Dynamics of peat accumulation processes in the areas of the periglacial zone of the basin watershed of Tugur-Nimelen rivers

V V Chakov1*, E V Parkhomchuk2,3, and E N Zakharchenko1

1 Institute of Water and Ecology Problems of Far East Branch of the Russian Academy of Sciences, Khabarovsk Federal Research Center of Far East Branch of the Russian Academy of Sciences, 56 Dikopolsteva Street, Khabarovsk, 680021, Russia
2 Novosibirsk State University, 2 Pirogova Street, Novosibirsk, 630090, Russia
3 Institute of Archaeology and Ethnography of the Siberian Branch of the Russian Academy of Sciences, 17 Academician Lavrent'ev Avenue, Novosibirsk, 630090, Russia

*Corresponding author’ e-mail: Chakov@ivep.as.khb.ru

Abstract. The paper considers the features of waterlogging of a flat watershed, unique in its structure and evolution, between the valley complexes of the two largest watercourses of Khabarovsk Territory. The Tugur and Nimelen rivers had rather powerful debit of water flows during the Pleistocene and were repeatedly redirected from the northern azimuth (the Sea of Okhotsk) to the southern one (the Amur catchment). This process continued partly at the early stages of the Holocene, as the stratigraphy of the peat deposits of the bogs formed indicates here.

1. Introduction
The area under study is confined to the Evur-Nimelensky depression, extending from south to north from the Chukhagirskoye lake to the Tugursky Bay of the Sea of Okhotsk. In geomorphological terms, it is an accumulative plain with ridges of hummocks and low island mountains, rising 30–80 m above flattened boggy areas with absolute elevations (70±5 m) in the valleys of the Simitka and Nimelen rivers. Within the flat boggy watershed of Tugur-Nimelen rivers surface elevations reach values of 100 m.

In the west of the study area lie the mountain ranges Dusse-Alin and Yam-Alin, from the eastern spurs of which the rivers Kerbi and Nimelen originate, classified as a part of the system of a large left tributary of the Amur – the Amgun.

The accumulation of sedimentary rocks of light texture (pebbles with an admixture of gravel with sand, less often loamy, filler) in the valley of the Semitka River mainly happened in the Middle Pleistocene. Subsequently, they were overlain by Upper Pleistocene alluvial deposits with interlayers and lenses (up to 3.5 m thick) of sands, loams and clays [1, 2]. Most often, sand lenses (with an admixture of pebbles and gravel) are noted in the upper part of the sedimentary cover. The exposed thickness of such rocks here is about 27 m. In the Tugur part of the depression, sands with pebbles and nests of loams were uncovered in a member to a depth of 22 m.
For the Upper Pleistocene, the most pronounced stage of sedimentation is associated with the Kar- zantsevo interglacial, noted in the interval from 125 to 95 thousand years ago [3]. Judging by the palinological data of these deposits, which are dominated by thermophilic forms ( Juglans, Ulmus, Quercus), this was the most optimal climatic period for this territory and for the region as a whole. A significant warming of the climate in the indicated interglacial intensified thermokarst phenomena as well as the melting of huge mountain snowfields and flat surfaces, which led to intensive sedimentation in depressions and lowlands.

The large-scale overlapping of Pleistocene frozen sedimentary rocks by organogenic deposits in the area under consideration dates back to the early Holocene, when favorable paleoclimatic conditions were created here for the formation of wetland ecosystems. At the same time, the centers of bog formation arose both directly in aquatic bodies (the formation of rafters, the accumulation of phyto- and zoobenthos), and in areas of waterlogged land (the settlement of hydro-hygrophytes).

2. Materials and Methods

An extensive bog massif with oligotrophic and meso-oligotrophic complexes of phytocenoses on the considered flat boggy watershed reaches 8 km in diameter, and in length is about 10 km located almost linearly along the valleys of the Nimelen (south) and the Tugur (north) rivers (Fig. 1). The study of bog ecosystems within its boundaries was carried out by means of geobotanical research of the vegetation cover structure using methods generally accepted in bogology, enabling to identify and characterize in detail the most typical biotopes for the entire massif. The description of vegetation by tiers was carried out on plots under study with an area of 100 m² by assessing the projective cover of vascular plants and sphagnum mosses [4]. The Latin names for bryophytes are given in accordance with the list of mosses of Eastern Europe and Northeast Asia [5], vascular plants according to the approved lists [6]. The sounding of peat deposits and sampling for botanical analysis were carried out with an Instorf drill in accordance with the genetic structure of the deposits. The species identification of sphagnum mosses, as well as the botanical composition of peat was carried out using a Nikon LV 100 POL optical microscope.

The vegetation cover of bog massifs, judging by the color scale and structure of the picture on satellite images (Fig. 1), is not uniform. The hydrophilic plant communities that form in hollows in the immediate vicinity of lakes and lakelets are characterized by a two-tiered (shrub-grass and moss) structure of phytocenoses. In contrast to them, phytocenoses represented on sphagnum carpets and ridges usually have all four tiers: arboreal, shrub, dwarf-grass and moss. Moreover, in the first case the shrub-dwarf-grass layer covers 45% of the surface and is usually formed by Menyanthes trifoliata (10%), Pedicularis palustris (10%), and Carex limosa (10%). Eriophorum vaginatum, Iris laevigata, and Vaccinium microcarpus each occupy 5%. Droseras (Drosera rotundifolia and D. anglica), Chamaedaphne calyculata, Andromeda polifolia may be present sporadically here. In the moss layer with 100% hollow coverage, Sphagnum jensenii accounts for 70%. Also, S. flexuosum and S. aongstroemii are added in equal shares of 15% of the coverage. The latter gravitates towards barely expressed cushions and ridges. For carpets and ridges, sparse Larix gmelinii of a depressed form and up to 3 meters in height and Pinus pumila clumps of up to 5 m² and 2.0–2.5 m high are characteristic. The shrub-grass layer occupies up to 45% of carpet surfaces, ridges and cushions with a height of 25–35 cm with a compacted peat deposit. Here, Rubus chamaemorus accounts for 10%, Chamaedaphne calyculata – 10%, Ledum palustre – 10%, Vaccinium microcarpum – 10%, Eriophorum sp. – 5%, Drosera rotundifolia – singly. The projective cover of the moss-lichen layer is 100%, of which 5% are lichens, 95% are sphagnum mosses, among which S. fuscum accounts for 15%, S. lenense – 20%, S. rubellum – 5%, S. papillosum – 3%, with admixture of S. divinum.

Radiocarbon dating of peat was performed using the accelerator mass spectrometer (UMS) of the Institute of Nuclear Physics of the Siberian Branch of the Russian Academy of Sciences at the Centre for Collective Use “AMS Golden Valley” [7]. The conversion of the radiocarbon age to the calendar date was carried out using OxCal software [8].
3. Results and Discussion

With the development of bog massifs with a central oligotrophic type, the thickest peat deposits, as a rule, are localized in areas with maximum hypsometric levels, which are watersheds. It is in such areas that peat samples are taken for botanical composition and radiocarbon analysis for paleoreconstruction of hydrological and natural-climatic conditions for the development of the objects under study. In this case, the sampling point of peat was located 350 m south of the Perevalnoye lake in the area of an oligotrophic bog with a fairly dense peat deposit. The results of their analysis are displayed in Fig. 2, which shows the stratigraphic column of the peat deposit with the values of the degree of decomposition of phytodetritus, its composition and the proportion of plant residues, as well as the moisture indices of the peat substrate.

The lower layer of the peat deposit located in the depth interval 200–270 cm, lying on the gley loam, has extremely high values of the degree of decomposition (80–95%) of phyto- and zoodetritus. Its formation took place over the course of about 3,050–3,270 years (the entire Boreal period), which
is considered the warmest segment of the Holocene in the Far East. It was during this period that the intensive melting of the rudiments of mountain glaciers and snowfields of Yam-Alin and, as a consequence, extremely high floods in the valleys of the Tugur and Nimelen rivers occurred. Thus, in the warmest season, the watershed territory turned into a relatively large body of water. This is evidenced by the inclusion of sapropels (up to 20%) in the composition of this peat layer.

![Figure 2. Stratigraphy of the peat deposit in the central part of the flat boggy watershed of the Tugur-Nimelen rivers and its characteristics.](image)

Peat types: 1 – high-moor-sphagnum peat, 2 – high-moor herbal-sphagnum peat, 3 – high-moor dwarf shrub-herb-sphagnum peat, 4 – transitional sphagnum peat, 5 – transitional herb-sphagnum peat, 6 – transitional hypnum-sphagnum-herbal peat, 7 – low-moor herb-sphagnum peat, 8 – clay. Peat-forming matter: 9 – phyto- and zooplankton, 10 – chalcoal, 11 – green mosses, 12 – sphagnum, 13 – wood; 14 – herbs, 15 – dwarf shrubs, 16 – shrubs; 17 – decomposition degree; 18 – wetness index; 19 – radiocarbon age, cal. yr bp

The lacustrine stage of bog formation within the boundaries of the modern watershed changed to a dry one due to a decrease in the intensity of floods in watercourses on the one hand, and a more significant erosional incision of the channels, on the other. The first phenomenon is due to the paleoclimatic cooling (°C was below the present by 1.5–2.0 ° C) at the turn of the Atlantic and Subboreal periods, the second one is due to the light texture of the rocks of the alluvial Nimelen plain. Judging by the degree of dispersion of plant residues formed in the next three layers of peat with a total thickness of 75 cm, the microbiological activity in them during that period has significantly slowed down. This is evidenced by a drop in the degree of decomposition of peat from 90% to 40%. During this period of about 3,000 years, the composition of the main peat-forming plants in phytocenoses of that period also changed significantly. So, if the stage began with the formation of eutrophic hypnum-sphagnum-herbal phytocenoses, it ended with oligotrophic sphagnum formations in the date interval of 2,402–2,055 years ago at the beginning of the Sub-Atlantic period.

The next 50 cm of peat were forming until the middle of the Sub-Atlantic period over the course of about 1,200–1,375 years. During this period, three layers of oligotrophic peat species with different proportions of inclusions of remains of dwarf shrubs, herbaceous plants and meso-oligotrophic sphag-
num mosses were formed here. At the same time, the total proportion of remains of herbaceous plants and shrubs does not exceed 20% in these layers. Common to them is a higher degree of decomposition of phytodetritus, which indicates warmer and drier paleoclimatic conditions of that period within the boundaries of the flat boggy watershed.

The last stage of peat accumulation is represented here in two layers. The lower one, 5 cm thick, is a kind of transition from the stage of the shrub-grass-sphagnum meso-oligotrophic type of peat to the almost monotypic oligotrophic one. During its formation, the degree of decomposition of phytodetritus in it decreased from 50% to 30%, against the background of a significant decrease in paleophytocenoses of herbaceous plants by about 15% and shrubs up to 10%. From the authors’ point of view, this phenomenon is associated with the transition of the bog massif completely to atmospheric water supply with an extremely poor composition of mineral substances. The top layer of peat, 60 cm thick, fully corresponds to the modern plant composition of oligotrophic sphagnum bogs in the area under consideration. The main feature of peat accumulation in this particular case under consideration is the pronounced stability of peat moistening and, as a consequence, a relatively low degree of destruction of sphagnum detritus.

4. Conclusion
The uniqueness of the bog massif under consideration on the flattened watershed of the Tugur-Nimelen lies in its lacustrine genesis at the initial stage of formation. Judging by the fact that the lacustrine stage of bog formation fell on the warmest periods of the Holocene, the conclusion about the periglacial nature of excess moisture in the territory under consideration suggests itself. The same feature is indicated by ridge-hollow and lakelet-ridge-hollow bog complexes located on surfaces with weakly expressed slopes. The latter are characterized by the manifestation of cryogenic solifluction phenomena in the form of the formation of peculiar ridges and depressions oriented across the main slopes (runoff lines).

Acknowledgments
This work was supported by the Center for International Forestry Research (CIFOR) in close collaboration with the Ministry of Agriculture, Forestry and Fisheries, Japan (MAFF) and the CGIAR (LoA dated July 10, 2020; LoA dated June 9, 2021), and also by the Ministry of Science and Higher Education of the Russian Federation (state assignment theme No. 0294-2019-0001).

ORCID IDs:
V V Chakov, https://orcid.org/0000-0001-9939-4289
E V Parkhomchuk, https://orcid.org/0000-0003-2200-884X
E N Zakharchenko, https://orcid.org/0000-0002-3918-8878

References
[1] Ganeshin G S 1972 General patterns of development of the river network of the East of the USSR Problems of the study of the Quaternary period (Moscow: Nauka) pp 404–10
[2] Ganeshin G S, Soloviev V V, and Chemekov Yu F 1972 Paleogeography of the territory of the USSR in the Quaternary period Problems of the study of the Quaternary period (Moscow: Nauka) pp 372–8
[3] Alekseev M N and Druschchits V A 2001 Climatic events of the Kazantzevo interglacial and Holocene of the eastern part of the Russian shelf and Siberia Bull. Comm. Study Quat. Period 64 pp 78–88
[4] Field Geobotany 1972 V 4 Ed. E M Lavrenko and A A Korchagina (Moscow, Leningrad: Nauka)
[5] Ignatov M S, Afonina O M, Ignatova E A et al. 2006 Check-list of mosses of East Europe and North Asia Arctoa 15 pp 1–130
[6] Vascular plants of the Soviet Far East 1986–1996 vol 1–8 (Leningrad: Nauka)
[7] Parkhomchuk V V, Rastigeev S A 2011 Accelerator mass spectrometer of the center for collective use of the Siberian Branch of the Russian Academy of Sciences J. Surf. Invest. X-ray, Synchrotron and Neutron Techniques 5(6) pp 1068–72