Sod-podzolic soils with a complex organic profile of the southern Vyatka River basin

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Abstract. The article is devoted to the morphology and substantive properties of the sod-podzolic soils with a complex organic profile having the second humus horizons and found on the southern right bank of the lower Vyatka River. The research results of the mineral and organic phases are the evidence of the relict origin of the second humus horizon as well as the evidence of profile polygenicity of the given soils. They went through two fundamentally different pedogenesis stages during the postglacial period: 1) the developmental accumulative evolution stage in the first half of the Holocene and 2) the accumulative-eluvial stage of erasing evolution including the elements of inheriting evolution in the second half of the Holocene. Keywords: granulometric composition, fractional and group composition, humus age, genesis, soil evolution

1. Introduction

Soils with a problematic profile structure are widespread in the soil mantle of the lower Vyatka River basin, which is situated between the southern taiga and mixed forests. This soil type was originally attributed to the gray forest type. The reason for this was a transitional accumulative-eluvial horizon (Ahh) in the profile. However, the verification of these soils was called in question due to the following special studies [1-4]. The information below confirms this.

2. Object, subject and methods of research

The object of the study is the sod-podzolic soils with a complex organic profile on the covering silt found between the rivers Vyatka and Yaran under the virgin fir and spruce forests, secondary birch forests and agricultural landscapes. The subject of the research is morphology, the mineral and organic phases of soils. The authors of the article used the following research methods: comparative soil-geographical method, morphological and genetic profile method, balance method, method of granulometry and bulk chemical analysis of the mineral part, method of fractional-and-group and radiocarbon humus analysis.

3. Results of the study

3.1. Soil morphology
The objects under research vary considerably in their appearance. The Ya-1 cut of the sod-podzolic silty clay loam residual calcareous soil with the second humus horizon on the carbonate covering silt is situated in the upper flattened part of the undulating Yaran-Izhsk water divide. It lies under the virgin spruce and fir forest, wood sorrel and aise-weed forest. Atmospheric moistening is sufficient; the type of soil moisture regime is periodically flushing.

Profile structure:

The O horizon (0-2 cm) contains wet pine needles, twigs, cones, leaves, stalks of grass and moss. It is brown, slightly decomposed and loose. The transition is clear, straight and distinguishable by color and degree of organic decomposition.

The OAY horizon (2-5 cm) is wet, black-and-brown, silty clay loam, loose, grainy, friable, enriched with humified organic residues. The roots are abundant; the transition is clear and distinguishable by color.

The AY horizon (5-14 cm) is wet, dark gray, variegated in color. Intensely colored lumps are found when the soil is dry. Some aggregates are light gray outside and dark gray inside. The horizon is silty clay loam, granular and lumpy, loose, grainy; it contains many small rounded gray-brown hardpans sized 2-3 mm and more. There are many roots; the transition is clear and distinguishable by color and structure.

The Eh horizon (14-24 cm) is wet, flaky laminated, silty clay loam, loose, smoky-gray, but becoming light gray after drying. The inner part of the aggregates is darker. There is intense whitish silica powder on the structural units. There are many small grayish brown hardpans; the roots are sparse; the transition is gradual, wavy and having a large local pocket.

The Bh horizon (24-52 cm) has a humified local pocket of 40 cm wide in the upper part and 25 cm at the bottom. The horizon is wet, carbon-black having whitish powder at the top which gradually disappears at the depth of 48 cm. The aggregates are evenly impregnated with humus. The impregnation is less intense along the pocket periphery. There are whitish spots of silica up to 3-4 cm in diameter at the depth of 32-50 cm. The horizon is clay loam, and clay in a deeper layer having a heterogeneous structure. Downstream the platy aggregates gradually change to fine- and coarse nutty ones. The roots are sparse; the transition is clear and distinguishable by color and structure.

The El horizon (24-32 cm) is wet, whitish pale, clay loam, laminal-platy, loose, friable; bleached silica powder is abundant. There are many small grayish brown hardpans. The roots are sparse; the transition is gradual and tongue-like.

The ElB horizon (32-41 cm) is wet, whitish brown, clay, platy, nutty, compact, friable with lots of whitish bleached silica weakening in a deeper layer. There are few hardpans; the roots are sparse; the transition is gradual, tongue-like.

The Bt1 horizon (41-58 cm) is wet, brown, clay, nutty, dense. It has dark humus varnishing and easily falls into structural units. On the surface of aggregates there is whitish silica weakening in a deeper layer; in the lower parts of the aggregates there are small clay papillary cutans. The roots are sparse; the transition is gradual.

The Bt2 horizon (58-94 cm) is wet, yellowish brown, clay, prism-shaped and nutty, dense, slightly viscous. It has dark humus varnishing which is less intense compared to the Bt1 horizon. Whitish silica powder is distinguishable only on the large cracks between aggregates. There are few cutans; the roots are single, the transition is gradual.

The BCa horizon (94-135 cm) is wet, yellowish brown, clay loam, prism-shaped, dense; it is more viscous than the Bt2 horizon. There is slight humus varnishing on the surface of aggregates and along the walls of root pores. There are few clay cutans; at the depth of 120 cm there are small calcareous pipes as well as weak effervescence caused by HCl solution. The roots are single, the transition is gradual.

The Cca horizon (135-160 cm) is wet, yellow-brown, variegated in color, clay loam, viscous, non-structured and has slight reticulated humus varnishing in root pores. At the depth of 150 cm there are mottlings of reddish and grayish green units consisting of Perm clay eluvium. The horizon contains
soft pink-white calcareous grit. In the lower part the soil has signs of mixing and dislocation. The roots are single; the transition is gradual.

The CDca horizon (160–220 cm) is wet, brownish-red, heterogeneous, clay, nutty, dense. It contains pinkish and grayish-greenish mottlings, but there are less calcareous units in comparison with the Cca horizon. The mineral matter has signs of mixing.

Morphological analysis indicates that the profile clearly differentiates between accumulative-eluvial and illuvial parts. The upper and lower humus horizons vary in their appearance considerably. The AY horizon of the virgin soil has features of a typical accumulative horizon. The plowing layers of the arable soil have lost their natural structure.

The AElh horizon is characterized by a contrasting combination of accumulative and eluvial horizon features, i.e. dark gray or carbon-black coloring, brittle slab-shaped or slab-shaped granular structure, silica powder on the surface of aggregates impregnated with humus, and sparse roots.

The morphological appearance of the ElB horizon is typical of transient sub-eluvial parts of soil profiles with heavy granulometric composition which are distinguished by whitish-brown coloring, slab-shaped or slab-shaped and fine-nutty structure, and whitish silica. Humus varnishing and clay cutans are specific features of the texture-illuvial horizons.

Depth of the sod-podzolic soil horizons with a complex organic profile can be summarized as follows: O (2 cm) + OAY (3 cm) + AY (10 cm) + AElh (12 cm) + ElB (8 cm) + Bt₁ (24 cm) + Bt₂ (33 cm) + BC(ca) (28 cm) + C(ca) + (D).

3.2. Granulometric composition

The granulometric composition shows a clear differentiation of the profile (Table 1). The upper 30-35 cm stratum is considerably depleted of physical clay and has a silty clay loam composition. There is almost no difference between the humus horizons regarding the content of particles less than 0.01 mm. Their quantity increases substantially in the ElB horizon. The middle part of the profile (Bt horizons) is characterized by the highest number of physical clay particles and always has a silty clay granulometric composition. In the C horizons the level of physical clay slightly decreases.

The reason for eluvial and illuvial differentiation is the similar profile distribution of clay with the minimum level in the A horizons. Both humus horizons are close in their characteristics, although the lower one tends to have more clay. The Bt horizons are defined by the maximum concentration of the clay fraction. The amount of clay in the soil-forming material is reduced. Negative clay balance was found in the profile of the soils under research by means of balance calculations of the absolute clay fraction content (Table 2).

Bulk chemical analysis confirms sharp textural differentiation which is especially noticeable in the virgin soils (Table 3). Their organogenic horizons O and OAY are clearly isolated due to the considerable amount of biophile elements (Ca, Mn, K, P, S, etc.) and due to the relatively low amount of silica. The underlying humus horizons A and AElh are characterized by the maximum concentration of \( \text{SiO}_2 \); as a result they are depleted of iron oxide, aluminum, alkaline earth cations. The number of the last mentioned substantially increases in the illuvial stratum and, on the contrary, the content of silica decreases.

A characteristic feature of the clay fraction is the fact that its composition is stable. And it is proved by the profile distribution of bulk forms of silicon and aluminum oxide as well as \( \text{SiO}_2 : \text{Al}_2 \text{O}_3 \) ratio (Table 3). The latter shows that there is no significant chemical decay in the aluminosilicate core of the secondary clay minerals. Substantial iron subtraction from eluvial horizon clay is an indicator of surface gleyfication [5-6].

This fact is confirmed by a high content of hardpans sized 0.25-5 mm – in the lower humus horizon the amount is up to 18%, and in the upper humus horizon it is up to 8%. It is proved also by a high amount of polyvalent cations – Mn, P, and Fe [1]. Both the negative balance of clay and the presence of large amounts of replaceable aluminum can possibly indicate acid hydrolysis of fine-dispersed mass of eluvial horizons.
It is most probably that leaching, illimerization, and exogleying processes as well as acid hydrolysis influenced the activation of the vertical differentiation of the soil profile in the Late Holocene.

**Table 1.** Granulometric composition of the sod-podzolic soils with a complex organic profile in the lower Vyatka River basin.

| Horizon, depth of the sample, cm | Bulk weight, g/cm³ | Hygroscopic moisture, % | 1-0.25 | 0.25-0.05 | 0.05-0.01 | 0.01-0.005 | <0.001 | <0.01 | Clay accumulation, % |
|--------------------------------|--------------------|------------------------|--------|-----------|-----------|-------------|--------|-------|----------------------|
| OA                             | 2-5                | 8.3                    | 8.3    | 14.4      | 47.1      | 13.0        | 13.7   | 9.8   | 36.5                 | –72 |
| AY                             | 5-14               | 0.96                   | 4.6    | 0.6       | 13.5      | 47.3        | 16.2   | 14.6  | 7.8                  | –77 |
| Elh                            | 14-24              | 1.23                   | 2.0    | 0.3       | 8.0       | 52.2        | 13.6   | 20.3  | 5.6                  | –84 |
| El                             | 24-32              | 1.42                   | 1.7    | 0.2       | 20.3      | 38.9        | 13.1   | 15.7  | 11.8                 | –66 |
| Bh                             | 28-32              | -                      | 1.4    | 0         | 14.1      | 43.4        | 13.5   | 16.3  | 12.7                 | –63 |
| Bh                             | 32-45              | -                      | 2.3    | 0         | 18.0      | 41.2        | 10.2   | 17.1  | 23.5                 | 50.8 |
| EIB                            | 32-41              | 1.47                   | 3.7    | 0         | 12.1      | 34.6        | 9.1    | 13.9  | 30.3                 | 53.3 |
| Bt1                            | 41-50              | 1.48                   | 4.7    | 0         | 8.3       | 32.0        | 9.1    | 12.7  | 37.9                 | 59.7 |
| Bt1                            | 50-58              | 1.48                   | 4.9    | 0         | 11.6      | 30.4        | 9.0    | 11.4  | 37.6                 | 58.0 |
| Bt2                            | 70-80              | 1.49                   | 4.6    | 0         | 12.7      | 31.2        | 8.4    | 13.3  | 34.4                 | 56.1 |
| BCca                           | 110-120            | -                      | 4.1    | 0.5       | 19.1      | 37.0        | 9.4    | 5.5   | 28.5                 | 43.4 |
| Cca                            | 135-145            | -                      | 4.4    | 3.0       | 18.6      | 29.7        | 6.3    | 18.7  | 23.7                 | 48.7 |
| CDca180-190                    | -                  | 5.2                    | 6.5    | 16.0      | 28.0      | 14.7        | 25.9   | 8.9   | 49.5                 | -    |
| CDca210-220                    | -                  | 6.2                    | 1.2    | 13.0      | 25.9      | 14.5        | 31.6   | 13.8  | 59.9                 | -    |
| PY                             | 0-26               | 1.21                   | 2.0    | 0.6       | 15.6      | 46.7        | 13.6   | 16.0  | 7.5                  | 37.1 |
| AEElh                          | 26-32              | -                      | 1.8    | 0         | 14.1      | 44.3        | 15.9   | 16.8  | 8.9                  | 41.7 |
| EIB                            | 26-32              | 1.48                   | 2.8    | 0         | 10.4      | 42.6        | 9.2    | 14.2  | 23.6                 | 47.0 |
| Bt1                            | 32-42              | 1.46                   | 4.0    | 0         | 9.0       | 34.9        | 9.9    | 13.5  | 32.7                 | 56.1 |
| Bt1                            | 43-53              | 1.46                   | 4.8    | 0         | 8.7       | 30.7        | 9.0    | 13.9  | 38.1                 | 61.0 |
| Bt2                            | 70-80              | -                      | 4.5    | 0         | 11.5      | 34.1        | 8.1    | 12.4  | 33.9                 | 54.4 |
| BC                             | 95-105             | -                      | 4.2    | 0.6       | 12.1      | 33.9        | 8.7    | 14.6  | 30.1                 | 53.4 |
| Cca                            | 115-125            | -                      | 4.0    | 6.1       | 22.7      | 22.9        | 6.3    | 16.1  | 25.9                 | 48.3 |
| CDca140-150                    | -                  | 3.9                    | 11.5   | 28.2      | 15.0      | 5.3         | 16.1   | 23.9  | 45.3                 | -    |

### 3.3. Humus content and composition

The second humus horizon in the sod-podzolic soils with a complex organic profile predetermines a significant total depth of their humus accumulative stratum of about 27 cm (Table 4). The lower humus horizon retains quite a high amount of humus (1.7% on average), but it is less than that of the AY (PY) horizon.

A lot of observations have proven a strong fluctuation in the humus content in the AY horizon, and a slight fluctuation in the AEElh horizon.

This fact denotes fundamental differences in the conditions of humus formation and humus accumulation processes in the comparable horizons: the upper ones are closely related to the modern pedogenesis ecology, while the lower ones are autonomous. The latter indirectly indicates the formation of organic matter in the AEElh horizon which took place under conditions different from the present-day ones.
The analysis of the humus group composition in the soils under research reveals a number of fundamental differences between some parts of the profile. The upper humus accumulative stratum is characterized by fulvate-humate and humate composition of organic matter while the illuvial part of the profile has a fulvate nature. The average Cha:Cfa ratio (carbon of humic acid to carbon of fulvic acid) for the AElh horizon is 2.5. In the upper accumulative horizon this ratio is close to 1. In the AElh horizon the ratio is much higher: from 2.5 to 5. There is a correlation between the degree of bleaching and humus group composition in the AElh horizon. The humate composition results in a strong dark color of the lower humus horizon while the organic matter quantity is relatively small. The humus group composition in the upper horizon is similar to the organic matter in sod-podzolic soils in the southern taiga. The humate nature of the AElh horizon shows its discrepancy with the modern conditions.

**Table 2.** Balance of the clay fraction in the sod-podzolic soils with a complex organic profile in the lower Vyatka River basin [7].

| Horizon, depth, cm | Reserves, kg/sq. m (and %) | Excluding tracking substance | Including tracking substance |
|--------------------|-----------------------------|----------------------------|----------------------------|
|                    | Initial | Real | Balance | Initial | Real | Balance |
|                    | Ya-1 cut |       |         |         |       |         |
| AY 5-14            | 38.2    | 6.7  | -31.5   | 29.7    | 6.7  | -23.0   |
| Elh 14-24          | 42.5    | 6.9  | -35.6   | 41.1    | 6.9  | -34.2   |
| El 24-32           | 34.0    | 13.4 | -20.6   | 36.4    | 13.4 | -23.0   |
| EIB 32-41          | 38.2    | 40.1 | +1.9    | 41.6    | 40.1 | -1.5    |
| Bt1 41-50          | 38.2    | 50.5 | +12.3   | 41.4    | 50.5 | +9.1    |
| Bt1 50-58          | 34.0    | 44.5 | +10.5   | 36.8    | 44.5 | +7.7    |
| Bt2 58-94          | 152.9   | 184.5| +31.6   | 152.9   | 184.5| +31.6   |
| BC ca 94-135       | 174.1   | 0    | -       | 380.0   | 346.5| -33.5   |
| 5-94               | 377.9   | 346.5| -31.4   | 380.0   | 346.5| -33.5   |
| 5-135              | 552.0   | 520.7| -31.3   | -       | -    |         |
| Ya-2 cut           |         |      | (-5.7%) |         | (-9.7%) |       |
| PY 0-26            | 114.3   | 23.6 | -90.7   | 92.6    | 23.6 | -69.0   |
| AElh 26-32         | 26.4    | 7.9  | -18.5   | 28.2    | 7.9  | -20.3   |
| Bt1 32-58          | 114.3   | 134.4| +20.1   | 109.2   | 134.4| +25.2   |
| Bt2 58-87          | 127.4   | 143.5| +16.1   | 124.6   | 143.5| +18.9   |
| BC 87-112          | 94.5    | 109.9| +15.4   | -       | -    |         |
| CDca 112-125       | 49.1    | 49.1 | 0       | -       | -    |         |
| 0-87               | 382.4   | 309.4| -73.0   | 345.7   | 309.4| -43.5   |
| 0-125              | 526.2   | 468.4| -57.8   | -       | -    |         |
| (-12.3%)           |         |      |         |         |      |         |

*aTotal content of TiO₂ is assumed as tracking substance*

**Table 3.** Bulk chemical composition of the sod-podzolic soils with a complex organic profile in the lower Vyatka River basin.

| Horizon, depth of the sample, cm | Percentage of calcined material weight |
|----------------------------------|---------------------------------------|
|                                  | SiO₂  | CaO  | MgO  | Fe₂O₃ | Al₂O₃ | TiO₂ | P₂O₅ | MnO  | Na₂O | K₂O | SO₃ |
|                                  |       |      |      |       |       |      |      |      |      |     |     |
| Ya-1 cut (soil)                  |       |      |      |       |       |      |      |      |      |     |     |
| O 0-2                            | 69.21 | 6.86 | 1.29 | 3.40  | 12.39 | 0.82 | 0.88 | 0.69 | 1.66 | 2.52 | 0.16 |
| OA 2-5                           | 72.02 | 3.72 | 1.23 | 3.32  | 12.28 | 0.83 | 0.56 | 0.58 | 1.45 | 2.26 | 0.15 |
| AY 5-14                          | 75.04 | 1.18 | 1.18 | 4.37  | 12.49 | 0.93 | 0.14 | 0.49 | 1.15 | 2.04 | 0.14 |
The fractional composition of HA indicates fundamental differences between the eluvial and illuvial parts of the profile. In the upper part humic acids are represented primarily by a fulvous HA1 fraction which is associated with iron and aluminum. And in the lower part they are represented only by the second black fraction (calcium humate). The latter illustrates that they do not correspond to the modern bioclimatic conditions.
Table 4. Humus composition of the sod-podzolic soils with a complex organic profile in the lower Vyatka River basin, % of carbon total quantity [2], [8].

| Horizon, depth of the sample, cm | C total, % | HA1<sup>a</sup> | HA2<sup>b</sup> | FA 1a<sup>b</sup> | FA1<sup>b</sup> | FA2<sup>b</sup> | IR<sup>c</sup> | Cha: Cfa |
|---------------------------------|-----------|-----------------|-----------------|-----------------|-----------------|-----------------|---------|---------|
| Ya-1 cut                        |           |                 |                 |                 |                 |                 |         |         |
| O 0-2                           | 25.39     | 15.3            | 3.4             | 1.8             | 13.4            | -               | 66.1    | 1.2     |
| OA 2-5                          | 17.77     | 18.6            | 3.7             | 1.4             | 16.8            | -               | 59.5    | 1.2     |
| AY 5-14                         | 5.50      | 20.0            | 2.0             | 4.0             | 17.5            | 3.8             | 52.7    | 0.9     |
| Elh 14-24                      | 1.09      | 28.4            | -               | 11.9            | 12.8            | 1.9             | 45.0    | 1.1     |
| El 24-32                       | 0.46      | 13.7            | 4.1             | 13.0            | 2.2             | 1.8             | 65.2    | 1.0     |
| ElB 32-41                      | 0.36      | 12.2            | 2.5             | 13.9            | 3.3             | 12.5            | 55.6    | 0.5     |
| Bh 28-32                       | 0.83      | 25.3            | 19.3            | 8.4             | 3.6             | 6.0             | 37.4    | 2.5     |
| Bh 32-45                       | 0.83      | 8.4             | 30.1            | 7.2             | 7.2             | 3.6             | 43.5    | 2.1     |
| Bh 41-50                       | 0.41      | -               | 12.4            | 9.8             | 18.5            | 0.8             | 58.5    | 0.4     |
| Bt1 50-58                      | 0.38      | -               | 11.8            | 10.5            | 14.7            | 5.1             | 57.9    | 0.4     |
| Bt2 70-80                      | 0.31      | -               | 11.9            | 9.7             | 7.1             | 10.0            | 61.3    | 0.4     |
| BCCA 110-120                   | 0.21      | -               | 9.5             | 9.5             | -               | 81.0            | 1.0     |         |
| Cca 135-145                    | 0.19      | -               | 7.9             | 10.5            | -               | 81.6            | 0.8     |         |
| Ya-2 cut                       |           |                 |                 |                 |                 |                 |         |         |
| PY 0-26                        | 1.40      | 23.6            | -               | 6.4             | 11.6            | 10.5            | 47.9    | 0.8     |
| AElh 26-32                     | 1.0       | 43.0            | -               | 8.0             | -               | 11.0            | 37.0    | 2.3     |
| ElB 26-32                      | 0.35      | -               | 20.0            | 20.0            | 8.6             | -               | 51.4    | 0.7     |
| Bt1 32-42                      | 0.34      | -               | 10.0            | 19.1            | 15.0            | 3.0             | 52.9    | 0.3     |
| Bt1 43-53                      | 0.37      | -               | 8.1             | 13.5            | 15.7            | 5.9             | 56.8    | 0.2     |
| Bt2 70-80                      | 0.28      | -               | 9.3             | 7.1             | 10.7            | 1.5             | 71.4    | 0.5     |
| BC 95-105                      | 0.23      | -               | 12.6            | 13.0            | 3.2             | 5.7             | 66.5    | 0.6     |
| CDca 115-125                   | 0.22      | -               | 11.4            | 9.1             | -               | 4.0             | 75.5    | 0.8     |
| CDca 140-150                   | 0.19      | -               | 13.2            | 10.5            | -               | 4.7             | 71.6    | 0.8     |

<sup>a</sup> HA – humic acid  
<sup>b</sup> FA – fulvic acids  
<sup>c</sup> IR – insoluble residue  

According to the mentioned above we can claim that there are at least two distinct phases in the history of organic matter formation in the soils with the AElh horizon. The humate nature of the lower humus horizon as well as large quantities of the black HA2 fraction in its composition point out the initial formation of the studied soils under conditions of a neutral or even weakly alkaline reaction of the medium. Apparently, intense organic-accumulative processes took place at the same time that resulted in a relatively thick and dark-colored horizon. Its thickness approximately conformed to the total depth of the modern AY and AElh horizons. The similar conditions took place in the Boreal-Atlantic Holocene stage about 9-5 thousand years ago [9].

On the basis of the ratio difference between the first and second HA fractions which correlate with the relictness degree of the AElh horizon we can make an assumption that the fraction HA1 transforms into HA2 in case of leaching of the bases with a high eluvial character of the soil formation processes. The precondition for this is the increased mobility of iron and aluminum after calcium and magnesium subtraction.

The profile FA distribution is characterized by the highest absolute level (% of the soil weight) of the most active (FA1) and aggressive (FA1a) fractions in the accumulative-eluvial stratum. They are especially abundant in the forest litter and in the upper humus horizon. The absolute level of active FA forms is considerably lower in the AElh horizon. In the textural illuvial stratum the absolute level of active and aggressive FA fractions is substantially reduced.
According to the content of humus carbon in various horizons their distribution is different. In this case the relative increase in the content of FA1 and FA1a fractions at the top of the illuvial stratum becomes an important issue. It is considered as an area of intense mineral phase destruction of the profile in the modern period.

3.4. Humus age
Table 5 shows the results of radiocarbon dating of humic acids in the AY, AEh and Bh horizons of the sod-podzolic soils with a complex organic profile.

The analysis points out sharp differences of the HA age of the upper and lower humus horizons. According to the most dated HA fractions (second and third) the formation of the AEh horizons took place in the Atlantic Holocene stage (7.5-5.5 thousand years ago).

A younger age of the fraction HA1 (humates associated with iron and aluminum) can possibly be a result of its formation in the upper profile leached bases. The radiocarbon dates of the first HA fraction of the AEh horizon indicate the time when the accumulative Boreal-Atlantic phase of soil formation changed to accumulative-eluvial between the Atlantic and Subboreal stages (about 5000 years ago).

The fact that there are several horizons in one and the same profile which are qualitatively different in their age (and the humus composition) indicates a quick direction change of soil formation processes which took place about 5000 years ago between the Atlantic and Subboreal stages.

Table 5. The age of humic acid of the sod-podzolic soils with a complex organic profile in the lower Vyatka River basin.

| Cut, № | Horizon | Depth of the sample, cm | HA fraction | Age acc. to $^{14}$C, years | Laboratory sample, № |
|--------|---------|------------------------|-------------|-----------------------------|----------------------|
| Ya-1   | AY      | 5 – 14                 | HA1         | 600±90                      | LU-1502              |
|        |         |                        | HA2         | 1580±180                    | LU-1501              |
|        |         |                        | HA3         | 2590±140                    | LU-988               |
|        | Elh     | 15 – 25                | HA1         | 5580±140                    | LU-994               |
|        |         |                        | HA2         | 6600±430                    | LU-993               |
|        |         |                        | HA3         | 6740±300                    | LU-984               |
|        | Bh      | 35 – 50                | HA1         | 5530±160                    | LU-995               |
|        |         |                        | HA3         | 7630±390                    | LU-985               |

Combining heterochronous humus compounds in one and the same profile explains a shift of landscape zones on the territory of the Vyatka-Kama region in the last 10 thousand years. In the early Holocene the boundary of soils with a complex organic profile ran to the Cheptsa River valley, and now it is moving to the south.

4. Conclusion
The sod-podzolic soils under research went through two major stages of pedogenesis: 1) accumulative-eutrophic – it is a developmental evolution stage in the Atlantic phase of the Middle Holocene, and 2) accumulative-eluvial stage of erasing evolution with the elements of inheriting evolution in the Subboreal-Subatlantic phase of the Late Holocene.

In the last 300-400 years, the processes of spontaneous evolution have been superimposed by agro-anthropogenic degradation resulted in mechanical destruction of relict humus horizons caused by plowing and soil erosion.

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