PALEOCRYPGENESIS AND SOIL FORMATION

THE IMPACT OF VEGETATION ON THAW DEPTH IN TUNDRA SOILS OF SUBMONTANE LANDSCAPES OF THE PAI-KHOI RIDGE (SOUTH-WEST OF YUGORSKY PENINSULA)

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The interrelation of the vegetation cover with thaw depth in the soils of foothill plains of the Bolshezemelskaya tundra adjacent to the low-mountain Pai-Khoi ridge (the basin of the Vasyaha River, south-west of the Yugorsky Peninsula) has been characterized. The main groups of vegetation communities associated with certain soil types (subtypes) and thaw depths have been identified. Based on seasonally and perennially frozen horizons occurrence in the middle of the vegetation season, the main soil profile types have been determined. The impact of certain parameters of the vegetation and soil cover on the thaw depth in permafrost-affected soils has been assessed. The specifics of soil map compilation, based on vegetation maps, have been demonstrated for the key site. Analysis of soil cover structure considering the thaw depth has been carried out.

Vegetation communities, tundra soils, active layer, permafrost, soil cover structure

INTRODUCTION

Currently attention of scientists has been attracted to the complex studies of the soils of the tundra zone of the European northeast – the region of Russia, which is quite sensitive to the modern climate changes [Mazhitova, 2008; Oberman and Shesler, 2009]. Still topical are the issues of studying permafrost-affected soils and of the underlying permafrost rocks in interrelation with the vegetation cover in the permafrost zone [Mazhitova, 2008]. Due to the difficult access to the Yugorsky Peninsula, it remains to be the least investigated region of the European northeast in terms of soils and vegetation [Koroleva and Kulyugina, 2007]. Vegetation and soils are the major indicators of the condition of landscapes in the permafrost zone. Development of vegetation communities on the peninsula is determined by the permafrost-affected conditions of its soils [Yelsakov and Kulyugina, 2014].

A monograph by V.N. Andreyev [1935] is the earliest complete compilation of materials relating to the vegetation cover of the Yugorsky Peninsula, which provides the zonal details and geobotanical zonation; the vegetation communities are characterized, and their areal breakdowns are provided. The information on the flora and the vegetation of the region is provided in later publications [Gribova, 1980; Lavrinenko, 2010; Kulyugina, 2013; Yelsakov and Kulyugina, 2014].

Currently distinct trends are being observed testifying to degradation of permafrost, which is manifested by northward movement of its limits on the foothill plains of Priuralye and of the low-mountain Pai-Khoi ridge [Yelsakov, 2013]. This is evidenced by the facts of movement up to dozens of kilometers in the period of 1970–2005 of the limits of permafrost subzones and by the emergence of numerous discontinuous taliks on the watersheds, and by the rise in the temperatures of permafrost soils on the Yugorsky Peninsula due to climate changes [Oberman and Shesler, 2009]. At this background, due to northward movement of large-shrub plant communities, the producing capacity of the vegetation communities has increased [Yelsakov and Kulyugina, 2014].

The structure of the soil cover of the Yugorsky Peninsula is satisfactorily shown on a scale of 1:250 000 of the soil map of the Atlas of the Arkhangelskaya Region [Atlas..., 1976] and on the map sheet of the Soil Map of RSFSR [Soil Map..., 1988]. Sheets of the State Soil Map on a scale of 1:1 000 000 for the territory of extreme northeast of Europe have not yet been published. Beginning with 2000s, only individual areas of tundra soils have been studied on the Yugorsky Peninsula.

It has been previously ascertained for the region that the depth of seasonal thawing in the soils of southern tundras is strongly differentiated depending on the character of the vegetation cover [Mazhitova, 2008]. The depth and density of the ground cover, of the shrub layer, and the depth of the peat horizon of the soil are the major factors of impact for the depth of seasonal freezing and thawing [Tyrtikov, 1966].
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Significant transformation of the permafrost zone and the change in the structure of the plant communities in the region make the studies of the vegetation and soil covers even more topical, with an emphasis on their interaction with the permafrost conditions in the European north – in the typical tundra zone.

In this regard, the objective of the present study was to characterize the impact of the vegetation cover on the depth of seasonal thaw of tundra soils in the submontane landscapes of the southwestern Yugorsky Peninsula.

The studies of the key site had the following goals:

– to reveal the main types of the vegetation communities, to determine their landscape association, the characteristic types (subtypes) of soils and the seasonal thaw depths of the soils;
– to determine the main types of the soil profiles by the character of the location of seasonal and permafrost horizons in the middle of the vegetation period;
– to evaluate the impact of individual parameters of the vegetation and soil covers (the depth of the organogenic horizon, the height and density of the shrub layer) on the seasonal thaw depth of the permafrost soils;
– to analyze the structure of the soil cover of the area under study considering the seasonal thaw depth.

THE CHARACTERISTIC OF THE AREA UNDER STUDY

The study area is 26.7 km² and is located on the border of the Bolshezemelskaya tundra adjacent to the Pai-Khoi ridge in the southwestern part of the Yugorsky Peninsula (Fig. 1). The key area under study is located in the basin of the Vasyakha River (a tributary of the Korotaikha River) in its upper reaches. The territory is characterized by the subarctic moderately continental and moderately cold climate. The mean annual air temperature is –7 °C, the mean July temperature is +10 °C, and that of January is –21 °C. The mean annual precipitation is 600–650 mm, with about 70 % precipitation falling in the warm season. In winter, winds of the southwestern and southern directions prevail, while in summer the prevailing winds blow from the north and east [Atlas..., 1976]. On average, the maximum depth of the snow cover is 40–60 cm [Yelsakov, 2013].

The area under study was a hilly piedmont plain (180–230 m asl), adjacent in the northeast to the low-mountain Pai-Khoi ridge (the region of the Malay Padeya Mountain, 250–330 m asl). The plain is dissected by the valleys of the Vasyakha River, of its tributaries and by lake beds. The characteristic shapes of the landscape are moraine hills, locally bogged lacustrine-alluvial beds and depressions, and alluvial terraces [Danilov, 1962].

The soils are formed by the following deposits of the piedmont plain: Quaternary littoral-marine deposits, glacial-marine, moraine, lacustrine-glacial, and lacustrine and alluvial deposits [Danilov, 1962; Atlas..., 1976]. Moraine and glacial-marine sediments are represented mostly by loams; lacustrine-alluvial sediments are represented by sandy and sandy-loam sediments. The total thickness of the Quaternary deposits reached 60–75 m and decreased as we approached the mountain ridges and residual mountains of Pai-Khoi. At the heights above 200 m asl, dense Palaeozoic bed rocks emerge on the day surface.

The Yugorsky Peninsula is characterized by a rather dense river network. The sinuosity of the river channels is caused by the permafrost lying under the ground surface. Rivers and lakes are free from ice only during three or four months in a year, usually freezing down to the bottom in winter. The biggest river studied, the Vasyakha River, is 1 m deep and up to 3 m wide in its upper reaches. In the area investigated, there are many shallow thermokarst lakes. The territory is referred to the continuous permafrost zone with permafrost 300–400 m thick and the mean annual temperature being –3…–5 °C [Geocryological Map..., 1998].

Fig. 1. The geographic position of the area under study.
1 – borders of the site.
In accordance with the geobotanic zoning [Aleksandrova, 1977] the territory under investigation belongs to the Ural-Pai-Khoi subprovince of the Eastern-European-Western-European province of subarctic tundras. According to S.A. Grigoreva [1980], the territory is situated within the boundaries of arctic and low-bushy tundra; and according to N.V. Matveeva [1998], it is situated in a typical tundra. The territory is characterized by the monotonity of vegetation and by severe bogging [Andreyev, 1933]. This region is largely influenced by the presence of permafrost, which is continuous here [Yelisakov and Kulyugina, 2014]. The harsh climatic conditions account for the slow pace of peat accumulation.

In accordance with the geographical and soil zoning, the territory is referred to the Kaninsko-Pechorskaya province of the tundra gley and tundra iluvial-humus permafrost soils [Dobrovolsky, 1999]. In accordance with the Soil Map of RSFSR on a scale 1:2 500 000, the territory under study has arctic tundra humic-gley, tundra gley peat-like and peaty soils [Soil Map..., 1988].

**METHODS OF INVESTIGATIONS**

The field studies of soils and vegetation were held on July 16–31, 2010 by a complex expedition of the Institute of Biology of the Komi Science Center of the Ural Branch of the Russian Academy of Sciences. The vegetation cover was investigated using common geobotanical methods [Kucherov and Payankina, 1993; Santesson, 1993; Ignatov et al., 2006] and considering the seasonal thaw depth. For the soils of short bog and tundra vegetation communities, field observations and remote sensing of the Earth’s surface with Landsat TM_5 satellites. Participation of the species was evaluated by the Brown-Blanke abundance-occurrence scale [Mirkin et al., 2001]. In classification of the geobotanical material, approaches of floristic classification of Brown-Blanke and the software package Graphs [Novakovsky, 2006] were used. The species’ names were given in accordance with the modern taxonomy [Santesson, 1993; Cherepanov, 1995; Ignatov et al., 2006]. In Table 1, the names of the syntaxons are provided in accordance with the International Code of Phytosociological Nomenclature [Weber et al., 2000] and considering the previously published data on the region’s vegetation [Kulyugina, 2013; Teteryuk and Kulyugina, 2014; Koroleva and Kulyugina, 2015].

Within the main contours of the vegetation communities, 20 base soil profile cuts and 50 small trench-gates were made. Base soil cuts were made on the “lake bed/river valley—watershed knap” transects. In the field conditions, the morphological parameters of soils and of the underlying permafrost were investigated. The taxonomic names of the soils were given in accordance with the Classification and Diagnostics of the Soils of Russia [Classification..., 2004].

The soil thaw depth was determined with a graduated steel probe 10 mm in diameter [GOST 26262-84]. In making the soil cut, samples were taken from each soil horizon of the annual thawed layer (ATL). In the lower seasonally freezing and permafrost horizons, bore specimens were taken from the depths of 1.0–1.5 m by boring down a steel pipe 40 mm in diameter.

In the middle of summer, the soil thaw depth does not yet reach the ATL bottom. As a rule, seasonal permafrost persisted in the lower part of the soil profile. In continuous permafrost soils, the depth of the ATL bottom was determined using a cryostructure method [GOST 26262-84]. In soils with discontinuous permafrost (the permafrost depth exceeding 1–2 m), the presence of seasonal permafrost allowed the seasonal thaw depth to be assessed. The seasonal thaw depth was determined by the lower limit of the residual seasonally freezing layer.

The influence of the thickness of the peated horizon and of the height of the vegetation cover on the depth of soil thawing was determined by calculating correlative ties. The correlation coefficient (r) was found for the soils of short bog and tundra vegetation communities between the thickness of the organogenic horizon and the thaw depth. For the soils of rare and tall willows, multiple regression was used, where the soil thaw depth was taken to be a dependent variable, whereas the thickness of the organogenic horizon (cm), the height of the shrub layer (cm), and the density of the shrub layer (%) were taken to be independent variables. The calculations were made with the software code STATISTICA 10.0 (the General Linear Models nodule).

Using the materials of satellite survey (Landsat_TM5, survey conducted on 21.07.2000 and 13.07.2009) and the data of geobotanic descriptions in Erdas Imagine 9.1, stepwise controlled classification of the vegetation cover was performed, which allowed a digital vegetation map on a scale of 1:100 000 to be made. Based on the vegetation map and using field and calculation data (matrices) of the landscape, a soil map was made. Topographic variables (slope steepness and absolute altitude), the mean values were calculated as additional characteristics of the main types of vegetation and soils. The map was finalized, and calculations of the structure of the soil and vegetation cover were made with ArcGis 9.1 software. For the polygons of the digital vegetation map, the mean values of the following indices were calculated: NDVI (normalized difference vegetation index) and DI (damage index of vegetation) (Table 2). Based on the soil map of the study area, area calculations were made, and the soil cover structure was analyzed considering the seasonal thaw depth.
### Table 1. Consolidated characteristic of vegetation community groups

<table>
<thead>
<tr>
<th>Vegetation communities</th>
<th>Dominating species</th>
<th>Position on the relief</th>
<th>Prevailing soil types (subtypes)</th>
<th>Freezing type of soil profile</th>
<th>Depth of actual thawing, cm</th>
<th>Permafrost table depth, cm</th>
<th>Cryotextures seasonal thaw layer/permafrost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sedge-dwarf shrub-moss</td>
<td>Sedges (Carex arctisibirica), dwarf shrubs (Salix polaris, S. reticulata, Dryas octopetala), mosses (Hylocomium splendens, Aulacomnium turgidum, Tomen-thynnum nitens)</td>
<td>Uplands of low highlands, on the surface of which frost boils occur</td>
<td>Humic cryoturbic permafrost-affected gleezems</td>
<td>Permafrost-affected</td>
<td>20–70</td>
<td>70–90</td>
<td>Massive/Thin shliren</td>
</tr>
<tr>
<td>Grass-dwarf shrub-lichen</td>
<td>Dwarf shrubs (Dryas octopetala, Salix nummularia, Salix polaris), grasses (Carex arctisibirica, Equisetum arvense), mosses (Pleurozium) and lichens (Cladonia)</td>
<td>Knap tops and flat slopes of knaps, primarily of southern exposure, high shore terraces of rivers and lakes</td>
<td>Humic permafrost-affected gleezems</td>
<td>Permafrost-affected</td>
<td>20–70</td>
<td>70–90</td>
<td>Massive/Thin shliren</td>
</tr>
<tr>
<td>Sedge-moss bogs</td>
<td>Carex concolor, green mosses – Warnstorfoa exannulata, Calliergon cordifolium</td>
<td>Flat intra-knap depressions, low lacustrine terraces</td>
<td>Cryogenic ferruginized permafrost-affected gleezems and permafrost-affected peaty gleezems</td>
<td>20–60</td>
<td>70–100</td>
<td>Massive/massive and thin shliren</td>
<td></td>
</tr>
<tr>
<td>Cloudberry-sphagnum bogs</td>
<td>Dwarf shrubs (Rubus chamaemorus, Eriophorum scheuchzeri) and sphagnum mosses (Sphagnum warnstorffii, Sphagnum girgensohnii, Sphagnum russowii, Sphagnum squarrosum)</td>
<td>Flat intra-knap depressions</td>
<td>Permafrost-affected peaty gleezems</td>
<td>Permafrost-affected</td>
<td>30</td>
<td>70–80</td>
<td>Massive /Thin shliren</td>
</tr>
<tr>
<td>Scarc willows</td>
<td>Salix glauca, S. lanata, S. phylicifolia</td>
<td>Low lacustrine terraces, low parts and bottoms of knap slopes</td>
<td>Gleezems, peaty-gleezems</td>
<td>Deeply frozen</td>
<td>90 and more</td>
<td>100–200</td>
<td>Massive</td>
</tr>
<tr>
<td>Tall willows</td>
<td>Salix glauca, S. lanata</td>
<td>Intra-knap depressions, low parts of slopes, along rivers and streams, on lake shores</td>
<td>Cryogenic ferruginized gleezems and permafrost-affected peaty gleezems</td>
<td>Non-permafrost with shallow freezing</td>
<td>Undetermined</td>
<td>Upper permafrost table is absent within 2 m</td>
<td>Cryotextures are absent</td>
</tr>
<tr>
<td>Grass-sedge-moss meadows</td>
<td>Under upland conditions: Carex concolor, Polemonium autiflorum, Calamagrostis holmii, mosses – Polytrichum commune, Sanionia uncinata; near streams: Carex concolor, Alopecurus pratensis, Poa pratensis</td>
<td>Along rivers and streams, bands 10–50 m wide, in intra-knap depressions, on grassy shores of lakes, surrounded by scarce willows</td>
<td>Dark humus gley soils</td>
<td>Non-permafrost with deep freezing</td>
<td>80 and more, or permafrost is absent</td>
<td>–</td>
<td>Massive /–</td>
</tr>
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</table>
In this paper, a characteristic of seven main groups of the vegetation communities and the corresponding relief components (soils, thaw depth and permafrost table depth, relief, soil-forming deposits, etc.) is provided (Tables 1, 2).

The first four groups of the vegetation communities are formed on soils with close-to-surface (within 1 m) position of permafrost.

1. **Sedge-shrub-moss tundras** are associated with flat-top hills (at the altitudes of 200–215 m above sea level), on the surface of which there are frost boils. The vegetation communities occupy 24% of the area of the key site. The soils have expressed signs of cryoturbation (Table 1; Fig. 2). The height of the dense sedge-shrub story reaches 20 cm (16.0 ± 1.9 cm). Mosses form a thick carpet up to 8 cm thick (6.0 ± 0.5 cm).

2. **Grass-shrub-moss-lichen tundras** are formed on the most drained positions (201–330 m asl). These communities are located randomly on the study site, occupying about 1% of its area. They are characterized by high density of the upper (15 ± 2 cm high) and ground (4.0 ± 0.8 cm high) stories.

3. **Sedge-moss bogs** occupy large areas (about 12% of the site area) in relief depressions, often under conditions of excessive moisture at absolute altitudes of 190–204 m above sea level. In the soils of low-lacustrine terraces, the thickness of the organogenic horizon does not normally exceed 10 cm (5 ± 1 cm), in the intra-knap depressions – up to 20 cm (12 ± 5 cm). Loamy soils in the intra-knap depressions are characterized by small thaw depth (44 ± 8 cm). In the littoral communities, the permafrost table in the sand soils is located at the depth of 74 ± 27 cm. The vegetation cover is closed (its height is 47 ± 3 cm), it is composed mostly of sedge. The moss cover (5–10 cm high, on average 8.0 ± 1.4 cm) is extremely rarefied (5–30% of the cover). The vegetation communities are often flooded; due to this, the dead parts of the sedge decompose badly, forming a significant (up to 30% of the cover) amount of grassland litter near the soil surface.

<table>
<thead>
<tr>
<th>Vegetation community group</th>
<th>Maximum height of stories, cm</th>
<th>Closeness of the top story, cm</th>
<th>Closeness of the ground story, cm</th>
<th>NDVI index</th>
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<td>Sedge-dwarf shrub-moss</td>
<td>20</td>
<td>0.9–1.0</td>
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<td>20</td>
<td>1.0</td>
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<td>Sedge-moss bogs</td>
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<td>Scarce willows</td>
<td>60</td>
<td>0.6–0.8</td>
<td>0.5–1.0</td>
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<td>0.73</td>
<td>200.1</td>
<td>0.72</td>
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<tr>
<td>Tall willows</td>
<td>100–170</td>
<td>0.6–0.95</td>
<td>0.1–1.0</td>
<td>0.49</td>
<td>−0.76</td>
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<td>0.69</td>
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<td>Grass-sedge-moss meadows</td>
<td>30–50</td>
<td>0.3–0.95</td>
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**CHARACTERISTIC OF THE GROUPS OF VEGETATION COMMUNITIES**

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**Table 2. Additional characteristic of the vegetation community groups**

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**Fig. 2. A complex physical and geographic profile “watershed–thermokarst lake valley”, the basin of the Vasyakha River (30.07.2010).**

1 – shrubs; 2 – dwarf shrubs; 3 – grassy vegetation; 4 – seasonally thawed (ST) and thawed (T) horizons; 5 – seasonally frozen horizons (SF); 6 – permafrost (P); 7 – rivers and lakes.
4. **Cloudberry-sphagnum bogs** occupy flat intra-knap depressions, low lacustrine terraces, composed of loam deposits. At the site under study, these communities are very limited (less than 1% of the area), normally located within the contours of the sedge-mass bogs. The height of the grass story is 23 ± 2 cm, and that of moss is 7 ± 2 cm, with a highly dense plant community. A thick (24 ± 6 cm) peat horizon and a closed moss cover account for minimal seasonal thaw depths of soil (Table 1, 2; Fig. 2). The near-surface location of permafrost under these communities is attributed to formation of loamy soils in the areas exposed to the wind with low snow thickness in winter, which contributes to significant cooling of the soils and of the underlying deposits [Mazhitova, 2008].

Scarcie willow tundras are very common on soils with permafrost table lying 1–2 m under the ground surface.

5. **Grass-moss-scarce willows** occur in the lower and middle parts of the knap slopes and depressions of the lake beds. The ecotopes near the lakes are characterized by excessive moisture content, sometimes leading to bogging. This is manifested by the presence of sphagnum mosses, sedges, and cloudberry in the vegetation cover. On the flat slopes of the hills, the number of shrubs grows significantly in the vegetation communities. Plant communities are formed at the absolute altitudes of 193–211 m asl, occupying 32% of the area under study. In these communities, three stories are identified: the scarce shrub story (38 ± 8 cm and taller), the closed grass-dwarf shrub story (24 ± 3 cm) and the moss story (4.0 ± 0.4 cm). Scarcity of the upper story and insufficient closeness of the moss story, as well as the relatively low thickness of the peat horizon (5 ± 4 cm), contribute to greater warming of the soil in the summer period. The depth of the permafrost table usually goes down to 1.5 m in loamy soils and to 2 m in the soils of light granulometric composition (Table 1; Fig. 2).

On non-freezing soils, where permafrost lies at the depths of over 2 m, primarily relatively tall willows and meadow communities are common.

6. **Grass-moss tall willow communities** are common in flat intra-knap depressions, lower parts of slopes, along rivers and streams and on the shores of lakes at absolute altitudes of 193–227 m asl. The communities occupy 19% of the area of the key site under study. These plant communities are characterized by maximum density for the studied territory and by the height of the shrub story (115 ± 9 cm); the grass-and dwarf-shrub story is scarce (the height of 28 ± 3 cm), as well as the moss story (4.0 ± 0.5 cm) [Tyrtikov, 1969]. The closed high canopy of the willows, retaining a large amount of snow in these ecotopes, and the poor peated underlayer account for the mild temperature regime of the soils and the respective absence of permafrost in the soil profile (Tables 1, 2; Fig. 2) [Tyrtikov, 1969].

7. **Grass-sedge-moss meadows** occur on upland soils: between knaps, on overgrown lake shores and along rivers and streams 10–50 m wide. They occur at the absolute altitudes of 197–203 m and occupy about 3% of the area of the territory studied. Low thickness (2.0 ± 0.2 cm) and significant fragmentation of the moss story contribute to the absence of permafrost within the limits of 2 m (Tables 1, 2; Fig. 2).

**DIFFERENTIATION OF SOILS FOR THE CHARACTER OF THE LOCATION OF SEASONALLY FROZEN AND PERMAFROST HORIZONS**

In the period of the study, thaw depth in permafrost-affected soils varied within 30–60% of the active layer depth (Table 1). The seasonal thaw and permafrost table depths on the soils based on sandy soil-forming deposits are approximately 1.5 times greater than those of the loamy soils. On the Bolshezemelskaya tundra, about 60% of the active layer thaw by the end of July [Shamanova, 1970]. These data agree with our many years’ research results on the CALM R2 site [Mazhitova and Kaverin, 2007]. In soils with continuous permafrost, the seasonally thawed horizons were characterized by massive cryogenic textures, whereas the permafrost horizons were characterized by laminar textures. In the soils of meadow and rare willow communities, a shallow frozen horizon was often observed at the depth of 80–100 cm. The presence of residual seasonal permafrost in these cases resulted from deep winter freezing of the soils, with seasonal frost not merging with permafrost. In the soils under tall willows, no signs of seasonal frost were found in the middle of July, which is related to shallow winter freezing of the soils. It is to be noted that in the period of maximal seasonal thaw (September) seasonal frost thaws completely and is not found in the soils. However, its presence in the middle of the summer allowed us partly to make conclusions regarding the depth of seasonal winter freezing.

Due to the above, in field studies of tundra soils in the middle of the vegetation period, it is reasonable to consider these soils as a system combining seasonally thawed and permafrost horizons (Table 1; Fig. 3). The following types of the soil profiles with different combinations of these horizons are identified:

I. Permafrost-affected soils (continuous permafrost) have a three-layer system of horizons: seasonally thawed (ST)–seasonally frozen (SF)–permafrost soils (P).

II. Deeply frozen soils (discontinuous permafrost) have a four-layer system of horizons: ST–SF–permanently thawed (T)–P.

III. Non-permafrost soils, in the profiles of which permafrost is not found, may be present in two vari-
ants: IIIa) with deep seasonal freezing (ST–SF–T); IIIb) with shallow seasonal freezing (ST/T).

Identifying permafrost-affected, deeply frozen and non-permafrost types of soil profiles agrees with the classification principles of the WRB [IUSS, 2014] system, where they are differentiated at a high taxonomic level and are identified as Cryosols, Gelic Gleysols и Gleysols, respectively. In the most recent version of the Classification of Russian Soils [Fieled Soil Ranger..., 2008], permafrost-affected gleezes and peaty gleezes are identified as subtypes. The study conducted has shown that in diagnosing the types of gleezes and peaty gleezes, it is possible to recommend that a subtype “deeply frozen” should be added to the soil classification. Adding this subtype will allow the permafrost situation to be more clearly presented in making soil maps and in analyzing the structure of the soil cover in the permafrost territories (Fig. 4). Special attention to the permafrost component in identifying the subtypes of the tundra gley soils contributes to bringing the Russian classification of soils closer to the principles of international taxonomic systems [Soil Taxonomy, 1999; IUSS, 2014].

The effect of the organic layer thickness is most sensitive to the seasonal thaw depth in the areas of moss-lichen vegetation [Mazhitova et al., 2004]. In the soils under communities of short vegetation, increase in the thickness of the organogenic horizon accounts for decrease in the seasonal thaw depth. In the soils under dwarf shrub-moss-lichen communities (the number of points in the sample \( n = 15 \)) and under sedge-moss bogs (\( n = 17 \)), the seasonal thaw depth is inversely proportional to the thickness of the organogenic horizon (the correlation coefficient \( r = -0.6 \), the statistical confidence level \( p\)-level \(< 0.05 \)).

The influence of the organogenic horizon is smoothened in the areas covered with relatively tall shrubs. The multiple regression calculations have shown that in the soils of willow tundras (\( n = 18 \)), the main factor which affects the thaw depth is the height of the shrub story, which accounts for the 46 % variability of actual thawing.

The thaw depth satisfactorily (\( r = 0.72 \), \( p\)-level \(< 0.05 \)) correlates with the height of the shrub story (the linear regression equation \( y = 0.6521x + 7.7437 \)). Thickness of the peat horizon in the soils under willow communities has insignificant impact on seasonal thawing (3 %).

It has been revealed that in the study area in the zone of typical tundras with the shrub height exceeding 50 cm, the permafrost table occurs below 1 m, not merging with the seasonal frost. Here form non-permafrost and deeply frozen types of soil profiles, which agrees with the similar conclusions made previously for the southern tundra [Mazhitova, 2008]. When the height of the shrub story exceeds 80–100 cm, no permafrost table is found within the limits of 2 m.

THE STRUCTURE OF THE SOIL COVER

It is known that the depth of seasonal thawing is inversely proportional to the values of the normalized difference vegetation index (NDVI). This allows direct mapping of the seasonal thaw depth based on remote sensing data [Khomutov, 2010]. During inter-
pretation of the vegetation cover of the key territory, the spectral characteristics of different vegetation classes are determined by a high separability level, especially areas with tall willows growing [Yelsakov and Kulyugina, 2014].

Calculations of the average NDVI for each group of the vegetation communities revealed their differentiation for this index (Table 2). Analysis of the vegetation indices has shown that, in addition to the NDVI, the damage index (DI) indicating the degree of damage of the vegetation cover may be used. Communities with non-permafrost soils (tall willows and tundra meadows) are clearly differentiated by the high values of the NDVI index (Table 2). The vegetation communities with $NDVI \leq 0.46$ and $DI \geq 0.2$ are formed primarily on soils with underlying permafrost within the limits of the soil profile (permafrost-affected and deeply frozen soils).

Analyzing the structure of the soil cover considering the seasonal thaw depth necessitated making a large-scale soil map. The soil map of the key site has been made on the basis of a vegetation map considering the ratios between the classification soil types and vegetation community types. Analysis has shown that gley soils dominate in the structure of the soil cover in combination with locally spread peaty gleezems (Fig. 4). The relative share of automorphous soils is much higher than that of half-hydromorphous peaty gleezems. The high share of automorphous soils is attributed to the landscape position and the specific development of the alluvial bench. In total, the frozen types of soils occupy a significant part of the key site (38%). Yet, at least half of the site area (54%) is covered by deeply frozen and non-permafrost types of profiles. Thus, analysis of the structure of the soil cover of the site under study allows us to add data to the previously obtained results [Yelsakov and Kulyugina, 2014]: the advancement of shrub vegetation within the limits of the Yugorsky Peninsula over the recent decades has been accompanied by the gradual increase of the share of deeply frozen and non-permafrost types of soils.

CONCLUSIONS

Seven main groups of vegetation communities and of soils characteristic of them were identified on the site in question. Four groups of vegetation communities were identified in the areas of close-to-surface permafrost: sedge-shrub-moss lichen tundra, grass-shrub-moss lichen tundra on gley soils; sedge-moss and cloudberry-sphagnum bogs on gleezems and peaty gleezems. Scarce willow tundras are widespread on gleezems and peaty gleezems with the permafrost table lying at the depth of 1–2 m. On non-permafrost gleezems and on dark humus gley soils, in which permafrost is located at the depth of over 2 m, primarily tall-willow and meadow communities are common.

In the field studies of the tundra soils in the middle of the vegetation period, it is reasonable to consider them as a system of combination of thawed and frozen horizons. The following types of soil profiles with different permafrost conditions are identified: permafrost-affected, deeply frozen, and non-permafrost types (with deep or shallow seasonal freezing of the soil).

Differentiation of the seasonal thaw depth in dwarf shrub and bog plant communities is caused by spatial non-homogeneity of the peaty horizon ($r = -0.6, p$-level < 0.05). In willow tundras, the thaw depth is in satisfactory agreement ($r = 0.72, p$-level < 0.05) with the height of the shrub story.

Determining the interconnections between the groups of vegetation communities and the types of soils allows a soil map to be made on the basis of a vegetation map. In the structure of the soil cover of the key site, gley soils are dominating in combination with locally spread peaty gleezems. The permafrost-affected types of the soil profiles occupy a large share of the key site (38%). About 54% of the site area is occupied by deeply frozen and non-permafrost types of soils, which is the result of advancement of the shrub vegetation on the Yugorsky Peninsula over the recent decades.

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