ISSN 1064-2293, Eurasian Soil Science, 2024, Vol. 57, No. 5, pp. 751–761. © Pleiades Publishing, Ltd., 2024.

GENESIS AND GEOGRAPHY OF SOILS

Morphogenetic Features of Soils of the Svyatoi Nos Peninsula Coast (Eastern Cisbaikalia)

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Received August 10, 2023; revised December 15, 2023; accepted December 15, 2023

Abstract—We have studied soils of the western coast of the Chivyrkui and Barguzin bays on the Svyatoi Nos Peninsula, which is the largest peninsula of Lake Baikal in the Republic of Buryatia. Morphogenetic characteristics of soils on the main types of coasts of the peninsula—low abrasion with isolated lagoons, low abrasion, accumulative, and ingression—are given. Rocks in the basis of the coasts of the bays are an important factor of soil formation. It is shown that the genesis of soils depends on the distance from the lake and the altitude, resulting in the difference in their structure and properties. The soils are not directly affected and flooded by lake water due to high mountainous coasts, which are often rocky with steep slopes. Soil formation beyond the floodplain regime is also typical for soils of the closest to the lake level: soddy podzols, which occupy low shores of accumulative types. The particle-size composition of the studied soils varies widely from loose sand to light clay. The common properties of soils include acid and weakly acid reaction, the regressive-accumulative type of humus distribution, and differentiation of bulk oxides along the profile. The revealed evidences of podzolization in Al–Fe-humus soils and of clay accumulation in brown soils are related to sufficient moistening of the coasts and the warming effect of the lake water mass. The research results may be used in landscape planning in territorial organization and monitoring work in recreation areas.

Keywords: types of shores, Lake Baikal, soil chemical properties, particle-size distribution, Entic Podzol (Skeletic), Cambisols, Umbric Podzol

DOI: 10.1134/S1064229323603633

INTRODUCTION

Soils of lake coasts are among the most interesting objects for soil-geographical research. Coastal areas are zones with complicated exogenic-dynamic processes and with contrasting environmental conditions for the formation of soil and plant cover. In addition, coastal areas are very attractive for tourists, and this increases the anthropogenic impact on them. The Svyatoi Nos Peninsula on the eastern shore of Lake Baikal is one of such territories. The effect of water mass of Lake Baikal, temperature inversions, fresh water of the lake, various types of shores, continental climate, and mountainous terrain determine the diversity and characteristics of soils. The coasts of the Chivyrkui and the Barguzin bays are attractive places with unique landscapes and different types of shores [6, 34]. The morphology of shores and terraces of Lake Baikal is determined by the complicated geological history of the rift zone. Tectonic shores are represented by high fault scarps, and abrasion types of shores are characterized by cliffs in the unconsolidated deposits of Baikal terraces and of river fans. Beaches and spits are assigned to accumulative coastal forms. Capes and bays are formed in abrasion shores of the structural-denudation dissection. Technogenic types are distinguished in the classification of shores of Lake Baikal during the period of their intensive development and use of coasts with stabilization structures [18].

Lake terraces on the shores of Baikal are rarely formed and are mainly represented by local forms allocated to tectonic benches or horsts. There are also false terraces on the shores of the Lake: washed-out fans, piedmont aprons, and other similar formations of different abrasion rate and ranges of heights of cliffs [32]. The total number of terraces and hypotheses about the role of tectonic, climatic, hydrological, and anthropogenic factors in their formation are still discussed. Special studies have revealed high terraces on the eastern lake shore, including to 14 levels on the Svyatoi Nos Peninsula. The level of Lake Baikal in the Middle Pleistocene was by about 120–130 m higher than the modern one [20]. Current changes in the level of Lake Baikal and its impact on the status of the lake ecosystem is related to the operation of the Irkutsk hydroelectric power station. As a result of its construction in 1956–1959, the mean water level in Lake Baikal was raised by 0.8–1.2 m relative to the natural one. The water line was four times lower than the permissible minimum (457 m) in the period from 2015 to 2018 and two times higher in 2020–2021. Potential geomorphologic risks caused by lake level fluctuations are related to the transformation of the shores: abrasion, landslides, and destruction of the low eastern shore, including coastal forests and recreational areas [4]. Variations in the level regimes of lakes and rivers can cause changes in water-temperature parameters, physicochemical properties, and the redox conditions in soils [36, 38, 39]. Thus, the heterogeneity of the coasts in combination with the effect of various factors creates variegated soil-forming conditions.

Published works devoted to special soil studies of the Svyatoi Nos Peninsula are few. Soils of the Svyatonosskii Ridge were studied in the natural soil catena from the subgoltsy altitudinal belt to the piedmont part of the slopes [8]. The background of the catena was formed by raw-humus and gray-humus lithozems, podburs, and burozems. The increase in humidity and in the effect of relatively warm microclimate from the upper part of the ridge to the foot of the macroslope on the coast is reflected in morphological and physical properties of soils [8]. Soils of the peninsula are in general characterized in [16, 23, 31]. Soddy-forest lithogenic and podzolic humus-illuvial soils, podzolized podburs, and alluvial peat soils have been identified on the coasts of the Chivyrkui and the Barguzin bays.

Special attention should be paid to burozems of Cisbaikalia. Areas of burozems are traditionally identified in the south of the Far East, in the foothills of Altai, Western Sayan, and the North Caucasus under broad-leaved and coniferous–broad-leaved forests in a moderately warm climate [17, 19, 24, 25]. The application of modern diagnostic principles of substantive genetic classification of soils of Russia has resulted in the expansion of the geographical range of burozems, and their area now includes mountains with deciduous and dark coniferous forests in the continental climate in other regions: the Circumpolar, Northern, and Middle Urals [15, 27, 28] and Kuznetsk Alatau [29]. Burozems in the Baikal Region are allocated to ridges, stretching along the southeastern shore of Lake Baikal [7, 10]. Raw-humus burozems were first discovered at the southern boundary of the cryolithozone of Transbaikalia in the south of the Vitim Plateau [5]. Beyond the Svyatoi Nos Peninsula, raw-humus burozems are revealed in the mountain taiga belt of the Barguzin Range at the altitudes of 600–1200 m [2] and under taiga with *Abies sibirica* of the Khamar-Daban Range within the altitudes of 600–1000 m [35]. Contrary to burozems of the Svyatoi Nos Peninsula, their formation is related to greater altitudes of the ridges, to the effect of water mass of Baikal, and to the direction of the general transfer of air masses in the circulation activity of the atmosphere.

Thus, genesis, morphological diagnostics, and the classification of soils of the Svyatoi Nos Peninsula remain insufficiently studied. The Peninsula is located in the Zabaikal'skii National Park and is assigned to specially protected natural areas. Recreational nature management here includes beach-camp recreation, fishing, and walking with insufficiently developed tourist routes. The number of vacationers now rapidly increases, in summer in particular. The performed research will contribute to the collection and systematization of data on soils and soil cover of specially protected natural areas.

The purpose of this work is to determine the main regularities of soil formation, depending on the type of lake shore on the Svyatoi Nos Peninsula and to identify morphological diversity and physicochemical properties of the soils.

OBJECTS AND METHODS

The object of the research was represented by soils of the western coast of the Chivyrkui and the Barguzin bays on the Svyatoi Nos Peninsula. The areas of the following types of shores were chosen on the peninsula: low abrasion ones with separated lagoons, low abrasion shores, and ingressive types [6]. Terrain studies were performed in the most accessible areas of the coast on representative test plots located in the localities of Glinka, of Monakhovo, of Kurbulik, and of Krestovskaya Bay (Fig. 1). The soils were identified by conventional morphological and chemical-analytical research methods of soil science [22, 30]. Micromorphological analysis was performed according to [21, 40]. We determined the humus content by Tyurin's method modified by Ponomareva and Plotnikova, pH potentiometrically, the content of non-silicate iron in the extracts by Tamm and Mehra–Jackson, and the total composition by atomic absorption spectrometry [30]. The classification and diagnostics of soils were performed according to [17] and the WRB [37]. The particle-size composition was determined by laser diffraction, using an Analysette-22 MicroTec Plus particle-size analyzer. Measurements were made for each sample in six–nine replications [12]. The soil profile differentiation by clay (S) and the argillization coefficient (K) were calculated [26]. The soil density was analyzed by the drilling method and then calculated as the ratio of the mass of undisturbed dry soil to the unit volume [13].

The geological history of the area is related to the isolation of the mountain range. The initial Island of Svyatoi Nos was then connected to the mainland by the accumulative Chivyrkui Isthmus with lake-marshy landscape. The Svyatoi Nos Peninsula is a mountain range with the same name, which rises above the Lake Baikal level by more than 1400 m. The range consists of two en-echelon jointed ranges with sharp ridged watersheds. Its highest point is Mount Markov (1877 m) [14]. Gravitational-nival and erosion-denudation geological processes play an important role in the formation of the relief on the background of neotectonic activity. Residual peneplains are preserved in the highlands of the peninsula. Mountain slopes are steep and sometimes scarps occur. The relief of the peninsula coast is

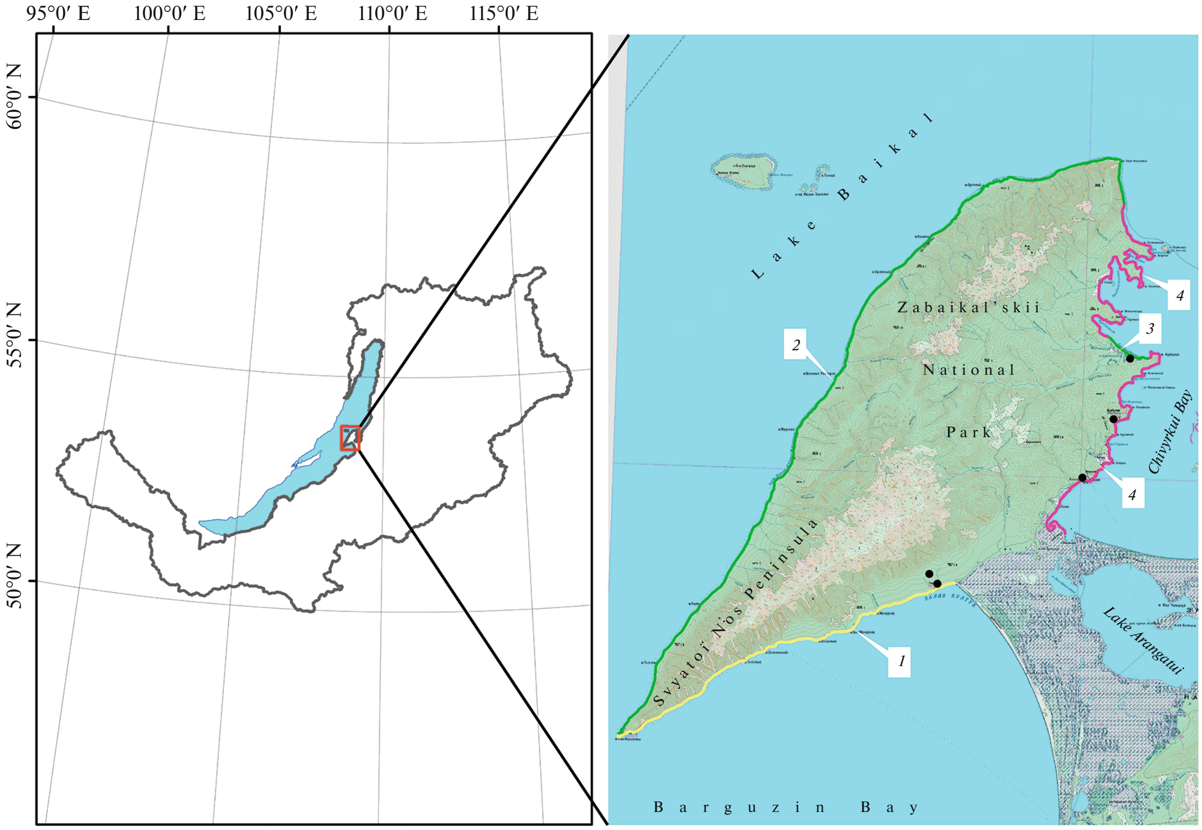

Fig. 1. Scheme of test plots location on different types of shores: (*1*) low abrasion shores with separated lagoons, (*2*) low abrasion shores, (*3*) low abrasion (accumulative) shores, (*4*) ingression shores, ●—test plots.

formed by folded-block low mountains with the altitude below 1000 m above sea level.

The geological structure of the peninsula is complicated. Sedimentary-metamorphic rocks are represented by biotite and hornblende groups, amphibolites, gneisses, and shale. Igneous Late Proterozoic and Paleozoic rocks include gneiss-like biotite granitoids, syenites, and diorites. Lower parts of the slopes of the ridges are composed of gravelly deposits and heavy loams. Quaternary deposits on lacustrine-alluvial terraces 2–3, 4–6, and 10–12 m above the level of Lake Baikal are composed of pebbles and stratified sands [16]. According to permafrost zoning [6], the peninsula is assigned to the area of local permafrost allocated to damp and swampy areas and mountains above 1000 m.

The climate of the peninsula is sharply continental with strong fluctuations in the air temperature during the day and year. According to temperature parameters and humidity, it is assigned to the North Baikal Climatic District of the West Barguzin Coastal-Mountain Region [6] with specific mild Baikal limnoclimate [31]. The mean long-term annual air temperature for the district is –3.3°C. The mean annual precipitation is 382 mm, including 279 mm in the warm season and 103 mm in the cold one. Lake coasts have the features of the seaside microclimate determined by the thermal effect of the lake water mass. They are distinguished by relatively mild winter and cool summer. The mean annual temperature here is 1.9°C. Temperature differences at various mountain altitudes and at a distance from water in autumn and early winter may reach 11.4°C [6]. The thickness of the snow cover reaches 120 cm. Air masses are replenished with moisture over Lake Baikal in November–December due to local evaporation from the open water surface, and more intensive precipitation on the coast. The annual rainfall may reach 500 mm and more.

Changes in climatic parameters—in the heat to moisture ratio—create conditions for the plant cover differentiation and for the formation of altitudinal complexes: goltsy, subgoltsy with larch thin forests, and taiga mainly with pine forests. A specific type of vertical zoning is formed on gently sloping coastal plains (the piedmont part) due to the effect of Lake Baikal and temperature inversions (wet Cisbaikalian type of vertical zoning [32]), which results in the spread of subgoltsy vegetation on the shore of Lake Baikal [31]. Mixed birch-pine forests with diverse forbs occupy the eastern coast of the peninsula.

RESULTS AND DISCUSSION

Low abrasion shores with separated lagoons are characterized by the Glinka test plot. It is located at a distance of 700 m from the locality of Glinka in the Kultuk Bay of the Barguzin Bay. The altitude is 548 m above sea level (91 m above the level of Lake Baikal). The coordinates are 53°36′10.3″ N and 108°50′29.3″ E. The area represents a forest strip on thepiedmont plain connected with the accumulative lake-marsh isthmus of the peninsula. The strip is no more than 3 km wide. Duschekia-birch-larch-pine forests widely spread in the area are located at the contact with the littoral without a belt of lake meadows. The shrub layer is dominated by dwarf pine *Pinus pumila, Rhododendron dauricum,* and *Vaccinium vitis-idaea*. The surface is covered by true mosses and *Cladonia*. Such low coastal belts under the direct cooling (in summer) and moistening effect of Lake Baikal are termed the subbelt of temperature inversion or the false subgoltsy belt [32].

The soil pit was laid 350 m from the water edge in an undisturbed area, which is still under the impact of the lake. Lake Baikal exerts a cooling effect on coastal slopes facing it to the mean altitude of 250–500 m, which may be significantly greater or smaller due to the influence of wind currents. During the cold period, the warm effect of Lake Baikal is recorded to a distance of 2.0–2.5 km from the lake and to 30–50 km^2 along river valleys [11].

The soil profile (pit 3SV-13) comprises O–BHFe–BHF–C horizons. The litter horizon, no more than 5-cm thick, consists of moist slightly decomposed mosses, roots, and needles. The podzolized horizon is represented by a thin layer (to 3 cm) of a whitish light gray color, sandy texture, and weak crumb structure. Formation of the podzolized horizon is related to sufficient moistening of soils of the coastal strip. The increase in humidity and the effect of relatively warm microclimate on soils in the sequence from the ridge top to the coast decreases with the distance from the lake, and evidences of soil podzolization are absent [8]. The BHF Al–Fe-humus horizon under the BHFe horizon is yellowish-brown, its structure is similar to that of the overlying horizon, but it is more compact. The profile is formed on sands. The thickness of the entire profile does not exceed 50 cm. Soils with such profile compostion are assigned to podzolized podubrs according to the classification and diagnosis of soils of Russia [17].

Micromorphological studies revealed sandy microfabric, which is replaced by plasmic-sandy one in the BHF and C horizons. Sandy material in the podzolized horizon is bleached, and there are no films on the surface of minerals. There are local ferruginated plasmic microzones, probably because the podzolic horizon is poorly formed and thin. In the underlying Al-Fe-humus horizon, mineral grain surfaces are covered by iron-clay films (Fig. 2a). Clay plasmic material is also detected in the soil-forming rock, which corresponds to an increase in the number of fine clay particles in soils (Table 1). The soils are in general characterized by sandy loamy particle-size composition with uniform distribution of fractions along the profile, except for coarse silt, the amount of which becomes lower in the soil-forming rock.

The soil reaction changes from acid to weakly acid in the deeper soil horizons (Table 2). The base saturation in the podzolized horizon is low and the hydrolytic acidity is high in comparison with the underlying horizons. Relatively high content of humus (4%) and of exchangeable Ca^{2+} and Mg^{2+} and the distribution of SiO_2 are not typical for podzolized horizons. However, the morphological properties of the Al–Fe-humus horizon, differentiation of genetic horizons by pH values, and eluvial-illuvial distribution of total Fe_2O_3 and Al_2O_3 confirm the diagnostics of the podzolized horizon, although indicate its poor manifestation (Table 3). The illuvial accumulation of iron compounds results in the formation of the BHF horizon. The content of non-silicate and amorphous forms of iron in this horizon is maximal in the soil profile.

In addition to podzolized raw-humus podburs, brown forest soils are formed on this type of coast at altitudes close to the level of Lake Baikal. They are allocated to loamy sediments under moss-forbs vegetation at a distance of no more than 300 m from the coastline. The plant cover is mainly composed by shrubs of *Pinus pumila* and *Rhododendron dauricum,* by *Vaccinium vitis-idaea,* and by forest grasses: *Thalictrum baicalense*, *Lathyrus humilis*, *Rubus saxatilis*, etc. The soil pit is dug at the altitude of 10 m above the lake level, and its geographical coordinates are 53°35′48.6″ N and 108°51′01.5″ E.

The morphological profile of these soils (pit 5 SV-13) includes friable gray-humus horizon with weak crumb structure below the falloff layer. The structural-metamorphic horizon under the gray-humus one is characterized by nonuniform color: from yellowish to ochreous-brownish. The horizon is compacted with medium subangular blocky and crumb structure. Fine material impregnates the soil mass and binds mineral grains. In some microzones, there are clay coatings. The clay material is more abundant in ochreous-brownish areas of the structural-metamorphic horizon, where it forms homogeneous coatings. This is the evidence of lessivage or clay-illuvial process. The alternation of areas of heterogeneous color in the horizon is probably caused not only by iron compounds, but also by migration of clay material with the formation of zones of its concentration. The properties of these soils are discussed below in comparison with other burozems.

Ingression shores. In addition to the low-abrasion shores with separated lagoons, brown forest - burozems - occupy the coasts of the ingression type. Contrary to the Glinka test plot, the shores are represented by high gentle slopes of structural-denudation

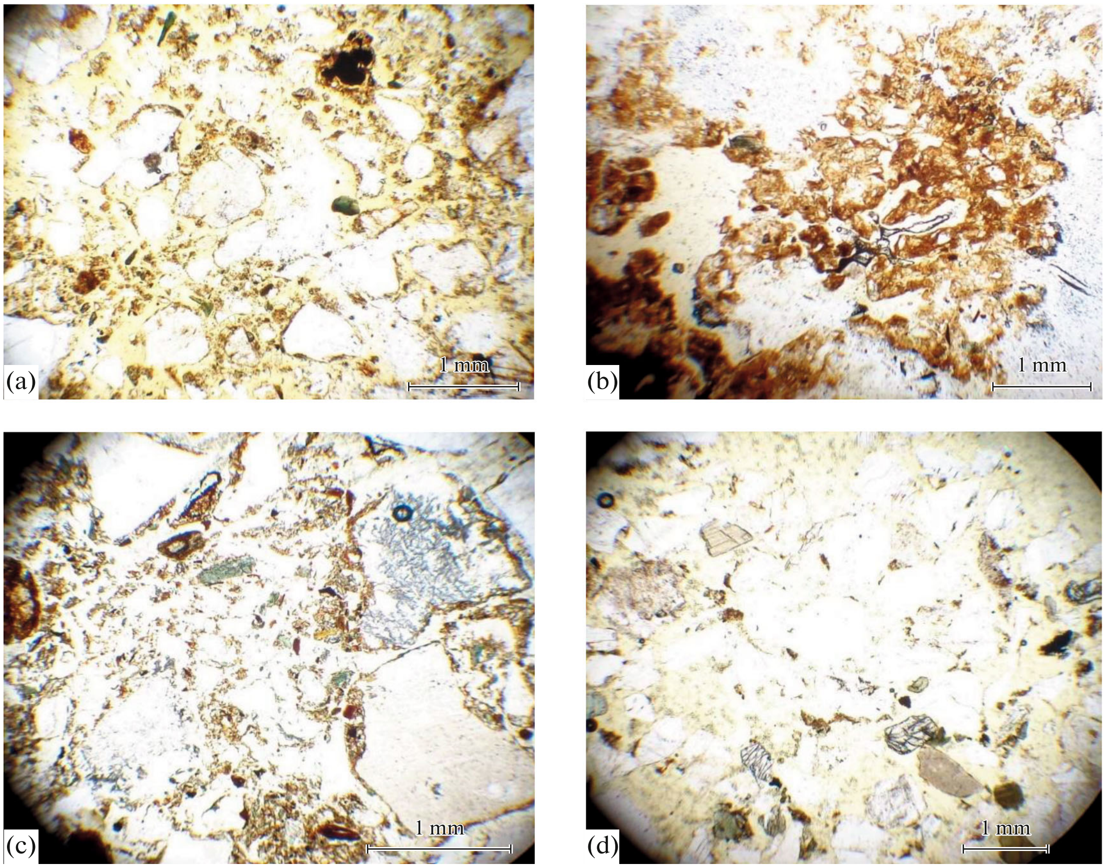

Fig. 2. Micromorphological properties of soils: (a) the general structure of the BHF horizon in podzolized podbur (N II), (b) clay plasma in the BM horizons of burozems (N II), (c) clay-iron films on the surface of minerals in the BF horizon of soddy podbur (N II), (d) loose mineral skeleton and depletion of plasma material in the E horizon of soddy podzol (N II).

origin close to the lake shore. The Kurbulik test plot is located near the settlement of Kurbulik between the Pokoiniki and the Kulemnyi capes. The soil pit is made in the lower part of the southeastern slope 10°–15° steep at a distance of 50 m from the lake edge at the altitude of 34 m above the level of Lake Baikal. The coordinates are 53°42′16.0″ N and 109°02′00.9″ E. Soils are formed under a cranberry birch-pine forest with forest forbs. The soil profile (pit 5 KB-14) includes the following horizons: O–AYao–BM1–BM2–BC. The fragmentary AYa gray-humus horizon to 5 cm thick is located under dry debris. The horizon is discontinuous, because the soil is formed on the slope, where gravitational shifts are possible. The horizon is characterized by dark gray color and weak crumb structure. It is underlain by the BM1 and the BM2 metamorphic horizons with slight color differentiation. They are compact with medium subangular blocky-crumb structure due to loamy particle-size composition. Clay material is also diagnosed as plasma in thin sections. Clay coatings are identified at pedfaces in the lower metamorphic horizon. The soil is formed on loams with admixture of stone debris.

The soil profile in both pits (5SV-13 and 5 KB-14) is more than 100 cm deep, a pronounced pedogenic structure in metamorphic horizons, clay illuviation, and the absence of podzolization, which corresponds to the diagnostic features of typical burozems.

The BM structural-metamorphic compact horizon with subangular blocky and crumb structure is the main diagnostic feature of the Baikal variant of burozems. Clay plasma is recorded, sometimes clay coatings occur, indicating subsurface weathering and migration of clay particles (Fig. 2b). Conditions for their migration are created by a sufficient precipitation amount in the coastal part and thick snow cover.

The studied brown soils are characterized by the maximal content of physical clay (55–58%), so their particle-size composition is the heaviest among all the soils of the coast. The sandy loamy texture of their upper horizon abruptly changes in the structural-metamorphic horizons: to medium loamy in burozems of the Glinka test plot and to light clay in burozems of the Kurbulik test plot. The clay content increases 3–3.5 times as compared to the overlying horizon, and coarse silt becomes dominant, reaching more than 50%. An increase in the content of the clay fraction is typical for Baikal burozems [7, 35], which is obviously related to intensive weathering of sand fractions and their transfer as suspension under humid climate. Taking into

Table 1. Particle-size composition

Horizon	Depth, cm	Content of fractions (size, mm, %)						
		1–0.25	0.25–0.05	0.05–0.01	0.01–0.005	0.005–0.001	<0.001	Total of particles <0.01
Low abrasion shores with separated lagoons								
Glinka test plot. Pit 3SV-13 podzolized podbur (Entic Podzol (Skeletic))								
BHFe	5–7/8	42.0	23.3	19.2	6.3	7.7	1.4	15.4
BHF	7/8–20	40.1	21.2	21.9	6.5	8.5	1.8	16.8
C	20–45	46.9	17.2	14.7	8.1	10.9	2.2	21.2
Glinka test plot. Pit 5 SV-13 clay-illuvial burozem (Cambisol (Clayic))								
AYao	6/7–14	14.6	35.6	32.9	7.0	8.4	1.5	16.9
BM1	14–65/70	0	4.6	56.9	13.3	20.8	4.4	38.5
BMC	65/70–95	0.5	17.5	49.5	12.3	16.8	3.5	32.6
C	95–110	40.1	23.6	17.8	6.3	8.3	2.0	16.6
Ingression shores								
Kurbulik test plot. Pit 5 KB-14 clay-illuvial burozem (Cambisol (Clayic))								
AYao	0–5	11.0	31.6	37.1	8.5	10.0	1.8	20.3
BM1	5–32	4.9	12.4	24.2	18.5	34.3	5.8	58.6
BM2	32–86	3.4	10.9	38.3	1.4	27.8	5.3	47.5
BC	86–110	0	4.7	40.1	14.5	34.6	6.3	55.4
Monakhovo test plot. Pit 1 M-14 litho-barrier soddy-podbur (Leptosol)								
AY	5–10	23.9	45.4	22.9	3.4	3.9	0.6	7.8
Bf	10–33	13.4	21.8	40.3	9.7	12.4	2.4	24.5
M	33–40	–	–	–	–	–	–	–
Low abrasion (accumulative) shores								
Krestovskaya Bay test plot. Pit 3Kr-14 soddy podzol (Albic Podzol)								
AY	10/12–20	79.2	12.0	6.5	1.0	1.1	0.2	2.3
E	20–29	80.0	13.0	4.0	1.4	1.5	0.1	3.0
Cf	29–50	84.2	9.3	2.5	1.8	1.7	0.5	4.0

account the concentration of clay and silt in the metamorphic horizons of these soils, we have determined the total differentiation coefficient of the soil profile by clay content (*S*). It is calculated as the ratio of the clay content in the BM horizons to that in the AYao horizon, taking into account soil density, which ranges from 0.5 to 1.0 g/cm^3 in the AYao horizons and from 1.3 to 1.5 g/cm^3 in the BM horizons. The coefficient *S* is 7.7 in burozems of the Glinka test plot and 4.8 in burozems of the Kurbulik test plot, which corresponds to the strpongly differentiated soil profile. Micromorphological features, the accumulative type of the clay fraction distribution in the soil profile, and data by various authors on argillization in the middle horizons enable us to specify the clay-illuvial subtype of burozems [1, 3].

Burozems are formed under conditions of acid and weakly acid reaction: pH_{H_2O} varies within 5.2–6.7 in the soil profile. The compared burozems differ in physicochemical properties of the upper AYao and BM1 horizons. The difference among soils on the same soil-forming rocks and under the same vegetation is related to relief and altitude above sea level of different types of lake coasts. Burozems on low abrasion coasts with separated lagoons are characterized by the highest acidity in the humus-accumulative horizon, a high base saturation, and, as a result, a relatively high content of exchangeable Ca^{2+} and Mg^{2+}. In deeper horizons, these properties become similar. The humus content profile distribution in all burozems is regressive-accumulative with the maximum (8.9%) in the AYao horizon. The content of humus, exchangeable cations Ca^{2+}, and oxalate- and dithionite-soluble forms of iron compounds in burozems on the slopes of ingression coasts is lower. The obtained analytical data may be explained by the position of soils in relief: in addition to migration down the profile, mountain

Table 2. Physicochemical soil properties

Horizon	Depth, cm	pH_{H_2O}	Ac, cmol(c)/kg	Exchangeable bases, cmol(c)/kg		V	Humus	Fe_2O_{3d}	Fe_2O_{3o}
				Ca^{2+}	Mg^{2+}	%			
Low abrasion shores with separated lagoons									
Pit 3SV-13 podzolized podbur									
BHFe	5–7/8	4.8	12.5	11.5	3.9	55	4.0	0.63	0.48
BHF	7/8–20	5.6	4.4	5.6	1.1	60	1.2	1.21	0.60
C	20–45	5.8	2.7	5.2	1.0	70	0.6	0.62	0.48
Pit 5 SV -13 clay-illuvial burozem									
AYao	6/7–14	5.2	2.0	24.1	1.7	93	8.9	1.80	0.44
BM1	14–65/70	6.0	3.4	17.6	6.8	88	0.4	4.71	0.73
BMC	65/70–95	6.7	1.2	13.1	6.0	94	0.5	3.53	0.41
C	95–110	6.7	0.4	6.0	2.0	95	0.2	1.51	0.34
Ingression shores									
Pit 5 KB-14 clay-illuvial burozem									
AYao	0–5	5.6	8.1	14.0	2.5	67	7.8	0.80	0.32
BM1	5–32	5.5	3.8	7.0	3.0	72	0.7	0.83	0.52
BM2	32–86	6.1	2.7	14.9	7.2	89	0.3	1.10	0.60
BC	86–110	6.1	1.2	4.3	2.3	84	0.1	0.73	0.24
Pit 1 M-14 litho-barrier soddy-podbur									
AY	5–10	6.3	6.5	45.6	13.5	90	7.8	0.95	0.56
Bf	10–33	5.3	6.8	12.6	7.9	75	2.6	0.70	0.48
M	33–40	–	–		–	–	–	–	–
Low abrasion (accumulative) shores									
Pit 3Kr-14 soddy podzol									
AY	10/12–20	4.1	8.1	3.7	0.5	34	3.3	1.80	0.08
E	20–29	4.4	4.3	3.3	0.6	48	0.9	1.11	0.04
Cf	29–50	6.2	2.1	2.6	0.5	59	0.5	1.23	0.16

V is base saturation; Ac is total (hydrolytic) acidity.

slopes with active denudation-gravitation processes are the transit zones of chemical substances. The profiles of all burozems are characterized by a relatively weak differentiation of the total iron content. An increase in the proportion of Fe_2O_{3d} in the BM horizons indicates the development of soil argillization. This process may be assessed by the argillization coefficient (K), calculated by comparing the soil (the BM horizons) with the soil-forming rock by the ratio between particles <0.001 and <0.010 mm ($K > 1$ reflects soils with the strongest argillization). The K values in the BM1 and the BMC horizons in burozem of pit 5 SV-13 are 1.04 and 0.9, which indicates the slight development of this process in the layer from 14 to 70 cm. The BM2 horizon of pit 5 KB-14 of plot Kurbulik is characterized by intensive argillization, where K is maximal (8.75), while in the 5- to 32-cm-thick horizon, it reaches only 0.72. The argillization intensity here is mainly related to sufficient humidification of the slopes near the shore. They are characterized by the greatest moisture condensation and the intensive heat and moisture exchange between the lake and the atmosphere.

Soddy podburs are also formed on the coasts of the ingression type. They occupy rocky steep tectonic shores in the form of high fault scarps with a deeply dissected coastline. They are assigned to the structural abrasion type of shores [18] and are well pronounced and widely spread on the Svyatoi Nos Peninsula. They are mainly composed of igneous and metamorphic rocks, which are very resistant to the effects of waves and are practically not eroded.

The soil pit is located within the test plot of Monakhovo at the altitude of 65 m above the level of Lake Baikal. Its coordinates are 53°40′00.6″ N and 109°00′06.7″ E. It is located in the middle part of the western slope 10° steep under a birch-pine forest with forest forbs. The morphological profile of the soil here

Table 3. Total chemical composition of soils, %

Horizon	Depth	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	TiO_2	P_2O_5	MnO	Na_2O	LOI
Low abrasion shores with separated lagoons												
Pit 3SV-13 podzolized podbur												
BHFe	5–7/8	70.60	2.28	12.80	1.73	0.50	3.30	0.42	0.19	0.22	4.15	3.81
BHF	7/8–20	67.50	2.79	14.80	1.80	0.55	3.58	0.46	0.33	0.09	4.17	3.66
C	20–45	69.20	2.94	15.20	1.88	0.61	3.52	0.47	0.18	0.05	4.13	2.20
Pit 5 SV-13 clay-illuvial burozem												
AYao	6/7–14	53.60	2.60	11.90	1.63	0.76	2.78	0.48	0.22	0.45	2.91	22.06
BM1	14–65/70	60.10	5.92	17.20	1.66	1.64	3.29	0.66	0.18	0.08	3.13	5.80
BMC	65/70–95	62.30	4.79	16.60	1.90	1.47	3.42	0.66	0.21	0.09	3.67	4.24
C	95–110	69.40	2.73	14.90	1.65	0.56	3.95	0.33	0.18	0.03	4.29	1.40
Ingression shores												
Pit 5 KB-14 clay-illuvial burozem												
AYao	0–5	61.90	2.77	13.30	2.03	0.62	2.78	0.55	0.13	0.27	3.59	12.06
BM1	5–32	67.10	3.98	15.20	1.92	1.03	3.24	0.68	0.19	0.06	3.73	2.68
BM2	32–86	63.30	5.25	16.50	1.82	1.36	2.95	0.64	0.17	0.08	3.34	4.60
BC	86–110	71.27	3.47	14.67	1.49	0.29	3.00	0.28	0.12	0.04	3.82	1.55
Pit 1 M-14 litho-barrier soddy-podbur												
AY	5–10	56.00	5.39	14.90	6.15	2.74	1.46	0.66	0.45	0.34	3.92	7.82
Bf	10–33	60.10	5.80	16.40	6.13	2.85	1.51	0.62	0.72	0.17	3.98	1.70
M	33–40	57.90	8.20	16.50	6.99	4.07	1.29	0.96	0.26	0.09	2.78	0.96
Low abrasion (accumulative) shores												
Pit 3Kr-14 soddy podzol												
AY	10/12–20	61.30	1.86	17.70	4.49	1.37	3.52	0.36	<0.1	0.04	4.75	4.32
E	20–29	63.20	1.69	18.30	4.29	1.25	3.69	0.35	<0.1	0.04	4.89	2.22
Cf	29–50	62.70	2.56	17.70	5.41	1.92	3.30	0.46	0.11	0.06	4.76	1.04

LOI is loss on ignition.

(pit 1 M-14) includes the horizons O–AY–Bf–M, which enables us to assign this soil to soddy podbur. The AY gray-humus horizon of brownish dark gray color underlies a thin (to 5-cm-thick) dry debris layer of needles and leaves. The horizon is friable with crumb structure and sandy loamy particle-size composition. It has a single-grain microstructure, the skeleton grains size varies from fine silt to coarse sand. The horizon is non-aggregated the skeleton grains are separated and not rounded. Humus-clay plasma occurs as microzones. The transition to the underlying horizon is sharp by color. This is the illuvial Al-Fe-humus compact horizon of yellowish-brown color with loose crumb structure. The brownish color is caused by iron compounds. Grains of minerals are covered by clay-iron films of different thickness, and the same material fills the packing voids between skeleton grains in microzones of fine silt accumulation (Fig. 2c). The Al-Fe-humus horizon is formed on the eluvium of ochreous-brown bedrocks, mainly of granitoid type.

The gray-humus horizon of soddy podburs is characterized by sandy particle-size composition, which changes to light loamy in the lower horizon. Fine earth is dominated by sand fractions here and by coarse silt in the illuvial horizon. The clay proportion is minimal. The change in composition and distribution of fractions in soils on the shores of Lake Baikal are mainly related to the recreational effect [9].

The soil reaction is weakly acid throughout the profile, soils are base-saturated, the content of exchangeable cations (mainly Ca^{2+}) in the organic horizon is high, and the content of non-silicate and amorphous iron is increased. The values of these parameters sharply decrease in the illuvial horizon parallel to the humus content. Soddy podburs are characterized by poorly pronounced differentiation by the content of total SiO_2, MgO, and K_2O: there is a tendency to their weak accumulation in the Bf horizon. The total CaO undergoes biological accumulation throughout the profile: its content varies from 6.15 to 7%. The content of total magnesium oxide in these soils is slightly lower; similarly to Fe_2O_3: it is maximal in the lower part of the profile, which is related to the elevated content of these elements in soil-forming rocks. Taking into account the shallow soil profile and dense soil-forming rock, on the weathering products of which it is formed, as well as weak evidences of Al–Fe-humus migration, these soils are diagnosed as litho-barrier soddy podburs.

Low abrasion shores are assigned to the accumulative group of shores allocated to the deltaic parts of rivers [18]. The Krestovskaya Bay test plot is located in the bay of the same name in the Chivyrkui Bay. The bay is a low deltaic plain of the Marshalikha and the Krestovskaya rivers, which stretches for 4 km along the coastal sand beach. Low shores are composed of loose deposits of Baikal terraces and are overgrown by *Pinus pumila* and *Rhododendron dauricum*. The soil pit is located at the altitude of 459 m above sea level (2 m above the level of Lake Baikal), at a distance of 20 m from the lake water line.

The soil profile comprises the following horizons: O–AY–E–Cf. The AY gray-humus horizon is formed under mosses. The thickness of the litter horizon increases with the distance from the lake. The dark gray and slightly compacted AY horizon is characterized by weak crumb structure and sandy texture. Sand grains in the plasma-sand microfabric are rounded and semi-rounded. Humus plasma unevenly fills the packing voids. The underlying whitish podzolic horizon is also loose and apedal. The absence of structure is well seen in thin sections: the mineral skeleton is not aggregated and separated (Fig. 2d). Sand grains are washed of coloring films, and the soil mass is devoid of plasma, which indicates the removal of finely dispersed products of soil formation. The soil is formed on well-sorted medium-grain sands characterized by nonuniform color and stratification. Yellowish-ochreous interlayers and spots are the evidences of humus-iron compounds accumulation. The soils are not waterlogged, and there are no features of gley due to high sand content, which provides strong water permeability. The morphological profile corresponds to the type of soddy podzols. The soil properties confirm that the soil exists now not in the floodplain regime, and is not subjected to waterlogging and periodical flooding.

Soddy podzols are characterized by the lightest texture: coarse sand is the dominant fraction, the content of which reaches 85%. The content of the clay fraction in the profile is minimal, and its distribution is of eluvial-illuvial type.

These soils are the most acid. They are unsaturated with bases, and the content of exchangeable cations and humus in them is minimal in comparison with other soils of the coast. The eluvial-illuvial redistribution of the clay fraction of fine earth, of oxalate- and dithionite-extractable iron compounds, and of total Fe_2O_3, CaO, MgO, and TiO_2, as well as the relative accumulation of SiO_2 in the E horizon indicate the removal of mobile compounds from the soil. Sufficient soil moisture in combination with the plain topography on low accumulative shores, where atmospheric moisture completely penetrates into the soil, favors the development of Al–Fe-humus migration.

CONCLUSIONS

Burozems and soils of the Al–Fe-humus group are formed on the coast of the Svyatoi Nos Peninsula. Specific features of the formation of these soils depend on the geological and geomorphological particularities of different types of lake shores. They are mainly represented by low abrasion shores with separated lagoons, by low abrasion (accumulative) shores, and by ingressive types, on which soils with particular morphological and physicochemical properties are formed. Soddy podburs are formed on the eluvium of bedrocks at the altitudes significantly higher than the level of Lake Baikal. Soddy podzols are allocated to alluvial sands of the low abrasion (accumulative) coasts of the deltaic plains. Burozems occupy low abrasion shores with separated lagoons, as well as shores of ingression type composed of loamy deposits, if they are formed in the lower parts of the slopes close to the lake. Podburs are soils of mountains formed at the altitudes above 500 m above the lake level, and therefore, occur on different types of shores in the inner areas of the peninsula.

The fluctuation of the reservoir level is one of the key factors, affecting the formation of biogenic and accumulative types of shores. Low abrasion (accumulative) shores with soddy podzols are the most susceptible to the lake level rise. The studied soils on low abrasion shores and ingressive high rocky shores are not subject to flooding by lake water and direct impact of waves. The soils on such shores are formed in the mountains at altitudes significantly above the level of Lake Baikal. These are podburs, soddy podburs, and burozems. These soils are acid and slightly acid, with different development rates of the Al–Fe-humus and the burozem-forming processes. They are characterized by agrillization and metamorphism of the mineral mass, which are especially intensive in the zones of piedmont forest strips on low abrasion shores at very small heights above the lake level. The effect of humid and relatively warm microclimate changing from the upper part of the ridges to the coast favors podzolization and activation of metamorphic argillization in soils. From the altitude of more than 500 m above sea level (30 m above the level of Lake Baikal), the altitudinal differentiation becomes the dominant factor of soil formation, related to the change in the relief and composition of soil-forming rocks. Burozems give way to soddy podburs and podburs, the structure and properties of which are similar to those of their analogs in the taiga forest zone in Transbaikalia. The results of the research have revealed the diversity of soils and their morphological and chemical properties, depending on the type of shore of the peninsula. They may be used as a basis for the territory planning of the recreational environment of the Zabaikal'skii National Park and for monitoring works.

FUNDING

This work was supported by the Institute of General and Experimental Biology, Siberian Branch, Russian Academy of Sciences, project no. 121030100228-4.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This work does not contain any studies involving human and animal subjects.

CONFLICT OF INTEREST

The authors of this work declare that they have no conflicts of interest.

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Translated by I. Bel'chenko