. 1) that ice-content within them increases from above downwards. This is due to the gradual decrease of the vertical temperature gradient as hummocks grew with freezing, and to longer moisture migration towards the lower horizons of the frozen core. As the core deteriorates, the lower (iciest) layers are the first to thaw out while all the less icy (upper) horizons persist (Fig. 3).

Simultaneously, the formation of a peat-undershrub edge progresses. Snow is blown off from the convex surface of the hummock and accumulates at its base. While the upward development of the hummock takes place, the snow does not exert any noticeable warming-up effect upon the ground. But as soon as the heat equation at the hummock surface restored by the warming climate ceases to ensure a sufficient preponderance of heat efflux from the ground over its influx from below the core begins to thaw out from above in places of snow accumulation. Along the perimeter of the base cavities are forming small at first but developing gradually (Fig. 3 b). As the frozen core sinks and the hummock volume becomes reduced, the width of the cavity increases and the hummock is found to stand on sort of a flat saucer with upturned edges. The final result of this process is a ring edge with a flat inner surface (Fig. 3 d, Pl. 3). The hummock is completely submerged and thawed out.

Degradation of domed-hummocky peatbogs cannot be studied without the specificity of their thermal regime being taken into account, which specifity is further related to the dimensions and heights of the hummocks.

As mentioned above ground temperature in hummocks falls gradually with their increasing height. At the same time a dependence of the dimensions of hummocks on their number in the aggregate has been observed: the more numerous the aggregate, the larger the hummocks.

Major aggregates of hummocks while occupying a large area, exert a thermal influence (cooling, in the given case) down to relatively significant depth, since the depth of thermal effect of the landscape is directly related to its dimensions; likewise minor groups of hummocks establish thermal regime of the grounds down to more insignificant depths. The smallest depth of thermal influence is traced under isolated hummocks. Thus the perennially frozen cores in separate hummocks actually, turn into permafrost islands considerably thick under major hummock aggregates.

Naturally the thawing of frozen grounds proceeds with various degrees of intensity in isolated and in group hummocks. The larger the hummock aggregate, the greater the outflow of heat from the ground exceeding its inflow from below. Certain thermal equilibrium is established, owing to which hummocks of large aggregates do neither thaw out actively nor develop. In such cases thawing of hummocks may start from above due to such various chance causes as mentioned by Tyrtikov (1969) which are: disturbance of the vegetation cover, persistence of snow in the cavities, etc. The smaller the hummock aggregate is in areal extension, the greater the thermal balance between heat flows from above and from below upsets towards predominance of the latter, with peatbog degradation from above being seldom observed. Such a state of non-equilibrium is best-expressed in medium-sized and small hummock aggregates and all the more in separate forms, and peatbog thawing proceeds mainly from below.

Summing up, it may be said that the domed-hummocky peatbogs of the northern taiga in Western Siberia are hummocks of heaving developed as a result of water migration towards the freezing ground and are relict formations. They were formed in the Late Holocene, in the epoch of temperature fall following the thermal maximum and are no longer developing at present. These formations are now at various stages of degradation whose principle mechanism is the thawing out from below of the frozen hummock cores.

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