Revista Mexicana de Ciencias Geológicas, v. 24, núm. 2, 2007, p. 270-282

Rapid change in Chernozem properties during their Holocene evolution: a case study of paleosols buried under kurgans in the pre-Ural steppe, Russia

Olga Khokhlova

Institute of Physical, Chemical and Biological Problems of Soil Science,
Russian Academy of Sciences, Pushchino, Moscow region, 142290, Russia.
akhokhlov@mail.ru, olgakhl@issp.serpukhov.su

ABSTRACT

An extensive chronosequence of Chernozem-type soils developed on loamy sands was studied in the pre-Ural steppe, Russia. Paleosols were buried under kurgans that belonged to three main periods of construction: the Early Bronze Age (forth to third millennium BC), the Early Iron Age (eighth century BC to forth century AD) and the Middle Ages, the time of the Mongols and the Golden Horde (thirteenth to fourteenth centuries AD). Several paleosol profiles of the same archaeological chronointerval were studied as a soil chronosequence. This study restricted soil chronosequences not only to the duration of one archaeological culture but to the separated chronological phases of it. This allowed the documentation of soil property changes in time with the maximal possible resolution, and to understand the time scale of those changes. In order to take into account the changes of sets of soil properties in time, all soil features under study were attributed to either "arid" or "humid" environmental conditions, and numerical grades were assigned to each of them. For each soil of the chronosequence, the sum of numerical grades for the "arid" and "humid" properties were calculated and plotted against time. Two important conclusions were made after analyzing the curves: (1) it is necessary to distinguish the direction of change of the properties under study, and (2) the short time scale (sub-centennial or centennial) over which changes of soil properties occur. The morphological and analytical properties that change in sub-centennial or centennial time scales include the character of the lowest boundary of the humus horizon, the degree of biological activity (coprolites, humus-enriched root and mesofauna channels), the morphological patterns of carbonate accumulation, and the percentages of humus, carbonate and exchangeable sodium down through the profiles.

Key words: geoarchaeology, Chernozem, time scale, centennial, sub-centennial, pedogenesis, paleoenvironmental reconstruction, secondary carbonates, Russia.

RESUMEN

Se estudió una cronosecuencia extensa de suelos de tipo Chernozem desarrollados a partir de arenas limosas en la estepa pre-Ural en Rusia. Se analizaron varios paleosuelos sepultados bajo montículos mortuorios (kurgans) cuya construcción data de tres periodos distintos: la Edad de Bronce temprana (4º a 3er. milenio AC), la Edad del Hierro temprana (siglo octavo AC a siglo cuarto DC) y la Edad Media, específicamente la época de los mongoles y la Horda de Oro (siglos XIII y XIV DC). Se estudiaron varios paleosuelos correspondientes al mismo intervalo de tiempo dentro de cada etapa *arqueológica conformando una cronosecuencia. Además se intentó restringir las cronosecuencias no sólo a la duración de una cultura arqueológica, sino también a las distintas fases cronológicas de la misma. Lo anterior permitió documentar los cambios en las propiedades de los suelos con el tiempo a una resolución máxima posible y así comprender las escalas temporales en las que se dan estos cambios. Con la finalidad de reconstruir los paleoambientes en los que se formaron estos suelos, se agruparon las características típicas, ya sea de ambientes áridos o húmedos, a las cuales se les asignaron grados numéricos en función de la expresión de dichas características. Estos grados numéricos se graficaron contra el tiempo. Lo anterior permitió concluir sobre dos aspectos importantes: (1) la necesidad de considerar la dirección del cambio al analizar la evolución de las propiedades de suelo en el transcurso de la pedogénesis durante el Holoceno, y (2) los lapsos cortos de tiempo (cientos de años) en los que ocurren cambios en las propiedades de los suelos. Las propiedades que cambian en escalas de tiempo de décadas a siglos en los Chernozems estudiados incluyen el carácter del límite inferior del horizonte humificado, la intensidad de la actividad biológica (coprolitos, canales de raíces y de organismos de la mesofauna rellenos con materiales humificados) y los patrones morfológicos de las acumulaciones de carbonatos de calcio secundarios, así como la distribución a profundidad de los contenidos de materia orgánica humificada, los carbonatos y el sodio intercambiable.*

Palabras clave: geoarqueología, Chernozem, escala temporal, siglos, décadas, pedogénesis, reconstrucción paleoambiental, carbonatos secundarios, Rusia.

INTRODUCTION

Pedological methods are widely used in the study of archaeological sites, and the results often provide a basis for paleoenvironmental reconstruction (Holliday, 1992; Chambers, 1993; Barham and Macphail, 1995; Brown, 1997). This new discipline, named archaeological pedology, is now quickly developing in Russia (Demkin, 1997; Dergacheva. 1997). Unlike in Europe, investigations of paleosols in Russia are mainly carried out in soils buried under archaeological monuments –artificial earth embankments (barrows, burial mounds, tumulus, kurgans). A great number of ancient cemeteries that included tens and hundreds of kurgans, and paleosols of various ages buried under them, have been studied in the steppe area of Russia during the last 30 years. Different research models of natural soil evolution and environmental change during the late Holocene have been proposed in this area over time scales of 500 to a few thousand years (Serebrjanaya, 1976; Ivanov, 1992; Velichko *et al.*, 1994; Alexandrovskiy, 1995, 2002; Demkin, 1997; and others). Unfortunately, even from this large body of research there are still large and controversial discrepancies in our understanding of soil and environmental changes during the late Holocene, including how soil properties responded to environmental changes in the Russian steppe.

One of the most important questions concerns time scales of soil property changes and the climatic fluctuations that are usually reconstructed on the basis of soil properties. This question has not been adequately addressed in geoarchaeology or archaeological pedology. By convention, it is suggested *a priori* that soil properties can reflect environmental changes after not less than 500 years, and more often, after thousands of years or periods of the Holocene. Some investigations have recently tried to consider soil evolution over shorter time scales, say of several centuries (the centennial time scale) (Demkin, 1999; Pesochina *et al.*, 2000; Morgunova *et al.*, 2003). The peculiarities of sub-centennial changes of soil properties are still unknown, although such study is necessary to understand time scales of soil property changes and, ultimately, to aid paleoenvironmental reconstruction.

To examine the changes of soil properties at the sub-centennial time scale it is necessary to consider a chronosequence with short (from tens to 100 years) chronointervals between paleosols inside the chronosequence. To realize this idea, a special research approach was previously introduced (Khokhlova, 2003). The novelty of this approach is to study several paleosols that correspond to the same chronointerval within an archaeological culture as a soil chronosequence. The consecutive construction of kurgans during the existence of an archaeological culture is the main hypothesis guiding this approach. This approach allows the detection of regularity in the variability of properties in paleosols buried under monocultural kurgans, interpreting them as environmentally directed changes and placing the paleosols in order of their burial dates. To confirm that order, archeological methods and radiocarbon dating are usually used. Evidently, climatic conditions were not stable from the Early Bronze Age through the Middle Ages, and the paleosols buried under kurgans will reflect the differences in paleoenvironments. As a rule, in such chronosequences the chronointervals between the dates of paleosols burial vary from tens of years to 100 years (sub-centennial time scale). In all previous studies in archaeological pedology, the paleosols buried under kurgans of the same culture are considered as a single indicator of the past climatic conditions of a historical epoch. This assumption is flawed however, because the duration of archaeological cultures can be highly different. For instance, it is 900–1000 years for the Pit-grave or Yama Culture, 300–350 (and up to 400) years for the Early Sarmatian Culture, and about 200 years for the Golden Horde period in the pre-Ural steppe.

This work studies natural soil evolution with the goal of understanding the time scale of changes of soil properties during the late Holocene using paleosols buried under archaeological kurgans in the pre-Ural steppe, Russia.

STUDY OBJECTS AND METHODS

The study site is located near Shumaevo village in the Orenburg region, Russia (Figure 1). Burial mounds are situated on the first flat terrace of the Irtek River. Geomorphologically, this area is part of the Ural River valley, and the Irtek River is one of its tributaries. The terrain is generally undulating with prevailing elevations of about 100 m. Parent materials within the first true surface terrace of the Irtek River are late Pleistocene banded sandy to loamy and sandy non- or slightly calcareous alluvial deposits. Time zero of soil formation is considered to be marked by the stabilization of the land surface at the beginning of the Holocene. The earliest buried paleosol and all other paleosols in the soil chronosequence studied are Chernozem-type soils. The modern soil cover of the area is composed of the Southern (tongued) Chernozems according to the Russian soil classification (Shishov *et al.*, 1997) or Calcic Chernozems (FAO, 1998).

Within the Chernozem steppe belt of the Orenburg region, the climate is warm and dry: the mean temperature of January is –15 °C, and of July is +22 °C. The mean annual precipitation is about 350 mm; evaporation exceeds precipitation by 1.5 times. About 60% of precipitation falls during the growing season. As a rule, summer precipitation consists of heavy rains that fall under high air temperature and evaporate very quickly. The temperature on the soil surface sometimes reaches 65 °C and is highest in June-July, and even in September the soil surface heats up to 50 °C during several days. Snow covers the land from the end of November till the end of February; the average snow depth is 30–40 cm (110 cm maximal) and the average depth of soil freezing is about 100–120 cm. The characteristic feature of the soils in the pre-Ural steppe is a tongue-like lower boundary of the humus horizon. The tonguing features are related to cracking of the soil mass due to the very high soil surface temperatures in summer and the filling of the cracks with humus rich material from the soil surface (Erokhina, 1959; Dobrovolsky and Urusevskaya, 1984; Gerasimova, 1987). Vegetation of the non-arable sites consists of steppe communities with the predominance of feather grass *(Stipa pennata)* and fescue.

Figure 1. Location of the study site. Conventional signs on the inset, 1: second Shumaevo burial ground; 2: isolated Shumaevo kurgan N2; 3: first Shumaevo burial ground.

Archaeological excavations in the kurgan cemeteries Shumaevo I and II, and one isolated large kurgan N2 were conducted by a team from the Archaeological Laboratory of the Orenburg Pedagogical University under the leadership of Prof. N.L. Morgunova. The archaeological materials obtained are discussed in a special paper (Morgunova and Khokhlova, 2006). The kurgans near Shumaevo village were found to belong to three main periods of construction: the Early Bronze Age (forth to third millennium BC), the Early Iron Age (eighth century BC to forth century AD), and the Middle Ages, specifically the time of the Mongols and the Golden Horde (thirteenth-fourteenth centuries AD). We studied the paleosols buried under all the kurgans, which were excavated by archaeologists near Shumaevo village. Table 1 presents the list of the soil pits studied. The dates of kurgan construction and the soil burial were obtained mainly archaeologically and, in some cases, by the radiocarbon method (Table 2).

The earliest chronological period of kurgan construction near Shumaevo village belongs to the Yama archaeological culture of the Early Bronze Age. Since the Yama culture developed in this territory over a comparatively long period (since the boundary of the forth and third millennia BC until the last quarter of the third millennium BC) an additional effort was needed to study sub-centennial time scale soil property changes in this case. Archaeologists recognize different phases within the Yama culture development in the region, which are the early, advanced, and late ones, but those phases do not have distinct chronological limits. Near Shumaevo village, the nine excavated kurgans belonged all to the Yama culture. It was difficult to attribute the excavated kurgans to particular phases of the Yama culture archaeologically, because almost all their burials either had no grave goods or had been looted. So all the paleosols buried under the Yama culture kurgans were divided into three groups based on field morphological observations, and we assumed that those three groups of kurgans were constructed at three different phases of the Yama culture. Then, from the separate kurgans and paleosols assigned to different groups, carbonaceous materials were collected

Table 1. The peculiarities of objectives studied.

No. of kurgan, archaeological culture, assumed archaeological age	Pit	Height of kurgan mound: in place of the pit location / at mound centre (cm)	Depth of soil effervescence from HCl (cm)	Integrity of buried paleosol			
				Presence of the A diagenetic horizon	Thickness of the [A1] horizon (cm)	Thickness of the [A1] horizon (cm)	Presence of diagenetic carbonates in the [A1] horizon
Shumaevo I burial ground							
2, Yama, third millenium BC	1b/00	70/80	-****	-*	12	+*	+
3, -II-	5b/00	130/200	30	+	32	-	-
4, -II-	3b/00	40/50	-	-	10	+	+
7, Early Sarmatian, fourth century BC	6b/00	30/30	-	-	30	+	+
5, Golden Horde, 13th–14th centuries AD	4b/00	25/30	-	-	45	+	+
6, -II-	12b/02	55/60	85 – 90	+	60(65)	-	+
Modern soil	2m/00	Нет	100 – 105	None**	65***	None	None
Shumaevo II burial ground							
3, Yama, third millenium BC	8b/01	70/70	35 – 40	-	35	-	+
4, -II-	3b/01	20/20	-	-	35	+	+
5, -II-	5b/01	50/50	-	-	30	+	+
6, -II-	10b/01	40/40	40 – 45	-	35	-	+
7, -II-	7b/01	105/105	50 – 55	+	33	-	-
2, Savromatian, fourth century BC	11b/01	25/30	-	-	50	+	+
9, Early Sarmatian, third to second centuries BC	14b/02 15b/02	35/40	- -	- -	35(37) -	+ +	+ +
8, Late Sarmatian, second half of the second century AD	9b/01	30/50	50 – 55	-	55	+	-
11, Golden Horde, second half of the 14th century AD	13b/02	20/30	-	-	55(60)	+	+
Modern soil	6m/01	Нет	100 – 105	None	65	None	None
Isolated kurgan							
2, Yama, third millenium BC	4b/01	230/>250	50	+	30(33)	-	-

Notes: +*: feature is observed; –*: feature is absent; None**: feature is characteristic for the buried paleosols but not for the background modern soils; ***: thickness of the A1 horizon of the modern soil; -****: it was not possible to determinate the depth of soil effervescence from HCl in some cases; -II-: the same.

Table 2. Radiocarbon dates of the materials from burials and soil humus for the Shumaevo kurgans.

No.	Burial ground/ kurgan/ burial or horizon in buried soil	Lab. No.	Radiocarbon age (BP)	Intervals of calibrated age, 1σ		Sample	Probable archaeological age
				Cal BC	Cal BP		
The first group of the Yama culture kurgans							
1	ShBG I/3/6	LE-6091	4,300 ± 150	3,300 – 2,600	5,250 – 4,550	human bones	Boundary between the fourth and third millennium BC
The second group of the Yama culture kurgans							
2	–/2nd isolated/2	LE-6088	4,100 ± 40	2,810 – 2,590	4,760 – 4,540	wood, wheel	First half of the third millennium BC
3	–/2nd isolated /2	IGAN-2448	3,980 ± 50	2,563 – 2,457	4,512 – 4,406	wood, wheel	-II-
4	–/2nd isolated /2	LE-6090	4,060 ± 120	2,870 – 2,490	4,820 – 4,440	human bones	-II-
5	ShBG II/6/6	LE-6087	4,070 ± 45	2,860 – 2,500	4,810 – 4,450	wood, wheel	-II-
6	ShBG II/6/6	LE-6089	4,080 ± 100	2,870 – 2,500	4,820 – 4,450	human bones	-II-
The third group of the Yama culture kurgans							
7	ShBG-II/ 7/soil hor. [Ad+A1] 0–10 cm	IGAN-2476	4,610 ± 190	**2,631 – 2,036** 3,631 – 3,036 (3,360)	**4,581 – 3,986** 5,581 – 4,986 (5,309)	soil humus	The second half of the third millennium BC

Notes: 2nd isolated: the isolated Shumaevo kurgan N2; ShBG I: the first Shumaevo burial ground; ShBG II: the second Shumaevo burial ground; -II-: the same. Radiocarbon date for soil humus (sample N7) can be used for the archaeological age determination if we subtract from the radiocarbon date obtained for humus, the characteristic value of humus age (1,000 years for the uppermost 10 cm of humus horizon in the Chernozems) according to the approach by Chichagova (1985) and Alexandrovskiy *et al.* (1996) (calculated dates are shown in bold).

to determine the chronological limits of each group by the radiocarbon method.

In the field, all soil profiles were morphologically described and sampled, and drawings were made. All paleosols were examined for signs of disturbance of their surface at the time of burial and for diagenetic carbonatization that might have occurred after their burial (Table 1). A previous study was devoted to the diagenetic carbonates in the buried paleosols (Khokhlova *et al.*, 2000), which showed that diagenetic carbonatization may affect about 30–50 cm of the uppermost part of the buried paleosol and change the percentage of carbonates in this layer by no more than 0.2%.

In the laboratory, the humus content (wet oxidation with $K_2Cr_2O_7$), exchangeable sodium, CO_2 of carbonates and, in some samples, particle-size distribution (using pyrophosphate for dispersion) were determined. The pedogenic carbonates were classified according to Ovechkin (1984). This classification suggests that in Russian Chernozems, the carbonate efflorescences and veins, probably filaments and faint coatings in the classification by Gile *et al.* (1966), represent migrational (or mobile) carbonate accumulations, whereas nodules ranging from soft white spots to very hard loess dolls and compact laminations are segregational (or comparatively stable) ones. The idea of differing mobility of pedogenic carbonates in Russian Chernozems was developed previously in a special paper (Khokhlova *et al.*, 1997). Radiocarbon dating of bones and wood collected from burials, and humus from paleosols was performed in St. Petersburg (Institute of History of Material Culture, Russian Academy of Sciences) and in Moscow (Institute of Geography, Russian Academy of Sciences).

RESULTS AND DISCUSSION

Nine pits of paleosols buried under the Yama culture kurgans near Shumaevo village (Table 1) have been divided into three groups based on their morphological patterns observed in the field. The pits 1b/00, 3b/00 and 5b/00 are attributed to the first group of the Yama paleosols, the pits 3b/01, 4b/01, 5b/01, 8b/01 and 10b/01 to the second group, and 7b/01 to the third group. The integrated morphological patterns of pits for each of those three groups are shown in Figures 2a, 2b and 2c. From the first (Figure 2a) to the third (Figure 2c) group of the Yama paleosols, note the loss of the tongue-like lower boundary of the humus horizon and the increase of humus horizon thickness, the leaching of carbonates and replacement of comparatively stable forms of carbonates (such as compact laminated carbonate enrichment of the lower soil horizons and white soft spots with clear boundaries) by mobile forms (carbonate impregnation mottles and faint filaments).

The humus content in the Yama paleosols increases from the first to the third groups (Figure 3a). The carbonate maximum is gradually displaced to the deeper horizons of the paleosols, from the first group to the third group (Figure 4a). Also, the exchangeable sodium from the exchange complex is displaced into deeper horizons (Figure 5) and the clay depth functions become smoother (Figure 6a). The radiocarbon dates obtained for the Yama kurgans of each group and represented in the figures are calibrated ages (Table 2). The dates are expressed in slightly rounded numbers to facilitate their use hereinafter. For the second group, the simple average of five dates (Table 2) was calculated. For the first group of the Yama paleosols, the rounded date is 4,900±350 cal. years BP, for the second is 4,600±150 cal. years BP, and for the third is 4,300±300 cal years BP. Archaeologists associated the kurgans of the first, second and third groups to the early, advanced, and late phases of the Yama culture, respectively. The chronointerval is about 300–700 years between the first and the second group of the Yama kurgans and about 300–600 years between the second and third group, which corresponds to a centennial time scale. Nevertheless, the Yama paleosols were not identical inside of each isolated group. The differences in morphological patterns and content of humus, carbonate, and exchangeable Na between paleosols inside of each group were examined.

Three Yama paleosols belong to the first group: pits 1b/00, 3b/00 and 5b/00 buried under kurgans 2, 4, 3, respectively, in the Shumaevo I burial ground (Table 1). At first it appeared that kurgan 3 was built earlier than kurgans 2 and 4. Observations made in the paleosols confirm this: the thickness of the humus horizon of paleosols buried under kurgans 2 and 4 was 10–15 cm less than in the paleosols buried under kurgan 3. Kurgans 2 and 3 were evidently built on a previously scalped surface where the humus material had been removed to build the mound for the kurgan 3. Additionally, the stratigraphic section exposed during the excavation showed that the ditches around the kurgans 4 are laid above the ditches of kurgan 3.

The tongue-like lower boundary of the humus horizon was clear in pit 5b/00 and became more diffuse in pit 3b/00 and even more so in pit 1b/00. The pit 5b/00 shows massive sub-parallel calcareous layers in the Bca horizon, while in the other two pits these features are less developed.

Figures 7a, 7c and 7e show the humus, carbonate, and exchangeable Na contents of all the studied paleosols of the first group of the chronosequence, from the earliest buried paleosol (5b/00) to the latest buried ones (1b/00 and 3b/00). Clear trends of humus increasing in the uppermost meter, along with carbonate and exchangeable Na decreasing in the middle and lower parts of profiles are observed

From the archaeological estimation based on the similarity of grave construction, all the kurgans of the first group were built within 50–60 years (not more than 100 years), therefore the time scale of the chronosequence of the Yama paleosols of the first group may be regarded as sub-centennial. For this time interval, we were able to note clear changes in morphological and analytical properties of humus and carbonate profiles and exchangeable sodium content in the soils of the chronosequence (Figure 7).

Five Yama paleosols belong to the second group: pits 8b/01, 5b/01, 3b/01, 10b/01 and 4b/01 buried under kurgans 3, 5, 4, and 6 of the Shumaevo II burial ground

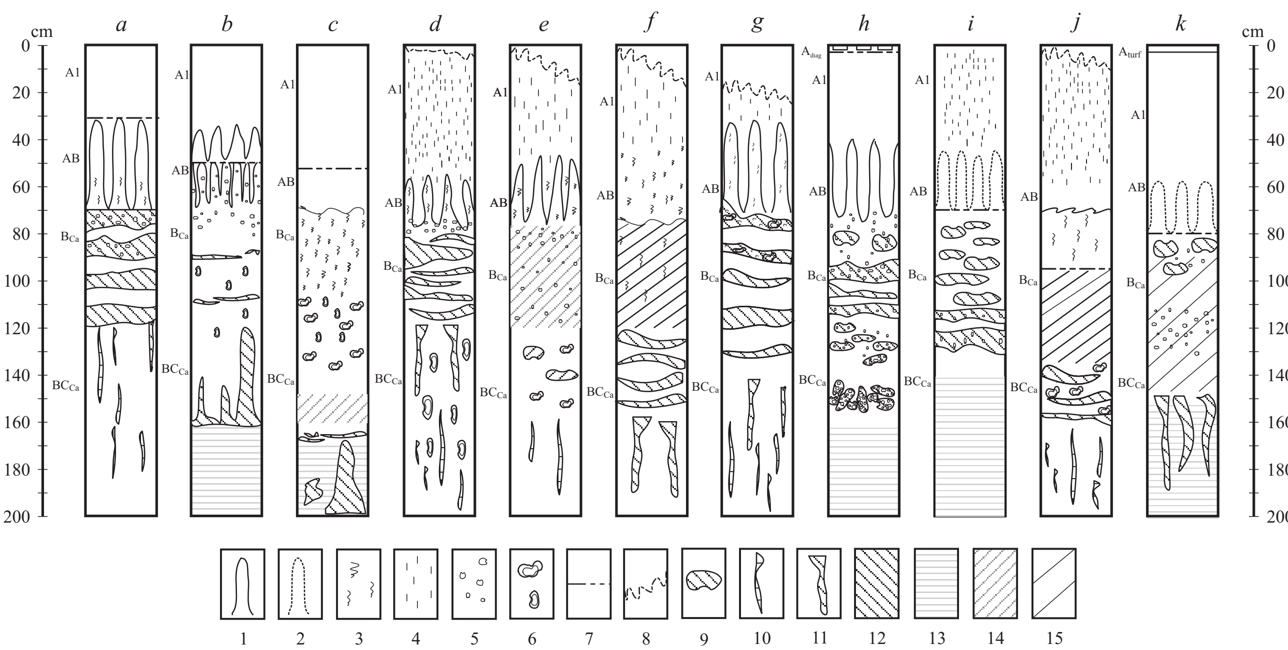

Figure 2. Schemes of morphological patterns of soil profiles in the Shumaevo chronosequence. Conventional signs, 1: well-marked humus "tongues"; 2: smeared tongued boundary of the humus horizon; 3: carbonate faint filaments; 4: diagenetic veins; 5: carbonate white soft spots with clear boundaries; 6: carbonate white soft spots with diffuse boundaries; 7: effervescence line; 8: line showing that the soil surface was disturbed; 9: impregnation mottles; 10: calcitans along fissures and root channels; 11: mottles of carbonate impregnation with tongues going downwards; 12: carbonate impregnation; 13: layers of carbonate enriched sand; 14: weak carbonate impregnation; 15: whitish hue in the colour of soil mass. Paleosols buried (a) 4,900±350 BP, (b) 4,600±150 BP, (c) 4,300±300 BP, (d) 2,550±50 BP, (e) 2,325±25 BP, (f) 2,250±50 BP, (g) 2,225±75 BP, (h) 1,825±25 BP, (i) 700±100 BP, (j) 625±25 BP and (k) modern Chernozem.

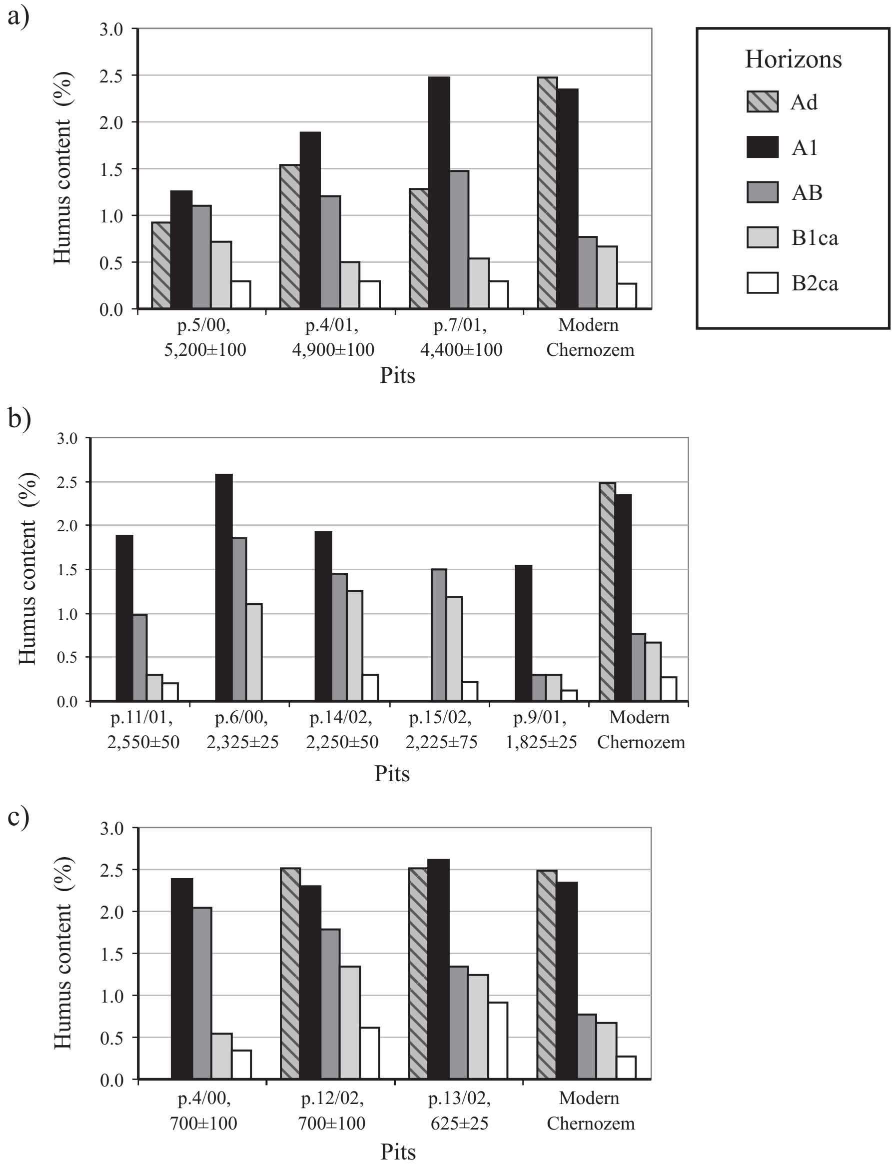

Figure 3. Content of humus in soils within the Shumaevo chronosequence.

and under the isolated single large kurgan 2, respectively (Table 1). From paleosols buried under kurgans 3 and 5 (8b/01 and 5b/01) to those buried under kurgan 6 and the isolated kurgan 2 (10b/01and 4b/01), the signs of humus accumulation and carbonate leaching become stronger both in morphological and analytical data (Figures 7b and 7d). In the paleosols buried under kurgans 3 and 5, the maximum content of exchangeable sodium occurs in the deep horizon B2ca, whereas in the paleosols buried under kurgan 6 and isolated kurgan 2 the distribution of this element is more or less uniform throughout the profile (Figure 7 F). We did not sampled the pit.3b/01 because of its thin mound and the large degree of disturbance of the paleosol beneath kurgan 4 (Table 1).

Some of the Yama kurgans of the second group had very similar sets of archaeological finds: the remains of wooden vehicles in graves inside kurgans 6 and isolated 2; similar plant and animal rawhide for "pillows" under the heads of the dead in graves inside kurgans 4 and 5 (Morgunova *et al.*, 2003). They were built within 100 to 200 years, based on archaeological estimation. The chronointerval of kurgan construction for the second group was longer than that of the first group, and the differences in the soil properties observed within the second group are more evident.

There was no additional evidence to determine the relative order of construction of the second group of kurgans. At first, we suspected that kurgans 3 and 5 were built earlier than kurgans 4, 6, and isolated 2, because on the Yama paleosols of the second group, soil properties that are produced under more humid conditions are more pronounced. But strictly speaking, the scenarios of the devel-

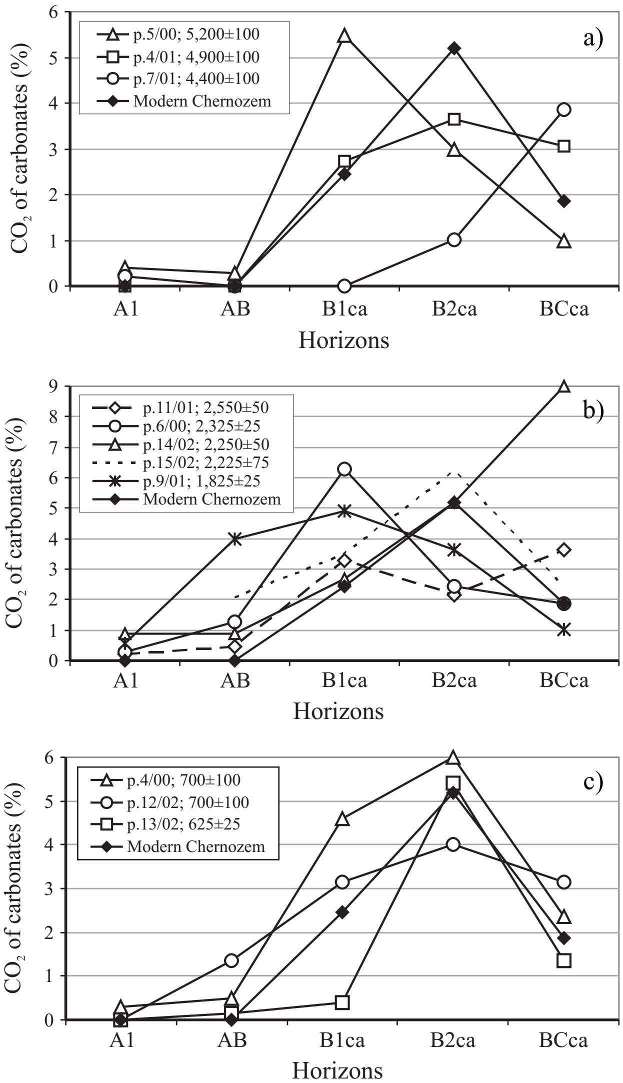

Figure 4. Content of CO_2 of carbonates in soils within the Shumaevo chronosequence.

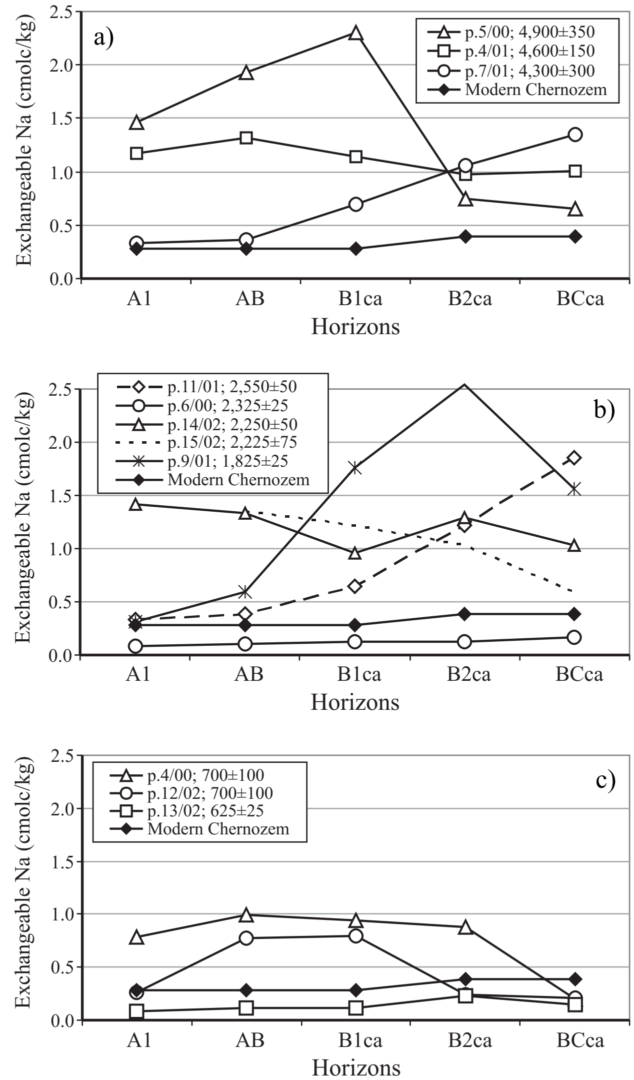

Figure 5. Content of exchangeable sodium in soils within the Shumaevo chronosequence.

opment of soil properties in the direction of enhancement both of "humid" or "arid" ones in this soil chronosequence are equitable and seem to be related to the suspected order of kurgan construction. Hence, we can not reconstruct the paleoenvironment for the chronointerval of the Yama paleosols of the second group with confidence.

Only one paleosol is assigned to the third group of Yama paleosols. It was buried under the kurgan 7 (pit 7b/01) in the Shumaevo II burial ground (Table 1). The relatively long chronointerval between the dates of burial of the Yama paleosols of the second and third groups (about 600 years) does not allow us to examine the changes of soil properties at a sub-centennial time scale in this case and to reconstruct the paleoenvironments of this chronointerval.

The following periods of kurgan construction are associated with the Early Iron Age (eighth century BC to forth century AD) and the Middle Ages, the time of the Mongols and the Golden Horde (thirteenth to fourteenth centuries AD). The paleosols buried under those kurgans were also studied.

Figure 2 demonstrates the chronosequence of paleosols studied near Shumaevo village as a whole. There were 10 paleosols of different ages in the Shumaevo chronosequence in addition to the modern background Chernozem. All the paleosols in the chronosequence (excluding the Yama paleosols) were dated archaeologically with certainty. The analysis of the morphological patterns of all soils in the Shumaevo chronosequence (Figure 2) allows the conclusion that the morphological characteristics of paleosols experienced repeated and contrasting environmental changes over the last 5,000 years. The analytical properties of the soils are correlated with the morphological patterns of their profiles (Figures 3, 4, 5, 6).

Examination of the ages of paleosol burial and the

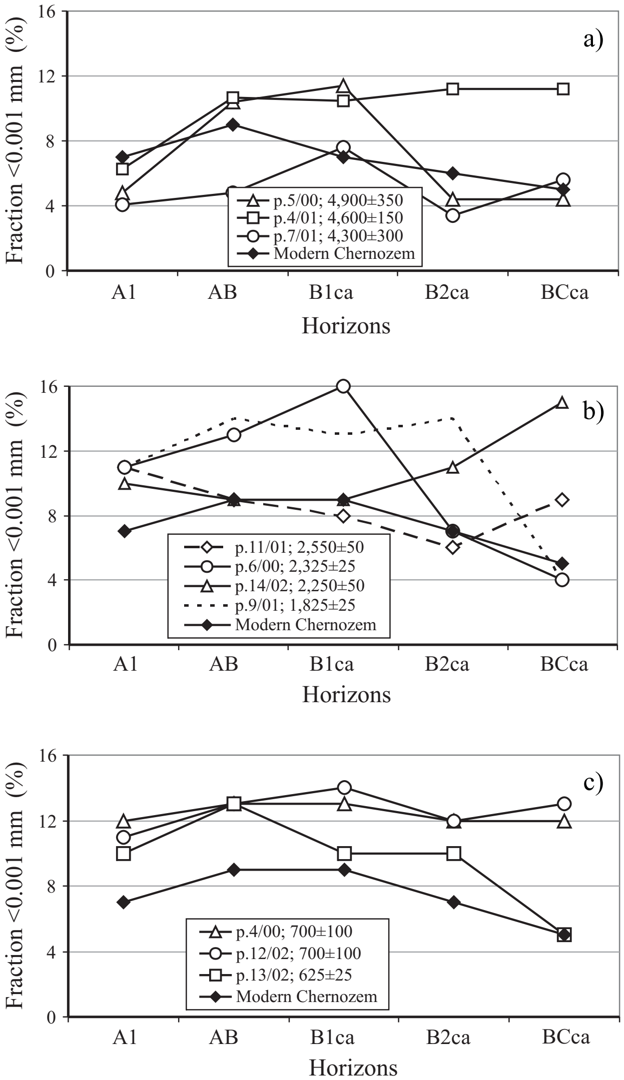

Figure 6. Content of fraction <0.001 mm in soils within the Shumaevo chronosequence.

chronointervals between the paleosols in the whole chronosequence show that the soil chronosequence documents soil changes over centennial time scales. In addition, a few opportunities to study sub-centennial time scale changes of soil properties were presented by the two groups of the Yama paleosols described above and two paleosols buried under kurgan 9 of the Early Sarmatian Culture.

Two paleosols were found buried under the two-layer kurgan 9 in the Shumaevo II burial ground (Figure 8). The first construction phase of the large kurgan 9 buried an early paleosol (pit 14b/02, date of burial is 2,250±50 years ago). Later, the uppermost layer of this mound was constructed, and the second (or late) paleosol (pit 15b/02, date of burial is 2,225±75 years ago) was buried. Based on finds in graves, archaeologists established that (1) all the burials of the kurgan 9 belonged to the same tribe associated with the Early Sarmatian Culture, and (2) all those burials were made within about 50 years. This is important because the differences in properties of two paleosols buried under early and late mounds of kurgan 9 mark sub-centennial time scale changes. For this time period, the indistinct tongue-like lower boundary of humus horizon is completely absent in the paleosol buried 2,250±50 years ago (pit 14b/02), but it appeared in the late paleosol buried 2,225±75 years ago (pit 15b/02). In place of faint filaments and whitish hue observed in the Bca horizon of the early paleosol of pit 14b/02, in the late paleosol of pit 15b/02 the Bca horizon has more impregnation and compact laminated carbonate enrichment appearing higher in the profile (Figures 2f and 2g). The maximum carbonate content is found in the deep BCca horizon of the early buried paleosol and in the B2ca horizon of the late buried one (Figure 4B). Unfortunately, the uppermost horizon of the late buried paleosol (pit 15b/02) was truncated during the excavation and we are not able to compare the humus and other properties of the A1 horizons of the two paleosols buried under kurgan 9.

In order to compare changes of not only an individual soil property but of a set of them over time in the chronosequence studied, the soil properties were rated using a numerical graded approach. For instance, considering the presence of tongues in the lower boundary of the humus horizon, the presence and clear manifestation of this characteristic was evaluated by 1, the presence and weak manifestation of this characteristic by 0.5, and its absence was taken as zero. Considering the percentage of humus, CO_2 of carbonates, and exchangeable sodium in the soils of the chronosequence, the maximal content of each component was taken as 1 (unit), and grades for lesser values were calculated proportionally. All the soil properties under study were tentatively divided into "arid" and "humid" ones bearing in mind that some of them typically develop in a dry and continental climate, while others are indicative of wetter and milder conditions in Chernozems. Conventionally "arid" properties are as follows: presence of tongues in the lower boundary of the humus horizon, high content of exchangeable sodium in the exchangeable bases and carbonates, and clear morphological forms of carbonate accumulations. At the same time, signs of desalinization, dealkalinization, accelerated accumulation of humus, high biological activity (*e.g.*, coprogenic structure of humus horizon), leaching of carbonates and desegregation of carbonate accumulations are attributed to the "humid" properties (Table 3). All these soil properties have been studied in the paleosols buried under kurgans in the Chernozem steppe of Russia to reconstruct the paleoenvironments of the Holocene (Gennadiev, 1984; Akhtyrtsev and Akhtyrtsev 1986; Ivanov, 1992; Demkin, 1997; Alexandrovskiy, 2000). But the set of soil properties may be different depending on the peculiarities of a study site and are not used universally.

Then, for each soil of the chronosequence the sum of numerical grades for the "arid" and "humid" properties are calculated (Table 3) and plotted (Figures 9a and 9b). The curves allowed us to visualize the changes of the set of soil

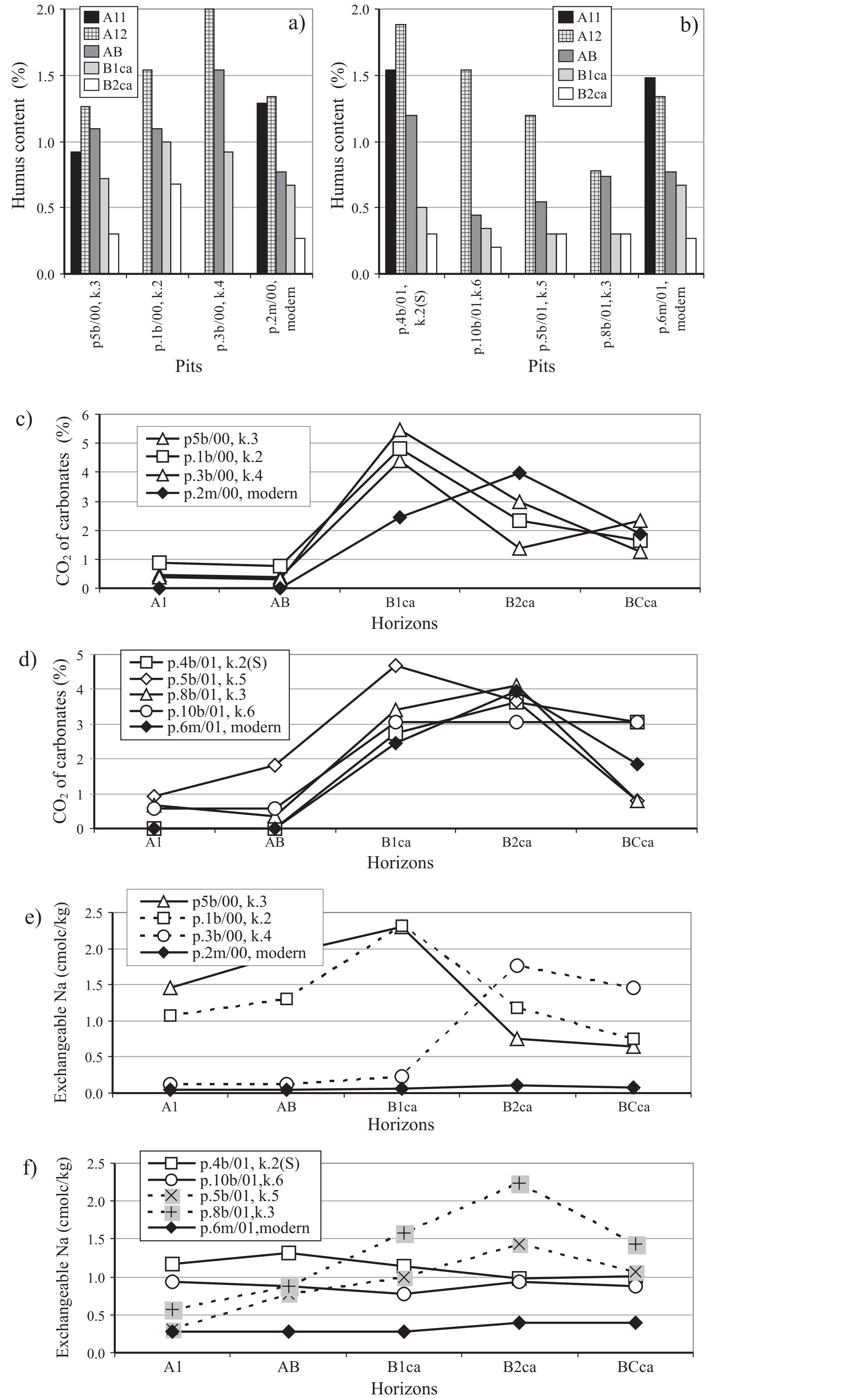

Figure 7. Content of humus, CO_2 of carbonates, and exchangeable sodium in the first (A, C, E) and second (B, D, F) of the Yama paleosols.

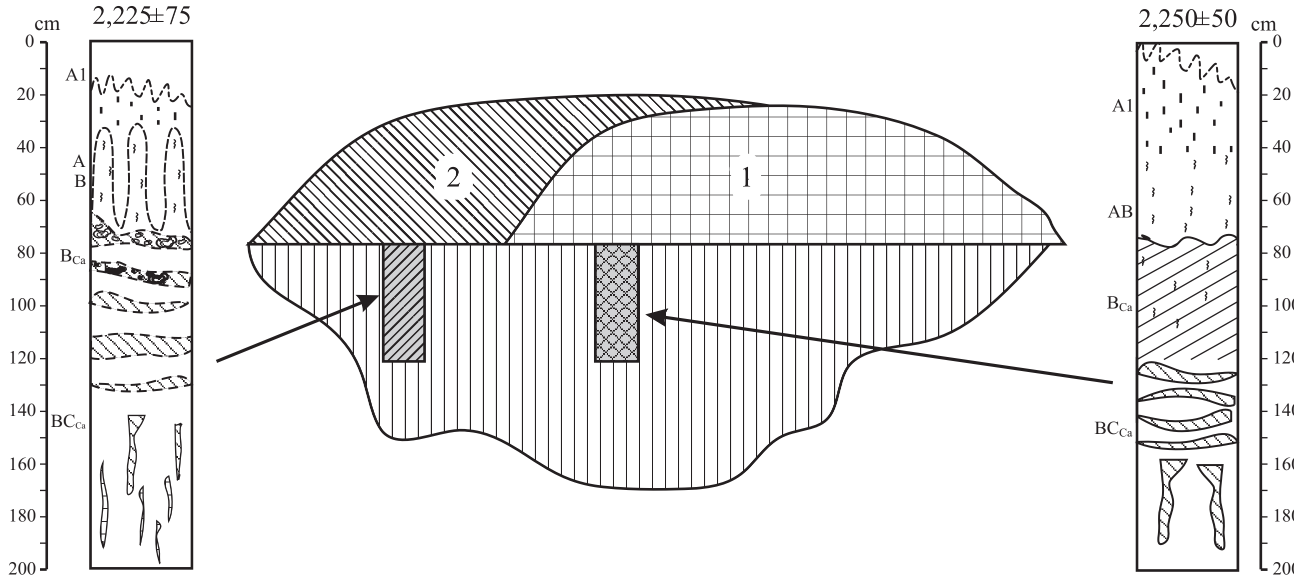

Figure 8. Scheme of the two-layer kurgan 9 in the Shumaevo II burial ground with the early (pit 14b/02, date of burial: 2,250±50 years ago) and late (pit 15b/02, date of burial is 2,225±75 years ago) paleosols buried under the first and second mounds, respectively.

properties in the chronosequence under study and the direction of these changes. The paleosols buried 4,900±350 and 4,300±300 years ago appear to have formed under relatively humid conditions, however, as stated previously, the direction of change can not be determined with confidence since the relative order of construction of the second group of kurgans is unknown. The curves plotted with the calculated grades of the Early Iron Age paleosols (between the dates of 2,550±50 and 1,825±25 on Figure 9) show a turning point in soil property changes in the sub-centennial chronosequence. This turning point could be ascertained very accurately by the example of two paleosols buried under kurgan 9. In the sequence of paleosols buried 2,550±50, 2,325±25 and 2,250±50 years ago in the Early Iron Age, the sum of numerical grades for "arid" decrease and those for "humid" soil properties increase. Whereas in the paleosol buried at 2,225±75 the direction of soil property changes is opposite (Table 3 and Figures 9a, 9b).

Hence, it is necessary to introduce a new idea formulated as "a direction of soil property changes with time". The analysis of these curves shows that the points (or paleosols) lying on different branches of the curve by their directions

Table 3. Sums of numerical grades for "arid" and "humid" properties of soils within the chronosequence.

	«Arid» soil properties						«Humid» soil properties				
Date of paleosol burial (years BP)	**Tonguing lower boundary of humus horizon**	**Clear carbonate soft spots in B1ca horizon**	**«Carbonate crust» in B2ca horizon**	**Carbonate CO_2 content in B1ca horizon**	**Exchangeable Na content in B1ca horizon**	**Sum of numerical grades**	**Biogenic aggregation of A1 horizon**	**Humus content in A1 horizon**	**Smeared carbonate soft spots in B1ca horizon**	**Carbonate micelium**	**Sum of numerical grades**
4900±350	1.0	1.0	1.0	1.0	1.0	5.0	0	0.5	0	0	0.5
4600±150	0.5	1.0	0.5	0.5	0.5	3.0	0.5	0.8	0.5	0.0	1.8
4300±300	0	0	0	0	0.3	0.3	1.0	1.0	1.0	1.0	4.0
2550±50	1.0	0.5	0.5	0.6	0.3	2.9	0.5	0.7	0	0	1.2
2325±25	0.5	0.5	0	0.5	0.1	1.6	0.5	0.9	0.5	0	1.9
2250±50	0	0	0	0.5	0.4	0.9	0.5	0.8	1.0	0.5	2.8
2225±75	0.5	0.5	0.5	0.6	0.5	2.6	0.5	0.7	0.5	0	1.7
1825±25	1.0	1.0	0.5	0.8	0.8	4.1	0	0.6	0	0	0.6
700±100	0.5	0.5	0.5	0.8	0.4	2.7	0.5	0.8	0	0	1.3
625±25	0	0	0	0.1	0.1	0.2	0.5	1.0	0.5	0.5	2.5
0	1.0	1.0	0	0.4	0.1	2.5	0.5	0.5	0.5	0.5	2.0

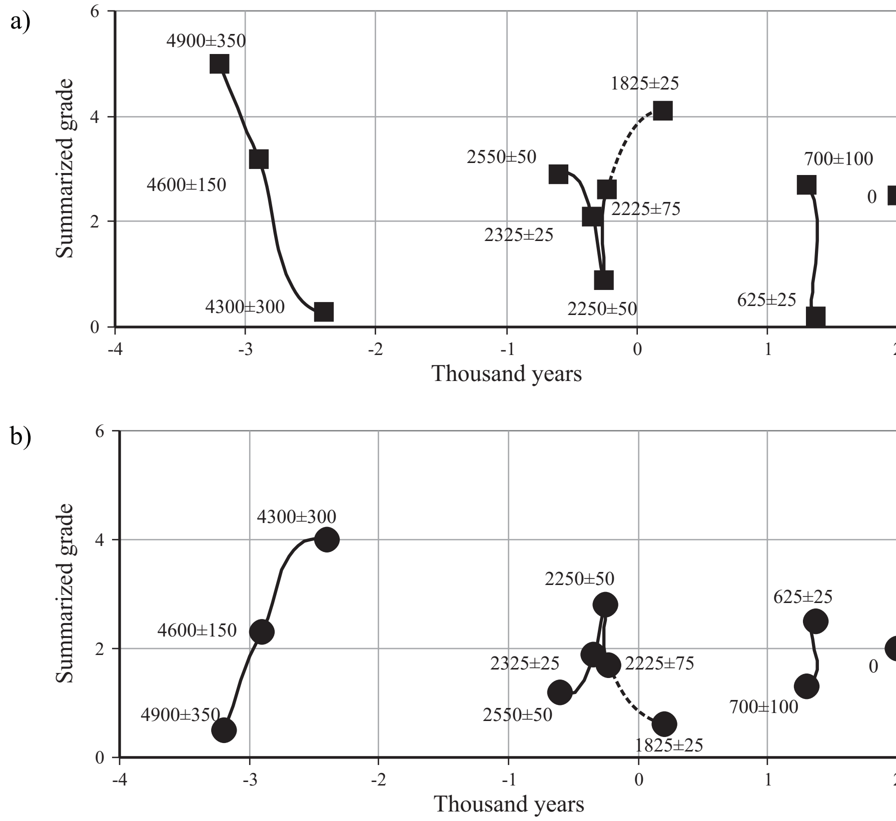

Figure 9. Distribution of summarized grades for "arid" (a) and "humid" (b) properties of soils within the Shumaevo chronosequence.

(for instance, paleosols buried 2,325±25 and 2,225±75 years ago on the curves obtained, Figures 9a, 9b) may have equal sums of numerical grades (Table 3). It means that the paleosols lying on the segments of the curves opposite by their direction have a similar set of properties. This example is interpreted to indicate that soil property evolution under the influence of environmental factors changing in either a more arid or humid direction can have a similar set of properties at one moment. Thus, to adequately assess the direction of environmental change recorded in a soil chronosequence we have to determine correctly the direction of soil property changes with time, otherwise our paleoenvironmental reconstruction may be incorrect.

It is especially necessary to take note of soil properties that change over sub-centennial or centennial time scales. The morphological properties that are informative in the paleosols studied for these time scales were as follows: the character of the lowest boundary of the humus horizon, the degree of biological activity (coprolites, humus-enriched root and mesofauna channels) and the morphological patterns of carbonate accumulation observed in the field. In the laboratory, the percentage of humus, carbonate, and exchangeable sodium down through the profiles have been used for this purpose. All studied soils developed in loamy to sandy parent material and are characterized by high rates of soil-forming processes.

ACKNOWLEDGEMENTS

This work has been supported by the Russian Foundation for Basic Research (Grants 07-05-00905, 07-06-00148). I am very grateful to Christina Siebe for many suggestions and helpful discussion, and to Peter Jacobs for improving the English manuscript.

REFERENCES

Akhtyrtsev, B.P., Akhtyrtsev, A.B., 1986, Evolution of soils in the Middle-Russian forest-steppe zone in Holocene [in Russian], *in* Ivanov, I.V. (ed.), Evolution and Age of Soils in the USSR: Pushchino, Scientific Centre of Biological Research Press, 163-173.

Alexandrovskiy, A.L., 1995, The Holocene evolution of the soil cover of the Russian plain: Eurasian Soil Science, 28(3), 258-264.

Alexandrovskiy, A.L., 2000, Holocene development of soils in response to environmental changes: the Novosvobodnaya archaeological site, North Caucasus: Catena, 41, 237-248.

Alexandrovskiy, A.L., 2002, Development of soil in the Eastern Europe in Holocene [in Russian]: Moscow, Institute of Geography, Russian Academy of Sciences, Doctoral Thesis in Geography, abstract of dissertation, 48 p.

Alexandrovskiy, A.L., Chichagova, O.A., Shishlina, N.I., 1996, ^{14}C studies of burial mounds in the steppe zone: chronology and paleoenvironment, *in* 11th International Workshop on Isotope-Geochemical Research in the Baltic region, Varch 14-16, Lohusalu, Estonia, 19 p.

Barham, J.A., Macphail R.I. (eds.), 1995, Archaeological Sediments and Soils; Analysis, Interpretation and Management: London, University College of London, Institute of Archaeology, 239 p.

Brown, A.G., 1997, Alluvial Geoarchaeology; Floodplain Archaeology and Environmental Change: Cambridge, Cambridge University Press, 377 p.

Chambers, F.M. (ed.), 1993, Climate Change and Human Impact on the Landscape; Studies in Palaeoecology and Environmental Archaeology: London, Chapman and Hall, 303 p.

Chichagova, O.A., 1985, Radiocarbon dating of soil humus [in Russian]: Moscow, Nauka, 157 p.

Demkin, V.A., 1997, Paleopedology and Archaeology [in Russian]: Pushchino, Scientific Center of Russian Academy of Sciences, 213 p.

Demkin, V.A., 1999, Buried soils of defense lines of ancient Russia and the problems of ancient and recent history of soil formation: Eurasian Soil Science, 32(10), 1128-1136.

Dergacheva, M.I., 1997, Archaeological pedology [in Russian]: Novosibirsk, Publishing house “Izdatelstvo SO RAS”, 228 p.

Dobrovolsky, G.V., Urusevskaya, I.S., 1984, Geography of soils [in Russian]: Moscow State University Press. 415 p.

Erokhina, A.A., 1959, Soils of the Orenburg oblast [in Russian]: Moscow, Academy of Sciences of USSR Press, 164 p.

Food and Agriculture Organization (FAO), 1998, World Reference Base for Soil Resources: Rome, Food and Agriculture Organization of the United Nations, World Soil Resources Reports, 84, 88 p.

Gennadiev, A.N., 1984, Changes of Chernozems properties in time and evolution of environment (Stavropol’ Upland): Moscow University Geographical Bulletin, 39, 10-16.

Gerasimova, M.A., 1987, Geography of soils in the USSR [in Russian]: Moscow, Vysshaya shkola Press, 224 p.

Gile L.H., Peterson F.F., Grossman R.B., 1966, Morphological and genetic sequences of carbonate accumulation in desert soils: Soil Science, 101(5), 347-360.

Holliday, V.T. (ed.), 1992, Soils in Archaeology; Landscape Evolution and Human Occupation: Washington, DC., Smithsonian Institution Press, 254 p.

Ivanov, I.V., 1992, Evolution of soils in the steppe zone in Holocene [in Russian]: Moscow, Nauka, 144 p.

Khokhlova, O.S., 2003, Paleoclimatic reconstruction on the basis of complex investigation of soils buried under the Early Iron Age kurgans in the Orenburg region [in Russian], *in* International Archaeological Meeting (XVI Uralskoje), Abstracts: Perm’, Permsky State University press, 256-257.

Khokhlova, O.S., Mergel, S.V., Kovalevskaya, I.S., 1997, An approach to reconstruction of the CO_2 regime in semi-arid soils of Russia on the basis of their carbonate profile data, *in* Lal R., Kimble, J., Follett, R. (eds.), Soil Properties and Their Management for Carbon Sequestration: Lincoln, NE, United States Department of Agriculture, Natural Resources Conservation Services, National Soil Survey Center, 11-18.

Khokhlova, O.S., Oleinic, S.A., Kovalevskaya, I.S., 2000, The distinctions between diagenetic and epigenetic types of carbonate concentrations in the buried Holocene soils of the chernozemic zone: Eurasian Soil Science, 33(1), 23-31.

Morgunova, N.L., Golyeva, A.A., Kraeva, L.A., Meshcheryakov, D.V., Turetskyi, M.A., Khalyapin, M.V., Khokhlova, O.S., 2003, Shumaevo’ kurgans [in Russian]: Orenburg, Orenburg State Pedagogical University Press. 392pp.

Morgunova, N.L., Khokhlova, O.S., 2006, Kurgans and nomads: new investigations of mound burials in the southern Urals: Antiquity, 80(308), 303-317.

Ovechkin S.V., 1984, The genesis and mineralogical composition of carbonate features in Chernozems of the Ukraine and the Middle Volga Basin. Soils and soil cover of forest and steppe zones of USSR and their rational use [in Russian]: Moscow, V.V. Dokuchaev Soil Science Institute, 184-189.

Pesochina, L.S., Golyeva, A.A.. Zaytsev, S.V., 2000, Changeability of soil and natural conditions on the northern-east part of Priazov’e in the Middle Sarmatian Time: Eurasian Soil Science, 33(6), 619-626.

Serebrjanaya, T.A., 1976, Relationship between forest and steppe in the Middle Russian upland in the Holocene [in Russian], *in* History of biocenoses of the USSR in the Holocene: Moscow, Nauka, 159-166.

Shishov L.L. Tonkonogov V.D., Lebedeva I.I., (eds.), 1997, Classification of Russian Soils [in Russian]: Moscow, V.V. Dokuchaev Soil Science Institute, 236 p.

Velichko, A.A., Andreev, A.A., Klimanov, V.A., 1994, Dynamics of vegetation and climate of the Northern Eurasia in the Late glacial epoch and Holocene [in Russian], *in* Short-term and Abrupt Landscape and Climatic Changes during last 15,000 years: Moscow, Institute of Geography, Russian Academy of Sciences, 4-60.

Manuscript received: October 17, 2005
Corrected manuscript received: March 3, 2007
Manuscript accepted: May 15, 2005