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Geodatabase of Buried Soils for Reconstruction of Palaeoecologic Conditions in The Steppe Zone of East European Plain.

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ABSTRACT

In this article we carried out the analysis of amorphous and floodplain soils chronological sequences, which were arranged according to archeological and radiocarbon dating. The connection between climatic changes and soil types during the Subboreal and Subatlantic ages of the Holocene has been analyzed. Paleographic research database in the steppe zone of East European Plain has been formed.
Keywords: buried soils, pedogenesis, paleoenvironmental changes, Late Holocene.

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INTRODUCTION

One of the most important natural archives revealing natural rhythmics throughout the Holocene are buried soils and their chronological sequences. After first works and records on the soil-building rate, which were based mainly on the historical method and specific activity of ^{14}C in the humus measuring results, the new stage has been formed. Quick growth of the data quantity due to active use of soil archeological dating method and the study of soil evolution occurred within four recent decades. A lot of works [e.g. 1-5] devoted to the study of soils buried under archaeological monuments, including the ones focused on the reconstruction of climatic changes on buried soils [6-8 et al.].

The study of buried soils and palaeosols provides an opportunity to obtain climofunction changes of paedogenesis conditions throughout the Holocene [9]. However considerable amount of information continues to lack and in some cases it may be inaccurate and interpreted only for suggestions concerning physiographic conditions of the past [10, 11].

The necessity of research of Holocene soils is explained by the fact that they constitute the basis for subsurface stratigraphy, determine the cyclicity of palaeoclimatic fluctuations. Their study makes it possible to determine palaeolandscape conditions, specify the evolution of natural processes and improve the approaches to the explanation of the current state of landscapes. Buried soils can be a marker to determine the degree of man-made impact on the soil mantle that can serve as the basis of soil conservation measures later [12, 13].

The change of Holocene natural conditions proceeded differently depending on regional climatic characteristics. Therefore most often climatic changes throughout recent 10,300 years are considered in terms of a region, though there are some researches of a generalizing integral type to determine general principles. For the first time [6] the condition of natural dynamic soil formation functioning – denudation caused by centuries-long astroclimatic cycles. Characterization of the Holocene and its separate stages is performed as a rule by its division into shorter chronological phases reflecting the rhythmics of interdecadal climatic changes [14, 15].

The paleographic principle of soil research both contemporary and belonging to preceding geological periods involves the research of any ancient nature event or component as an interconnected element of a landscape mantle. Therefore the palaeopedosphere and ancient soils are researched not only as the derivates from physiographic conditions of the past, but also as the result of soil-formation factors interaction of that time period [16].

MATERIALS AND RESEARCH METHODS

We studied regional Holocene soils development characteristics in the steppe zone of East European Plain (Odessa, Nikolayev, Belgorod regions, the Republic of Crimea) including the basin of the Southern Bug river. The study of different Holocene soils pedogenesis stages on the key sites 15 and 16 for automorphous and floodplain conditions respectively.

To research Holocene soil bodies in the South Bug basin we applied an integrated palaeopedologic method, within which we used morphological study of the soil profile, laboratory physical-chemical analyses.

The use of morphological study arises from the fact that the soil is a hierarchic natural system including morphological elements off different levels. Internal bodies of the soil profile having clear or diffuse boundaries and also characterized by specific features should be considered the components of this system [17].

For the purpose of finding organic carbon in the soils in natural and decarbonized specimens we determined their carbon content using carbon express analyzer AH-7529. For evaluation of soil organic matter (SOM), the soil organic carbon (SOC) were determined and group analysis of humus was conducted (according to Ponomareva and Plotnikova's modification of Tyurin's method). SOM was fractionated into 3 humic acid (Cha), 4 fulvic acid (Cfa), and base-insoluble fractions (BIF). The age determination of the soil bodies under study was conducted by means of uncalibrated results of radiocarbon dating (^{14}C).The age determination of the subject using the radiocarbon method is only possible when the specimen was not polluted by carbon materials of later or earlier origin [18, 19]. The archaeological dating margins of error of the life end time for the Iron Age cultures make 25 – 30 years, and the differences of the late Bronze Age cultures stages are estimated at 100 years.

Taking into account a substantial number of parameters according to which the Holocene soils can be characterized, the possibility of their distribution according to the terms of space-time aspect, the extent of factual material of large scale research, a stereoscopic database of empiric study was created. It performs not only the storage function but also enables the search of necessary data. To create the stereoscopic database we applied free cross-platform QGIS.

The soil geodatabase consists of two parts: a) dataset of soil's empirical research and b) additional spatial data (ecosystems, cities, administrative areas, etc.). Combination of different parameters in a single geoinformational system allows to create comprehensive description of modern soils and soils of the past and to compare them.

Soil information is represented in the following spatial layers: Palaeopedologic Data, Geochemistry Data and Media Info. Palaeopedologic Data layer includes information about soil type and soil structure, color and grain size and contains full morphological descriptions for most sites. Geochemistry Data layer aggregates quantitative information about genetic horizons based on laboratory analysis. Most of fields of this dataset have decimal or integer formats and include data about humus, carbonates and heavy metals concentration. This information is available for making queries and for further modelling by means of interpolation modules. Media Info is a necessary layer for visualisation of soil sites and soil horizons. This layer includes different photos and other images which are related to spatial vector objects by using their ID and action functions of QGIS interface.

THE MAIN PART

The Subboreal soil bodies (SB, 5000-7000 years ago) were formed under the influence of natural conditions generally characterized by their relative aridity and noticeable continentality alongside with increasing seasonal contrast of the climatic indexes and they determined soil range shifting to the north.

In the Bug area we determined 10 stages of the Subboreal floodplain soils corresponding the periods of aridization, decrease of alluvium accumulation processes intensity (Table 1).

Table 1: Studied Holocene stages of soil formation in the river valley of the Southern Bug

Stage	Age of soils	Climate characteristic	Soil type	Nature area	Location studied key areas
SA	700±60 BP	cooling, aridity	Typical alluvial sod	forest-steppe	Novoarhangel'skij district, Kirovogradskaja reg.
	1640±60 BP	humidity maximum in SA	Layered alluvial meadow	forest-steppe	Vinnickij district, Vinnickaja reg.
	1720±60 BP		Alluvial meadow primitive	forest-steppe	Krivoozerskij district, Nikolaevskaja reg.
	1730±60 BP	maximum aridity in SA	Layered alluvial sod	deciduous forests	Letichevskij district, Hmel'nickaja reg.
	1850±60 BP		Typical alluvial sod	steppe	Dobrovelichkovskij district, Kirovogradskaja reg.
	2040±70 BP	humidity	Alluvial marsh	forest-steppe	Gajvoronskij district, Kirovogradskaja reg.
	2310±60 BP	short-term aridity	Alluvial sod	forest-steppe	township Savran', Savranskij district, Odesskaja reg.
	2420±70 BP	overall cooling, humidity	Typical alluvial meadow	steppe	Krivoozerskij district, Nikolaevskaja reg.
	2470±60 BP		Alluvial meadow marsh	forest-steppe	Vinnickij district, Vinnickaja reg.
SB	2830±80 BP		Typical alluvial meadow	forest-steppe	Gajvoronskij district, Kirovogradskaja reg.

	2870±70 BP	alternating phases of aridity and humidity	Alluvial sod	forest-steppe	Gajvoronskij district, Kirovogradskaja reg.
	3110±70 BP		Typical alluvial sod	forest-steppe	Katerinopol'skij district, Cherkasskaja reg.
	3210±110 BP		Typical alluvial meadow	forest-steppe	Lisjanskij district, Cherkasskaja reg.
	3360±110 BP	maximum aridity in SB	Typical alluvial meadow	forest-steppe	Gajvoronskij district, Kirovogradskaja reg.
	3500 BP		Dark brown soils	steppe	Novobugskij district, Nikolaevskaja reg.
	3860±90 BP		Typical alluvial sod	forest-steppe	Gajsinskij district, Vinnickaja reg.
	3890±60 BP		Alluvial sod carbonate	forest-steppe	Vinnickij district, Vinnickaja reg.
	4150±80 BP	aridity, increase continentality	Typical alluvial sod	forest-steppe	Gajvoronskij district, Kirovogradskaja reg.
	4740±100 BP	aridity	Alluvial meadow gley	forest-steppe	Gajvoronskij district, Kirovogradskaja reg.

According to the chronological division of the Holocene [13] the designated pedogenesis stages belong to microclimate epochs I – hl_{b2-1}, hl_{b2-3}, hl_{b2-4}, hl_{b2-5}.. Soils $hl_{b2-1\ c}$ at the age of 4740±100 BP are represented by alluvial, gley, meadow ones, the formation of which proceeded under the conditions of the aridization period beginning with isochronous temperature indexes reduction. The beginning of microclimate epoch hl_{b2-3} (4150±80 BP) was distinguished by the increase of the climate aridizaton and the temperature peak of the Subboreal age causing the development of alluvial sod typical soils in the central parts of flood plains. The cold microclimate epoch hl_{b2-4} coincides with the Subboreal age aridization peak with simultaneous temperature reduction. This chronological interval is represented by livery zonal soils within the limits of contemporary common chernozems geographical ranges and two soil bodies of different ages, which are the alluvial sod carbonate soils (3890±60 BP) and alluvial sod typical soils (3860±90 BP).

The differentiation of the middle Subboreal soils at the type and kind level is the evidence of short-term (100-150 years) fluctuations of temperature indexes and humidity against of the general trend to aridization. The end of the Subboreal age (hl_{b2-5}) was characterized by the general trend of aridization level reduction aid increasing arid and humid stages interchange rate. As a result soils began their development in flood plains, formation of is characteristic for more humid conditions than the ones of the previous microclimate epochs: alluvial meadow typical soils (3360±110 BP, 3210±110 BP, 2830±80 BP). The stages of temporary aridization of hl_{b2-5} corresponded to alluvial sod typical soils (3110±70 BP, 2870±70 BP).

The Subatlantic age of the Holocene (SA, 2700 – present day) was characterized by the reduction of temperature and increasing humidity. Despite the common trend, substantial fluctuations of hydrothermal indexes took place both in time and space aspects.

The beginning of the Subatlantic age (hl_{b2-6}) was marked by the reduction of temperature indexes and humidization, which was manifested itself in the spread of alluvial meadow-boggy soils in flood plains (2470±60 BP) and alluvial meadow typical ones (2420±70 BP). The stage of short-term aridization of microclimate epoch hl_{c1-1}, was the time period 2310±60 BP, throughout which alluvial sod soils were developing. Further increase of climate humidity took place at the beginning of microclimate epoch hl_{c1-1}, when alluvial boggy soils were forming in flood plains (2040±70 BP). The aridization peak of the Subatlantic age in combination with the general climate warming takes place during hl_{c1-1} and it is represented by two stages of floodplain soil formation, in course of which alluvial sod typical (1850±60 BP) and alluvial sod fibrous soil were developing. The end of hl_{c1-1} was marked by the highest degree of humidization for the Subatlantic age against the reduction of average annual temperatures. At that time alluvial soil bodies started to develop in flood plains and they were represented by fibrous (1720±60 BP) and primitive (1640±60 BP) soils. At the end of microclimate epoch hl_{c1-3} sod soils were formed, that is the evidence of of the aridization of the climatic indexes against an insignificant fall of temperature 700±60 BP.

The soil mantle of the present formed during the recent 100-150 years reflects the pedogenesis stage, which is under the influence of not only short-term fluctuations of climatic indexes but also human pressure. The soil bodies of this time period are represented by alluvial sod carbonate, meadow typical fibrous and meadow typical primitive ones. Among the primary elementary soil processes we should emphasize the carbonatization, humification and active bioturbation.

Previously [20] it was found for the moderate climate that the depth of humification expressed by Ch:Cfa for humus horizons of automorphous soils correlates at a high degree of reliability with the period of biological activity (PBA). And later [21] an empiric formula was suggested to describe the correspondence Ch:Cfa from PBA. As there is a certain correspondence correlated between PBA parameter and the annual value estimates of radiation energy consumption on soil formation (Q, MJ/(m^2·year)) – [22], then the principles found according to the correspondence of Ch:Cfa from PBA can be used to explain humus type differences in the process of climate change (through Q and, respectively PBA). It was demonstrated [23] that the Q parameter controls the potential of soil formation process that enables the simulation of edaphoclimatic relations [24, 25].

Applying the data on climatic variables in East European Plain area (zones distribution), represented in the work [20] we deduced the correspondences of Ch:Cfa from PBA and Q from Ch:Cfa.

$$f\left(PBA\right)=192.685-\frac{1}{0.0149(C_{ha}/C_{fa})},$$

and

$$f\left(\mathrm{Q}\right)=1256.421-\frac{1}{0.002414(C_{ha}/C_{fa})},$$

where:
Cha humic acid; Cfa fulvic acid.

Within the chernozem zone modern differences of soil subzones (from north to south) vary according to PBA from 119 to 155 days, according to Q from 800 to 1026 MJ/(m^2·year). If Q value determines average annual power potential of pedogenesis then we may judge by PBA value on the term of the time period, when the average air temperature was steadily more than 10 °C, and the soil productive moisture deposit is not less than 1-2% [20], i.e. on the most effective vegetation period for the plant matter formation:

$$f(PBA)=1135\cdot10^{-1144/\mathrm{Q}}+70;\ r=0{,}85.$$

Correspondingly due to the differences of Ch:Cfa ratio in contemporary conditions from 0.91 to 1.80, the chronological ranges of the buried soils demonstrate wider range of the average values 1.81±0.89 (0.92÷2.70).

Favorable climatic conditions for pedogenesis in the North Pontic region were marked 1300-2200 years ago, but especially 5000-7000 years ago (Table 2).

Table 2: The composition of the organic matter (SOC) reference (Holocene) and buried soils of the steppe zone of East European Plain

The study area[1]	The study object	Horizon	Duration soil (burial), years	Depth, cm	SOC, %	% C			Cha/Cfa
						Cha	Cfa	BIF	
Chernozems ordinary (standard)									
1	Gerasimovka	A	10300	0-36	2.68	49.5	27.4	23.1	1.8
Chernozems southern (standard)									
2	Chernomorskoe	A	10300	0-22	3.03	26.8	21.6	51.6	1,2
Dark brown soils (standard)									
2	Vitino	A	10300	0-17	2.40	22.4	24.5	53.1	0.9
Chernozems ordinary									
3	Trajanov val	[A]	2000	32-45	1.26	25.4	12.7	61.9	2.0
	Krinichnoe	[A]	1100	33-62	0.98	26.5	14.3	59.2	1.8

Chernozems southern									
4	Usatovo	[A]	5200	79-110	2.55	33.7	16.9	49.4	2.0
		[Ae]		99-110	3.45	32.5	13.3	54.2	2.4
5	Staroe Bugovo	[Ae]	3000	75-103	1.71	18.7	8.8	72.5	2.1
Dark brown soils									
6	Bejkush	[A+AB]	2465	107-150	0.60	10.0	23.3	66.7	0.4
	Zakisova Balka I	[A]	2540	81-111	0.97	44.0	19.6	36.4	2.2
6	Chertovatoe II, necropolis	[A]	2475	59-84	0.66	40.9	30.3	28.8	1.4
7	Ieniduni, fortress	[Ae]	220	36-58	2.39	27.2	17.2	55.6	1.5
		[AB]		58-82	2.12	28.3	16.5	55.2	1.7
1	Gerasimovka	[Ae]	7000	44-54	1.21	64.0	16.0	20.1	4.0
2	Airchi	[A]	2360	0-16	0.59	41.9	33.4	24.8	0.6
				16-20	0.67	28.8	21.5	49.7	0.6
	Airchi	[A]	2060±80 BP	0-24	0.66	41.8	29.7	28.5	1.4
		[AB]		24-38	0.45	16.9	25.3	57.8	0.7

1 – Belgorod region; 2 – Republic of Crimea; 3 – Odessa region, Bolgrad district; 4 – Odessa region, Belyaevsky district; 5 – Odessa region, Il'ichevsk; 6 – Nikolaev region, Ochakov district; 7 – Odessa region, Kominternovskiy district.

By the beginning of the 5th century BC the climatic aridization had an impact on deterioration of soil quality (at the average the pedogenesis power potential (according to Q) was 2.46-fold lower as compared to the contemporary one). It is noteworthy that at the beginning of the first half of the 5th century BC in the North Pontic region (the rural district of the ancient Olbia polis) most of agricultural settlements cease to exist [26, p. 7].

CONCLUSION

The conducted integrated palaeopedologic research of Holocene soil bodies at different stages of pedogenesis within the autonomous landscape locations and in river valleys enables to solve a number of fundamental tasks on the soil development history, determine the direction of their evolutionary development, find the general trends of geochemical indexes changes in terms of space-time aspect.

SUMMARY

Space-time changes of Holocene soil types are determined by hydrothermal climatic indexes pattern, which led to the shift of natural zones northwards during the Subboreal age and southwards – during the Subatlantic age. According to the results of the integrated palaeopedologic research we determined the following soil evolution chains:

- Subboreal dark chestnut soils → contemporary chernozem soils common in the steppe zone;
- Subboreal alluvial meadow typical soils → Subatlantic alluvial boggy soils → contemporary alluvial sod typical in the broadleaved forests area;
- Subboreal alluvial sod typical carbonate soils → Subatlantic alluvial meadow typical fibrous soils → contemporary alluvial sod primitive soils in forest steppes.

The results of the study of soils belonging to different time periods can be applied to form forecast models of soil mantle development in the future on the basis of the past to reconstruct living environment of an ancient man, and also for the purpose of determination the degree of human impact on the soil cover.

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