# АГРОХИМИЯ И ПОЧВОВЕДЕНИЕ

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**Alina O. Kurasova[1], Alexandr O. Konstantinov[2], Sergey P. Kulizhskiy[1], Elizaveta Yu. Konstantinova[3], Vitaliy Yu. Khoroshavin[2], Sergey V. Loyko[1, 4]**

*[1] Tomsk State University, Tomsk, Russian Federation*
*[2] University of Tyumen, Tyumen, Russian Federation*
*[3] Southern Federal University, Rostov-on-Don, Russian Federation*
*[4] Tomsk Oil and Gas Research and Design Institute, Tomsk, Russian Federation*

## Patterns of soil cover organization within the northern part of the Kondinskaya lowland (Western Siberia)

*The paper presents the results of the studies devoted to the morphological features and properties of soils representing different geomorphological conditions within the elevated relief forms of the Kondinskaya lowland, with the example of the Kondinskie Lakes Natural Park area. The northern part of the Kondinskaya lowland is characterized by a contrasting and diverse relief, which is generally not typical of the middle taiga zone of Western Siberia. Soil-morphological and -geomorphological methods formed the structural framework of this research. The results showed that Folic Albic Podzols (Geoabruptic) formed on the flat tops of ridges are characterized by a moderate thickness of the E horizon, the largest number of rock fragments, as well as by bedding with loams that have signs of paleocryogenic deformations. Albic Podzols of terraced slopes have more developed E and Bs horizons with large wedge like tongues having depth of about one meter. This group of soils is distinguished by the most diverse structure of the upper part of the profile due to the variability of morphological elements related to biogenic pedoturbations. Albic Lamellic Arenosols occupying steep slopes of the ridges are less developed, and erosional processes often interrupt soil development within this geomorphic position. Albic Gleyic Podzols (Turbic) formed under the steep slopes of high ridges develop over buried Podzols, and often contain charcoal-enriched interlayers in the bottom and middle parts of the profile. Formation of a complex profile, with series of burials, is possibly associated with the activation of erosional processes related to fires and ancient human activity. Study results showed that there is a strong relationship between the lithology on the one hand, and the intensity of podzolization and variability of soil morphological elements related to biogenic pedoturbations on the other hand.*

*The paper contains 5 Figures, 1 Table and 51 References.*

**Key words:** Albic Podzols; middle taiga; Kondinskie Lakes Natural Park; Western Siberia; buried soils; morphological elements; binomial deposits.

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## Introduction

The main patterns of soil diversity, as well as evolution trends within the boreal zone of Western Siberia, are largely determined by the specific features of the relief, parent rocks, and hydrological conditions of the region. Most of the research works devoted to the soil cover of the taiga zone of Western Siberia mention a high degree of bogging, waterlogging characteristics, even for interfluves and the relative uniformity of automorphic soils, as characteristic features of this territory [1-5]. Such a situation is typical of most territories within the boreal zone of Western Siberia, and, especially, for its central parts: the Vasyugan lowland, northern part of Tomsk region, and the central part of the Ob river basin [6-8].

At the same time, conditions of soil formation in the taiga zone can differ significantly within the vast territory of Western Siberia, especially in the peripheral parts of the lowland, since they have a different history of geological and geomorphological evolution, a more dissected relief, and a greater variety of parent rocks. For example, such a situation is typical of the near Ural regions of the Khanty-Mansi Autonomous Okrug, in particular, in the north of the Kondinskaya lowland [9]. The territory under consideration is characterized by the alternation of boggy plains with ridges (“mineral islands”) covered with pine forests [10]. Soil cover is much more contrasted under such conditions: automorphic and hydromorphic soils are clearly delineated without gradual transitions through series of semihydromorphic soils, and the erosional processes are more intensive. Al-Fe humus soils prevail on sandy and, to a lesser extent, on loamy sediments in well-drained positions, while vast floodplains and boggy plains are mainly occupied by organogenic peat soils. Thus, under conditions of well-drained ridges, the organization of soil cover is controlled by lithological-geomorphological rather than hydrological factors.

Another important feature of the territory under consideration is the wide distribution of binomial covering sediments that significantly complicate soil cover within the elevated landscape positions. It is obvious that sandy covering deposits are an integral component of the loamy-sandy lithological framework of soil-forming sediments within the territory of Northern Eurasia. This fact can be explained by landscape peculiarities and the geomorphological evolution of this territory in the Late Quaternary, which significantly contributed to the wide distribution of three types of glacial and periglacial deposits: moraines, loesses, and sandy deposits [11-12]. These types of covering sediments alternate with a gradual increase in the proportion of sands and moraines to the north of the region, along with a decrease in the proportion of subaerial loams [13]. Note that soil formation on different parent rocks representing the lithological framework of covering deposits within Northern Eurasia is significantly uneven, and soils developed on sands as well as on binomial deposits; when loams underlie sands, they are the most unexplored in terms of the geographical aspect. Soils with abrupt textural contacts are most typical of Europe and Scandinavia [14-19], while for Western Siberia, they are less characteristic and can only appear in the middle and northern taiga, in accordance with the spread of moraine-like deposits and silt-dominated periglacial covers [20]. It is also important to mention that soils formed on binomial sediments are much less studied for the middle taiga zone of Western Siberia in comparison with Central and Eastern Europe and Scandinavia. At the same time, they are of significant interest for better understanding how soil formation occurs on substrates with abruptic textural contacts under continental climate conditions.

The studies devoted to the diverisity of soils are especially important for the territory of middle taiga of Western Siberia, as as they can be basis for the protection and monitoring of soil cover in the context of anthropogenic impact due to the exploration of oil and gas fields. Recent studies performed for the reserves within the bogged territories of the East European Plain showed that soils of elevated ridges inside the bog massifs are important for the environmental monitoring of protected sites [21].

The aim of the research was to study the main patterns of soil cover organization within the northern part of the Kondinskaya lowland (Western Siberia) using the example of the territory of the Kondinskie Lakes Natural Park.

## Materials and methods

The study area is located in the northern part of the Kondinskaya lowland, within the territory of the Kondinskie Lakes Natural Park. The main objectives of the reserve are related to the protection of Arantur, Pontur, and Rangetur lakes, as well as the adjacent landscapes. According to the administrative structure of the Khanty-Mansi Autonomous Okrug, the study area corresponds to Sovetsky district (Fig. 1).

The geomorphological framework of the study area was formed as a result of upper quaternary glaciofluvial processes, and under the influence of the latest tectonic movements [22]. At the same time, a number of issues related to the genesis of the modern relief within the northern part of the Kondinskaya lowland (for example, the possible influence of Quaternary glaciations) continues to be debated due to the low exploration maturity of the study area with respect to quaternary geology and geomorphology. In general, the research area is a flat, boggy plain complicated by separated ridges [23]. Positive topographic forms have relative excesses of up to 8-15 m. A significant part of the natural park is occupied by the valleys of the Konda River and its tributaries. Sands, sometimes with interlayers and lenses of loams, represent the most widespread covering deposits within the study area.

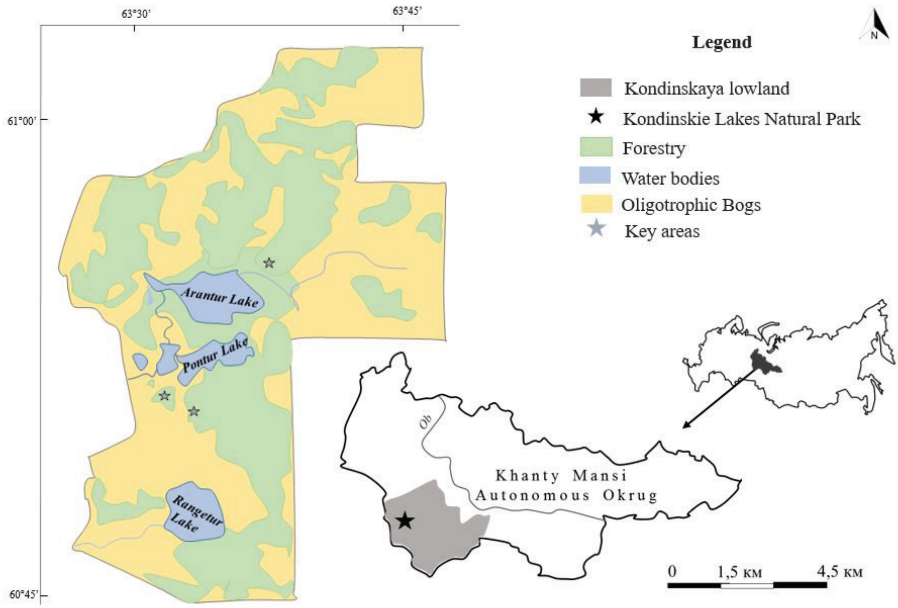


**Fig. 1.** Study site location within the territory of the Kondinskie Lakes Natural Park, Khanty-Mansi Autonomous Okrug

The climate of the territory is continental with short off-season periods and frequent fluctuations of weather conditions. Average annual temperature is -0.7 ºC, and average annual precipitation is 533 mm. The territory of the natural park is located within Sovetsky district of pine green-moss, lichen, and spruce-cedar green-moss forests of the middle taiga subzone of the forest zone [24]. Forest, bog, and meadow types of vegetation [10] are the most common within the territory of the Kondinskie Lakes reserve. Pine lichen, moss-lichen, or moss-shrub forests predominate on sandy substrates, while mixed pine and pine-spruce forests are common on sands underlined by loams [25-26]. In accordance with soil-geographical zoning, the territory of the Kondinskie Lakes Natural Park is located in the Boreal geographical zone of the West Siberian taiga-forest soil-bioclimatic region, in the subzone of podzolic soils of the middle taiga (with intrazonal bog soils). *Albic Podzols* are the most common soils within well-drained ridge surfaces. Hydromorphic soils, including *Histosols*, *Fuvisols*, and *Gleysols*, occupy a significant area within the territory of the natural park.

Exploitation of the Talnikovoe oil field that affects the northern part of the natural park is the main source of anthropogenic impact within the study area [10]. In addition, archaeological sites dating to the Early Iron Age were discovered in the immediate vicinity of the study sites [23], which speaks well for longstanding ancient human activity within the territory of the reserve.

Soils of three large ridges (“mineral islands”) located in the central part of the natural park (Fig. 1) were selected as objects for detailed studies. Two sites were located in the immediate vicinity of the Natural Park observation station at a distance of 700 m (60°51'26.1"N 63°30'43.8"E) and 2000 m (60°51'8.6"N 63°31'49.7"E) to the east of the Ah River. The last one was located at a distance of 4.5 km to the north of Lake Arantur (60°57'39.0"N 63°30'23.8"E). Field studies were conducted in the summer of 2018. The main objectives of the proposed research were: (1) to examine the role of lithological and geomorphological factors in the organization of soil cover; (2) to reveal the influence of these factors on the morphological and analytical properties of soils in the northern part of the Kondinskaya lowland. Therefore, catenary and soil-morphological methods of studies were chosen as the main research approaches. In total, 14 soil pits were analyzed. A field description of the soil profiles was made according to the *Guidelines for Soil Description* [27]. Soil classification was given according to the *World Reference Base for Soil Resources* [28]. The color of soil horizons was determined according to the Munsell scale, as well as by using a spectrophotometer VS450 (X-Rite, USA) to obtain the color characteristics of the studied soils in the CIE L*a*b* color space. Soil samples were air dried and sieved through 1 mm sieves.

Analytical studies included measurements of pH $H_2O$ and 1M KCl values in a solution 1:2.5 soil/liquid ratio by the potentiometric method, the content of the total organic carbon (TOC) by the bichromate oxidation method according to Ivan Tyurin [29], the content of oxalate-soluble iron ($Fe_o$) according to the Tamm and dithionite extractable iron ($Fe_d$) according to Mehra and Jackson methods. The concentrations in the extracts were determined spectrophotometrically using a spectrophotometer SmartSpec Plus (Bio-Rad Laboratories Inc., USA). Analysis of particle-size distribution was done with laser-diffraction particle-size analyzer LS 13 320 (Beckman Coulter, USA) after the preliminary treatment of soil samples with sodium pyrophosphate. Soil size fractions and soil texture classes were determined according to the East European texture classification system [30]. Polished thin sections were prepared form micro monoliths of selected soil samples, representing loamy material from lenses and interlayers in the bottom parts of *Folic Albic Podzols (Geoabruptic)*, collected in field. Samples were dried and saturated with resin. Micromorphological studies were carried out in polished thin sections using polarization microscope Eclipse LV 100 POL (Nikon, Japan). The description of thin sections and individual elements of the microstructure was carried out according to Gerasimova et al. [31].

Data processing and visualization of morphological and analytical properties of the studied soil profiles were performed using Microsoft Office software and Grapher 11 (Golden Software, USA).

## Results and Discussion

### *Soil morphology and classification*

Soils of "mineral islands" could be conditionally subdivided into several groups that differ in thickness of the profile, podzolization process intensity, the diversity of soil morphological elements, and the degree of hydromorphism, depending on the specific geomorphological conditions and the lithology of parent rocks. Figure 2 shows photographs of the most representative soil pits for each of the discussed groups.

*Folic Albic Podzols (Geoabruptic)* represent the soils of the flat tops of the ridges (pits KO-1-18, KO-4-18). In general, the soils of the tops of "mineral islands" are characterized by moderate thickness of the E horizon and a large number of rounded rock fragments varying in size, from coarse to fine pebbles, in the middle part of the profile. Small tongues are the most common morphological elements of the profile, while deep wedge like structures are absent, and the maximum depth of these morphological elements often coincides with bedding depth with loams (40-50 cm). The loamy material lies in the form of separate interlayers with a thickness of up to 50 cm, and often shows signs of cryogenic transformations manifested in the presence of pronounced traces of cryogenic turbations, as well as paleopermafrost gleying. This assumption is also supported by the fact that loamy deposits do not form a continuous cover with consistent thickness: they are often replaced by sandy material from the above and underlying horizons in the form of lenses, interlayers, or individual large structures with signs of turbations. *Albic Podzol* at the top of the largest "mineral island" (pit KO-9-18), where no bedding with loam was observed, differs from other soils of this geomorphic position. In this case, tongues have a greater depth (up to 80 cm), and thin lamellas are well expressed in the C-horizon, which indicates greater intensity of the podzolization process.

*Albic Podzols* (pits KO-3-18, KO-6-18, KO-8-18, KO-13-18, and KO-14-18) represent the soils of the terraced subhorizontal slopes of the "mineral islands". The soils of these geomorphic positions are characterized by the presence of a powerful E horizon with separate large tongues penetrating to a depth of 1 m, and a well-defined thick Bs horizon. Rock fragments are much fewer than those in the soils of the flat tops of "mineral islands". As a rule, large charcoals, confined to soil morphological elements that have characteristic signs of tree-fall-related pedoturbations [32], are present at a depth of 30-40 cm near the border of the E and Bs horizons. In general, this group of soils is characterized by the most diverse structure of the upper part of the profile related to the variability of biogenic structures (tongues and mounds), as well as the highest intensity of podzolization.

The soils of the steep slopes of the mineral islands have a clear horizontal stratification from a depth of about 12 cm (pit KO-11-18). In these positions, soil formation is extremely dynamic and periodically interrupted due to the activation of erosional processes, probably related to fires and the anthropogenic activity of ancient people. Lichen cover in such positions is fragmented and often absent. The soil profile consists of separate interlayers of deluvial or aeolian origin, thin interlayers of loamy material. The differentiation of the profile because of pedogenic processes is weakly expressed; the podzolization process manifests itself slightly in the form of clarification of the upper part of the C horizon. On the basis of the profile's structural features, these soils can be classified as *Albic Lamellic Arenosols (Abruptic, Aeolic)*.

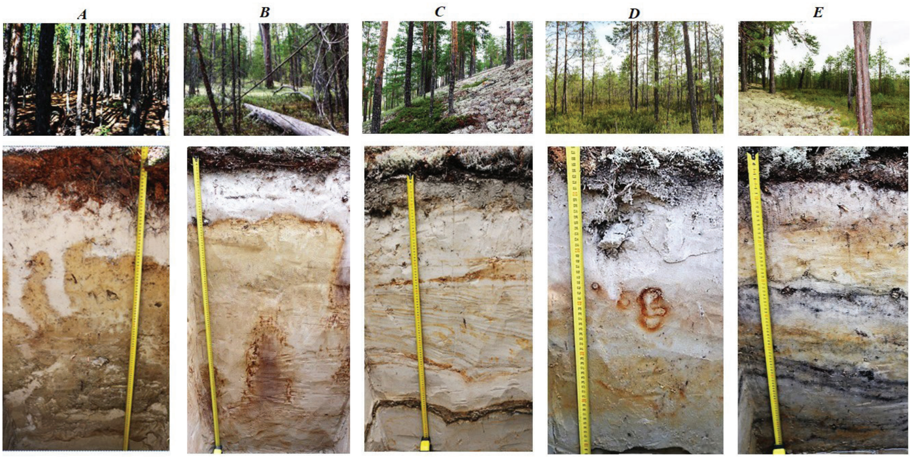


**Fig. 2.** Photos of the soil profiles representing different landscape and geomorphic positions: *A - Folic Albic Podzol (Geoabruptic)* at the top of the large ridge (KO-4-18); *B - Albic Podzol* on the terrace within the gentle slope of the "mineral island" (KO-8-18); *C - Albic Lamellic Arenosol (Abruptic, Aeolic)* of the steep slope of a large ridge (KO-11-18); *D - Albic Gleyic Podzol (Turbic)* in the lower part of the gentle slope of a large ridge (KO-7-18); *E - Albic Gleyic Podzol (Turbic)* developing over series of buried Albic Podzols under a steep slope (KO-5-18). Photos by Alexandr Konstantinov

The soils of the contact zone of the mineral islands and the boggy plain significantly differ depending on the type of the slope. *Albic Gleyic Podzols (Turbic)* occupy the lower parts of the gentle slopes of large mineral islands (pits KO-2-18, KO-9-18). These soils have a relatively short profile (groundwater appears at a depth of 1 m) and are practically completely devoid of rock fragments. The upper part of the profile often has signs of turbations, and the E horizon is represented as separate discontinuous patches, sometimes alternating with the slightly developed humus horizon. Signs of gleying appear at a depth of 15-20 cm in the Bs horizon.

Different conditions of soil formation can be observed in areas of contact between mineral islands and the swampy plain under the steep slopes. These landscape positions are characterized by the occurrence of *Albic Gleyic Podzols (Turbic)* developing over series of buried *Albic Podzols*. In addition to buried soils, the lower parts of soil profiles in this geomorphic position also include separate layers enriched with charcoals and burnt wood (pits KO-5-18, KO-12-18). For example, soil, opened in pit KO-12-18, has the following profile structure: O-E-Bs-[E]-[Bs]-Bc/[E]-C/[Bs]. Rock fragments are scarce in the buried soils, and the thickness of the E horizon varies in the range of 2-8 cm. The formation of a complex profile with a series of burials is probably associated with the intensification of erosional processes due to fires and the activity of ancient people, as indirectly evidenced by the proximity of soils under consideration to the archaeological sites. The soils of this group were formed under conditions of constant waterlogging, and the lower part of the profile contains Fe-Mn nodules and concretions. It is interesting to note that this group of soils has a rather small and well-defined distribution area with respect to relief and vegetation changes: a contrasting transition from *Gleysol* to *Albic Gleyic Podzol*, developed over a series of buried soils, can be observed in soil pit KO-5-18.

***Analytical properties***

Figure 3 illustrates the particle-size distribution of the most representative soil pits for each geomorphic position. All studied soils are characterized by the predominance of fine (0.05-0.25 mm) and medium sand (0.25-0.5 mm). The content of the coarse sand (0.5-1 mm), as a rule, did not exceed 5-6%, with a tendency toward a slight increase in the C horizons, with the exception of the upper part of the *Albic Podzol* studied in pit KO-1-18. In almost all horizons of the studied soil, the total content of sand fractions was up to 90-95%, which is generally characteristic of *Podzols* formed on sandy substrates in the taiga zone of Western Siberia. The content of clay fraction, as a rule, does not exceed 1%, increasing to 5-6% only in pits where bedding with loam was observed.

In soil profiles where the natural sequence of genetic horizons is not strongly disturbed by tongues and other biogenic pedoturbations, there is a tendency for Bs horizons to be enriched with a clay fraction, which is typical of *Podzols* [33-34]. In all studied soils, coarse silt (0.01-0.05 mm) predominates over fine and medium silt. The content of silt fraction for the soils of the tops and gentle slopes of large ridges without bedding with loam, as a rule, does not exceed 5-7%. Higher contents of the silt fraction are characteristic for horizons and lenses composed of loamy material (up to 70%), and for soils with series of burials formed in the foot of steep slopes (up to 20%). In general, a nearly twofold increase in the contents of silt fraction in the Bs in comparison with the overlying E and underlying C horizons is typical of soils of flat tops and the terraced slopes of ridges.

Soils under consideration are characterized by an acidic reaction: from strongly acidic in O horizons, to acidic and weakly acidic in mineral horizons (Fig. 3). Only in the C horizon of *Folic Albic Podzol (Geoabruptic)* (pit KO-11-19) the reaction of the medium was close to neutral. On average, pH $H_2O$ values varied from 3.7 in O to 5.6 in C, and pH KCl from 2.6 to 4.7, respectively. It can be noted that for all the soils studied, there is a tendency to increase pH values (both $H_2O$ and KCl) with depth. The local maximum of pH values is also characteristic for Bs horizons. In *Albic Gleyic Podzols (Turbic)* developed in the contact zones of the mineral islands and the boggy plain, both under gentle and steep slopes, pH $H_2O$ values were generally lower than those in soils of well-drained geomorphic positions; even in C horizons and did not exceed a value of 5.0. A rather uniform distribution of pH $H_2O$ values along the profile was observed in *Albic Gleyic Podzols* with burials. Moreover, in buried E horizons, and layers enriched with charcoal and burnt wood, a noticeable decrease in pH KCl values was observed. A significant decrease in pH values is also characteristic for layers and lenses of loamy material in *Albic Podzols (Geoabruptic)*. For example, in the pit KO-1-18, pH $H_2O$ decreased from 5.7 in Bc, composed of sandy material, to 4.9 in the underlying loam, while pH KCl decreased from 4.6 to 3.4, respectively.

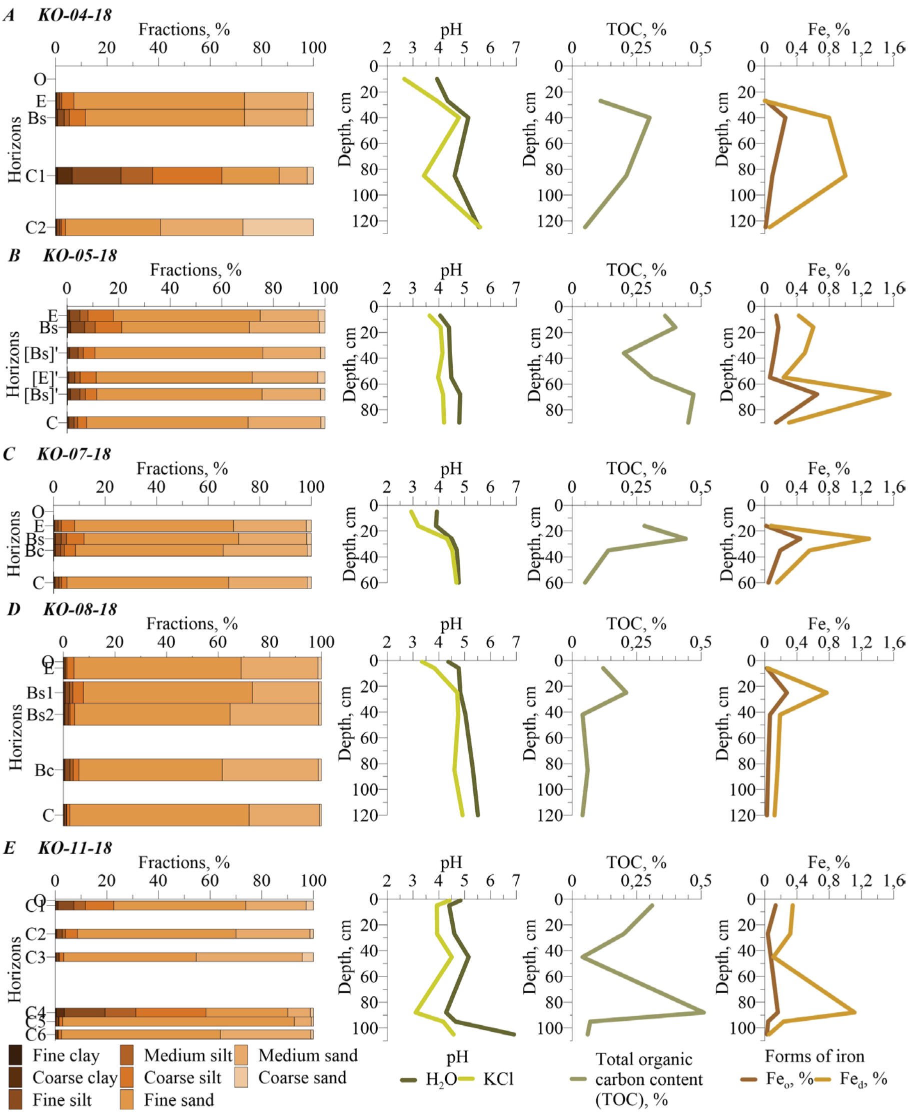


**Fig. 3.** Texture and chemical properties of soils representing different landscape and geomorphic positions: *A - Folic Albic Podzol (Geoabruptic)* of the large ridge top (KO-4-18); *B - Albic Podzol* on the terrace within the gentle slope of the "mineral island" (KO-8-18); *C - Albic Lamellic Arenosol (Abruptic, Aeolic)* of the steep slope of a large ridge (KO-11-18); *D - Albic Gleyic Podzol (Turbic)* of the lower part of the gentle slope (KO-7-18); *E - Albic Gleyic Podzol (Turbic)* developing over series of buried *Albic Podzols* under a steep slope (KO-5-18)

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The content of organic carbon in the studied soils was rather small and sharply decreased with depth (Fig. 3). The content of organic carbon close to 1% is typical only of fragmentary humus horizons, formed under conditions of waterlogging in *Albic Gleyic Podzols* (pit KO-2-18), developed under the gentle slopes of mineral islands, as well as for buried soils and layers enriched with charcoal in *Albic Gleyic Podzols* developed under steep slopes. In most soils of well-drained positions, TOC was 0.1-0.2% in E horizons, 0.3-0.4% in Bs horizons, and less than 0.1% in C horizons. A small increase in TOC up to 0.2% is typical of interlayers composed of loamy material. LOI values varied from 90% in O horizons of *Albic Gleyic Podzols* to 70% in *Albic Podzols* of well-drained landscape positions; in mineral horizons, as a rule, TOC do not exceed 1%.

Contents of $Fe_o$ and $Fe_d$ have slightly different distribution patterns (Fig. 3). In the Albic Podzols of flat tops and gentle terraced slopes of mineral islands, the maximum values of $Fe_o$ were observed in Bs horizons (0.3-0.4%), sharply decreasing in C, while in E horizons these values were less than 0.1%. Differences in $Fe_o$ content in E and Bs horizons of *Folic Albic Podzols (Geoabruptic)* were less pronounced in comprehension with *Albic Podzols* developed on sands without bedding with loams. In such soil profiles, the $Fe_o$ content in Bs horizons did not exceed 0.1-0.2%, but there was a slight increase in the content of oxalate-soluble iron in the underlying loamy sediments. Higher $Fe_o$ values are characteristic for C horizons in *Albic Gleyic Podzols*. A similar distribution type characterizes dithionite extractable iron: maximum $Fe_d$ values were characteristic for interlayers and lenses of loamy material in the *Folic Albic Podzols (Geoabruptic)* of flat tops, which is directly related to the texture of the bedding material. In Bs horizons of *Albic Podzols* developed on terraced slopes, these values reached 1.3%, while in E horizons, these values did not exceed 0.1%, which is probably related to the highest intensity of the podzolization process. In *Albic Gleyic Podzols* in the bottom parts of slopes, the $Fe_d$ content in Bs horizons was also rather high (up to 1.29%), which can be explained as a result of lateral podzolization [35-36]. It is interesting to note that $Fe_d$ values were higher in the buried Bs horizons of *Albic Gleyic Podzols* developed under the steep slopes in comparison with Bs horizons of modern soils. This fact can be an indirect sign of higher-intensity podzolization during the previous stages of soil development. It can also be noted that the $Fe_d$ content in the studied soils, as a rule, coincides with the chromatic maximum, and strong relations of these parameters were reported for similar soils in other regions [37].

For *Albic Lamellic Arenosols (Abruptic)* of steep slopes, all studied soil properties and their variability along the profile (Fig. 3) are strongly determined by the lithological heterogeneity of slope sediments, as well as soil-forming processes that are frequently interrupted by erosional processes. Therefore, the analytical properties of these soils slightly reflect current pedogenic processes.

***Relationships between lithological and geomorphological factors, and morphological features of soils within the Kondinskie Lakes Natural Park***

The nature of the parent rocks and their position in the relief have a significant effect on the intensity of the main pedogenic processes and, first of all, podzolization. The main morphological and chemical parameters for E and Bs horizons in Podzols are presented in Table. Available analytical and morphological data showed that the highest intensity of podzolization is characteristic for *Albic Podzols* of terraced slopes.

The results of morphological and analytical studies allowed us to conclude that the nature of the parent rocks and their position in the relief determine the variability of the soils within this territory (Fig. 4). The most obvious pattern of soil cover organization is a direct relationship between the number and size of rock fragments, and the presence of bedding with loams on the one hand and the depth and variability a extrahorizontal morphons (tongues) on the other. Strong influence of the underlining lithology on the morphology and properties of soils was reported for slope sequences of Podzols in Poland [17]. The close occurrence of dense loamy sediments and numerous large rock fragments at the border between E and Bs horizons most likely limits tongue thickness, the depth of which, as a rule, does not exceed 40-50 mm in the *Folic Albic Podzols (Geoabruptic)* of flat tops of ridges. In such landscape- geomorphic positions, small tongues prevail, while deep wedge-like tongues are almost absent. In addition, it is remarkable that soils at the tops of large ridges are characterized by the most diverse mineralogical composition of rock fragments. On the contrary, in *Albic Podzols* of gentle terraced slopes, numerous large tongues penetrate to a depth of more than a meter. In such geomorphological context, the upper and the middle parts of the profiles are often complicated by spotty or streaky structures caused by treefalls, pit-and-mound complexes, and thin tongues developed over root channels with different deposits associated with the bottom boundaries of old pits [32]. Charcoals often present in the forms of interlayers displaced by treefalls are more common in soils of terraced slops in comprehension with flat tops.

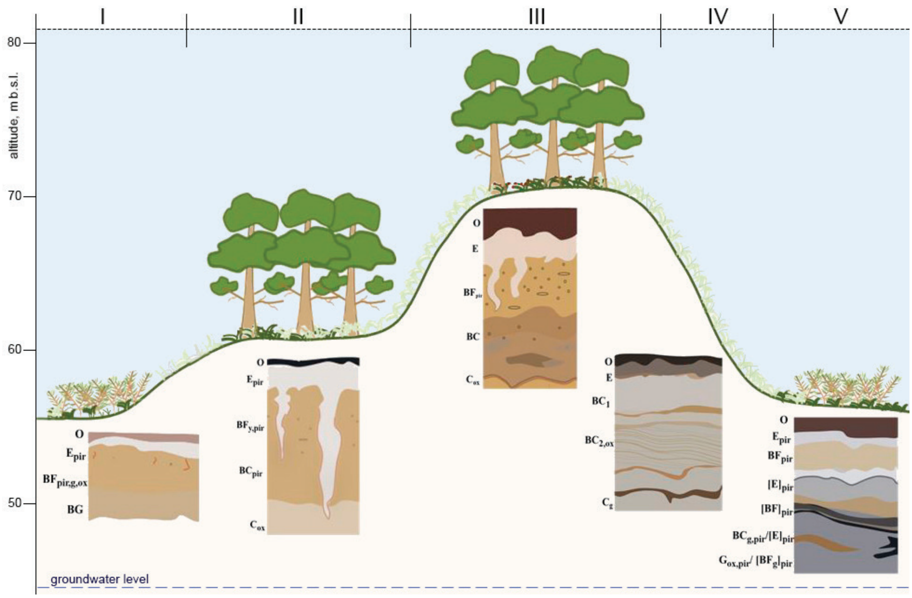


**Fig. 4.** Scheme illustrating relationships between lithological and geomorphic conditions and morphological parameters of soils: I - steep gentle slopes of large ridges with *Albic Gleyic Podzol (Turbic)*; II - terraces within the gentle slopes of ridges with *Albic Podzols;* III - flat tops of ridges with *Folic Albic Podzol (Geoabruptic)* or *Folic Albic Podzol (Lamellic)*; IV - steep slopes of ridges with *Albic Lamellic Arenosols (Abruptic, Aeolic)*; V - bottom parts of steep slopes with *Albic Gleyic Podzol (Turbic)* over series of buried *Albic Podzols*

**Main morphological parameters and properties of E and Bs horizons in soils representing various geomorphic positions and parent rocks**

| Parameters | | *Albic Podzols (Geoabruptic)* (*n*=3) | | *Albic Podzols* (*n*=5) | | *Albic Gleyic Podzols* (*n*=3) | | *Albic Gleyic Podzols* with burials (*n*=2) | |
|---|---|---|---|---|---|---|---|---|---|
| | | E | Bs | E | Bs | E | Bs | E | Bs |
| Geomorphic position | | Flat tops | | Terraced slopes | | Lower parts of gentle slopes | | Lower parts of steep slopes | |
| Horizon thickness, cm | | 9-16 | 21-26 | 5-29 | 17-60 | 14-25 | 30-40 | 6-16 | 27-53 |
| Abundance of rock fragments, % | | 0-2 | 15-40 | 0-2 | 5-15 | 0-2 | 2-5 | 0-2 | 0-2 |
| Tongue depth, cm | | <50 | | ~100 | | 5-10 | | 5-12 | |
| Color | L* | 66.5-71.5 | 59.1-66.8 | 66.6-70.2 | 65.7-67.6 | 63.3-67.7 | 53.7-67.7 | 52.9-57.9 | 58.3-62.8 |
| | a* | 3.0-4.1 | 4.1-7.2 | 3.0-3.4 | 4.6-6.8 | 3.1-3.9 | 4.7-8.1 | 3.4-4.5 | 3.4-4.8 |
| | b* | 10.1-11.6 | 19.7-25.1 | 9.4-10.6 | 21.2-23.7 | 10.7-12.6 | 23.2-25.2 | 12.9-13.6 | 15.9-20.1 |
| Clay-fraction content, % | | 0.4-2.4 | 2.4-30.3 | 1.2-1.7 | 1.2-3.7 | 1.6-4.1 | 1.6-7.4 | 2.6-8.1 | 2.4-6.3 |
| $pH_{H2O}$ | | 4.2-4.7 | 4.8-5.1 | 4.8-5.6 | 4.8-5.5 | 3.9-4.6 | 4.5-5.1 | 4.1-4.2 | 4.1-4.4 |

Table (end)

| Parameters | *Albic Podzols (Geoabruptic)* (*n*=3) | | *Albic Podzols* (*n*=5) | | *Albic Gleyic Podzols* (*n*=3) | | *Albic Gleyic Podzols* with burials (*n*=2) | |
|---|---|---|---|---|---|---|---|---|
| | E | Bs | E | Bs | E | Bs | E | Bs |
| $pH_{KCl}$ | 3.4-3.9 | 4.4-4.8 | 3.8-4.4 | 4.7-5.2 | 3.2-4.0 | 4.3-4.6 | 3.3-4.1 | 4.3-4.1 |
| Total organic carbon content, % | 0.1-0.3 | 0.1-0.3 | 0.1-0.12 | 0.08-0.14 | 0.1-0.3 | 0.1-0.4 | 0.1-0.3 | 0.1-0.4 |
| $Fe_o$, % | 0.01-0.02 | 0.10-0.41 | 0.01-0.03 | 0.04-0.28 | 0.01-0.03 | 0.16-0.44 | 0.04-0.14 | 0.08-0.17 |
| $Fe_d$, % | 0.01-0.30 | 0.2-1.0 | 0.03-0.04 | 0.09-0.77 | 0.05-0.10 | 0.33-1.29 | 0.06-0.42 | 0.23-0.60 |

The obtained results support the predominant role of the biogenic factor in the formation of tongues and other morphological elements of the upper part of soil profiles within the study area. Signs of biogenic pedoturbations are less expressed and rarer in *Folic Albic Podzols (Geoabruptic)*, as well as the penetration depths of pine-root systems are limited by dense loams, which promotes development of horizontal roots. There, tree-fall-related pedoturbations occur less frequently in soils of tops, and their signs are worse preserved and not so evident. It is also possible that the presence of loamy lenses and interlayers in sandy soils stabilized the water regime [36, 38], and pine forests developed on flat tops limited by high steep slopes are more persistent to fires, which explains smaller contents of charcoals in the upper part of their profiles. It is important to note that our studies have not revealed any direct signs [39-40] of a significant role of cryogenic processes typical of *Podzols* in the northern taiga and forest tundra for the formation of morphological elements in *Albic Podzols* of the Kondinskie Lakes Natural Park area.

***Modern soil cover of the Kondinskie Lakes Natural Park as a source of paleogeographical information on the evolution of the natural environment in the north of the Kondinskaya Lowland***

The modern soil cover of various geomorphic positions within the study areas contains information on the evolution of landscapes in the north of the Kondinskaya lowland, both in the Late Holocene and earlier periods.

Positive landforms within the study area often have steep slopes that, in turn, predetermine a rather high intensity of erosion processes in the considered territory, especially in comparison with other regions of the middle taiga zone of Western Siberia. Accordingly, *Albic Gleyic Podzols* with buried *Podzols* and sediments formed at the feet of steep slopes are unique natural archives that store information about the various stages of erosional activation. Investigation of colluvial sediments and burials is important for the reconstruction of natural and natural-anthropogenic dynamics of landscapes in Holocene for different territories with dissected relief [41-43]. At the top of one of the mineral islands selected for detailing, there is a monument of the early Iron Age “island fort”, described by SA Terekhin in 2006 [23]. Archeological studies concluded that it had no fortification significance, and no cultural layer was found. Thus, taking into account the time, which is required for the formation of a 4-5 cm thick E horizon that is about 1000 years old for the taiga zone of Northern Eurasia [44-45], we can conclude, that there were several stages of erosional processes that occurred during the period about 3000-4000 years ago. This idea is in good correlation with archeological data about the periodic nature of human presence within this territory, at least from the early Iron Age. A similar situation related to the appearance of several stages of ancient human activity can be observed for archeological sites of adjacent parts of Western Siberia, including the Surgut Ob Region [46]. Paleogeographical reconstructions available for the middle taiga zone of Western Siberia [47] also support the idea of a strong relationship between human activity and fire history for the bogged landscapes of eastern and central parts of the Khanty-Mansi Autonomous Okrug. Further studies, including radiocarbon dating of material from burials, would allow us to more accurately establish the time of erosional and pyrogenic events for the territory under consideration.

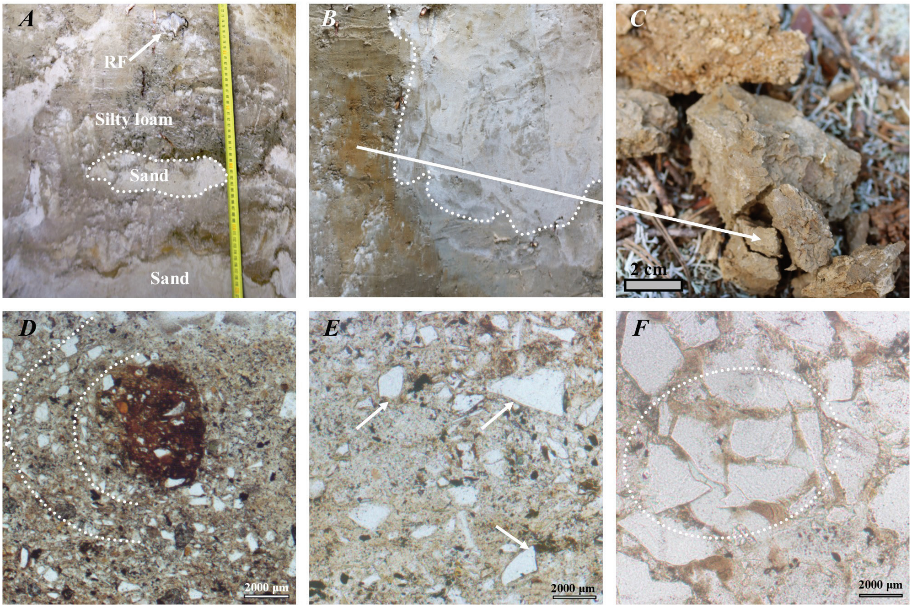


**Fig. 5.** Macro- and microfeatures of silty loams: *A* - large rock fragments and alternation of lenses with sandy material and silty loam in the bottom part of KO-4-18 pit; *B* - possible sign of paleocryogenic turbations in the bottom of KO-1-18 pit; *C* - silty-loam aggregates with a well-developed structure; *D* - possible signs of a circular pattern of sand-grain distribution (KO-1-18; PPL); *E* - single grains with signs of frost cracking (KO-1-18; PPL); *F* - fracturing of quartz grains (KO-4-18, PPL). Photos by Alexandr Konstantinov

Loamy beds that underlie sand deposits at the tops of large ridges are also extremely interesting as a source of information about the evolution of the territory under consideration in the Late Quaternary. They are characterized by a noticeable predominance of silt fraction in particle-size distribution, as well as probable traces of cryogenic turbations and permafrost gleying. When studying the material of loamy deposits in thin sections (Fig. 5), characteristic signs of deposits that underwent cryogenic processes [48-50], such as the ring, arrangement and frosty cracking of sand grains can be seen. Thus, features of particle-size distribution and the presence of morphological and micromorphological signs of cryogenic transformations allow us to suggest that these deposits may be considered as silt-dominated periglacial cover [15, 51].

## Conclusion

The conducted studies allowed us to draw a number of conclusions regarding soil cover features of the Kondinskie Lakes Natural Park. *Folic Albic Podzols (Geoabraptic)* represent soils of autonomous positions. They are characterized by a moderate thickness of the E horizon, the largest number of rock fragments, and silty loams often underlying sandy material that forms the upper part of the profile. The close occurrence of dense loamy deposits and numerous large rock fragments on the border of E and Bs likely limited the thickness of the tongues, the depth of which, as a rule, does not exceed 40-50 mm. *Albic Podzols* occupy gentle terraced slopes of ridges. This group of soils is distinguished by the highest diversity of morphological elements in the upper part of the profile due to biogenic pedoturbations and the podzolization process being the most intensive in such conditions. The soils of steep slopes are *Albic Arenosols*. Stratification of the soil profile in such conditions is related more with erosional than pedogenic processes. *Albic Gleyic Podzols* are common at the foot of slopes. In cases when soil formation occurs under steep slopes, *Albic Gleyic Podzols* develop over series of buried Podzols and charcoal-rich sediments.

We can conclude that the nature of parent rocks and their position in the relief determine soil for the territory under consideration. There is a direct relationship between the number and size of rock fragments, the presence of abrupt textural contacts on the one hand, and the thickness of the E horizon and the variability of morphological elements on the other. The soil cover of the Kondinskie Lakes Natural Park is an archive of paleogeographical information related to the evolution of landscapes within the northern part of the Kondinskaya lowland in the Holocene and, probably, earlier periods.

It is also important to mention that it is generally believed that, in Western Siberia, restrictions on the development of root systems are mainly related to permafrost and waterlogging, as well as a significant part of the region is located in the cryolithozone and is very flat. Abrupt textural contacts related to the presence of dense rocks that restrict the depths of root systems are more characteristic and typical of the middle taiga of Fennoscandia. However, the soils of the mineral islands of the Kondinskie Lakes Park are atypical of Western Siberia, where the presence of unfavorable dense loams with pebble-boulder material leads to the "compression" of the soil profile and the appearance of Geoabruptic features.

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**Author info:**
***Kurasova Alina O*,** Postgraduate Student, Department of Soil Science and Soil Ecology, Institute of Biology, Tomsk State University, 36 Lenin Ave., Tomsk 634050, Russian Federation.
ORCID iD: https://orcid.org/0000-0003-4479-3789
E-mail: kurasovalina@gmail.com
***Konstantinov Alexandr O*,** Researcher, Laboratory of Sedimentology and Paleobiosphere Evolution, Institute of Environmental and Agricultural Biology (X-BIO), University of Tyumen, 6 Volodarskogo Str., Tyumen 625003, Russian Federation.
ORCID iD: https://orcid.org/0000-0002-6950-2207
E-mail: konstantinov.alexandr72@gmail.com
***Kulizhskiy Sergey P*,** Dr. Sci. (Biol.), Professor, Head of the Department of Soil Science and Soil Ecology, Institute of Biology, Tomsk State University, 36 Lenin Ave., Tomsk 634050, Russian Federation.
ORCID ID: https://orcid.org/0000-0001-5545-1296
E-mail: kulizhskiy@yandex.ru
***Konstantinova Elizaveta Yu*,** Junior Researcher, Research Institute of Biology, DI Ivanovsky Academy of Biology and Biotechnology, Southern Federal University, 105 Bolshaya Sadovaya Str., Rostov-on-Don 344006, Russian Federation.
ORCID iD: https://orcid.org/0000-0002-9836-8721
E-mail: konstantliza@gmail.ru
***Khoroshavin Vitaly Yu*,** Cand. Sci. (Geog.), Head of the Institute of Earth Sciences, University of Tyumen, 6 Volodarskogo Str., Tyumen 625003, Russian Federation.
E-mail: purriver@mail.ru
***Loyko Sergey V*,** Cand. Sci. (Biol.), Senior Researcher, BIO-GEO-CLIM Laboratory, Tomsk State University, 36 Lenin Ave., Tomsk 634050, Russian Federation; Researcher, Tomsk Oil and Gas Research and Design Institute (TomskNIPIneft), 72 Mira Ave., Tomsk 634027, Russian Federation.
ORCID iD: https://orcid.org/0000-0003-2020-4716
E-mail: s.loyko@yandex.ru

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