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Soil Mapping And Active Layer Monitoring In Intensive Reindeer Herding Region ("Erkuta" Research Station, Central Yamal).

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ABSTRACT

Monitoring sites are crucial for adequate assessment of current state of arctic ecosystems. Predicted Arctic warming results in degradation of permafrost, hence the goal of permanent monitoring of active layer thickness is sharply risen. Herein, soil mapping is very for maintenance of any monitoring activity. This work is aimed to specify soil diversity of Erkuta river monitoring site, perform vertical electrical resistivity sounding for evaluation of active layer thickness and create a comprehensive soil map of investigation area. Soil cover of studied site is very complex and diverse. It is determined by high complexity of micro- and nanorelief forms, different moisture regimes and high variability permafrost table. In general, active layer thickness was found at the level of 100 cm.

Keywords: permafrost-affected soils, active layer, soil mapping

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INTRODUCTION

Landscapes of cryolithozone cover about 60 percent of Russian territory, their distribution is not limited only by the Arctic zone.

There are numerous key issues in the study of soils in polar regions: soil diversity, soil evolution, soil geography and interpretation of soil properties via the prism of bioclimatogenic or geogenic approaches [8]. Existing frictions in interpretation of polar soils taxonomy, classification and morphology lead to necessity of development of three-dimensional approaches for studying soils, *i.e.* the study of soil cover, soil cover pattern, genesis, evolution and ecology. Application of such methods to the polar regions seems to be a significant goal of modern pedology [8]. Until recently, polar soils have been considered via the paradigm of bioclimatic properties, while the lithological (or so-called geogenic) peculiarities were underestimated [8]. Studying the influence of permafrost on soil formation processes is one of the most significant issues for both fundamental and applied soil science concerning polar regions [15, 23].

Permafrost-affected landscapes are mainly determined by climatic conditions and influence of permafrost. The diversity of permafrost-affected landscapes is underestimated, but it determines peculiarities of geochemical flows in polar ecosystems, soil diversity, development and functioning of hydrological network, terrestrial elements cycles.

Permafrost-affected soils are characterized by specific conditions for soil-forming which is mainly reflected in low temperatures and seasonal freezing and thawing processes [16]. It leads to development of strong heaving forces, development of segregated and massive ice, various patterned ground features and types (Fig.1). Underlying by permafrost makes soils often wet and cold at the same time, since permafrost limit free drainage.

Among the main soil processes which mainly determine soil diversity of the Arctic it should be named peat accumulation, cryoturbation, stagnification and superficial accumulation.

However, podzolization and spodification processes are also taking place very often in different Arctic soils in conditions of well-drained tundra sites. Weak-developed soils are formed mainly in mountain and foothills conditions and usually accompany by high gravel content in soil profile. Alluvial and stratified soils characterize landscapes of river floodplains and terraces.

Predicted climate change, especially its polar amplification, and permafrost thawing require permanent monitoring of environments. Herein, monitoring of active layer thickness in the Arctic is crucial. For this purpose CALM program (Circumpolar Active Layer Monitoring) was established. However, it should be stated that different sectors of the Arctic are covered equally by monitoring sites (Fig.5). Moreover, the data reported in CALM database are mostly obtained by the methods of direct measurements of active layer thickness which often lead to mechanical disturbance of soil and vegetation cover and, consequently, overestimation of permafrost degradation. That is why the problem of development of uniform non-direct methods for evaluation of active layer depth is sharply risen. For this purpose geophysical approaches can be used (i.e. vertical electrical resistivity sounding).

Soil mapping is very important step for establishing of any monitoring site. Development of digital technologies served as a prerequisite for the new level of soil mapping. Moreover, specificity of soil cover (which are discrete-continuous in space) is a reason of existing technological and theoretical problems, which are rising during soil mapping procedures [7]. This work is aimed to specify soil diversity of Erkuta river monitoring site and create a comprehensive soil map of the site reflecting conditions of soil forming. For this purpose the following goals were established:

- to perform complex study of morphological and taxonomical diversity of studied area;
- to perform geomorphological and botanical description of studied sites;
- to perform active layer thickness evaluation both by direct mechanical method (using of steel bar) and non-direct vertical electrical resistivity sounding (VERS) of soil and permafrost layers to assess active layer thickness and construct 3D model of its spatial distribution on example plot.

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MATERIALS AND METHODS

Regional setting

This study was performed during two complex expeditions “Yamal-Arctic” in 2016 and 2017. Research station “Erkuta” is located on the first terrace of Erkuta river in central Yamal in the zone of shrub tundra (Fig. 1). The functioning of seasonal research station is closely connected with indigenous population of this area – many data are collected from reindeer herders families. This site is crucial for transport logistics of Yamal region.

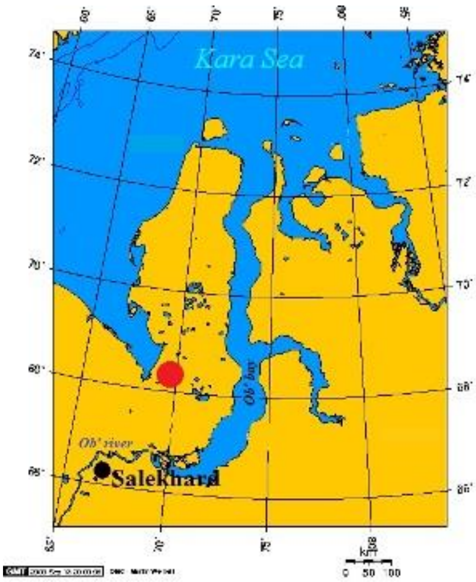

Fig 1: Location of investigation area on the map of northern Western Siberia.

The climate this part of Yamal peninsula is severe and continental. The values of radiation balance is about 18-20 kcal/cm^2 per year. Relative humidity in the entire peninsula is high (70-90%) throughout the year. It is caused by low air temperatures and proximity to the cold waters of the Kara Sea. Average precipitation varies from 230-270 mm**.** Small amount of precipitation in the northern part of peninsula is caused mainly by slight moisture content of arctic air masses [5]. The annual amount of evaporation is not high (about 250 mm per year). The number of days with snow cover is about 240 days. Winter lasts 7-7.5 months, the average temperature of January is -23-25 ° C. Spring is usually short (35 days) and cold, with a sharp change in weather, with frequent returns of cold and frost. The growing season is 70 days. Average temperature of the warmest month + 5 ° C. Autumn is short, with a maximal volatility of the pressure gradient, an abrupt change in temperature and frequent early frosts. The site is in a zone of excessive moisture [22].

Yamal region is very sensitive to climate warming, during last 30 years. Forbes et al. reported 1-2 ^oC increase in the average air temperature (Forbes et al., 2009). This is significant for enhancing of rates of soil organic matter humification and climate-relevant gases emission to the atmosphere [15]. It is potentially a factor of unbalancing the current carbon balance.

It should be reported that summer seasons 2016 and 2017 was extraordinary warm for Yamal region. The mean air temperature of air during field work in July (data from expedition Yamal-Arctic is not included in this work) was about +27-30 ^oC, which is much higher that mean temperature stated in literature for recent decade. The data collected from permanent monitoring station in Erkuta river testify the fact of increasing mean summer temperatures of soil during last two years (Fig.2).

The first terrace of Erkuta river is characterized by complexity of micro- and nanorelief, presence of lides, over moistened microdepressions, relatively dry microelevations and frost mounds. On the bedrock bank of Erkuta river it was also described ice-wedges with Yedoma deposits.

Fig 2: Soil temperatures (0-10 cm) over the season August 2016-June 2017 as collected from permanent monitoring plot at Erkuta river derived from thermologgers

Investigation methods

Brief vegetation description has been performed according to the Braun-Blanquet method [4]. Dominant species was estimated according to their coverage of surface area (in %).

Soil samples were taken from the field for further laboratory analysis. In laboratory, all samples were dried at 40 °C to constant weight, sieved (1 mm) and partly grounded. Determination of the main soil parameters has been performed by standard procedures. Values of pH in water and salt suspension were measured using pH-150 meter (1:2.5 soil:solution ratio). Exchangeable and hydrolytic acidity were measured by adding KCl and CH_3COONa, respectively (1:2.5 soil:solution ratio). Texture class analysis was performed according to pipette-sedimentation method [11].

Soil diagnostics was performed according to Russian soil classification system [22] and WRB system [6]. Mesomorphological characterization of selected diagnostic soil horizons has been performed using mesomorphological equipment. The soil map was drawn in ArcGis software.

To perform actual permafrost table location vertical electrical resistivity sounding (Schlumberger geometry approach) was used. The Schlumberger array consists of four collinear electrodes. The inner two electrodes (MN) are the potential electrodes whereas the outer two (AB) electrodes are current electrodes. The potential electrodes are installed at the centre of the electrode array at small separation. The current electrodes are increased to greater separation during the survey, while the potential electrodes remain in the same position until the observed voltage becomes too small to measure [12, 20].

RESULTS AND DISCUSSION

It was described soil diversity of first river terrace on the left bank of Erkuta river and river floodplain. 1st river terrace is characterized by presence of laydas, over-saturated microdepressions, microelevations and sorted circles. Yedoma deposits with ice-wedges were also described on the high left bank of the river. Vegetation cover is represented mostly by shrub-moss tundra. Soils were classified predominantly as Histic Stagnic Cryosols/Peaty Gleyzems underlain by permafrost (TE-Gox-CG) at saturated sites and Turbic Cryosols/Typic Cryozems (O-CR-BC) in sorted circles. River floodplain was characterized by predominance of Fluvic-Stagnic Cryosols and Fluvisols/Alluvial soils underlain by permafrost (Fig.3).

Analysis of the main soil properties for two studied soils revealed that they are characterized by predominantly acid values of pH (Table 1). Values of exchangeable acidity ranged from 0.10 to 0.80 $cmolP^+/kg$. The highest values were found in topsoil buried humus horizon. Values of hydrolytic acidity ranged from 0.20 до 0.80 $cmolP^+/kg$. The highest values were found in buried horizon as well. It is explained by presence of colloidal matrices which are the source of exchangeable hydrogen. Soils are characterized by predominance of silty clay loam and clay loam fractions (Fig. 4).

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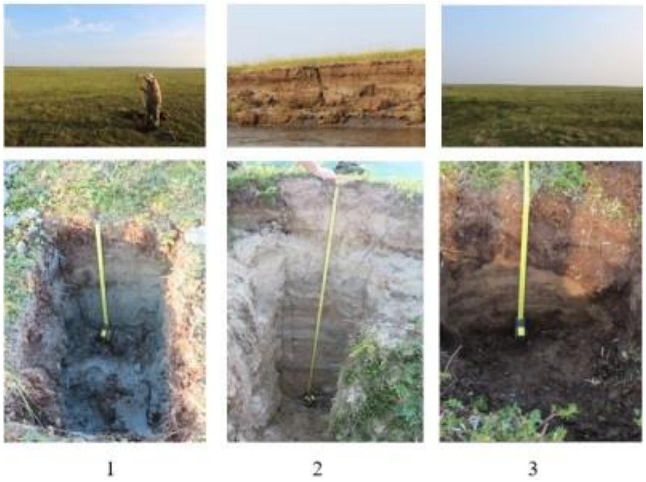

Fig 3: Soil diversity of Erkuta monitoring site. 1 – Histic Stagnic Cryosol/Peaty Gleyzem unvderlain by permafrost; 2 – Fluvic Crysol/Alluvial grey-humus soil underlain by permafrost; 3 – Turbic Cryosol/Typic Cryozem.

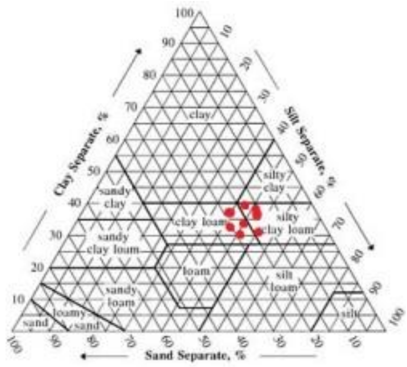

Fig 4: Results of analysis of particle size distribution in studied soils.

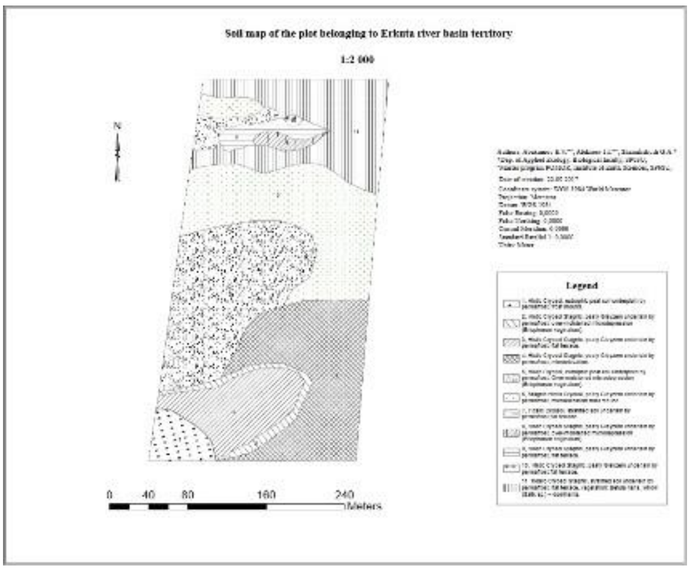

Fig 5: The soil map of Erkuta river monitoring site. Names in the legend in WRB/Russian Soil Classification systems

Investigation of morphological and taxonomical diversity of studied area together with is geomorphological and botanical descriptions served as a base for creating the soil map of “Erkuta” monitoring

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site (Fig. 5). As it is seen form the map soil cover of studied site is very complex and diverse. It is determined by high complexity of micro- and nanorelief forms, different moisture regimes and high variability of the upper boundary of permafrost. Previously it was found that non-linear character of permafrost table is one of the reasons of complicated organization of soil mass above (active layer) and various mechanisms of process and time interactions of soil and permafrost [8]. Thus, wide spatial distribution of components of microcomposition of soil cover which are not correlated with modern bioclimatic conditions testifies polygenetic state of soils [18]. At the same time, degree of manifestation of permafrost table microrelief depends mainly on position in mesorelief (the highest – on flat surfaces of watersheds, gentle slopes and depressions; the lowest – on steep slopes), active layer thickness and cryogenic mass transfer [13].

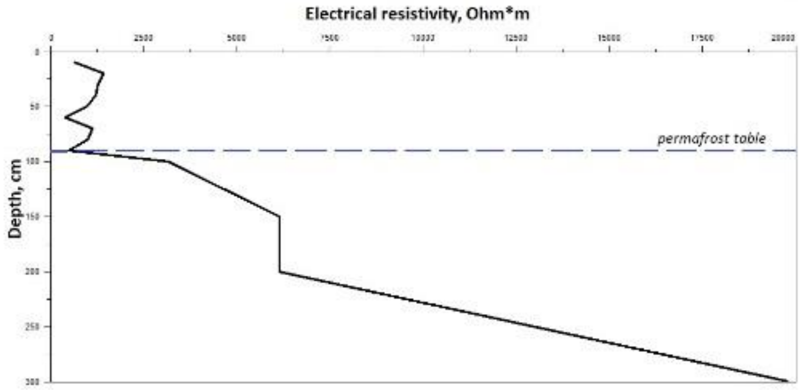

Fig 6: Averaged profile distribution of electrical resistivity values in studied soil profiles.

The most typical trend in the profile distribution of electrical resistivity (Ra) values at studied site is an increase along the depth with many disturbances (fluctuations), which mainly occur within the soil profile (Fig. 6). These disturbances are caused by the influence of permafrost inhomogeneity and appearance of the water-saturated layer of soil in contact with the permafrost table (at a depth about 100 cm). When the water-saturated layer appears in the soil bottom horizon, electrical resistivity decreases [17]. Fluctuations in Ra values within permafrost strata may be connected with its instability and irregularities. In general, the permafrost table lies at a depth of 100 cm.

The results on soil electrical resistivity reported in this work coincides with the data on permafrost-affected soils obtained earlier by some authors both in Arctic and Antarctic [1, 2].

The general trend of gradual increasing electrical resistivity values with the depth is theoretically and practically approved. It has been previously shown that electrical resistivity is decreasing with higher amount of gravitational type of water in soil pores [14, 17, 19]. When the water-saturated layer appears in the soil bottom horizon, electrical resistivity decreases [17]. Fluctuations in Ra values within permafrost strata may be connected with its instability and irregularities. Similar trends have been described earlier in soils of the northern part of the Gydan peninsula [1, 3] and with the soils of Antarctica [2].

Active layer thickness was also assessed using direct method of measuring – penetrating the solum steel bar. The results of direct measurements are represented in Fig. 7. This model reflects landscape variability of active layer thickness caused by nano- and microrelief features (microdepressions, microelevations of different origin).

Monitoring key plot is characterized by predominance of Histic Stagnic Cryosols/Peaty Gleyzems underlain by permafrost. However, vegetation cover are more depended on spatial variation of surface manifested in presence of hummocks, over-moistened microdepressions and small frost mounds. Vegetation cover ranged from relatively dry tundra associations to wet tundra associations (with *Eriophorum vaginatum* as determinant) (Fig. 8). At some places sharp variation of vegetation types is represented - black turfy surfaces with almost no low percentage of higher vegetation (black color) are combined with wet tundra.

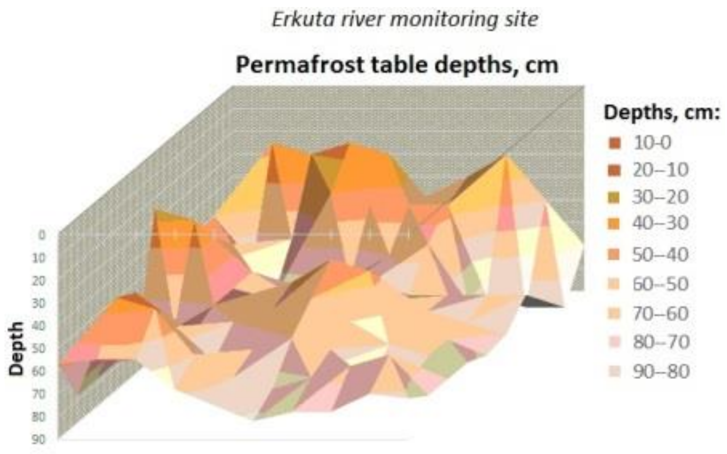

Fig 7: Three-dimensional representation of permafrost-table depths at monitoring plot in the area of Erkuta river

Fig 8: Typical vegetation type (wet tundra with Eriophorum vaginatum as determinant) Example of sharp variability of vegetation types at monitoring site in the area of Erkuta river

CONCLUSIONS

High soil diversity of studied monitoring site is explained by high complexity of micro- and nanorelief forms, different moisture regimes and high variability of the upper boundary of permafrost.

Active layer thickness and soil-permafrost boundary are one of the most important indicators for classification of polar soils. Vertical electrical resistivity sounding performed in the studied area allowed us to determine the heterogeneity of the soil-permafrost strata in terms of electrical resistivity values. Vertical electrical resistivity sounding can be effectively used for identification of active layer thickness, specification of horization of soil profiles which is especially important in case of complicated soil profiles (stratification due to sinlithogenesis, buried organic horizons, mixing of soil mass due to cryogenic mass transfer etc.) in field conditions. Equipment for such geophysical investigation is easy to handle, its using is non-time consumable. While using of traditional methods for investigation of active layer thickness (consist of soil sampling and mechanical disturbance of soil cover surface), using of geophysical methods is non-disturbative for soil and vegetation cover which is very important for highly sensible tundra ecosystems and crucial for adequate evaluation of soil parameters and soil cover dynamics over time under predicted global warming.

Predicted Arctic warming requires a larger attention of scientific community for creating of monitoring sites around the variety of tundra landscapes in different sectors of the Arctic. The data reported in this work should be assessed only as a contribution for global monitoring of the Arctic environment.

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