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GENESIS AND GEOGRAPHY OF SOILS

Dynamics of the Soil Cover in the Southeast of Europe and in the Southern Trans-Ural Region during the Subboreal Period

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Abstract—An inventory of published data on the natural evolution of forest-steppe, steppe, and semidesert soils in the southern part of the East European Plain and in the southern Trans-Ural region during the Subboreal period of the Holocene has been performed. Schematic maps of the thickness of soil humus profiles and the depth of soil carbonates have been developed for the chronosections of 5000–4200, 4100–3900, and 3800–3200 years ago. On this basis, the areas with specific patterns of natural evolution of soils in the Subboreal period are delineated.

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INTRODUCTION

A characteristic feature of the development of paleosol studies in Russia and in many other countries of the CIS is the wide use of soils buried under earthy (kurgans, ramparts, etc.) archaeological monuments of different ages as key objects for paleopedological reconstructions. This is particularly true with respect to the south and southeast of the East European Plain. It seems that the number of studies of archaeological objects in these regions for paleopedological purposes is unprecedentedly high. The rapid growth of scientific publications devoted to soil–archaeological studies in Russia took place in the second half of the 20th century [14, 30]. In recent years, this tendency has been preserved. Thus, at present, it is high time to generalize the obtained data. In particular, it would be interesting to develop cartographic interpretations of quantitative changes in the properties of paleosols from the southern part of the Russian Plain for different chronosections of the second half of the Holocene.

The aim of this work is to analyze the spatial–temporal dynamics of morphogenetic features of soils that developed in the south of the Russian Plain and in the southern Trans-Ural region during the Latest Neolithic Age and the Bronze Age (5000–3200 years ago).

BIOCLIMATIC CONDITIONS AND SOIL FORMATION DURING THE SUBBOREAL PERIOD

Considerable interest in the character of soil evolution during the second half of the Middle Holocene and its transition to the Late Holocene is confirmed by the huge number of papers devoted to this time period corresponding to the Latest Neolithic and Bronze ages.

Numerous investigations have proved that the bioclimatic conditions of soil formation within a larger part of the East European Plain during the Subboreal period (5 (4.8)–2.8 (2.5) ka ago) were different from those observed at present. Active transformation of bioclimatic conditions toward their current status took place during the second half of the Subboreal period and during the Subatlantic period.

According to the existing data, the changes in the bioclimatic and soil conditions within the southern part of the Russian Plain during the Subboreal period can be described as follows.

In the central chernozemic region, the beginning of the Subboreal period was marked by the climatic cooling accompanied by the southward shift of vegetation zones within the northern part of this region [44]. However, in the southern part of this region, within the forest-steppe zone on the Central Russian Upland, ordinary chernozems that developed by the end of the Atlantic period remained the dominant soils [4, 48]. In the northern part of the steppe zone (within the Dnieper Plain), ordinary chernozems evolved into southern chernozems. Thus, in this area, the northward shift of vegetation zones took place [28]. Climatic cooling accompanied by some aridization of the climate was the main reason for the evolution of ordinary chernozems into southern chernozems at the boundary between the Atlantic and Subboreal periods. At the beginning of the Subboreal period, an anticyclonic regime of air circulation was established in the northern part of the Prichernomorskaya Lowland and on the

Dnieper Plain. The summer seasons were relatively hot, and the winter seasons were cold and dry. This favored the development of tonguing of the humus horizon in paleochernozems of the Early Subboreal period. Humus tongues penetrating deep into the mineral mass result from the frost cracking of the soil mass. At present, this cracking does not take place in chernozems developing in the south of the Russian Plain [3].

According to Zolotun [27], the climate became somewhat milder and wetter about 4500 years ago. This was accompanied by an increase in the degree of soil leaching and in the thickness of humus horizons in the paleochernozems.

In the Middle Volga region, the scenario of paleoenvironmental changes during the Subboreal period has been developed on the basis of paleobotanical and paleosol reconstructions. The study of pollen spectra in peat deposits within the Buzuluk pine stand (i.e., in the forest-steppe zone near its boundary with the steppe zone) demonstrated that the climatic conditions in this area during the Early Subboreal period were very similar to those at the end of the Atlantic period. The interval from 6000 to 4500 years ago is considered to be optimal with respect to the heat and water supply in the entire Holocene [35]. For the Kama region to the north of the forest-steppe zone, the beginning of the Subboreal period was also characterized by relatively mild climatic conditions. The boundary between the Atlantic and Subboreal periods (5000 years ago) is considered the beginning of further warming and humidization of the climate [42]. These reconstructions are in agreement with the data obtained by Blagoveshchenskaya [9] on the basis of the pollen and radiocarbon analyses of peatlands from the Privolzhskaya Upland, according to which the Holocene climatic optimum in this area took place in the period from 6000 to 4500 years ago and a considerable cooling of the climate took place at the end of the Subboreal period. A comparative analysis of paleosols buried under the kurgans and of surface soils in the lower reaches of the Sok River (near the boundary between the forest-steppe and steppe zones) made it possible for Demkin [16] to suggest that the degree of climatic humidity in this region during the first half of the Subboreal period (up to 4000 years ago) remained higher than that at present.

Thus, it can be supposed that, in the interval from 5000 to 4000 years ago, the soil cover in the forest-steppe and steppe zones within the Central Russian Upland and within the Middle Volga region developed under conditions of a differently changing climate.

Aleksandrovskii [1] determined that ordinary chernozems predominated on the northern macroslope of the Great Caucasus Ridge in the Atlantic period and during the first half of Subboreal period in the area of the modern forest-steppe and broad-leaved forest zones. At present, gray forest soils and leached chernozems are developed there. Khokhlova with coauthors [46] argued that steppe communities existed on the territory of the Ingush Republic up to 4000 years ago; the evolution of typical steppe soils (ordinary chernozems) into forest-steppe soils (typical and leached chernozems) took place later.

According to Gennadiev [13], in the interval from 3700 to 3500 years ago, ordinary chernozems were widespread in the east of the Stavropol Upland, which confirms the existence of relatively dry climatic conditions in the steppe zone during that time.

In the Caspian region, the most ancient paleosols studied under the kurgans date back to 5800 years ago [25]. They were studied in the northern part of the Ergeni Upland within the dry steppe zone in the northwest of the Caspian region. These soils were classified as dark chestnut soils. It is supposed that their formation took place under somewhat wetter climatic conditions in comparison with those at present (at present, typical chestnut soils are developed in this area). The authors of this study found that the general trend of pedogenesis in the interval from 5800 to 4000 years ago was directed toward the formation of semidesert soils under more continental climatic conditions [25].

Paleosols of the first half of the Subboreal period within vast plains in the north and northwest of the Caspian region have distinct features of relict hydromorphism inherited by these soils from the Late Atlantic period with the high level of relatively fresh ground water [12, 20, 34].

Ryskov and Demkin [43] generalized published data and their own results on the paleosol development in the dry steppe zone of the Trans-Volga region and in the southern Ural region. According to them, the optimal climatic phase of the Holocene in these regions ended about 5000 years ago. The Subboreal period was characterized by the progressive aridization of the climate and a northward shift of soil-geographic zones in the interval from 4500 to 3500 years ago [43].

The evolution of chernozems during the second half of the Holocene in the southern Trans-Ural region was less contrasting than that on the East European Plain and in northern Kazakhstan. This can be explained by the greater stability of the climatic conditions in the Trans-Ural region shadowed by the large mountain system, the high elevation of this territory, and the good degree of drainage within the Trans-Ural peneplain [49].

As seen from these data, the first half of the Subboreal period was characterized by some worsening of the bioclimatic conditions (an increase in the degree of climatic continentality and aridity) within a vast territory encompassing the Prichernomorskaya Lowland, the Dnieper Plain, the central chernozemic region, the Stavropol Upland, the northern Caspian region, and the southern Cis-Ural region. These paleoclimatic changes were accompanied by the corresponding lowering of the soil fertility. At the end of this stage (about 4000 years ago), a sharp aridization of the climate took place. In the northern part of the Ergeni Upland and in the southeast of the central chernozemic region, this aridization had the character of an ecological catastrophe [52, 53]. In that period (according to Spiridonova, from 4130 to 3960 years ago (noncalibrated) [44]), semidesert vegetation predominated in the south of the central chernozemic region and the development of thin, highly calcareous, and deflated chestnutlike soils took place in the area corresponding to the modern dry steppe zone in the northwestern part of the Caspian region (these soils do not have modern analogues) [23, 25].

During the second half of the Subboreal period, the climatic conditions became somewhat milder; some researchers consider this period as the Middle Subboreal climatic optimum. In the area of Ryn Sands (the zone of modern light chestnut soils), steppe chernozems were formed in the interval from 4000 to 3600 years ago [29]. The humus reserves in the meadow soils of river valleys in the southeastern part of the central chernozemic region were two times higher than those at present [51]. The humus reserves in the profiles of the meadow-steppe chernozems on the interfluves of the Central Russian Upland were comparable with those in the modern soils or even exceeded them [48].

At the same time, the Middle Subboreal climatic optimum was not pronounced on the territory of the Prichernomorskaya Lowland [27] and the Dnieper Plain [28]. There are no data on this optimum for the North Caucasus and for the Cis-Ural and Trans-Ural regions.

As follows from this review, the Subboreal period in the southern part of the East European Plain was characterized by the pronounced dynamics of paleoclimatic and paleosol conditions with considerable regional differences in the degree and character of the paleoclimatic changes.

STUDY OBJECTS

The available data on the features of Subboreal paleosols and modern soils in the south of the East European Plain and the Trans-Ural region are summarized in Tables 1 and 2. Most of the dates of soil burying were obtained by the archaeological method or via using archaeological dates together with noncalibrated radiocarbon dates [2–8, 10, 11, 14, 34, 36–41, 43, 46, 48–50]. Calibrated dates are given in a few works [45, 47]. In our study, we recalculated them into noncalibrated dates using the data on deviations between the noncalibrated and calibrated dates given on p. 19 in [4].

Soils developed in the automorphic conditions (on leveled interfluves, gentle slopes, or on the drained river terraces) on the loamy or clayey parent materials were analyzed. For the territories where the appropriate soils are absent (the Ryn Sands and the Black Sands areas), data on the loamy sandy soils were taken [29, 45].

The soil features that are usually used as diagnostic indices to judge soil evolution in steppe and semidesert areas were analyzed: the thickness of the soil humus profiles (the A1 + A1B horizons in the chernozems, dark chestnut, and chestnut soils and the A1 + B horizons in the light chestnut and brown semidesert soils) and the depth of soil carbonates. In the areas where the background surface soils were subjected to plowing and had decreased bulk density values in the topsoil horizons (as compared with the virgin soils), the morphometric indices of paleosols buried under the kurgans are given in Tables 1 and 2 without any correction, i.e., direct field data are used. In the case when the background soils are represented by virgin soils, the morphometric indices of paleosols buried under the kurgans (the thickness of the soil humus profiles and the depth of soil carbonates) are increased by 2 cm; this is a correction factor to take into account the paleosol compression under the weight of the kurgans and the diagenesis of the soil humus in the upper horizons of the paleosols [28]. Finally, data on the thickness of the humus horizons and the depth of soil carbonates in the paleosols dating back to the particular time periods were recalculated in percent of the corresponding values typical of the modern background soils. Thus, we obtained relative estimates of the closeness of the paleosol cover in different chronosections of the Subboreal period to the modern soil cover in corresponding regions.

The available factual material (taking into account the uneven distribution of the paleosol data on the time scale and in space) and the analysis of existing notions about the bioclimatic heterogeneity of the Subboreal period make it possible to group the available data into three chronointervals: 5000–4200 years ago (when a tendency for worsening of the bioclimatic conditions was observed on a larger part of the studied territory), 4100–3900 years ago (when the aridity of the climate reached its maximum), and 3900–3200 years ago (when the paleoenvironmental conditions improved again).

RESULTS AND DISCUSSION

Schematic maps compiled by us (Figs. 1, 2) show the unevenness of the soil cover development in the Subboreal period.

In the period from 5000 to 4200 years ago, the thickness of the humus horizons of chernozems within the forest-steppe and steppe zones in the south of the East European Plain and in the North Caucasus comprised 50–85% of the modern values (Fig. 1). In the same period, forest-steppe and steppe chernozems in the Volga region were characterized by more considerable depths of soil carbonates, which were relatively close to those observed in the modern period. Thus, the climatic conditions in this region were wetter than those in the Dnieper and Don basins and in the North Caucasus region.

In the northern and western parts of the Caspian region, the effervescence line was found higher and the

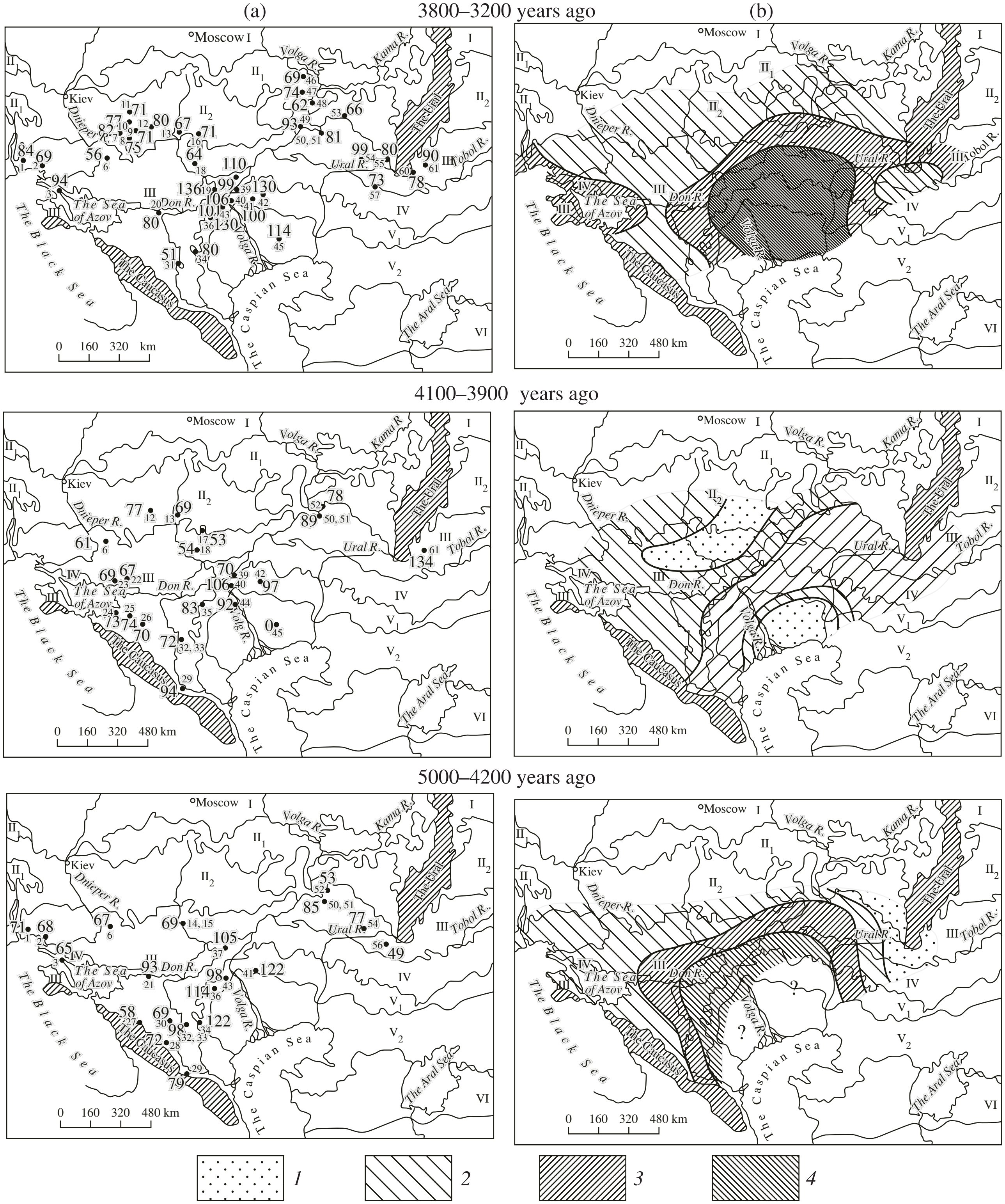

Fig. 1. Thickness of paleosol humus profiles in different chronointervals of the Subboreal period. (a) Plot numbers (small figures) and the relative thickness of humus profiles (% of the modern values, large figures); (b) isolines and areas with different relative thickness of the humus horizon (*1*) <60; (*2*) 60–80; (*3*) 80–100; (*4*) > 100%. Soil-geographical zones (see also Fig. 2): (I) southern taiga with soddy-podzolic soils; (II) forest-steppe with gray forest soils (II_1) and with podzolized, leached, and typical chernozems (II_2); (III) steppe with ordinary, southern, and Cis-Caucasian chernozems; (IV) dry steppe with dark chestnut and chestnut soils; (V) desert-steppe with light chestnut (V_1) and with brown desert-steppe (V_2) soils; and (VI) desert zone with gray-brown desert soils.

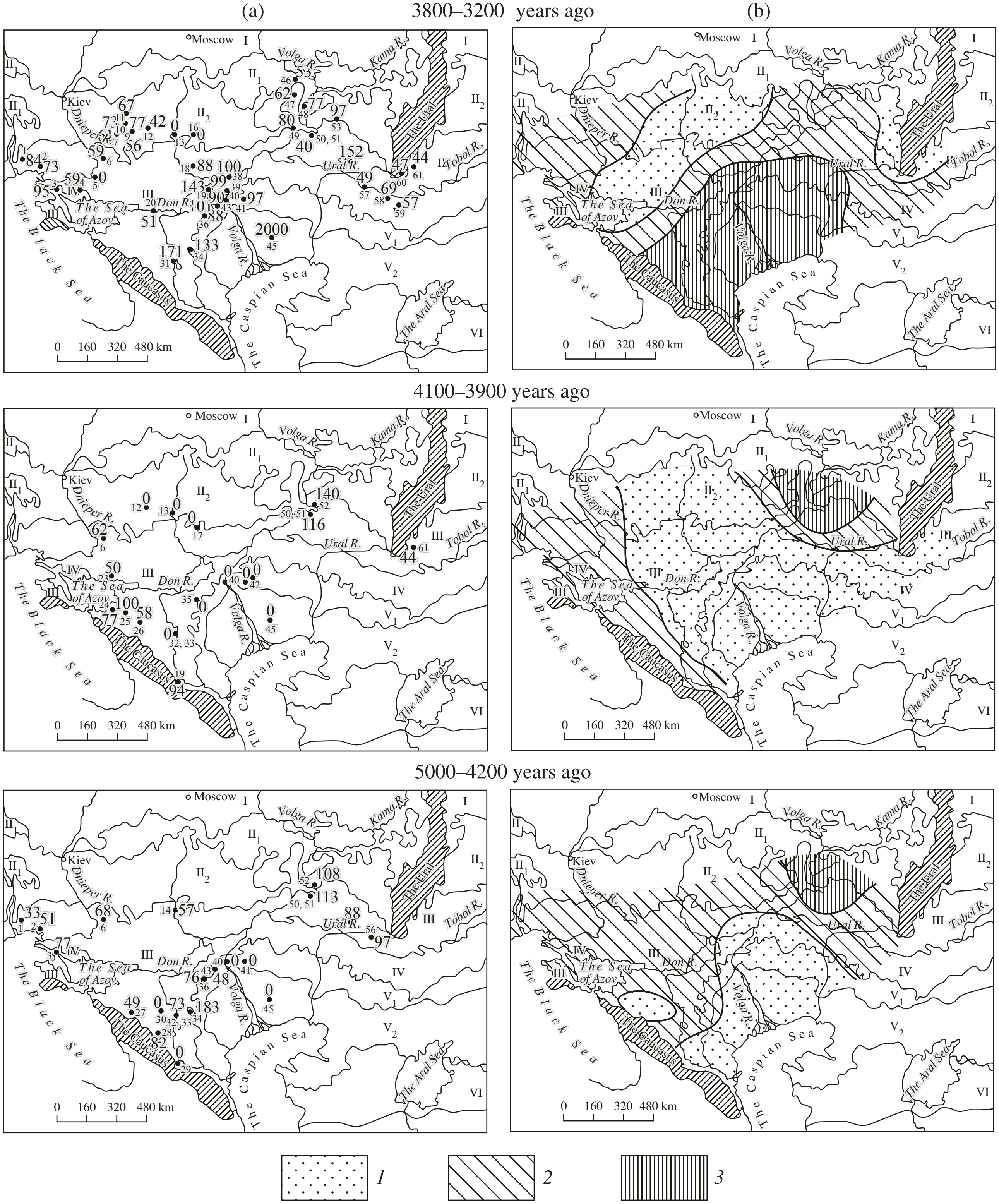

Fig. 2. Depth of effervescence in the paleosols from different chronointervals of the Subboreal period. (a) Plot numbers (small figures) and the relative depths of effervescence (% of the modern values, large figures); (b) isoline and areas with different relative depths of effervescence (*1*) <50; (*2*) 50–100; (*3*) > 100%.

Table 1. Paleosol features under kurgans of the Latest Neolithic–Bronze ages studied in the southern part of the East European Plain, % of the values typical of the modern background soils (data on long soil chronosequences)

Plot no., place, literature source	Characteristics	Chronointerval, ka ago													
		n	≥5.0	*n*	4.9–4.7	*n*	4.6–4.5	*n*	4.4–4.2	*n*	4.1–3.9	*n*	3.8–3.6	*n*	3.5–3.2
6, Bogdanovka, Shandrovka, Terny [28]	Humus profile	2	74.4	1	75.4	1	71.9	1	48.0	1	61.4	3	49.1	1	63.2
	Soil profile		134.0		89.8		82.3		78.3		88.4		80.7		68.7
	Depth of effervescence		84.2		69.7		67.9		66.7		62.5		63.9		53.6
13, 16, Oka-Don [7, 8]	Humus profile	No data								1	68.8	1	67.0	3	71.4
	Soil profile										54.7		–		92.0
	Depth of effervescence										0		0		0
14, 15, 17, 18, Steppe Belogory [3, 48]	Humus profile	No data				1	55.6	1	83.3	1	53.2	No data		1	64.1
	Soil profile						66.7		90.5		47.2				–
	Depth of effervescence						–		56.7		0				88.5
32, 33, Iki-Burul [10, 23]	Humus profile	1	111.8	No data				3	93.1	3	71.6	No data			
	Soil profile		97.8						90.0		71.3				
	Depth of effervescence		80.0						72.5		0				
35, 36, Pereguznoe, Abganerovo [25]	Humus profile	2	145.0	No data						1	83.3	1	130.0	No data	
	Soil profile		114.5								75.6		118.2		
	Depth of effervescence		76.0								0		88.0		
39, Chestnut soils of the Lower Volga region [17, 18]	Humus profile	No data						5	91.4	3	70.0	12	98.6		
	Soil profile								–		–		–		
	Depth of effervescence								32.3		41.4		48.6		
40, 41, Lenino, El'ton [20, 24]	Humus profile	No data						3	122.0	3	106.1	7	100.0	9	105.5
	Soil profile								120.5		107.6		110.3		134.8
	Depth of effervescence								0		0		80.0		91.3
43, Light chestnut soils of the Lower Volga region [17, 18]	Humus profile	2	No data					5	98.3	No data		8	98.3	8	103.3
	Soil profile								–				–		–
	Depth of effervescence								48.3				56.7		56.7
45, Ryn Sands [29]	Humus profile	6	228.6	Soils are absent (windblown sands)								4	114.3	Soils are absent (windblown sands)	
	Soil profile		128.6										142.9		
	Depth of effervescence		800										2000		
50, 51, Samara area [11]	Humus profile	No data		10	81.5			6	89.0			1	81.0	No data	
	Soil profile				–				–				–		
	Depth of effervescence				110.0				115.7				40.0		
52, Lopatino [16, 26, 33]	Humus profile	2	62.1	1	53.9	No data		1	41.5	1	77.8	No data			
	Soil profile		–		–				–		85.0				
	Depth of effervescence		108.4		–				–		140.0				

Note: Plot numbers are indicated in Figs. 1 and 2; *n* is the number of kurgans studied; dashes denote the absence of corresponding soil data.

Table 2. Paleosols features under kurgans of the Latest Neolithic–Bronze ages studied in the southern part of the East European Plain, % of the values typical of the modern background soils (data on short soil chronosequences)

Plot no., place, literature source	Characteristics		Plot no., place, literature source	Characteristics	
1, Lower Bug [27]	Time, ka ago	4.8–4.5/4	20, Azhinov [41]	Time, ka ago	3.7/1
	Humus profile	71.0		Humus profile	79.6
	Depth of effervescence	32.8		Depth of effervescence	51.2
	Time, ka ago	3.5–3.0/4	21, Azov [31]	Time, ka ago	4.5–4.2/1
	Humus profile	83.7		Humus profile	92.9
	Depth of effervescence	53.8	22, Neklinovka [31]	Time, ka ago	4.0/1
2, Lower Dnieper [27]	Time, ka ago	5.3–4.2/20		Humus profile	66.7
	Humus profile	67.8	23, Taganrog [40]	Time, ka ago	4.0/1
	Depth of effervescence	51.4		Humus profile	69.2
	Time, ka ago	3.5–3.0/7		Depth of effervescence	50.0
	Humus profile	69.3	24, Priazovskii [39]	Time, ka ago	4.0/1
	Depth of effervescence	73.2		Humus profile	73.1
3, Sivash [27]	Time, ka ago	4.5–4.2/2		Depth of effervescence	76.9
	Humus profile	64.7	25, Bryukhovets [31]	Time, ka ago	4.0/1
	Depth of effervescence	76.9		Humus profile	74.0
	Time, ka ago	3.8–2.8/2		Depth of effervescence	100.0
	Humus profile	93.9	26, Krasnogvardeisk [39]	Time, ka ago	4.0/1
	Depth of effervescence	94.9		Humus profile	70.0
4, Akimovka [36]	Time, ka ago	3.5/1		Depth of effervescence	57.6
	Depth of effervescence	58.7	27, Novosvobodnaya [4, 5]	Time, ka ago	5.0–4.6/1
5, Zelenyi Gai [36]	Time, ka ago	3.5/1		Humus profile	57.6
	Depth of effervescence	0		Depth of effervescence	49.2
7, Graivoronovo [48]	Time, ka ago	3.5/2	28, Inozemtsevo, Rosshevatskii [4]	Time, ka ago	5.0–4.5/2
	Humus profile	81.5		Humus profile	72.4
	Soil profile	93.5		Soil profile	100.0
	Depth of effervescence	60.6		Depth of effervescence	81.7
8, Belgorod [48]	Time, ka ago	3.5/1	29, Ekazhevo-2 [46]	Time, ka ago	≥5.0/1
	Humus profile	75.0		Humus profile	78.6
	Soil profile	79.3		Soil profile	76.7
	Depth of effervescence	55.6		Depth of effervescence	0
9, Prokhorovka [48]	Time, ka ago	3.5/1	29, Ekazhevo-1 [46]	Time, ka ago	4.0–3.8/2
	Humus profile	71.3		Humus profile	93.8
	Soil profile	81.7		Soil profile	97.4
	Depth of effervescence	37.2		Depth of effervescence	93.9
10, Drozdy [39]	Time, ka ago	3.5/1	30, Zolotarevka [4]	Time, ka ago	5.0–4.5/1
	Humus profile	73.1		Humus profile	68.8
	Depth of effervescence	73.1		Soil profile	74.5
11, Dubrashina [2]	Time, ka ago	3.5/1		Depth of effervescence	0
	Humus profile	71.0	31, Stavropol [13]	Time, ka ago	3.7–3.5/2
	Soil profile	84.3		Humus profile	51.3
	Depth of effervescence	67.0		Soil profile	104.8
12, Gubkino [48]	Time, ka ago	4.2–3.7/1		Depth of effervescence	170.8
	Humus profile	76.9	34, Chernozemel'skii [45]	Time, ka ago	4.2–4.1/1
	Soil profile	88.0		Humus profile	122.2
	Depth of effervescence	0		Soil profile	103.3
	Time, ka ago	3.5/2		Depth of effervescence	183.3
	Humus profile	79.5		Time, ka ago	3.5/1
	Soil profile	91.0		Humus profile	88.9
	Depth of effervescence	42.3		Soil profile	116.7
19, Zagadochnyi [21]	Time, ka ago	3.4–3.2/1		Depth of effervescence	133.3
	Humus profile	136.0	37, Dark chestnut soils of the Lower Volga region [17, 18]	Time, ka ago	4.5–4.1/3
	Soil profile	102.7		Humus profile	104.7
	Depth of effervescence	143.0		Depth of effervescence	61.8

Table 2. (Contd.)

Plot no., place, literature source	Characteristics		Plot no., place, literature source	Characteristics	
38, Ilovlya [22]	Time, ka ago	3.9–3.6/2	54, Mustaevo-5 [47]	Time, ka ago	4.9–4.7/2
	Humus profile	109.8		Humus profile	77.4
	Soil profile	94.4		Soil profile	84.3
	Depth of effervescence	100.0		Depth of effervescence	87.5
42, Dzhanybek [19]	Time, ka ago	4.0/1		Time, ka ago	3.5–3.0/2
	Humus profile	96.7		Humus profile	98.6
	Soil profile	61.9		Soil profile	95
	Depth of effervescence	0		Depth of effervescence	152.5
	Time, ka ago	3.5/1	55, Orenburg [17]	Time, ka ago	3.5/3
	Humus profile	130.0		Humus profile	80.0
	Soil profile	81.4		Soil profile	138.9
	Depth of effervescence	0	56, B. Dedurovskii Mar [15]	Time, ka ago	4.5/1
44, Brown desert-steppe soils of the Lower Volga region [17, 18]	Time, ka ago	4.0/3		Humus profile	48.5
	Humus profile	92.3		Depth of effervescence	96.9
	Depth of effervescence	38.7	57, Pokrovka [43]	Time, ka ago	3.5/9
	Time, ka ago	3.9–3.7/9		Humus profile	72.7
	Humus profile	92.3		Soil profile	94.5
	Depth of effervescence	85.3		Depth of effervescence	48.5
46, Chechkany [33, 39]	Time, ka ago	4.0–3.5/1	58, Khlebodarovka [38]	Time, ka ago	3.5–3.0/1
	Humus profile	69.2		Depth of effervescence	69.2
	Depth of effervescence	53.3	59, Aktyubinsk [38]	Time, ka ago	3.5–3.0/1
	Time, ka ago	3.5/1		Depth of effervescence	57.1
	Humus profile	77.0	60, Solonchanka-1 [50]	Time, ka ago	3.6–3.5/2
47, Buyanovo, Shimkusy, Novo-Izambaevo [6, 37]	Time, ka ago	4.0–3.5/2		Humus profile	77.5
	Humus profile	61.4		Soil profile	95.0
	Depth of effervescence	51.1		Depth of effervescence	47.0
	Time, ka ago	3.5–3.0/2		Time, ka ago	3.5–3.0/2
	Humus profile	87.3		Humus profile	90.0
	Depth of effervescence	62.2		Soil profile	96.0
48, Cherdakly [36]	Time, ka ago	3.5/1		Depth of effervescence	44.0
	Depth of effervescence	77.2	61, Aleksandrovskii-2 [32, 49]	Time, ka ago	4.0–3.9/1
49, Nizhneozeretskii [28]	Time, ka ago	3.5–3.0/1		Humus profile	134.3
	Humus profile	92.6		Soil profile	96
	Depth of effervescence	80.0		Depth of effervescence	44.0
53, Chulpan [28]	Time, ka ago	3.7–3.5/3		Time, ka BP/*n*	3.5–3.0/2
	Humus profile	66.1		Humus profile	90.0
	Depth of effervescence	96.9		Soil profile	96.0
				Depth of effervescence	44.0

thickness of the soil humus horizons was greater than those in the modern background soils. As known, the depth of soil carbonates is more sensitive toward changes in the bioclimatic conditions in comparison with the soil humus profile [28]. It can be supposed that the increased thickness of the paleosol humus horizons in the Caspian region during the stage of climatic aridization (5000–4200 years ago) was inherited from the pluvial epoch of the Atlantic period. At the same time, the specificity of the analyzed soil properties could be due to a denser vegetation cover that protected the soil surface from wind erosion and to the specific seasonal weather regimes favoring the accumulation of pedogenic carbonates and soluble salts, on the one hand, and the development of humus accumulation, on the other hand.

In the area of Ryn Sands, soil formation was virtually absent during that period; windblown sands predominated in this area [29].

In the period from 4100 to 3900 years ago, the paleosol cover was subjected to considerable transformation. In the Caspian, Lower Volga, and central chernozemic regions, the thickness of the soil humus horizons decreased and the depth of the soil carbonates became shallower. In the North Caucasus region, these changes were of smaller amplitude; in some cases, the thickness of the soil humus horizons somewhat increased. Similar changes also took place in the Prichernomorskaya Lowland and on the Dnieper Plain. The most favorable paleoenvironmental conditions during that period existed in the forest-steppe of the Middle Volga basin, where the thickness of the soil humus horizons continued to increase and the leaching of soil carbonates was rather intensive.

In the period form 3800 to 3200 years ago, the paleosol cover changed again. During that time, the thickness of the humus profiles in the paleochernozems of the Cis- and Trans-Ural regions comprised 73–99% of the modern values; in the Dnieper basin and in the central chernozemic region, it was lower (54–82%). The chernozems of the forest-steppe and steppe zones in the Middle Volga region occupied a transitional position (62–93%). Within the Prichernomorskaya Lowland, the increase in the thickness of the soil humus horizons (as compared to those during the previous time interval) was more considerable in comparison with the central chernozemic region and with the Dnieper Plain.

In the same period, the depth of the soil carbonates in the steppe and forest-steppe soils of the vast region from the Prichernomorskaya Lowland and the Dnieper Plain to the Trans-Ural region varied from 0 to 152% of the modern values; values of 60–75% predominated. The highest position of the effervescence line was observed in the western part of the studied region (from the Sea of Azov to the Oka–Don Plain). In the western, central, and northern parts of the Caspian region, the bioclimatic conditions of that period were more favorable than those at present: the thickness of the soil humus horizons and the degree of soil leaching from carbonates increased. It is probable that favorable paleoenvironmental conditions with a wetter climate that existed in the Caspian region during the Middle Subboreal optimum also affected neighboring territories. This conclusion is confirmed by the increased thickness of humus profiles and the deep position of the effervescence line in the steppe paleochernozems from the eastern macroslope of Stavropol Upland (plot 31, [13]) and in the chestnut soils from the extreme southeast of the Central Russian Upland (plot 19, [21]).

CONCLUSIONS

(1) Within the southern part of the East European Plain and the Trans-Ural region, the Subboreal period was characterized by considerable changes in the thickness of the soil humus profiles and in the depth of soil carbonates. The most contrastive changes were observed within the Caspian Lowland. Minimum changes were observed in the Middle Volga and southern Ural regions.

(2) The soil development within the forest-steppe and steppe zones in the central chernozemic and Middle Volga regions during the Subboreal period was metachronous: in the central chernozemic region, the improvement of paleoenvironmental conditions after 3900 BP was accompanied by the increasing thickness of the humus profiles of chernozems; in the Middle Volga region, paleochernozems from the first half of the Subboreal period were deeper and better leached from carbonates in comparison with the soils of the second half of this period. In the latter region, the worsening of the paleoenvironmental conditions (the cooling and aridization of the climate) began after 3900 BP.

(3) In the western and northwestern parts of the Caspian region, the paleosol properties attest to the existence of the Middle Subboreal climatic optimum; this period is considered as a pluvial epoch. The soil leaching from carbonates and the thickness of the soil humus profiles increased during it in most of the paleosols studied in the Caspian region. The relatively wet climatic conditions in this region were also traced in the neighboring territories (in the eastern part of the North Caucasus region and in the southeast of the Central Russian Upland). The paleosols buried during the Late Subboreal period in these regions display an increased depth of the line of effervescence and an increased thickness of the humus profiles.

The conclusions reached in this work have a tentative character, and they may be refined in the course of further studies.

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