



## Paleosols and climate of the steppe zone in early iron age: Identifying short term warming of climate on slightly- sensors soils

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### Abstract

Studies on paleosols under an archaeological landmark of a rare type (a complex of kurgans with “whiskers”) dating from the Early Iron Age (the fourth century AD) have been performed in the steppe zone of the Transural Plateau. The size and shape of third-order soil polygons under stony ridges (“whiskers”) between the kurgans have been described in detail. The results have shown that the paleosol under the kurgans erected at the turn of the Late Sarmatian and Hun times (1600 years ago) is characterized by a higher humus content and deeper location of the carbonate horizon, compared to the recent soil. This indicates that an increase in atmospheric humidity took place in the fourth century AD..

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### Introduction

In climatic terms, the Early Iron Age (the first millennium BC to the first millennium AD) was characterized by alternation of short humid and arid periods, which had a considerable effect of the direction of soilforming processes. Paleopedological data on the Eastern European steppes are more detailed than those on the Western Siberian and Central Asian steppes. Conceptual regional models of the Holocene history of soil development have been proposed, including those for the Southern Urals and some regions of Siberia and Central Asia (Demkin and Demkina, 2003). In the steppe zone of the Transural Region, paleosols have been studied in a small number of objects dating mainly from the Bronze Age (Ivanov and Chernyanskiy, 1996; Ivanov et al., 2001; Plekhanova, 2004; Plekhanova and Demkin, 2005; Plekhanova et al., 2007). There is a need for a more detailed reconstruction of paleoclimatic changes in the Transural Region during the Early Iron Age, the basis for which is provided by studies on paleosols under kurgans (burial mounds).

The archaeological remains from nomadic cultures are usually limited to burials under kurgans. Their topography and paleoecological situation, including soil–landscape conditions, are of primary importance for elucidating problems such as seasonal migrations, their routes and dates, and social life rhythms of large nomadic communities.

Ecosystems of different landscapes and human societies responded differently to the same changes in climatic conditions, and several types of such nature–society interactions have been distinguished (Ivanov and Lukovskaya, 1998). Moreover, it is known that differences in the composition of rocks and the degree of drainage account for different responses of soils to the same climatic changes (Demkin, 1984; Chernyanskiy,

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1999; Plekhanova, 2004). In well-drained areas, soils evolved into generally the same type (chernozem or chestnut soils), with variations taking place at the subtype level (Demkin, 1997); poorly drained areas, such as low terraces in river valleys, were characterized by repeated alternation of soil salinization and desalinization over the Late Holocene. Evidence for climatic changes is more distinct and better preserved in soils of plain areas, which may be explained, in particular, by differences between the daily amplitudes of temperature in river valleys and on watersheds (Plekhanova, 2004).

The purpose of this study was to analyze the dynamics of soil properties in relation to climate variation at the turn of the Late Sarmatian and Hun times (fourth century AD).

## Material and Methods

### Study region, objects, and methods

The Transural Plateau is in the temperate zone of the Western Siberian Region, which accounts for the continentality of its recent climate: the Ural Mountains weaken the moderating influence of Atlantic air masses, whereas the effect of atmospheric highs (especially the Asian High) is considerable. The sum of daily average temperatures above 10°C ranges from 1500 to 2300°C, precipitation amounts to 250–330 mm over the year and 130–180 mm over the growing season, and the hydrothermal coefficient is 0.8–1.0 (Agroklimaticheskie..., 1977). We studied soils in the Solonchanka IX site comprising five kurgans with stony ridges ("whiskers"), where archaeological excavations were performed by Dr. I.E. Lyubchanskii. This landmark is near the fortified site of Alandskoe at the confluence of the Suunduk and Solonchanka rivers (Kvarkenskii raion, Orenburg oblast). Before describing the soils of kurgans with whiskers, it is necessary to expand on characteristic features of this rare and poorly known type of archaeological landmarks.

Kurgans with whiskers in the Transural Region are complex constructions comprising several (usually five) mounds connected with each other by stone or, in some cases, earth ridges with an average length of 120–140 m (Lyubchanskii, 1998). In the site located near the village of Kondurovka, they extend for more than 200 m. (Figure 1 and 2). Kurgan complexes are hardly noticeable on the day surface, and most of them have been discovered by analyzing aerial photographs (Figure 3). Three of about 60 such landmarks located in Chelyabinsk and Orenburg oblasts (Solonchanka I, Solonchanka IX, and kurgans near Kondurovka) have been excavated. Lyubchanskii (1998) dates them from the fifth to eighth centuries AD and attributes them to Iranian and Turkic peoples of the post-Hun period. However, opinions concerning their dating differ. In general, kurgan complexes of the Bronze and Early Iron Ages in the southern Transural Region are related to the ideology and practice of ancient astronomy.



Figure 1. Complex Kurgan with "whiskers" under Kondurovka. For the production of the picture I had to fly up on a hang glider to a height about 300 m.



Figure 2. Complex Kurgan with "whiskers" under Kondurovka. The view from the surface. The length of the "whiskers" more than 200 m.

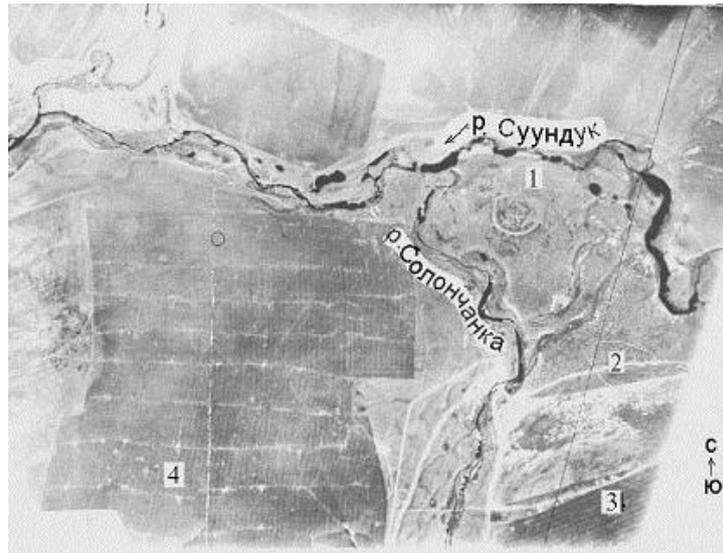


Figure 3. Aerial view of a key area Aland (provided by I.M. Batanina, S.S. Chernyansky): 1 - the first terrace of land near the ancient city walls of Aland; 2 - mound with a "whiskers" Solonchanka I; 3 - burial mound Solonchanka II; 4- barrow in arable land, which includes complex mound with a "whiskers" Solonchanka IX.

Contemporary astronomical knowledge was materialized in the forms that changed with time, depending on the intended use of kurgans and ideology of corresponding rites. The millennial kurgan tradition reflects progressive development of ancient astronomical culture. The results of studies on the kurgans with whiskers show that their design reflects the main events of the annual solar cycle. Therefore, they provided the means for measuring and documenting the passage of time (Figure 4 and 5). Thus, the observer atop the central kurgan could take bearings of sunrise and sunset relative to reference elevations, and these year-round observations could provide the basis for a calendar, with the summer or winter solstice being taken as the starting point (Zdanovich and Kirillov, 2002). Similar conclusions were also made by Beisenov (1996), who studied such kurgan complexes in central Kazakhstan. The Iranian and Turkic peoples who designed them in the fifth to eighth centuries AD probably intended to show that they carry on the tradition of the past. Not only astronomical knowledge but also skills in land survey and layout were necessary for creating these landmarks. Archaeologists consider that this work involved inordinate intellectual and material expenditures (Zdanovich and Kirillov, 2002).

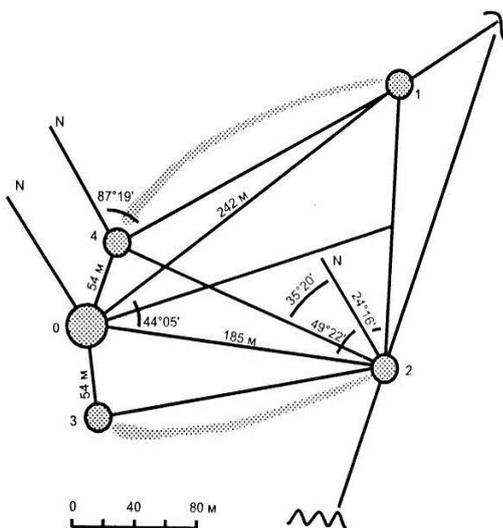


Figure 4. Complex Kurgan with "whiskers" under Kondurovka. Astronomical azimuths and corners of complex objects (Zdanowicz and Kirillov, 2002).

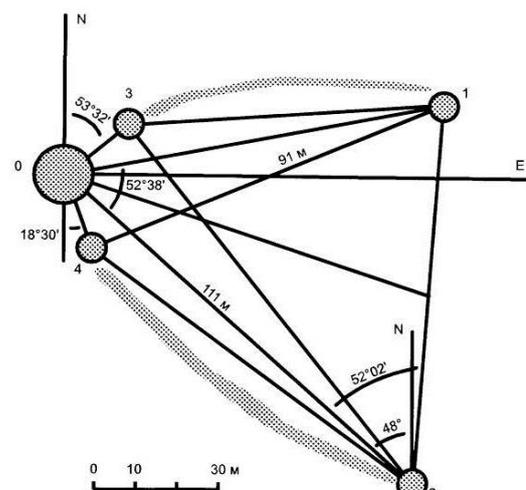


Figure 5. Scheme of complex Kurgan with "whiskers" Solonchanka IX». Astronomical azimuths and corners of complex objects (Zdanowicz and Kirillov, 2002).

The Solonchanka IX complex of kurgans with whiskers rests on a denuded outlier with a Paleozoic rock base that wedges into the second floodplain terrace on the left bank of the Suunduk. It consists of one central kurgan and four smaller kurgans connected pairwise by stone ridges (Figure 6). The kurgans are 15–20 m in diameter and 25–30 cm high. The northern and southern ridges are 86.5 and 103 m long, respectively. The complex dates from the late fourth century AD (the turn of the Late Sarmatian and Hun times); therefore, its age is 1600 years (Lyubchanskii and Tairov, 1999). As a result of Hun invasion, the Sarmatians living in the steppe zone were exterminated or assimilated by other peoples (Abramova et al., 1989; cited from Demkin, 1997), and this archaeological culture as such ceased to exist in the late fourth century AD. Nevertheless, its elements can be found in Eurasian nomadic cultures of the fifth to eighth centuries AD.

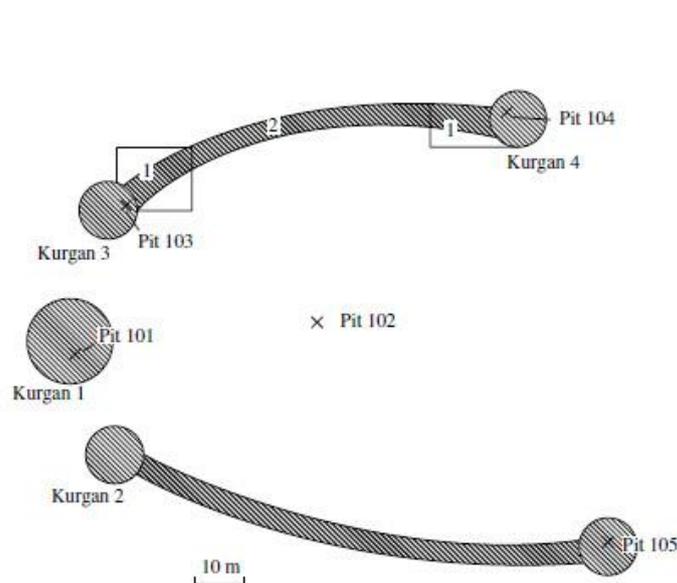


Figure 6. Locations of soil pits in the Solonchanka IX kurgan complex: (102) background soil pit, (103–105) buried soil pits; (1) sites of soil polygon description, (2) stony ridges (“whiskers”).

The Solonchanka IX site lies amid plowed ground but remains undisturbed, being protected by stonework on kurgans and ridges. Its vegetation consists of herbsheep’s fescue-grass associations and plants of ruderal and synanthropic ecological group with a total coverage of 30–40%.

Comparative chronological, comparative geographic, and soil archaeological methods were used. Morphological parameters of soils were described, and their chemical properties were determined by conventional methods (Arinushkina, 1970). The particle-size composition of soils was described according to Kachinskii’s classification in the category “soils of the steppe type” (Myakina and Arinushkina, 1979). Magnetic susceptibility was measured with a KT-5 instrument.

## Results and Discussion

### Morphological and chemical properties of buried and recent soils

The buried soil is characterized by sand–loamy sand interlayering to a depth of 80 cm, with a sand layer lying directly beneath it. The background soil has a similar structure to a depth of 90 cm, where it is underlain by loamy sand. The water table is at a depth of no less than 3–4 m. In the humified material of the mound (kurgan 5), a fragment of heavier texture is present; it was probably excavated from a depth of 1 m of the initial soil. This is evidence for the use of traditional construction technology. The structure of these soils is described as follows (figures in parentheses show the average depth to the bottom of the horizon, cm): background soil, A1 arable (24); AB (30(50)); A/B (40(60)); B (90); BC Ca nodules (120); CD (190) (for two soil pits); buried soil, [A] (15); [AB] (25); [A/B] (30(40)); [B] (70(80)); BC (100); C (110(130)); CCa(150) (for four kurgans). A loamy sandy, thin, tonguing, slightly differentiated, deeply effervescent, ordinary chernozem with residual gley features in the deep horizons was formed on the loamy sandy and sandy (stratified) alluvial deposits. The background and buried soils are basically similar in texture, differing only in proportions of some particle-size fractions. In both cases, the coarse and medium sand fraction is dominant throughout the soil profile (70–80 and 58–88%, respectively), and the proportion of fine sand

fraction reaches 10–13%. The buried soil contains up to 10% of coarse dust in the [B] horizon, compared to 6% in the background soil, and is also richer in the clay fraction: 13–20% vs. 9–14%.

Similarity in texture allows comparison of these soils with respect to other properties. The relatively homogeneous humus horizon of the buried soil is 25–30 cm deep. In the background soil, its depth is approximately 30 cm but increases to 50 cm at the boundaries of third-order polygons. Humus content in the buried soil is close to that in recent soils (about 2%). It is considered that (Demkin, 1997), relative to the initial value, the present-day humus contents in the upper horizon of buried soils in kurgans of the Bronze, Early Iron, and Middle Ages are about 30% [ $k=3.3$ ], 40% [ $k=2.5$ ], and 50% [ $k=2$ ], respectively. According to our reconstruction, humus contents in the upper horizon of buried soils are 3.26–1.58% in kurgan 1 and 3.90–1.80% in kurgan 5, being almost two times higher than in the background soil (where humus loss is additionally increased due to plowing).

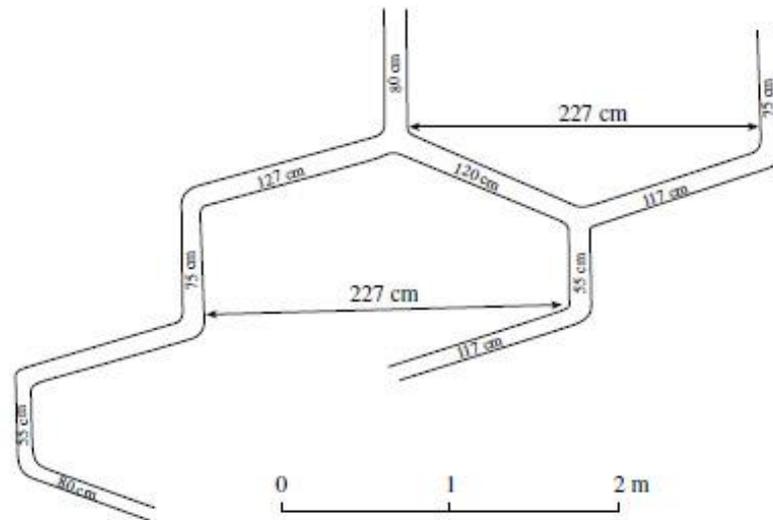


Figure 7. Scheme of location and dimensions of third-order soil polygons in kurgan 3 of the Solonchanka IX kurgan complex

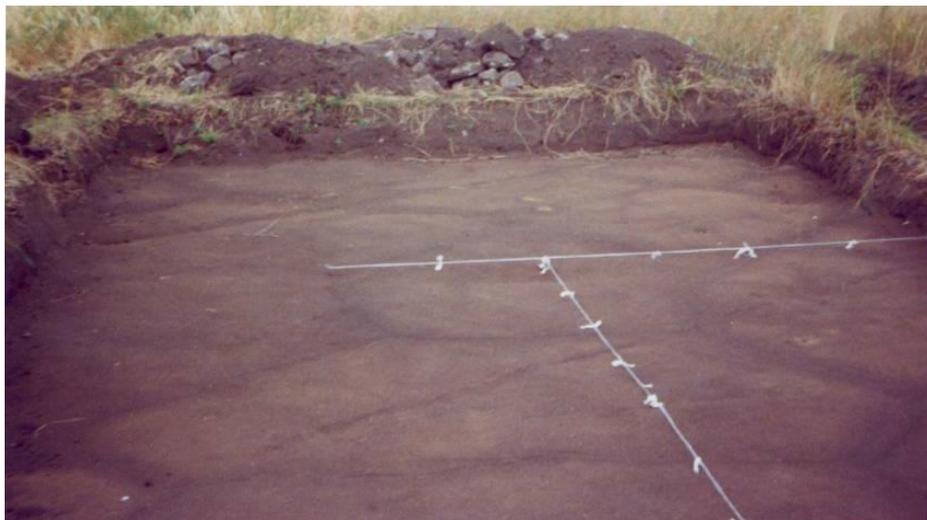


Figure 8. Polygonal of the third order in the soils of the early Iron Age. Kurgan with "whiskers" Solonchanka IX.

Shallow tonguing in the A/B horizon is explained by cryogenic fissuring of the soil upon freezing under certain moisture conditions. The soil is classified as a loamy sandy, thin, low-humus, deeply effervescent ordinary chernozem developed from stratified alluvial deposits. Near kurgans 3 and 4, under the stone ridge, we revealed third-order soil polygons (up to 2–3 m across) with boundaries marked by humified gray bands (about 15 cm wide) against the brownish light gray background of the "archaeological continent" (AB

horizons of recent soil) (Figure 7 and 8). Such polygonal cracking is characteristic of areas with cold, arid, or sharply continental climate. First-order polygons are small (10–30 cm, depending on soil texture), with cracks being no more than 2–5 cm wide and 20 cm deep. Since the humus layer is usually deeper, such polygons are not always visible against its background, since the material in the cracks is the same. Several first-order polygons comprise a second-order polygon (about 1.5 m across) delimited by wider and deeper cracks. Finally, several second-order polygons comprise a third order polygon. The size of the latter reaches 2–3 m, and cracks are 0.5–1.0 m deep. It is difficult to detect them, since excavations in large areas are necessary for this. We found such polygons under the stonework of ridges connecting the kurgans.

Carbonates in the background and buried soils are of hydrogenic origin. They concentrate at considerable depths: more than 80 cm in the background soil and more than 120 cm from the buried soil surface under the central kurgan. In the buried soil, accumulated carbonates form a 2-cm “roof” at depths varying from 110 to 130 cm (in the background soil, 80–120 cm); carbonate patches and nodules occur in the BC horizon at depths of 130–140 cm (in the background soil, 90–110 cm).

Table 1. Weighted average parameters of Early Iron Age soils in kurgan complexes Solonchanka IX (1600 years ago) and Solonchanka I (1500 years ago)

Time section, years ago	Soil	Layer, cm						
		0–50	50–100	100–150	150–200	0–100	0–150	0–200
		CaCO <sub>3</sub> contents, %						
1600	Buried (kurgan 1)	0.0	0.2	4.1	2.5	0.1	1.4	1.7
	Buried (kurgan 5)	0.4	1	–	–	0.7	–	–
	Recent	0.0	0.7	8.6	1.6	0.4	3.1	2.7
1500*	Buried	7.1	6.8	–	–	7.0	–	–
	Recent	6.4	8.2	–	–	7.3	–	–
		Readily soluble salt content (by dry residue), %						
1500*	Buried	0.77	1.08	–	–	0.93	–	–
	Recent	0.53	0.29	–	–	0.41	–	–
		Humus content (with regard to reconstructed values), %						
1600	Buried (kurgan 1)	1.90	0.64	0.17	0.00	1.27	0.90	0.68
	Buried (kurgan 5)	2.64	0.67	–	–	1.66	–	–
	Recent	0.98	0.27	0.05	0.00	0.63	0.43	0.33
1500*	Buried	1.5	0.5	–	–	1.0	–	–
	Recent	2.4	0.7	–	–	1.6	–	–
		Magnetic susceptibility, $n \cdot 10^{-5}$ SI units						
1600	Buried (kurgan 1)	20	16	12	11	18	16	15
	Buried (kurgan 5)	23	6	–	–	15	–	–
	Recent	21	9	9	3	15	13	6
1500*	Buried	102	48	–	–	75	–	–
	Recent	104	77	–	–	90	–	–

\* Weighted average values for Solonchanka I (1500 years ago) were calculated from data obtained by Chernyanskii et al. (1999).

The soil is leached of readily soluble salts, and its magnetic susceptibility varies from 38 to  $3 \cdot 10^{-5}$  SI units. The peaks of magnetic susceptibility in both background and buried soils are observed in humus horizons. An abrupt decrease in this parameter (to  $5 \cdot 10^{-5}$  SI units) is characteristic of the carbonate “roof,” with the carbonate-free horizon above and the calcareous horizon below it having magnetic susceptibility of about  $18 \cdot 10^{-5}$  SI units. Loamy sand soils generally have a low sensor capacity: traces of slight fluctuations in soil-forming conditions usually disappear within a short period of time, since this soil recovers quasi-equilibrium with the environment more rapidly than do its heavier analogs.

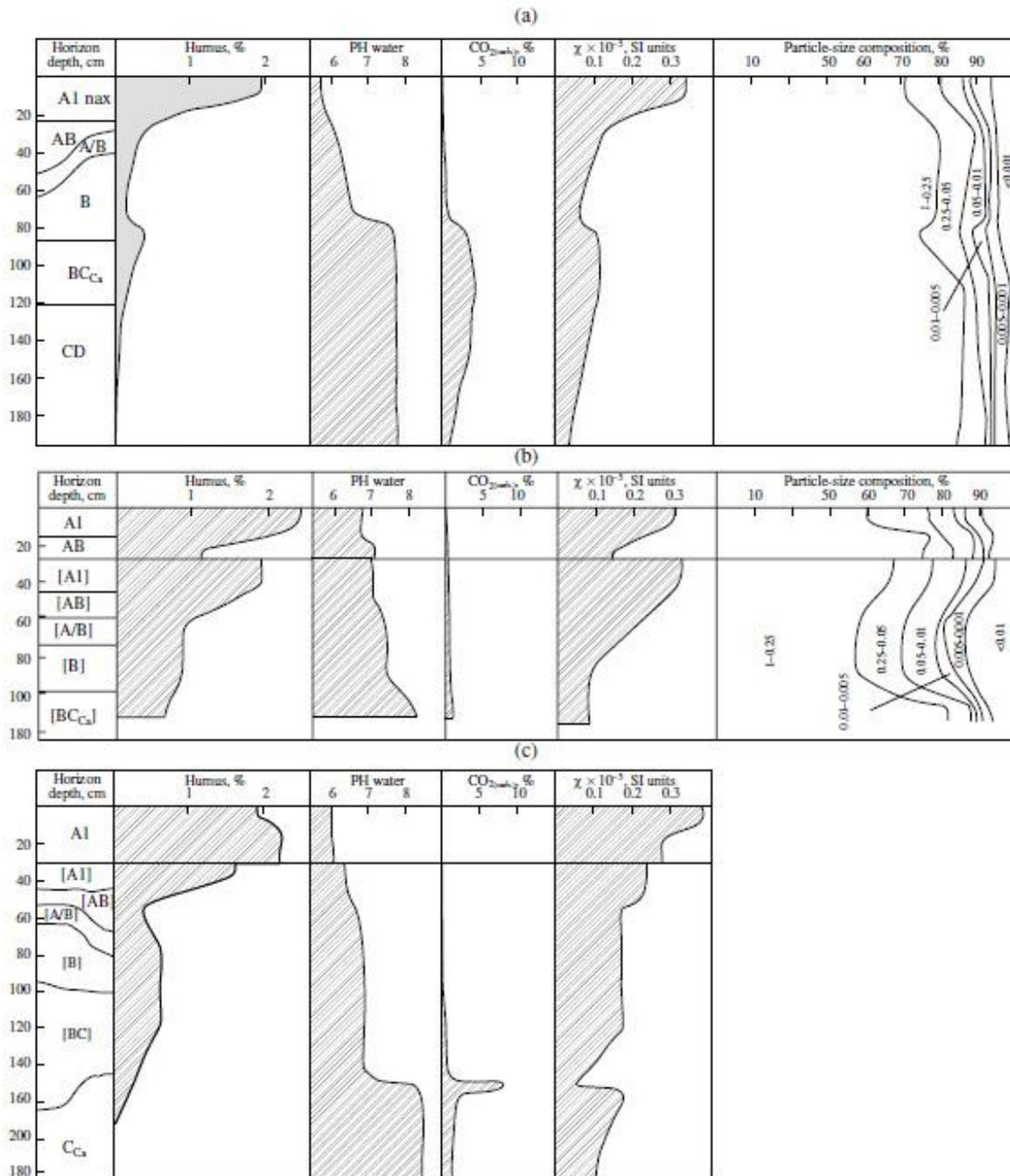


Figure 9. Physicochemical properties of soils in the Solonchanka IX kurgan complex: (a) background soil, pit Al-102-99; (b, c) soil dating from the turn of the Late Sarmatian and Hun times: (b) kurgan 5, pit Al-105-99; (c) kurgan 1, pit Al-101-99.

Studies in the Solonchanka IX site allow us to compare ancient and recent soils from an unusual aspect: the former are well preserved, have a higher humus content, and show no significant signs of disturbance, whereas the latter are plowed and deflated. However, the soil buried under the kurgans provides evidence that a humid episode took place in the fourth century AD: the recent soil contains less humus and has a wellformed, deep carbonate-accumulative horizon, with its roof lying closer to the surface (at a depth of 80–90 cm, compared to 120–140 cm in the buried soil). Conclusive evidence for a humid episode in the late third and early fourth centuries AD was also obtained in the desert–steppe zone of the Volga–Don interfluvium (Demkin et al., 1998; Borisov, 2002).

Pairwise comparisons of buried soils and their background analogs are usually made with respect to the weighed average values of parameters such as the contents of humus, carbonates, and readily soluble salts and the values of magnetic susceptibility (Table 1).

The contents of carbonates in the upper 50-cm soil layer correlates with climatic fluctuations (Borisov, 2002). In the soil dating from the turn of the Late Sarmatian and Hun time sand its recent analog, this layer contains no carbonates; their respective contents in the next layer (50–100 cm) are 0.2% and 0.7%; in the third layer (100–150 cm), 4.1% and 8.6%; in the 0–100 cm layer, 0.1% and 0.4%; and in the 0–150 cm layer, 1.4 and 3.1%. These values provide evidence for a humid climate at the time of kurgan building and for progressive carbonate accumulation in the recent soil. In 1994, paleopedological studies of a similar kurgan complex were performed in the Solonchanka I site (Chernyanskii, 1999) dating from the fifth to the early sixth centuries AD (Lyubchanskii and Tairov, 1999).

This site is at the level of the first floodplain terrace, and its soils are of heavy loam texture, which does not allow their direct comparison with soils of Solonchanka IX, although these sites are close to each other. However, the calculation of weighted average parameters provides means to compare objects pertaining to different landscape elements. We made such calculations for the 1500-year time series (chronosection) of Solonchanka I soils using the data obtained by Chernyanskii et al. (1999) (Table 1) and plotted the ratios of weighted average contents of certain components in different soil layers, taking the corresponding parameters of the background soil as 100%.

The buried soil of this site is a heavy loamy, medium deep, low-humus, calcareous, solonetzic-solonchakous, medium saline meadow chernozem (Chernyanskii et al., 1999). The ridges between the kurgans are no more than 10–20 cm high, but their width (together with crumbled fragments) reaches 4 m. Chernyanskii et al. (1999) consider that the buried soil (under the 66-cm kurgan mound consisting of stone blocks and boulders) -effervescent at the surface, with disperse carbonates, soda salinization, and a hydromorphic-solonchakous distribution of readily soluble salts has not undergone any diagenetic changes.

In the past 4000 years, heavy loam and clay soils of the first floodplain terraces have shifted from the meadow chernozem to the solonetz developmental pathway and have acquired a more complex structure of the soil profile, with qualitatively new morphological features and horizons (Chernyanskii, 1999).

As follows from data on humus content and magnetic susceptibility, the humid episode at the turn of the Sarmatian and Hun times was relatively short, as evidence for climate aridization appeared in low-terrace soils only 100 years later.

## Conclusion

The calculation of relative parameters (weighed average contents of humus, carbonates, and readily soluble salts and magnetic susceptibility relative to their background values taken as 100%) makes it possible to compare the properties of soils comprising different chronosections, either pertaining to different topographic elements or separated spatially. Let us consider several factors noted by Ivanov and Lukovskaya (1998) as crucial for soil development in different relief elements. Relatively well-drained clay-loam landscapes show a moderate response to increasing atmospheric humidity, as 50% of precipitation flows away with surface and subsurface runoff. In contrast, this response in poorly drained, stagnant landscapes leads to a rapid rise of the water table, increasing hydromorphism, and higher biological productivity.

Soil processes in clayey loam soils develop less rapidly in loamy sand soils, and they require more time for achieving quasi-equilibrium with the environment. Points in soil catenas may form complementary chorogenetic series, with the points located at higher levels having probably passed through the stages of development at which the underlying points currently are. However, the greater the difference in elevation between relief elements, the lesser the probability that the development of corresponding soils followed the same course. The soil of each relief element may develop through its specific series of stages, which is not reproduced in other elements (Ivanov and Lukovskaya, 1998).

Loamy sand and sandy soils arrive at quasi-equilibrium more rapidly. When atmospheric humidity becomes higher, they respond by a rapid increase in biological production due to active plant growth. The response of these soils to aridization is manifested in their deflation, which becomes especially severe under additional grazing load (Ivanov and Lukovskaya, 1998). The soil buried under the kurgans dating from the turn of the Late Sarmatian and Hun times (the late fourth century AD) reflects a humid episode in climate development: it is relatively rich in humus, leached of carbonates, and has higher values of magnetic susceptibility than the recent soil. A similar episode dated to the late third to fourth centuries AD left its traces in soils of the

Transvolga semideserts (Demkin et al., 2004) and the desert-steppe zone of the Volga-Don interfluvium (Demkin et al., 1998; Borisov, 2002). The turn of epochs in the Azov steppe was also marked by considerable climatic changes (Pesochina, 2004). Arid conditions of soil formation characteristic of the fourth to second centuries AD became more humid in the second to fourth centuries AD, with the magnitude of evolutionary changes not exceeding the generic taxonomic level.

These data confirm the concept that the process of chernozem soil formation, with a constant set of genetic horizons, has prevailed for 4000 years in the light-textured soils of well-drained Transural steppe landscapes (Chernyanskii et al., 1999). For landscapes with less effective drainage, Ivanov and Lukovskaya (1998) distinguish the epoch of early and middle Subatlantic microarid and micropluvial periods of the Sarmatian time (SA1 and the first half of SA2, from the fourth century BC to the fourth to fifth centuries AD). According to Klimentenko (2000, cited in Tairov, 2003), the turn of the third and second centuries BC and the fourth century AD were characterized by the highest temperatures over the period from the mid-first century BC to the mid-seventh century AD.

Our paleopedological data are consistent with existing concepts, specifying them for the Transural steppes. They confirm that arid climatic conditions in this region became more humid during the Early Iron Age, which is reflected in different parameters of paleosols, including the distribution of humus, salts, carbonates, and gypsum over the soil profile.

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### References

- Agroklimaticheskie resursy Chelyabinskoi oblasti (Agroclimatic Resources of Chelyabinsk Oblast), Leningrad: Gidrometeoizdat, 1977.
- Arinushkina, E.V., 1970. Rukovodstvo po khimicheskomu analizu pochv (Handbook of Chemical Soil Analysis), Moscow: Mosk. Gos. Univ.
- Borisov, A.V., 2002. Development of Soils in the Desert-Steppe Zone of the Volga-Don Interfluvium over the Past 5000 Years, Cand. Sci. (Biol.) Dissertation, Moscow: Mosk. Gos. Univ.
- Chernyanskii, S.S., 1999. The History of Soil Development in the Chernozem Zone of the Transural Region in the Second Half of the Holocene, Cand. Sci. (Geogr.) Dissertation, Moscow: Mosk. Gos. Univ.
- Chernyanskii, S.S., Ivanov, I.V., Demkin, V.A., Tairov, A.D., 1999. Chernozem and Solonetz Soils of the Transural Region in the Second Half of the Holocene: Results of Soil- Archaeological Studies, in Kurgan s "usami" Solonchanka- I (The Solonchanka-I Kurgan with "Whiskers"), Tr. Muz.-Zap. "Arkaim," Chelyabinsk, pp. 98-138.
- Demkin, V.A., 1984. The Holocene Developmental History of Soils in the Desert-Steppe Zone of the European Soviet Union, Istoriya razvitiya pochv SSSR v golotsene (The Holocene Developmental History of Soils in the Soviet Union), Pushchino, pp. 130-131.
- Demkin, V.A., 1083. Soils of Dry and Desert Steppes of Eastern Europe in the Ancient and Middle Ages, Extended Abstract of Doctoral (Biol.) Dissertation, Moscow: Moscow State Univ.
- Demkin, V.A., 1997. Paleopochvovedenie i arkhologiya (Paleosol Science and Archaeology), Pushchino: PNTs RAN.
- Demkin, V.A., Demkina, T.S., 2003. Archaeological Soil Science at the Turn of the Third Millennium, Problemy evolyutsii pochv: Mat-ly IV vsers. konf. (Proc. IV Akll-Russia Conf. "Problems in Soil Evolution"), Pushchino, pp. 29-34.
- Demkin, V.A., Dergacheva, M.I., Borisov, A.V., 1998. Soil Evolution and Climate Change in the Semidesert Zone of Eastern Europe during the Late Holocene. Pochvovedenie 2: 148-157.
- Demkin, V.A., Demkina, T.S., Borisov, A.V., 2004. Transformation of Soils and Environmental Conditions in the Semidesert Low Volga Region within the Past 4000 Years, Pochvovedenie 3: 271-283.
- Ivanov, I.V., Chernyanskii, S.S., 1996. General Regularities in the Development of Chernozems in Eurasia and Evolution of Chernozems in the Trans-Uralian Region, Pochvovedenie, 9: 1045-1055.
- Ivanov, I.V., Lukovskaya, T.S., 1998. Dynamics of Natural Soil-Forming Conditions and Nature-Society Interactions in Eurasian Steppes: Some Problems in Holocene Paleogeography, in Ekologiya i pochvy: Izbrannye lektsii I-VII Vserossiiskikh shkol (Ecology and Soils: Selected Lectures at All-Russia Workshops I-VII), Dobrovolskii, G.V., Ed., Pushchino, vol. 1, pp. 283-302.
- Ivanov, I.V., Plekhanova, L.N., Chichagova, O.A., 2001. Paleosols of the Arkaim Valley and Samara River Basin as Indicators of Ecological Conditions in the Bronze Age, Bronzovyi vek Vostochnoi Evropy: kharakteristika kul'tur, khronologiya i periodizatsiya: Mat-ly mezhdunar. nauch.konf. (Proc. Int. Sci. Conf. "The Bronze Age in Eastern Europe: Characteristics of Cultures, Chronology, and Periodization"), Samara, pp. 375-384.
- Lyubchanskii, I.E., 1998. Chronological Aspects of "Whiskered" Kurgan Complexes in the Eurasian Steppes, in Kul'tury evraziiskikh stepei vtoroi poloviny I tisyacheletiya n.e.: Voprosy khronologii (Eurasian Steppe Cultures in the Second Half of the 1st Millennium AD: Problems of Chronology), Samara, pp. 303-310.

- Lyubchanskii, I.E., Tairov, A.D., 1999. Archaeological Studies on the Solonchanka-I "Whiskered" Kurgan Complex, in Kurgan s "usami" Solonchanka-I (The Solonchanka-I Kurgan with "Whiskers"), Tr. Muz.-Zap. "Arkaim," Chelyabinsk, pp. 5–62.
- Myakina, N.B., Arinushkina, E.V., 1979. Metodicheskoe posobie dlya chteniya rezul'tatov khimicheskikh analizov pochv (Methodological Guidelines for Reading the Results of Chemical Soil Analysis), Moscow: Mosk. Gos. Univ.
- Pesochina, L.S., 2004. Development of Soils and Natural Environment in the Lower Don Region in the Second Half of the Holocene, Extended Abstract of Cand. Sci. (Biol.) Dissertation, Moscow: Moscow State Univ.
- Plekhanova, L.N., 2004. Natural and Anthropogenic Evolution of River Valley Soils in Steppes of the Transural Region in the Second Half of the Holocene, Extended Abstract of Cand. Sci. (Biol.) Dissertation, Moscow: Moscow State Univ.
- Plekhanova, L.N., Demkin, V.A., 2005. Ancient Soil Disturbances in River Valleys within the Steppe Zone of the Southeastern Urals, Pochvovedenie 9: 1102–1111.
- Plekhanova, L.N., Demkin, V.A., Zdanovich, G.B., 2007. Evolyutsiya pochv rechnykh dolin stepnogo Zaural'ya vo vtoroi polovine golotsena (Evolution of River Valley Soils in Steppes of the Transural Region in the Second Half of the Holocene), Moscow: Nauka.
- Tairov, A.D., 2003. Izmeneniya klimata stepei i lesostepei Tsentral'noi Evrazii vo II–I tys. do n.e. Materialy k istoricheskim rekonstruktsiyam (Climate Changes in Steppes and Forest-Steppes of Central Eurasia in the Second and First Millennia BC: Materials for Historical Reconstructions), Chelyabinsk.
- Zdanovich, D.G. Kirillov, A.K., 2002. Kurgannye pamyatniki Yuzhnogo Zaural'ya: arkheoastronomicheskie aspekty issledovaniya (Kurgans in the Southern Transural Region: Archaeoastronomic Aspects), Chelyabinsk: Krokus.