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GENESIS AND GEOGRAPHY OF SOILS

Soils and Cultural Layers of Ancient Cities in the South of European Russia

A. L. Aleksandrovskii, E. I. Aleksandrovskaya, A. V. Dolgikh, I. V. Zamotaev, and A. N. Kurbatova

Institute of Geography, Russian Academy of Sciences, per. Staromonetnyi 29, Moscow, 119017 Russia

e-mail: alexandrovskiy@mail.ru, dolgikh@igras.ru

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Abstract—Antique cities in the south of European Russia are characterized by a considerable thickness of their cultural layers (urbosediments) accumulated as construction debris and household wastes. Under the impact of pedogenesis and weathering in dry climate of the steppe zone, these sediments have acquired the features of loesslike low-humus calcareous and alkaline deposits. They are also enriched in many elements (P, Zn, Ca, Cu, Pb, As) related to the diverse anthropogenic activities. The soils developed from such urbosediments can be classified as urbanozems (Urban Technosols), whereas chernozems close to their zonal analogues have developed in the surface layer of sediments covering long-abandoned ancient cities. Similar characteristics have been found for the soils of the medieval and more recent cities in the studied region. Maximum concentrations of the pollutants are locally found in the antique and medieval urbosediments enriched in dyes, handicrafts from nonferrous metals, and other artifacts. Surface soils of ancient cities inherit the properties and composition of the cultural layer. Even in chernozems that developed under steppe vegetation on the surface of the abandoned antique cities of Phanagoria and Tanais for about 1000—1500 years, the concentrations of copper, zinc, and calcium carbonates remain high. Extremely high phosphorus concentrations in these soils should be noted. This is related to the stability of calcium phosphates from animal bones that are abundant in the cultural layer acting as parent material for surface soils.

Keywords: urbosediments, urban soils, urbanozems, soils of extreme anthropogenic sites, buried soils, pedolithogenesis

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INTRODUCTION

Soils of cities (urban soils) remain insufficiently studied. Up to the 1990s, these soils did not attract attention of researchers, and the number of publications devoted to them was relatively small. Most of the studied objects were found in parks and in the peripheral zones of cities, where slightly transformed natural zonal soils predominate. At the same time, the study of urban soils has a long history. In 1889, Dokuchaev developed a program of comprehensive studies of urban soils and environment in Saint Petersburg [11]. Unfortunately, this program was not fully realized [33]. In a century, large-scale studies of urban soils developed from thick anthropogenic deposits (cultural layers) were initiated in Moscow and other cities of Russia [9, 23, 29, 30]. These studies demonstrated a specific character of urban pedogenesis and its difference from pedogenesis beyond the cities in different parts of the world [37–41]. In recent years, detailed studies of the organic matter in urban soils have been performed, and its pools have been assessed [10, 26]. Special works have been devoted to classification of urban soils [24, 25] and their mapping [7, 32].

Soils and cultural layers of ancient cities are the examples of soil systems strongly transformed by the anthropogenic activity. It is of great interest to study the entire thickness of urban deposits together with the soils buried under them [2]. Such studies have shown significant differences between urban soils and urban sediments (urbosediments, habitation deposits, cultural layers) developed in different landscape zones [5, 13]. Urban soils and cultural layers of the cities differ from the initial soils developed from natural parent materials in a greater thickness and much more significant anthropogenic transformation. In archaeology, a cultural layer is subdivided into archaeological objects (artifacts) and the medium (filling substrate), in which these artifacts are found [20]. For natural sciences, the cultural layer of cities and other settlements can be defined as a complex natural–anthropogenic formation developing under the impact of both pedogenetic and sedimentation processes [12, 31].

Thick anthropogenic deposits of ancient cities usually include allochthonous materials differing in their composition from the natural parent materials characteristic of a given place. These deposits are formed under the impact of a set of processes of the anthropogenic sedimentation combined with pedogenetic pro-

Fig. 1. Location of studied objects.

cesses. The latter may differ from the pedogenetic processes that have shaped the initial (background) soils. As sedimentation processes are relatively fast, pedogenesis proper can only slightly transform the material of the cultural layer; later, it becomes buried at a considerable depth, where it is subjected to the action of deep-soil and diagenetic processes differing from those in the upper part of the cultural layer. Soil–lithogenic formations of urban areas—cultural layers, pedolithosediments, or urbosediments—can be attributed to the anthropogenic modification of soil sedimentation systems developing upon gradual accumulation of fine earth on the soil surface without interruption of the synchronously acting pedogenesis [12]. Thus, the layer of urbosediments is formed under combined impact of sedimentation and pedogenetic processes.

Deep cultural layers of the cities differ not only from the natural deposits and soils characteristic of a given place but also from one another. Under conditions of dry climate of the steppe zone, predominantly *mineral*, often loesslike cultural layers are formed; they are composed of construction debris of bricks and lime, as well as of turluk, saman, and adobe.[1] In contrast to the cities of the forest zone, peatlike *organic* layers composed of the debris of wood and other organic substances are absent in the cultural layers of the cities in the steppe zone [36].

The cultural layer mainly consists of construction debris of organic and mineral natures. It also includes diverse domestic wastes (manure, foodstuffs, woody remains, bones, pottery fragments, etc.), production wastes (ashes, slag, remains of tools, metal casts from firepots, etc.), the remains of hearths and furnaces with the zones enriched in calcined earth;, ash layers, charcoal layers, layers of the underlying parent material excavated onto the ancient surface of the cultural layer from deep pits, alluvial sediments, and soils.

Urban soils and urbosediments have their own history. Up to six stages of the evolution of cultural layers can be distinguished: from the preceding (pre-anthropogenic) stage to the stage of post-anthropogenic transformation (metamorphism) [31]. The major stages are the stages of the accumulation of urbosediments in functioning cities and their transformation under the impact of pedogenesis and diagenesis. In the cities with a long history, these two stages are often combined together.

Cultural layers in the southern cities of Russia differ from those in the northern cities in the character and intensity of geochemical processes, including their capacity to accumulate and store diverse chemical substances. The soils developing from these cultural layers are also different. It is important that urban soils and urbosediments with their specific composition are the zones of active transformation of the matter. The rates of this transformation can be estimated from data on the archaeological ages of the particular layers.

The aim of our study is to characterize the morphology, properties, and evolution of urban soils and thick layers of urbosediments in ancient cities in the south of European Russia and to assess the role of the environment and anthropogenic activities in their development.

OBJECTS AND METHODS

The cities with studied sites differ in their age, geographic location (Fig. 1), and the character of modern pedogenesis.

Phanagoria is found on the Taman Peninsula, on the shore of the Taman Bay to the west of the settlement of Sennoi. Two sea terraces elevated at 5–10 and 20–25 m above sea level are clearly distinguished in this area. Terrace deposits are covered by a thick cultural layer. The cultural layer on the upper terrace is underlain by the Cimmerian (Tertiary) marine sedi-

[1] Turluk is a fence construction made of wattle mixed with clay; saman is a construction material made of clay with straw; and adobe is a sun-dried unburned brick. These terms are often used in archaeology and geoarchaeology.

ments composed of sands with clayey interlayers. Chernozems with migrational and segregational forms of carbonate concentrations (Haplic Chernozems (Pachic)) [21] predominate in the soil cover of the Taman Peninsula. They are characterized by the deep humus horizon with relatively low humus content. Loamy sandy soils on the terrace surface around Phanagoria are gray-humus soddy soils (Eutric Arenosols). We studied the "Upper City" (Verkhnii Gorod) archaeological excavation. The cultural layer in this place is up to 5.5 m in thickness; its archaeological dates are from the 6th century BC to the 9th century AD, i.e., the anthropogenic sedimentation at this site lasted for about 1500 years.

The accumulation of urbosediments in the antique city of Hermonassa also began in the 6th century BC. However, in contrast to Phanagoria, this city under different names (Tamatarkha, Tmutarakan, Matrega, and Taman) has been functioning almost continuously up to the present time. The background soils around this city are also Haplic Chernozems; the same soils are found under the cultural layer. The modern soils of the city are urbanozems (Urbic Technosols).

The cultural layer of the city of Tanais on the high strath terrace of the Don River was formed in the period from the 3rd century BC to the 5th century AD. The soils buried under it, as well as modern background soils, are chernozems with migrational and segregational forms of carbonate concentrations (Haplic Chernozems). The thickness of urbosediments together with the surface soil is relatively small (2.0–2.5 m). These sediments are silt loams with a considerable content of gravels and stones.

The city of Lgov is found on the Central Russian Upland, at the boundary between the zones of dark gray forest soils (Greyzemic Phaeozems) and chernozems (Haplic Chernozems). In the center of this city (on the right bank of the Seim River) that appeared in the 17th–18th centuries AD, the initial Haplic Chernozems developed from loesslike sediments and dark-humus carbolithozems (Rendzic Leptosols) developed from the colluvium of marl bedrock are covered by a 1.5-m-deep cultural layer with an urban soil (Urbic Technosol) shaped in its surface horizons.

The climatic characteristics of the studied cities are somewhat different. In the semiarid steppe zone (Phanagoria, Hermonassa–Taman, and Tanais), mean annual temperatures are about +9–11°C, mean annual precipitation reaches 350–450 mm, and the humidity factor (the precipitation-to-potential evaporation ratio) is 0.4–0.6. In the forest-steppe zone (Lgov), the mean annual temperature is lower (+4.6°C), the precipitation is higher (550 mm/yr.), and the humidity factor is 1.05. Natural vegetation communities are represented by herbaceous steppes and broadleaved forests.

Soil analyses were performed in the Analytical Laboratory of the Institute of Geography of the Russian Academy of Sciences in Moscow and included the determination of the pH of soil water suspension (potentiometric method), the organic carbon content (Tyurin's method of wet combustion), the content of carbonates (by the method of Kozlovskii), and the particle-size distribution (pipette method with pyrophosphate pretreatment). The bulk elemental composition of the samples was determined by the X-ray fluorescent method in the laboratories of the Dokuchaev Soil Science Institute; the Institute of Geology of Ore Deposits, Petrography, Mineralogy, and Geochemistry of the Russian Academy of Sciences (IGEM RAS); and Belgorod National Research University.

RESULTS AND DISCUSSION

The thickness of urbosediments (cultural layers) together with the upper soil layer developed from them in the studied ancient cities varies from 1.5 to 10 m on leveled surfaces and may be considerably larger in the depressions of the relief.

Phanagoria. Urbosediments were examined in the central part of this city, in its acropolis (the Upper City excavation) with an area of more than 1000 m^2. Their thickness reaches 5.5 m. After the city was abandoned in the 9th century AD, a well-developed chernozemic soil was formed in the surface part of the cultural layer. The soil buried under the cultural layer in the 6th century BC is a loamy sandy gray-humus soil with ferruginous lamellae (Lamellic Arenosol). It differs from the surface gray-humus soils of the background territory. The profile of the buried soil consists of the gray-humus (AY) horizon and the illuvial pseudofibrous (lamellic) Bff horizon. The transition from the buried loamy sandy soil to the urbosediments composed of the light brown sandy loam with mottles and interlayers of light gray, yellowish, and dark gray materials (Fig. 2) is marked by a sharp change in the texture of the sediments. Urbosediments accumulated under the impact of anthropogenic activity differ from the natural sandy substrates; urbosediments are mainly derived from the debris of sun-dried bricks made of marine clay with some admixture of clay.

The soil buried under the cultural layer has been subjected to the strong alkalization; the pH of water suspension from this soil is up to 9.7. As this soil does not contain carbonates, such a high pH can be explained by the input of some other salts with an alkaline reaction. The alkalinity of the cultural layer is even higher (pH_{H_2O} 10.2).

The thickness of urbosediments contains numerous traces of former fires in the form of charcoal and ash-rich interlayers. In one of these interlayers, the remains of the palace of Mithridates Eupator burned down in 63 BC were found. Antique pottery, animal bones, and fragments of plaster (in some cases, with traces of paints) are also present in the urbosediments.

Hermonassa–Taman. The thickness of urbosediments accumulated in this city in the past 2600 years is

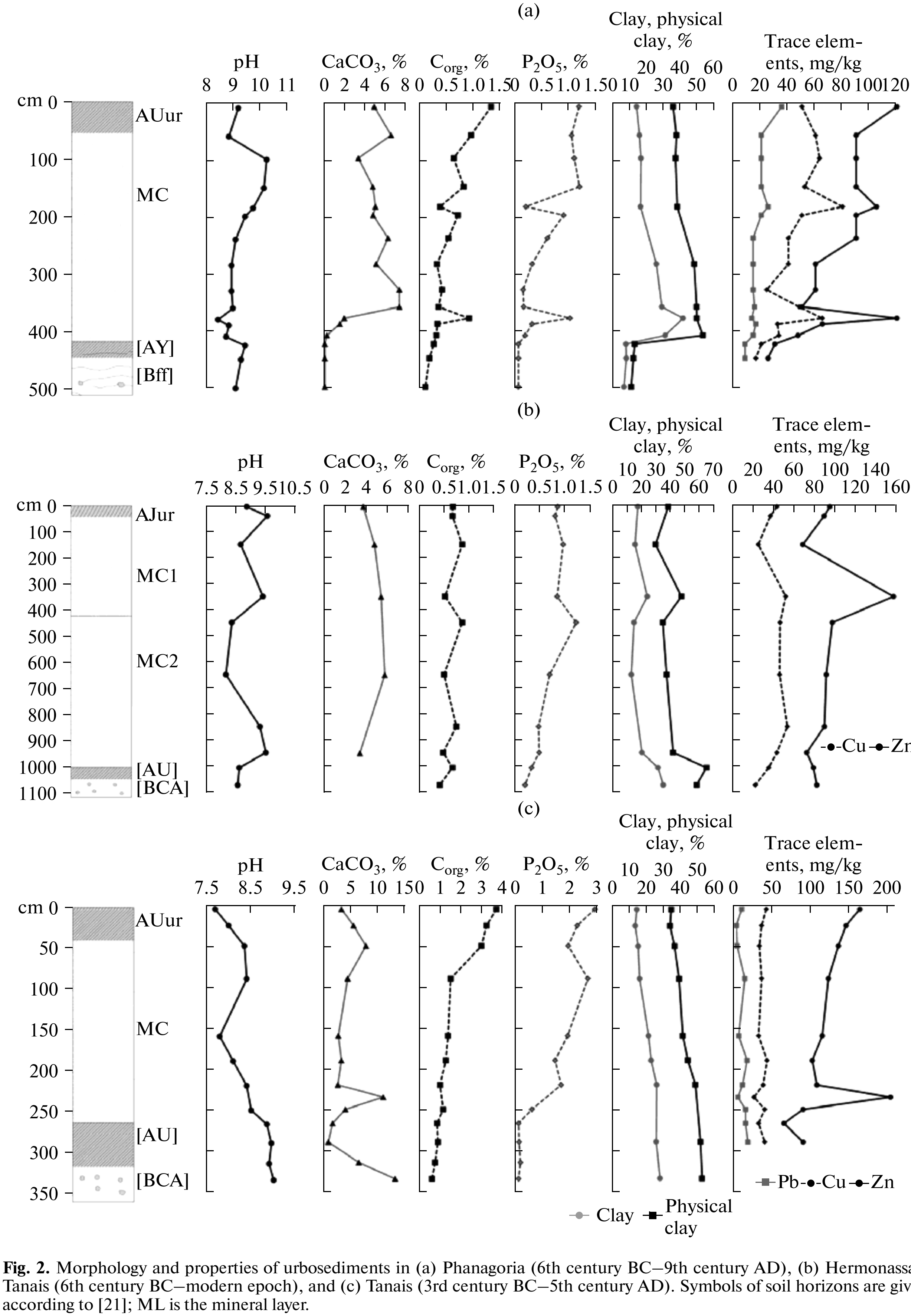

Fig. 2. Morphology and properties of urbosediments in (a) Phanagoria (6th century BC–9th century AD), (b) Hermonassa–Tanais (6th century BC–modern epoch), and (c) Tanais (3rd century BC–5th century AD). Symbols of soil horizons are given according to [21]; ML is the mineral layer.

up to 10 m (Fig. 2), including 6 m of the deposits dating back to the antique time and 4 m of the deposits that have been accumulated since the medieval epoch (since the 5th century AD). The cultural layer of Hermonassa is underlain by the chernozem developed from loess. This buried soil is generally similar to the background chernozems of the Taman Peninsula with the migrational and segregational forms of carbonate concentrations. An urbanozem has developed in the upper part of the cultural layer.

The morphology and properties of urbosediments studied in Hermonassa and Phanagoria proved to be very similar. Moreover, in urbosediments of Hermonassa, their nature remains the same in the entire 10-m-deep thickness accumulated in the past 2600 years, including the antique period and the recent period. These urbosediments are characterized by the increased concentrations of phosphorus and carbonates, the high alkalinity, and the low content of C_{org}.

The development of soils and urbosediments in these ancient cities was specified by the continuous accumulation of construction debris and other wastes, anthropogenic turbation of the material, arid climate, and the predominance of steppe vegetation. Under conditions of the dry climate of the Taman Peninsula coupled with good drainage and aeration of the cultural layer, the transformation of organic and mineral substances was very intense. The great thickness and considerable age of urbosediments in Phanagoria and Hermonassa make it possible to estimate the rates and characteristic depths of these processes.

The average rate of the accumulation of urbosediments is about 40 cm/100 years. It is probable that we have somewhat underestimated this value, because the layers of urbosediments were sometimes cut off in order to level the surface for further construction works. Under such rates of the accumulation of new sediments, they are only slightly transformed by pedogenesis. It is important that the accumulation of urbosediments proceeded unevenly; there were periods with very low rates of sedimentation. However, they were not long. As a rule, long periods of the relative stability of the surface without accumulation of the new portions of sediments are marked in the profile by the presence of distinct buried soil layers. No such soils have been described in the studied cultural layers of Hermonassa and Phanagoria.

At the surface of the cultural layer of Phanagoria dating back to the 9th century AD, a well-developed soil is found. It is diagnosed as a chernozem with a deep humus horizon and differs considerably from the loamy sandy Lamellic Arenosol buried under the cultural layer. This difference is definitely explained by the predominantly silt loamy texture of the cultural layer that served as the parent material for the chernozem. This chernozem also differs from background chernozems of the Taman Peninsula by the higher contents of humus and major nutrients (especially, phosphorus). Owing to this, the profile of this chernozem is even deeper than that of the background chernozems of the Taman Peninsula; the tunnels of burrowing animals (mole-rats) and carbonate concentrations (“white eyes”) are not clearly manifested in the chernozem developed from the urbosediments.

The loamy sandy soil buried under the cultural layer of Phanagoria has a well-shaped horizon with ferruginous lamellae (pseudofibers), which allows us to suppose that this soil had been under forest vegetation for a relatively long time before it was buried [5]. The analysis of charcoal particles indicated that broadleaved forests with a predominance of oak trees existed in this area [4].

Tanais. A characteristic feature of the urbosediments of this antique city is their low thickness (2.0–2.5 m) and an increased stoniness (as compared with the urbosediments of Phanagoria and Hermonassa). This is explained by a relatively short period of life of this city and by the presence of stone constructions. The stones for buildings were taken from the adjacent territory, where the outcrops of hard bedrock are widespread. The stones were repeatedly used for new buildings. The practice of construction from unburned bricks was not so widespread as in Phanagoria and Hermonassa. Therefore, the accumulation of fine earth in the cultural layer was weaker.

The soils and cultural layers of Tanais and Phanagoria are characterized by the high concentrations of phosphorus and carbonates. The carbonates (3–8%) are more or less evenly distributed in the cultural layer, whereas in the chernozems buried under it and in the background surface chernozems, carbonates are clearly differentiated in the profile with a distinct horizon of the carbonate accumulation (up to 15% of $CaCO_3$ in the BCA horizon). The content of organic matter in the soil and urbosediments of Tanais is much higher than that in the soils and urbosediments of Phanagoria and Hermonassa (Fig. 2). The content of carbonates in the urbosediments of Tanais is somewhat lower, and the reaction is less alkaline than that in the urbosediments of Phanagoria and Hermonassa. These features can be related to a higher humidity of the climate in the Lower Don reaches in comparison with the Taman Peninsula.

Lgov. The urbosediments of this city represent a system of layers with inclusions of rock fragments (including fragments of marl) and fragments of soil horizons. The remains of wood, stone pavements, brick-made bases of destroyed houses, and other artifacts are abundant in the urbosediments of Lgov. These materials serve as the substrate for relatively thin urbanozems developed at the surface. Though Lgov is much younger than Phanagoria, Hermonassa, and Tanais, the properties of its urbosediments and soils are generally similar to those described above. With respect to the contents of carbonates and phosphorus, they do not differ much from the urbosediments of the

Table 1. Major properties of urbosediments and pedogeochemical conditions of ancient cities

City (excavation)	Stratigraphic horizon; depth and type of the layer; chronology*	Texture**	pH_{H_2O}	C_{org}, %	Zc***	$CaCO_3$, %	P_2O_5, %
Phanagoria (Upper Town)	Modern soil (Ch), 0–100 cm, 9th–20th centuries AD	SL	8.8–10.2	1–3	3.1–4.8	1.0–6.4	1.0–1.4
	Upper; 100–300 cm, ML; 1st–9th centuries AD	SL	9.4–10.1	<1	2.0–7.2	4.6–6.1	0.6–1.2
	Lower; 300–500 cm, ML; 6th–1st centuries BC	HL	8.4–9.7	<1	2.0–5.7	0.2–7.2	0.1–1.7
	Initial soil (LA)	Loamy sand	8.8–9.4	<1	<2	0	0.1
Hermonassa	Modern soil (Ur); 0–60 cm; 13th–21st centuries AD	SL	8.85–9.55	<1	4.5–5.4	2.0–3.6	0.7–0.9
	Upper; 60–500 cm, ML; 6th–18th centuries AD	SL/HL	8.35–9.4	<1	3.4–5.8	4.0–5.4	0.7–1.0
	Lower; 500–1000 cm, ML; 6th century BC–6th century AD	SL	8.15–9.50	<1	2.0–6.5	3.0–5.7	0.5–1.2
	Initial soil (Ch)	HL/Cl;	8.6	<1	<2	–	0.2–0.3
Tanais	Modern soil (Ch); 0–60 cm; 13th–21st centuries AD	SL	7.7–8.3	3.0–3.7	2.1–4.5	3–8	1.7–3.0
	ML, 3rd–1st centuries BC	SL	7.8–8.4	1.0–1.5	3.9–7.5	2.5–4.3	1.5–2.7
	Initial soil (Ch)	SL	8.9–9.0	<1	<2	2.0–8.2	0.1–0.2
Lgov	Urbanozem; 0–140 cm; 17th–20th centuries AD	LL/SL	8.0–9.0	1.5–3.9	3–10.8	4.4–21.7	0.2–1.9
	Initial soil (Ch/Km)	HL	No data	No data	<2	No data	0.1–0.2

* Urbosediments: ML—mineral layer; soils: Ch—Chernozem, Ur—urbanozem (Urbic Technosol), LA—gray-humus (Lamellic Arenosol).

** LS—loamy sand, LL—light loam, SL—silt loam, HL—heavy loam, Cl—clay.

*** Zc is the total contamination index (Cu, Zn, Pb, Ni, and As) according to [27].

studied antique cities and the soils developed from them.

GEOCHEMISTRY OF SOILS AND URBOSEDIMENTS

Since ancient times, humans have been changing the chemical composition of the anthroposphere by applying new chemical elements for their needs [3, 34]. An important factor of the formation of urban environments is the input of various trace elements into urban soils and urbosediments [1, 14, 18, 42]. There are facts attesting to the absence of significant migration of heavy metals through the cultural layer of the cities; moreover, heavy metals are usually localized in the cultural layer near their direct sources [34]. It is also proved that the urbosediments contain increased concentrations of a large number of pollutants beginning from their lowermost layers. In the soils buried under the cultural layer, the concentrations of these pollutants sharply decrease and usually do not exceed background values [14, 35]. This is explained by the high content of carbonates ensuring firm sorption of heavy metals in the cultural layer. A comparative characterization of the geochemical properties of the studied soils and urbosediments is presented in Table 1.

The urbosediments of the antique cities are characterized by increased concentrations of calcium, phosphorus, copper, zinc, bromine, and some other trace elements (Fig. 2; [5]). Calcium is accumulated in the form of calcium carbonates. It is interesting that the surface soils developed from the urbosediments of Phanagoria and Tanais are also enriched in carbonates and phosphorus. The concentrations of P_2O_5 above 0.4% in loamy soils are considered to be excessively high [24]. In the studied soils developed from the urbosediments of the antique cities, the concentrations of phosphorus (P_2O_5) are as high as 1.2–3%, though these soils have been developing under natural steppe vegetation for 1000 and 1500 years (after the end of the accumulation of the urbosediments). The extremely high phosphorus concentrations are preserved in the topmost soil horizons, which attests to the great stability of calcium phosphates in the soils developed from the cultural layer enriched in animal bones [6].

Table 2. Concentrations of some elements in separate objects from the Upper Town (UT-1) and East Necropolis excavations in Phanagoria

Object	CaO	Fe_2O_3	Mn	Cu	Zn	As	Br	Pb	Rb	Sr
	%		mg/kg							
	clarke									
	1.5	5	1000	30	76	2	2.5	13	78	384
Excavation VG-1; plaster, red dye	40.0	4.0	800	12	20	12.0	–	10	–	800
Red dye, square 66, pavement	1.67	40	410	510	3820	5890	–	23630	–	–
Red fresco, square 111, item 10	49.5	9.07	1000	100	400	800	–	–	–	–
Object 294-3; blue balls, floor	3.93	0.27	–	8500	100	–	–	–	–	–
East Necropolis. Burial place 117, fine earth	1.9	7.4	920	37	142	1.0	2	28	117	202

Our data indicate that the concentrations of phosphorus, copper, zinc, lead, and arsenic in calcareous urbosediments accumulated under conditions of a relatively dry climate of the steppe zone are somewhat lower than those in the organic urbosediments accumulated in the cities of the forest zone [12]. Thus, though here are many artifacts with the high concentrations of these elements that may serve at their sources in the urbosediments, their sorption in the mineral urbosediments is weaker than that in the organic urbosediments of the forest zone. The same phenomenon was noted by other researchers [14, 15].

Elevated concentrations of copper, zinc, and lead are characteristic of the upper and middle parts of the cultural layer of Phanagoria (Fig. 2). It is known that the cultural layer around metallurgical furnaces becomes enriched in these particular elements. Their concentrations depend on the composition of ore materials used for producing metals and their alloys. Among the three considered metals, copper and lead formed the basis of the nonferrous metallurgy of the ancient time.

Higher (up to extremely high) concentrations of a large set of elements were determined in some samples characterizing the particular archaeological objects (furnaces, pits, filling of ancient pots, dyes, etc.) from the cultural layer of Phanagoria (Table 2). Many of these elements are toxic; they are present in concentrations that could impair the health and even behavioral traits of the citizens [3, 34].

The concentrations of calcium, phosphorus, manganese, copper, and zinc in the urbosediments and soils of Hermonassa–Taman are also high. Thus, the average concentration of copper is about 40–50 mg/kg (the same as in the urbosediments of Phanagoria), and the concentration of zinc is about 100 mg/kg.

The concentrations of copper and, especially, lead in the cultural layer of Tanais are relatively low. However, this cultural layer is richer in zinc in comparison with the cultural layers of Phanagoria and Taman. The soil shaped in the upper part of the cultural layer is also rich in zinc and contains considerable amounts of dispersed charcoal particles. Especially high concentrations of zinc, as well as carbonates and phosphorus, are typical of the layers enriched in ash material and in fish scale and bones. Close relationships between the increased concentrations of zinc and the input of fish remains into the cultural layer were also observed on other archaeological sites [3, 16].

The soils of Lgov in the old central part of the city often contain increased concentrations of heavy metals similar to those in the soils around large modern sources of industrial emissions (Table 3). Elevated concentrations of metals with the relative abundance ratio (Kc) of about 2–6 (according to [27]) have been determined in six layers (0–10, 10–22, 32–50, 50–60, 60–70, and 110–140 cm) for zinc, in three layers (50–60, 60–70, and 70–82 cm) for lead, and in one layer (60–70 cm) for copper.

The accumulation of zinc, lead, and copper in the middle and lower parts of the profile (32–140 cm) dating back to the 17th–18th centuries AD is evidently related to the development of metallurgy and jewelry and the production of weapons, glass, and various construction materials [17, 19]. Thus, in the layers of excavation of Lyushin settlement (in Lgov district), the artifacts made of glass (fragments of green and black bracelets), bronze (a ring and a bracelet), iron (awls, knives, spindles), and a chip mold made of marl were found [22, 28]. The contamination of urbosediments in Lgov, in contrast to the modern accumulation of microelements [16], has a local character and does not spread beyond the most ancient part of this city. The high concentrations of a number of elements in the urbosediments attest to continuous pollution of the environment for several centuries and confirms the very low rate of the soil self-purification from toxic heavy metals.

The increased concentrations of strontium were found in all the horizons of the urban soils and urbosediments. This is explained by the considerable content of marl debris enriched in this element. The

Table 3. Concentrations of some elements in the urbanozem developing over the chernozem with migrational and mycelial forms of carbonate concentrations in the right-bank part of Lgov

Horizon (layer)	Depth, cm	Trace element, mg/kg									
		Cu	Pb	Ni	Zn	Ga	Rb	Y	Zr	Sr	Nb
U1ca	0–10	24	24	28	**256**		44	18	187	**165**	10
U2ca	10–22	24	25	14	**313**	7	40	14	294	**169**	5
U3ca	22–32	22	27	14	74	6	50	16	199	**266**	7
U4ca	32–50	27	**44**	14	**124**	9	51	18	216	**363**	11
U5ca	50–60	4	**103**	9	**206**	7	38	17	276	147	8
U6ca	60–70	**46**	**153**	16	**166**	12	26	16	206	**216**	6
U7ca	70–82	29	**58**	9	63	5	28	11	149	107	4
U8ca	82–90	33	**42**	12	74	4	50	16	162	**491**	10
U9ca	90–100	**43**	**45**	20	**113**	9	78	19	240	**291**	10
U10ca	100–110	23	11	14	96	7	80	20	208	**393**	9
[AUca]	110–140	27	17	17	**149**	12	117	15	228	**218**	12
[BCca]	140–150	17	8	22	55	11	86	17	193	**296**	7
D1 (marl)	150–170	9	6	16	44	12	60	14	116	**596**	8
Mean natural background value for Kursk oblast		23	25	30	62	10	84	30	450	106	15

The values exceeding the mean natural background concentration with Kc> 1.5 are given in bold.

concentrations of other microelements (Ni, Ga, Y, Zr, Nb, and Rb) in the examined profiles are within the limits typical of the background territories.

In the new part of Lgov on the other bank of the Seim River, construction works were performed relatively recently (mainly, in the 20th century). As a result, two isolated areas of the increased contamination of urban soils with heavy metals have appeared: the area with the high concentrations of heavy metals is allocated to the old part of the city, whereas the modern part of the city is characterized by the lower concentrations of heavy metals in the urbosediments. At present, these parts of the city do not differ in the intensity of modern technogenic emissions. Thus, the contamination of the urban soils and urbosediments with toxic microelements is characterized by the pronounced cumulative effect.

MORPHOLOGY AND COMPOSITION OF URBOSEDIMENTS. THE EFFECT OF PEDOGENETIC AND DIAGENETIC PROCESSES

The cultural layers of the considered cities have a considerable age. As a result of pedogenesis and diagenesis under conditions of a semiarid climate, these layers have lost the major part of their organic matter; they contain abundant secondary carbonates in the form of fine veins, carbonate pseudomycelium, and small concretions. Certain features typical of loesslike sediments have appeared in them. These are characteristic features of urbosediments in the semiarid zone making them different from the humus-rich and/or peaty urbosediments in the forest zone [13, 36].

The composition of urbosediments and soils developing in their surface horizons is controlled by the deposition of the anthropogenic matter and its further transformation. The cultural layer of settlements receives considerable amounts of woods and other organic materials used in construction and household activities (fuels, foodstuffs, fodder, etc.). However, because of the high activity of the organic matter mineralization under dry climatic conditions, the remains of wood and organic detritus disappear from the accumulated sediments within several decades. Charcoal particles are preserved much better, as well as collage-containing animal bones. Burnt horizons typical of the urbosediments usually contain not only charcoal but also ashes with the high content of calcite [42]. This favors a general increase in the content of calcium carbonates in the urbosediments.

The thickness of urbosediments is subjected to the action of many other pedogenetic and diagenetic processes. Proper pedogenetic processes acting in the soils lead to aggregation of the soil mass, humus accumulation, and bioturbation. Besides them, deep-soil processes can be distinguished; in particular, this is the migration of carbonates in the deep soil layers. Migrational forms of carbonate concentrations are clearly seen on the surface of pottery fragments and other archaeological objects. Deep-soil and diagenetic processes also affect the soils buried under urbosediments; as well as the cultural layer, these soils are subjected to alkalization and the accumulation of carbonates. Carbonates and phosphorus compounds leached off from the cultural layer precipitate in the upper part of the buried soil. The high alkalinity is also typical of the modern soils on the surface of the cultural layer. The material of the latter is subjected to the most active transformation by pedogenetic processes in the upper part, within the profile of the newly forming surface soil. In this part of the urbosediments, the degree of preservation of the initial archaeological stratification is minimal and depends on the duration of the exposure of the urbosediments.

Modern soils on the surface of urbosediments in the studied antique cities, especially Phanagoria and Tanais, are well developed, because these cities were abandoned long ago. On the stable surface of the former Phanagoria, typical steppe biomes with deep chernozems have developed in the past 1000 yrs. They differ from the zonal chernozems developing from natural parent materials in a lower depth of carbonates (often, they are found in the uppermost soil horizon) and a higher content of phosphorus and a number of microelements. Though the city of Tanais was abandoned somewhat earlier, the chernozems that developed from its urbosediments have been disturbed by the recent anthropogenic activity, because the territory of the ancient city has become a part of a relatively large (about 2000 inhabitants) modern settlement of Nedvigovka. The modern soil inherits the high contents of carbonates, phosphorus, and a number of trace elements from the ancient urbosediments. As the climate in Tanais is somewhat wetter than that in Phanagoria, the modern soil is characterized by a higher content of C_{org} in the humus horizon and by the distinct maximum of $CaCO_3$ in the BCA horizon (Fig. 4). The modern soil in the upper part of urbosediments of Hermonassa–Taman is less developed, because this city has never been completely abandoned. The concentrations of C_{org}, P_2O_5, and $CaCO_3$ inherited from the urbosediments remain relatively stable in the soil profile.

Alkalization processes affect not only the cultural layers of the studied cities but also the soils buried under them. The alkalinity of a loamy sandy carbonate-free soil buried under the cultural layer of Phanagoria is even higher than that of the loamy paleosols buried under the cultural layers of Hermonassa and Tanais. Changes in the groundwater level because of the general change in the hydrological regime of the territory can contribute to the alkalization of the buried paleosols. This process is also favored by the absence of the input of fresh organic matter as the source of organic acids into the buried paleosols coupled with continuing mineral weathering with the release of calcium, sodium, and other elements.

The thickness of the modern soil profile shaped in the upper part of the urbosediments of Phanagoria and Tanais is about 1.0–1.5 m. Within this profile, the activity of soil fauna, roots, aggregation processes, and humus accumulation leads to the homogenization of the initial stratification of the cultural layer. Various archaeological objects, brick walls, other elements of construction, hearths, basement pits, interlayers of burnt materials, and some other artifacts that are clearly seen in the cultural layer at a greater depth are subjected to destruction in the upper soil layer, so that only fragments of ceramics and stones are preserved. In the periphery of the ancient cities, the thickness of the cultural layer decreases, so that modern soil processes affect the whole cultural layer and transform it. Thus, in the peripheral zone of ancient Tanais, the thickness of the cultural layer is only about 60 cm, and modern pedogenetic processes have destroyed its initial lithological (and archaeological) stratification. The upper part of the buried paleosol is also transformed by the pedogenetic and diagenetic processes; it is characterized by dull colors owing to the mineralization of humus and by numerous earthworm holes and root paths; the fissures in this paleosol are filled with the material from the overlying horizons. Thus, the former cultural layer, the soil buried under it, and the modern surface soil gradually merge together to form a single modern soil profile.

Similarity of the morphological features and physicochemical properties of the urbosediments of Hermonassa and Phanagoria, as well as similarity of urbosediments accumulated in Hermonassa in the antique period and in the medieval time, attest to a general tendency in the formation of urbosediments under conditions of a semiarid climate. These urbosediments are characterized by the loesslike features, low content of humus (0.5–1.0%), considerable content of carbonates (5–10%), and by the slightly increased concentrations of trace elements (Cu, Zn, Br, and Pb).

CONCLUSIONS

(1) The studied cities are found under similar bioclimatic conditions and somewhat different lithological conditions. The development of their soils and urbosediments proceeds according to a general pattern. The accumulation of construction debris and other urban wastes for hundreds and thousands of years results in the development of thick loesslike urbosediments represented by sandy loams. These sediments are characterized by the alkaline reaction, low humus content, and the high content of phosphorus. The intense alkalization is typical of the buried paleosols with the initially neutral or slightly acid reaction.

(2) The urbosediments of the studied cities are enriched in many trace elements, including copper, zinc, lead, and, in some cases, arsenic and bromine. At the same time, maximum permissible concentrations of these elements are not always exceeded. Extremely high element concentrations are only observed in the local zones within the entire thickness of the urbosed-

iments; they are allocated to the findings of specific artifacts, such as dyes, products from nonferrous metals, etc. In general, the urbosediments and the soils developing from their upper parts have higher concentrations of microelements in the central parts of the cities with deepest cultural layers. In the peripheral zones of the cities with less significant accumulation of urbosediments, the concentrations of trace elements are usually lower.

(3) The stable and high contents of zinc and copper in the soils developed from the urbosediments are preserved even after a long period of natural pedogenesis in the abandoned cities with the formation of zonal soils. The extremely high content of phosphorus (1.2–3% P_2O_5) is also typical of the soils developing from the urbosediments under steppe vegetation for 1000–1500 years. This is explained by the high stability of calcium phosphates in the soils shaped from the urbosediments enriched in animal bones.

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