Directed variability of paleosols properties in short chronosequences studied by the statistical approach (a case-study of kurgans in Orenburg region, Russia)

Olga S. Khokhlova[A] and Julia L.Meshalkina[A]

Institute of Physical, Chemical and Biological Problems in Soil Science of RAS, Pushchino, Moscow region, 142290, Russia.
Soil Science Department, Lomonosov Moscow State University, Leninskyje Gory, Moscow, 119991, Russia.
Email, akhokhlov@mail.ru; olga_004@rambler.ru

Abstract
The relative chronology of kurgans (burial mounds) construction in two ancient cemeteries was established by studying the properties of paleosols buried under kurgans. This chronology has been later confirmed by the radiocarbon dating of humus and carbonates from the paleosols. The paleoenvironmental reconstruction based on paleosols properties changes the influence of their spatial variability. Soil group composition was based on principal component and cluster analyses and using the relative values for each paleosol property on the basis of correlation with modern background soil-analogue. The differences in humus and carbonate supplies in paleosols are statistically reliable for "short"chronosequences with 100-150 years duration.

Key Words
Paleosols, chronosequences, kurgans, paleoclimatic reconstruction, Holocene, directed variability of soil properties, relative values.

Introduction

At present, large-scale researches of paleosols buried under archaeological monuments (burial mounds or kurgans) in the steppe area of Russia are carried out aiming at the reconstruction of paleoenvironmental and climatic conditions for the second part of Holocene. Schemes of soil evolution and reconstructed paleoclimatic conditions as a result of these researches both for the same region and for the steppe zone as a whole do not coincide in many cases and are often contradictory. The possible reasons of these discrepancies, in our opinion, can be (1) study of paleosols buried under archaeological monuments of the same culture as a uniform indicator of conditions of the environment for a whole epoch (while various cultures functioned) and (2) not taking into consideration the variability of properties of paleosols buried under kurgans of the same culture as a result of climatic fluctuations having a shorter time scale.

We offer the special approach where paleosols buried under kurgans of the same archaeological culture in a studied burial ground are considered as a short chronosequence (Khokhlova *et al.* 2007). The assumption considers that kurgans in the large burial grounds constructed by ancient people belonged to one archaeological culture and had appeared step-by-step during the existence of the given culture. The under-kurgan paleosols are divided into groups by similarity of their properties within one group, and then we try to determine a relative or absolute chronological order of burial of soils and a construction of kurgans in a burial ground on the basis of archaeological data or radiocarbon dating. When we deal with short time intervals of functioning of burial grounds (100-200 years) the spatial variability of soil properties can make difficulties for revealing their variability connected with changing climatic conditions in the period of paleosol burial. For the decreasing of influence of spatial variability, it is proposed to calculate the relative values for each paleosol property on the basis of correlation with modern background soil-analogues. Searching for a modern soil-analogue for each paleosol is carried out on the basis of similarity of their particle-size pattern. One modern soil-analogue may be in agreement with any group of paleosols if they are similar on the basis of particle-size distribution.

Natural conditions of the study site

The paleosols studied are buried under kurgans in two burial grounds of the Orenburg region. Within the Chernozem-steppe belt of the Orenburg region, the climate is the warmest and driest in the study area: the mean temperature of January is –15°C, and that of July is +22°C. The mean annual precipitation is about 350 mm; evaporation exceeds precipitation by 1.5 times. Among the unfavorable climatic phenomenon is the periodical high temperature on the soil surface. Sometimes in June-July this temperature reaches to 65°C and higher. The characteristic sign of the soils in the Orenburg steppe is taken to be a tongue-like lower boundary of humus horizon. The cracking of soil mass due to continental climate, very high soil surface temperatures

in summer and filling up the cracks with humus material are common. Vegetation of the non-arable sites is represented by steppe communities with the predominance of feather grass and fescue.

Results and discussion

In the Skvortsovsky burial ground two kurgans (№.3 and 4) referred to early narrow chronological horizon of the Timber Grave archaeological culture, 18^{th}-17^{th} centuries BC, have been studied. Each of two kurgans had mounds consisted of two layers and two paleosols buried under both the central (first) and peripheral (second) mound layers. That the peripheral mound layer was built after the central one is unambiguously visible in stratigraphy of the each earth mound studied. This case has been used for modeling since at construction of short chronosequence from the Timber Grave paleosols we were guided by the given or known order of paleosol burial and could understand the reliability of differences in chemical properties of paleosols in the constructed chronosequence on the basis of a statistical approach. The absolute and relative (comparatively with modern soil-analogue) values of storage of humus and carbonates for 0-100 and 0-180 cm thickness were examined in the paleosols. The received differences for "extreme" paleosols in a short chronosequence are statistically reliable. The order of construction of different layers of kurgan mounds studied is in agrrement with radiocarbon dating of pedogenic carbonates. It has been fixed that from the beginning to the end of the Timber Grave Time examined there was an accumulation of humus and leaching of carbonates in soils and the climate varied in the direction favorable for the life of the nomadic population – a fall of temperature and increase of precipitation. As mentioned before, the study site is situated in modern dry-steppe area with high summer temperatures with a precipitation deficiency.

The Fillipovka 1 burial ground was situated 200 km to west from the Skvortsovsky one and functioned during the period of the Early Sarmatian culture – from the middle of the 5^{th} till the middle or the end of the 4th centuries BC. The lithological background on which soils in burial ground territory developed differed considerable in diversity and influenced the considerable spatial soil property variability. Therefore the identification of paleosol groups and their modern soil-analogues has been carried out using cluster analysis and principal component analysis (PCA). 10 cm intervals of modern soils were chosen for PCA. Exchangeable cations (bases), carbonate content and particle-size pattern have been used as variables for the PCA, because these properties could be related with depth of the entire soil profile. The first main component is completely defined by lithological features of the layer. These results have been compared to cluster analysis results based on the profile distribution of one property - the content of particles size less than 0.01 mm. The results were in close agreement, but in the last case they were less stable and depended on the selected joining rule. Therefore, for further analysis the results obtained by PCA have been used and the clusters formed by modern soils and paleosols have been established. For each of the clusters, only one modern analogue for paleosols was chosen, the closest one.

Differences of environmental conditions have been revealed by comparison of differences of humus, carbonate and sum of the exchangeable cation storages in paleosols and their modern analogues. Within the period of the Filippovka 1 burial ground functioning, one group of kurgans were built in more "arid" environmental conditions (the first early group of kurgans), and other one – in more «humid» environmental conditions (the second, latter group of kurgans). In paleosols buried under kurgans of the early group in comparison with paleosols of the latter one, the decrease of humus storage in the upper part of profile and increase of carbonate and the exchangeable cations, specifically Ca storage in the middle part of the profile are statistically reliable.

It was shown that the proposed approach together with the standard approaches – archaeological and radiocarbon dating, can be used for reconstruction of the order of kurgans construction on the basis of the variability of properties of paleosols buried under kurgans. Special attention should be given to the fact that differences in humus and carbonate contents (the basic profile-forming properties in steppe soils) that are statistically reliable in paleosols of short chronosequences that functioned within 100-150-200 years.

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