STRATIGRAPHY OF PEAT DEPOSITS AND MIRE DEVELOPMENT IN THE SOUTHERN PART OF THE FOREST ZONE OF WESTERN SIBERIA IN HOLOCENE

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This article provides a historical review of the peatlands study in the Middle and South taiga, as well as Subtaiga zone of Western Siberia, and summarizes the data on the structure of peat deposits in mires of the region, accumulated by the senior author over many years of field research (1980-2004). The features of the main types of stratigraphic structure, as well as a description of the development history of peat mires, are given based on a detailed study of macrofossil composition of peat cores and peat sections. Peat cores were selected within the landscape-ecological profiles, covering all relief elements from the raised bogs of the watershed plains to the mires of river valleys and gullies of ancient water runoff in different climatic zones and subzones (Subtaiga, Southern taiga and Middle taiga).

The oldest peat deposits are associated with the deep thalwegs and ancient hydrological system. Peat formation started simultaneously within the taiga zone and the present subarctic zone of Western Siberia and reached the high distribution level in Boreal period. The peatlands development process tightly followed the climate humidity – in the wet periods, the watershed mires actively developed and floodplain mires' development was constrained by the alluvial deposition process; in the dry periods, the floodplain mires developed actively and the watershed mires grow was stagnated.

Key words: macrofossil, peat deposit, watershed mires, floodplain mires, peatlands, paleoecology, Western Siberia.

INTRODUCTION

The first published information on the stratigraphic structure of peat mires in forest zone of Western Siberia is associated with works of expedition of State Meadow Institute under leadership of A.Ya. Bronzov [Baryshnikov, 1929; Bronzov, 1930, 1936]. The large-scale exploration of peat mires launched in the 1950s by the "Giprotorfrazvedka" Institute, in order to identify and assess the region's peat resources, were of decisive importance for the study of peat deposits in Western Siberia [Loginov, 1957, 1958]. In the 1960s, similar works under the leadership of A.V. Predtechensky were carried out in the Middle Taiga zone, in the basins of the Tromyegan, Vakh, Ket', and Vasyugan rivers.

As a result of these research contributions, reference books of peat deposits of the Novosibirsk, Omsk, Tomsk and Tyumen regions, a summary map (1:1 000 000) and an Atlas of the West Siberian Plain peat deposits were compiled; a primary analysis of peat resources and regional features of the peat deposits' stratigraphy were carried out [Erkova, 1957; Yasnopolskaya, 1964, 1965; Loginov, Khoroshev, 1972; Tyuremnov et al., 1971; Tyuremnov, 1976; Predtechensky, Skobeeva, 1974]. The study of the peat deposits' structure was included in a Program of hydrological studies carried out in the '60s by an expedition of the State Hydrological Institute. The results were partially published [Romanova, 1964, 1967; Romanova, Usova, 1969].

A great contribution to the study of the peat deposits and general patterns of the peat mires' development in Western Siberia in the Holocene was made by geobotanists of Moscow State University [Liss et al., 1976; 1988; Liss, Berezina, 1978, 1981; Liss, Polkoshnikova, 1979; Berezina, Liss, 1983; Liss, 1992, 1998]. The last generalizing work in this direction was the collective monograph "Bog systems of Western Siberia and their nature conservation value" [Liss et al., 2001].

As a result, extensive material was accumulated on the stratigraphic structure of peat mires in Western Siberia, and on the main stages that mires passed through in their development, as well as peculiarities in different climatic zones. However, the revealed patterns relate mainly to very large and generalized stages of the mire development, associated primarily with a change in the type of their water-mineral nutrition due to an increase in the thickness of peat and a decrease in the role of soil-groundwater in the mire nutrition. Smaller changes in the structure of the peat deposits mostly remained outside of the researchers' view, as exemplified by the peat sampling methodology with steps 25 cm, which is designed to identify generalized 'layer-forming' types of peat without taking into account the thin, but often very informative layers. Given the current state-of-the-art of paleoreconstruction and mire study, closer attention to the detailed structure of peat deposits in mires – which are the richest source of paleogeographic information – must be paid. The beginning of a comprehensive study of mires in Western Siberia, based on a very precise approach to the detailed study of peat deposits with sampling of peat vertically every 10 cm, was laid by Yu. A. L'vov [1974].

As a result, a large amount of factual material was accumulated in the form of stratigraphic peat cores, reflecting the dynamics of vegetation and the peat deposits' structure of different mire types located on the floodplains, watersheds, river terraces and valleys of ancient gullies [L'vov, Mul'diyarov, 1974; L'vov, 1977; Lapshina, 1985; Bazanov, 1980; Mul'diyarov, 1980, 1989; Lapshina et al., 2000a, b; Lapshina, Mul'diyarov, 2002, etc.]. Based on the study of the detailed structure of peat deposits, theoretical concepts of mire landscape units (facies) were developed, and regularities of their distribution over the area of peatland and in corresponding peat layers in the peat deposits were traced [L'vov, 1974, 1977; Lapshina, 1987]. New methods have been developed for studying and analyzing peat deposits, including the method of retrospective ecological analysis of peat [L'vov, 1979; Lapshina, 1987, 1995b], which gives new opportunities for paleoclimatic reconstructions and for detection of relationships in the climate-vegetation-peat-carbon system.

Reflection on the climatic conditions of Holocene in the peat deposits

In order to reconstruct the climatic conditions of the Holocene, the data on the evolution of forest vegetation in the landscapes surrounding the mire, obtained by layer-by-layer spore-pollen analysis of peat deposits, are most widely used. It is generally accepted that pollen diagrams make it possible to reproduce the general landscape appearance of the vegetation cover. Therefore, paleoclimatic reconstructions based on pollen analysis first proceed from the dynamics of the temperature characteristics of the climate, which can cause a shift in zonal boundaries, and on this basis, with a certain degree of probability, logical conclusions are made about certain changes in moisture content. To date, a large amount of palynological data has been accumulated in Western Siberia. The most complete sections investigated by the spore-pollen method are published for the forest zone [Neishtadt, 1957; Glebov et al., 1974; Khotinsky, 1977; Arkhipov et al., 1980; Volkova, Levina, 1982; P'yavchenko, 1985]. The completion of a whole stage in the study of the West Siberian Holocene nature lead to the creation of two generalized paleoclimatic curves characterizing the temperature and humidity of the climate [Volkova, 1999] for a period of 12 thousand years, taking into account the absolute age data.

On the other hand, with the accumulation of radiocarbon data on the age of major native historical events in postglacial period, it was possible to clarify the onset time of individual epochs of the climatic moisture rhythm discovered by A.V. Shnitnikov [Shnitnikov, 1973]. Notably, the climate humidification curve of Western Siberia constructed by V.S. Volkova is highly similar to the epochs of moisture content on the Northern Hemisphere continents created by A.V. Shnitnikov. These two reconstructions were made independently from each other, using different initial data proxy, which indicates the objectivity of the reflected processes. Later, more detailed palynological data were obtained, clarifying the general patterns [Blyakharchuk, Klimanov, 1989; Pitkänen et al., 2002; Blyakharchuk, 2000, 2012; Blyakharchuk et al., 2019, etc.].

Another very informative, but still insufficiently appreciated, source of paleogeographic information is a detailed peat botanical (macrofossil) analysis. Most authors assume that peat, being a product of incomplete decomposition of mire vegetation, reflects the main features of the parent plant communities, though in a slightly modified form [Bogdanowskaya-Guihéneuf, 1945; Tyuremnov, 1976; L'vov, 1974, 1977]. As shown by numerous studies, the distortion of phytocenotic information in peat is caused by the different rates of mire plants' decomposition [Kozlovskaya et al., 1978; Kozlovskaya, 1984], as well as by the peculiarity of the peat formation by different plants' life forms, which to varying degrees causes secondary diagenesis in the plant residues ratio of peat [Bogdanowskaya-Guihéneuf, 1945; L'vov, 1977; P'yavchenko, 1984]. However, in most cases, the dominant core of parental phytocenoses is reflected in the plant remains of peat [L'vov, 1977; L'vov, Mul'diyarov, 1984]. Therefore, according to the composition of a well-defined homogeneous layer, with a known correction for differences in tissue destruction and secondary diagenesis, the reconstruction of the past vegetation cover may be carried out. An accurate peat macrofossil analysis links to the geobotanical description, because it reveals the species' composition and quantitative ratio of the dominant species of the parent phytocenosis [L'vov, 1977]. Consequently, the botanical analysis methods can be applied to the peat, and in particular, the method of phytoindication determines the habitat ecological features by the composition of its vegetation cover [Ramenskiy et al., 1956].

There has been successful experience in the application of standard ecological scales of L.G. Ramenskiy to indicate mire paleohabitats by the botanical composition of peat [Kurkin, 1976; L'vov, 1979; L'vov, Mul'diyarov, 1984; Lapshina, 1987, 1995b; Tsyganov et al., 2021]. The main factors of the mire process, according to which the ecological assessment of habitats is carried out, are as follows: real (assimilated by plants) fertility, measured in grades of the ecological scale of active soil richness; and total wetness, measured in grades of the wetness scale [Ramenskiy et al., 1956]. The real fertility of mire peat soils changes gradually or abruptly, reflecting the stages of the endoecogenetic process of the mineral nutrition depletion on the mire as the peat deposit grows, with the shift occurring when the mire passes into the ombrotrophic stage of development (raised rain fed bog). In the case of floodplain mires (fens), it remains relatively constant throughout the entire period of their existence.

The factor of general moisture is more variable during the mire development. Mire ecosystems react to changes in wetness by changing their composition and structure. During drying, the ratio of less moisture-loving plant species increases; upon watering, they reduce their abundance or completely drop out, giving way to the moisture-loving species, which affects the botanical composition of peat through a sufficient duration of the process. In the patterned peatlands, a change in the ratio of different structural elements occurs: in the dry periods, the area of hummocks and ridges increases; in the wet periods area of inter-hummocks depressions and wet hollows increase. In the peat core collected at the border of such elements, an alternation of hollow and ridge peat types is found [L'vov, 1976, 1979; Vleeschouwer, 2010].

In case of high-resolution peat sampling combined with detailed macrofossil analysis, the depth-factor plot can be created. The position of each sample in this scale is calculated according to ecological scales and reflects the successive changes in habitat from the moment of the mire origin to the present time [Blyakharchuk, Chernova, 2013]. The resolution of the method depends on the sampling frequency. For example, during collecting the peat samples at the Ubinskoe mire (forest-steppe zone) with 25 cm step, only long-term fluctuations with a period of 1500-2000 years were generally revealed [Kurkin, 1976]. At the same time, according to the wetness curve of the peat section of Chaginskoye mire (near Tomsk), analyzed with a 10 cm step, fluctuations of two types were clearly distinguished: the larger ones corresponding to the long-term moisture cycles of A.V. Shnitnikov (4-5 throughout the entire period of the mire existence) and smaller ones, featured to the shorter periods and smaller amplitudes of deviations [L'vov, 1979].

Thus, the detailed peat botanical analysis makes it possible to reasonably identify the climatic periods of the Holocene with different degrees of wetness and, in this respect, significantly expands the possibilities of paleoecological reconstructions. Changes in the humidity of the Holocene climate are most clearly reflected in the peat deposits of rised ridge-hollow bogs. *Sphagnum* mosses in the complex vegetation cover act as dominants and edificators, and its changes are reflected directly and adequately in the structure of peat deposits [L'vov, 1977].

Among the minerotrophic peat mires (fens), the peat mires of the steppe zone are informative because they are subject to strong drying during the dry periods [Shnitnikov, 1957; Kurkin, 1976]. The structural features of lowland fens of the forest zone are rather rare used for reconstruction because they are constantly abundant of wetness, and composed of similar ecology plant species, but different life forms, which in the process of peat accumulation may significantly transform the previously deposited layers of the peat [Bogdanowskaya-Guihéneuf, 1945; L'vov, 1977], making them homogeneous and therefore uninformative. Nevertheless, as our experience shows, with the correct choice of a peat core location and sufficiently detailed botanical (macrofossil) analysis, these difficulties can be overcome, and the peat deposits of fens turns out to be suitable for paleoclimatic reconstructions, in particular, for identifying the rhythms of climate humidity [Lapshina, 1987, 1995a, b].

The purpose of this article is to publish materials of long-term peat mires' stratigraphic structure studies, to identify patterns of spatial-temporal changes along landscape-ecological and geographical gradients in the southern part of the forest zone of Western Siberia.

MATERIALS AND METHODS

The field data for this work were results of long-term studies of peat deposits of mires in the southern part of the taiga zone of Western Siberia. The study is based on the detailed investigation of 9 key areas each about 100-200 km^2 – covering the diversity of all main types of geological and geomorphological surfaces in the south of the West Siberian forest zone in different bioclimatic zones and subzones – Subtaiga, Southern and Middle taiga (Fig. 1).

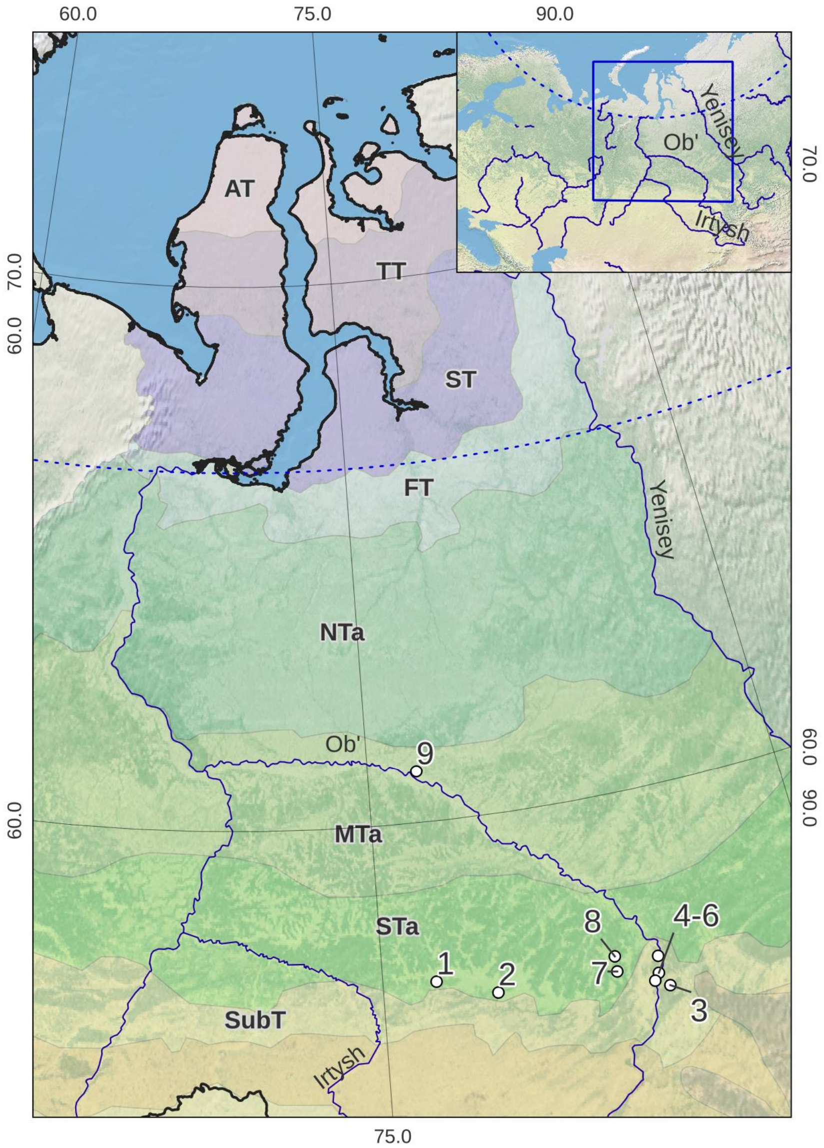

Figure 1. Location of study key areas. Great Vasyugan bog: 1 – 'Uzas', western Vasyugan key area, 2 – 'Malaya Icha', eastern Vasyugan key area; 3 – '86th Kvartal', Ob'–Tom' Rivers interfluve; segments of the Ob' River floodplain: 4 – Podobinsky, 5 – Shegarsky, 6 – Desyatovsky; 7 – Plotnikovo, (Bakcharskoe mire), 8 – 'Borodinsk' (Semenovskoe mire), 9 – Nizhnevartovsk (Savkino mire).

Bioclimatic zones (according Il'ina et al., 1985): AT – Arctic tundra, TT – typical tundra, ST – South tundra, FT – forest-tundra, NTa – North taiga, MTa – Middle taiga, STa – Shouth taiga, SubT – Subtaiga.

In total, 9 hypsometric leveling profiles were studied, with a total length of more than 50 km, on which 355 sampling and sounding cores were drilled.

Peat samples were taken with a Russian peat sampler (3.5 x 50 cm) in a continuous column with step every 10 cm for each sample, to the entire depth of the peat deposit [L'vov, 1974]. The macrofossil composition and the degree of peat decomposition were determined in each sample in %. In total, about 5000 peat samples were analyzed to characterize the stratigraphic structure of peat deposits for macrofossil composition. In order to visualize the results of the peat macrofossil analysis, and to construct stratigraphy, the specialized program PeatGraph [Dyukarev, 2003] was used. On the basis of individual peat cores with a known bulk density, the actual distribution of organic matter and carbon in peat deposits during the Holocene was studied.

Radiocarbon analysis was performed in the Institute of Geology, Russian Academy of Sciences (Moscow). Samples were taken from the bottom layer and from two depths (usually 50 and 200 cm) in the middle part of the deposits. In the deepest cores, the age of the layers was determined every 50-100 cm. The dates obtained by radiocarbon analysis were converted to dendrochronological (calibrated) dates [Stuiver, Reimer, 1993]. For the Holocene periodization, the corresponding (refined by dendrochronological scales) age boundaries of the periods were used: Preboreal (PB) – 9980-11960, Boreal (BO) – 8830-9980, Atlantic (AT) – 5300-8830, Subboreal (SB) – 2740-5300 , Subatlantic (SA) – 2740 to date. In total, 134 absolute age dates were obtained during research within the forest zone of Western Siberia.

RESULTS AND DISCUSSION

The main types of mire stratigraphy and the history of their development, based on a detailed study of the peat macrofossil composition, are presented. The peat cores were sampled within the landscape-ecological profiles spanning from the raised watershed plains to the river valleys and ancient gullies in different climatic zones and subzones.

Stratigraphy and development history of Subtaiga mires

This article focuses on the south of the Western Siberian forest zone, and the Subtaiga zone in which there is a dominance of small-leaved (birch-aspen) forests. The key areas were located on the watershed plain mires between the Ob' and Irtysh rivers, in the valleys of ancient gullies in the Ob'-Tom' interfluve and in the floodplain of the Ob' River.

The watershed plains peatlands

The stratigraphic structure and development history of the mires were studied in the southern part of the Great Vasyugan bog. The Great Vasyugan bog (GVB) is a system of a large number of initially isolated bogs that appeared and merged together throughout the Holocene [Bleuten, Lapshina, 2001; Lapshina, Mul'diyarov, 2002].

The three main types of stratigraphic structure of peat deposits can be distinguished within the axial part and the southern slope of the Great Vasyugan bog. These types reflect the general process of development and changes in bog phytocenoses in the genetic centers of primary bog:

- raised bog *Sphagnum* (*fuscum*) deposit in the genetic centers of convex oligotrophic bog called "ryam", adjacent to the water area of primary bog lakes;
- mixed (mainly raised *Sphagnum* bog) deposit in the genetic centers of terrestrial eutrophic swamping (ancient flat-topped fens of a complex structure in the axial part of the GVB);
- predominantly minerotrophic sedge-herb-brown moss fen deposit under the open fens of eutrophic terrestrial paludification of the Middle and Late Holocene age.

It is generally accepted that the average thickness of peat deposits in the GVB does not exceed 2 m [Khotinsky et al., 1970; Inisheva et al., 2003]. This idea is based on the stock data of the "Giprotorfrazvedka" Institute, which carried out large-scale surveys, mainly in the eastern part of the GVB system and on its northern spurs. As a result of our studies, it was found that in the central and western parts of the GVB the peat deposits are an average thickness of around 4 m, and much older than previously thought. According to radiocarbon (calibrated) data, the peat accumulation in the most ancient waterlogging centers in the south of the Ob'-Irtysh watershed began about 9.5-10 kyr BP ago. The initial stages of peat accumulation within the GVB are associated with numerous flat, often less deep, lake depressions or waterlogged lowlands, where the groundwater level constantly stays at the surface.

With mire formed by the overgrowing of aquatic plants, the peat deposits themselves are underlined by lacustrine sediments with the remains of aquatic macrophytes (*Potamogeton, Nymphaea, Typha*). The thickness of the layer of lacustrine deposits usually does not exceed 0.5 m, but occasionally it can reach 2-2.5 m near the former primary lakes' aquatories, many of which still persist to day. The total thickness of organogenic deposits in the bog primary genetic centers is 6.5-7.0 m.

The main stratigraphic types identified in the genetic centers of the GVB within the Subtaiga zone are described below [Lapshina, Mul'diyarov, 2002; Lapshina, 2004]:

1. Raised *Sphagnum* (*fuscum*) deposit is featured in the most ancient genetic centers of lacustrine origin. Within large lacustrine basins with a diameter of a few hundred meters to 1.5-2 km, the upper 5-6-meter peat layer of slightly or moderately decomposed homogeneous *Sphagnum* (*fuscum*) peat is underlained by transitional (*Sphagnum divinum*, dwarf-shrub-*Sphagnum*) and minerotrophic (fern, sedge-fern) types of peat, which in total do not exceed 1-1.5 m. The ratio of the thickness of the layers of minerotrophic, transitional and oligotrophic *Sphagnum fuscum* peat in these areas is on average 1:0.5: 6-7 m (see Appendix 1, Fig. 2, V24). The age of the bottom peat layer is estimated 10 kyr BP, and the shift of the minerotrophic fen to the transitional (mesotrophic) mire and oligotrophic raised bog development stages in such areas took place about 9.5 and 9 ka BP respectively.

A simpler version of this peat stratigraphic type is presented on the shores swells of former lake basins on their southern side. The slight slope of the Vasyugan Plain and the constant inflow of surface waters from higher hypsometric levels of the Ob'-Irtysh watershed, provided a characteristic southern displacement of the peat deposits' domes of oligotrophic 'ryams' to the north from their genetic centers (Figure 2, II, V21, V24).

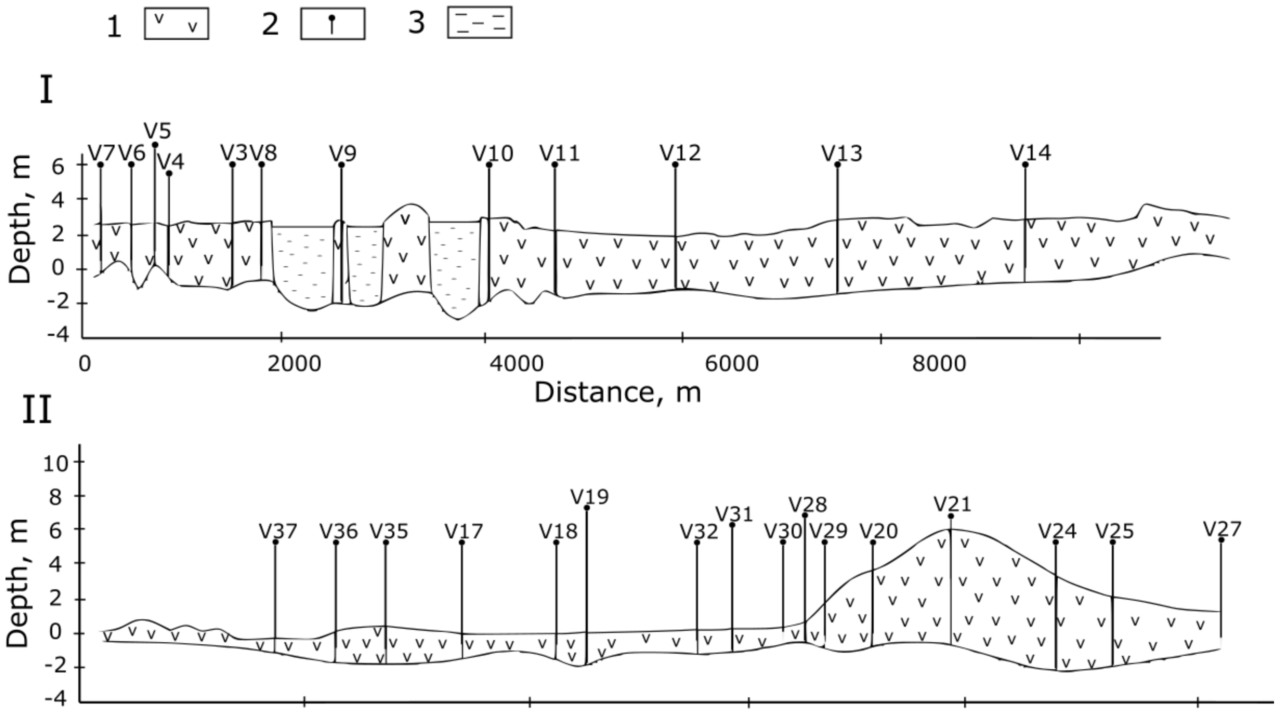

Figure 2. Cross-sections of peat deposits of the Great Vasyugan bog: I – ('Uzas' – western Vasyugan key area, II – 'Malaya Icha' – eastern Vasyugan key area (Subtaiga zone).

Legend: 1 – peat; 2 – drill locations with number; 3 – water.

One of the peat cores sampled on the hypsometric leveling profile in the central sector of the GVB illustrates this type of deposit (see Appendix 2, Fig. 1, V21).

Peat accumulation began here about 9.5 ka BP with a relatively short period of the open mesotrophic *Sphagnum* fen dominated by *Sphagnum teres*, which deposited 40 cm of *Sphagnum teres* peat. Peat macrofossil analysis showed that typical vegetation of an oligotrphic (rain fed) raised bog (ryam) dominated by stunted Scots pine (*Pinus sylvestris*) 1-3.5 m height, dwarf shrubs (*Ledum palustre, Chamaedaphne calyculata*) and *Sphagnum fuscum* formed in this area at the beginning of the Boreal period (about 9 ka BP) and since then it has been preserved to the present day without any significant changes.

At present, ancient oligotrophic 'ryams' of lacustrine origin are dome-like, rising 6-8 m above the surrounding surface of the younger sedge-brown moss fens. At the same time, the total thickness of the peat deposit in such 'ryams' can reach 11 m. In the present landscape cover of the GVB, such mires adjoin or surround the water areas of large primary lakes. By their origin and by the peat deposits' structure, they are similar to the raised peat bogs 'ryams' of the forest-steppe zone – Ukrainsky Ryam, Ubinsky Ryam [Khotinskiy, 1977].

2. The second stratigraphic type of peat deposit is characteristic of large (up to 7-10 km across) ancient flat-topped ombrotrophic mires in the axial part and along the southern margin of the GVB. The transverse profile showed the vast areas of the GVB, often adjacent to the bog of primary lake basins, were formed by mineral soils' paludification of flat depressions with developed hydrophilic herbaceous vegetation (Fig. 2, I, V11-13). The peat accumulation began here later than in the lake depressions, at the beginning of the Atlantic period (about 8-8.5 ka BP). [1]

In the stratigraphy of the peat deposit, similar to the ancient lacustrine origin bog, three layers can be distinguished. Unlike the lacustrine origin bogs, there are no lacustrine deposits, and the thickness of oligotrophic peat does not exceed 3 m with an average total peatland depth of 4.5-5 m. The lower peat layer is composed of well-decomposed fern, sedge-fern, or sedge (*Carex lasiocarpa*, *C. rostrata*) peat types about 1 m thick (see Appendix 1, Fig. 2, V12, 13).

Open fern and fern-sedge fens started actively overgrowing by dwarf birch (*Betula nana*) about 6-5.5 ka BP. These dwarf birch fens were covered by oligotrophic *Sphagnum* moss communities (*Sphagnum divinum* (which earlier was considered as *S. magellanicum*), less often *S. angustifolium*) with the cotton grass (*Eriophorum vaginatum*) and *Ericaceae* dwarf shrubs (*Chamaedaphne calyculata, Ledum palustre*, *Oxycoccus palustris*) soon. In general, the thickness of the transitional layer varies from 0.5 to 1 m. It is composed of dwarf shrub, dwarf-shrub-cotton grass-*Sphagnum* and *Sphagnum* (*S. divinum*) peat types.

A decrease in the influence of the groundwater and an increased role of atmospheric precipitation caused by the peat accumulation led to a sharp change in environmental conditions. As a result, at the beginning of the Subboreal period (5.5-5 ka BP), the typical pine-dwarf shrub-*Sphagnum* ('ryam') vegetation of a raised rain fed bog was formed in place of mesotrophic plant communities.

Over the past 2.5-3 ka years, as the lateral and vertical growth of the bog slowed down, its surface flattened and the runoff in the central parts decreased. The development of numerous wet hollows and secondary lakes began, which led to the formation of ridge-hollow and ridge-hollow-lake complexes on the place of former homogeneous convex 'ryams'. This process was reflected in the layers as of the hollow *Sphagnum* peat (*Sphagnum balticum, S. jensenii, S. papillosum*) among more dense *Sphagnum fuscum* peat (see Appendix 1, Fig. 2, V13). The thickness of the complex upper layer reaches 2-3 m.

3. The third stratigraphic type is a minerotrophic sedge-herb-brown moss deposit. This type is widespread under the open minerotrophic fens of eutrophic paludification of mineral soils in the suffosion depressions appeared in the Middle-Late Holocene age. The thickness of such deposits and their stratigraphic structure in some parts of the GVB depends on the peatland and its development stage. The thickness of peat varies from 1.8 to 3 m, reaching 4-4.2 m in the most ancient genetic centers. Radiocarbon and detailed peat macrofossil analysis showed the large-scale distribution of such mires at the end of the Atlantic and first half of the Subboreal periods (5.5-4.0 ka BP) on the areas of moist sedge-reed plant communities. Deep depressions were paludified at the beginning. While the mire developed and groundwater level increased, the process of peat accumulation was initiated in flatter depressions. Gradually, hydromorphic herbaceous vegetation on mineral soils gave way to the open grass mires dominated by ferns and large sedges, which deposited 1-1.5 m of fern, sedge-fern, or sedge peat layers (see Appendix 1, Fig. 2, V23; Appendix 2, Fig. 1, V26). With the peat accumulation, grass mires of rich ground feeding were replaced by the open sedge and sedge-brown moss fens with homogeneous or complex vegetation structure, with the spots of dwarf birch

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[1] here and further, when describing the history of the development of peat bogs in the region, as well as in stratigraphic columns (Appendixes 1 and 2), calibrated radiocarbon dates are used as the true age.

and rare chains of stunted tree birches, fed by mixed (atmospheric-runoff-ground) water supply. The general landscape appearance and vegetation of such fens, with slight variations, are still preserved over vast areas of the GVB today.

In the sedge-brown moss fens with a complex structure and slow through flow, there is a more complicated form of the peat stratigraphic type, where the top layer of 1 meter consists of *Sphagnum* (*S. divinum, S. fuscum)* peat that is weakly or moderately decomposed. This type of peat deposit develops under the convex 'islands' of ombrotrophic 'ryam' and 'tall ryam' vegetation, which rise 40-60 cm above the surface and occupy no more than 1-2% (less often up to 5%) of the minerotrophic fen complexes area. Their diameter, depending on age, varies from 2-3 to 50 m.

A detailed study of the peat's stratigraphy showed that sometimes such insulated 'islands' of a 'tall ryam' on minerotrophic sedge-brown moss fens are located above the elevated mineral bottom. This means that they were presented in the vegetation cover and peatland landscape structure, from the first stages of their development. However, convex 'islands' with ombrotrophic vegetation appeared at much later stages of the peatland development or appeared quite recently, without having time to deposit any well-defined layer of *Sphagnum* peat. We guess that the origin of such insulated 'ryam' islands (called 'shelomki') among the minerotrophic sedge-brown moss fens in the south of the forest zone of Western Siberia connected with the regular development of seasonal permafrost (called 'pereletki') and with the emergence of insular permafrost during the cold periods of the Holocene.

The peat deposits' structure in the confluence zones of primary bogs

The types of peat deposits described above predominate in the area, but do not exhaust the entire diversity of the stratigraphic structures of this huge mire system. Other types of peat deposits are revealed in the contact (confluence) zone of the primary bogs, as well as in the peripheral zone of the mire system and the zone of recent paludification.

The structure of peat deposits in the contact zone of isolated mires is well expressed in the landscape, and is determined by the stage of the latter development (peat thickness, type of water-mineral nutrition), the lithology of the mineral bottom and the contact zone position in the general system of hydrological flows (paragenetic series of mire landscapes), due to the watershed plain macro-relief and the meso-relief of the surface of peat land unit types.

During development of the convex ombrotrophic raised bogs, the surface of the surrounding minerotrophic fens is overlapped. At the same time, under conditions of a permanent inflow of water from the peat mound at the contact site, an extensive bog complex with flat-topped ombrotrophic *Sphagnum* mounds (islets) formed by *Spahgnum fuscum*, scattered among minerotrophic sedge-moss (*Carex rostrata, C. omskiana, Warnstorfia* spp*., Scorpidium scorpioides, Sphagnum teres*) fens are forming. As a result, in the upper part of the peat deposit, a layer of complex peat (thickness up to 1-1.5 m) is formed, including the remains of sedges, *Rhynchospora alba*, *Warnstorfia-Scorpidium* and *Sphagnum* mosses, underlain by sedge and sedge-brown moss peats typical for the minerotrophic fens of the GVB.

A peat deposit of two-layer structure develops on the southern side of the convex raised bogs in the zone of hydrological influence of acidic oligotrophic waters flowing down the watershed southern slope. In this case, the minerotrophic sedge or herb-sedge-brown moss deposit is overlain by a layer of homogeneous transitional sedge-*Sphagnum*, dwarf shrub-*Sphagnum*, or cotton grass-sedge-*Sphagnum* peat formed by the remains of *Betula nana, Carex rostrata, C. lasiocarpa, Eriophorum vaginum, Sphagnum fallax, S. angustifolium*. Similar types of peat deposits were found in vast mesotrophic and meso-oligotrophic fens, which develop surrounding the convex raised bogs.

The herb-woody peat deposits are formed on the mineral bottom previously covered by (automorphic) zonal forest vegetation, and later swampy forests. The lower parts of these deposits are composed of woody (fir, birch, pine) or sedge-woody peat (see Fig. 2, II, V28, 30, 31; Appendix. 1, Fig. 2, V28, 30). The areas on the border between the ombrotrophic 'ryams' and minerotrophic fens are directly overlapped by *Sphagnum fuscum* peat during the expansion of the raised bog.

Meso-oligotrophic catchment areas of run-off water called 'gal'i' are presented mostly on the northern slope of GVB and its northern spurs, where they are essential elements of the Middle Ob' basin raised watershed bogs [Bronzov, 1930; Lapshina et al., 2000a, b]. In the GVB southern slope landscape structure, the weakly wooded pine-dwarf birch (*Betula nana*)-moss fens develop downstream of local mire run-off water catchments where the river network begins). Minerotrophic peat deposits in such areas do not exceed

1.5 m and are represented by alternating sedge and wood-sedge (dwarf shrub-sedge) peat types with a high content of horsetail, fern and reed remains (see Appendix 1, Fig. 2; V38).

Ancient ice marginal valley mires

Mires of various geomorphological location and water-mineral nutrition types were surveyed along the landscape-ecological profile through a local watershed of two left tributaries of Tom' River – Zhukovka and Elovka Rivers within the ancient ice marginal valley in the Ob'-Tom' interfluve (Fig. 3) [Bleuten, Lapshina, 2001].

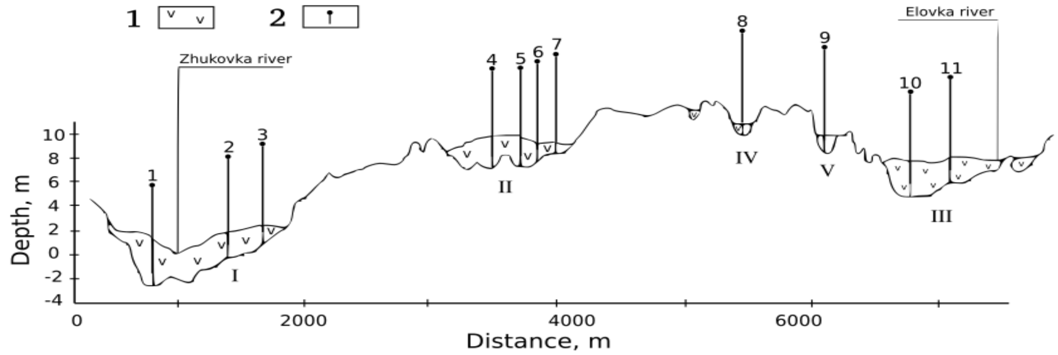

Figure 3. Distribution of peat deposits on the landscape-ecological topographic cross-section through the local watershed within ancient ice marginal valley ('86th Kvartal' key area, Subtaiga zone).

Peat mires (I-V) and numbers of peat cores (1-11). I – Zhukovskoe mire: 1 – Zh0; 2 – Zh1; 3 – Zh2; II – Kirgiznoye mire: 4 – Kir1; 5 – Kir2; 6 – Kir3; 7 – Kir4; III – Bolshoe Elovochnoe mire: 10 – E2; 11 – E1; IV – Elovochnoe mire-1: 8 – E4; V – Elovochnoe mire-2: 9 – E3.

Legend: 1 – peat; 2 – drill locations with number.

The mires' genetic centers in the valley of the Zhukovka River were shallow water bodies, because the lacustrine deposits' (0.5-1.5 m thickness) occur in the deepest parts of the ancient valley. As the climate became warmer and drier with the onset of the Boreal period, most of the small water bodies began to shallow and turn into swamps. At first, in their place *Typha* spp. communities with *Menyanthes trifoliata* developed, and deposited the low peat layer at the 7.3-8.0 m depth. Further drying up of the shallow water caused the mosses (*Drepanocladus, Warnstorfia* spp.) and herb (*Menyanthes, Equisetum, Thelypteris palustis*) communities to spread. Since the middle of the Boreal period (8960 ± 70), from the depth of 7.3 m, the peat deposit has a relatively monotonous structure and is composed of a regular alternation of *Menyanthes*-sedge-brown moss, and brown moss-sedge peat types (see Appendix 2, Fig. 2 , Zh0). Brown mosses have similar ecological requirements regarding the conditions of habitat wetting to sedges and mire herbs (bogbean, horsetail, and fern), but cannot endure any prolonged flooding from the surface. Hence, it can be assumed that the increase in the role of sedges and *Menyanthes* remains in the peat generally corresponds to more humid climatic periods, when the peat mire was flooded by river waters, or by run-off waters flowing from the valley slopes, when the discharge was impeded. In the dry periods, constant supply of ground waters ensured the active development of brown mosses, the proportion of which in the peat increased significantly in comparison to sedges and *Mentyanthes* remains. As a result, almost pure brown moss peat was deposited for a long time at the end of the Atlantic and beginning of the Subboreal periods (see Appendix 2, Fig. 2, Zh0).

The dark coniferous herb-tussock sedge swamps (so called 'sogra' communities) developed and deposited 1.5-4.0 m layers of woody peat, in relatively good drainage conditions among the river bed and near the valley slope (see Appendix 1, Fig. 3, Zh1). The width of the 'sogra' belt varied in accordance with climate humidity change, which caused a shift in drainage conditions. This is reflected in the alternation of woody and herb-moss peat types in the peat deposit. On the outskirts of the river valley near terrace, the peat is composed of woody remains to the full depth.

Mire Bolshoye Elovochnoe completely occupies a relatively shallow incised valley of the Elovka River. Peat accumulation began here at the end of the Atlantic period in the deepest near-slope part of the valley (Fig. 3; see Appendix 1, Fig. 3, E2, 5970 ± 80) with deposition of woody 'sogra' peat. The 3-meter peat deposit is definited by frequent alternation of swamp herb species from the remains of the *Menyanthes trifoliata* and horsetail (*Equisetum fluviatile*), woody-herb and tussock sedge peat from the remains of *Carex juncella*, which reflects the change in ecological conditions associated primarily with the climate humidity dynamics, the river water content and the amount of run-off water supplied from the valley slopes during the peatland development. Towards the river, while drainage conditions improve, the peat deposits become more homogeneous and almost to the entire depth composed of woody peat with thin layers of herb-sedge peat (Fig. 3; see Appendix 2, Fig. 2, E1).

Completely different development processes, and a different peat deposit structure, are found in mires located in depressions of various shape and size outside the river valleys. In deep depressions at high surface level, the paludification process began much later (the end of the Atlantic period) than in the thalwegs of the ancient ice marginal valley inherited by the present Zhukovka River valley (Fig. 3; see Appendix 2, Fig. 3, Kir1, 5943 ± 100).

The development of the Kirgiznoye mire proceeded by paludification of mineral soils and the formation of sedge-reed and sedge-herbaceous (*Thelypteris palustris, Menyanthes trifoliata*) communities with rare birch trees. The minerotrophic stage of mire development is characterized by a wide distribution of open *Sphagnum*-reed, sedge-reed, and sedge-*Sphagnum* communities with the participation of *Sphagnum teres, S. obtusum, S. subsecundum* in the moss layer, and brown mosses (*Warnstorfia* spp. and *Calliergon* spp.). As peat accumulated and filled up the primary basin, the main role in the mire nutrition passes to nutrient poor surface waters. A short transitional stage in the mire development is represented by mesotrophic *Scheuchzeria*-sedge, *Scheuchzeria*-sedge-*Sphagnum* plant communities that deposited peat. Further growth of the peat deposit led to formation of a convex surface and the transition of the mire to the ombrotrophic feeding stage. As a result, the upper 2 m of the Kirgiznoye mire peat deposits is composed of oligotrophic cotton grass-*Sphagnum* (*Eriophorum vaginatum, Sphagnum angustifolium, S. divinum, S. fuscum*) and pure *Sphagnum fuscum* peats (see Appendix 2, Fig. 3, Kir1; Appendix 1, Fig. 3, Kir3).

On the slopes of deep hollows and in the various shallower depressions fed by surface runoff water and nutrient poor groundwater, paludification process begins from the mesotrophic stage (see Appendix 1, Fig. 3, Kir2, 4). The average thickness of *Sphagnum* peat within the key site is 1-1.5 m. The oldest layer of raised bog peat deposits in this region formed in the Subatlantic period (about 2 ka BP).

Thus, within the incised thalweg of ancient ice marginal valley, currently occupied by small rivers, the minerotrophic sedge-brown moss and woody (woody-herb) peat types absolutely prevail in the mire deposits. Outside the river valleys, in various depressions of the local watershed, the different peat types are found. Only peat deposits deeper than 2.5 m have perceptible layer of minerotrophic peat, usually no more 1-1.5 m. Peat deposits less than 2-2.5 m are composed of only mesotrophic or mesotrophic-oligotrophic peat types over the entire depth.

The Ob' River floodplain mires

Two geomorphologic peatland types develop in the Ob' River floodplain on the south of Western Siberian forest zone. The first type is the deep depressions adjacent to terraces and the second – flat inter-ridge depressions of the central floodplain. Near-terrace peatlands are featured by an asymmetric structure. Their peat body cross-section has the greatest depth under the steeply abrupt side of the terrace and stretches, shallower, towards the central floodplain. The surface of such peatlands is slightly convex with a barely noticeable slope towards the river. The second type is the peatlands of the central floodplain, which are completely isolated from the terraced water. They have a flat or slightly concave surface, a more symmetrical shape of peat body and peat deposit structure [Lapshina, 1995a; Lapshina, 2004, 2006; Lapshina, Bleuten, 2000] (Fig. 4).

The direct influence of flooding water saturated with alluvium is observed only in peatlands of the central floodplain and, less often, in a narrow peripheral strip of near-terrace peatlands. The main part of the peatland is saturated by moisture due to ground water and surface-runoff terrace water dampened by river waters only during floods [Schipper et al., 2007].

The main features of the floodplain mires' structure are formed due to changes in the properties (chemistry and dynamics) of the water flow from the terrace to the river and differentiating the floodplain into 5 zones of water-mineral nutrition [Lapshina, 1995a]:

I – zone of spring feeding, which is a narrow contact strip of the mire, creeping up the slope of the terrace, with a wide variety of plant communities (reed, reed-sedge, birch-willow-sedge-reed, birch-brown moss);

II – zone of pressure-ground water feeding the near-terrace part of the wide segments of the floodplain, characterized by the development of the open or slightly wooded sedge-brown moss mires and elongated complexes (called 'veret'ya');

III – zone of predominantly groundwater supply of the central part of peatland, in which wooded herb-tussock sedge communities are widely developed;

IV – zone of mixed peatland-river feeding along the periphery of terrace mire, which is regularly exposed to flooding waters under the powerful influence of moisture flowing down from the surface of the peatland, where various wooded tussock sedge- and birch-willow-herb communities develop;

V – zone of river feeding, in which the tussock sedge and birch-willow-tussock sedge peatlands of the central floodplain are located, delimited from the terraces by channels.

Primary peatlands in the Ob' River floodplain appeared about 7.5-8 ka BP, at the end of the dry (low-water) epoch (the first half of Atlantic period), remote from the river near-terrace depressions of the wide floodplain segments. Bottom layers of woody, woody-sedge, or woody-reed peat lie directly on lacustrine sediments (gittja) containing remnants of aquatic macrophytes (see Appendix 1; Fig. 4, boreholes 44, 14).

This indicates that in the conditions of floodplain, the mires develop not by natural overgrowing and filling old water bodies by floating mire, but during dry periods, when the near-terrace depressions cease to be flooded with river water and the reservoirs with lake sediments located there dry up, enabling tree communities to grow there. Only the largest floodplain lakes that exist today went through overgrowing by aquatic plants, then by the reed, marsh trefoil-fern, or brown moss stages (see Appendix 1; Fig. 4, borehole 3).

Peatlands on the extended floodplain areas occupied about one third of their present area during the late Atlantic and early Subboreal periods (about 6-5.3 ka BP), concurrent with the end of another low-water period. During this period, shallow peatlands arose in the narrowed areas of the floodplain, where woody or woody-bog-grass peat filled the deepest depressions (see Appendix 1, Fig. 4, borehole 14a). Differentiation of the extended floodplain segment peatlands took place in accordance with the zones of water-mineral nutrition, under the conditions of increasing climate humidity at the beginning of the Subboreal period.

Around 4 ka BP, the separate floodplain segment near-terrace peatlands reached their modern boundaries and merged into large peatland systems. Due to a decrease in the inflow of terraces water and the limited influence of the flooding waters of the river, woody swamps ('sogra') and woody-*Menyanthes*-tussock sedge mire facies (plant communities with peat layer produces by them) become widespread. Numerous initial paludification sites arise in depressions of the central floodplain. However, in the next high-water period (about 2-2.5 ka BP), all shallow peatlands were overlain with river alluvium. Only much later, as the general level of the floodplain uplifted due to the peatland growth in the near-terrace floodplain area and the annual deposition of alluvial sediments in the central and near-channel floodplains, the conditions sufficient for paludification of the central floodplain segment parts were created again. The development of present peatlands began 1.9-1.5 ka BP in one of the next dry periods of the climatic rhythm, as evidenced by the results of bottom peat layer radiocarbon dating (Appendix 1, Fig. 4, core 24).

During the last high-water phase, the abundant inflow of soil-ground water from the terraces caused an expansion of the brown moss fens areas, and an increase in the alluvial influence from the river facilitated the spreading of the wooded tussock sedge and tussock sedge communities (*Carex caespitosa* and *C. juncella*) far into the peatlands. At present, a decrease in the water content of these mires is observed, that corresponds to the next low-water period of the climatic rhythm, which manifested in a noticeable reforestation of the once open sedge-brown moss fens and an increase in the areas of dwarf birch (*Betula fruticosa*) thickets on their place.

Thus, in the process of the alluvial deposits' formation on the local lowered floodplain areas, the conditions favorable for the paludification process and peat accumulation were regularly created. But the peatland formation was prevented by the alluvial-floodplain river regime. These two processes are antagonistic. Peat accumulation occurs only in those parts of the floodplain and only during those development periods where and when the alluvial regime is absent or weakly expressed. Peatlands in the Ob' River floodplain appeared in one of the low-water periods, and during the entire subsequent period, the growth of peat deposits in the adjacent terraces areas and the accumulation of alluvial sediments in the near-channel and central parts of floodplain proceeded in parallel, making up a single sedimentation process of the floodplain formation [Lapshina, 1995a, b].

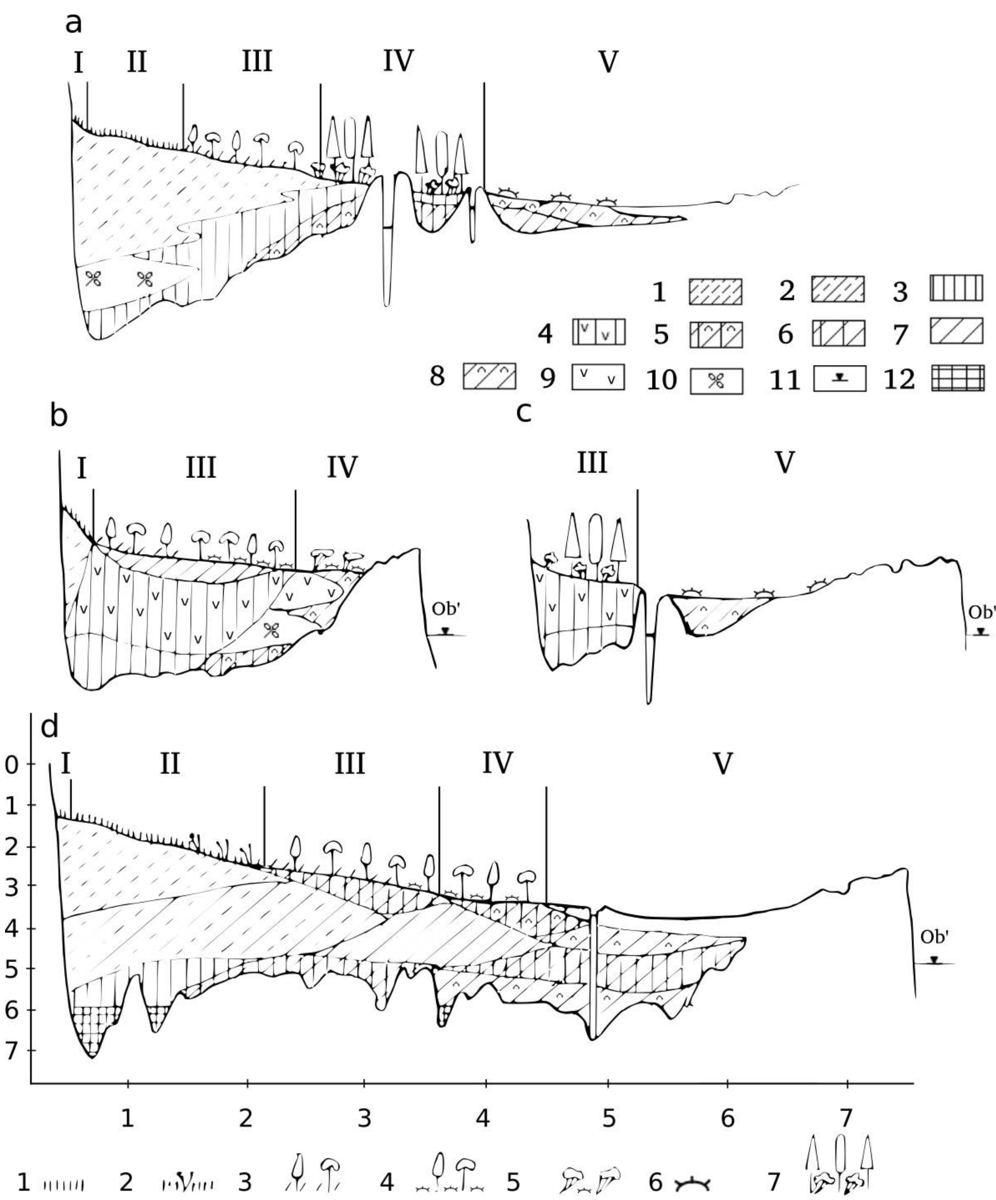

Figure 4. Stratigraphic structure of peat deposits of floodplain mires of the Ob' River valley in the south of the forest zone of Western Siberia (Subtaiga zone).

Floodplain segments: Podobinsky (a), Shegarsky (b, c); Desyatovsky (d). Zones of water-mineral nutrition: I – spring water, II – pressure-ground water, III – ground water, IV – mixed mire-river water, V – river water nutrition.

Types of peat: 1 – brown moss, 2 – sedge-brown moss, 3 – wood, 4 – wood-herb, 5 – wood-tussock sedge (*Carex caespitosa*), 6 – wood-sedge, 7 – sedge, 8 – tussock sedge, 9 – herb, 10 – *Menyanthes*; 11 – mineral soil; 12 – water level; 13 – gyttja.

Plant communities: 1 – open and poorly wooded brown moss fens and string complexes; 2 – sedge-brown moss dwarf birch (*Betula fruticosa*) communities; 3-4 – woody herb-tussock sedge swamps – 'sogras' (*Betulo fruticosae–Pinetum sylvestris*); 5 – willow-grass communities; 6 – open and birch-wooded willow-tussock sedge communities (*Carici juncellae–Salicetum rosmarinifoliae*); 7 – adjacent to riverbed 'sogras' (*Frangulo alni–Laricetum sibiricae, Betulo fruticosae–Pinetum sylvestris*).

Stratigraphy and the development history of the Southern taiga mires

Mires of the periglacial watershed plains

The stratigraphic structure and the main stages in the development of watershed peatlands of the West Siberian Southern taiga (periglacial zone) were studied in detail through the example of the Bakcharskoe mire. This mire stretches in a wide strip (10-25 km) for almost 200 km along the watershed of the Iksa and Bakchar Rivers to the north of the GVB main area [Lapshina et al., 2000a, b].

The age of the Bakcharskoe watershed bog in the deepest points was previously estimated as 8-9 ka [Neishtadt, 1977], based on the published absolute age data of the most ancient West Siberian organogenic deposits. On this basis, the rate of lateral mire growth was calculated from its inception to the present. According to our data, the absolute age of the eastern Vasyugan watershed mires is actually half the age that was previously assumed. Peat accumulation began at the end of the Atlantic and the beginning of the Subboreal periods (5.2-4.8 ka BP). The age of the most ancient paludificated areas with a peat deposit thickness 3.6-4 m is estimated as 5.5-6 ka, while the age of the most areas with a peat thickness 2.5- 3 m does not exceed 3.5-4 ka.

According to the spore-pollen analysis data, there were no significant changes in the forest types composition for the entire mire existence period; only the ratio of dark coniferous and deciduous species changed slightly [Levina, 1980; Blyakharchuk, Klimanov, 1989; Blyakharchuk, 2000, 2012], reflecting the regenerative dynamics of forests during pyrogenic (post-fire) successions. At the same time, the mire vegetation and the external appearance of the mire landscapes during this period have repeatedly changed dramatically.

Sedge-forb meadows and sparse forests with wet meadow vegetation under conditions of constant ground and periodical surface moisture occupied significant areas on the flat interfluvial spaces before the beginning of paludification process. At present, such landscapes are spread along the border between forest and forest-steppe zones of Western Siberia [Dyukarev et al., 2000]. The primary waterlogging centers were numerous small depressions, where vegetation consisted of ferns, sedge-ferns, sedge-reed, rarely of horsetail communities, open areas and sparse thickets of birch and willow. Accordingly, in the lower part of the peat deposit, the same-named herbaceous peat species were deposited, where content of woody residues did not exceed 5-15% (see Appendix 1, Fig. 5, A, B). After filling the primary depressions, the peat-forming process quickly moved on the flat watershed plateaus, where various types of sedge-grass peat began to be deposited on semi-hydromorphic highly wet meadow soils (see Appendix 1, Fig. 5, C). At the same time, the scattered primary paludification centers merge into a single peatland. The process proceeded so quickly that the soils did not have time to undergo any significant changes and went under peat in the form, and with the nutrients supply, that had been accumulated in their profile before the beginning of paludification [Lyubimova, Simakova, 1977; L'vov, 1991]. As a result, humified plastic clays underlay the peat deposits everywhere. The mineral nutrient soil richness ensured the development of uniform sedge, sedge-grass and sedge-reed communities throughout the watershed area.

The turning point in development of the watershed mires started when the peatlands reached the edges of the watershed plateau and came out onto the slopes of the interfluvial areas. By this time, the thickness of the minerotrophic peat deposit reached an average of 1-1.2 m, and in the genetic centers of primary depressions 1.5-1.8 m. Water and mineral nutrition depletion alongside the accumulation of peat deposits and a noticeable increase in the role of atmospheric precipitation in the nutrition, led to an abrupt change in the mire vegetation. In the central part of the mire, *Scheuchzeria*-sedge, *Scheuchzeria*-sedge-*Sphagnum*, and sedge-cotton grass-*Sphagnum* plant communities (*Carex limosa, Scheuchzeria palustris, Eriophorum vaginatum, Sphagnum fallax, S. flexuosum*), deposited a layer of mesotrophic peat species with a thickness of 0.4 -0.6 m (see Appendix 1, Fig. 5, A 2.2-2.7 m; B 2.0-2.5 m).

From the time when the peat mounds increased so much that they left the boundaries of the watershed plateau, the intensity of the territory paludification increased significantly and its mechanisms changed [L'vov, 1991]. The relatively free runoff of low-mineralized (acidic) mire waters along the peatland slope promoted the development of mesotrophic paludification of the dark coniferous and mixed forests around the mire. As a result, mesotrophic forested-shrub-sedge and forested-bog-herb-*Sphagnum* communities are wide spread along the periphery. They deposited bottom peat layers in the upper parts of the watershed mire slopes (see Appendix 1, Fig. 5, D 2.5-2.8 m).

At the turn of the Subboreal and Subatlantic periods (about 2.5-2.7 ka BP), the eastern part of Vasyugan watershed mires passed into the oligotrophic (ombrotrophic) development stage. The beginning of this stage is marked by spreading of watered *Shagnum* and cotton grass-*Sphagnum* mires (*Sphagnum divinum, S. papillosum, S. balticum*) on the most peatland, while oligotrophic Scots pine-*Sphagnum* communities (*Pinus sylvestris, Sphagnum angtifolium, S. divinum*) spread on periphery of peatlands (see Appendix 1, Fig. 5, D 1.7-2.5 m). The ratio of the main type areas of the peatland landscapes during the Subboreal period did not stay constant. In dry periods, when the water content of the watersheds decreased, Scots pine-*Sphagnum* communities from the periphery extended far to the center of the mire, depositing cotton grass-*Sphagnum* peat (see Appendix 1, Fig. 5, B 1.2-2.0).

Raised bog with ridge-pool complexes, ridges-pool-waterlogged hollow complexes and ridges-hollow complexes began to form in the central part of the peatlands about 1500-1000 years ago. The ridges are formed by stunted Scots pine-dwarf-shrub-*Sphagnum* communities (*Pinus sylvestris* f. *Litwinowii, Ledum palustre, Chamaedaphne calyculata, Sphagnum fuscum*), called 'ryam' in Siberia. The vegetation cover in the waterlogged hollows is formed by mosaic of oligotrophic cotton grass-*Sphagnum*, and sedge-*Scheuchzeria*-*Sphagnum* communities (*Carex limosa, Scheuchzeria palustris, Rhynchospora alba, Sphagnum balticum, S. jensenii, S. majus, S. jensenii, S. papillosum*). Oligotrophic complexes form complex *Sphagnum* peat. The total thickness of oligotrophic *Sphagnum* peat overlapping a layer of transitional peat reaches 1.5-2.0 m.

In the last 500-1000 years, 'ryams' have begun to play a more prominent role in the landscape structure of the mire complexes. They develop mainly on the gentle slopes of watershed plateau peatland and deposit homogeneous, weakly decomposed *Sphagnum* peat, composed of remains of *S. fuscum* (see Appendix 1, Fig. 5, C 0-1.2 m).

In the Subatlantic period, the peatland hydrographic network was finally formed through the development of the surface watershed inverted relief, and the drainage network of the peat mound watersheds slopes formed. The tallest mineral ridges remained among the peatlands as insulated islands of forests, longer than other areas, begin to waterlog. As the peat deposit grows and the level of peatland water rises, the mineral ridge became paludified. Stagnant and through-flow shallow-peat fens, known in Siberia as 'galya', are formed. Over such fens, water discharged from the raised peatland areas into the river network and there formed the river and stream heads of local catchments. The vegetation cover of such through-flow fens is represented by mesotrophic and mesooligotrophic sedge-*Sphagnum*, less often horsetail-sedge-*Sphagnum* plant communities (*Carex rostrata, C. lasiocarpa, C. limosa, Equisetum fluviatile, Sphagnum fallax, S. majus, S. obtusum*). In some places, the remains of cattail (*Typha latifolia*) confined to the water horizons inside the peat deposit are found. Peat deposits do not exceed 1-1.5 m and have a simple stratigraphic structure (see Appendix 1, Fig. 5, F). *Sphagnum* and sedge-*Sphagnum* peat types are deposited here, composed of the *Carex rostrata, C. limosa, Sphagnum fallax, S. obtusum*, less often *Equisetum fluviatile, Comarum palustre* remains.

Today, the paludification process of the marginal strip occurs in different ways depending on the surface slope relief of the interfluvial spaces, determining the paludification mechanism and ultimately expressing the vegetation nature and structure of the peat deposits. At the peatland – low mineral shore contact zone, when bog waters spread over the surface – eutrophic paludification of dark coniferous forests around peatlands takes place. These paludified coniferous forest mire types ('sogra') deposit the minerotrophic woody peat of a high decomposition degree.

The paludification process of the mineral shore elevated areas is caused by oligotrophic bog water, immediately determining development of the raised bog type's paludification process. In such conditions, oligotrophic pine-dwarf shrub-*Sphagnum* communities develop directly in place of dark coniferous or mixed forests, depositing raised bog cotton grass-*Sphagnum* peat (see Appendix 1, Fig. 5, F). As a result, the peripheral areas with a peat thickness of 1-2 m and the zone of modern paludification of watersheds, covered by weakly raised watershed peatlands, are characterized by a high spatial heterogeneity of the peat deposit types with their relatively simple stratigraphic structure.

Thus, in the West Siberian South taiga forest zone, in the area of widespread carbonate mantle loams, the mire development preceded the eutrophic paludification process, which implies a long-term development of herbaceous forb-sedge landscapes of the wet meadow type. According to radiocarbon dating, the watershed peatland's age turned out to be significantly younger than previously assumed. Initial areas of peat accumulation, playing a significant role in the watershed landscape, appeared only at the end of the Atlantic-beginning of the Subboreal period 5.2-4.8 ka ago [Blyakharchuk, 2012]. Until the end of the Subboreal, the landscape structure of the peatlands was poorly differentiated. From the time when the watershed mires spread to the slopes of interfluvial spaces, they divided into the open central part and wooded periphery. In the paludification zone, different types of peat deposits and mire plant communities were formed in accordance with the surface relief and the difference in the conditions of water-mineral nutrition. As the peat deposit grows and the area of mires increases, a regular shift of the landscape unit boundaries between the outskirts is observed.

The mire structure and development of the small river valleys

The features of the peat mires' stratigraphic structure in the valleys of small rivers within the Vasyugan Plain were studied in the Semenovskoe mire example [Bleuten, Lapshina, 2001]. This mire is located 17 km north of the village of Plotnikovo on the left bank of Iksa River. The stratigraphic profile, crossing the peatland from the external valley side to the river, passes three flat depressions oriented along the channel. The thickness of peat deposits along the profile varies from 1.3 to 5.5 m (Fig. 5).

The mire development started almost simultaneously by overgrowing two shallow lakes by aquatic plants in the middle of the Atlantic period about 7.1-7.2 ka BP. However, just two thousand years later (about 5 ka BP), the mire filled the transverse profile of the valley, reaching its present size. An extensive open brown moss fen with *Meesia triquetra, Calliergon* spp., *Hamatocaulis vernicosus, Drepanocladus sendtneri* occupied the entire central part of the valley, starting from the first bog development stages. In conditions of water-mineral supply constancy by pressurized ground water, they dominated for a long time and deposited a homogeneous 3-4 m layer of brown moss peat.

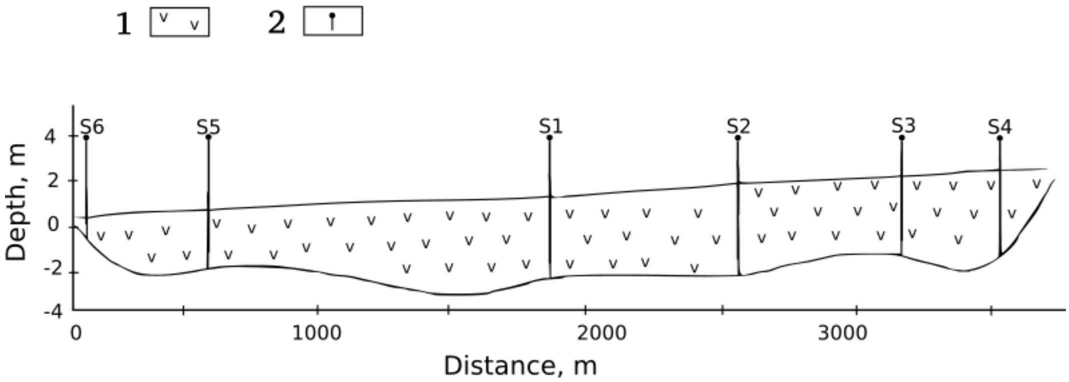

Figure 5. Profile of peat deposits of the Semenovskoe mire on the left-bank valley of the Iksa River ('Borodinsk' key area, Southern taiga subzone).

Legend: 1 – peat; 2 – drill locations with number.

In the last 1.5-2 thousand years, the vegetation of open brown moss fens gave way to lowland sedge-*Sphagnum*-brown moss (*Carex lasiocarpa, C. diandra, Sphagnum warnstorfii, Tomentypnum nitens, Aulacomnium palustre*) communities. This vegetation was replaced by birch shrub (*Betula nana*)-*Sphagnum* (*S. warnstorfii*)-sedge (*Carex lasiocarpa*), which appeared initially in parts of the peatland farthest from the river (see Appendix 1, Fig. 6, S1-S3). Later, open sedge-brown moss fens began to be actively occupied by stunted trees. At present, sedge-*Sphagnum* communities, wooded with low birch and pine, cover about half of the area of the once open brown moss fens.

The peat deposit stratigraphy along the peatland edges has a complex structure. Despite the similar absolute age (5530 ± 80 and 5640 ± 50), the thickness of peat deposits at different profile ends was 1.3 and 5.1 m (see Appendix 1, Fig. 6, S4, S6) due to a sharp difference in conditions of peat accumulation, under conditions of stable groundwater moistening in the part of the peatland adjacent to terrace slope. The rate of peat accumulation was four times higher than on the mire periphery facing the river, where oxygen-rich water – regularly supplied with melted snow and river water – promoted active decomposition of accumulating peat. In addition, in dry seasons, the edge of the bog facing the river could dry out and be exposed to fires.

The lower part of the peat deposit near the river valley slope, initiated in the dry period of the climatic rhythm, is featured by the alternation of woody and grassy peat types formed by remains of *Menyanthes* and fern, reflecting repeated changes of open and weakly wooded sedge-moss and forest like 'sogra' mire communities. These successions took place due to changes in the groundwater and run-off water supplying the mire. In the subsequent high-water period of the climatic rhythm, the area of open and weakly wooded communities and dwarf birches thickets significantly expanded. They reached the edges of the river valley, dominating there to the present day, depositing sedge-brown moss and herb-brown moss peat types (see Appendix 1, Fig. 6, S4).

The peripheral part of the peatland facing the river is featured by the predominance of woody 'sogra' peat in combination with numerous thin layers of herbaceous peat types from the remains of horsetail, *Menyanthes* and fern. To identify the real stratigraphic structure of the peat deposit and its relationship with paleoecological conditions in this part of the peatland, it is necessary to increase the frequency of peat sampling analysis to 2-5 cm (see Appendix 1, Fig. 6, S6).

Stratigraphy and history of the bog development in the Middle taiga

A detailed study of the stratigraphy and development history of peat deposits in the Middle taiga zone was carried out on a large representative ombrotrophic peatland. The peatland, known as the Savkino mire, is located 5 km southeast of the city of Nizhnevartovsk on the right-bank terrace of Vakh River near the confluence with the Ob' River. The mire arose about 10 ka BP by peat formation in insular depressions in gullies (thalweg) of the ancient glacial water runoff. The mire became a separate ombrotrophic peatland area with a chain of mineral islands on the place of the highest ridge (ancient coastal wall) about 7 ka BP [Lapshina, Pologiva, 2011].

At present, about 75% of the peatland area is occupied by large ridge-hollow and ridge-hollow-lake oligotrophic complexes. A noticeably smaller area (about 15-20%) on naturally drained, slightly convex areas is occupied by pine-dwarf shrub-*Sphagnum* plant communities – 'ryams'. About 5-10% of the area is covered by open sedge-*Sphagnum* and dwarf-shrub-sedge-*Sphagnum* peripheral fens (laggs), which develop in a zone of present paludification along the edge of the mire and around mineral islands. Detailed radiocarbon dating of the peat deposits indicates that the peat accumulation began between 10.3 and 9.2 ka BP. At the same time, two thousand years after beginning of peat accumulation, the mire has almost reached its present size. Only narrow, marginal parts of the bog were covered with peat during the last 1000-1500 years (Fig. 6; Appendix 1, Fig. 7).

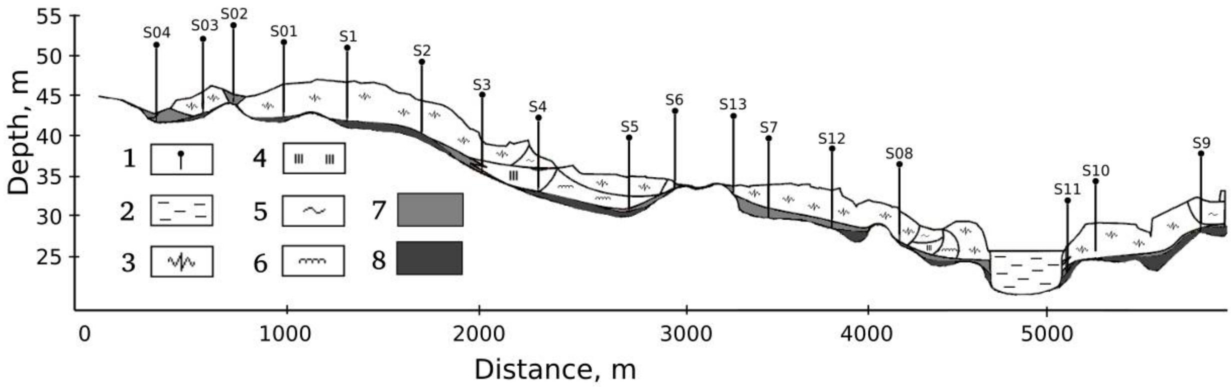

Figure 6. Stratigraphic section of the Savkino mire in the right-bank part of the Vakh River in the vicinity of Nizhnevartovsk (Middle taiga subzone).

Legend: 1 – sampling points of peat cores and their numbers, 2 – lake water; 3-8 – types of peat: 3 – *Sphagnum fuscum*-peat, 4 – raised bog and transitional *Sheuchzeria* peat, 5 – *Sphagnum* hollow peat, 6 – *Sphagnum* raised bog peat, 7 – cotton grass peat, 8 – minerotrophic-herbaceous and woody-herbaceous peats.

Within the main peatland area, the average peat depth varies from 3.5 to 4.5 m. The maximum peat thickness (4.0-5 m), is found in the genetic centers. The peat depth on slopes of peat mound, where the peat accumulation began 1-1.5 ka years later, differs insignificantly in range 3.6-3.8 m. The minimum peat depth is found on the periphery (0.6-1. 2 m). The peat deposit in the genetic centers (see Appendix 1, Fig. 7, NV2, NV74(12)) almost on the entire depth is composed of raised bog *Sphagnum* peat of weak (0-5%) or moderate (10-25%) decomposition degree. In the upper part, the peat deposit is composed by remains of *Sphagnum fuscum*, and in the lower part, by alternating layers of *Sphagnum fuscum* and *S. angustifolium* peat, with a greater or lesser admixture of cotton grass (*Eriophorum vaginatum*). The bottom layer, 20-60 cm thick, is composed of well-decomposed woody-herbaceous and herbaceous peat from the remains of spruce, birch, horsetail, and fern. The decomposition degree of this layer reaches 60-65%. The transitional horizon between the minerotrophic and raised bog (ombrotrophic) peat layers in the bog genetic centers usually does not exceed 10-20 cm, rarely 50 cm. This layer is usually represented by transitional cotton grass peat. Peat deposits on the slope locations (see Appendix 1, Fig. 7, NV7, 8) adjacent to genetic centers are 7.3-8 thousand years old. Peat accumulation began here directly with the deposition of transitional, usually cotton grass peat with thickness 50-60 cm. The upper peat deposit, as well as the genetic centers, is composed of ombrotrophic *Sphagnum* peat.

The peripheral parts of the peatlands are aged between 2.3 and 1.0 ka BP. The peat deposit of the peripheral fens, developed along the boundaries of the peatland, is entirely composed of transitional (cotton grass, cotton grass-*Sphagnum*, *Sphagnum*) peat type (Appendix 1, Fig. 7, NV04). In the transit through-flow fens surrounding insulated mineral islands, peat deposits are represented by transitional and raised bog peat types (Appendix 1, Fig. 7, NV51(6), NV61-62(13)).

CONCLUSION

This paper has reviewed the main stratigraphic structure types and the development history of peat deposits in different subzones and landscape-geomorphological positions of the southern part of the West Siberian Plain. The oldest primary initial areas of the early Boreal peat-forming process within watersheds and river valleys are associated with the remains of the ancient hydrographic network and the deepest thalweg of ancient runoff gullies. The beginning of paludification of the Western Siberian plain, as noted by many authors, belongs to the ancient Holocene [Tyuremnov, 1957; Neyshtadt, 1977; Khotinsky, 1977, etc.]. It is generally assumed that, the formation of proper peat deposits began only in the Boreal period. Peat mires of more ancient age are rare, and the peat layers with an absolute radiocarbon (uncalibrated) age of more than 9 ka are mostly represented by lacustrine (gyttija) sediments or ancient soil formations of the hydromorphic series. Recent data on the age of peat deposits in Western Siberia, obtained by dating small samples using accelerators, often turn out to be more older 10.5-11(12) ka [Pitkänen et al., 2002]. The most ancient peat deposits on the left bank of the Yenisei near the village Zotino [Schulze et al., 2015] and on the left bank terraces of the Irtysh in its lower reaches (Mukhrino bog, unpublished data) are 11-12 ka old according to the Max Planck Institute Radiological Laboratory in Jena, Germany.

The formation of primary initial peat accumulation areas at the end of the Pre-Boreal and in the first half of the Boreal period began almost simultaneously within the taiga zone and the present Subarctic zone of Western Siberia. Much later, peat formation began in the extreme north and south of the West Siberian plain. The age of the Arctic zone polygonal mires, apparently, does not exceed 3-3.5 ka [Novikov et al., 1999]. In the forest-steppe, the most ancient isolated ‘ryams’ date to the beginning of the Subboreal, and the reed marshes (‘zamishcha’) to the beginning of the Subatlantic period [Liss, Berezina, 1978].

Two main models in the development of peatlands are distinguished in the evolution of mires in the taiga zone depending on the origin centers [Lapshina, 2004]. The mires of the first model of development originated in various depressions of non-floodplain surface types (interfluvial areas, river terraces, gullies of ancient runoff). They emerge from the influence of groundwater and surface runoff water and pass into an autonomous development stage, becoming independent of adjacent landscapes. The conditions of water-mineral nutrition and development dynamics at the later stage are associated exclusively with the dynamics of the moisture and aerosols income, and from the atmosphere.

The second development model is typical for mires, which throughout the history of their development occupied geochemically subordinate relief positions (river floodplains, ravine bottoms, slope bases). A distinctive feature of their development is the absolute predominance of changes caused by external factors. The influence of the external environment on the mires of this group is expressed mainly in the change of the water inflow to the peatland. This inflow contains several components, but ultimately depends on the amount of precipitation forming the soil-ground and river runoff.

The development history of the floodplain mires is closely related to the dynamic of the general moisture content depending on the regional climate and changes in the river discharge over the entire existence period. In the formation process of the alluvial deposits in the local lowered floodplain areas, conditions favorable for the mire development and peat accumulation were regularly created, but the peat mires’ formation was prevented by the alluvial-floodplain river regime. These two processes are antagonistic, and peat accumulation occurs only when the alluvial regime is absent or weakly expressed. Peat mires in the large river floodplains arose in one of the dry periods at the early development stages. During the entire subsequent time, the peat deposits’ growth in areas adjacent to terraces, and the accumulation of alluvial sediments in the near-channel and central parts of the floodplain, proceeded parallel, making up a complex sedimentation process.

The development of watershed mires proceeded through eutrophic paludification in most of the South forest zone of Western Siberia, with widespread carbonate mantle loam. Numerous initial areas of peat accumulation appeared here at the end of the Atlantic and beginning of the Subboreal periods. Until the end of the Subboreal, the peatland landscape structure was poorly differentiated. Only after the watershed peatlands reached the slopes of the interfluvial spaces, due to lateral space growing, they were divided into an open central part and a wooded periphery.

On the relatively poor sandy soils of the central part of Western Siberia within the Middle taiga (the Savkino mire, Salym-Yugan mire system, Mukhrino, Zotino), the first peat accumulation centers, confined to the thalvegs of the ancient hydrographic network, appeared 10-11(12) thousand years ago [Pitkänen et al., 2002; Schulze et al., 2015]. Here, already at the end of the Boreal period, most of the interfluvial spaces and river terraces peat mires passed into the oligotrophic stage of the development of atmospheric water supply.

A detailed study of the peat deposits' stratigraphy in Western Siberia shows that the climate has a significant impact on the development of all types of mire throughout the Holocene, but the degree and form of links between mire and climate varied significantly. There is a certain asynchrony of the appearance and development of floodplain and upland mires; if the floodplain mires appear during dry periods, the upland mires' emergence and development are associated with the maximum climatic humidity.

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