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GROUND ICE CONTENT OF FROST MOUNDS IN THE NADYM RIVER BASIN

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The "classical type" ice-cored frost mounds (palsas) are widespread in the northern taiga of Western Siberia. Besides, morphologically different forms of permafrost hummocky landforms are developed, differentiating from the "classical" frost mounds by size and flatter top surface. Using core samples from ten-meter deep boreholes, we have analyzed the total thickness of segregated ice and the contribution of ice inclusions to the total soil ice content, to determine the origin of such flat-topped mounds. A good correlation has been revealed between surface elevations and volumetric ice content of sediments composing flat-topped peat mounds, whose ice content is found to be higher than in the intermound depressions. These facts indicate the local nature of ice segregation and therefore suggest that the investigated landforms were formed by the frost heave processes, rather than being remnant permafrost landforms.

Frost mound, remnant permafrost landforms, ice content, segregation ice, volumetric ice content

INTRODUCTION

Characterization of the cryogenic structure, morphology and origin of permafrost (frost) mounds, such as palsas (a peaty frost mound with a core of alternating ice and peat) and flat-topped peatlands is provided in many research works [*Pyavchenko, 1949, 1955; Konstantinova, 1963; Popov, 1967; Belopukhova, 1972; Shpolyanskaya and Evseev, 1972; Evseev, 1976; Vasil'chuk, 1978; Vasil'chuk and Lakhtina, 1986; Kashperyuk and Trofimov, 1988; Vasil'chuk and Vasil'chuk, 1998*]. However, opinions differ in respect to some issues related to the origin of frost mounds. Thus, according to *A.I. Popov* [*1967*], the height of the "migrational" (i.e. formed as a result of soil moisture migration towards the freezing front) frost mounds (palsas) corresponds to the total thickness of segregated ice in the layer of active cryolithogenesis.

The inference made later by Yu.K. Vasil'chuk was corroborated by the following observation: the height of a frost mound most commonly either differs from the total thickness of segregated ice lenses, or the ice core occurs at a depth of 10–12 m and below. Besides, some researchers suggest the thermal-degradation origin of individual frost mounds (remnant permafrost landforms).

Degradation (remnant) landforms are understood here as partly degraded mounds, representing hummocks of thermokarst origin raised above the surrounding surface, which was lowered due to the thermoerosional niches formed beneath them by melting of ground ice [*Timofeev and Vtyurina, 1983*]. In the northern taiga of Western Siberia, remnant mounds were described by *A.P. Tyrtikov* [*1979*]. According to N.Y. Pyavchenko, a flat-topped peatland (peat plateau) develops as a result of erosional processes and thermokarst dissection of polygonal peatlands.

CRYOLITHOLOGICAL CRITERIA FOR DISTINCTION BETWEEN FROST MOUNDS AND REMNANT PERMAFROST LANDFORMS

Palsas, as a type of frost mounds, and hummocky peatlands are widespread in the northern taiga zone of Western Siberia. These also include landforms resulting from frost heaving and include remnant permafrost peat landforms. The morphology of hummocky landforms is in part represented by solitary frost mounds of "classical type" (segregation-heaving type of mounds), which are generally ice-rich (ice-filled peat mounds) and have a round shape in plan, indicating thereby that such terrain types formed as a result of frost heaving. These landforms coexist with morphologically different hummocky terrain types having coalesced bases and successively connected convex surfaces. Some peatlands exhibit traces of erosional processes. The origin of such hummocky landforms can be associated with both frost heaving and erosional-thermokarst dissection of the primary terrain. In the case when morphological characteristics bear no clear evidence of frost heaving, it is critical to look for the cryolithological criteria allowing distinguishing between frost mounds and the remnant permafrost peat landforms. As such, the criterion is largely based on the distribution of ice content over the section.

According to the V.A. Kudryavtsev's definition, "the origination of frost mounds is associated with the processes of locally enhanced ice formation". Within the context of palsas development, "intensive local segregation of ice tends to be contributed by moisture migration to the freezing front..." [*Kudryavtsev, 1978*].

Thus, the increased (in comparison with the surrounding area) local segregation of ice (ice-core) in the palsa section constitutes the main criterion for distinguishing between frost mounds (palsas) and remnant permafrost peat landforms, i.e. the total thickness of segregated ice lenses in the section is suggested to be different for the axial part of the palsa and for intermound depression. In addition, after A.I. Popov, the height of palsa should correlate with the total thickness of lenses of segregated ice to a depth of 8–13 m.

According to Yu.K. Vasil'chuk, the predominance of mound's height over the total thickness of ice schlieren (the difference may be 4–6 m) is characteristic of most palsas of segregation-heaving type. At this, erosion processes are interpreted as a major contributing factor, leading to "the removal of soil mass from the near-mound spaces, which was only negligibly compensated by the substance transport from the mounds' surface" [*Vasil'chuk et al., 2008*].

Besides, "in many palsas, shallow drilling detected no ice, inasmuch as the ice core occurs at a depth 12–15 m and below" [*Vasil'chuk, 1983*].

The presence of ice-rich sediment to a depth of 15–20 m is accentuated by A.I Popov in respect to dome-shaped peatland. At this, should the height of the frost heave mounds correlate with the stacked ice thickness in the layer of active cryolithogenesis, the total ice thickness in the upper part of the layer of passive cryolithogenesis will correspond to the total height of peat massif [*Popov, 1967*]. The data obtained by *Yu.K. Vasil'chuk* [*1983*] allow to ascertain that the height of frost heave mounds (specifically, having a large (>50 m) diameter at the base) can be defined as the sum of thicknesses of ice lenses to a depth of 20 m.

The data obtained by *V.P. Evseev* [*1976*] suggest that the volumetric ice content of sediment contributed by ice inclusions in the flat-interfluve conditions (not subjected to heaving) constitutes to 10–20 % and cannot be interpreted as layer with higher ice content. After V.P. Evseev, the values of volumetric ice content for palsas tend to be more than 20 % at the expense of ice inclusions.

STUDY AREA

The study area is located in the northern taiga zone of Western Siberia in the basin of the Kheigiyakha river (Nadym tributary) within the 3rd fluvial-lacustrine plain. The absolute surface elevations range between 20 and 40 m. The mean annual air temperature (MAAT) is –5.6 °C. The thickness of peat deposits formed from the surface downward is up to 1.5 m (rarely, up to 5 m). The underlying fluvial-lacustrine deposits intricately alternating to the replacement of loamy-sands, loams and sands, with the latter forming a water-saturated layer. In addition, there is a shallow occurring top of potentially frost-susceptible loamy deposits (from first meters to 10–15 m). The fraction of the 3rd fluvial-lacustrine plain area occupied by palsas and mound peatlands constitutes 70 %.

Peat deposits with a thickness of up to 6.4 m occur from the surface downward in the rear part of the Kheigiyakha floodplain. These are underlain by frost susceptible loamy deposits of the floodplain facies. More than 90 % of the surface is occupied by swamp stows (landscapes). The present-day temperature of modern permafrost deposits at a depth of 10 m has been showing an increasing trend since the end of 1970's: from –1.8 to – 0.4 °C (palsa bogs) and from –1.0 to –0.2 °C (flat-topped peatlands) [*Moskalenko et al., 2012*]. In recent years (the period spanning from 2009 through 2017), lower temperatures (–1.5 °C) have been reported only for a solitary peat-mineral palsa (6.7 m in height) (well # 1-2009) on the 3rd fluvial-lacustrine plain.

Landscape characteristics of the studied sites

During the period from 2009 to 2013, the authors studied palsa mounds located in the Kheigiyakha basin.

One of the wells (well # 4-2009) was drilled into the mound in the rear part of the Kheigiyakha floodplain (Fig. 1, *a*). The absolute elevation of the floodplain surface is about 18 m. The vegetation cover is represented by Ledum-Cladonia community with solitary Pinus sibirica 5–10 m in height. The palsa mound is surrounded by an extensive fen bog (depth: 1.5 m). On the western side, the palsa mound is adjacent to the escarpment of the 3rd fluvial-lacustrine plain (well-drained riverside terrain type), which consists of two parts which measure 3.1 m (the drill site), and about 1 m in height, respectively. The water-logged hollows between them are assumingly located in the place of melted middle part of the ice

Fig. 1. Frost heave landforms in the Kheigiyakha Rv. basin:

a – frost mound (height: 3.1 m) in the rear part of the Kheigiyakha river floodplain, within its elevated portion (left), – well # 4-2009; *b* – frost mound (height: 6.7 m) in the northern part (right) – well # 1-2009; *c* – palsa ridge (height: 2.5 m) in the axial part – well # 11-2012; *d* – young frost-heave landform (height: 0.35 m) in the axial part – well # 8-2010; *a*, *b*, *d* – photo by N.M. Berdnikov; *c* – photo by A.G. Gravis.

core. The high (eastern) part of the palsa mound is about 10 m in diameter. The east-facing slope most subjected to degradation abruptly ends towards the bog. The palsa cross-section is composed of peat to a depth of 6.4 m. The floodplain loam occurring deeper (to a depth of 10 m) contains numerous organic inclusions.

The remaining wells were drilled within the 3rd fluvial-lacustrine plain (lake-bog terrain type), encompassing the mound (well # 1-2009, Fig. 1, *b*) and the palsa ridge (well # 11-2012, Fig. 1, *c*). Besides, several wells are located within the bounds of inter-mound hollows on peatlands (wells # 2-2009, 3-2009, 12-2013), and one was drilled on a young frost-heave form (well # 8-2010, Fig. 1, *d*). A high (6–7 m) frost mound (Fig. 1, *b*) is located within the 3rd fluvial-lacustrine plain. The absolute elevations near the mound are 25–27 m. The vegetation is represented by the Betula nana-Ledum-Cladonia community. The mound is occasionally bordered by narrow stretches of bogs.

Some slopes of the mound are adjacent to the neighboring doming surfaces. The mound is more than 100 m in diameter. The thickness the peat layer measured in wells # 1-2009 and 9-2011 drilled into the mound's top and slope was 0.5 m and up to 1 m, respectively. The sandy layer was penetrated by drilling from the top to a depth of 7.2 m. Well # 9-2011 drilled on the mound's slope did not penetrate ice-rich loams occurring below. Well # 2-2009 drilled into the intermound hollow failed to penetrate the ice-rich loam near the mound, either. Given that the entire section (to a depth of 10.2 m) is composed of sand with massive cryostructure occurring beneath the peat layer (thickness: 1.3 m), the heave-susceptible loams in this area were therefore penetrated only in the axial part of the mound (well # 1-2009, Fig. 2, *a*). The palsa ridge encountered on the 3rd fluvial-lacustrine plain was also studied (Fig. 1, *c*). The observed features of the palsa ridge included: absolute surface elevations near the ridge are about 22–23 m; a steep west-facing slope abruptly grades into a fen; the vegetation cover is represented by the Betula nana-Ledum-Cladonia community; sporadic signs of degradation. The east-facing slope is more gentle and grades into the surface of flat-topped peatland. Well # 11-2012 was drilled into a peat patch (5 m in diameter) devoid of soil cover. The palsa ridge is 2.5 m in height and more than 20 m in diameter. The ridge section is composed of peat to a depth of 2.2 m. While sand bed with interlayers of peat and peaty loam occurs to a depth of 8.4 m beneath the peat blanket. Sand is commonly peaty. Heaved loam occurs deeper down, to a depth of 10.2 m.

ICE CONTENT OF DEPOSITS COMPOSING THE STUDIED LANDFORMS

The data on ice-content indicate heaving characteristics both of frost mounds of "classical" type (se-

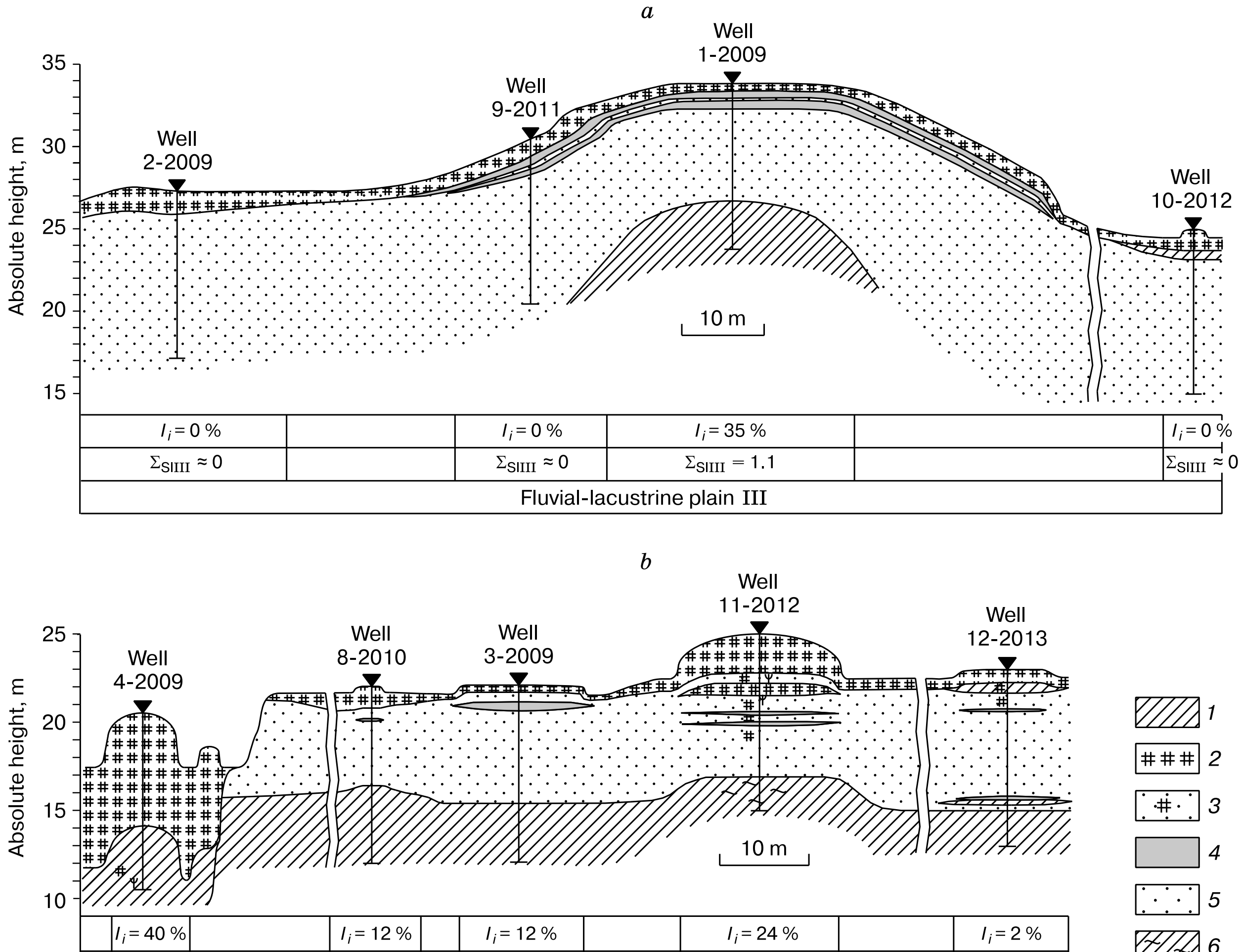

Fig. 2. Schematic type profiles of palsa mounds in the Kheigiyakha Rv. basin:

a – across the high (>6 m) frost mound with large (>100 m) diameter; *b* – across hummocky landforms at different geomorphic levels; *1* – loam; *2* – peat; *3* – peaty sand; *4* – loamy sand; *5* – sand; *6* – loam grading into clay; *7* – peaty loam with plant residues. I_i – volumetric ice content of ice inclusions in the loamy layer, %; $\Sigma_{SI\ III}$ – total thickness of lenses of segregated ice (to a depth of 10 m), m.

parately-standing and having a spherical shape), and morphologically differentiating types of hummocky landforms. Volumetric ice content contributed by ice inclusions to the section of intermound hollows (peatlands, etc.) account for less than 20 % at all of the studied sites. Such values are typical of flat-interfluve conditions, rather than being representative of a layer with higher ice content. Taking into account the volume of ice inclusions in the deposits composing all the studied frost mounds and palsa ridges, their volumetric ice content will exceed 20 %. According to the data provided by *V.P. Evseev* [*1976*], such values are typical of ice-rich layers of frost mounds. Ice-rich sediment (>50 %) is uncharacteristic of the cores of the studied palsas, rather its high values show up only within certain depth ranges in the section of the mound located in the rear part of the Kheigiyakha floodplain. But even there, the average volumetric ice content at the expense of ice inclusions is not more than 50 %. This is corroborated by the research results obtained by Yu.K. Vasil'chuk: ice content of loam in the section of a high palsa studied in the Fore-Ob area, varies from 20 to 50 % [*Vasilchuk et al., 2012*].

In [*Evseev, 1974*], the volumetric ice content contributed by ice inclusions constituted from 40–50 to 15–20 % , averaging 30–40 % (3.5 m-high segregation-heaving frost mound in the Ob-Poluy watershed), 20–30 % (1.7 m-high palsa on the 1st above-floodplain terrace of the Gorny Poluy river), 30–50 % (2.5 m-high palsa in the area of Pangody village); and 10–12 % (schlieren ice (lenses of segregated ice) content in the section of flat-topped peatland near Pangody village).

After [*Trofimov et al., 1989*], loamy sediments (outside palsa) on the 3rd fluvial-lacustrine plain (the Ob-Nadym region) are characterized by the 20–25 % schlieren ice content. Results of the study of the Kheygiyakha basin showed that ice content (at the expense of ice inclusions) of loams on the surface (outside palsa) is 2–12 %, while it was 24 % for palsa ridge and reached 35 and 40 % for frost mounds. Due to ice inclusions in the studied mounds the volumetric ice content is generally consistent with the values given in the literature. However, despite the revealed similarity in ice-content levels, the studied palsas in the Nadym basin are slightly higher than those described by V.P. Evseev. Nevertheless, the volumetric ice content of ice inclusions in the sections of hummocky landforms studied by the authors is higher than in intermound depressions. This suggests local ice formation, which is inherent in the heaving processes (Fig. 2).

The volumetric ice content of ice inclusions was calculated for the layer of frost susceptible loams, with its roof occurring at a depth of 5–8 m in the studied areas, i.e. comprising the depth interval from 5–8 to 10.2 m (Fig. 3). The depths of loams occurrence measured in wells are reported in the range from 6.4 to 10.2 m (well # 4-2009), from 7.2 to 10.2 m (well # 1-2009), and from 8.4 to 10.2 m (well # 11-2012). The total thickness of the lenses of segregated ice was also calculated for the frost susceptible loams at the same depths. Except for well # 11-2012, drilled into the palsa ridge where individual thin lenses of segregated ice were encountered in loamy sand and peat layers within the sandy bed (the 2.8–4.4 m depth interval). The thickness of ice lenses with microschlieren cryostructure in the topmost peat layer was ignored at the studied sites.

In the total thickness of ice lenses obtained from well # 4-2009 drilled on palsa mound at the floodplain, only distinct interlayers formed due to moisture-migration were taken into account (Fig. 3). In the case where ice grains were concentrated within a low depth range, the ice interlayers were considered indistinct. Ice inclusions in the form of ground-ice were taken into account only when calculating the volumetric ice content of ice inclusions. The total thickness of the segregated ice lenses of the heaving loam bed was calculated for its upper part penetrated

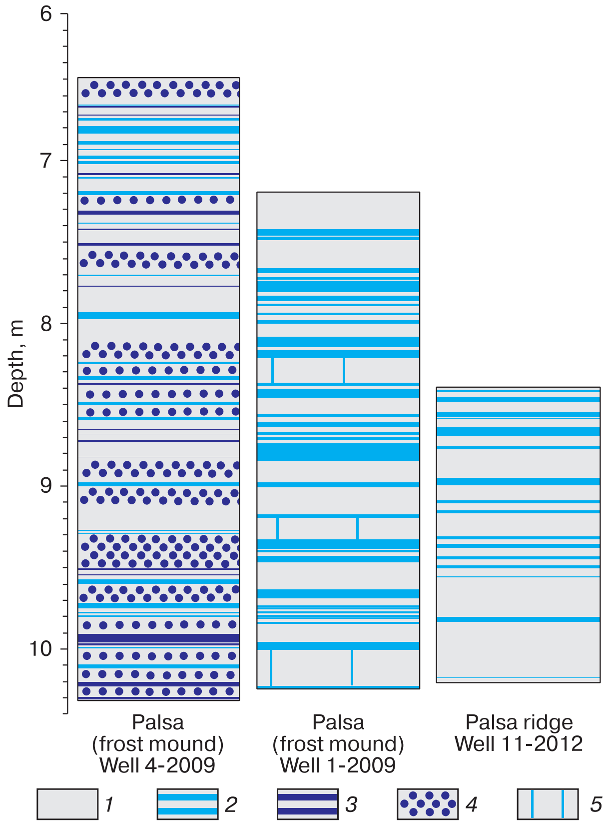

Fig. 3. Distribution of ice inclusions in the layer of heaving loams of frost mounds and palsa ridge in the Kheigiyakha Rv. basin:

1 – layer of heaving loams; *2* – distinct lenses of segregated ice; *3* – indistinct lenses of segregated ice; *4* – ground-ice; *5* – vertical streaks of ice.

by drilling. At this, the volumetric ice content of ice inclusions is also characteristic of deeper-seated layers of the ice core, not penetrated during shallow drilling (to a depth of 10 m).

Ice content of loams in the section of the studied palsa ridge corresponds to the background shclieren ice content discussed in [*Trofimov et al., 1989*], which, however, exceeds shclieren ice content obtained for the intermound depressions in the present work and described by V.P. Evseev for a flat-topped peatland in the vicinity of Pangody village [*Evseev, 1974*]. Local ice segregation inherent in frost heaving is therefore also observed in the section of the studied convex ridge landform.

Relative surface heights exceed the total thickness of lenses of segregated ice (to a depth of 10 m) for most of the studied landforms (Table 1). A strict correlation between these values is observed only for one of the studied flat-topped peatlands (well # 3-2009). According to the measurements in well # 8-2010, the thickness of segregated ice lenses beneath a 0.35 m high young frost-heave landform totaled 0.55 m (Fig. 1, *d*), which is slightly higher, than relative height of this landform. The total thickness of schlieren ice is lower than relative height of each of the studied palsa, with the difference constituting 5.6 m (frost mound, according to the data from well # 1-2009), 1.65 m (palsa ridge / well # 11-2012), and 2.7 m (palsa in the rear part of the floodplain/well # 4-2009) (Fig. 1, *b*, *c*, *a*). As such, these irregularities could be viewed as an indirect indication of a remnant

Table 1. **Ice content parameters of permafrost composing palsa mounds and flat-topped peatlands**

Landform	H_{rel}, m	$\Sigma_{SI\ III}$, m	I_i, %	h, m
Rear part of the Kheigiyakha Rv. floodplain				
Frost mound (palsa) (well # 4-2009)	3.1	>0.4	40	6.4
3rd fluvial-lacustrine plain				
Frost mound (palsa) (well # 1-2009)	6.7	1.1	35	7.2
Palsa ridge (well # 11-2012)	~2.5	0.85	24	8.4
Flat-topped peatland (well # 2-2009)	0.7	~0	0	>10
Flat-topped peatland (well # 3-2009)	0.4	0.4	12	6.7
Small roller-landform (well # 10-2012)	0.5	~0	0	>10
Young frost-heave form (well # 8-2010)	0.35	0.55	12	5.6
Flat-topped peatland (well # 12-2013)	0.5	0.05	2	7.4 (8)

Note. H_{rel} is relative surface elevation; $\Sigma_{SI\ III}$ is the total thickness of segregated ice lenses (depth: up to 10 m); I_i is volumetric ice content at the expense of ice inclusions (in the layer of heaving loams); h is depth of the roof of layer of loams.

permafrost origin of the studied mounds. However, it should be noted that the ice-rich layer can extend downward to a depth of 20 m. Assuming that the 35 % volumetric ice content (frost mound, well # 1-2009) in loams does not vary over the thickness, then the base of the ice-rich layer, which ensures the mound's height of 6.6 m, should be seated approximately at a depth of 25 m. In the case when the layer of loams with maximum ice content was not penetrated while drilling, the real thickness of the heaving loam layer may be essentally lower than 25 m, actually not more than 18–21 m. This is consistent with the data obtained by Yu.K. Vasil'chuk on ice cores of palsas located at a depth of 10 m and below. It stands to reason that the erosion processes taking place in the intermound space in this area prompted the palsa's growth in height after its frost heaving terminated.

Considering that the 24 % volumetric ice content of loam at the expense of ice inclusions (palsa ridge, well # 11-2012) is constant with depth, the base of ice-rich layer, providing for the ridge height of 2.5 m should occur at a depth of 15–17 m. It can thus be assumed that this landform was produced by frost heaving alone, without prior involvement of the erosion processes in the intermound space.

Despite the smallest total thickness (0.4 m) of the lenses of segregated ice in the palsa mound in the rear part of the Kheygiyakha floodplain, its section has the highest volumetric ice content due to the contribution from ice inclusions. This is because of the distinct ice lenses constitute a small proportion of the cumulative thickness of ice inclusions, most of which are represented by small ice grains, often visible as indistinct lenses and pockets. Given that ice grains tend to be concentrated at small-depth intervals, this reflects the suppressed nature of the formation of ice lenses suggesting high water saturation degree of the floodplain loams [*Berdnikov, 2012*]. The height of this mound significantly exceeding the total thickness of segregation ice lenses allows to interpret its origin as a remnant frost heave landform. The place of drilling therefore does not correspond to the axial part of the originally incepted landform, and hence the segregation ice thickness is relatively small. This agrees with the insights provided by F. Zuidhof that the remnant stage of mound development can represent by itself elongated ridges or ring structures in combination with disconnected ponds [*Zuidhoff, 2003*].

Palsa mound located in the rear part of the Kheygiyakha floodplain (well # 4-2009) has the greatest volumetric ice content (40 %) of ice inclusions (Table 1) owing to a greater extent of waterlogging of soils composing the rear part of the floodplain. In addition, the width of the fen surrounding the floodplain palsa exceeds the size of swamps adjacent to the mounds on the 3rd fluvial-lacustrine plain, which constitutes a larger moisture supply zone to provide for the frost heaving processes.

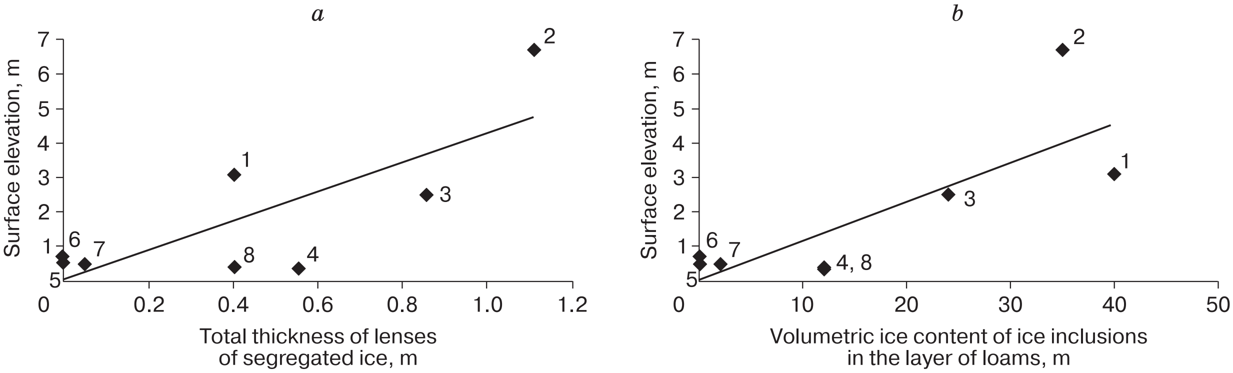

Fig. 4. Landform's elevation versus (*a*) total thickness of lenses of segregated ice and (*b*) volumetric ice content of ice inclusions in the layer of loams (data from eight wells).

1 – frost mound (well # 4-2009); 2 – frost mound (well # 1-2009); 3 – palsa ridge (well # 11-2012); 4 – young frost –heave landform (well # 8-2010); 5 – minor roller landform (well # 10-2012); 6 – flat peatland (well # 2-2009); 7 – flat peatland (well # 12-2013); 8 – flat peatland (well # 3-2009).

Even though the frost mound located on the 3rd fluvial-lacustrine plain (well # 1-2009) is much higher than the one located on the floodplain (6.7 m vs. 3.1 m), it has a slightly lower ice content (35 %) of ice inclusions (Table 1). Ice formation in this area proceeds less intensely, with the mound's ice core likely occurring within a greater depth interval, which is also confirmed by a large (>100 m) diameter of the mound's base.

The section of palsa ridge (well # 11-2012) on the 3rd fluvial-lacustrine plain is characterized by the lowest volumetric ice content (24 %) of ice inclusions (Table 1), which is explicable, inasmuch as its height is the lowest (2.5 m) among the studied mounds. In the absence of a strict correspondence between the surface elevation and total thickness of segregated ice, the revealed good correlation (correlation coefficient r = 0.78) between these characteristics (Fig. 4, *a*) indicates enhanced local ice segregation in the deposits composing the palsa mounds and palsa ridges, as compared to the surrounding intermound hollows occupied by lower landforms (predominantly, flat-topped peatlands).

However, not all the investigated sites are close to the line of approximation (Fig. 4, *a*), which is accounted for the fact that both frost mounds and palsa ridges are characterized by a great variability of ice content in the surrounding environment. Thus, the total thickness of distinct ice lenses in palsa mound in the rear part of the Kheigiyakha floodplain (well # 4-2009) is fairly low, as most of the segregated ice does not form clear lenses and occurs as ice soil.

A good correlation (r = 0.8) was revealed between the surface elevation of landforms and the volumetric ice content of ice inclusions (Fig. 4, *b*). The volumetric ice content of ice inclusions constituted from 2 to 12 % for flat-topped peatlands (height: <1 m), and from 24 to 40 % for frost mounds and palsa ridges (Table 1).

Unlike soils composing the surrounding flat terrain, those composing palsas bear the evidence of local ice segregation, which is inherent in frost mounds, rather than remnant permafrost landforms, i.e., higher ice content is localized in soils composing palsa mounds and palsa ridges, whereas the surrounding intermound hollows are composed of ice-poor sediments. Supposing the studied mound-like landforms are remnant permafrost landforms, such a relationship between the surface irregularity and ice content would have been impossible.

CONCLUSIONS

1. Ice content of the deposits composing all the studied frost mounds and palsa ridges was high (>20 %) at the expense of ice inclusions, which is characteristic of ice-rich layers of frost mounds (palsas). While the flat-topped peatlands and low (up to 1 m) landforms had lower ice content contributed by ice inclusions (<20 %), which is typical of intermound hollows. Thus, local ice segregation was revealed in deposits composing both ice-rich frost mounds of "classical type" and morphologically different forms of hummocky landforms. This indicates the leading role of frost heave processes in the formation of the studied landforms.

2. Neither frost mounds, nor flat peatlands showed a strict correlation between the surface elevation and total thickness of segregated ice lenses, which is accounted for the fact that drilling to a depth of 10 m allows penetrated only the upper part of ice-filled layer. The revealed relationship (correlation coefficient r = 0.78) between the terrain's elevation of the studied landforms and the total thickness of segregated ice lenses indicates locally increased ice for-

mation, confined to soils composing ice-rich mounds "classical type" and morphologically different hummocky landforms.

3. A good correlation ($r = 0.8$) between the landforms' height and the volumetric ice content at the expense of ice inclusions was revealed despite the lack of strict correspondence between the palsas' height and the total thickness of ice lenses. This contradiction is explained by the fact that ice lens thicknesses were measured only in the upper part of the layer of heaving loams, whereas the volumetric ice content is also characteristic of deeper layers of the ice core not penetrated while drilling.

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