ISSN 1064-2293, Eurasian Soil Science, 2013, Vol. 46, No. 1, pp. 15–27. © Pleiades Publishing, Ltd., 2013.
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GENESIS AND GEOGRAPHY OF SOILS

Buried Late Holocene Paleosols of the Nienshants Cultural–Historical Monument in St. Petersburg

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Received April 19, 2011

Abstract—Buried Late Holocene paleosols of the Nienshants historical monument at the junction of the Neva and Okhta rivers (St. Petersburg) have been studied. These soils developed from estuary deposits of the Littorina basin with abundant artifacts of the Neolithic and Early Iron ages (7–2 ka BP). The soil cover of the area consists of the mature dark-humus profile-gleyed soils on elevated elements of the mesotopography (3.0–3.5 a.s.l.) and dark-humus gley soils in the local depressions (2.0–2.6 m a.s.l.). The soils are characterized by the low to moderate content of humus of the fulvate–humate type. The beginning of humus formation in the dark-humus gley soil on the slope facing the Neva River is estimated at about 2600 yrs ago; for the dark-humus profile-gleyed soils of the studied paleocatena, at about 2000 and 1780 yrs ago; and for the dark-humus gley soil, at about 1440 years ago. Judging from the spore–pollen spectra, the development of these soils took place in the Subatlantic period under birch and pine–birch forests with the admixture of spruce and alder trees. The gleyed horizons of the buried soil at the depth of 1.6–1.2 m on the Neva-facing slope date back to the Late Subboreal period (2500–2600 yrs ago), when pine–birch–spruce forests were widespread in the area. The new data contribute to our knowledge of the environmental conditions during the Neolithic and Iron ages.

Keywords: Artifacts of the Neolithic and Early Iron ages, dark-humus profile-gleyed soils, dark-humus gley soils

DOI: 10.1134/S1064229313010079

INTRODUCTION

The study of buried soils in the area of the junction of the Neva and Okhta rivers in St. Petersburg is of great interest, as this site is considered to be a unique object of cultural heritage for the entire northwestern Russia. In the recent years, large-scale archaeological investigations of the Neolithic, Early Iron, and Medieval epochs have been conducted there [11, 26, 27]. The presence of artifacts in the Middle and Late Holocene deposits in this area necessitates thorough paleogeographic and paleosol studies, because the layers with these artifacts are usually overlain by paleosols that have not been preserved in other parts of the city. Meantime, these paleosols serve as a valuable source of information on the paleoenvironmental conditions in the Late Holocene, during the Late Neolithic and Early Iron ages. The Late Holocene paleosols were developed from estuary deposits of the Littorina Sea after the connection between Lake Ladoga and the Finnish Gulf was established (i.e., after the appearance of the Neva River).

Several preliminary reports on these soils were published [9, 20, 21, 23]. We examined full-profile urban soils (that include the cultural layers and the buried paleosols and pedosediments) in the area of Bol'shaya Okhta; the morphogenetic characteristics of the buried soddy gley soils and their biological activity were studied [24, 37].

Before the recent anthropogenic development of this area that began in the 17th century (or in the 13th century), the soils had been developing as natural bodies. The paleogeographic information contained in them is important, as it characterizes the ancient history of this territory during the Iron Age. In our study, we tried to characterize the topography of the ancient paleosol surface; to estimate the beginning, duration, and stages of pedogenesis on different elements of the relief and on different parent materials (subaqual and subaerial); and to identify the major components of the soil cover and their genetic specificity. Simultaneously, we determined the character of vegetation and climate, their changes during the soil-forming

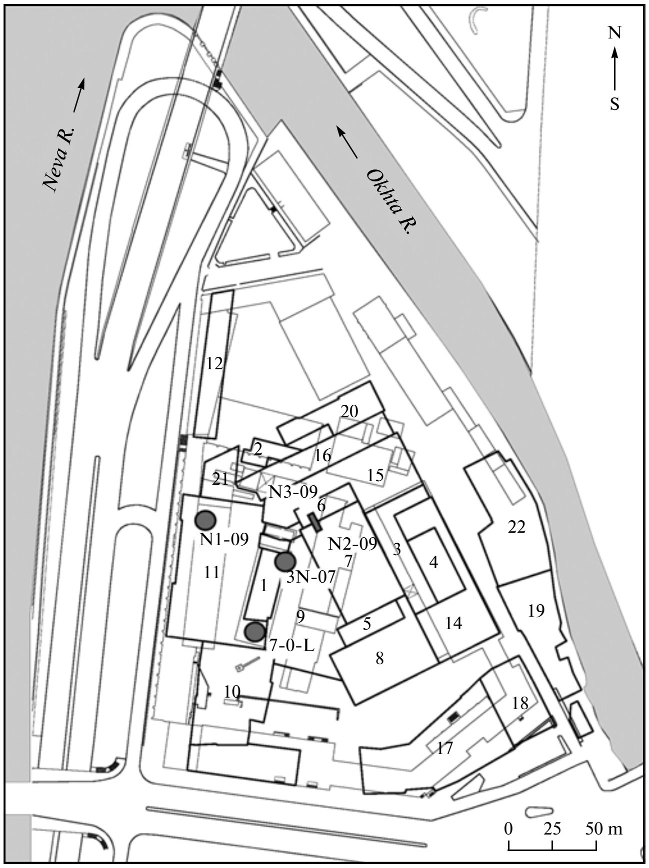

Fig. 1. Schematic map of archaeological excavations on the Okhta Cape (developed by the St. Petersburg Archaeological Expedition). The locations of separate pits of buried soils (3N-07 and N1-09), the paleocatena (pits N2-09 and N3-09), and the place with the charcoal layer (pit 7-0-L) are indicated.

period, and their potential effect on the life of ancient humans.

STUDY OBJECTS AND GENERAL GEOLOGICAL AND GEOMORPHIC SITUATION

The topography of the paleosol surface is characterized by three major features: (a) a general lowering of the surface from the south (3.0–3.5 m a.s.l.) to the north (2.0–2.5 m a.s.l.) of the studied territory, (b) the presence of a levee with absolute heights of about 3.0–3.5 m and with a width of several tens of meters stretching along the along the Neva in the north-northwestern direction in the western part of the plot (the Neva levee); and (c) the presence of several transverse (sublatitudinal) hollows and levees with the amplitude of heights of up to 1.0–1.2 m in the central part of the excavation. These features of the paleotopography predetermined not only the spatial differentiation of the buried paleosols but also the settling pattern of ancient people, including the location of their fishing plots.

It is known that before the appearance of the modern channel of the Neva River, this area was drained by the Pra-Tosna River. In the Middle Holocene, it was the major relief-forming river in this region. The formation of the western slope of the levee, the valley of the modern Okhta River, and the modern divide between the Neva and Okhta rivers took place during the outflow of the Neva River from Lake Ladoga about 3000 years ago (according to ^{14}C data) [16–19].

Archaeological artifacts in the thickness of sediments above sea level are found in the redeposited state, mainly in the coarse sandy layers to the east of the levee toward the bed of the modern Okhta River. On the western slope of he levee, only one thin sand layer without artifacts was described in pit N-09-1. We suppose that it was deposited during the outflow of the Neva River about 3000 years ago. Other layers in this pit are of the autochthonous genesis, which should be taken into account in the paleogeographic reconstructions.

Paleosols buried in the mouth of the Okhta River were studied in separate pits and in the paleocatena (Fig. 1). These soils mark the Medieval surface and are included in the profiles of modern urban soils with the upper allochthonous technogenic layer. The classification position of studied soils is given according to the new Russian soil classification system [8]. The depths of the horizons of the buried paleosols were measured from their surface (under the technogenic sediments).

Pit 3N-07 was examined in the southern part of the studied territory, at the northern end of archaeological excavation 1. At the depth of 1.5 m from the surface, under the covering layer of technogenic sediments, the paleosol surface can be clearly traced. It is inclined toward the west at about 8° and descends in this direction by about 1.5 ± 0.5 m at a distance of 5–8 m. This paleosol represents a loamy sandy dark-humus gley soil developing from the stratified fluvial loamy sands. The total thickness of the soil profile reaches 0.5–0.7 m and increases up to 0.8–1.0 m at the footslope of the levee without significant changes in the soil morphology.

Pit N1-09 (Fig. 2a) was excavated by us to the northwest of archaeological section 11, 20–30 m to the west of the Neva levee, i.e., on its gentle (1°–2°) slope facing the Neva River. The examined wall of the pit has a submeridional direction. The absolute height of the paleosol surface (under the layer of technogenic sediments) is 2.6 m a.s.l. This paleosol represents a light loamy dark-humus gley soil developing from sediments of the Littorina Sea.

Pits N2-09 (Fig. 2b) and N3-09 are found in the central part of the studied area, within a 9-m-long paleocatena (Fig. 3) on the western wall of archaeological excavation 6. The absolute height of the buried paleosol surface reaches 2.0 m. This paleosol is developed from the subaqual deposits with two cultural lay-

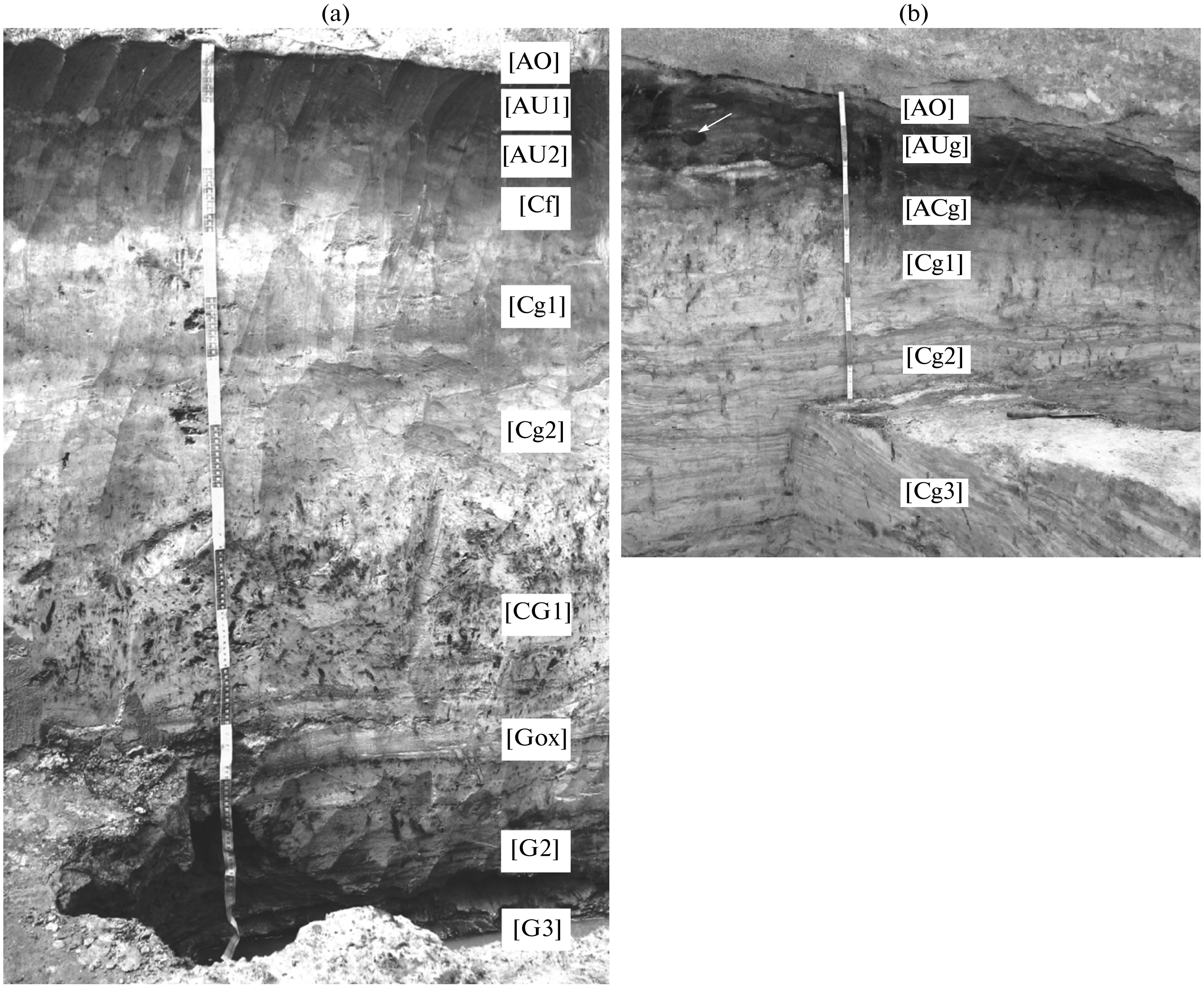

Fig. 2. Morphology of the profiles of (a) buried light loamy dark-humus gley soil (pit N1-09) and (b) buried light loamy dark-humus profile-gleyed soil (pit N2-09) developed from the basin deposits.

ers corresponding to the 7th–13th centuries AD (with chopped logs) and to the Neolithic Age. The paleosol surface has a distinct microtopography with small mounds and hollows. This paleosol represents a medium loamy dark-humus gley soil.

METHODS

In this study, we used the methods of geomorphology, paleopedology, and paleobotany with due account for the archaeological data. The results are presented in an integral way.

The soil particle-size distribution was determined by the pipette method with sodium pyrophosphate pretreatment (according to Kachinskii) [22]. The chemical and physicochemical properties of the buried soils were analyzed by standard procedures [2]. The group composition of humus was determined by the method of Kononova and Bel'chikova [10]. The radiocarbon age of the samples was determined in the extracted humic acids. This analysis was performed in the Raidocarbon Laboratory of the Institute of Geography of the Russian Academy of Sciences (headed by O.A. Chichagova) and in the Laboratory of Paleogeography and Geochronology of the Quaternary Period (headed by Kh.A. Arslanov) at St. Petersburg State University.

The palynological analysis was performed by standard methods. To separate pollen and spores, the soil samples were treated with HCl, NaOH, and heavy liquid KK-2.6 with the bulk density of 2.29 g/cm^3 [4]. Special atlases were used to identify spores and pollen from different plants [12, 13, 36]; we also used the collection of pollen preparations of the Palynological Laboratory of St. Petersburg State University. The palynological diagrams were developed with the use of TILIA and TILIA GRAPH software [34].

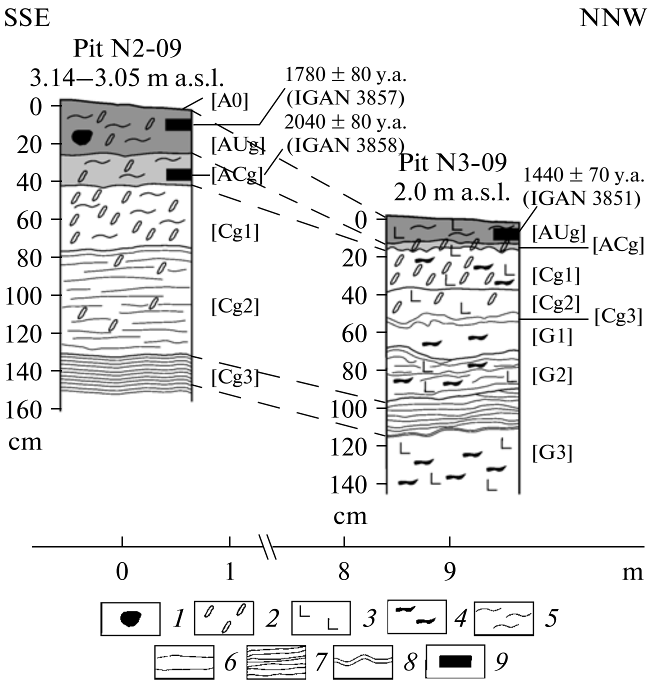

Fig. 3. Paleosol catena studied in archaeological excavation 6/2. The location of studied pits (N1-09 and N2-09) and the obtained radiocarbon dates are indicated. Conventional signs: (*1*) krotovina, (*2*) ferrugination along ancient root paths, (*3*) remains of ancient roots, (*4*) humified interlayers, (*5*) residual layering of the deposits, (*6*) thin (0.5–1.0) layering, (*7*) very thin (<0.5 cm) layering, (*8*) interlayers of coarse sand, and (*9*) location of samples taken for the radiocarbon dating.

RESULTS AND DISCUSSION

Morphogenetic analysis of buried paleosols. The studied soils belong to the orders of gley soils (pits 3N-07, N1-09, and N3-09) and organo-accumulative soils (pit 2N-09). The humus horizons are clearly pronounced in all of them; they are gradually replaced by the slightly altered estuary sediments. The pedogenic organization of the middle parts of the profiles is indistinct. The total thickness of the paleohumus gleyic horizons varies from 12 to 28 cm; the thickness of the entire humus layer (including the [ACg] horizon) varies from 22 to 41 cm. The lowest thickness of the humus layer was observed in pits 3N-07 and N3-09 to the east of the Neva levee, in the lower part of the soil paleocatena. The color of the humus horizons is dark gray to black; some layering of the material of these horizons can be seen. The upper parts of the paleosol profiles contain abundant charcoal particles and wood fragments; ferruginated zones are clearly seen along the roots; bleached quartz grains are present (Fig. 3). Often, the buried humus horizons contain paleokrotovinas, whose presence attests to the activity of small burrowing mammals and, hence, to relatively good drainage conditions.

A characteristics feature of the studied soil profiles (except for pit N2-09) is the presence of the organo-accumulative AO horizon in the topsoil. Though its thickness is small (1–2 cm), this horizon has an important diagnostic meaning. Its preservation in the upper part of the paleosol profiles attests to the absence of strong anthropogenic impacts (including plowing) on these soils and to the absence of strong erosional processes. It also allows us to trace the microtopography of the paleosol surface.

In all the pits, the middle-profile horizons are characterized by some initial lithogenic layering of the parent material partly destroyed by pedogenesis. The greatest thickness of the horizon with this residual layering (75–76 cm) was found in the soils on elevated elements of the microtopography (pits N1-09 and N2-09 at 2.6–3.1 m a.s.l.) in comparison with the soil at the lower hypsometric layer (pit N3-09, 2 m a.s.l.) in which the lithogenic layering was observed from the depth of 51 cm. This difference may attest to a shorter period of active pedogenesis on the lower surfaces that remained in the subaqual state for a longer time.

The lower parts of the buried paleosol profiles (from the depth of 80–100 cm) have distinct subhorizontal thin layering (Fig. 2). Iron pedofeatures—rusty mottles and rhizoconcretions—appear in these horizons; dead root remains are also present (Figs. 4e–4h). These features attest to the presence of woody (tree–shrub) vegetation with the deeply developed root system despite the presence of gley features.

An important morphological feature of the middle- and lower-profile soil horizons is the presence of humified gray-colored interlayers. The latter are clearly seen in the [Cg1] horizon (42–52 cm) of pit N1-09 on the western slope of the Neva levee. The development of humus accumulation in the form of humified interlayers during the stage of sediment accumulation attests to certain interruptions of this process, when the soil was exposed to the surface and transformed by the pedogenetic processes. Then, it was buried again under the estuary sediments.

Analytical characteristics. Particle-size distribution data (Table 1) indicate that all the studied loamy sandy and light and medium loamy coarse silty–sandy soil varieties are developed from similar, relatively homogeneous fine-grained shallow-water sediments. The fine sand fraction predominates, and the coarse and medium sand contents are low. Some increase in the content of coarse sand fractions is observed in separate interlayers in profile N3-09. This reflects the dynamic conditions of sedimentation. A sharp increase in the content of coarse and medium sand in the interlayer of 94–96 cm is also accompanied by the presence of gravelly material (which is absent in other layers). The content of the coarse silt fraction in the buried paleosols is generally low. The maximum content of the fine and medium silt is observed in the dark-humus paleosol developing in the lower part of the paleocatena (pit N3-09). This soil profile is also characterized by the increased content of the clay (<0.001 mm) (up to 17%) and physical clay (<0.01 mm) fractions. The heavier texture of this soil is surely related to its position in the depression of the relief.

Data on the morphology and particle-size distribution in the profile of the dark-humus gley soil (pit 3N-07) indicate that this soil was developed from the layered loamy sands deposited in the water basin. Note that the composition of this soil remains the same along the entire length of the slope (5–8 m). This means that the entire slope with the amplitude of heights of 1–2 m emerged from the water basin almost simultaneously, i.e., the level of the former water basin dropped down by 1–2 m very quickly. According to the radiocarbon data on the age of the soil humus, this could happen before the 6th century AD. The soil formation on the new surface could last up to end of the 12th century AD, when the log path was constructed on the soil surface in the lower part of the slope.

A general trend toward coarsening of the soil texture down the soil profiles can be traced in all the pits. This attests to certain changes in the conditions of sedimentation: the initially coarse sediments in the lower parts of the soil profiles were replaced by finer and well-sorted sediments in the upper parts of the soil profiles.

Despite the dark gray or dark brown color of the humus horizons of the buried paleosols, the humus content in them is generally low and sharply decreases down the profiles (Table 2). This can be explained by the effect of diagenetic processes. The dark-humus (AU) horizons of paleosols in pits N1-09 and N2-09 contain 2.8–2.9% of humus. A higher humus content (3.7–3.9%) was found in the [AO] horizons of these soils. The humus content in the humus horizon of pit 3N-07 reaches 4.3–5.3%. The [AO] horizon of this soil is also enriched in the organic matter. In contrast to this group of soils, the dark-humus gley paleosol in the lower part of the catena (pit N3-09) has the high humus content (8.3%) in the [AUg] horizon and the moderate humus content in the transitional [ACg] horizon. This explained by the position of this soil in the waterlogged depression of the relief.

Elevated content of the organic matter is also observed in some layers in the middle- and deep-profile horizons. Thus, in pit N3-09, the organic carbon content at the depth of 80–90 cm (in the [G2] horizon) reaches 2.0%. These data confirm the presence of humified interlayers in the lower parts of the soil profiles.

Data on the group composition of humus in the dark-humus horizons of the buried paleosols and in the humified interlayers in the lower parts of their profiles attest to the predominance of the fulvate–humate type of humus. The humate–fulvate type of humus was only determined in the [ACg] horizon of the dark-humus gley soil in the lower part of the catena (pit N3-09). However, in the underlying [G3] horizon of the latter soil, the C_{ha}-to-C_{fa} ratio increases up to 1.5. A tendency for an increase in this ratio in the deep soil horizons is also observed in other pits. It can be explained by the slowing of the oxidative destruction of organic matter against the background of more active anaerobic processes in the deep parts of the soil profiles [1].

The dark-humus gley soil (pit N1-09) is clearly differentiated with respect to its actual acidity. The soil reaction changes from the slightly alkaline in the upper part of the profile to the acid and strongly acid in the deeper horizons. Such a high contrast with an increase in the soil alkalinity in the upper horizons

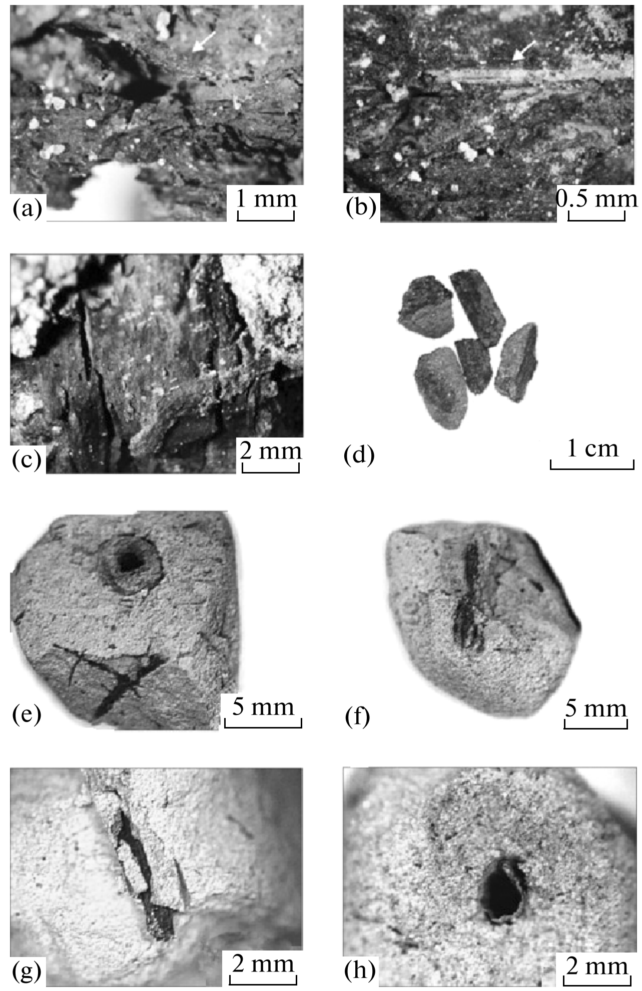

Fig. 4. Mesomorphological features of the buried paleosols in the mouth of the Okhta River: (a) thin peat interlayer with rusty mottles (indicated by arrow) and bleached quartz grains, pit 3N-07, [AO] horizon; (b) decomposed roots (indicated by arrow) and bleached quartz grains, pit 3N-07, [AO] horizon; (c) fragments of wood remains, pit 3N-07, [AUg1] horizon; (d) charcoal inclusions, pit N2-09, [AUg] horizon; (e) rhizoconcretion (upper part) and residues of ancient roots (lower part), pit 1N-09, [G2] horizon; (f) traces of ancient roots, pit 2N-09, [Cg2] horizon; (g) fragment of ancient root with the zone of iron concentration around it, pit 3N-09, [CG2] horizon; and (h) fragment of ancient root, pit 3N-09, [CG2] horizon.

Table 1. Particle-size distribution data on the buried paleosols in the mouth of the Okhta River

Horizon	Depth, cm	Fraction content, %; particle size, mm						
		1–0.25	0.25–0.05	0.05–0.01	0.01–0.005	0.005–0.001	<0.001	<0.01
Pit 3N-07								
[AUg1]	1–3	3	75	11	4	1	6	11
[AUg2]	3–12	2	80	6	4	2	6	12
[ACg]	12–22	1	77	12	3	2	5	10
[CG]	22–44	2	81	6	4	2	5	11
[G]	44–64	5	76	10	2	1	6	9
Pit N1-09								
[AU1]	2–13	0	60	17	1	8	14	23
[AU2]	14–25	0	58	19	0	9	14	23
[Cf]	30–40	0	64	20	0	4	12	16
[Cg1]	42–52	0	44	29	3	9	15	27
[Cg2]	55–75	0	57	24	1	7	11	19
[CG1]	80–100	5	47	26	4	11	7	22
[Gox]	113–121	17	71	0	2	2	8	12
[G2]	121–126	0	50	28	1	7	14	22
[G3]	130–150	7	80	1	2	3	7	12
Pit N2-09								
[AUg]	2–10	1	54	14	2	19	10	31
	10–25	1	69	0	2	21	7	30
[ACg]	25–38	1	50	18	0	24	7	31
[Cg1]	45–75	4	64	9	0	6	17	23
[Cg2]	75–90	1	61	14	2	7	15	24
	100–120	1	67	10	0	11	11	22
[Cg3]	120–140	3	72	7	2	8	8	18
Pit N3-09								
[AUg]	0–10	0	31	30	8	18	13	39
[ACg]	10–16	0	43	20	8	17	12	37
[CG1]	20–35	0	34	28	10	18	10	38
[ÑG2]	40–50	1	32	30	12	17	8	37
[CG3]	51–56	38	47	5	0	8	2	10
[G1]	60–70	0	30	34	6	13	17	36
[G2]	80–90	0	21	39	23	12	5	40
[G3]	94–96	60	23	4	2	8	3	13
	120–140	1	61	25	1	2	10	13

Note: Skeletal (fine gravel) grains were only found in the [CG3] horizon in pit N3-09 at the depth of 94–96 cm; their content reached 16%.

may be explained by the migration of alkaline solutions from the overlying habitation deposits.

At the same time, taking into account the position of this soil on the Neva-facing slope of the Neva levee, we cannot exclude the effect of dispersed calcitic materials eroded from the Izhory Plateau and carried by the Neva River. Indeed, this soil pit is the closest to the river channel. In pits N2-09 and 3N-07, the soil reaction varies within neutral or slightly alkaline values. The dark-humus gley soil in the lowest part of the paleocatena (pit N3-09) has the acid to strongly acid reaction. The initial soil reaction was also acid, because this soil contains the remains of acidophilic horsetail plants in the humus horizon.

Table 2. Physicochemical properties of the buried paleosols in the mouth of the Okhta River

Horizon	Depth, cm	pH		Ac_{tot}	CEC	C_{org}, %
		H_2O	KCl	meq/100 g		
Pit 3N-07						
[AO]	0–1	7.3		Not det		19.4*
[AUg1]	1–3	7.7		″		3.1
[AUg2]	3–12	7.5		″		2.5
[ACg]	12–22	7.4		″		0.6
[CG]	22–44	7.7		″		0.3
[G]	44–64	7.5		″		0.2
Pit N1-09						
[AO]	0–1	7.3	Not det		24.4	2.28 ± 0.13
[AU1]	2–13	7.3	″		20.4	1.68 ± 0.04
[AU2]	14–25	7.5	″		14.0	0.97 ± 0.09
[Cf]	30–40	7.2	″		9.0	0.48 ± 0.09
[Cg1]	42–52	6.5	5.9	0.4	11.6	0.57 ± 0.03
[Cg2]	55–75	6.3	5.7	0.5	5.0	0.34 ± 0.04
[CG1]	80–100	5.0	4.6	1.2	3.8	0.36 ± 0.03
[Gox]	113–121	3.4	3.2	1.5	1.5	0.27 ± 0.00
[G2]	121–126	5.8	5.2	0.8	4.5	0.38 ± 0.05
[G3]	130–150	6.2	5.9	0.6	3.5	0.29 ± 0.00
Pit N2-09						
[AO]	0–2	7.9	Not det		38.0	2.13 ± 0.13
[AUg]	2–10	7.1	″		15.0	1.65 ± 0.03
	10–25	7.0	6.4	″	11.7	1.35 ± 0.02
[ACg]	25–38	6.9	6.3	0.7	11.2	0.54 ± 0.05
[Cg1]	45–75	7.5	7.0	Not det	8.6	0.15 ± 0.07
[Cg2]	75–90	7.3	6.6	″	6.5	0.19 ± 0.05
	100–120	7.7	7.3	″	5.2	0.34 ± 0.04
[Cg3]	120–140	6.7	5.6	0.6	1.0	0.05 ± 0.04
Pit N3-09						
[AUg]	0–10	5.2	4.8	5.5	23.6	4.81 ± 0.18
[ACg]	10–16	5.2	4.7	4.6	16.0	2.53 ± 0.00
[CG1]	20–35	5.0	4.4	2.6	10.9	0.55 ± 0.05
[CG2]	40–50	5.0	4.3	2.4	8.1	0.46 ± 0.10
[CG3]	51–56	3.7	3.5	1.6	4.0	0.13 ± 0.04
[G1]	60–70	4.6	4.1	3.5	13.6	1.06 ± 0.06
[G2]	80–90	2.9	2.7	19.1	21.9	2.02 ± 0.03
[G3]	94–96	3.1	3.0	4.2	4.8	0.25 ± 0.07
	120–140	3.2	3.2	6.5	6.8	0.46 ± 0.00

* Loss on ignition.
Ac_{tot} is the total (hydrolytic) acidity and CEC is the cation exchange capacity.

The maximum total acidity in pit N3-09 is observed in the horizon with the second maximum of the organic carbon. This horizon is also specified by the increased cation exchange capacity (21.9 meq/100 g soil). A close relationship between the cation exchange capacity and the organic carbon content is observed in all the profiles of the buried paleosols.

Time and duration of pedogenesis (as judged from the radiocarbon dating). The radiocarbon age of the soils was determined in the samples enriched in humus and found under the habitation deposits of the 8th–20th and/or 12th–14th centuries. According to the archaeological data, the upper parts of the profiles of buried soils date back to the medieval period (the 13th century) [7, 25]. The age of the lower horizons of the soil profiles with the low humus remained unknown. It was important to distinguish between the period of the subaerial development of the territory and the period of active pedogenesis and humus accumulation.

By the time of our studies, when no radiocarbon dates were available, it was supposed that the soil formation on the first terrace of the Okhta River in its estuary could last until the end of the 13th century AD, when the Landskron fortress was built there [26]. However, there were no dates for the beginning of the soil formation. In 2008–2009, five samples for the radiocarbon analysis were obtained from several points, including the slopes of the Neva levee that escaped the attention of archaeologists and paleogeographers.

Sampling point 1. Sample 7-0-L was taken in the southwestern part of the study area (Fig. 1). The surface of the buried paleosol in this place is found at 3.6 m a.s.l. (the highest point). The humus horizon of this dark-humus gley paleosol has a thickness of 0.3–0.4 m and is buried under the cultural layer. In the uppermost 3–5 cm, the paleosol contains abundant charcoal particles that were subjected to the radiocarbon dating. The ^{14}C date of the charcoal—1580 ± 80 yrs (IGAN-3859)—corresponds to the calendar age of 403–567 AD. Thus, a strong forest fire took place in this area of the Okhta River estuary in the middle of the first millennium AD. It is probable that this was an intentional fire to clear up the territory for agriculture. This means that the surface with the absolute height of 3.0–3.5 m a.s.l. in the southern part of the Okhta estuary could be developed in that time. Taking into account the great thickness of the humus horizon, we can assume that the intensive accumulation of humus in this paleosol began much earlier (before the Christian Era).

Sampling point 2 characterized deep soil horizons in the paleocatena crossing the central part of the Okhta Cape (Fig. 3). In the southern part of this catena, the humus horizon of the semihydromorphic paleosol is developed from the subaerial deposits underlain by the estuary deposits. In the northern part, the humus horizon is immediately underlain by the loamy deposits of the Littorina Sea. Thus, we may conclude that the drying of the southern (elevated) part of the territory took place earlier, and that the age of the humus horizons in this part of the catena should be greater than that in the northern part of the catena crossing the local sublatitudinal hollow. Two samples were taken from the paleosol in the southern part of the catena (pit N2-09), and one sample was taken from the paleosol in the northern part of the catena (pit N3-09). In pit N2-09, humus from the upper part of the dark-humus [AUg] horizon (3–17 cm) had the age of 1780 ± 80 yrs (IGAN 3857), and humus from the underlying [ACg] horizon (35–40 cm) had the age of 2040 ± 80 yrs (IGAN 3858). In pit N3-09, humus in the upper [AUg] horizon (5–10 cm) had the age of 1440 ± 70 yrs (IGAN-3851). These dates indicate that the development of the humus profile in the northern part of the catena began somewhat later, after drying of the low-lying surface at 1.85 m a.s.l. This happened no later than in the middle of the 6th century AD, or even earlier. We did not determined the radiocarbon age of humus in the lower part of this soil. It is interesting that there are no traces of fire (charcoal particles) in this northern pit. This allows us to suppose that a sharp lowering of the water level and the general drying of the surface took place soon after the beginning of the Christian Era. Higher surfaces were dried earlier, which is indicated by the older age of humus in the soil profile in the southern part of the catena. The radiocarbon age of charcoal from the upper part of the humus horizon shows that the humus accumulation in this place began no later than in the beginning of the 1st century AD. The age of humus in the samples from the [ACg] horizon is older. We suppose that the beginning of humus formation in this place dates back to about 3000 years age, when the outflow of the Neva River from Lake Ladoga to the Littorina Sea took place, and when the significant downcutting of the riverbeds was observed.

Sampling point 3 characterizes the age of the upper humus horizon [AU1] (2–13 cm) of the dark-humus gley soil developed on the Neva-facing slope of the levee. The radiocarbon age of humus—2570 ±120 yrs (LU 6709)—is the oldest age obtained for the buried paleosols in the mouth of the Okhta River. As the dated paleohumus horizon is underlain by another paleohumus horizon ([AU2]), the beginning of the humus formation in this place could take place earlier. The humified interlayer at the depth of 42–52 cm in the [Cg1] horizon could form during the exposure of the surface immediately after the breakthrough of the Neva River 3000 years ago.

In general, the results of the radiocarbon dating of the humus horizons of buried paleosols indicate that the beginning of the humus formation in this area took place earlier than it was supposed before our studies: no later than in the 6th century BC on the elevated plots and no later than in the 5th–6th centuries AD in the local depressions.

Palynological analysis. This method was applied to the deposits in two soil pits, in which the minimum redistribution of the mineral substrate could be supposed.

In pit 3N-07 (southwestern part of the study area), four samples of the buried dark-humus gley paleosol were studied: [AO] (0–1 cm), [AUg1] (1–3 cm), [AUg2] (3–12 cm), and [ACg] (12–40 cm). The number of microfossils (spores and pollen) in them varied from 220 to 417 grains (Fig. 5). The results of the analysis allow us to judge the environmental conditions during the development of the upper part of this soil profile. The degree of preservation of most of the spores and pollen is poor: they are disrupted or twisted. This transformation can be explained by some processing of the grains in surface water streams. It is also possible that the poor degree of preservation of spores and pollen is related to the high microbiological activity in the soil.

All the samples contain single deformed grains of the pollen of rye (*Secale*). In the topmost horizon (0–1 cm), two pollen grains of wheat (*Triticum*) and of common weed (*Centaurea* spp.) were also identified; they have the good degree of preservation. The presence of the pollen of cereals attests to the agricultural impact of humans on the territory. Three upper horizons also contained the pollen of Onagraceae with a maximum (6%) at the depth of 1–3 cm. In the same horizon, an increase in the amount of fern (Polypodiaceae) spores was observed (up to 42% against 30% in the lower horizons). The presence of pollen of the Onagraceae family in large amounts and a simultaneous increase in the content of Polypodiaceae spores may be related to the effect of fires. Note that the charcoal particles sampled in the same area dated back to the 5th–6th centuries AD; abundant charcoal particles were also found in pit N1-09 located to the north of pit 3N-07.

A predominance of birch, alder, and pine pollen grains in the samples and a relatively low content of spruce pollen (in comparison with other sections in the northwestern part of Russia) are indicative of the Subatlantic period of the soil formation.

In the samples from pit N1-09 on the Neva-facing slope of the Neva levee, the number of pollen grains varied from 80 to 450. Quantitative data on the proportions between pollen grains of different plants (Fig. 5) allow us to distinguish between four palynological zones (from the bottom to the top). Pollen of tree species predominates in all the samples; its content averages 85%; in the uppermost horizon (palynological zone 4), it decreases to 75%.

Several circumstances should be taken into account for the interpretation of palynological data from pit N1-09. First, this pit is found on the Neva-facing slope of the levee. The regime of sedimentation in this area was greatly affected by the breakthrough of the Neva River into the Finnish Gulf about 3000 years ago. This event was recorded in the composition of lithological columns studied in the boreholes [31]. In pit N1-09, a coarse sandy layer (layer 6, Fig. 5b) is clearly distinguished at the depth of 112–123 cm (at absolute heights of 1.5–1.6 m). We suppose that it was deposited by the powerful water flow along the modern deeply incised (with a depth of up to 28 m) channel of the Neva River. The radiocarbon age of the upper humus horizon in this soil pit—2600 yrs—is in agreement with this interpretation. In terms of palynological data, this means that some redistribution of the microfossils took place in the layer of 1.1–1.2 m; these microfossils could be derived from the sediments eroded upstream. To some extent, this is also true for the overlying sediments at the depth of 0.5–1.1 m. At these depths, palynological zones 2 and, partly, 3 are distinguished. Let us examine the palynological data for the separate palynological zones.

Palynological zone 1 (157–123 cm) is characterized by the high content of spruce pollen (up to 60%). The contents of pollen of other tree species (pine, alder, and birch) vary from 5 to 35%; pollen of herbs and spores are present in small amounts. Sediments with such a palynological spectrum in the northwestern part of Russia are typical of the Subboreal time [28, 32, 33].

Palynological zone 2 (123–52 cm) is characterized by an increased content (up to 20%) of the pollen of broadleaved tree species; the pollen of alder predominates. In the northwest of Russia, the amount of pollen of broadleaved tree species even in the deposits of the Atlantic period rarely exceeds 10–15%. In particular, this has been found for the deposits on the Neva terraces [14]. The high content of alder pollen (up to 60%) usually attests to the existence of alder thickets in waterlogged places [3]. However, in this particular case, we can assume that the microfossils were brought by the river together with suspended sand particles. In general, the pollen spectrum in this palynological zone is rather specific. A similar character of the spore–pollen spectra was described by Malakhovskii with coauthors for the deposits of the Early Subatlantic period (SA-1) [14, 15]. The high content of alder pollen (>40%) in the Subatlantic sediments was also determined in the sections on the east coast of the Finnish Gulf [28]. At the boundary between palynological zones 2 and 3, the content of alder pollen sharply decreases, and the contents of spruce and pine pollen increase. Microfossils of the freshwater *Pediastrum* algae disappear from the spectrum. The boundary at a depth of 0.4–0.5 m can be considered the boundary between the subaqual and the subaerial types of sedimentation. Above this boundary, pollen grains are strongly damaged, the soil mass contains the inclusions of charcoal, and the palynological spectrum is characterized by the presence of allochthonous spores of the Pre-Quaternary spore-forming plants.

Palynological zone 3 (52–32 cm) is characterized by the high content of spruce pollen (up to 40%). In the Neva Park section (15 km upstream the Neva valley), the content of spruce pollen is also high and reaches 35% [35]. This may be correlated with the so-called second spruce maximum of the Holocene in the northwest of the Russian Plain.

At the depths from 106 to 45 cm (in palynological zones 2 and 3, Fig. 5a), we discovered several cluster concentrations of pollen grains of *Alnus, Picea, Tilia*, and *Quercus*. Such concentrations contained more than five spore grains. Their presence may attest to the immature character of the pollen grains, or to the interruption of their normal development because of

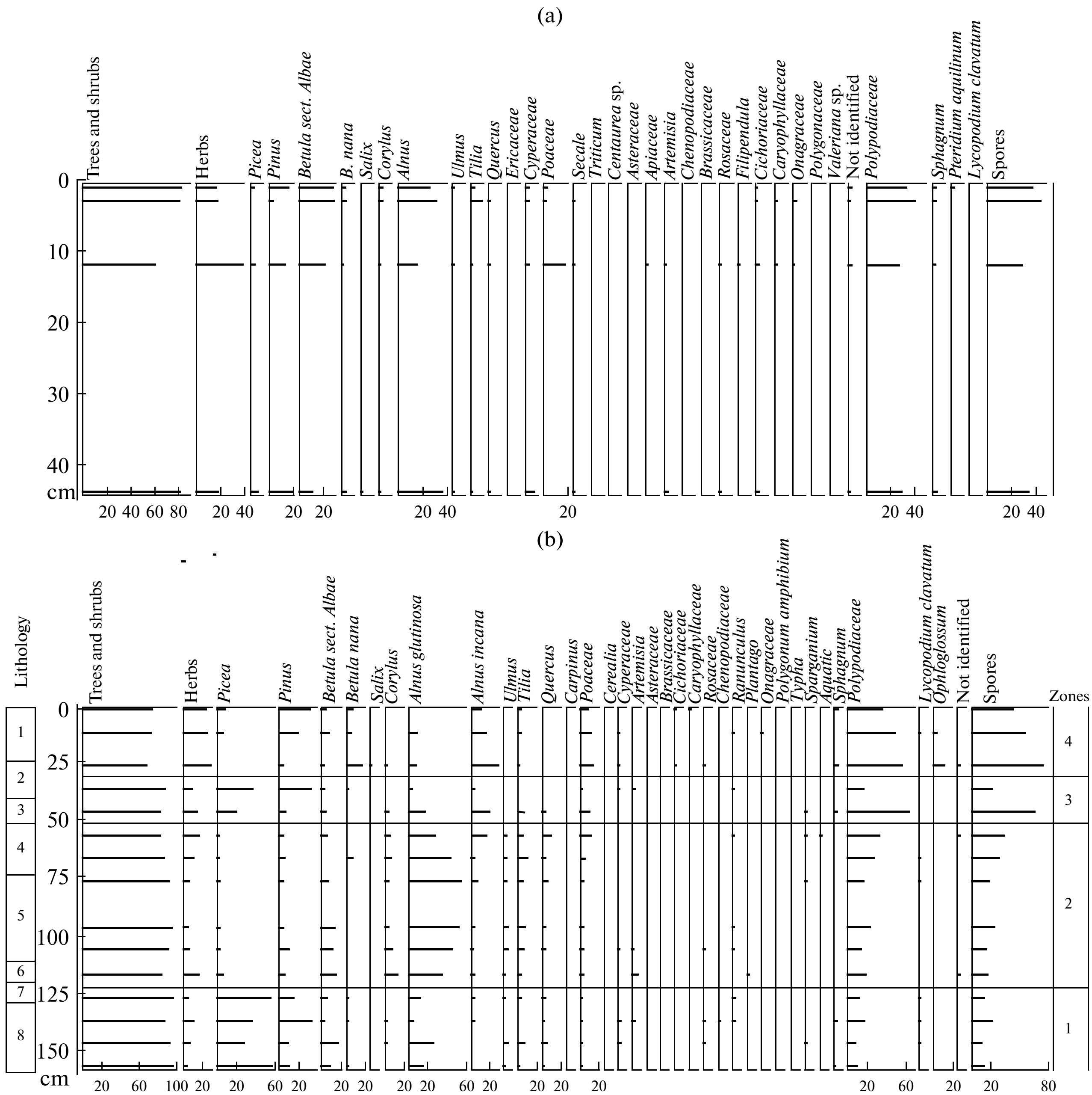

Fig. 5. Spore–pollen diagrams of the buried (a) light loamy dark-humus gley soil on the basin deposits (pit 3N-07) and (b) loamy sandy dark-humus gley soil on the basin deposits (pit 1N-09). Lithological features: coarse silty–sandy loams with the residual (1 and 3) and clearly expressed (5 and 7) layering; coarse silty–sandy loamy sands with the residual layering (2 and 4); loamy sands with clearly expressed layering (8); and coarse sandy loamy sands (6).

the high floods or the high water level in the major basin. This conclusion is in agreement with the lithological data.

At the depth of 67–45 cm (in the [Cg1] and [Cg2] horizons), we found pollen grains (from 1 to 7) of shallow-water and wetland plants of the *Typha* and *Sparganium* genera. At the depths of 47, 67, 97, and 127 cm, single cells (from 1 to 4) of green algae *Pediastrum* were present. The presence of pollen of green algae and shallow-water species attest to the accumulation of sediments in the coastal shallow-water environment; the same conclusion can be derived from the lithological descriptions of the sediments.

Palynological zone 4 (32–0 cm) is characterized by the poor degree of preservation of pollen and spores; their grains are strongly deformed and/or mineralized. This zone corresponds to the humus and raw-humus paleosol horizons that formed under subaerial conditions similar to those that exist at present. Pine forests with admixture of spruce and birch predominated in the region, and alder thickets were widespread on the floodplains. This palynological zone is also characterized by the abundant pollen of forbs and grasses (Poaceae), including single grains of cultivated cereals (Cerealia) attesting to the agricultural activity of humans. This is confirmed by the archaeological data [5]. In the two uppermost soil samples (0–3 and 10–13 cm), charcoal particles and microfossils of dark brown color (probably, because of the effect of burning) were found in considerable amounts. The layer of 25–28 cm contained large charcoal fragments. These features, as well as the results of macro- and mesomorphological soil descriptions, attest to the effect of fires that could take place under continental conditions.

Thus, palynological investigations allow us to distinguish between the following periods of the soil evolution: (a) the Subboreal period characterized by the abundance of spruce pollen (palynological zone 1), (b) the transitional period (palynological zone 2) characterized by the input of allochthonous sandy material with redeposited microfossils, and (c) the Subatlantic period (palynological zones 3 and 4). The boundaries between these palynological zones are related to changes in the conditions of sedimentation and the hydrological regime of the territory rather than to the climatic changes. The radiocarbon age of the humus horizon of this paleosol (2570 ± 120 yrs (LU 6709), palynological zone 4) does not contradict the results of the palynological analysis. Taking into account data on the time of the breakthrough of the Neva River into the Finnish Gulf (3000 BP), this date allows us to estimate the interval of the accumulation of estuary sediments from the coarse sandy horizon at the bottom to the transition to the subaerial regime at about 400 years.

At present, only several key sections in the Okhta River mouth are supplied with palynological data [7, 11, 30]. According to these studies, pollen of cereals predominates (50–67%) in the pollen spectra of cultural layers of different ages on the right bank of the Okhta River [7]. In the paleosol studied by us, its content does not exceed 30%. It can be supposed that the cultural layers of the 17th century characterized by Dzyuba and Sorokin [7] were formed much later than the soil horizons described in our study. A comparison of our data on pit N1-09 with previously published data [11, 30] shows that all the sections contain the horizons with the high content of spruce pollen (from 30 to 60%). However, the age of this horizon is estimated differently. According to [11], it corresponds to the Atlantic period; according to [30], it corresponds to the Atlantic and Subboreal periods. Our data indicate that this horizon was formed in the Subboreal period.

General environmental features of the studied site before and during the development of buried paleosols. The profiles of buried dark-humus gleyed soils and gley soils developing from loamy sandy deposits have been described by us at the Nienshants site. These soils mark the stage of the subaerial evolution of the territory and the topography of the surface before the anthropogenic development of this territory in the 12th–14th centuries AD. The well-developed humus horizons of the paleosols attest to the activity of humus-accumulative processes in the preceding period of pedogenesis.

The topography of the paleosol surface and the radiocarbon dates obtained for the humus horizons indicate that the stage of the subaerial development of the territory (and, hence, the possibility for settling of humans) at the heights of 2.5–3.5 m a.s.l. began before the Christian Era; at the same time, it happened after the breakthrough of the Neva River into the Finnish Gulf 3000 yrs ago. Before this, only regularly flooded shallow-water areas of the Okhta River estuary could be used by humans. The soil formation on relatively elevated parts of the territory, including the Neva levee, could begin after that time, when the base of erosion dropped considerably. In the local depressions of the relief (<2.0–2.5 m a.s.l.) to the northeast of the Neva levee, soil formation began somewhat later. The distribution of the paleohumus horizons by the elements of the local topography and their radiocarbon dates indicate that a general drying of the territory was due to a sharp lowering of the water level in the adjacent basin. A particularly informative record of the history of this territory is preserved in pit N1-09 on the Neva-facing slope of the Neva levee.

In this pit (Fig. 5b), the transition from the shallow-water estuary sedimentation to the subaerial sedimentation at the absolute heights of about 2.5–3.2 m can be clearly seen. The subaerial stage of the territory development without considerable disturbances by humans lasted until the 13th–14th centuries AD. The changes in the character of pollen spectra at the boundaries between the distinguished palynological zones (i.e., at the depths of 123, 52, and 32 cm) could be due to the following reasons. The boundary at the depth of 123 cm marks radical changes in the conditions of sedimentation (Table 1) because of the input of sand material carried by the powerful water flow from the upstream areas. This redeposited sand also contained redeposited microfossils. The boundary at the depth of 52 cm coincides wit the appearance of a humified interlayer in the soil profile. This interlayer is distinguished according to its morphological characteristics (Fig. 2) and according to analytical data (as it has an increased C_{org} content (Table 2). The formation of this interlayer could be related to the rapid downcutting of the Neva River bed with the temporal exposure of the surface. Later, the estuary sedimentation during the floods continued. Finally, the boundary at the depth of 32 cm corresponds to the beginning of the active subaerial pedogenesis with the accumulation of humus. According to the radiocarbon dating, the initial stage of the humus formation in this pit could take place about 2.6 thousand years ago.

Palynological data obtained by us confirm the existing notions about the widespread development of pine–birch–spruce and pure spruce stands in the northwest of European Russia during the Subboreal period [6, 28, 29, 32, 33, 35]. At the end of this period (the uppermost sediment layers of this period in the sections studied by us could be washed out by the Neva flow) and during the Subatlantic period, the portion of spruce forests considerably reduced. Birch–pine forests with insignificant admixture of spruce predominated in the area. The Subatlantic period within the Neva Lowland was the period of the subaerial development.

CONCLUSIONS

The studies at the Nienshants site in St. Petersburg offer a unique possibility to trace the sequence of events upon the transition of the low-lying surface from the subaqual to the subaerial stages of the development about 3000–2000 years ago and during the further pedogenesis before the stage of the anthropogenic development of this territory in the medieval epoch. The paleosols studied at this site bear valuable information for reconstructing the environmental conditions in the region in the Late Holocene (at present, this unique object is completely destroyed).

The study of buried paleosols in the Okhta River mouth allowed us to characterize the character of pedogenesis before the foundation of St. Petersburg in place of the earlier constructed (in the 13th and 17th centuries AD) Landskron and Nienshants fortresses. After the retreat of the sea, dark-humus profile-gleyed soils were formed on the elevated elements of the local mesotopography (at the absolute heights of about 3.0–3.5 m), and dark-humus gley soils (Gleysols) were formed in the local depressions (at the absolute heights of about 2.0 m) from the estuary sediments. The stage of active subaerial pedogenesis lasted for about 2000 years. Then, these soils were buried under the anthropogenic sediments (the cultural layer). Though the studied paleosols differ in their classification position, they have a number of common morphological features: (1) distinct dark-humus horizons (in some cases, raw-humus horizons) with a gradual transition toward the lower-lying coastal continental and estuary sediments, (2) clearly expressed iron concentrations along the roots (including rhizoconcretions) within the upper meter of the soil profiles, (3) half-decomposed remains of tree roots in the same layer, and (4) abundant charcoal particles in the paleohumus horizons attesting to the considerable effect of forest fires.

The first radiocarbon dates obtained for the humus horizons of the buried paleosols (ca. 1780 and ca. 2000 yrs for the [ACg] and [AUg] horizons of the soils on the local mesoelevation, respectively, and ca. 1440 yrs for the [AUg] horizon of the soil in the local depression) indicate that the active stage of the subaerial humus accumulation began no later than in the 6th century BC on the elevated elements of the local topography and no later than in the 5th–6th centuries AD in the depressions. The general drying of the territory and the initial pedogenesis on the exposed surface was related to the outflow of water from Lake Ladoga to the Finnish Gulf through the Neva River channel. This was accompanied by the sharp downcutting of the Neva River (and, hence, the Okhta River) channels with a general lowering of the base of erosion and drying of the territory.

According to palynological data, the buried dark-humus gleyed soils developed from loamy and sandy–loamy estuary deposits had a relatively long history of their evolutionary development in the Late Holocene. The lower parts of the soil-forming sediments were accumulated during the Subboreal period. The upper parts of the soil profiles with dark-humus horizons were formed during the Subatlantic period.

ACKNOWLEDGMENTS

This study was supported by the Russian Foundation for Basic Research (project no. 11-04-00392a) and by the Government of the Russian Federation (grant no. 11.G34.31.0025).

The authors are thankful to P.E. Sorokin for his assistance in the fieldwork at archaeological excavations, to O.A. Chichagova and E.P. Zazovskaya for the radiocarbon dating of the samples, to A.I. Popov for his help in the interpretation of data on the group composition of humus, and to A.A. Aleskandrovskii for his valuable comments on the manuscript of this paper.

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