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Soils of the Lena River Delta, Yakutia, Russia: Diversity, Characteristics and Humic Acids Molecular Composition

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Abstract: Soils of the Lena River Delta were discussed in terms of morphology, diversity, main chemical, physical properties and HAs molecular composition. It was shown that the investigated soils are formed under the influence of several soil-forming processes, the processes of cryogenic mass exchange are considered as a main soil formation process, the second most important process is alluviation and formation of Umbric Cryosol (Fluvic, Arenic, Reductaquic) with pronounced features of soil stratification. Erosion of the floodplain and resedimentation on its surface of suspended particles in the water results in formation of stratified soils, underlain by solums with well-expressed cryogenic features. Soils of the delta are characterized by high amount of carbon, accumulated in fine earth, and well-expressed formation of folic horizons in topsoil layers. Texture soil classes were represented by four categories: sand, loamy sand, sandy loam and silt loam. This suggests a large amount of alluvium deposits in the delta and that settling of large particles results from fast river flow. Humic acids of selected soils were investigated in terms of elemental and structural composition with special reference to evaluation of organic matter stabilization degree and assessment of carbon species distributions in the molecules with use of solid-state ^{13}C-NMR spectroscopy. It was shown that the prevailing of aromatic compounds on the aliphatic one is more pronounced in the Lena River Delta than in other Arctic soils.

Zusammenfassung: Die Böden des Lena-Deltas wurden hinsichtlich ihrer Morphologie, Diversität, den wichtigsten chemischen und physikalischen Eigenschaften sowie der molekularen Zusammensetzung der Huminsäuren untersucht. Es wurde nachgewiesen, dass die Böden des Lena-Deltas unter dem Einfluss von verschiedenen bodenbildenden Prozessen entstanden sind. Hierbei stellen die Prozesse des kryogenen Masseaustauschs den wichtigsten Bodenbildungsprozess dar, gefolgt von Anschwemmung und Bildung von Fluvisolen mit ausgeprägten Merkmalen einer Bodenschichtung. Die Erosion des Überschwemmungsgebiets und die Resedimentation von in Wasser gelösten Partikeln auf deren Oberfläche resultiert in der Bildung von geschichteten Böden, deren Unterlage von Sola A- und B-Horizonten mit deutlich ausgeprägten kryogenen Merkmalen geprägt ist. Die Böden des Deltas sind durch eine große Kohlenstoffmenge geprägt, akkumuliert in Feinerde und deutlich ausgeprägter Ausbildung von histischen Horizonten in den Oberbodenschichten. Bodengefügeklassen sind in vier Kategorien vertreten: Sand, lehmiger Sand, sandiger Lehm und sandiger Lehm. Dies deutet auf eine große Menge an Alluvialböden, die im Delta abgelagert werden. Die groben Partikelgrößen sind das Ergebnis hoher Fließgeschwindigkeit des Flusses. Huminsäuren ausgewählter Böden wurden hinsichtlich ihrer Element- und Strukturzusammensetzung untersucht, unter besonderer Berücksichtigung der Bewertung des Stabilisierungsgrades des organischen Materials und der Erfassung der Verbreitung der Kohlenstoffarten in den Molekülen mit Hilfe der Festkörper-^{13}C-NMR-Spektroskopie. Es konnte gezeigt werden, dass das Überwiegen aromatischer gegenüber aliphatischer Komponenten im Lena-Delta stärker ausgeprägt ist als anderswo in der Arktis.

Keywords: The Lena River Delta, 13C-NMR spectroscopy, permafrost-affected soils, Arctic region, carbon pools.

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INTRODUCTION

Soils, located in permafrost-affected terrestrial ecosystems of the cryolithozone are known as very diverse in terms of morphology, profile organization and main chemical and physical properties. The area of the distribution of permafrost on the Earth reaches 35 million km^2, accounting for up to 25 % of the world's total land area (Jones et al. 2010). Specific signs of permafrost are the negative temperature and the presence of ice, characteristic of frozen layers for a long time (Konischev 1997). In Eurasia, permafrost occupies about 13 million km^2 and extends from circumpolar latitudes to 44°N. In Russia, permafrost occupies more than 10.7 million km^2, which is about 65 % of the country's territory. The most widely permafrost is widespread in the north of Western Siberia, in Eastern Siberia, and in Transbaikalia. One of the most likely and important feedback from sustainable warming in high-latitude ecosystems is the thawing of permafrost soils and the release of soil organic carbon into the atmosphere through the microbial respiration of CO_2 or methane, or by leaching out as dissolved organic carbon (Dutta et al. 2006). Soil organic matter is among the largest global reservoir that exchanges carbon with the atmosphere, it is an important reservoir for a large fraction of the global soil carbon pool (Dutta et al. 2006, Schimel 1995, Davis 2001). This pool of soil carbon, climatically protected by cold and waterlogged conditions, is thought to be highly susceptible to change in temperature and permafrost thawing (Bischoff et al. 2013).

Soils that are belonging to the cryolithozone, including soils of the Lena River Delta, form under influence of severe arctic polar climate, which are characterized by negative average annual temperatures (-13°C) and low average perspiration (about 323 mm). Climate description for the study regions is given in Table 1. Vegetation cover is represented by tundra associations: grass-sedge-moss community are prevalent, moss-sedge polygonal wetlands locate in the low areas (Bolshiyanov et al. 2013). This results in the formation of soil profiles with well pronounced features of cryogenic mass exchange. On the other hand, soil formation in the Lena River Delta is strongly affected by fluvic processes, related to alluvial activity of the river.

Soils of floodplains can be divided to young soils of recently formed areas (coast shallows, overgrown by vegetation bodies of water) slightly affected by soil forming processes and relatively older soils of the areas drifted away from the floodplain processes influence and are covered by developed soils with signs of indicative features of zonal soil formation (Dobrovolsky 1994, 2005, Boike et al. 2013, Kutzbach et al. 2004).

Climate parameters	Lena River Delta
Mean annual air temperature (°C)	-13
Mean air temperature (ºC): of the warmest month (July) of the coldest month (January)	 6,5 -32
Number of days with mean daily air temperature: above 0°C above 5°C above 10°C	 73 35 11
Freezing depth (cm)	30-50
Snow thickness (cm)	23
Annual precipitation (mm) in summer (mm)	323 125

Tab. 1: Climate parameters of the study region (Data obtained from the station "Samoylov Island")

Tab. 1: Klimatische Parameters des Untersuchungsgebiets (Daten von der Station „Samoylov Island" erhalten)

In the floodplains, soil formation takes place under the action of soil forming several factors: alluvial, floodplain and zonal processes (DOBROVOLSKY et al. 2011). Alluvial processes are sediments transportation by an action of water, erosion of a floodplain, redeposition of sediments within a floodplain. Floodplain processes are flooding of different areas of floodplain by water which considers fine-grained sandy and clay material (DOBROVOLSKY 2005). Zonal process of soil formation in the arctic zone is cryogenesis (cryogenic mass transfer and exchange, gleification (stagnification) redistribution of organic matter (GUBIN et al. 2008).

The characteristic features of the Arctic region are continuously frozen ground (permafrost), extensive wetlands with shallow lakes and ponds, large seasonal fluctuations in solar energy, and a short vegetation period (BOIKE et al. 2013). Rivers of high latitudes serve as a link between soil carbon pools, atmosphere, and Arctic Ocean shelf. They play a key role in redeposition and transformation of carbon, which is received to the ocean (ZIMOV et al. 2006). The Lena River flows into the Laptev Sea and has a great impact in the Arctic Ocean. The River is one of the major receivers of organic and inorganic carbon and defines the organic carbon cycle in the Arctic basin in many ways. (LARA et al. 1998).

Particular attention is being paid to the influence of the river flow on exchanging processes between the atmosphere and the ocean and formation of the planetary maximum of greenhouse gases accumulating in the high latitude (DUTTA et al. 2006). The consequences of current and future warming of arctic climate will be stronger than the average worldwide. In response to arctic warming, the area of permafrost landscapes will decrease, and the thickness of the active layer will increase. Then organic carbon, that was frozen in permafrost, will become available for microbial degradation, resulting in the formation of carbon dioxide (CO_2) and methane (CH_4) (KNOBLAUCH et al. 2013, WAGNER et al. 2007).

It is essential, therefore, to investigate regional soil diversity that locates in conditions of continuous redeposition of materials and matters and cryogenic processes that are being actively developed. Arctic soils and peatlands act as large carbon stocks, but our understanding of feedback mechanisms caused by rising temperatures and their effect on trace gases remains has not been studied (BOIKE et al. 2013). The distinctive properties of deltaic soils of the north of Russia are: abundance of non-humified organic matter, low microbiology activity of soil microorganisms, a large amount of Fe^{+2} compounds and low mobility of phosphorus and potassium in the soil complex, as well as a low content of humus, in comparison with soils that do not undergo flooding (DOBROVOLSKY et al. 2011). Soils are characterized by a low activity of microorganisms at a high potential of microflora in flooded areas. This is due to the fact that delta soils have a high potential biological activity, which is associated with the annual intake of nutrients coming from the hollow waters of the river. The decomposition processes reach a peak in the upper horizons of the soil and weaken down the profile. In conditions of constantly excessive moisture and high-water capacity, it is very often possible to observe stagnant moisture and undifferentiated organic residues in the profiles. In such soils, the valence of iron changes from Fe^{+3} to Fe^{+2}. There is a large number of compounds of phosphorus and sulfur in the soil complex (DOBROVOLSKY 1994).

A significant amount of carbon of organic compounds accumulates in the soils of the Lena River Delta. The organic matter presents various properties to the type of humus content of soils, depending on the location in the relief. In connection with this, it is important to study the humic acids of the soils of the Lena River Delta, using the method of nuclear magnetic resonance.

The advantage of this method is the ability to quantify the content of groups of structural fragments and identify individual structural fragments in humic acid molecules and is also used to assess changes in SOM during decomposition and humification. So far, studies of the quality of SOM from polar environments have revealed a generalized low-degraded nature of organic molecules that retain most of the chemical nature of their precursor material due to the low progress of humification (DAVIDSON & JANSSENS 2006, DZIADOWIEC et al. 1994, ABAKUMOV et al. 2015).

The investigation of the Lena River Delta soils was elaborated through the four characteristics:

1. The pedodiversity in the different landscapes positions.
2. The morphological and chemical diversity in different parts of the Lena River Delta.
3. Research of the major ecological functions of the study region.
4. Estimation of the rate of stabilization of soil organic matter using precise molecular methods.

MATERIALS AND METHODS

The study sites

Materials for this study were collected during two expeditions within the project "Lena River Delta" in 2015-2016, organized by the Arctic and Antarctic Research Institute, St. Petersburg.

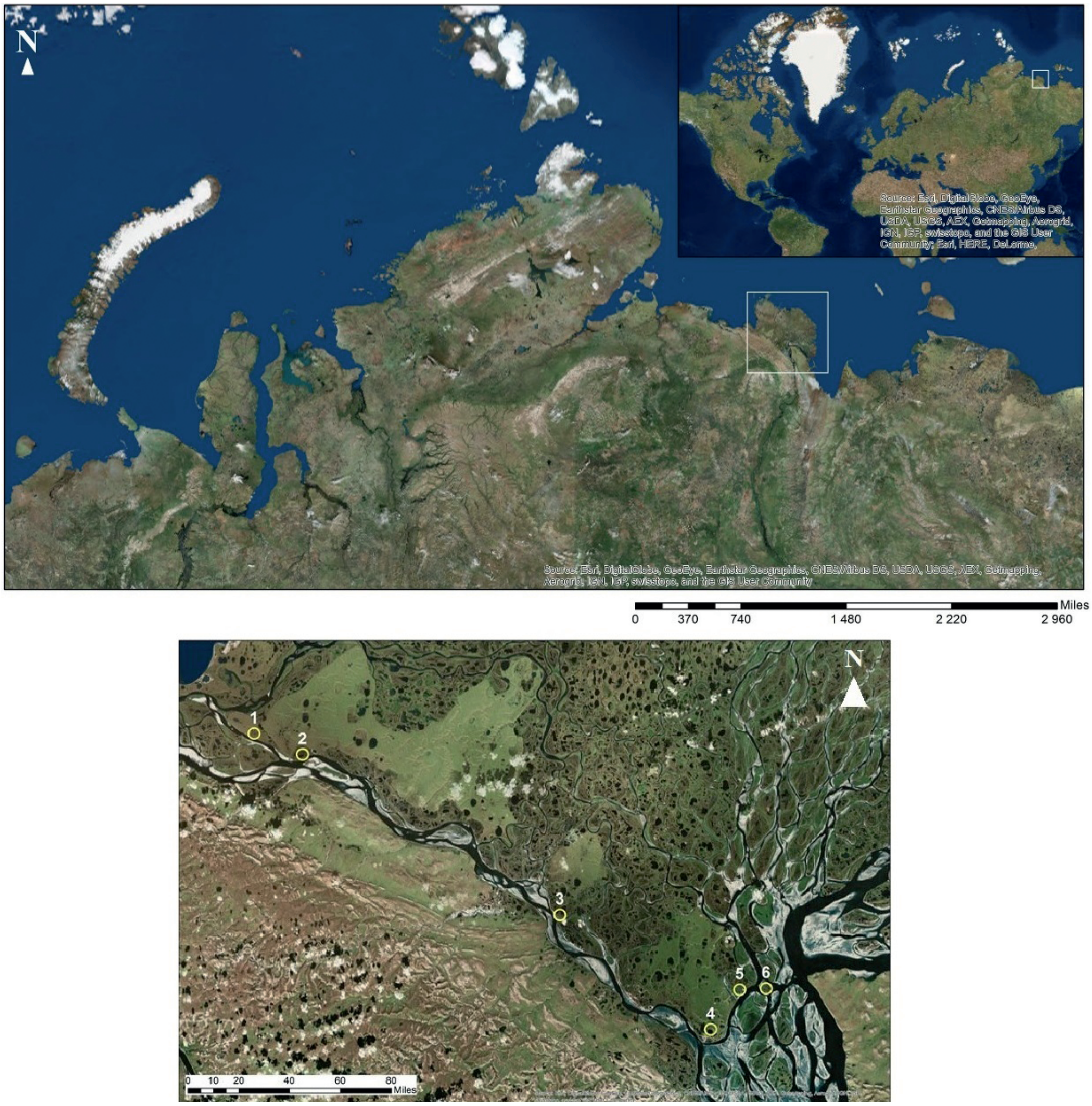


Fig. 1: The key study sites of the Lena River Delta, Russian Arctic. Investigation sites. Distribution of soils within investigation area: 1) isl. Hardang (Folic Cryosol; Reductaquic); 2) isl. Hardang (Umbric Cryosol; Loamic, Reductaquic); 3) isl. Jan-Gylach (Cryosol; Oxyaquic, Loamic, Reductaquic); 4) isl. Kurungnagh (Turbic Cryosol; Loamic, Reductaquic); 5) isl. Kurungnagh (Folic Cryosols; Reductaquic, Subaquatic); 6) isl. Samoylov (Umbric Cryosol; Fluvic, Arenic, Reductaquic).

Abb. 1: Untersuchungsstandorte im Lena-Delta, russische Arktis, und Verteilung der Böden innerhalb des Untersuchungsgebiets: 1) Hardang-Insel (Folic Cryosol (Reductaquic); 2) Hardang-Insel (Umbric Cryosol; Loamic, Reductaquic); 3) Jan-Gylach-Insel (Cryosol; Oxyaquic, Loamic, Reductaquic); 4) Kurungnagh-Insel (Turbic Cryosol; Loamic, Reductaquic); 5) Kurungnagh-Insel (Folic Cryosols; Reductaquic, Subaquatic); 6) Samoylov-Insel (Umbric Cryosol; Fluvic, Arenic, Reductaquic).

The Lena River Delta is the largest northern delta in the World, which is located in the Arctic zone and covers around 29630 km^2. The delta has a great influence on water regime and biogeochemical state of the Arctic Ocean due to its huge area and disposition. The delta supplies a great amount of fresh water to the least salty ocean of our planet. The delta resulted from river activity: redeposition of sediments, erosion, and abrasion due to fluctuations of sea level and crust movements (Bolshiyanov et al. 2013, Boike et al. 2013, Zubrzycki et al. 2014) (Fig. 1).

Eastern and western parts of the delta are different in terms of density of river network and the number of islands and their sizes. Thus, the western part of the delta has a density of river network 0.13 km/km^2 and is represented by large-size islands, that have the high heights of the surface. The largest island of the western part of the delta: Arga-Muora-Sisyo (18 % of the total area of the delta), Hardang-Sisyo (1136 km^2), Kurungnag (355 km^2) and Jangylah (169 km^2), the total number of islands in the western part of the delta amounts to 235 (Bolshiyanov et al. 2013).

The environmental peculiarities of the eastern part of the delta are entirely different from the conditions in the western part due to river flow activity and the northeastern direction. As a result, the eastern part is represented by a lot of islands – 764. A density of river network is 0.34 km/km^2, the territory of the eastern part of the delta is riddled with a network of numerous flows that destroy materials, redeposit the sediments and form small area islands (Bolshiyanov et al. 2013, Galabala 1987). Moreover, sea waters affect the delta. Western and northwestern coasts are under influence of Laptev Sea, the surface sea temperature here is much lower than on eastern and northeastern coasts. There temperature defines by the Lena River warm flow. The temperature in August on the western coast is 3°C, on the eastern coast – from 4 to 9°C. In addition to physical properties, chemical properties also changes, sea waters activity affects the salinity which reached 14 ‰ in the western and northwestern parts of the delta.

The territory of the delta includes at least 27165 lakes over 0.25 km^2 and 10 lakes over 10 km^2. Most of the lakes are concentrated in the western part of the delta, that due to the fact this part of the delta is the oldest and the largest islands are located here. In the eastern part lakes related to the riverbed lakes and oxbow lakes dominate. A large amount of water passes through the Lena River Delta, annual average discharge is 15400 m^3/s, annual sediments run-off is 5.8×10^{13} g. Turbidity of the water is 23 g/m^3 (Bolshiyanov et al. 2013, Galabala 1987, Ivanov 1963).

Vegetation cover is represented by tundra species: grass-sedge-moss community are prevalent, moss-sedge polygonal wetlands locate in the low areas. Vegetation cover is not continuous but spotted. The Lena River Delta is characterized by the domination of moss-lichen vegetation. Moss community predominates on loamy soils, and lichens – on the coarse rocky soils. Near the lakes of glacier origin, sedge-cotton grass groups replace moss-lichen vegetation. On the warm southern slopes on the well-drained rocks covered by sandy soils, there are areas with grass community (floodplain and tundra meadows). With different positions in the relief certain types of vegetation are associated, so to the wet tundra (wet central parts of polygons, negative forms of relief) relate: *Drepanocladus revolvens, Meesia triquetra, Rhizomniumpunctatum, Calliergongiganteum, Carexchordorrhiza, Comarum palustre, Pedicularis sudetica*. Dry tundra (well-drained locations) is covered by: *Hylocomium splendens, Dryas punctata, Peltigera, Polygonumviviparum, Saxifragapunctata, Astragalusfrigidus, Luzulatundricola, Lagotisglauca, Saxifragahirculus, Valeriana capitata*. Floodplain meadows: *Salix glauca/reptans/lanata, Equisetum sp., Alopecurus alpinus, Festuca rubra, Deschampsia borealis*. Flooded sites of small lakes – *Arctophila fulva* (Boike et al. 2013, Kutzbach et al. 2004, Schneider et al. 2009).

The Lena Delta can be divided in three different geomorphic terraces with an active seasonal flooded level. The active seasonal flooded level is the first terrace (1-12 m) this is the youngest part of the river delta. The first terrace was formed during the Middle Holocene and is mainly represented in the eastern part of the Lena Delta. The second terrace (12-30 m) formed in the interval between the late Pleistocene and the early Holocene and it includes about 23% of the delta area and is characterized by sand fractions containing and a small amount of ice. The polygonal relief is less pronounced, the most typical feature for this area is a large number of thermokarst lakes. The third terrace (30-60 m) is the oldest terrace in the Lena Delta. It does not belong to a river delta block, it is an erosion residue of the late Pleistocene, consisting of a fine-grained, containing organic matter, ice-covered material that accumulated in front of the Chekanovsky and Kharulakh mountain ridges. The surface of the third terrace is characterized by a polygonal terrain, due to the formation of ice veins and a network of permafrost tundra polygons, with developed thermokarst processes (Bolshiyanov et al. 2013, Schwamborn et al. 2002).

The key areas

The key areas of the study are the islands of the southwestern and central parts of the Lena River Delta. The study sites are located along the Olenek channel on the third terrace and include the islands: Hardang (N 72.46 E 123.56), Ebe-Basin-Sisse (N 72.54 E 123.15), Jan-Gylakh (N 72.30 E 125.16) (Fig. 2). The island of Hardang and Ebe-Basin-Sisse is a sandy-silty stratum up to 25 m. Sands and aleurites are horizontally-layered or wavy-layered, which indicates sedimentation in the basin. The ice component is small and it is present in the form of cement. The island of Jan-Gylakh is composed of quartz fine-grained yellowish-gray sands, stratification is predominantly horizontal. Samoilovsky Island (N 72.370 E 126.467), where the Research center "Samoilovsky" is based, is located on the first terrace and periodically submerged by river water. The island covers an area of about 5 km^2. The western part is formed by recent channel reshaping and aeolian processes. Eastern part with ice veins and small thermokarst lakes. The islands consisting of heterogeneous sediments are typical for the Lena Delta, this geological structure indicates a change in the sedimentation both in the lateral vector and in time.

Hardang Island (N 72.46 E 123.56) is located in the western part of the delta, 45 m.a.s.l., on top hill is composed the ice complex, with a moss cover. A specific relief is formed due to erosion from the river side and in the inner parts of the island (along the edges of thermokarst basins and local erosional thermokarst valleys). The ice complex is underlain by horizontally layered quartz sands and siltsoils containing plants residues, there are inclusions of ice veins, in some layers, small pebbles of quartz, jasper, carnelian are accumulated, as a result of aeolian processes of sand destruction (Bolshiyanov et al. 2013).

Ebe-Basin-Sise Island (N 72.54 E 123.15), the western part of the delta, the ice complex is also located on top and underlain by alternately changing layers of sands and silt soils, with plants residues in the form of detritus. The sands are horizontally-layered and wavy-layered, this indicates the accumulation of precipitation in basin (Bolshiyanov et al. 2013).

The island of Jan-Gylakh (N 72.30 E 125.16) is a continuation part of the Kurungnakh Island, separated by a small canal, up to 40 meters high, on top is composed by the ice complex underlain by sands and siltsoils (Bolshiyanov et al. 2013).

Sampling strategy and procedure

The soil samples were taken taking into account the spatial picture of the vegetation cover and the position in the landscape. Samples of soil were selected in various elements of the landforms. Several profiles were made in the areas subject to annual flooding and the places of the already-released conditions. The depth of the soil pits reached 79 cm for Umbric Cryosol (Fluvic, Arenic, Reductaquic) and up to 50 for the other soil types. Soil profile was located in various elements of the landscape. They served: micro depressions, hills, flooded areas, slopes of terraces.

Chemical and physical methods

The dried samples were grounded passed through a 1 mm sieve. Soil samples were selected for each horizon to analyze physical and chemical properties. Analyses were conducted in the certified laboratory of St. Petersburg State University at the Department of Applied Ecology, Russia. Soils were analyzed according to the following methods: determination of actual acidity (pHH_2O), potential acidity CaCl2), by a stationary pH meter in aqueous solution and 1N CaCL2 solution, respectively. The microbiological activity of soils, the basal respiration, using incubation chambers was determined (Kimble & Follett 2001). The humus content estimated based on the ratio Cha/Cfa (Kimble & Follett 2001). To evaluate the volumetric content of carbon in the fine earth we had used data of "dry combustion" (Cco_2). The determination of Cco_2 is based on sample direct combustion and further evaluation of emitted CO_2 by chromatography. During oxidation all the organic carbon turns into carbon dioxide. Further on, in resulting products of combustion utilized from chlorides and other halogens, the measurement of carbon dioxide takes place (Abakumov & Popov 2005). Cco_2 and N content were determined using an element analyzer (Euro EA3028-HT Analyser) with dry combustion procedure.

Humic acids were extracted according to the standard procedure (Schnitzer 1982). Solid-state ^{13}C-NMR spectra of humic acids were measured with a Bruker Avance 500 NMR spectrometer (Karlsruhe, Germany, 2003) in a 4-mm ZrO_2 rotor. The groups of structural fragments were identified by the magnitude of the chemical shift (Chefetz et al. 2002). This is very important since polar soils are characterized by a specific composition of humification precursors. Humic acids were extracted from five soil samples: (1) Cryosol (Oxyaquic, Loamic, Reductaquic); (2) Folic Cryosol (Reductaquic); (3) Umbric Cryosol (Loamic, Reductaquic); (4) Turbic Cryosol (Loamic, Reductaquic); (5) Cryosol (Oxyaquic, Loamic, Reductaquic) (Fig. 6). Samples were taken from the upper soil horizons from Kurungnakh Island, the central part of the Lena River Delta, and from the Stolb Island, remains of the bedrock relief, where the process of humification is most active. All soils belong to the third terrace (ice complex) and are not involved in the annual flooding process. Samples were selected from the upper horizons of soils, where the process of humification is the most intensive.

RESULTS AND DISCUSSION

Soil morphology and diagnostics

Diagnostics of the soils, conducted according WRB has shown that they belong to the following types: Umbric Cryosol (Fluvic, Arenic, Reductaquic), Turbic Cryosol (Loamic, Reductaquic), Folic Cryosol (Reductaquic), Folic Cryosols (Reductaquic, Subaquatic), Umbric Cryosol (Loamic, Reductaquic), Cryosol (Oxyaquic, Loamic, Reductaquic) (Table 2) (World Reference Base for Soil Resources 2014).

The allocation of each type of soil depends on certain conditions of formation: the position in the landscape, remoteness from the floodplain, humidification degree, vegetation, activity of cryogenic processes that produce cryoturbated horizons, frost heave, thermal cracking, ice segregation and patterned ground microrelief.

Soils confined to the delta area develop under the influence of two groups of factors, alluvial and cryogenic processes. The following types of soils develop on recently formed parent material without the introduction of fresh river alluvium: Umbric Cryosol (Loamic, Reductaquic) the soils have recently emerged from the regime of the seasonal flood and are characterized by a one humus horizon, located in the topsoil. The transitional horizon as an separated genetic formation is not expressed (Fig. 2e). Appearance signs of gley processes, related to stagnification on the suprapermafrost layer was pronounced in many of soils investigated on the border with permafrost, the ground water is high. The soils developed on rocks of alluvial origin of a light texture class. Cryogenic mass transfer is observed. The flora is represented by the same species as in Umbric Cryosol (Fluvic, Arenic, Reductaquic).

The next type of soil developing in the delta of the Lena River is associated with the accumulation of iron and aluminum at the contact border with permafrost, this type is characterized by an reddish color forming under oxidative conditions. Cryosol (Oxyaquic, Loamic, Reductaquic) develop on rocks of light texture class (Fig. 2f). The texture class of the soil is sandy loam, the color is fawn, crumb-like structure, appear red and brown spots. Signs of gleyic and cryogenesis processes develop in the horizons near the permafrost. Flows of humus and cryogenic mass transfer near the permafrost table are observed. The vegetation cover represented by *Drepanocladus revolvens, Meesia triquetra, Rhizomnium punctatum, Calliergon giganteum, Carex chordorrhiza, Comarum palustre, Pedicularis sudetica*.

Another type – Turbic Cryosol (Loamic, Reductaquic): the soils develop on well-drained territories, but there are also signs of gley on contact with permafrost. The soils have a grayish-brown color, the texture class is represented by silty loam, has a crumb-like structure, red spots are present (Fig. 2b). On the contact border with permafrost form on the suprapermafrost horizon a geochemical barrier that serves as a site for accumulation of organic-mineral compounds. Ice cracking, cryoturbation, thixotropy is observed. Flora is represented by the following species: *Hylocomium splendens, Dryas punctata, Polygonum viviparum, Saxifraga punctata, Astragalus frigidus, Luzula tundricola, Lagotis glauca, Saxifraga hirculus, Valeriana capitata*.

Folic Cryosols (Reductaquic, Subaquatic) develop under conditions of over humidification, occupying local meso- and micro-depressions (Fig. 2d). Characterized by the presence of a Folic horizon underlain by the Cryic horizon. The color is dark gray with bluish spots, light – medium loam, crumb-like structure. Patterned ground microrelief, flow of humus and iron along the profile is observed. Flora is identical to the species developing on the Folic Cryosol, mosses predominate.

Folic Cryosol (Reductaquic) develop on the drained positions, characterized by the presence of a surface Folic horizon of

Soil	Horizon	Depth	Soil horizon description	Location, vegetation description, Total vegetation cover (TVC) and individual cover of some plants, inclusions,coordinates, height m.a.s.l.
Umbric Cryosol (Fluvic, arenic, Reductaquic) (a)	Umbric	0-7	7,5 YR 7/3 sandy loam, roots	Samoylov isl., first-terrace, TVC 90%, Salix glauca/reptans/lanata 90%, Equisetum sp. 10%, N 72,37085 E 126,46750, 3 m.a.s.l., Permafrost table from 70 cm, the water table is 63 cm.
	Cryic	7-12	7,5 YR 6/3 loam, roots	
	Umbric	12-22	7,5 YR 8/3 sand, roots	
	Cryic	22-41	7,5YR 6/3 loam, roots	
	Umbric	41-47	7,5 YR 7/4 sand, roots	
	Cryic	47-70	7,5 YR 5/3 loam, wet, rusty spots	
Umbric Cryosol (Fluvic, arenic, Reductaquic) (b)	Umbric	0-17	7,5 YR 7/3 sand	Samoylov isl., first-terrace, TVC 95%, Salix glauca/reptans 70%, Alopecurus alpinus 30%, N 72.37206 E 126.46976, 4 m.a.s.l., Permafrost table from 79 cm, the water table is 65 cm
	Cryic	17-79	7,5 YR 8/3 stratified sand of different sizes, roots	
Turbic Umbric Cryosol (Loamic, Reductaquic) (a)	Umbric	0-14	10 YR 3/2 organic mattr	Kurungnagh isl., third-terrace, TVC 95% Hylocomium splendens 70%, Timmia austriaca 15%, Dryas punctata 8%, Polygonum viviparum 7%, N 72.37550 E 126.24898, 21 m.a.s.l., Permafrost table from 18 cm, the water table is 16 cm
	Cryic	14-18	10 YR 6/1 loam, rusty spots	
Turbic Cryosol (Loamic, Reductaquic) (b)	O	0-7	10 YR 4/3 organic matter	Kurungnagh isl., third-terrace, TVC 90%, Hylocomium splendens 70%, Timmia austriaca 30%, N 72.47421 E 126.23158, 60 m.a.s.l., Permafrost table from 35 cm, the water table is 34 cm
	Cryic(1)	7-16	7,5 YR 4/3 sandy loam roots	
	Cryic(2)	16-27	10YR 6/3 loam, oxidized	
	Cryic(3)	27-35	10YR 6/1 loam, oxidized	
Folic Cryosol (a)	Folic	0-18	10YR 3/2 organic matter	Hardang isl., third-terrace, TVC 100%, Hylocomium splendens 70%, Timmia austriaca 15%, Climacium dendroides 15%, N 72 46,637 E 123 56,946, 23 m.a.s.l., Permafrost table from 18 cm, the water table is 17 cm
Folic Cryosol (Reductaquic) (b)	Foilic	0-8	10YR 4/3 organic matter	Kurungnagh isl., third-terrace, TVC 100%, Hylocomium splendens 70%, Timmia austriaca 30%, N 72.47643 E 126.27939, 66 m.a.s.l., Permafrost table from 20 cm, the water table is 19 cm
	Cryic	8-20	10YR 3/2 oxidized	
Folic Cryosols (Reductaquic, Subaquatic) (a)	O	0-7	10 YR 4/3 organic matter	Kurungnagh isl, third-terrace, TVC 100%, Hylocomium splendens 70%, Timmia austriaca 30%, N 72,32508 E 126,26555, 56 m.a.s.l., Permafrost table from 25 cm, the water table is 23 cm
	Folic	7-20	7,5 YR 6/3 loam, roots	
	Cryic	20-25	Gley 2 6/10BG loam, rusty spots	
Folic Cryosols (Reductaquic, Subaquatic) (b)	Folic	0-5	10YR 4/3 organic matter	Kurungnagh isl, third-terrace, TVC 100%, Hylocomium splendens 70%, Timmia austriaca 30%, N 72.35526 E 126.21431, 43 m.a.s.l., Permafrost table from 30 cm, the water table is 25 cm
	Cryic	5-30	Gley 2 5/10BG loam, rusty spots	
Umbric Cryosol (Loamic, Reductaquic) (a)	O	0-7	10YR 4/3 organic matter	Hardang isl., third-terrace, TVC 76%, Salix glauca/reptans/lanata 80%, Festuca rubra 10%, Deschampsia borealis 10%, N 72 46.530 E 123 46.874, 10 m.a.s.l., Permafrost table from 60 cm, the water table is 55 cm
	Umbric	7-30	7,5 YR 7/3 sandy loam, roots	
	Cryic	30-60	7,5 YR 6/1 sandy loam, rusty spots	
Umbric Cryosol (Loamic, Reductaquic) (b)	Umbric	0-6	7,5 YR 7/1 sand	Kurungnagh isl., third-terrace, TVC 75% Salix glauca/reptans/lanata 70%, Alopecurus alpinus 15%, Festuca rubra 15%, N 72.34949 E 125.94101, 30 m.a.s.l., Permafrost table from 55 cm, the water table is 53 cm
	Cryic	6-55	7,5 YR 4/1 loam, rusty spots	
Cryosol (Oxyaquic, Loamic, Reductaquic) (a)	Cryic(1)	0-15	7,5YR 7/3 sandy loam, roots	Jan-Gylach isl., third-terrace, TVC 70%, Drepanocladus revolvens 70% , Meesia triquetra 15%, Rhizomnium punctatum 15%, N 72 30.831 E 125 16.474, 25 m.a.s.l., Permafrost table from 60 cm, the water table is 57 cm
	Cryic(2)	15-28	7,5YR 6/4 rusty streaks	
	Cryic(3)	28-60	10YR 6/3 loam, rusty spots	
Cryosol (Oxyaquic, Loamic, Reductaquic) (b)	Cryic(1)	0-18	7,5 YR 7/3 sandy loam, roots	Kurungnagh isl., third-terrace, TVC 73%, Drepanocladus revolvens 60%, Carex chordorrhiza 20%, Comarum palustre 15%, Pedicularis sudetica 5%, N 72.35070 E 125.95138, 19 m.a.s.l., Permafrost table from 35 cm, the water table is 33 cm
	Cryic(2)	18-35	7,5YR 4/3 loam, rusty spots	

Tab. 2: Locations where soil and vegetation samples were collected, Samoylov isl., Kurungnagh isl., Hardang isl., Jan-Gylach isl.
Tab. 2: Standorte, an denen Boden- und Vegetationsproben entnommen wurden: Samoylov-Insel, Kurungnagh-Insel, Hardang-Insel, Jan-Gylach-Insel

Fig. 2: Morphological diversity of soils in the Lena River Delta: A- Umbric Cryosol (Fluvic, Arenic, Reductaquic), B- Turbic Cryosol (Loamic, Reductaquic), C- Folic Cryosol (Reductaquic), D- Folic Cryosols (Reductaquic, Subaquatic), E- Umbric Cryosol (Loamic, Reductaquic), F- Cryosol (Oxyaquic, Loamic, Reductaquic).

Abb. 2: Morphologische Diversität der Böden im Lena-Delta: A- Umbric Cryosol (Fluvic, Arenic, Reductaquic), B- Turbic Cryosol (Loamic, Reductaquic), C- Folic Cryosol (Reductaquic), D- Folic Cryosols (Reductaquic, Subaquatic), E- Umbric Cryosol (Loamic, Reductaquic), F- Cryosol (Oxyaquic, Loamic, Reductaquic).

different composition, which is underlain by permafrost-affected soils (Fig. 2c). In the soils occur the processes of organic formation and organic accumulation. A color is dark gray, the profile contains organic remains of varying degrees of decomposition, appear signs of gleying on the contact border with permafrost. Thermal cracking is observed. Flora is represented by typical tundra species and is identical to the species of Turbic Cryosol (Loamic, Reductaquic)s, with the exception, here the mosses occupy the most percentage of cover.

The soils of the Lena River Delta develop under the influence of several processes: the alluvial and zonal processes of soil formation (peat formation, gleying and cryogenesis). Therefore, the soil diversity of the Lena River Delta is represented by the following types: Umbric Cryosol (Fluvic, Arenic) – the youngest soils of the delta, develop under the conditions of the alluvial process, the constant resedimentation of fresh river alluvium and prolonged flooding during the high water period. Umbric Cryosol (Loamic, Reductaquic) – not so far away came out from under the influence of alluvial and seasonal flooding processes. Characterized by a single humus-accumulative horizon as a result of the alluvial accumulation of material. Cryosol (Oxyaquic, Loamic, Reductaquic) are characterized by the presence of organic-mineral complexes with ferrum and aluminum in the middle horizon, and their migration within the soil profile. Turbic Cryosol (Loamic, Reductaquic) are associated with actively implemented cryogenic processes, spots formation, cryogenic mass change, thixotropy, solifluction, thermokarst. These soils are zonal in the Arctic subzone and are formed in the river delta on the third terrace. Folic Cryosol (Reductaquic) are characterized by the accumulation of organic remains in the profile and its appearing in permafrost, these soils are also zonal. Folic Cryosols (Reductaquic, Subaquatic) are characterized by the gley horizon on contact with permafrost. Soils are the oldest in the Lena River Delta and develop on the top of the third terraces.

Umbric Cryosol (Fluvic, Arenic, Reductaquic) develop on the areas that annually are flooded and characterized by the alluvial accumulation of the material, mostly stratified (horizontal and wavy-horizontal) (Fig. 2a). The layers differ in color, the texture class, and structure that is associated with the power of the water flow, the faster the water flow, the large particles (sand) deposit, small particles (dust and silt) deposit when the flow is slow. The texture class is sandy-loam, color from dark gray to gray, non-structure, borders horizontal, wavy-horizontal. Also, the soil's chemical properties vary within the profile (which is up to 79 cm); organic carbon is redistributed in the soil, has a powerful profile up to 79 cm, signs of gleyic stagnification appear on contact border with permafrost (permafrost affected soils). This type of soil is the youngest formation in the delta. The vegetation cover is characterized by the following species: *Salix glauca/reptans/lanata, Equisetum sp., Alopecurus alpinus, Festuca rubra, Deschampsia borealis*.

Soil chemical characteristics

The soils of the Lena River Delta are characterized by acidic (4.5-5.5), slightly acidic (5.5-6.5) and neutral (6.5-7) and slightly alkaline (7-7.5) conditions. Neutral and slightly acidic conditions are related to the presence of carbonates in the middle and in the lower river flow that are transported here along with the sedimentary matter fluxes (Cauwet & Sidorov 1996). The acidic reaction is confined to the humus horizons and the layer on the border with the permafrost, where a geochemical barrier arises. A slightly alkaline reaction arises because of the proximity of the sea, the process of impulverization (brought by wind into the phytocenosis of sputtered mineral and organic substances) and the transfer of salts from the sea to the flooded areas of the soil occurs.

Depending on the landscape, and geochemical state of the pedoenvironment the soils differ from each other by pH range. Thus, for soils forming in the area of the first, flooded terrace, are characterized by the inflow of saline waters from the sea and alkalization. The soils that are no longer involved in the alluvial and seasonal flooding processes are acidic inside the profile and slight alkalization on the surface that is associated with the process of pulverization.

The soils is an important natural reservoir and the most significant source of biogenic carbon in terrestrial ecosystems Soils usually play an important role in stabilization of carbon and this feature is known as most pronounced in soils of cryolithozone. Soil CO_2 emission (soil respiration) includes the processes of microbiological decomposition of organic substances and autotrophic respiration of the roots. The emission of carbon dioxide is a summary (generalizing) indicator of the biological activity of soils. The rate of carbon dioxide production by soil – basal (microbial) respiration is one of the important indicators of the state of microbiocenoses of soils (Table 3).

The rate of the emission of carbon dioxide is related to the amount of available biogenic elements and to soil microclimate of the soil (Ivashchenko et al. 2014, Knoblauch et al. 2015, Ananyeva et al. 2011). The most active emission is observed in the upper horizons of the soil, where a large number of biological processes occur, related to the vital activity of organisms. Folic Cryosol (Reductaquic) have maximum emission values (up to 143 mg CO_2/100 g × day^{-1}). This is due to the fact that this type of soils has come out of the cycle of annual flooding in the period of high water; favorable hydrological conditions were formed on the sites in the well-drained positions; the peat layer retains heat and, under conditions of a short growing season, is able to maintain the activity of microorganisms until the freezing of soils begins. The intensity of microbiological activity in peat soils decreased downward along the soil profile, reaching 69 mg CO_2/100 g × day^{-1} at the boundary with permafrost. Flooding processes (fluvial and alluvial processes, etc.) are active in most of the delta's soils (the first terrace), while the second and third terraces are prone to zonal soil formation (peat formation and peat accumulation). The soils of the first terrace are confined to "floodplain meadows". The microbiological activity of such soils is much less (70-80 mg CO_2/100 g × day^{-1}), there Umbric Cryosol (Fluvic, Arenic, Reductaquic) are formed. The maximum emission was observed in the root zone at a depth of about 12-22 cm, after 22 cm a decrease in microbiological activity was observed.

Thus, microbiological activity is closely related to the site location, its microclimate, also the type of organic remains that accumulate in the soil (Rogovaya et al. 2016). On the territories associated with the areas where peat formation and peat accumulation occur, favorable conditions for microbial biomass was formed, which resulted in a high carbon dioxide emission rate. On the sites belonging to the areas where seasonal flooding occur, there was a decreased activity, indicating that the flooding processes have a negative effect on the vital activity of microorganisms (Hoffmann et al. 2017, Görres et al. 2014, Schneider et al. 2012, Gavrilenko et al. 2011).

The type of humus content allows to evaluate the degree of organic matter stabilization with special reference to environmental conditions. The fulvate type (HA/FA is <0,5) is characterized by the predominance of fulvic acids in the soil and the migration of organic-mineral complexes along the profile. The humate-fulvate type is also characterized by the predominance of fulvic acids (the ratio of HA/FA is 0.5-1), in soils with this type of humus content, the migration of substances to a greater extent occurs than its accumulation. The fulvate-humate type is characterized by the predominance of humic acids (the ratio HA/FA is 1-2), accumulation and fixation of organic-mineral complexes in the profile and its insignificant migration take place. The humate type is characterized by a high predominance of humic acids (HA/FA > 2) there is accumulation and fixation of organic-mineral complexes in the profile (Orlov 1985, Kimble & Follett 2001).

The type of humus content was determined in five samples from five profiles from three islands. Umbric Cryosol (Fluvic, Arenic, Reductaquic) are characterized by the humate-fulvate type. The migration of matter along the soil profile and fixing on the border with permafrost occurs, also organic-mineral compounds through groundwater release into the river basin. Umbric Cryosol (Loamic, Reductaquic) refer to a fulvate-humate type, humic acids predominate over fulvic acids, accumulation of organic-mineral compounds occurs in soil profiles. Cryosol (Oxyaquic, Loamic, Reductaquic) belong to the fulvate-humate type. The formation of organic-mineral

Horizon	Depth, cm	pH_{H2O}	pH_{CaCl2}	BR, $mgCO_2/100g \times day^{-1}$	C_{CO_2}, g/kg	N, g/kg	C/N	Particle-size classes		
								sand	silt	clay
Umbric Cryosol (Fluvic, Arenic, Reductaquic)										
Umbric	0-7	6,71	5,76	62,9	5,4±0,3	0,6±0,03	8,81	92	1	7
Cryic	7-12	7,18	6,38	62,9	18,1±0,9	1,4±0,07	12,7	66	2	33
Umbric	12-22	7,08	6,13	77	1,9±0,1	0,4±0,02	4,67	91	3	6
Cryic	22-41	7,2	6,75	44	17±0,9	1,4±0,07	12,4	90	1	10
Umbric	41-47	5,33	4,35	44	1,7±0,1	0,4±0,02	4,69	83	1	17
Cryic	47-70	5,95	5,7	38,5	29,4±1,5	2,2±0,11	13,1	52	1	47
Umbric Cryosol (Loamic, Reductaquic)										
O	0-7	6,21	5,33	49,5	16±0,8	1,1±0,06	14	-	-	-
Umbric	7-30	6,95	6,05	38,5	9,3±0,5	0,8±0,04	11	94	1	6
Cryic	30-60	6,83	5,67	31,4	3,3±0,2	0,5±0,02	7,22	96	1	4
Cryosol (Oxyaquic, Loamic, Reductaquic)										
Cryic(1)	0-15	6,9	6,25	69,1	5,4±0,3	0,6±0,03	8,81	79	1	20
Cryic(2)	15-28	7,65	6,53	60,5	18,1±0,9	1,4±0,07	12,7	90	1	10
Cryic(3)	28-60	7,17	6,08	44	14±0,7	1,2±0,06	4,67	82	1	17
Turbic Cryosol (Loamic, Reductaquic)										
O	0-7	5,1	4,2	132	32,2±1,6	1,8±0,09	17,7	-	-	-
Cryic(1)	7-16	6,61	5,53	81,7	26,2±1,3	1,9±0,1	13,6	83	1	16
Cryic(2)	16-27	6	4,53	49,5	29,5±1,5	2,3±0,12	12,6	66	6	29
Cryic(3)	27-35	6,53	4,48	22	22,4±1,1	1,3±0,07	17,1	66	1	34
Folic Cryosol (Reductaquic)										
Foilic	0-8	5,94	4,6	143	9±0,5	0,8±0,04	11,2	-	-	-
Cryic	8-20	5,46	4,37	69,1	10±0,5	0,9±0,04	11,2	86	2	12
Folic Cryosols (Reductaquic, Subaquatic)										
O	0-7	7,56	6,68	132	49,6±2,5	2,2±0,11	22,2	-	-	-
Folic	7-20	6,14	5,01	69,1	44,7±2,2	3,7±0,18	12,2	64	1	36
Cryic	20-25	5,76	3,79	25,1	24,7±1,2	1,5±0,08	16,4	40	2	59

Tab. 3: Chemical characteristics of different types of soils from Lena River Delta. Where BR - soil basal respiration (mg CO_2/100 g × day^{-1}), C_{CO_2} – carbon content, g/kg with SD.

Tab. 3: Chemische Eigenschaften unterschiedlicher Bodentypen des Lena-Deltas: BR – basale Bodenatmung (mg CO_2/100 g × Tag^{-1}); C_{CO_2} – Kohlenstoffgehalt mit SD, g/kg.

complexes of ferrum and humus occurs and transfer along the soil profile. Turbic Cryosol (Loamic, Reductaquic), are characterized by the fulvate-humate type, there is the formation of organic-mineral complexes close to the permafrost, with the cryogenic mass exchange, the mineral and organic part of the soil is redistributed along the profile. Folic Cryosol (Reductaquic), the type of the humus content – humate-fulfate, the ratio HA/HA is 1. This indicates that fulvic acids predominate and the substances migrate along the profile. Folic Cryosols (Reductaquic, Subaquatic) refer to a humate-fulvate type, fulvic acids predominate, iron and humus complexes migrate along the profile and accumulate on the contact border with permafrost. The soils of the Lena River Delta are characterized mainly by a fulvate-humate type of humus content (HA/FA is 1-2. This is due to the accumulation of humic acids in the soils and the formation of organic-mineral complexes of ferrum and humus, and also its low migration ability (Fig. 3). According to the type of humus content, the soils of the delta are referred to the humate-fulvate and fulvate-humate types, which were also observed in former studies (Zolotareva et al. 2009a, Zolotareva et al. 2009b, Dobrovolsky 2011, Okoneshnikova 2016, Desyatkin et al. 2011, Targulian 1971, Shishkin et al. 2001, Dymov et al. 2013, Vodyantsky 2008).

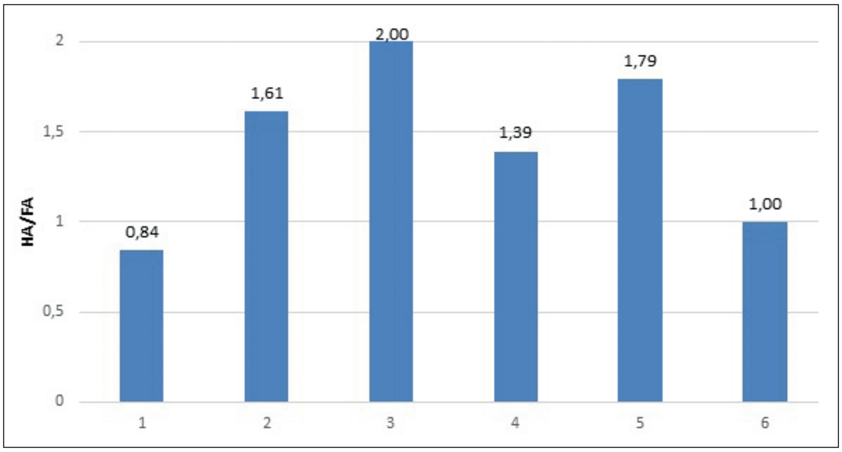


Fig. 3: Humus condition of soils (1 - Folic Cryosols (Reductaquic, Subaquatic); 2 - Umbric Cryosol (Loamic, Reductaquic); 3 - Umbric Cryosol (Fluvic, Arenic, Reductaquic); 4 - Cryosol (Oxyaquic, Loamic, Reductaquic); 5 - Turbic Cryosol (Loamic, Reductaquic); 6 - Folic Cryosol (Reductaquic).

Abb. 3: Humus-Bedingungen/Zustand der Böden (1 - Folic Cryosols (Reductaquic, Subaquatic); 2 - Umbric Cryosol (Loamic, Reductaquic); 3 - C; 4 - Cryosol (Oxyaquic, Loamic, Reductaquic); 5 - Turbic Cryosol (Loamic, Reductaquic); 6 - Folic Cryosol (Reductaquic).

Soil organic carbon

Soils of the Lena River Delta have a large storage of organic carbon in Umbric and Folic horizons. Accumulation of humus occurs in the upper layers of the soil and on the border with permafrost, due to humus transportation activity and the formation of geochemical barrier close to permafrost. Based on the obtained results, it is possible to reveal the dependence of the distribution and fixation of humus in the soil. Umbric Cryosol (Fluvic, Arenic, Reductaquic) are associated with stratification and low humus content along the profile, which indicates a low biological activity.

The stocks of organic carbon in the soils of the Lena River Delta were estimated. Thus, the soils formed in the zone of the seasonal flooding in the period of high water are characterized by the highest value of the organic matter, up to 17 kg/m^2. With floodwaters, a large amount of organic matter enter the soil and, under conditions of low biological activity, are able to accumulate in the soil. In Umbric Cryosol (Loamic, Reductaquic) organic remains are – 5 kg/m^2. Soils recently came out from the seasonal flooding regime have high stocks of accumulated organic material. Lower stocks of humus as the previous soils, 0.9 kg/m^2 characterize Folic Cryosol (Reductaquic). For Folic Cryosols (Reductaquic, Subaquatic) stock is 4.5 kg/m^2 . These soils are zonal in the delta, humus accumulation takes place mainly on the border with permafrost. Turbic Cryosol (Loamic, Reductaquic) and Folic Cryosol (Reductaquic) have 5.8 kg/m^2. Many studies are devoted to carbon stocks and organic carbon content in Arctic soils. The data we obtained now fully correlate to the data reported by others. Soils are characterized by increase to 24 % organic carbon content and up to 29 kg/m^2 of carbon stocks (Zubrzycki et al. 2013).

As can be seen from the Fig. 4, the largest stocks of humus occurs in the soils related to flooded areas. Smaller stocks of humus characterize soils related to the post-lithogenic group, which due to a close occurrence of permafrost with buried organic remains within. Depending on the natural zone, the carbon stock will differ. Soils of the Samarskaya Luka National Park have been investigated by other researchers, it is a part of the forest-steppe zone, Cambisols, Chernozems, Phaeozems and Podzols develop here (Abakumov et al. 2010). The humus reserve was estimated in the range from 13 to 41 kg/m^2. According to the author‘s data, the humus stocks depend on the exposition of the slope, vegetation cover, and fine soil content. The greatest stocks in Chernozems were observed.

Analytical results permit the determination of carbon stocks within each horizon:

$$SOC = \varrho \times Coc \times H \times 0.1 \qquad (1)$$

Where, SOC – soil organic carbon (kg/m^2); ϱ-horizon density; Coc – organic carbon content (%); 0,1 – conversion factor; H – depth.

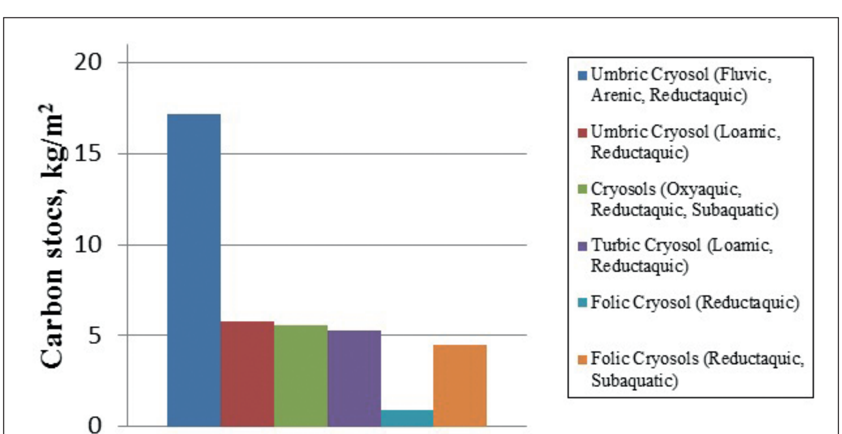


Fig. 4: Carbon stocks in different type of soils of Lena River Delta.

Fig. 4: Kohlenstoffgehalte verschiedener Bodentypen des Lena-Deltas.

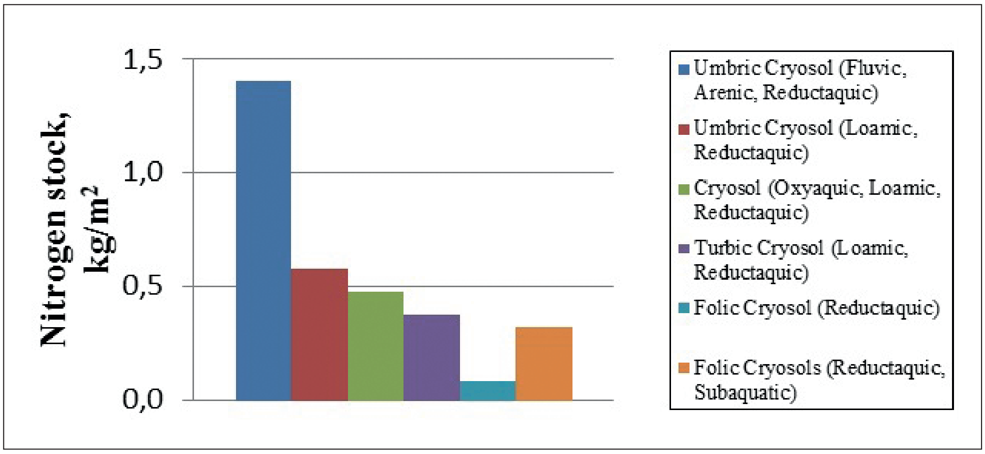


Fig. 5: Nitrogen stocks in different type of soils of Lena River Delta.

Abb. 5: Stickstoffgehalte in verschiedenen Bodentypen des Lena-Deltas.

We compared carbon stocks in various soils under the influence of permafrost-affected soils. According to the data by Nesterova from the Bie-Chumyshskaya plain (the right bank of the Ob) and the Priobskoe plateau (the left bank of the Ob), the humus stocks in the forest-steppe averages 55 kg/m² (NESTEROVA et al. 2004). The maximum of humus stock refers to a depth of 0 to 50 cm, which is due to the root layer and not intensive biological activity, which is related to the freezing of the soil in winter and the drying in the summer. These data indicate that the maximum carbon content is for the upper soil horizons, where the root system of plants is located and the biological decomposition processes take place.

We compared our soils with the volcanic soils of Kamchatka, according to the data by KISELEVA et al. (2016). The soils are represented by Aluandic Andosols, Folic Fluvisols and Silandic Andosols. The humus stocks are estimated at 29 kg/m² in Aluandic Andosols, 5.9 for Folic Fluvisols and 7.7 for Silandic Andosols. Such a distribution of quantities is associated with the vegetation cover of Kamchatka. These soils have similar estimates of carbon stocks with those obtained by us. This may be due to low biological activity in volcanic soils, as well as a high content of ash elements.

The carbon stocks of the Lena River Delta were compared with the soils of Central Yakutia; the reserve of humus here in the virgin lands reaches 20 kg/m² on Fluvisols, they are included in the group with a very high humus stock values (0-20 cm) (OKONESHNIKOVA 2004). Folic Fluvisols are characterized by stocks of 12 kg/m², and it was noted that during agricultural work the humus reserve decreases to 9 kg/m². Annually flooded permafrost soils of Yakutia have a higher indicator of humus content. These results confirm that annual flood processes contribute to an increase in the carbon content in the soil. These soils have favorable physic and chemical parameters (pH, texture class, etc.), contributing to the deposition of carbon in the soil.

Thus, according to the dynamics of the distribution of humus content among various natural zones, maximum values are observed in the zone of steppes and forest-steppe. Alluvial soils also have a high humus reserve due to the high amount of biogenic matter from the river alluvium. In general, the soils of the permafrost zone are characterized by humus stocks of 10-40 kg/m².

Nitrogen stocks

The nitrogen stocks in the investigated soils were estimated (Fig. 5). The nitrogen content in the soil varies from 0.3 kg/m² and up to 1.4 kg/m² for Umbric Cryosol (Fluvic, Arenic, Reductaquic). In general, nitrogen reserves are similar to soils in the northern part of the circumpolar Urals from 0.45 to 2.4 kg/m² (DYMOV et al. 2013). The maximum values are observed in Umbric Cryosol (Fluvic, Arenic, Reductaquic), this is possibly associated with the more rich nitrogen components of plant litter. For Umbric Cryosol (Loamic, Reductaquic), which are characterized by a physico-chemical and morphological properties of a nitrogen reserve – 0.5 kg/m². The floral composition here is similar to the composition on Umbric Cryosol (Fluvic, Arenic, Reductaquic), but in Umbric Cryosol (Loamic, Reductaquic) the prevalence of flowering plants is much lower and moss litter is formed, which in the soils of Umbric Cryosol (Fluvic, Arenic, Reductaquic) is practically not formed due to the long process of fertility. Nitrogen reserves were also studied earlier in the soils of Samoilovsky Island (ZUBRZYCKI et al. 2013), the reserve was determined in the amount from 0.41 kg/m² to 1.94 kg/m². The results are very similar to those obtained, with one exception, the maximum values for Zubrzycki were obtained in the region of Holocene sediments, the second terrace, and not the first one being flooded. He explains this definition by the fact that a large amount of nitrogen is stored in permafrost rocks of the Lena River Delta.

Nitrogen stocks in the soils of the Northern Caspian (Volgograd Region, Russia) (KULAKOVA 2014) were studied. Areas of work have become a steppe ecosystem and forest. For the steppe ecosystem, an average of 1.112 kg/m² is typical, for the forest ecosystem the average nitrogen reserve is 1.245 kg/m². This is due to the fact that in forest ecosystems consisting of broad-leaved trees the plant litter is more rich in nitrogen than the grass and shrub flora in the steppe ecosystem.

Thus, according to the dynamics of nitrogen stocks in various natural zones, a maximum is observed in zones of permafrost-affected soils. According to DYMOV et al. (2013), up to 2.4 kg/m² is stored in the soils of the circumpolar Urals. High levels of nitrogen reserves largely depend on the floristic composition of the ecosystem and microbiological activities. Analytical results permit the determination of nitrogen stocks within each horizon:

$$N = \varrho \times Nc \times H \times 0.1 \quad (2)$$

Where, N - nitrogen stocks (kg/m^2); ϱ-horizon density; Nc-nitrogen content (%); 0,1 - conversion factor; H - depth.

Texture class of soils

The investigated soils are divided into four categories: sand, loamy sand, sandy loam, silt loam. As can be seen from the figure, most of the treated samples belong to the category of sand. This suggests that a large amount of alluvium is deposited in the delta. This fact indicates a high flow rate, as a result of which large particles settle. The increase of silt fraction is due to the fact that, with a small change in the river bed and the flow rate, smaller particles settle, and the silt particles fall out in a very small amount. Sand is represented in soils developing in areas of floodplain meadows. On the third terrace, the soil develops with loamy sand, sandy loam and silty loam, which is associated mostly with the formation of the parent material.

Thus, the soils of the Lena River Delta are characterized by a clear variety of conditions. Floodplain meadows are represented by stratified soil with various hydrophysical properties. Here, the horizons rotate with the texture class of loamy sand and silty loam, and the amount of soil organic carbon in organic horizon is different from each other.
High aeration and light texture class prevent the formation of thermokarst lakes, as a result of which well-drained positions are formed on which the formation of soils takes place. This is primarily due to the fact that the islands were formed in a short time, because the settling of large sand particles occurs in a fast flow of water, and clay and silt particles – at a low flow rate.

Elemental Composition of humic acids

In general terms, elemental composition of the HAs is comparable with previously reported data for soils of polar environments (Abakumov 2017, Lupachev et al 2017, Ejyrque & Abakumov 2016, Abakumov et al. 2015). Characteristic features of HAs formed in cold conditions, and especially in soils exposed to permafrost, are a relatively high H content and a reduced O content compared to boreal and sub boreal soils (Lupachev et al. 2017). According to the obtained data (Table 4), the Turbic Cryosol (Loamic, Reductaquic) sample is characterized by active cryogenic processes (thermal cracking, ice segregation, cryogenic mass transfer). That is reflected in the elemental composition, the high index of H and the low value of O. Whereas the soils are formed in conditions of weak cryogenic processes characterized by higher N and O. Such a distribution may indicate active humus formation in condition of low degree of cryogenic processes in soils.

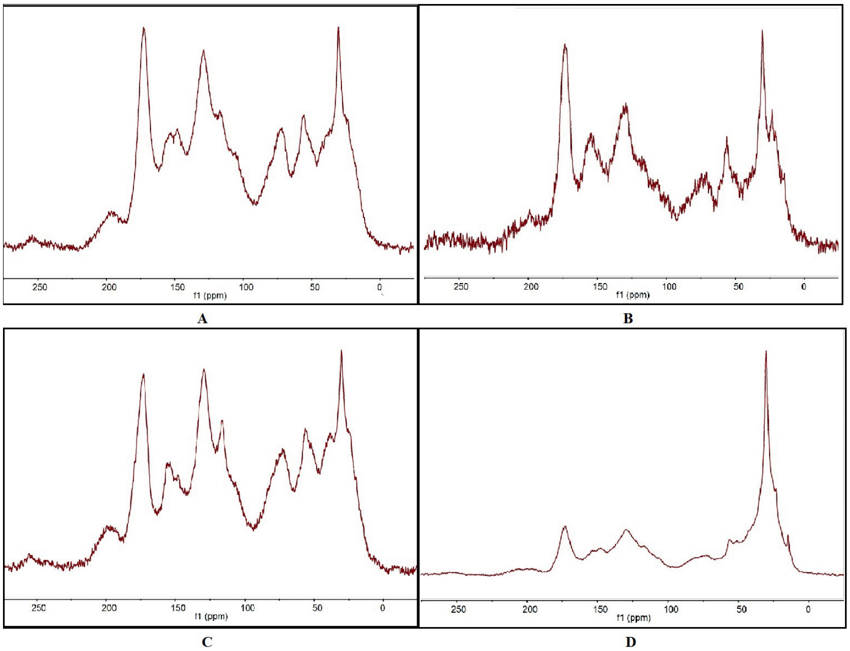
Characterisation of humic acids by ^{13}C-NMR spectroscopy

The composition of HAs is one of the most important properties, which is used as an indicator of the humification, of oxidation of humic acids and for an indirect assessment of the degree of its condensation (Lodygin & Beznosikov 2010, Lodygin et al. 2014). The greatest number of signals is obtained in the range of 110-144 ppm, which refer to the aromatic group that is characterized by high content of unsubstituted or alkyl-substituted aromatic carbon atoms. The presence of a high content of aromatic group for arctic soils is uncharacteristic that is associated with a low level of humification and accumulation of organic substances in the soil. An accumulation of alkyl groups occurs, its signals are located in the range 0-47 ppm, that is typical for the Turbic Cryosol (Loamic, Reductaquic) sample (Fig. 6 D). Most likely it is due to the low permafrost depth in the soil and the high degree of the cryogenic processes, accompanied by solifluction, and thixotropy. The other soils are characterized by the predominance of aromatic compounds including -OH, $-NH_2$, and $-OCH_3$ (144-164 ppm) groups, structural blocks of lignin and for oxygen compensated atoms of aromatic rings (syringyl and guaiacyl propane units) (147-149 ppm). Atoms of carboxyl fragments, polypeptides, and carbonyl-amides (164-183 ppm) and atoms of quinone fragments and the carbonyl groups of

Sample	N, %	C, %	H, %	O, %	C/N	H/C	O/C
Cryosol (Oxyaquic, Loamic, Reductaquic)	3,43	50,13	4,85	36,60	14,64	0,10	0,73
Folic Cryosol (Reductaquic)	3,52	42,83	4,55	44,11	12,17	0,11	1,03
Umbric Cryosol (Loamic, Reductaquic)	3,13	42,94	4,88	44,06	13,72	0,11	1,03
Turbic Cryosol (Loamic, Reductaquic)	2,95	53,39	6,14	32,53	18,13	0,12	0,61
Cryosol (Oxyaquic, Loamic, Reductaquic)	3,44	44,59	4,84	42,15	12,98	0,11	0,95

Tab. 4: Elemental composition (%) and atomic ratios in HAs. 1- Cryosol (Oxyaquic, Loamic, Reductaquic); 2- Folic Cryosol (Reductaquic); 3- Umbric Cryosol (Loamic, Reductaquic); 4- Turbic Cryosol (Loamic, Reductaquic); 5- Cryosol (Oxyaquic, Loamic, Reductaquic). Samples were taken from the upper horizons of the soil.

Tab. 4: Elementzusammensetzung (%) und ihre atomaren Verhältnisse in den Huminsäuren.



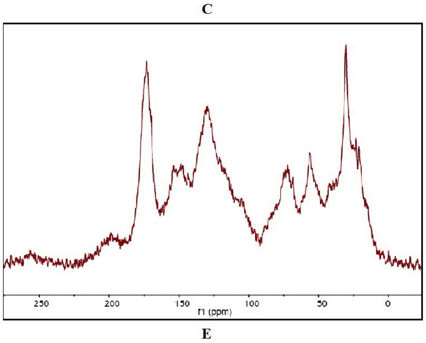


Fig. 6: CPMAS ^{13}C-NMR spectra of soils from the Lena River Delta (1- Cryosol (Oxyaquic, Loamic, Reductaquic); 2- Folic Cryosol (Reductaquic); 3- Umbric Cryosol (Loamic, Reductaquic); 4- Turbic Cryosol (Loamic, Reductaquic); 5- Cryosol (Oxyaquic, Loamic, Reductaquic)). X axes – chemical shift, ppm, vertical scale – relative intensity of individual signals.

Fig. 6: CPMAS ^{13}C-NMR-Spektra der Böden des Lena-Deltas (1- Cryosol (Oxyaquic, Loamic, Reductaquic); 2- Folic Cryosol (Reductaquic); 3- Umbric Cryosol (Loamic, Reductaquic); 4- Turbic Cryosol (Loamic, Reductaquic); 5- Cryosol (Oxyaquic, Loamic, Reductaquic); X-Achse – chemische Veränderung (ppm), Y-Achse – relative Intensität der individuellen Signale.

ketones and aldehydes (183-190 ppm) (Table 5). The values obtained apparently indicate the high level of humification in the soils with a low level of development of cryogenic processes. Data obtained is in controversy with data obtained by Lupachev for Kolyma Lowlands and Ejarques for Yamal region. In these works, it was shown a prevalence of aliphatic carbon on aromatic ones and this was related to increased hyrdomorphism of soils with features of stagnification and gleyfication. Soils of Lena Delta seems to be more aerated and this result in increasing of humification rate with simultaneous decreasing of aliphatic part.

Sample	Chemical shifts. ppm							Aromatic groups. %	Aliphatic groups. %
	0-47	47-60	60-110	110-144	144-164	164-183	183-190		
	Alkyl	O, N-Alkyl		Aromatic		Carboxyl, ester, amide	Quinone		
1	21	8	20	23	11	12	5	51	49
2	24	7	17	23	13	15	1	52	48
3	23	9	21	24	9	13	1	47	53
4	45	7	12	20	7	9	0	36	64
5	23	9	18	24	11	14	1	50	50

Tab. 5: Percentage of carbon in the main structural fragments of soils of the Lena River Delta (according to ^{13}C-NMR data). 1- Cryosol (Oxyaquic, Loamic, Reductaquic); 2- Folic Cryosol (Reductaquic); 3- Umbric Cryosol (Loamic, Reductaquic); 4- Turbic Cryosol (Loamic, Reductaquic); 5- Cryosol (Oxyaquic, Loamic, Reductaquic). Samples were taken from the upper horizons of the soil.

Tab. 5: Prozentualer Anteil des Kohlenstoffs an den Hauptstrukturfragmenten der Böden des Lena-Deltas (gemäß ^{13}C-NMR-Daten) 1- Cryosol (Oxyaquic, Loamic, Reductaquic); 2- Folic Cryosol (Reductaquic); 3- Umbric Cryosol (Loamic, Reductaquic); 4- Turbic Cryosol (Loamic, Reductaquic); 5- Cryosol (Oxyaquic, Loamic, Reductaquic)

CONCLUSIONS

(1) Soil diversity of the Lena River Delta is presented by six main types: Turbic Cryosol (Loamic, Reductaquic), Folic Cryosol (Reductaquic), Folic Cryosols (Reductaquic, Subaquatic), Umbric Cryosol (Loamic, Reductaquic), Cryosol (Oxyaquic, Loamic, Reductaquic) and Umbric Cryosol (Fluvic, Arenic, Reductaquic) develop in the areas annually flooded in the periods of high water, are characterized accumulation of material by the river. Other types of soil develop on recently formed parent materials without the influence of current alluviation activity introduction of fresh river alluvium. Umbric Cryosol (Loamic, Reductaquic) have recently emerged from the regime of the seasonal flood and are characterized by a single humus horizon. The medium horizon as an independent genetic formation is absent. The next type of soils developing in the Lena River Delta is associated with the accumulation of iron and aluminum at the contact border with permafrost, this type characterized by an ocher color forming under oxidative conditions. Cryosol (Oxyaquic, Loamic, Reductaquic) develop on rocks of the sandy texture, Folic Cryosols (Reductaquic, Subaquatic) develop under conditions of overmoisting, occupying local meso- and micro-depressions. Characterized by the presence of a Folic horizon underlain by the horizon with reductaquic features. Folic Cryosol (Reductaquic) develop on the drained positions, characterized by the presence of a surface Folic horizon of different composition, which is underlain by an organogenic parent materials. Processes of organic formation and accumulation occur in the soils. Turbic Cryosol (Loamic, Reductaquic) develop on relatively well-drained territories, but there are also signs of gleyification on contact with permafrost. The contact border with permafrost forms a geochemical barrier that serves as a site for accumulation of organic-mineral complexes. Due to such factors of soil formation as flooding processes, different time of formation of the first and third terraces, climatic features, the formation of such a number of soil types in the Lena River Delta is possible. A clear dependence of the distribution of soils on their position in the environment and vegetation was revealed. Annual flooding contributes to the transfer of mineral compounds into the soil and the removal of organic matter in the Laptev Sea. Umbric Cryosol (Fluvic, Arenic, Reductaquic) are most susceptible to the removal of organic compounds from the soil, because they participate in the annual flooding and, based on the results we have obtained, have the largest reserve of organic carbon that can be carried to the Arctic Ocean.

(2) The investigated soils, depending on the landform, are characterized by various acidity values. For soils that are no longer involved in the alluvial process, the acidic conditions within the profile and a slight alkalization from the surface are associated with the process of impulverization (brought by wind into the phytocenosis of sputtered mineral and organic substances).

Microbiological activity is effected by the environmental location of the initial site, its microclimate, relief, humidity, the type of organic remains that accumulate in the soil etc. On the territories associated with the areas where peat formation and peat accumulation occur, favorable conditions for microbial biomass was formed, which resulted in a high carbon dioxide production. On the sites belonging to the areas of flooding, the negative effect of a seasonal period of high water on the vital activity of microorganisms indicate. Based on the results obtained on the content of organic carbon: Umbric Cryosol (Fluvic, Arenic, Reductaquic) is associated with stratification and low content of humus along the profile, which indicates a low biological activity.

3. One of the most important ecological features of the soils of the Arctic zone was analyzed – the depositing capacity of carbon and nitrogen. The characteristics of nitrogen and humus stocks were calculated in six samples from six profiles from four islands. The soils formed in the zone of the annual influence of flooding differ in the largest indicator of the stock of organic matter, up to 20 kg/m^2. This is due to the fact that, with flood waters, a large amount of organic matter enters the soil and, under conditions of low biological activity, is able to accumulate and be buried in the soil. Other types of soils developing in the delta are marked by a lower reserve of humus up to 17 kg/m^2. Nitrogen reserve in soils varies from 0.3 to 1.4 kg/m^2; high nitrogen stock rates are observed in the youngest soils of the Lena River Delta Umbric Cryosol (Fluvic, Arenic, Reductaquic) and are caused by high nitrogen content in the vegetation litter. The C/N ratio of the soil is indicated by a low and very low enrichment of humus with nitrogen.

4. We conducted the first time ^{13}C-NMR spectroscopy and elemental analysis of the Lena River Delta soils. Soils with very active cryogenic processes are characterized by a reduced amount of oxygen and an increased amount of hydrogen (Turbic Cryosol). The opposite trend was fixed for soil, where cryogenic processes are not so highly developed (Umbric and Folic Cyosols). Soils with low degree of cryogenic processes are characterized by high content of aromatic hydrocarbon groups including -OH, -NH_2, and -OCH_3, structural blocks of lignin, atoms of carboxyl fragments, polypeptides, and carbonyl-amides and atoms of quinone fragments and the carbonyl groups of ketones and aldehydes, here oxygen compensated atoms of aromatic rings (syringyl and guaiacyl propane units). That is also represented in the elemental composition by increased concentrations of nitrogen and oxygen. In the soils with low degree of cryogenic processes active humus formation occurs, whereas in Turbic Cryosol type formation organic matter buries and conserves.

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