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GENESIS AND GEOGRAPHY OF SOILS

Soils, Vegetation, and Climate of the Southern Transural Region in the Middle Bronze Age (by the Example of the Arkaim Fortress)

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Abstract—Paleosols of the unique fortress of Arkaim located in the steppe zone of the southern Transural region (Chelyabinsk oblast) were investigated. The dating of the buried soils was performed using the radiocarbon method. The time of building this archeological monument is the Middle Bronze Age (the Sintashta culture; the calibrated dating with 1σ confidence is 3700––4000 years ago). Seven pits of paleosols and ten pits of background ordinary chernozems were studied. The soils are loamy and sandy-loamy. The morphological and chemical properties of the buried and background ordinary chernozems are similar; they differ by the lower content of readily soluble salts in the paleosols as compared to the background ones. The spore–pollen spectrum of the Arkaim paleosol is transitional from the steppe to the forest-steppe type. During the existence of this settlement, pine forests with fern ground cover grew, and hygrophytic species (alder and spruce) that nowadays are not recorded in the plant cover occurred. The main feature of the paleosols is the presence of pollen of xerophytic and halophytic herbaceous plants there. The few pollen grains of broad-leaved species testify to a higher heat supply as compared to the current one. Judging by the results of the spore–pollen and microbiomorphic analyses, the climate during the time of building the walls of the settlement was somewhat moister and warmer (or less continental) than the present-day climate. The duration of this period appeared to be short; therefore, soil properties corresponding to the changed environment could not be formed. They reflect the situation of the preceding period with the climatic characteristics close to the present-day ones.

Keywords: paleosols, soil properties, palynological analysis, reconstruction of the climate, radiocarbon dating
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INTRODUCTION

In the southern Transural region, 22 fortified settlements and numerous archeological sites forming a complex named *Country of Towns* were found [13, 32]. For the last 20 years, data on the paleosols there have been obtained. The reconstructions of the climate of the Bronze Age in the Cis-Urals and Transurals were carried out after studying some archeological sites of the Country of Towns [8, 13–16, 21–23, 29–32].

Archaeologists refer many of these sites to the Middle Bronze Age, the Sintashta archeological culture (3800–4100 years ago), and the Pit Grave culture [29]. The culture was named after the archeological complex located on the bank of the Sintashta River in Chelyabinsk oblast. The paleosols of the great Sintashta mound were characterized [8, 30]. The evolution of the Transural chernozems for the last 4000 years is shown; the similarities and differences in their development as compared to the chernozems of East Europe and northern Kazakhstan are shown. The possibility to use various characteristics of humic acids isolated from paleosols for the reconstruction of the six natural and agricultural landscapes in the past was revealed [11].

The ancient settlement of Arkaim. An aerial view. The scale is 1 : 5000.

The first well-preserved fortified site of the Bronze Age was found in Chelyabinsk oblast in 1987 and called Arkaim after the name of the highest point of the locality (398 m a.s.l.). The archeological sites occupy about 1% of the Arkaim valley area according to the interpretation of aerial photographs with the help of a special method [13]. People developed this territory mainly in the Bronze Age (74% of all the sites (out of the total of 73) are referred to this time). In 1991, the reserve with the same name was organized to preserve this unique object. The reserve is located in the territory of the steppe zone of the southern Transural region (Bredinskii district, Chelyabinsk oblast; 52°37–40′ N, 59°32–37′ E).

This article first presents the detailed characteristics of the paleosols and the results of the plant cover's reconstruction at the site of Arkaim. These data are important for characterizing the development of the soils, the environmental conditions, and the variability of the climate in the Bronze Age and revealing the reasons for the phased settlement of the Urals region.

OBJECTS

The paleosols buried under the walls of the fortified settlement of Arkaim and the present-day background soils were the objects for the studies. The archeological excavations were conducted under the guidance of Zdanovich [13]. The basis of the Arkaim fortifications was a ditch and inner and outside walls made of earthy materials and wood. According to the calculations of the archeologists, the height of the earth walls of the settlement was 0.7 and 1.4 m; presently, their height is approximately twice lower. The archeological site is located on a remnant (200 × 300 m^2) of the proluvial–alluvial surface at the confluence of the Utyaganka and Bol'shaya Karaganka Rivers (a tributary of the Ural River) at the altitude of 314.5 m (figure).

This remnant is isolated and surrounded by river valleys and a depression—the former channel. The background recent soils occupy small areas and are represented by ordinary chernozems.

Nowadays, the territory studied is referred to the steppe zone [18]. The climate of the region is continental. The mean annual temperature is +1 to +3°C, the mean temperatures of January and July are –17 to –18°C and +19 to +20°C, respectively. The sum of the temperatures above 10°C is 1950–2300; the duration of the frost-free period is 111–125 days. The annual precipitation is 300–360 mm: 45% of it falls as showers in the summer and 10–12% in the winter. The depth of the snow cover does not exceed 25 cm. The soils freeze to a depth of 0.8–2.0 m. Snow thaws on the frozen soil, and the water does not penetrate into it. The moisture coefficient is 0.4–0.8. Hot winds and deflation significantly damage the soils and crops. Before the organization of the reserve, the territory of the remnant was used as a pasture. The vegetation is represented by forbs–sheep fescue–stipa associations and spirea (*Spiraea hypericifolia* L. and *S. crenata* L.) and caragana (*Cargana frutex* (L.) C. Koch). The background soil is a shallow, low-humus, mid- and weakly saline, strongly solonetzic, sandy loamy ordinary chernozem.

METHODS

The field morphological method comprising the profile's description and photography was used for studying the soils. The reconstruction of the environmental conditions of the Bronze Age was performed considering the properties of the buried paleosols (seven pits) and the present-day background soils (ten pits). For the characterization of the background soils, the areas close in their altitude and texture to the soils of the cultural–historical complex were chosen. The territory is heterogeneous in terms of the particle-size composition of the parent rocks and soils. Therefore, ten test pits were made to the depth of 50 cm for the characterization of the background soils and their comparison with the paleosols. After analyzing their morphology, the place for the key pits for the background soils was chosen. The chemical properties of the soils were analyzed by traditional methods [2, 4].

Table 1. The results of the radiocarbon dating of the humus in the soil of the Arkaim Reserve

Soil, pit, depth, cm	Laboratory number	^{14}C age of the soil humus	
		uncalibrated BP, years ago	calibrated BC, years ago; probability
Paleosol, pit 3, 0–5 cm	Ki-17095	3840 ± 140	1σ 2490–2120, 57.4%, 1σ 2090–2030 BC, 7% 2σ 2700–1850 BC, 95.4%
Paleosol, pit 2, 25–50 cm	Ki-16811	3210 ± 130	1σ 1690–1370 BC, 64,4% 2σ 1900–1100 BC, 95.4%
Background pit 1, 0–25 cm	Ki-16812	450 ± 60	1σ 1400–1500 AD, 63.8% 2σ 1390–1530 AD, 76.3%, 2σ 1550–1640, 17.2%
Background pit 1, 38–62 cm	Ki-16814	3050 ± 70	1σ 1410–1250 BC, 57.4% 2σ 1450–1050 BC, 95.4%

The age of the site was determined from archeological findings according to the periodization and chronology of the historical cultures and using the radiocarbon dating of the paleosols' humus. The dating was accomplished at the Kiev Radiocarbon Laboratory (supervised by N.N. Kovalyukh) of the National Academy of Sciences of Ukraine. A sample of the paleosol was taken from the depth of 0–2 cm, i.e., directly from the buried surface. This sample was analyzed using the palynological method by Gerasimenko and the microbiomorphic one by Gol'eva. The percentage of different higher plant microfossils was determined using a semigroup method. The ratio of the woody plant taxa to the total pollen of trees and shrubs was calculated; that of the herbaceous plants, to the total pollen of grasses and dwarf shrubs; and the ratio of the spores, to the total microfossils. The plants producing pollen and spores and the reconstructed zonal and local paleophytocenoses existed and exist in a definite landscape–climatic environment. Therefore, the results of the spore–pollen analysis of the paleosols allow one to obtain information on the formation and evolution of the landscapes.

RESULTS AND DISCUSSION

The fortress site of Arkaim has a cultural layer testifying to one stage of its settlement, although, according to the results of the archeological method [13], the majority of the localities from the Country of Towns functioned in two (3800–4100 and 3600 years ago) or more stages. The accuracy of determining the age by this method for archeological sites of the Bronze Age is ±100–200 years. The dating of constructing the walls at the ancient site was also performed according to the ^{14}C of the organic matter in the upper (0–5 cm) layer of the paleosols buried under its walls. The age of the humus was determined from the ^{14}C of the background soils. As the data of the radiocarbon dating of the paleosol humus were used for determining the time of constructing the artificial mounds and burying the soils, an approach suggested by Chichagova and Aleksandrovskii [25, 26] was used. According to this method, the age of the buried paleosols is calculated as the difference between the age of the humus in the 0- to 5-cm layer of the paleosol and the age of the background soil. The uncalibrated age of the humus in the 0- to 5-cm layer of the paleosols is 3840 ± 140 years; its age in the 0- to 25-cm layer of the background layer is 450 ± 60 radiocarbon years (Table 1). Thus, the uncalibrated date of constructing the earth mound of Arkaim is about 3400 years ago, or the calibrated dates with the significance of 1σ and 2σ are 3700–4000 (57.4%) and 3400–4250 (95.4%) years ago, respectively.

Spore–pollen analysis. The palynological analysis of the 0- to 2-cm paleosol layer was performed in 3 replicates. All the microfossils, including the pollen of the gramineous plants, were well preserved, although usually it is weakly preserved. The spore–pollen spectrum contained pollen of herbaceous plants (68%), tree species (20%), and spores of ferns and mosses (12%) (Table 2). The pollen's composition was dominated by that of gramineous plants (33.5%) and forb species of 11 families (43.5%). The participation of sedges was 9%. Among the other monocotyledons (except for grasses and sedges), Liliaceae and Typhaceae were represented by a few pollen grains. The participation of xerophytic palinoforms was insignificant: *Artemisia* pollen (6.5%); the pollen of Chenopodiaceae, including *Chenopodium album, Ch. botrys*, and *Kochia prostrata* (5%); and one pollen grain of ephedra. In the pollen of the forbs group, the pollen of Lamiaceae predominated (14%); the participation of Rosaceae (6.5%, including *Spiraea* steppe shrub), Cichorinoideae (6%), Asteroideae (4%), and Fabaceae (5%) was also noticeable. The amount of Plantaginaceae (2%) and Ranunculaceae and Cannabaceae (1%) pollen was insignificant; a few pollen grains of Umbelliferae, Papaveraceae, and Boraginaceae were found. Among the pollen grains of

Table 2. The results of the spore–pollen analysis of the Arkaim soil

Taxon	Number	
	grains	%
Picea, spruce	1	0.5
Pinus sylvestris, Scots pine	36	16
Alnus glutinosa, black alder	2	1
Betula, birch	1	0.5
Ulmus, elm	1	0.5
Tilia cordata, lime tree	1	0.5
Acer tataricum, Tatarian maple	1	0.5
Malaceae, (including hawthorn, dogrose)	1	0.5
Lonicera, honeysuckle	1	0.5
Spiraea, spiraea	1	0.5
Poaceae, grasses	50	23
Cyperaceae, sedges	14	6
Lamiaceae	21	10
Rosaceae	10	5
Fabaceae, leguminous	8	4
Artemisia, wormwood	10	5
Cichoriaceae	9	4
Asteraceae	7	3
Chenopodiaceae	8	4
Apiaceae	1	0
Plantaginaceae	3	1
Papaveraceae	1	0.5
Boraginaceae	1	0.5
Cannabis, cannabis	2	1
Ranunculaceae	2	1
Ephedra, ephedra	1	0.5
Liliaceae	1	0.5
Typha latifolia, typha	1	0.5
Bryales, green mosses	9	4
Polypodiaceae ferns	12	5
Pteridium aquilinum	5	2
Total pollen of the trees and shrubs	45	20
grasses and shrubs	149	68
spores	26	12
forbs pollen	65	30
pollen of herbaceous xerophytes	19	9
Total palynoforms	220	100

grasses, large grains similar to those of cultural grasses (Cerealia) occurred.

The rich forbs and the significant share of Rosaceae and Cichorinoideae, among which there were few steppe plants, show that precisely meadow plants formed the vegetation cover. However, the elevated share of Cichorinoideae and Asteroideae may be also explained by the anthropogenic factor. Their pollen was usually found in settlements [6, 19, 27, 28]. In addition, the distribution of Plantaginaceae and Chenopodiaceae (*Ch. album* is a typical weed) might be related to the anthropogenic factor (trampling). Papaveraceae and Cannabaceae could also be weeds. The pollen of steppe plants predominated among the grains of Lamiaceae and Papaveraceae that were represented in the spectrum. Artemisia, hemp, and ephedra also belonged to these plants. The hemp pollen (in the size of its grain and pores) is very similar to that of the cultivated *Cannabis sativa*. On the whole, the participation of meadow elements was higher than that of steppe ones.

The problem of the cultivated cereals will be considered separately. The existence of farming in Arkaim in the Late Bronze Age (3600 years ago) is supposed [21]. The deposits studied by the authors of the article belong to an earlier time interval than that described by E.A. Spiridonova; the amount of pollen morphologically similar to that of Cerealia was greater than that in the settlements of the Srubnaya culture in the steppe zone of Ukraine. At the site of Arkaim, the macroremains of *Phragmites* and *Bromopsis* were found, and the pollen grains of these wild grasses (especially of *Phragmites*) were similar to the pollen of cultivated grasses. The presence of other hydro- and hygrophytic plants (*Typha* and sedges) confirms the relative closeness of the site to aquatic and waterlogged objects, from which *Phragmites* pollen could also be brought.

Among the spores, those of ferns (Polypodiaceae (5.5%) and *Pteridium* (2%)) predominated; the amount of green moss spores was 4%. Among the remains of tree species, the microfossils of pine amounted to 80%. Pollen of alder (2 grains), spruce, birch, apple, and honeysuckle (1 grain) were found. The presence of a few microfossils of broad-leaved species (elm, Tatarian maple, and *Tilia cordata*) is of special interest.

Well-preserved grains of Tatarian maple and elm were reliably identified. Macroremains of elm were also found in the ancient settlement of Arkaim [5]. One can suggest that, along with the above mentioned shrubs, these plants were in the undergrowth of pine forests or occurred as small steppe groves. The size of the lime tree pollen grains, as compared to those of this species palynoforms in Eastern Europe, was smaller as it was reduced (probably, it was produced by trees growing at the periphery of their natural range).

Based on the content (%) of the tree species pollen, one can suggest that the forests were located at some distance from the settlement. Probably, at that time, as nowadays, they occupied the upper parts of the valley slopes. When the settlement existed, pine forests with birch and spruce grew there; the forest margins were occupied by honeysuckle and representatives of Maleae (hawthorn, hedge rose, and gean). The ground cover consisted of Polypodiaceaeand, *Pteridium* ferns, and green mosses. Probably, on the steppe, the named Maleae shrubs (along with spiraea) formed separate formations that occupied small areas. On the shrub steppe of Donbass and eastern Crimea, the participation of Maleae (hawthorn, hedge rose, wild pear, and black thorn) in the spore–pollen spectra was much higher. Alder rarely occurred on the floodplains.

Thus, during the time under discussion, the Arkaim settlement was located on the forbs–grass or grass–forbs steppe with the significant participation of meadow forbs. At some distance from the settlement, open pine (*Pinus sylvestris*) forests with ferns in the ground cover and shrubs at their margins grew. Probably, there were small groups of steppe shrubs and not very high trees, including broad-leaved species—elm and Tatarian maple. At a small distance from the settlement, there were moist areas with sedges; typha; alder; and, probably, reed. The human effect on the vegetation was manifested in the higher participation of herbaceous plants (weeds) occupying the disturbed areas—Cichorioideae; Asteroidaea; Chenopodiaceae; and probably Plantaginaceae, Cannabaceae, and Papaveraceae. The morphology of the pollen of the grasses and cannabis, which are similar to their cultivated variants, requires further study.

Thus, the spore–pollen spectrum of the paleosol from the Arkaim settlement is referred to the steppe type, which is close to the transitional forest-steppe one. Based on the composition of the vegetation, the climate (or microclimate) was not supposed to be droughty and cool. The presence of pollen of broad-leaved species (elm, Tatarian maple, and lime trees), typha, and cannabis allows one to suggest that, at the time considered, the climate was somewhat warmer than the present-day one. In the remnant nearby the river, where the settlement was located, there were as many meadow plants in the grass cover as at the present time. The recent forest vegetation (small aspen–birch and larch–birch–pine forests with grass cover in steppe saucers), as compared to the pine forests with fern cover, reflects the more continental and cool climate conditions. Larch pollen did not occur in the paleosol; it is worth noting that this pollen is poorly preserved. In the present-day vegetation, alder and spruce are absent; these hygrophytes occurred at the time when the settlement existed. The main thing was that the low content of pollen of xerophytic and halophytic herbaceous plants in the paleosols did not correspond to the recent wide distribution of *Artemisia* and the vegetation typical for solonetzes [12].

Thus, the results of the palynological analysis showed that, during building the wall around the settlement, the climate of the region was more humid and warm than the recent one.

The microbiomorphic analysis of the 0- to 2-cm layer of the paleosol performed by A.A. Gol'eva allowed one to find well-preserved phytoliths: the content of dicotyledons was 46%, and those of steppe and meadow grasses were 29 and 17%, respectively. The number of phytoliths of coniferous trees, forest grasses, mosses, and ferns amounted to 2–3% each. One whole diatom and many cuticular clots of plants and the animals' coprolites were observed. The presence of whole diatom skeletons testified to the rather humid conditions that existed when the biocenosis developed, while water stagnation and water logging were not recorded. Thus, the microbiomorphic analysis showed that, during the formation of the ancient upper soil layer, meadow forbs and the steppe grasses predominated.

A spore–pollen analysis was first performed during the archeological excavations in the Arkaim settlement in the 1990s [21]. The palynological studies of the reference soils from the depth of 65- to 70 cm having the ^{14}C uncalibrated age of 4130 ± 110 demonstrated the existence of arid conditions at that time [21]. These data do not agree with our results, probably, due to the fact that E.A. Spiridonova used the soil samples of the more ancient radiocarbon age for the spore–pollen analysis.

The reference soils for the Arkaim site were studied in 10 pits. The lithological profiles are as follows: the upper layer up to the depth of 80–100 cm is sandy-loamy or loamy- sandy with a great amount of coarse and fine sand (57–68%), pebbles, and gravel (6–17%) (Table 3). The underlying layer 100–220 cm thick consisted of alternating coarse and fine sandy layers. Therefore, the pits were not dug deeper than 1.8–2.2 m. The upper horizons of the reference soils and the paleosols did not differ in their texture. In the reference soils, the texture of the second 0.5-cm layer became heavier; in the 50 to 100-cm layer of the paleosols, the content of physical clay decreased. The main properties of the soils studied are given in Table 4. The reaction (pH water) in the A1 and AB horizons of the reference soils was neutral to weakly alkaline; in the deeper horizons, it was alkaline.

The humus profile (A + AB) of the reference soils was 37 ± 4 cm, changing from 26 to 45 cm. The thickness of the humus horizon (A1) in these soils was 22 ± 6 cm (18–27cm). In the surface layer, the organic matter content was 3.04 ± 0.38%, and it drastically decreased downwards: in the AB horizon, down to 1.43 ± 0.18%; in Bca, down to 0.51 ± 0.14%. In this part of the soil profile, the dark-colored tongues alternated with the yellow brown ones. The tongues are formed due to the alternation of winter freezing and summer drying.

Table 3. The particle-size composition of the buried and reference soils

Depth, cm	Content of the fractions, %; particle size, mm					
	1–0.25	0.25–0.05	0.05–0.01	0.01–0.005	0.005–0.001	<0.001
	Buried soil, $n = 3$					
0–12*	51	10	13	6	10	10
35–67*	61	7	10	5	7	10
0–19	45	16	12	5	7	15
19–35	50	15	10	4	6	14
35–49	61	14	6	4	6	10
49–73	64	14	5	3	5	9
73–100	60	15	7	3	4	11
100–140	87	8	0	2	2	1
	Contemporary background soil, $n = 2$					
0–22	43	18	20	6	7	6
22–37	48	16	10	6	9	10
37–53	43	14	12	4	10	16
53–77	59	12	6	2	7	13
77–100	60	15	7	3	4	11

* Wall mound.

The reference soil effervesced from HCl at the depth of 25–35 cm in the space between the humus tongues; continuous effervescence was observed in the 38- to 220-cm layer. At the depth of 3–53 cm, the content of carbonates was 4.9 ± 3.7%. Their maximum (9.3–10.5%) was found at the depth of 70–150 cm; in the underlying rock, the carbonate content was insignificant. In the 0- to 1-cm layer, the weighed average of the $CaCO_3$ content was 7%. Carbonates occurred as rare mottles, small dots, and in a finely dispersed form. Gypsum was registered from the depth of 50 cm. Readily soluble soils appeared at the depth of 20–25 cm, and their content was 0.4–0.7%. In the upper soil layers, HCO_3^- predominated among the anions; in the lower layer, a significant share belonged to SO_4^{-2} and Cl^- along with HCO_3^-. Among the cations, the ions of sodium were the dominant ones. In the reference soils, alkalinity was revealed in the AB horizon. The degree of the soil's salinization is medium, while that of alkalinity is strong.

The content of the clay fraction determined using the elutriation analysis was 15–17%; the differentiation of the studied soil profiles in terms of the clay content is weak. The traditional method for the determination of the clay content with the preliminary treatment with sodium pyrophosphate provides for the weaker extraction of the clay fraction, especially from the A1 horizon. These data allowed one to conclude that, in the soil studied, a significant part of the clay fraction was in the composition of the aggregates that are not dispersed when treating with sodium pyrophosphate.

The paleosols buried under the wall of the settlement of Arkaim are dated to the Middle Bronze Age—the explosion of the Sintashta archeological culture. Seven buried soils were studied. The thickness of the humus horizon of the paleosols (35 ± 4 cm) is close to that of the reference soils. The humus content in the paleosols is a bit less than that in the recent soils. In the A1 horizon, the C_{org} content is 1.17%; its reconstructed content is 2.93 ± 0.33; the C_{org} content in the reference soils is 3.04 ± 0.38. In the course of the burial, the humus content in the paleosols decreased by 50–60% due to the diagenetic processes [14].

The morphology and distribution of the humus tongues within the buried and reference soils are similar. In the ancient soils of the Arkaim site, the maximal carbonate content is confined to the same depth as in the reference soils, but it is less strongly pronounced. The $CaCO_3$ concentration in this horizon is 6.3–7.3%. In the underlying rock, at the depth of 103–130 cm, it decreased to 4.5%. The weighted average of the $CaCO_3$ content in the 0- to 1-m layer is 6%. The reaction (pH water) is alkaline along the whole profile (9.3–9.5). The alkalinity is weak and medium.

Readily soluble salts occurred along the whole profile of the buried soils. In the upper layers of the

Table 4. The properties of the paleosols and the revalent reference ordinary chernozems ($n = 4–11$), %

Soil	Horizon	Lower boundary of the horizon, cm	pH water	C_{org}	CEC, meq/100 g	Exchangeable Na^+, % of the CEC	Particles <0.01 mm	$CaCO_3$	Gypsum, %	Total salts, %	Mobile, mg/100 g	
											P_2O_5	K_2O
Wall-mound	A1	0–12	6.9	2.83	12.7	0	26	1.6	0.01	0.04	3.0	26
	AB	12–22	7.9	2.0	11.9	8	22	1.9	0.01	0.09	1.4	21
	B1	22–35	8.9	1.83	42	3	24	2.7	0.11	0.21	–	–
	B1ca	35–67	9.3	1.2	47	9	22	7.6	0.12	0.21	0.7	27
Paleosol	A1	19 ± 3	9.4	$\frac{1.17 \pm 0.13}{2.93 \pm 0.33^*}$	23.9	10	27 ± 3.1	2.0 ± 1.3	0.07	0.18	1.1	28
	AB	35 ± 4	9.5	$\frac{0.61 \pm 0.05}{1.52 \pm 0.12}$	20.2	8	24 ± 3.8	2.2 ± 1.5	0.02	0.18	1.7	20
	B1	49 ± 7	9.3	$\frac{0.45 \pm 0.09}{1.13 \pm 0.23}$	19.0	9	19 ± 2.9	4.2 ± 1.2	0.05	0.17	1.3	5
	Bca	73 ± 5	9.3	$\frac{0.21 \pm 0.05}{0.52 \pm 0.12}$	17.8	6	17 ± 1.2	6.3 ± 3.5	0.4	0.24	–	5
	BCca	100 ± 5	9.3	$\frac{0.14 \pm 0.06}{0.35 \pm 0.14}$	–	–	18 ± 2.0	7.3 ± 2.0	0.44	0,08	–	–
	Dca	150 200	–	–	–	–	5	6.8 4.5	0.55 0.4	0.06 0.08	–	–
Reference	Asod + A1	22 ± 6	7.2	3.04 ± 0.38	22.2	5	19 ± 2.9	1.7 ± 0.5	0	0.08	1.5	33
	AB	37 ± 9	8.3	1.43 ± 0.18	25.5	18	26 ± 3.0	2.5 ± 2.1	0	0.40	1.6	31
	B1ca	53 ± 7	9.2	1.06 ± 0.14	23.0	16	31 ± 2.5	4.9 ± 3.7	0	0.53	–	–
	Bca	77 ± 4	9.3	0.51 ± 0.14	20.4	17	23 ± 2.2	9.3 ± 2.0	0.1	0.41	–	–
	BCca	100 ± 5	9.3	0.24 ± 0.05	–	–	18 ± 2.0	10.5 ± 3.2	0.5	0.20	–	–
	Dca	200	–	–	–	–	5	4.4	0.6	0.15	–	–

* Reconstructed C_{org} content;
Note: Dashes denote the absence of determination.

ancient soils buried under the earth walls, they appeared as a result of diagenesis, i.e., due to the partial migration of readily soluble salts from the material of the earth wall. The latter was made of a mixture of the ancient soil horizons that contained some amounts of carbonates and readily soluble salts. Presently, the lower layer of this material contains 0.21% readily soluble salts. Their concentration in the paleosols was less than in the reference soils (0.3%), and their composition was the same as that in the reference soils.

The content of the clay fraction was somewhat greater than that in the reference soil (17–19%). According to the data of the elutriation method, the yield of the clay fraction was lower than that determined by the pyrophosphate method. In the A1 horizon, the differences between these values were insignificant. Therefore, the amount of water-stable aggregates that were not disintegrated by pyrophosphate was much lower than that in the background chernozem.

Close characteristics of the properties were obtained for the paleosols of a mound constructed 3.9 thousand years ago nearby the settlement of Aleksandrovskii 1.5 km far from the Arkaim reserve [16].

Thus, one can note that the paleosols and the background soils are identified as ordinary chernozems. The differences between them were related to the higher salinity and alkalinity in the present period. Based on the comparison of the properties of the buried and reference soils, one can conclude that the climatic conditions in the time of the functioning of the fortress of Arkaim were close to the present-day ones.

According to the data of the palynological studies, we concluded that the climate during the construction of the settlement walls was much more humid and warm than the present-day one. The differences between the conclusions reached can be explained by the fact that the plant cover as compared to the soils is more sensitive to climatic changes. The plant cover reaches equilibrium with the environmental conditions faster than the soil does. Thus, in the time of building the fortress, as judged by the reconstruction of the plant cover using the palynological method, the climate was much warmer and more humid than nowadays. The duration of this period appeared to be short-term, and the soil's properties could not be transformed and reach an equilibrium with the changed environment. Therefore, they reflect the situation of the previous period with the climatic parameters close to the recent ones.

The southern Trans-Urals is a compact range of the developing Sintashta culture of the Middle Bronze Age. In this period, a full-scale economy of the productive type was completely established. This type of economy assumes a settled population living in permanent dwellings and fortified urban centers; developed pastoral herding and early farming first appeared in this region. For the organization of the fields, channels were dug, the old river beds were used for irrigation waters, and flood irrigation (liman system) was applied [13].

We should like to compare some characteristics of the paleosols and their environment in different regions during the Bronze Age that were obtained by other researchers. Close characteristics were obtained in studying the properties of the paleosols in the Arkaim site and the soils buried under the mound created 3900 years ago nearby the settlement of Aleksandrovskii at a distance of 1.5 km from the Arkaim reserve [16]. When studying 20 paleosols under mounds in the Orenburg Cis-Urals region, where archeological findings were dated using the radiocarbon method, it was established that, in the late Yamniy period (4000 years ago), the climate of this region was close to the present-day one; 3700–3800 years ago, the climate in the period of the Srubnaya culture was less continental than that at the present time, probably, due to the cooler summers [24]. The probable cooling in the initial and developed periods of the Srubnaya generality is confirmed by the results of studying the cultural layers of sites and natural sections in northwestern Orenburg oblast [22]. An analysis of the paleosols under the mounds in the Samara–Volga River basin dated by ^{14}C revealed that, in the period of the Potapovo archeological culture (3799–3900 years ago), the temperature was lower and the precipitation increased. As a result, the steppe chernozems were replaced by forest-steppe ones [11, 20].

Some specialists have not revealed sharp changes in the climate for the territory of the desert–steppe zone in the period of 3500–4000 years ago. This conclusion is derived from considering the main soil properties and the results of the biomorphic analysis of the soils under mounds and the specific features of the paleosols and the deposits of the Ergeni balka systems in the territory of Kalmykia [7]. Similar climatic characteristics of this period in the northwestern Caspian region were obtained when investigating some biogeocenoses: permanent shelters of mammals and birds and the vegetation (palynological data) [10, 17]. According to the results of the spore–pollen analysis and the radiocarbon datings of the samples from several pits (5 and 10 m deep) in the Volga-Akhtuba floodplain, continuous paleoclimatic records for 10 years were obtained [3]. Bolikhovskaya first revealed 26 stages of changes in the vegetation and climate of this region in the Holocene; the period of the Bronze Age (4200–3700 years ago), as compared to the present-day one, was characterized as the climatic optimum with warmer and more humid conditions [3].

There are contradictory opinions on the climate at that time in the southern Volga River and lower Don River basins and in the Middle Russian Upland [1, 9, 23]. The existence of contradictory conclusions concerning the paleoclimate during the Middle Bronze Age is explained by many reasons; they need special consideration.

CONCLUSIONS

(1) The comparison of the properties of the recent reference (10 pits) soils and paleosols (7 pits) preserved under the walls of the fortified settlement of Arkaim belonging to the Sinashta archeological culture (southern Transurals) at the turn of the 2nd to 3rd millennia BC has been accomplished.

(2) Based on the results of the palynological and microbiomorphic analyses, the plant cover of the paleosols (0–2 cm) was reconstructed. The pine forests with fern ground cover, the admixture of hygrophytic plants (alder, spruce), the low participation of xerophytes and halophytes in the steppe vegetation, and the significant role of meadow forbs correspond to more humid climatic conditions as compared to the recent ones. The presence of pollen of broad-leaved species (elm, Tatarian maple, and lime tree), typha, and cannabis testifies to the warmer climate at that time than nowadays. The spore–pollen spectrum of the paleosol from the Arkaim site is a transitional one from the steppe to the forest-steppe type.

(3) The duration of the warmer and more humid period was insignificant, and a plant cover more sensitive to climatic changes could develop, whereas the soil properties could not be transformed and correspond to the new environmental conditions. They reflect the situation of the previous period whose climatic parameters were close to the present-day ones.

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