Geoecological trends of natural and anthropogenic transformation of soils of Vyatka Ridge in the Holocene

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Abstract. The paper presents the morpho-analytical characteristic of the sod-podzolic soil section with the second humus horizon (SHH) located in the contact zone of the southern taiga and mixed forests of the east of the Russian Plain (Kirov region, Russia). The SHH is 17-25 cm deep from the surface, has darker color and is substantially different in many properties from the overlying humus horizon of modern soil. A retrospective analysis of spontaneous and technogenic history of modern landscapes of the research region and its soil cover was carried out based on the triune provision on soil as a focus, a mirror and memory of the landscape supported by analytical methods. It was shown that over the past 7,000 years, under conditions of retarded biocirculation, a number of properties and features of the early Holocene biocenoses have been partially preserved in modern soils, starting from the depth of 17 cm. Soil farming can fundamentally change the properties of polygenetic soils with SHH, thus making them almost fully losing their retrospective and prognostic functions.

1. Introduction

Soil as a unique natural multicomponent system is able to accumulate and preserve many signs of past natural eras in its body over a long period of evolution. This ability was called the soil memory [1, 2]. The components of this memory are diverse, their stability, as well as information capacity, is different. Over time, the soil memory is erased and layered depending on the types of evolution. The complex study of different components allows reconstructing geoecological trends of natural transformation of soils in the past and predicting the scenarios of their future development [3–5]. In this regard, the guiding methodological provision can be the following soil paradigm, which is widely known in natural sciences and, in soil science in particular:

• first, as the focus of landscape, where the threads of many physical, chemical, physical-chemical, biochemical interactions of different binding force are closely intertwined;
• second, as an open complex bioinert body of nature, the different components of which have a different degree of reflectance with respect to external influences and, accordingly, a different ability to record them in morphology and soil properties, on the one hand, as well as the ability to preserve former impacts in a changed geoecological environment, on the other.
2. Objects and methods

2.1. The object of the study was the soils of the south-east of the middle Russian south taiga soil province of sod-podzolic medium-humus soils located in the central part of the Kukar Plateau of the Vyatka Ridge (Kirov region). In many profiles of these soils there is the so-called second humus horizon (SHH or AEL [hh]), i.e. a humus horizon located at some depth, and which is different from the modern organo-mineral horizon AY by a number of signs – darker color, tile structure, greater density, etc. [6]. It can be both directly below the modern humus horizon and below the weakly developed separating eluvial horizon. The issues of different interpretation of the SHH genesis are not considered in this work, since for the soils of this region the genesis of the horizon is quite reliably defined as relict – Early Holocene [7]. It is this aspect that makes it possible to use the soil data of the region to characterize geo-ecological trends of soil transformation.

The materials are based on the studies of morphology and substance properties of the С-8 sod-podzolic soil section on a clay loam carbonate-free mantle located in the upper part of smoothed watershed under the spruce-fern-grass area. The second humus horizon – AEL [hh] – is located directly below the modern humus horizon AY.

2.2. Methods

Morphological description of cultural layers and buried soils are given according to the FAO Guidelines for Soil Description [8].

The analytical studies were performed using conventional techniques as described below.

The grain size analysis of the fraction <1 mm was made by conventional pipette method [9] to appropriate texture classes. The particle size distribution was analyzed for the Russian conventional fraction groups. Textural classes were determined according to the FAO Guidelines for soil description [8].

\( \text{pH}_{2\text{O}} \) and \( \text{KCl} \) was determined using a potentiometer EV-74 in suspension with soil to water ratio of 1:2.5 after a single shaking followed by settling for 30 min [10].

The organic carbon content was determined by the Tyurin method, which included the wet combustion of organic substance in a mixture of 0.4 N \( \text{K}_2\text{Cr}_2\text{O}_7 \) and concentrated \( \text{H}_2\text{SO}_4 \) (1:1) at 150 °C for 20 min. The humus was determined by the titration method with the Mora salt [11], and fraction-group composition of humus – according to Kononova and Belchikova [12].

The exchange of Ca and Mg was defined by complexometry with Trilon B.

The concentrations of macro- and microelements (bulk composition and trace elements) were determined according Arinushkina’s sintering technique with alkalies [11].

The phytolith analysis is the consecutive study of the different types of plant silica particles under a microscope. Fifty-gram samples were treated with a 30 % solution of hydrogen peroxide and then separated from quartz and other mineral grains by flotation in heavy liquid with a specific gravity of 2.3 g/mL (mixture of cadmium iodide and potassium iodide solutions). After centrifugation, the floating siliceous and organic microbiomorphs were collected and washed several times with distilled water, then immersed in oils (glycerin). The slides were prepared and analyzed under an Olympus BX51 TL RL optical microscope (Tokyo, Japan) at magnifications ranging from 400× to 900×. The phytoliths were identified and counted. The data obtained on phytolith assemblage composition in different samples were used for the analysis of the quantitative distribution of phytoliths along the column studied according to [13].

The absolute age of humic acids of both humus horizons (by radioisotope \( ^{14}\text{C} \)) is determined in the laboratory of paleogeography and geochronology of the quaternary period of SPbSU. The obtained radiocarbon data were translated into the calendar age using the CalPal calibration program of Köln University in 2006 (authors B. Weninger, O. Jaris, U. Danzeglocke) [14].
3. Results
3.1. Morphological Description
Horizon O, 0–2 cm: dead soil cover made of needles, leaves, small branches, some spruce bumps, wet, blackish-brown, crude, transition to the next horizon is clear and smooth.

Horizon OA, 2–5 cm: wet, blackish-brown, medium loamy, grainy, loose, mellow, enriched with strongly humanized mortmass with abundance of young thin roots of light grey and whitish colors, transition is clear and smooth.

Horizon AY, 5–17 cm: wet, ash-grey with whitish hue, medium loamy, fine blocky-laminar, loose, many small grey-brown hardpans, there are local whitish spots of skeletans, there are many roots, transition is clear, visible by darkening color.

Horizon AEL[hh], 17–25 cm: wet, carbonaceous-grey, with separate darker areas, heavy-loamy, coarse-grain-tile, loose, many small grey-brown hardpans, visible whitish powdering of skeleton, more intense on the periphery of tongues and pockets in the lower part of the horizon, aggregates are completely impregnated with humus, transition is gradual, rolling with some tongues up to the depth of 39 cm.

Horizon of VT1, 25–51 cm: wet, brown, with weak whitish hue and noticeable humic luster on the sides of aggregates and root pores, clay, nuciform, dense, easily broken up to aggregates, weak powder skeletons in the upper part, fine clay envelopes organized as lenticel can be found on aggregate walls, roots are rare, transition is gradual, noticeable by color and structure.

According to the Russian classification, soil is defined as sod-podzolic with the second humus horizon [15] or Eutic Retisol (Epic, Endoclayic, Cutanic), according to the International Classification WRB [16].

3.2. Analytical Properties
Soil is characterized by textural differentiation of the solid phase clearly fixed according to data on vertical distribution of silt fraction and basic rock-forming oxides, as well as exchange bases – Ca and Mg. The bulk chemical composition correlates with granulometric composition: there was also a change in the properties of the antecedent soil – substantial removal of Fe and Al oxides under the influence of eluvial processes (Table 1).

Table 1. Main characteristics of upper organo-mineral horizons of section 8.

| Horizon | Depth, cm | pH<sub>H2O</sub> | pH<sub>CT</sub> | Ca + Mg (cmol/kg) | C (TOC, %) | C/Cl | Cg/Ck | Fe<sub>2</sub>O<sub>3</sub> | Al<sub>2</sub>O<sub>3</sub> | C<sup>14</sup>VR | C<sup>14</sup>Cal (18) | Mm (% of C) | Phytoliths Total (% of Mm) |
|---------|----------|----------------|---------------|-----------------|------------|------|------|----------------|----------------|-------------|-----------------|-----------|--------------------------|
| AY      | 5–17     | 5.3            | 3.9           | 5.7             | 1.4        | 0.7  | 39   | 10.3          | 84             | 340±60      | 315–460         | 0.5        | 4.5                      |
| AEL[hh] | 17–25    | 5.9            | 4.2           | 8.4             | 0.9        | 0.9  | 7.2  | 5.9           | 3.3            | 6230±100    | 7000–7250       | 3.1        | 6.7                      |
| VT1     | 25–35    | 5.8            | 4.0           | 16.8            | 0.4        | 0.4  | 21.2 | 10.2          | 3.7            | –           | –               | 0.5        | 0.5                      |

SHH has acidic pH values of water and salt extracts, as well as adjacent soil horizons, which is consistent with the vertical distribution of aggressive and mobile fractions of fulvic acids and Ca and Mg exchange. Organic carbon is 1.5 times less than in the modern humus horizon (Table 1). At the same time, the NGL/ABC ratio in the SHH is more than 3, whereas in the modern humus horizon it is 0.9. In other words, according to the data for the AY horizon, the composition of the humus of the lower humus horizon is closer to the soils of the forest-steppe type of soil formation than to the podzolic, as is the case with the modern soil.

Among all microbiomorphs, the most informative was the phytolithic composition of both humus horizons. The second of them does not only contain more phytoliths, which is typical for meadow
communities (Table 1), but also the composition of fractions is different. SHH has more meadow phytoliths (28 versus 14% in the modern humus horizon), significantly less conifers (3 versus 12%). There are also forms typical for steppe cereals completely missing above (Figure 1).

![Distribution of diagnostic forms of phytoliths within the horizons: a – AY 5–17 cm; b – AEL[hh] 17–25 cm; c – VT1 25–35 cm. The figures in the legend show the following groups of phytoliths (%): 1 – dicotyledonous herbs; 2 – coniferous needles; 3 – forest cereals; 4 – meadow cereals; 5 – steppe cereals. The figures in the charts show the phytolith content (%).](image)

Below the SHH there are much smaller phytoliths, their composition is homogeneous and represented by forest cereals and mixed herbs. Apparently, early phytocenosis was predominantly forested. It changed to a meadow with the presence of steppe components. The forests did not dominate and were mostly deciduous. This does not correspond to the structure of modern, mainly coniferous forests of the region.

The analysis of the age of SHH humic acids made it possible to determine that the direction of soil formation changed about 7,000 years ago.

**4. Conclusion**

Thus, morphological, physicochemical, microbiomorphic and other important soil characteristics showed fundamentally different soil formation trends in the Holocene – from accumulative to accumulative-eluvial, which caused complete transformation of the upper part of the profile and restructuring of many soil parameters. In other words, in the first half of the Holocene there was a shift of the landscape zones of the Vyatka Prikamye about 200 km to the north with increasing role of meadow communities and nemoral component in biome structure. In the middle and late Holocene, the trend of soils was reversed and characterized by an increase in the proportion of boreal component in biomes. Such significant changes were certainly accompanied by radical changes not only in soil, but also in plant covers, hydrological regime, properties of soil-forming rocks, i.e. practically all components of the landscape. It is possible to talk not only about the temperature component, but also about the humanization of the climate, which increased the eluvial trend of soil development.

The soil memory components such as horizon color, structure, neoplasms, humic-fulvic acid ratio, radiocarbon age of humic acids, qualitative and quantitative composition of microbiomorphic fractions represent a reliable stable complex preserving its initial characteristics even after many thousands of years. At the same time, there is a process of gradual “deletion” of some diagnostic signs, and superimposition of late new parameters on earlier old ones. Thus, some forms typical for conifers are found in the phytolytic complex belonging to SHH. These particles have no influence on the general conclusion on the composition of the vegetation cover of the period of formation and functioning of the antecedent soil, but the fact that they are in the horizon is important. Obviously, they fell into the horizon through gradual migration from above. The speed of such migration is small, it decreases with depth, but over 7 thousand years some phytoliths got into the horizon of the meadow soil through...
cracks and animal tracks. This phenomenon is slower than the process of erasing the dark-colored residual horizon due to sulfonic acid hydrolysis. Thus, in the natural conditions of the delayed biocircle, the signs of early Holocene biocenoses are preserved in modern soils starting from the depth of 17 cm of the modern surface.

The most significant factor for the disappearance of soils from the SHH and any diagnostic indicators of change of evolutionary trends in the past is the anthropogenic factor, first of all plowing, the duration of which in this territory is not less than 300–400 years. During plowing, especially accompanied by agrogenic erosion, not only the upper (modern) humus horizon can be completely destroyed, but also the underlying horizon, including the SHH. When large doses of manure are introduced into the soil as a fertilizer, among other morphological and physical-chemical indices of the arable layer, a new phytolytic complex is formed, which has nothing in common with the original natural one, i.e. the comparative analysis of phytolytic complexes becomes impossible.

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