# SOIL INDICATORS OF LATE HOLOCENE FOREST-STEPPE LANDSCAPE EVOLUTION ON THE RUSSIAN PLAIN

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## ABSTRACT

Archaeological objects, such as fortification ramparts and burial mounds are widely spread on the Russian Plain and commonly buried soils have well preserved beneath. For Late Holocene, especially after 2500 BP, the climatic trends for the Russian Plain are still uncertain. Chronosequences of surface soils and soils buried under defensive ramparts of ancient settlements Mukhino, Ksizovo and Degtevoe in the Central Forest-Steppe zone, Lipetsk region was studied. Five defensive earthworks differ in age from 2500 to 1500 years BP providing a detailed record of Late Holocene landscape shifts. For paleoenvironmental reconstruction spore-pollen, phytoliths, and DNA analysis, for the comprehensive study of soil properties – micro- and mesomorphological methods were used.

In Early Iron Age environment was similar with modern one, which is confirmed by the similarity between surface soils and soils buried under three ramparts of 2500 years BP (Greyzemic Luvic Phaeozems). The peak of aridization 1500 years ago, resulted in the formation of Luvic Chernozems with higher carbonate table and carbonate films above clay cutans. By the obtained data, we proposed to divide the Second half of Holocene into five paleoclimatic periods.

**Keywords:** paleopedology, Holocene, geoarchaeology

## INTRODUCTION

Soil properties are commonly used to make interpretations of the archaeological record, including how the soil was formed, how it has been altered, and how it is preserved [7]. Buried soils were formed at the Earth's surface and subsequently covered by younger sediments, are excellent indicators of climate change or stability, forming under specific conditions which either contrast to or corroborate current conditions. Properties of buried soils are commonly used to make assumptions about the climate and vegetation of pre-existing landscapes. The main pedoarchaeological aim is an opportunity of linking diagnostic soil properties with causal processes. But once the soil is buried, it may undergo significant chemical and physical changes. Some of the original soils lost their properties while new features are acquired. The biotic, climatic, geomorphological

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and diagenetic processes which operate on archaeological soils affect their preservation potential [14, 15].

Archaeological objects are widely spread on the Russian Plain, and buried soils are often well preserved under fortification ramparts and burial mounds. There are numerous studies of the Holocene paleoclimatic variations. However, there is still no clear picture of climatic trends during Late Holocene, and especially since the Early Iron Age (2500 years BP).

In the Forest-Steppe zone the boundaries of the forest and steppe areas shifted as a result of changes in the temperature and precipitation: in the case of warming, the edges of steppe landscapes moved northward, in more humid conditions forest went into steppe [2]. Buried soils retain these records. The goal of this paper is revealing environmental dynamic in the second half of the Holocene by studying surface soils and soils buried under fortification ramparts of the Early Iron Age.

## MATERIALS AND METHODS

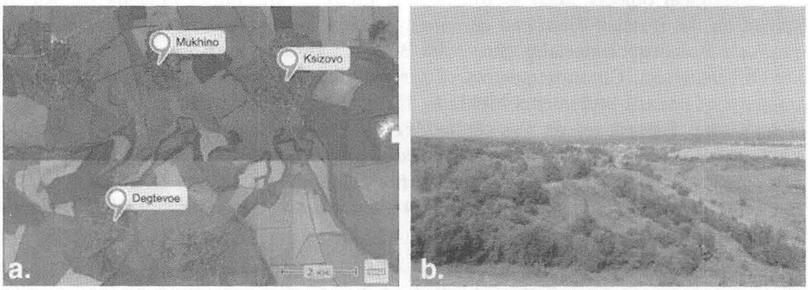


**Fig.1. a. Location of study sites, b. Forest-steppe landscapes of the research area**

The study sites are located in the Central Forest Steppe area in Lipetsk region. Defensive ramparts of the ancient settlements Mukhino, Ksizovo, and Degtevoe are situated near Zadonsk city, few km apart from each other (Fig. 1). For the enhanced protection of ancient settlements, particular landscape position was located on the upland surfaces, occupying narrow promontories formed by a junction of gullies with steep slopes and open to river valleys. E.g., the Mukhino settlement has two ramparts that were built 2500 and 1500 BP. Two earthworks of Degtevoe settlement were constructed within the period ~2200-2300 BP. Ksizovo settlement has one rampart of 2500 BP. The height of the earth walls is from 150 to 30 cm. We compared soils buried under the earth walls with the surface soils formed in similar landscape position in the proximity.

Valleys and gullies well dissect slightly undulating uplands in the study area. The main rivers are Don River and its tributary Snova. Loess sediments represent parent material up to 26 m thick, either carbonate or non-carbonate, sometimes with gypsum. The study area refers to the temperate continental climate, with mean temperature in July 23,5° C, in January -9,5°, and mean annual precipitation – 548 mm. Vegetation cover of the territory consisted of mixed-grass steppe and forest patches, represented by oak, birch,

aspen and *Pinus sylvestris*. The surface soils are Greyzemic Luvic Phaeozems formed in loess.
We described soil morphology according to the FAO Guide for Soil Description [6]. Soils were classified according to [8]. Soil colour was determined in the field using Munsell Soil Color Charts [10].
Two methods determined the granulometric composition of soils: Pipette method, in which soil is dispersed by treating it with a solution of sodium pyrophosphate ($Na_4P_6O_{18}$) and laser granulometry method on the device «Analysette 22. Laser Klasse 1. Fritsch". Total organic carbon (TOC) of soil was identified by Turin method, the ratio between humic and fulvic acids ($C_{HA}/C_{FA}$) by Ponomareva and Plotnikova method [12]. A conductivity meter was used to determine the pH of the soil. Tamm method was used for extraction of oxalate-soluble forms of iron, Mehra and Jackson method – for dithionite-extractable iron. X-ray fluorescence analysis (XRF) is performed on a continuous-wave X-ray fluorescence spectrometer with a dispersion along the wavelength, model PW 2400 (Philips Analytical 1997). The total carbonate content was determined on the base of the destruction of $CaCO_3$ by acid and subsequent precipitation of the carbonate ion.
Dates of burial were determined by the archaeological method. The accuracy of the method varies between 300-50 years and depends on population density. About 60 settlements of the Early Iron Age have been located around river Don valley.
Age of buried soils was determined by radiocarbon dating of humic acids substance extracted from Ah horizon. Radiocarbon dates were obtained by liquid scintillation counting methods (LSC) at the Radiocarbon Dating Laboratory of the Institute of Geography, Russian Academy of Sciences (marked by the IGAN index).
For studying undisturbed soil lumps (approx. 20x20x40 cm), the dental tool set kit was used. The lumps were gradually and stepwise carefully prepared. For capturing pictures with the magnification of 40x80 times, Canon MarkIII digital camera with a set of macro lenses was used.
Micromorphological features in thin sections from undisturbed oriented samples were studied under plain and polarized light with the magnification of 40 to 200 times using "Olympus BX51" polarizing microscope.
Analyses of biomorphs included phytoliths complex, plant remains and charcoal under a microscope [4,5]. Phytolith analysis was done using the standard procedure [11]. Palynological spectrum was determined using light microscope under magnifications 400x and 1000. Percentages of pollen groups were calculated from the total amount pollen; rates of spores were derived from the total amount of pollen and spores by E. Ershova in the Laboratory of Geobotany and Ecology of Plants of the Biological Faculty MSU.
The content of microbial genes was studied in the buried and surface soils based on qPCR (real-time PCR) analyses of rRNA genes of three groups of microorganisms (bacteria, archaea, and fungi). Soil samples were taken in triplicate from the middle parts of soil horizons and were kept in cryo-storage at a temperature of - 70oC until being analyzed. Total DNA was extracted from 0.2 g of the soil using a PowerSoil DNA Isolation Kit (MO BIO Laboratories). The reaction mixture was prepared from SuperMix EvaGreen (Biorad). Amplification was carried out in iCycler (Biorad) amplifier using primers Eub338/Eub518 for bacteria, ITS1f/5.8s for fungi, and arc915f/arc1059r for archaea. The results obtained for the three replicates were re-

calculated into the gene content of these three groups of microorganisms per gram of soil.

## RESULTS

*Mukhino site.*

The soil buried under rampart 2500 BP and the surface soil exhibit similar properties and determined as Greyzemic Luvic Phaeozems (Loamic). Greyzemic features are presented by bleached sand and silt grains in the lower part of Ah horizon, which is confirmed by micro- and mesomorphological survey and grain size distribution. Morphological features of buried soil 2500 BP as well as surface soil characterized by well-preserved cutan complex and carbonates appear from 100-105 cm and presented by hard nodules, soft powdery lime, rhizoliths. Phytoliths analysis indicates meadow-forest vegetation in the soil, buried 2500 BP.

Soil buried under the earth wall 1500 years BP meets the criteria for Luvic Chernozem. Abundant carbonates occur at depth 85 cm and presented by hard and soft nodules and carbonate films over clay cutans [13]. The thickness of Ah horizon is similar in all three soils, but the total organic content is different (Table 1). Paleobotanical reconstrucrion showed steppe vegetation with the participation of deciduous trees. Radiocarbon date of humic acids showed that Ah horizon of Buried Luvic Chernozem formed approximately 6330 cal BP. All the represented soil profiles in Mukhino combined presence of krotovinas.

*Degtevoe site.* Both earth walls of Degtevoe settlements are related to Early Iron Age with one earth wall slightly younger than the other (2300 – 2200 BP). Both soils are Greyzemic Luvic Phaeozems (Loamic, Gypsic). In the soil younger buried soil, Greyzemic features are better expressed sometimes showing clearly defined E horizon. Also in this soil cutan complex is more pronounced. The type of organic matter is different: in the older buried soil, the $C_{HA}/C_{FA}$ ratio exceed 2,1, that is which is typical for the steppe conditions, while in younger buried soil $C_{HA}/C_{FA}$ ratio is 1,4 that is indicative for forest soils. At last one cutans are more pronounced. Carbonates are presented by similar forms in both of soils (mostly soft nodules), but in the buried soil of 2200 BP they are less frequent and appear 30 cm lower. Both of soils content krotovinas though the profile.

*Ksizovo site.* Paleosols in settlement Ksizovo were buried in the interval 2200-2400 BP. Both buried, and surface soils are Endoferric Greyzemic Luvic Phaeozem (Loamic). Ah horizon in the buried soil is 15 cm less than in the surface soil and has much less TOC. Buried soil is characterized by well-presented Greyzemic features, which are less pronounced in surface soil.

The upper horizons of buried soils under both earth walls of Mukhino and Ksizovo site have 2–3 times lower bacterial genes content than surface soils (Fig.2). This result seems obvious, given the low carbon content in buried soils and its isolation from organic matter input. The structure of bacterial communities in buried and modern soils differs strongly, primarily by a low proportion of the bacterial phylum *Verrucomicrobia* in buried soils. Nevertheless, Ah horizon of buried soil in Ksizovo has a microbial community similar to that in modern soils.

*Table 1. Properties of buried and surface soils*

| RSG<br>Date of burial | Horizon sequence | TOC* (0-10 cm) | The thickness of Ah horizon | Parent material | Depth to carbonates | Carbonate forms ** | Abundance*** |
|---|---|---|---|---|---|---|---|
| | | | *Mukhino* | | | | |
| Buried Greyzemic Luvic Phaeozem 2500 years BP | Ahb<br>AhBkb<br>Btkb<br>Bkb<br>BCkb | 2,71% | 30cm | Carbonate loess | 105cm | HC, PM, D | M |
| Buried Luvic Chernozem 1500 BP | Ahb<br>AhBb<br>Btb<br>Btkb<br>Btkgb | 1,9% | 30cm | Carbonate loess | 85cm | HC, SC, carbonate covers | M |
| Surface Greyzemic Luvic Phaeozem | Ah<br>AhE<br>AhBt<br>Bt<br>Btk<br>Bk | 5,51% | 28-30cm | Carbonate loess | 100cm | HC, PM, D | M |
| | | | *Degtevoe* | | | | |
| Buried Greyzemic Luvic Phaeozem ~2300 BP | AhEb<br>AhBtb<br>Byb<br>Bckyb | 2,39% | 25cm | Carbonate loess with gypsum crystals | 105cm | SC | F |
| Buried Greyzemic Luvic Phaeozem >2200 BP | AhEb<br>Ebtb<br>Btyb<br>Byb<br>BCkb | 1,58% | 25cm | Carbonate loess with gypsum crystals | 130cm | SC | V |
| | | | *Ksizovo* | | | | |
| Surface Endoferric Greyzemic Luvic Phaeozem | Ah<br>AhB<br>Btg<br>BCg | 7,36% | 34cm | Non-carbonate loess | - | | N |
| Buried Endoferric Greyzemic Luvic Phaeozem 2200-2400 BP | AhEb<br>AhBtb<br>Bthb<br>Btgb<br>BCgb<br>Cgb | 1,53% | 19cm | Non-carbonate loess | - | | N |

*TOC – total organic content; **SC - soft concretions, HC - hard concretions, D - disperse powdery lime, PM – pseudomycellia; ***N – none, V- very few, M- many [6]

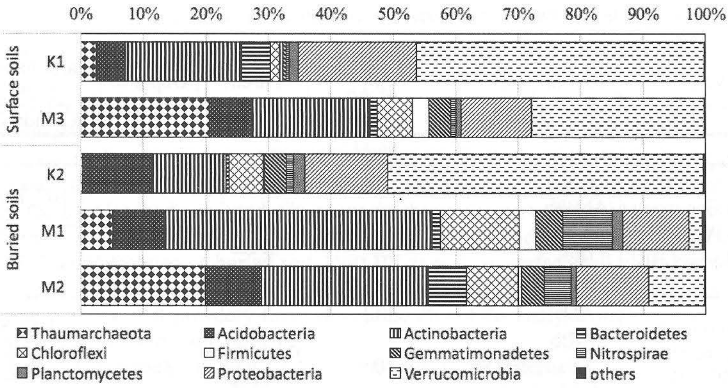


**Fig. 2. The composition of microbial communities at the level of phylums of prokaryotes.** Mukhino site: *M1 – Buried soil 2500 BP; M2 - Buried soil 1500 BP; M3 –surface soil;* Ksizovo site: K1- surface soil, K2 – buried soil

## DISCUSSION

All investigated buried, and surface soils in forest-steppe landscapes contain signs of both forest and steppe stages of soil formation. The detailed study of the properties of the buried soils incorporated with biomorphic data made it possible to carry out a paleoecological reconstruction and to distinguish five climatic stages during the second half of the Holocene:

*The first stage* was reflected in the soil profiles in the form of cutan complex, expressed in different degrees.

*The second stage.* The presence of krotovinas in all soil profiles indicates the steppe phase of pedogenesis. Paleokrotovinas are the signs of deep humic horizons of the Middle Holocene Chernozems [1]. The obtained radiocarbon dating confirms that the humus horizon was formed during the period of the highest deforestation of the territory [3].

*The third stage.* Environmental reconstruction for the period 2500-2200 BP could be presented in the following way: 2500-2300 years ago landscape features were similar to present time and characterized by meadow-forest vegetation. Forest-type pedogenesis manifested as Greyzemic features, and low carbonate table in soils supports this conclusion. The peak of humid pedogenesis occurred ~2200 ago, which is evidenced by the leaching of carbonates, and the presence of eluvial features in the lower part of Ah horizon.

*The fourth stage.* A new peak of aridization occurred around 1500 years ago when vegetation pattern was replaced by grassy meadows. As a result, the soils transformed from Greyzemic Luvic Phaeozems to Luvic Chernozems with no Greyzemic features but with carbonate films on top of clay cutans.

*The fifth stage.* The modern forest-steppe landscapes with the participation of broad-leaved species spread throughout the study area. Surface soils are identified as Greyzemic Luvic Phaeozems.

*Soil indicators* for the climatic reconstruction were divided on stable and unstable characteristics. The formation of such features as cutan complex and krotovinas take a long time. Unstable features can instantly emerge and disappear depending on natural conditions. They include secondary carbonates, organic carbon, microbiological communities. The content of organic carbon decreases without the additions of organic residues, but in some cases, the type of organic matter remains the same and $C_{HA}/C_{FA}$ ratio can be used to specify the type of previous pedogenesis but only if a complex of other methods is used [9]. DNA of the buried soils was found not to be a good proxy of past environments. When the soil is buried, the number and the diversity of microorganisms in it decreases, and insufficient depth of burial cannot protect the soil from the impact of the outer environment.

## CONCLUSION

Soil formation of the second half of Holocene in the forest-steppe zone was complicated by numerous climate variations that led to a significant change in the environment and the type of pedogenesis. The changing vegetation cover and the type of moisture regime well reflect different way evolution of soils of the forest-steppe landscapes. In the zone of deciduous forests, climate changes acted on the already formed profile and did not lead to a strong transformation of the soils, but in the forest-steppe, the climate fluctuations lead to a change in the type of soil. During the period of increasing humidity, the forest boundary shifted to the south, and the soils started to show Greyzemic features, the boundary of carbonate table dropped. In the peak of aridization steppe patches penetrated into the forested areas, the humus horizon, developing under grassy vegetation acquired a dark colour again, the carbonates were translocated up the profile and were deposited over the cutan complex in ped faces. The results of the study showed that the profiles of buried soils might preserve the signs both long and short-term evolution.

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