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THE EVOLUTION OF CLIMATE AND LANDSCAPES OF THE LOWER VOLGA REGION DURING THE HOLOCENE

ABSTRACT

The results of the palynological analysis and ¹⁴C dating of the most complete sequences of the Holocene sediments were used for a detailed reconstruction of multi-cyclic alternations of climate phases and zonal and intrazonal plant formations that were taking place the Lower Volga region during the last ten thousand years. Twenty-six phases in evolution of the natural environment during the Holocene were distinguished. Landscape-climatic characteristics and chronological boundaries were identified for these phases. Reconstructed paleoclimatic stages were correlated to the Holocene transgressions and regressions in the Caspian Sea region. The model developed for periodization of climatic events may serve as a climato-stratigraphical framework for future paleogeographical studies of the Holocene in the Northern Caspian region.

KEY WORDS: the Lower Volga region, Holocene, pollen assemblages, ¹⁴C dating, vegetation and climate reconstructions, paleo-environments, transgressions and regressions of the Caspian Sea

INTRODUCTION

Changes in landscape conditions that have been occurring in the northern Caspian Sea during the last 10,000 years are associated with climate change and fluctuations of the Caspian basin. Using data on geology, geomorphology history, archaeology, and

malacology and results of radiocarbon (¹⁴C) dating, experts have defined age, coastline hypsometry, and a hierarchy of multiple transgressions and regressions of the Caspian Sea in the Holocene [Leontiev et al., 1976; LowerVolga..., 2002; Rychagov, 1997; Svitoch, 2006; Varuschenko et al., 1987].

Climatic conditions and plant communities of the littoral areas of the Mangyshlak regression, of the maximum of the New Caspian transgression, and of different phases of the Late Atlantic period have been reconstructed from palynological analysis of the bottom sediments of the Caspian Sea and from analysis of lake, alluvial, and subaerial deposits of the northwestern and northeastern sectors of the Caspian region [Abramova, 1980; Abramova, 1985;

Vronsky, 1980; Vronsky, 1987; Yakhimovich et al., 1986 and many others]. For these paleogeographic stages, values of annual precipitation and values of annual, July, and January temperatures have been obtained with the help of mathematical methods to quantify paleoclimatic parameters of the spore-pollen assemblages [Abramova and Turmanina, 1988; Bukreeva and Vronsky, 1995].

A holistic understanding of vegetation and climate evolution during the entire modern interglacial epoch has been hampered by a lack of data on the Caspian sequences with the full representation of the Holocene sediments, sufficient palynological characteristics, and a series of ^{14}C dates.

The first results of a comprehensive palynological study of sediments fully dated with ^{14}C method that allowed us to reconstruct a continuous sequence of changes in vegetation and climate of the Lower Volga during the Holocene were obtained in the late 1980's [Bolikhovskaya, 1990; Bolikhovskaya et al., 1989]. Using materials of our subsequent research, we compared climatic and vegetation Holocene successions of the Volga-Akhtuba floodplain and the Volga delta and identified the patterns of landscape and climatic changes that have been occurring in the study area during the last 10,000 years [Bolikhovskaya and Kasimov, 2010; Bolikhovskaya and Kasimov, 2008].

This paper presents the results of detailed reconstructions of changes in the zonal vegetation types and the transformation of the zonal and intrazonal plant communities in the Holocene landscapes of the Lower Volga region that occurred under the impact of global climate fluctuations and changes of edaphic conditions. These reconstructions were based on a comprehensive palynological analysis and radiocarbon dating of paleogeographic sequences that were the most informative in regards to the Holocene period. The reconstructed

paleoclimatic events were correlated to the Caspian Sea transgressive-regressive phases in the Holocene. A detailed periodization scheme of individual paleoclimatic events has been developed. This scheme can serve as a framework for subsequent climato-stratigraphical and paleogeographical studies of the Northern Caspian region during the Holocene. The reconstructed chronological paleo-boundaries of vegetation, landscape, and climate change phases may serve as a climato-stratigraphical framework for subsequent paleogeographical studies of the Holocene of the Caspian basin. Furthermore, these findings may help to understand the magnitude of the transformation of the Holocene landscapes of the Northern Caspian region in various transgressive – regressive epochs.

MATERIALS AND METHODS. THE STUDY AREA

The main object of these research efforts was the Northern Caspian Sea region, specifically, the Volga-Akhtuba floodplain as it is the most indicative in palynological respect. Its vegetation (as shown by the results of this study) actively responded to climate change and the congruent Caspian Sea level fluctuations. The spore-pollen analysis of the sediments of two sections near the site Solenoye Zajmishche (47°54' N, 46°10' E; about – 19–20 m asl (i.e., above sea level); 5 km south of the city of Chernyi Yar, Astrakhanskaya oblast) was performed. Section 1 (S1) was a 5-meter thick layer uncovered by a well at a dry oxbow lake developed on the surface of a high floodplain. A detailed climato-stratigraphical interpretation was performed using palynological analysis of 50 samples taken at 10-cm intervals and ^{14}C dating of five samples (Table 1). It appeared that the process of accumulation of oxbow-lake clays continued through the entire Holocene. In the outcrop of the sediments, Section 2 (S2) uncovered a high floodplain towering 6–7 meters above the river's edge. Representative data have been obtained for the upper 3 m of the exposed sequence. On the base of pollen

Table 1. Radiocarbon and calendar dates for the Holocene sediments of the Sections at Solenoe Zajmishche.

Sample Number	Depth, m	¹⁴ C dates, yrs BP	Calendar (calibrated) dates, BP. (ca. ¹⁴ C yrs BP)
1	4,75–5,00	9560 ± 60	11060–10970
2	4,50–4,75	8500 ± 100	9500
3	2,25–2,50	3200 ± 60	3440–3400
4	2,00–2,25	2540 ± 130	2620
5	0,30–0,50	900 ± 60	900–800

assemblages, it may be dated to the late Subboreal and Subatlantic periods of the Holocene.

Palynological data were also derived for a 10-m thick layer penetrated by borehole N22 in the littoral area of the Volga Delta (45°43' N, 47°55' E) (–22 m asl) at the Damchik site of the Astrakhan Nature Reserve. The absolute age of this section's sediments identified by our colleagues in an international project from six ¹⁴C AMS dates varied from 7287 ± 44 to 3316 ± 34 BP. [Kroonenberg and Hoogendoorn, 2008]. The Holocene geological record in the sequences of the Volga delta [Bolikhovskaya and Kasimov, 2008] is incomplete, which has been confirmed by rigorous palynological and algological investigation of four sections of the delta carried out by K. Richards [Richards and Bolikhovskaya, 2010].

Currently, the Lower Volga is the place with the most arid and continental climate in the territory of not only the Volga region itself, but also of Europe as a whole. The area where the study sites are located – the Volga-Akhtuba floodplain and the Volga delta – belong to the province of the Volga-Akhtuba semi-arid landscapes [Nikolayev, 2007]. In the area of Solenoe Zajmishche, the Volga-Akhtuba floodplain is adjacent to a semi-desert zone dominated by sagebrush-gramineous communities. The Volga-Akhtuba province, which stretches from north to south for more than 350 km, differs from other provinces in this zone by a gradual depletion, in the same direction, of tree, shrub, and herbaceous flora and by

the greatest diversity of phytocoenoses. The Volga-Akhtuba floodplain is occupied by dense floodplain forests (mainly willow) and grassland communities (gramineous-herb, gramineous, gramineous-sedge, sagebrush-herb, etc.). Poplar, aspen, and maple grow in forests together with various types of willow. Oak (*Quercus robur*), ash (*Fraxinus excelsior*), elm (*Ulmus laevis*, *U. carpinifolia*), birch (*Betula pendula*, *B. pubescens*), and black alder (*Alnus glutinosa*) are less frequent. The dendroflora of the Volga delta is extremely poor: stands are formed mainly by white willow (*Salix alba*). Ash and elm can be found only occasionally in willow stands and only in the northern part of the delta. To the west and east, the Volga delta adjoins desert landscapes dominated by sagebrush (subgenera *Seriphidium* and *Dracunculus*). On the sands of the dunes, there are primarily tamarisk and dzhuzguna bushes. The vegetation of the littoral strip of the Caspian Sea consists mainly of halophytic and saltwort-sagebrush communities (*Halocnemum strobilaceum*, *Artemisia halophila*, *Suaeda altissima*, *S. confusa*). Thick growth of common reed grass (*Phragmites communis*) stretches along the sea. The poverty of the flora of the North Caspian Sea is the result of its development mainly during the Holocene.

We collected and studied samples from the modern alluvial and sub-aerial sediments in semiarid and arid areas of the Northern Caspian region. The results of the palynological studies clearly demonstrate that subrecent pollen assemblages of all samples analyzed adequately reflect the zonal type and structure of the pollen and

Table 2. Composition and percentage-share of dendroflora in pollen assemblages of the Sequences at Solenoe Zajmishche and Damchik-22 core

Section 1 Solenoe Zajmishche (Volga-Akhtuba floodplain)		Damchik-22 core (Volga delta)	
Taxa	Comnt during maxima, %	Taxa	Comnt during maxima, %
<i>Abies</i> sp.	3–5	<i>Abies</i> sp.	3–4
<i>Picea</i> sect. <i>Omorica</i>	22–48	<i>Picea</i> sect. <i>Omorica</i>	22–43
<i>Picea</i> sect. <i>Picea</i>		<i>Picea</i> sect. <i>Picea</i>	
<i>Pinus</i> subgenus <i>Haploxylo</i> n	12–26	<i>Pinus</i> subgen. <i>Haploxylo</i> n	1
<i>Pinus sibirica</i>		–	
<i>Pinus sylvestris</i>	45–58	<i>Pinus sylvestris</i>	45–55
<i>Betula pendula</i>	15–22	<i>Betula pendula</i>	46–67
<i>B. pubescens</i>		<i>B. pubescens</i>	
<i>Betula</i> sect. <i>Fruticosa</i>		<i>Betula</i> cf. <i>fruticosa</i>	
<i>Betula</i> cf. <i>nana</i>		<i>Betula</i> cf. <i>nana</i>	
<i>Salix</i> sp.	42–46	<i>Salix</i> sp.	63–75
<i>Alnus glutinosa</i>	4–11	<i>Alnus glutinosa</i>	12–20
<i>A. incana</i>		<i>A. incana</i>	
<i>Corylus avellana</i>	21–31%	<i>Corylus avellana</i>	13–20%
<i>Corylus colurna</i>		–	
<i>Fagus sylvatica</i>		–	
<i>Fagus orientalis</i>		<i>Fagus orientalis</i>	
<i>Quercus robur</i>		<i>Quercus robur</i>	
<i>Quercus petraea</i>		<i>Quercus petraea</i>	
<i>Carpinus betulus</i>		<i>Carpinus betulus</i>	
<i>Carpinus caucasica</i>		–	
<i>Carpinus orientalis</i>		<i>Carpinus orientalis</i>	
<i>Tilia cordata</i>		<i>Tilia cordata</i>	
<i>Tilia platyphyllos</i>		–	
<i>Tilia tomentosa /argentea/</i>		<i>Tilia tomentosa /argentea</i>	
<i>Tilia dasystyla</i>		–	
<i>Ulmus laevis</i>		<i>Ulmus laevis</i>	
<i>Ulmus carpini</i> folia / <i>foliaceae/</i>		<i>Ulmus carpini</i> folia	
<i>Ulmus glabra /scabra/</i>		–	
–		<i>Ulmus</i> cf. <i>pumila</i>	
<i>Fraxinus</i> sp.		<i>Fraxinus</i> sp.	
cf. <i>Morus</i> sp.		cf. <i>Morus</i> sp.	
<i>Tamarix</i> sp.		cf. <i>Tamarix</i> sp.	
–	<i>Elaeagnus</i>		
<i>Euonymus</i> sp.	<i>Euonymus</i>		
<i>Caprifoliaceae</i>	–		
<i>Juniperus</i> sp.	<i>Juniperus</i> sp.		
–	<i>Juniperus</i> cf. <i>foetidissima</i>		
Total number of taxa	35	Total number of taxa	30

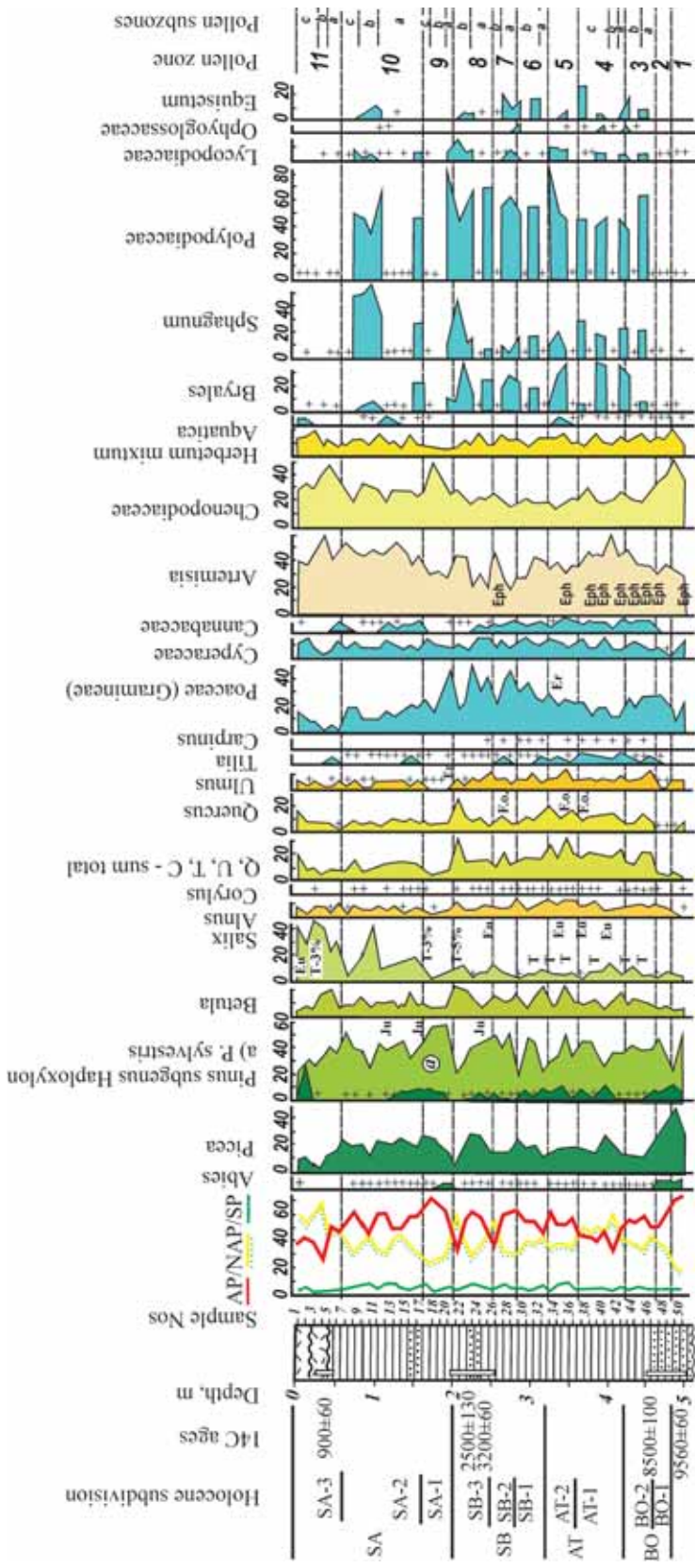


Figure 1. Pollen-spore percentage diagram of Section 1 near the site Solenoye Zajmishche.

1 – sample locations for radiocarbon dating (^{14}C); 2 – arboreal pollen (AP); 3 – non-arboreal pollen (NAP); 4 – spores (SP); 5 – pollen content less than 2%; 6 – *Juniperus*; 7 – *Tamarix*; 8 – *Euonymus*; 9 – *Fagus sylvatica*; 10 – *Fraxinus*; 11 – *Ericales*; 12 – *Ericales*; 13 – *Ephedra*

spore producing plant communities. Detailed descriptions of the pollen assemblages and reconstructed paleophytocenoses, as well as the methodological background of performed reconstructions, are given in a number of our previous publications [Bolikhovskaya, 1990; Bolikhovskaya and Kasimov, 2010; Bolikhovskaya and Kasimov, 2008].

Here, referring to the methodological aspects, we emphasize that climatological and stratigraphical interpretations of the fossil assemblages from the delta deposits were based on characteristic features of the pollen records of Solenoe Zajmishche, i.e., the chronology of peaks of pollen of dark coniferous trees, broadleaf trees, grass and xerophytic shrub communities, etc. Comparison of the composition and degree of participation of arboreal pollen in the assemblages of Solenoe Zajmishche and Damchik confirms the promising prospect of using the delta sequences for the investigation of vegetation and climate change in the littoral Caspian region and, consequently, of arriving at conclusions on sea level fluctuations. First, it appears that tree and shrub species of Damchik palynoflora, which consists of 30 taxa, is close to the arboreal pollen of Solenoe Zajmishche, which contains 35 taxa (Table 2). The maximums of percentages of coniferous pollen (i.e., fir *Abies* sp.), spruce (*Picea* sect. *Picea*), and common pine (*Pinus sylvestris*) in the dendroflora are also similar. However, systematic differences are also clearly seen, undoubtedly due to the differences in geography and paleozonal position of the sequences, as well as to the differences in edaphic conditions of growing trees in the floodplain and littoral areas. The following species are absent in the fossil Damchik dendroflora: Siberian pine (*Pinus sibirica*), common beech (*Fagus sylvatica*), some types of linden (*Tilia platyphyllos*, *Tilia dasystyla*), rough elm (*Ulmus glabra /scabra/*), and some representatives of the Caucasian forests, i.e., Caucasian hornbeam (*Carpinus caucasica*), hazelnut- tree or bearnut-tree (*Corylus colurna*). In addition, peaks of pollen of birch

(*Betula pendula*, *B. pubescens*), alder (*Alnus glutinosa*, *A. incana*), willow (*Salix* spp.), and of a complex of deciduous trees (*Quercetum mixtum*) are also markedly different.

The most dynamic components of the pollen assemblages of the Solenoe Zajmishche sequences were the pollen of Scots pine, cedar, spruce, deciduous trees (beech, oak, hornbeam, linden, elm, etc.), gramineous grasses, sagebrush, goosefoot, and spores of ferns and green and sphagnum mosses. Eleven spore-pollen zones were isolated on the spore-pollen diagrams based on the dynamics of major components and the stratigraphical-paleogeographical palynoflora characteristics (Figs. 1 and 2). Most of these zones were subdivided into a number of subzones and smaller palynostratigraphical units, which reflect successive changes of climate and the structure of zonal and local vegetation during the Holocene.

THE RESULTS OF LANDSCAPE AND CLIMATE RECONSTRUCTIONS

A detailed stratigraphical interpretation of the sediments studied and a description of 26 phases in the development of vegetation and climate during the Holocene in the Lower Volga region were performed using the palynological data and results of ¹⁴C dating obtained in this study (Table 3).

We correlated the reconstructed paleoclimatic events to the Caspian Sea level fluctuations defined according to geological, geomorphological, malacological, and other studies (Fig. 3).

PRE-BOREAL PERIOD (~10500/10300 – 9500/9200 BP)

The oldest sediments of Solenoe Zajmishche (4,8–5 m), dated to pollen zone 1 (see Fig. 1), are characterized by the dominance of tree pollen, mainly coniferous species (fir, spruce, cedar pine, and common pine). It is precisely here, that the maximal, for the Holocene sediments, pollen content of spruce (48 %) was found. In general, the amount

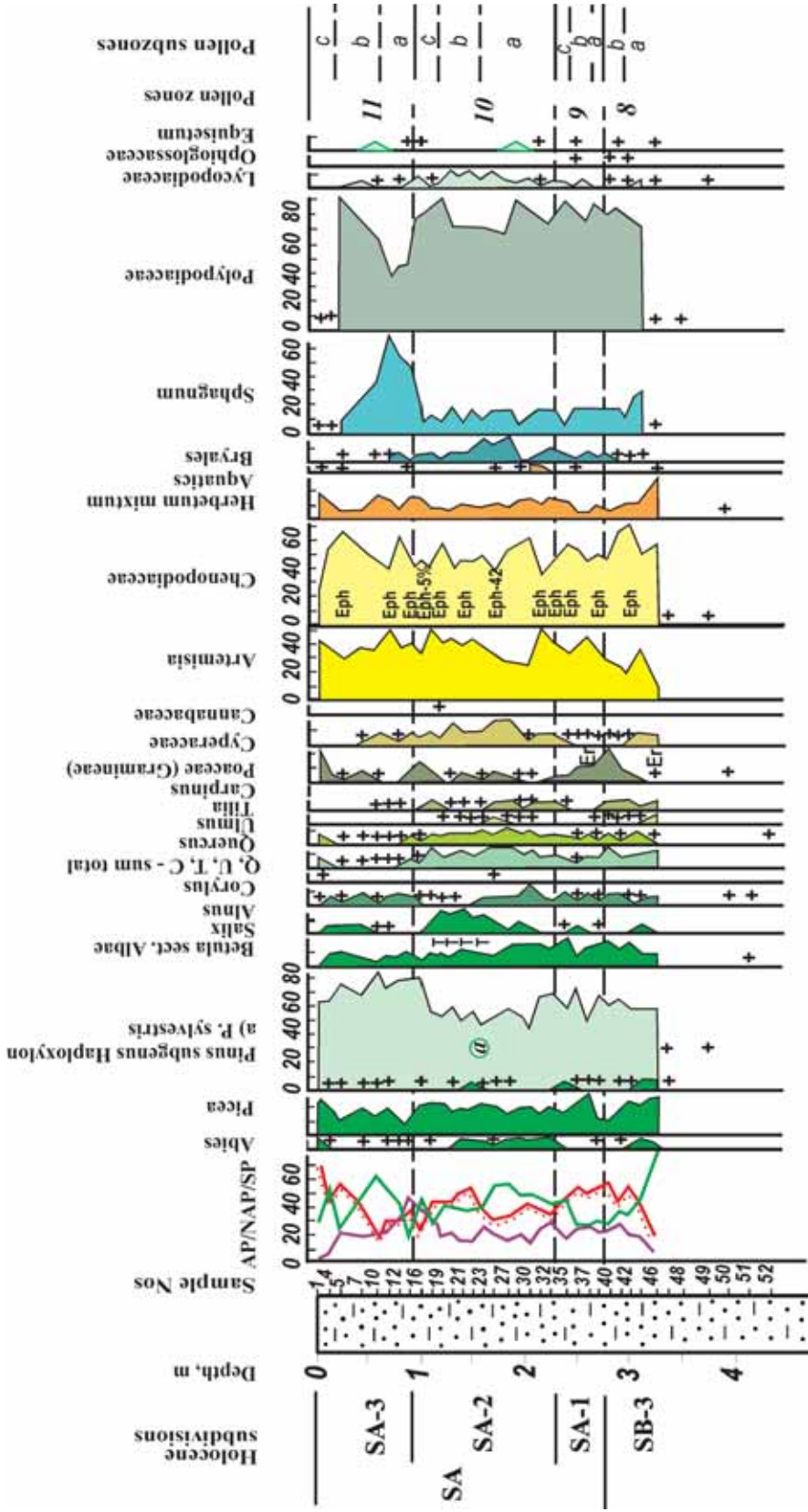


Figure 2. Pollen-spore percentage diagram of Section 2 near the site Solenoye Zajmishche (symbols are the same as in Figure 1).

Table 3. Climatic stages of the Holocene in the Lower Volga Region, their characteristic and ages according to pollen analysis and ^{14}C dating of the deposits from the Solenoe Zajmishche

Holocene subdivisions	^{14}C ages of climatic stages, years BP		Zonal vegetation	Climate
	Conventional	Calibrated		
SA-3	200-0	250-0	Semi-desert	Relatively warm and arid
	400-200	500-250	Semi-desert	Temperature fall, humidification
	700-400	670-500	Semi-desert	Temperature rise, humidification
	900-700	840-670	Semi-desert	Temperature fall, aridization
	1100-900	1030-840	Dry steppe	Cool and arid
SA-2	1300-1100	1270-1030	Steppe	Temperature rise, humidification
	1500-1300	1400-1270	Dry steppe	Temperature fall, aridization
	1700-1500	1600-1400	Steppe	Relatively warm and relatively humid
	1800-1700	1720-1600	Steppe	Warm and arid
	2100-1800	2080-1720	Steppe	Relatively warm and relatively humid
SA-1	2300-2100	2340-2080	Dry steppe	Temperature fall, continentalization
	2500-2300	2600-2340	Steppe	Temperature fall, humidification
SB-3	2700-2500	2780-2600	Steppe	Relatively warm and arid
	3500-2700	3770-2780	Forest-steppe	Relatively warm, humidification
SB-2	3700-3500	4040-3770	Dry steppe and semi-desert with Chenopodiaceae – Artemisia assemblages	Temperature fall, aridization
	4200-3700	4770-4040	Forest-steppe; mixed forests with broadleaved, birch and conifer stands	Warm and humid climate (III climatic optimum)
SB-1	4800-4200	5540-4770	Forest-steppe	Temperature fall and humidification rise
	5000-4800	5740-5540	Forest-steppe	Temperature fall, aridization
AT-2	6100-5000	6970-5740	Forest-steppe; mixed forests with hornbeam, beech, elm, lime, birch and conifer stands	Warm and humid (II – main – climatic optimum)
AT-1	7400-6100	8240-6970	Steppe	Warm and relatively arid
	7600-7400	8400-8240	Dry steppe with Chenopodiaceae – Artemisia assemblages	Temperature fall, aridization
	8000-7600	8900-8400	Steppe	Warm and relatively humid

Holocene subdivisions	¹⁴ C ages of climatic stages, years BP		Zonal vegetation	Climate
	Conventional	Calibrated		
BO-2	8300-8000	9350-8900	Steppe	Temperature fall, continentalization
	8500-8300	9500-9350	Forest-steppe; mixed forests with hornbeam, elm, lime, birch and conifer	Warm and humid (I climatic optimum)
BO-1	9200-8500	10350-9500	Steppe with Chenopodiaceae assemblages, park pine forests	Cool, continentalization
PB-2	10000-9200	11500-10320	Forest-steppe dominated by <i>Picea</i> , <i>Pinus</i> , <i>Abies</i>	Relatively cool and humid

of microfossils of dark-coniferous species (fir, spruce, and cedar pine) approached 60 %; the pollen of deciduous trees, i.e., the grains of oak and elm, comprised 6-7 %. In the group of grasses and small-shrubs, the pollen grains of xerophytes,

i.e., goosefoot, sagebrush, and ephedra, dominated. The spore-group contained the grains of boreal forest clubmoss species (*Lycopodium annotinum* L., *L. lagopus* (Laest.) Zinzerl.), and fern *Athyrium filix-femina* (L.) Roth).

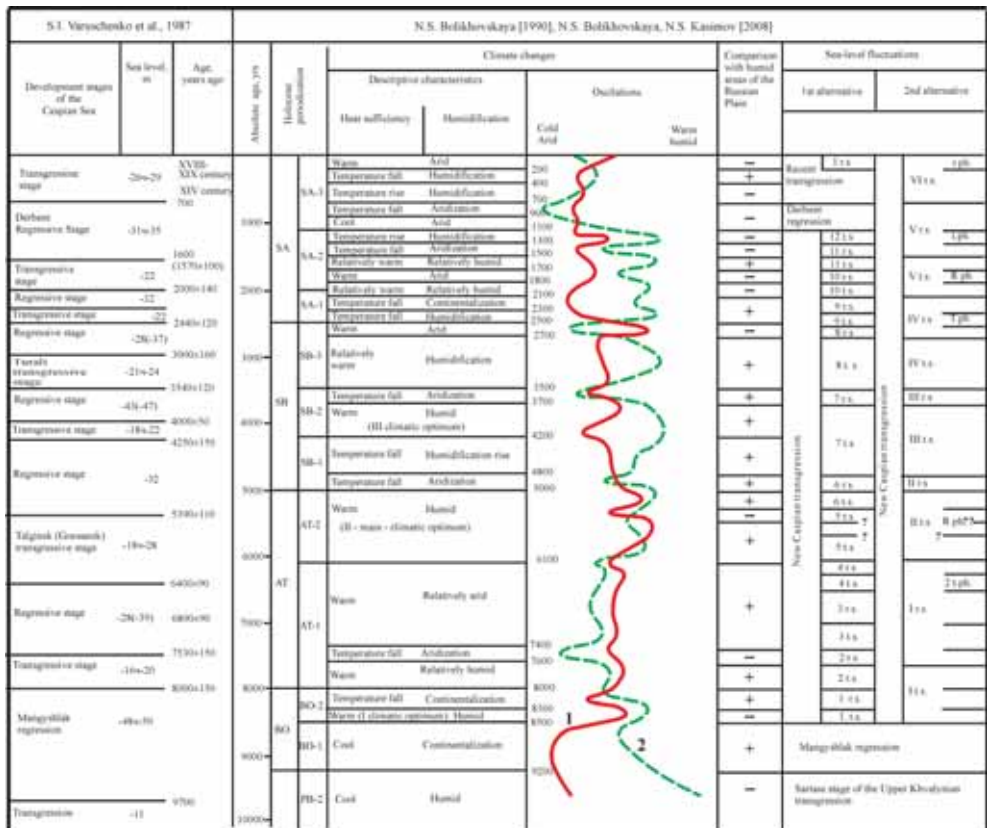


Figure 3. Reconstruction of climate changes in the Lower Volga Region during the Holocene and their correlation with transgressive and regressive stages of the Caspian Sea.
 1 – curve of fluctuations of heat supply; 2 – curve of fluctuations of moisture availability

These deposits may be dated to the second half of the Pre-Boreal period (PB-2) of the Holocene. This dating was based on the climato-stratigraphical and climato-phytocenotical reconstructions, the location in the section, and the ^{14}C date of $9560 \pm \pm 60$ BP at the depth of 4,75–5,0 m. It may be determined from interpolation calculations that these deposits were formed in the interval ~10000–9200 BP. We correlated this period to the Pereslavl cooling in the central regions of the East European Plain and to the final phase of the Sartass transgressive stage of the Late Khvalynian transgression of the Caspian Sea. The age of this stage is defined by the dates of 9700 ± 190 and $13110 \pm \pm 490$ BP based on ^{14}C dating of the Sartass sediments of Dagestan [Leontiev et al, 1976]; sea level of this stage was identified at –10 to –12 m asl from the data on sections of ancient beach ridges [Rychagov, 1997; and others].

At that time, in a cold and relatively humid continental climate, the Lower Volga region was dominated by forest-steppe landscapes with the extensive development of dark coniferous forests. Spruce forests occupied the most favorable habitats of the Volga floodplain, i.e., leached depressions of the inner floodplain rich in loamy sediments, depressions adjacent to the terraces, and the slopes facing the river. There, spruce grew together with fir, cedar pine, oak, and elm. Grass cover of these park forests consisted of scattered turf grass patches, ferns, clubmoss, horsetail, and herbs. Eroded sites (with sparse xerophytic shrubs and small-shrubs) and salinized substrates (with halophytic communities), developed during the earlier arid climatic phase, prevailed in open landscapes. Sites with reworked sands, i.e., natural storage reservoirs of fresh water, were the areas of sparse pine forest growth.

The palynological analysis of the Sartass marine sediments from the boreholes in the Northern Caspian region performed by V.A. Vronsky [Bukreeva and Vronsky, 1995] showed that during their formation in the littoral areas they were dominated by arid steppe vegetation with some wooded sites.

BOREAL PERIOD (~ 9500/9200–8000 BP)

Pollen zones 2 (4,6–4,8 m) and 3 (4,2–4,6 m) represent the deposits of the Boreal period (BO) and suggest that, during this Holocene phase, the study area was the zone of development of steppe and forest-steppe landscapes. Under the influence of climate fluctuations, significant changes in plant formations continued to occur there for over 800 years.

During the Early Boreal period (BO-1; pollen zone 2), when the climate cooled down and its continentality increased, steppes with the predominance of herb-gramineous and clubmoss-sagebrush formations became the dominant vegetation type in the Lower Volga region. Biotopes with the most favorable edaphic conditions were occupied by sparse spruce-pine stands with some fir, cedar pine, and isolated trees of oak and elm. The composition of palynoflora, reconstructed paleovegetation, and ^{14}C age of 8500 ± 100 BP (4,5–4,75 m) allowed us to correlate this sub-period to the Mangyshlak regressive stage of the Caspian sea, identified by most researchers in the range of ~ 9000–8000 yr BP [Leontiev and Rychagov, 1982; Varuschenko et al, 1987; Leontiev et al., 1976; etc.]. Semi-desert and desert landscapes dominated the dry shelf that was free of the Caspian Sea, which level dropped to the marks of no less than – 50 m during the Mangyshlak regression [Abramova, 1980; Vronsky, 1987]. The palynological analysis of the continental Mangyshlak sediments exposed in the boreholes in the northern Caspian Sea and analysis of marine sediments of the Mangyshlak regression from deep columns of the Middle Caspian that completely lacked woody vegetation, showed that the littoral area was inhabited only by the clubmoss family species, i.e., salt grass, glasswort, sarzasan, and other plants of salinized littoral zones [Bukreeva and Vronsky, 1995].

The sediments of the second part of the Boreal period of the Holocene (BO-2) were

deposited during the first climatic phase of the emerging New Caspian transgression of the Caspian Sea.

The Mid Boreal phase (pollen subzone 3a, Fig. 1) marks the beginning of a long-term invasion of deciduous dendroflora into the study region, most vividly expressed in the dominance of or a significant presence of broad-leaved forest formations in several forest-steppe and steppe phases of the subsequent Atlantic and Subboreal periods. Through interpolation, the age of this phase was estimated at ~ 8500–8300 BP. We can conclude, therefore, that the chronological framework of the preceding (Mangyshlak) regression was narrower than previously thought. Probably, the maximum decrease in the level of the Caspian Sea during the Mangyshlak regression occurred in the interval of ~ 9200–8500 BP.

We correlated the phase of the dominance of forest-steppe landscapes under significant warming and moistening of climate to the first Holocene climatic optimum of the Caspian, when the stands of riparian forests were dominated by deciduous trees: oak, common hornbeam (*Carpinus betulus*), elm, and linden. Oak and elm (*Quercus robur*, *Q. petraea*, *Ulmus laevis*, *U. foliacea*) were the edificatory species; the undergrowth contained oriental hornbeam (*Carpinus orientalis*) and hazel. The grass cover of forest communities was dominated by gramineous plants and grasses. Open spaces were occupied mainly by herb-gramineous formations. In this case, the heterogeneity of edaphic conditions determined the diverse composition of grass-shrub cover of steppes expressed by the development, along with these formations, of xerophytic and halophytic cenoses.

The final steppe phase of the Boreal period (3b) marked a short-term climate cooling dated to ~8300–8000 BP. The paleolandscapes of the Lower Volga region had greater presence of spruce and pine formations. The area of deciduous forests decreased; the share of mesophytic species,

i.e., ordinary hornbeam and linden, also decreased in these formations. Oak and elm continued to play the dominant role only in the floodplain forests. Willow stands spread into the floodplain sites. Published sources indicate that cooling at the boundary of the Boreal and Atlantic periods of the Holocene also occurred in many neighboring and remote regions of Northern Eurasia (the Lower Don, Ulyanovsk Volga Region, Bashkortostan, Eastern Transcaucasia, etc.) [Blagoveschenskaya, 1986; Klimanov and Nemkova, 1988; Mamedov and Veliyev, 1988; Spiridonova, 1991; etc.].

ATLANTIC PERIOD (~ 8000–5000 BP)

Vegetation and climate change that occurred in the Lower Volga region during the Atlantic period are reflected in the assemblages of pollen zones 4 and 5 (see Fig. 1).

Three phases in the evolution of steppe landscapes that dominated throughout the Early Atlantic time (AT-1) are represented by pollen zones 4a, 4b and 4c (3,6–4,2 m).

Climatic conditions and vegetation cover of the early phase of the Atlantic period (4a) with a significant expansion of deciduous forest formations dated to ~ 8000–7600 BP were close to a relatively humid forest-steppe phase (3a) of the Mid Boreal warming. Therefore, we have concluded that there was an extended phase of climate warming and humidization during ~ 8500–7600 BP interrupted briefly by the Late Boreal cooling. This was the climatic phase that corresponds to the early transgressive stage of the New Caspian basin, for which S.I. Varuschenko et al. [1987] indicate the ¹⁴C age within the range of 8000 ± 150 and 7530 ± 150 BP and the rise of sea level to –16 to –20 m asl. G.I. Rychagov [1997] considers this phase to be the maximal (according to him, the coastline was on –19 to –20 m asl) and dates it to ~ 8000–7000 based on the results of the study of coastal forms, terraces, and marine sediments of the Western Caspian Sea region (see Figure 2, 3. in [Lower Volga..., 2002]).

In the range of ~7600–7400 BP, pollen subzone 4b marks a short-term phase of aridization and cooling of climate with a reduction of deciduous forests and the expanse of the area of turf-free ecotopes. The pollen of this period is dominated by grass and shrubs, the maximal (for the sediments of the Atlantic period) peak of sagebrush, by a declining share of linden, and by a greater role of willow.

The next phase in the development of vegetation and climate, reconstructed from the spectra of pollen subzone 4c, reflects relatively long warming in the range of ~7400–6100 BP. It was a period of not only warm but also of a relatively dry climate. Given the climatic features of the last arid phase, we assume that the lowering of the New Caspian basin could have occurred not only in 7600–7400 BP but even later, i.e., in ~7600–6100 BP. This regressive phase corresponds to the regressive phase dated by ^{14}C to 6800 ± 90 and 6400 ± 90 BP with -28 (-39) m asl [Varuschenko et al., 1987].

Steppe remained the zonal vegetation type of the Lower Volga region in 7400–6100 BP. Global warming led to the growing contrast between zonal and intrazonal landscapes and between their plant formations. On watersheds, the area of open landscapes with grass-shrub communities expanded and their differentiation increased. Within the Volga-Akhtuba Valley, improved site conditions contributed to the enrichment of the composition of the deciduous forests. There were many other species in the mixed oak forests of the central part of the floodplain, e.g., linden (*Tilia cordata*, *T. dasystyla*), elm (*Ulmus laevis*), field elm (*U. carpinifolia*), common hornbeam (*Carpinus betulus*), oriental beech (*Fagus orientalis*), alder, etc. Species-depleted forest communities of less favorable habitats were composed of oak-elm, elm, alder, and willow stands. The undergrowth was represented by hazel (*Corylus avellana*), euonymus (*Euonymus* sp.), and willow. The grass cover was dominated by gramineous plants and herbs. Tree trunks were covered with vines of hops (*Humulus*

lupulus), which was constantly present, since the Mid Boreal period and until the end of the Subboreal time, in the Volga-Akhtuba forests.

The vegetation cover of the Late Atlantic period is reflected by pollen zone 5 (3,2–3,6 m). Its taxa composition is close to that of pollen zone 4. However, it differs from the latter in the dominance of the tree and shrub pollen, in increased (up to 31 %) amount of thermophilic dendroflora pollen, in the presence of Caucasian hornbeam (*Carpinus caucasica*), and in a greater role of pollen of alder, grasses, *Ericales*, and fern spores (see Fig. 1).

The late Atlantic interval (AT-2), which lasted from 6100 to 5000 BP, is characterized by the dominance of steppe vegetation and the highest, in the Holocene, number of thermophilic and moisture-loving species. This was the major Holocene climatic optimum within the study area in terms of the intensity and balance of heat supply and moisture availability for vegetation.

We associated the entire Late Atlantic period with the transgressive phase of the New Caspian basin (-18 to -28 m asl [Varuschenko et al, 1987] and -21 m asl [Rychagov, 1997]) and the ^{14}C age of 5940 ± 100 , 5540 ± 110 , and 5390 ± 110 BP). Using the palynological data, we identified the relative momentum of climate continentalization within this phase, which could have caused a short-term drop in sea level [Bolikhovskaya, 1990] ~5500–5400 BP.

Our reconstructions showed that during the Late Atlantic time, the forest belt of the Lower Volga Valley consisted of mixed oak forests with common and Caucasian hornbeam, oriental beech, and various types of elm, linden, birch and other trees. There were also oak-elm, elm, and pine stands. The spore assemblages of the ferns *Athyrium filix-femina*, *Botrychium matrycarifolium*, of the clubmoss *Diphazium complanatum*, and of other species are indicative of meadow and moisture-loving species in the grass cover of

the forests and the forest fringes. The stands of island placoric forests, confined to narrow valleys, steppe “saucers”, estuaries, and other depressions with a low level of groundwater, were the habitats of species less demanding for moisture, i.e., pine, birch, elm, English oak, etc.

Furthermore, the palynological studies of the Holocene sediments of the lower reaches of the river Ural found that, during the phase of the maximum Holocene warming and humidization in the Northern Caspian Sea region, there was the dominance of steppes with pine and deciduous species of oak, hornbeam, linden, and ash [Yakhimovich et al., 1986].

SUBBOREAL PERIOD (~5000–2500 BP)

The variability of the sediments of the Subboreal period (SB) (2,0–3,2 m) was increasing upward in the stratigraphy. Three pollen zones were isolated there; each zone was in turn subdivided into two pollen subzones. This fact indicates more frequent alternations of landscape-climatic conditions in the SB period compared to the Atlantic period.

Pollen zone 6 (2,8–3,2 m) allowed us to reconstruct the landscapes of the first one-third of the Subboreal period (SB-1) transformed under the influence of climate cooling, which began ~ 5000–4200 BP. This is manifested in the spore-pollen assemblages by decrease of the share (to 15–18 %) of the thermophilic tree pollen (due to decrease of the oak, elm, and linden pollen content and disappearance of the beech pollen). There is no reason to assume a fundamental change in the boundaries of the natural zones, but deterioration of climatic conditions led to a reduction in the forest cover and degradation of broad-leaved forest stands in still prevalent forest-steppe landscapes. By their very structure, the forests of the Volga-Akhtuba floodplain were close to the forests of the second half of the Early Subatlantic period. Clay-sediment formation in the oxbow lake during the first phase of the Early Subboreal

time took place in conditions of both cooling and aridization of climate, since in the lower part of the examined layer (pollen subzone 6a), the pollen of grass-shrub plants (where xerophytic species dominated) reached 45 %. The amount of arboreal (including spruce), shrub, grass, and sedge pollen grew upward in the stratigraphy (pollen subzone 6b).

The cooling, in combination with the aridization of climate on the turn of the Atlantic and Subboreal periods, caused the next regressive phase of the New Caspian basin, which, according to the pollen data, was of a short duration (approx. from 5000 to 4800 BP). The data obtained confirmed the assumption made earlier by A.N. Varuschenko et al. [1980] that the most likely period of regression to –32 m (Izberbash) was 3100–2400 BP (~ 5000–4400 BP). Later (~ 4800–4200 BP) and until the end of the Early Subboreal period, this cooling was accompanied by climate humidization and, possibly, by a gradual rise in sea level.

Pollen zone 7 (2,5–2,8 m) describes the Mid Subboreal warming (SB-2) that took place in the interval ~4200–3500 BP. The assemblages of pollen subzone 7a were dominated by the pollen of broadleaf species (up to 21 %), coniferous trees (mainly pine and spruce), gramineous plants (in grass-shrub formations), and by the pollen of a variety of herbaceous species. This fact suggests that the vegetation of the early phase was developing in a warm and relatively humid climate. At that time, prevailing forest-steppe landscapes had oak and oak-elm forests mixed with beech, hornbeam, linden, and elm (*Quercus robur*, *Fagus orientalis*, *Carpinus betulus*, *Tilia cordata*, *T. dasystyla*, *T. tomentosa*, *T. rubra*, *Ulmus laevis*, *U. glabra*, *U. carpinifolia*), spruce-pine forests, and herb-gramineous steppe formations. This period of warming and humidization (~ 4200–3700 BP), i.e., the third Holocene optimum of the Northern Caspian region, was inferior to the main (the second, Late-Atlantic) optimum in duration and thermal characteristics. It corresponds to the transgressive phase of sea level rise to –18 to –22 m asl in the ¹⁴C dated interval

of 4250 ± 150 and 4000 ± 50 BP isolated by S.I. Varuschenko et al. [1987].

This sub-period ended with a pulse climate drying ~ 3700 – 3500 BP (pollen subzone 7b), which led to the dominance of the steppe and semidesert communities on watersheds, to the degradation of herb-gramineous steppes and riparian deciduous forests, and to the expanse of the area of eroded sites with sparse cover of sagebrush, *Ephedra*, and other xerophytes. This phase corresponds to the regressive Caspian stage in the interval from 4000 ± 50 to 3540 ± 120 BP [Varuschenko et al., 1987].

Changes in phytocenotic and climatic conditions during the Late Subboreal phase (SB-3) (~ 3500 – 2500 BP) are reflected by pollen zone 8 (2,0–2,5 m). The dominance of arboreal pollen (spruce, pine, and broadleaf species), the dominance of the pollen of gramineous plants, forbs, and grasses, and the dominance of ferns in the spore-grain assemblages indicate that the Late Subboreal phase began with the humidization of climate that lasted approximately from 3500 to 2700 BP. This humidization led to the southern shift of dark-coniferous species boundary, to the return of steppes to the Lower Volga territory, to the emergence of elm (*Ulmus laevis*, *U. glabra*, *U. carpinifolia*) as the dominant species in the riparian deciduous forests, to a mesophication of grass cover of the Volga-Akhtuba floodplain, and to the dominance of herb-gramineous and gramineous cenoses.

The phase of climate humidization corresponds to the Late Subboreal cooling of the central regions of the Eastern European Plain and to the fourth (to -23 to -23 m asl, according to Rychagov [1997]) or to the Turalinskaya (according to Varuschenko et al. [1980]) transgressive phase of the New Caspian basin.

In the upper part of the section, the grass-small-shrub xerophytic pollen is prevalent in the assemblages of pollen subzone 8b. The share of spruce and pine pollen falls

dramatically. The pollen of small leaf and broadleaf trees begins to dominate. The amount of pollen of thermophilic arboreal elements reaches 30 %. The palynological data indicate that during the final phase of the Subboreal period, warming and increased dryness of climate, which lasted roughly from 2700 to 2500 BP, caused a new wave of steppification of the vegetation cover. In the open steppe landscapes of the Lower Volga region, goosefoot-sagebrush associated with gramineous formations. The composition of arboreal species was substantially depleted: conifer stands degraded almost entirely and hornbeam disappeared. At the same time, the area of forests consisting of oak and oak-elm with admixture of linden and beech (*Fagus sylvatica* L.) increased significantly. These forests were prevalent among the riparian forest formations of the Volga-Akhtuba and grew together with small leaf stands (birch, alder, and willow) and thickets of halophilic tamarisk (*Tamarix* sp.). In the grass-small-shrub layer, graminous grasses, sedges, and sagebrush dominated. The reduction in the area of the oxbow paleo-lake caused the waterlogging of its shoreline zone and the overgrowing of sphagnum moss. Judging from the palynological records, during all subsequent phases of the evolution of the Holocene vegetation of the Lower Volga, broad-leaved forests were significantly less common.

We correlated this phase of a relatively short-term aridization and warming of climate to the Alexandrbajskaya phase isolated by A.N. Varuschenko et al [1980], i.e., the regressive stage (sea level drop to -37 m asl).

SUBATLANTIC PERIOD (~ 2500 BP TO THE PRESENT TIME)

The results of ^{14}C dating (Table 1), the spore-pollen records of the upper 2-m thick clay layer from the oxbow lake (see Fig. 1), and the records of the floodplain alluvium of S2 (Fig. 2) indicate that, for the past 2500 years, the study area of the Northern Caspian region was initially dominated by steppes (\sim from 2500 to 900 BP). These steppes were replaced

later (from 900 BP to the present time) by semi-desert landscapes. The climate was generally colder and more continental than the climate of the Atlantic and Subboreal periods. The assemblages of pollen zones 9, 10, and 11, each subdivided into several palynostratigraphical units, suggest multiple changes of climatic conditions and the transformation of vegetation during the Subatlantic period.

The assemblages of the Early Subatlantic (SA-1) interval (~2500–2100/2000 BP) are mainly of the steppe type (pollen zone 9: 1,6–2,0 m in S1 and 2,3–2,75 m in S2). During cooling and humidization of climate, the initial phase (~2500–2300 BP) was dominated by open steppe and meadow-steppe (mainly gramineous) communities with patches of spruce-pine forests mixed with oak, ash (*Fraxinus* sp.), and linden (pollen subzone 9a). During the next phase (~2300–2100 BP), under the influence of climate continentalization and cooling, the deciduous stands almost completely disappeared from the vegetation of the Lower Volga Valley; they were replaced by pine park forests with admixture of spruce (pollen subzone 9b). Xerophytes dominated in the sparse grass-small-shrub cover of dry steppes that prevailed at that time. The Early Subatlantic interval ended with the emerging phase of climate humidization (~2100–2000 BP), which led to a greater spread of dark coniferous and broadleaf species in the forests and gramineous plants, sedges, and mesophilic species in the grass cover (pollen subzone 9c).

As shown by the assemblages of pollen zone 10 (0,6–1,6 m in S1 and 0,65–2,3 m in S2), the evolution of vegetation of a long-lasting Mid Subatlantic (SA-2) sub-period (~2100/2000–1100 BP) was influenced mainly by the continuing mitigation of climate continentality. The amount of arboreal thermophilic pollen increased in the assemblage of pollen subzone 10a (oak, elm, and linden together, up to 14%), while steppe remained the zonal vegetation type of the initial phase. Warming promoted

an even greater spread of mixed oak forests (English and sessile oak *Quercus robur* and *Q. petraea*, elm *Ulmus carpinifolia* / *foliaceae* /, rough elm *Ulmus glabra/scabra* /, cardiophyllous linden *Tilia cordata*, etc.) and the growth of hazel in the undergrowth of the wooded areas in river valleys, ravines, and depressions. The grass-small-shrub cover of the steppe coenoses was composed of herb-gramineous and haze-sagebrush communities. This long phase of warming and humidization of climate, dated to the interval ~2000–1500 BP corresponds to the Ulluchayskaya transgressive stage of the Caspian Sea that is ¹⁴C dated to the interval 2000 ± 140 – 1570 ± 100 BP according to S.I. Varuschenko et al. [22]. Perhaps within this transgressive stage ~1800–1700 BP, there was a short-term sea level drop caused by decrease in precipitation.

The next phase in the landscape development is reflected in the assemblages of pollen subzone 10b (0,8–1,05 m in S1 and 1,15–1,55 m in S2) with the overall reduced amount of the tree and shrub pollen (including spruce, pine, and broadleaf species) and the dominance of willow pollen. The grains of sagebrush and the *Chenopodiaceae* family dominate in the pollen of grass and shrub assemblages, while sphagnum moss prevails among the spores. These and other palynological characteristics indicate that cooling and aridization of climate in the interval ~1500–1300 BP significantly reduced the role of coniferous and broadleaf trees in the forests of the Volga Valley and promoted the development of willow species in the riparian stands. On placoric sites, the area of steppe communities with the prevalence of sagebrush and some species of the *Chenopodiaceae* family (as subdominants) expanded. Decrease in the mirrors of oxbow lakes led to the waterlogging and to the growth of the eutrophic sphagnum moss, horsetail, and other plants of wet floodplain ecotopes. It is possible that this stage of cooling and aridization of climate in the interval ~1500–1300 BP corresponds to the first phase of the Derbent regression of the Caspian Sea.

New warming and humidization of climate is reflected in the interval ~1300–1100 BP

by the assemblages of pollen subzone 10c (0,6–0,8 m in S1 and 0,95–1,15 m in S2). During this phase, the floodplain forests were dominated by spruce-pine, oak, and oak-elm stands. At the same time, the role of gramineous plants and sedges increased in the grass-shrub cover dominated by sagebrush.

Throughout the Late Subatlantic period (SA-3), i.e., during the last ~ 1100 years, the study area remained under unstable climatic conditions (pollen zone 11, 0,0–0,6 m in S1 and 0,0–0,95 m in S2). The initial phase of modern vegetation development is characterized by pollen subzone 11a. Amid the growing role of the pollen of grass-small-shrub communities (judging from the high content of the *Chenopodiaceae* grains), the amount of spruce, pine, and oak pollen decreased dramatically during that time while the role of small leaf tree pollen (i.e., willow (*Salix* sp.) and birch (*Betula pendula*, *B. pubescens*)) increased. Climatic and phytocoenotic conditions of this dry-phase that reflects climate cooling and aridization ~1100–900 BP were close to the interval of cooling and aridization of the interval 1500–1300 BP. The maximum of the Late Subatlantic climate cooling and aridization in the interval ~900–700 BP was marked by the absolute prevalence of the semidesert and desert associations and almost complete disappearance of broadleaf species from the Volga-Akhtuba forest belt composed primarily of willow stands (pollen subzone 11b – 0,3–0,4 m in S1 and 0,2–0,65 m in S2).

The combined assemblages of pollen subzones 10b, 10c, 11a, and 11b suggest that the Derbent regressive stage of the Caspian basin (isolated by D.C. Leontiev and G.I. Rychagov [1982] in the interval 1400–800 BP and by S.I. Varuschenko et al. [1987] from the middle of the V century to the XIV century (~1550–700 BP)) was probably aggravated by rising sea levels caused by climate warming and humidization ~1300–1100 BP; it is possible the regression to the lowest level of –34 to –35 m asl occurred ~ 900–700 BP.

Since the time level specified by the radiocarbon date of 900 ± 60 yr BP (cal. 900–800 BP) the Volga-Akhtuba region has been occupied by the arid semi-desert landscapes that are close to the modern autonomic semi-desert landscapes of the studied territory. This conclusion was reached based on analysis of the assemblages of pollen subzone 11c. The pollen assemblages from Sample 2 in S1 and Sample 4 in S2, where the amount of pollen of trees and shrubs increased (in the arboreal group, due to the cedar pine pollen), reflect cooling and humidization of climate in the interval ~ 400–200 BP and the greater expansion of coniferous species into the floodplain forests in the Northern Caspian region.

CONCLUSIONS

The research presented herein established the following dependencies in landscape-climatic changes in the Lower Volga region and in climate-dependent sea level fluctuations of the Caspian Sea during the Holocene.

1. Over the past 10,000 years, there were several changes in the vegetation cover and climate of the Lower Volga region. Palynological data indicate at least 26 phases in the evolution of the Holocene landscapes and climate of this territory. During the Early and Middle Holocene, in the interval ~ 10000–2500 BP, forest-steppe and steppe landscapes dominated under a more favorable and humid (compared to the modern time) climate in the study area. These landscapes underwent seven forest-steppe and seven steppe non-consecutive phases during their development. In the Late Holocene, in the interval ~ 2500–900 BP, there were eight phases that reflect the transformation of zonal and intrazonal phytocoenoses. During the last 900 years, the territory of the Lower Volga became the area of development of desert-steppe and desert landscapes, for which at least four climato-phytocoenotic alternations were identified; these phases reflected fluctuations of heat and moisture availability (see Fig. 3).

2. The main feature of the evolution of climatic processes in this region during the Holocene was expressed in the distinct climatic optimums that corresponded to the maximums of heat and moisture supply.

The Late Atlantic optimum (~ 6100–5000 BP) was the main optimum and the time of development of forest-steppe landscapes. The amount of thermophilic arboreal pollen in the pollen assemblages that represent this period reached 31 %. Mixed oak forest with admixture of common and Caucasian hornbeam (*Carpinus betulus*, *C. caucasica*), oriental beech (*Fagus orientalis*), different species of elm (*Ulmus laevis*, *U. foliacea*), linden (*Tilia cordata*), birch, and other trees, and coniferous forests comprised the forest belt of the Lower Volga floodplain. The Late Boreal (~ 8500–8300 BP) and the Middle Subboreal (~ 4200–3700 BP) optimums were close in character and were characterized by a lesser heat availability and greater moisture supply. They were both marked by the dominance of forest-steppe and, in some phases, of steppe landscapes. However, they differed from the Atlantic optimum by less favorable, for the growth of broad-leaved tree stands, conditions and by lesser participation of the broadleaf species in forests. The amount of pollen of broadleaf species in the pollen assemblages that describe these periods did not exceed 21–23 %.

It is possible to correlate these three phases to the maximal transgressive stages of the New Caspian basin with a high degree of confidence.

3. The fact of existence of the transgressive stages of the Caspian Sea is also supported by the phases of cold and relatively humid climate. First, this is expressed in the presence of the forest-steppe phase in the interval ~ 10000–9200 BP, which corresponds to the Sartass stage when, within the part of the Northern Caspian region free from the sea, there were wide-spread sparse pine forests and isolated forest stands dominated by spruce and fir. The phases of cooling and humidization were also identified in the

intervals ~ 4800–4200, 2500–2300, and 400–200 BP. The transgressive stages of the sea correlate also with the phases of warming and humidization of climate in the intervals ~8000–7600, 3500–2700, 2100–1800, 1700–1500, 1300–1100, and 700–400 years BP.

4. Regressions of different ranks may correspond to the reconstructed minimums of heat and moisture (the periods of cold and dry climate), as well as to the intervals of significant warming and aridization (the periods of relatively warm and dry climate).

Two of the most significant minimums of heat and moisture availability correlate with the Early Subboreal sub-period and to the first one-half of the Late Subatlantic sub-period. The first minimum corresponds to the time of the Mangyshlak regression of the Caspian Sea (~ 9200–8500 BP), while the second minimum corresponds to the Derbent regression (1500–700 BP).

Within the interval 8500–1500 BP, there was one phase of rapid warming and aridization of climate (~ 2700–2500 BP) and five phases of sharp cooling and aridization of climate (in the intervals ~ 8300–8000, 7600–7400, 5000–4800, 3700–3500, and 2300–2100 BP) that may correspond to a short-term but pronounced drop in the Caspian Sea level. The most significant decrease relates to the intervals ~ 7600–7400 and 3700–3500 BP. All phases of cooling and aridization of climate were marked by the prevalence of dry steppes and semideserts within the study region; there, xerophitic sagebrush and haze communities dominated the vegetation.

5. The comparison of landscape and climatic stages identified herein with the stages of development of natural humid areas of the Russian Plain that feed the Caspian Sea with water indicates multidirectional evolution of climate during the intervals of ~ 9700–9200, 8500–8300, 7600–7400, 5500–5400, 2700–2500, 2100–1700, and 1500–400 BP, as well as during the last century (see Fig. 3).

6. Based on the reconstructed climatic and vegetation successions, two paleogeographic models of the Caspian Sea in the post Mangyshlak time may be proposed (see Fig. 3). The first model is based on the fact that the Late Subatlantic interval, characterized by the dominance of semidesert and desert landscapes, is very different in phytocenological and climatical respect (with the exception of the last phase of the Subboreal period ~ 2700–2500 BP) from the entire preceding part of the Holocene. It should be also noted that the last (the newest) 700-year-long phase of the development of the Caspian basin is close to regressive and not to transgressive phases in paleo-climatic respect. The alternative model is close to the models developed by O.K. Leontiev and G.I. Rychagov

[1982], and A.N. Varuschenko et al. [1980], except for the interpretation of a regressive phase in the interval of ~ 5000–3500 BP. We suggest that this phase was developing as a pulse regressive phase (as determined from the palynological data) ~5000–4800 BP. This phase was replaced by a transgressive phase ~ 4800–3700 BP followed by a new pronounced pulse decrease in the Caspian Sea level ~ 3700–3500 BP.

7. The vast majority of subrecent pollen assemblages of the Volga Akhtuba region [Bolikhovskaya and Kasimov, 2008] indicate that in the last century, there were the most optimal thermal conditions (for the last thousand years) to support broadleaf species in the floodplain forests of the Lower Volga floodplain.

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