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The Early Khvalynian stage in the Caspian Sea evolution: Pollen records, palynofloras and reconstructions of paleoenvironments

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ABSTRACT

In addressing the controversial issues of the Late Pleistocene paleogeography of the Caspian basin, an important role is given to the results of the spore-pollen analysis and based on them reconstructions of climate and vegetation changes in the Northern Caspian region during the development of the Early Khvalynian transgression. In this paper we present the main results of the palynological study of deposits (chocolate clays and the overlying and underlying layers from the Srednyaya Akhtuba section) of maximum stage of the Early Khvalynian transgression; the materials are illustrated by pollen diagram with the data of spore-pollen analysis and the detailed list of palynoflora recovered from the studied Lower Khvalynian sequences, and complemented with photographs of pollen belonging to the principal autochtonous taxa and, for comparison, to some redeposited palynomorphs. Palynological materials indicate subaqual (brackish marine and freshwater) sedimentation of the sediments studied in periglacial landscapes and, for the most part, under very harsh climatic conditions. The performed climate-stratigraphic reconstructions do not contradict the data of absolute dating on the accumulation of the studied deposits during the Late Valdai (Ostashkov) late Glacial period. During this interval in the territory of the study area, plant communities of the glacial climate — tundra-steppe, periglacial forest-steppe, periglacial steppe, periglacial parklands and periglacial forests — were developed. The widespread occurrence in the composition of the periglacial vegetation cover of the studied region of the yernik formations from *Betula nana* and shrub communities from *Betula fruticosa*, *B. nana*, *Alnaster fruticosus*, *Juniperus*, etc. testifies to the severe climatic conditions and, possibly, the existence of sporadic permafrost in the cold stages (stadials) of the Ostashkov Late Glacial period.

1. Introduction

The Early Khvalynian stage in the Caspian Region was marked by a development of a unique complex of sediments and landforms; many constituents of the complex predetermined the development and present state of natural geosystems in the Northern Caspian region. The most important event of that interval was the Early Khvalynian transgression – one of the largest transgressions in the Pleistocene history of the Caspian Sea, which has been a major focus of interest for many investigators for more than a century.

The earliest data on the sediments appeared in works dated to the mid-19th century. The studies were performed as a part of general survey of the Caspian layers – the term then applied practically to all the upper sediments overlying the Caspian basin (Barbot de Marni, 1868; Andrusov, 1888; Pravoslavlev, 1908). The term "Lower Khvalynian deposits" came into usage much (about a century) later, in publications summing up the basic researches that provided vast factual material on paleogeography and Quaternary stratigraphy of the Northern Caspian region and the drainage basin of the Middle and Lower Volga (Fedorov, 1957).

At the Early Khvalynian time a series of 'chocolate clays' was formed in the Northern Caspian Lowland. It was first described by P.A. Pravoslavlev (1908) in a few sections at the Lower Volga. The data on the stratigraphy and paleogeography of the Lower Khvalynian deposits (including the 'chocolate clays') obtained by studies in the mid-20th century were published in a few monographs and large papers (Shantser, 1951; Britsina, 1954; Fedorov, 1957; Vasiliev, 1961; Moskvitin, 1962; and many others). In the recent decades a new stage began marked by active studies of the Northern Caspian paleogeography at the early Khvalynian time (Badyukova, 2000, 2007; Leonov et al., 2002; Yanina, 2012; Lavrushin et al., 2014; Svitoch et al., 2017; Yanina et al., 2017; Richards and Bolikhovskaya, 2010; Yanina, 2014; Tudryn et al., 2016; Arslanov et al., 2016; Makshaev and Svitoch, 2016; Richards et al., 2017; Yanina et al., 2018; and many others). New

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materials obtained in the process of those studies permitted to complement and specify the conclusions previously made.

Up to now, many works have been performed on the entire complex of the Early Khvalynian sediments in the Northern Caspian region. In the papers summarizing the results the most debatable problems are those related to the so-called 'chocolate' clays – their age, environments of deposition and facies-genetic characteristics.

At present there are several notions about the geological and absolute age of the Early Khvalynian time. On the basis of thermoluminescent dating, a number of specialists (Zubakov et al., 1974; Varuschenko et al., 1987; Rychagov, 1997) attribute the Early Khvalynian basin and its deposits to the time interval of 71–42 ka BP, the greatest part of which corresponds to the Kalinin ice age on the East European Plain. A "younger" age of the Lower Khvalynian deposits is suggested by the dates obtained by radiocarbon (^{14}C) analysis, optically stimulated luminescence (OSL) and uranium-thorium (U–Th) techniques. The absolute dates obtained by different methods for the deposits of the Early Khvalynian transgression have been summarized by T.A. Yanina et al. (2017).

Judging from published materials, the long-discussed problem of the Early Khvalynian transgression age and its correlation with paleoclimatic events in the glaciated regions of the East European Plain has been largely cleared up by absolute dates obtained in the last decade. More than 30 radiocarbon dates obtained using scintillation and AMS techniques for chocolate clay samples from sections Cherny Yar, Tsagan-Aman, Srednyaya Akhtuba, Raygorod, Svetly Yar in the Volga valley and Mergenevo, Kharkino, Inder (the Ural River valley) show that the deposition of the clays occurred in the course of a relatively short interval of the Ostashkov Late Glacial, that is 13 to 11 ka BP (16-13 cal ka BP (Svitoch and Yanina, 1997; Leonov et al., 2002; Lavrushin et al., 2014; Arslanov et al., 2016; Svitoch et al., 2017). The Ostashkov stage is used as a regional term for the north-west part of the East-European Plain. The term was proposed by A.I. Moskvitin in 1939 after investigations of moraine complexes in Kalininskaya area (north-west part of the East-European Plain) (Moskvitin, 1939). According to Shik (2014), Ostashkov stage corresponds to the Late Weichselian (Late Valdai) glaciation and MIS 2, respectively. The radiocarbon age of the chocolate clays is in a relatively good correlation with the dates obtained using OSL and U–Th techniques. According to the OSL data, the Lower Khvalynian deposits studied in the Srednyaya Akhtuba, Raygorod and Leninsk sections have been accumulated 15 to 13 ka BP (Yanina et al., 2017; Kurbanov et al., 2017). The uranium-thorium (U–Th) dates fall within an interval of 15.9–11.9 ka BP (Arslanov et al., 2016).

The depositional environments of the chocolate clays have long been the matter of discussion. Most of the authors argue for the clays being deposited in marine environments and stress the fact of their confinement to depressions of the pre-Khvalynian surface (Britsina, 1954; Fedorov, 1957; Svitoch et al., 2017). In the opinion of E.N. Badyukova (2000), the clays were deposited in the lagoons under conditions of the Early Khvalynian sea level fluctuations, accountable for a development of a series of lagoon terraces different in age. Some specialists lay stress on the periglacial characteristics of the clay deposition environments. According to G.I. Goretskiy (1966), the chocolate clays have some features in common with the deposits of proglacial lakes and may be more likely attributed to glaciofluvial formation. I.A. Chistyakova and Yu.A. Lavrushin (2004) suggest the leading role to belong to cryogenic processes – to the so called cryo-suspension flows providing material deposited later as the chocolate clay. One of recent papers (Tudryn et al., 2016) attributes the greatest importance in the fine material transport to the meltwater of the Late Valday ice sheet, the transported and deposited material being the source of the chocolate clay formation.

When dealing with controversial questions of the Late Pleistocene paleogeography of the Caspian Sea basin a great importance is attached to the palynological analysis that formed the basis for reconstructions of changes in climate and vegetation at the time of the Early Khvalynian transgression (Britsina, 1954; Moskvitin, 1962; Obedientova and Gubonina, 1962; Yakhimovich et al., 1986; Lavrushin et al., 2014; Svitoch et al., 2017).

The representative palynological data and reconstructions of the climate and environment changes in the Lower Volga region at the Early Khvalynian time (corresponding to the chocolate clay deposition as well as underlying and overlying layers) are presented in a number of papers (Grichuk, 1952; Voronina, 1959; Chiguryaeva and Voronina, 1960; Tyurina, 1961; Obedientova and Gubonina, 1962; Lavrushin et al., 2014).

It should be noted that some differences in opinions on the allochtonous and autochtonous components in the samples became noticeable since the beginning of the studies. The first comprehensive data of the palynological analysis of the Lower Khvalynian layers were obtained by V.P. Grichuk (1952) from the 2nd terrace section near the Verkhniy Balakley settlement; they were complemented with some fragmentary pollen spectra from other sections on the Lower Volga. In those spectra V.P. Grichuk has not recorded any pollen grains or spores redeposited from older Quaternary layers. An opposite conclusion was made by Chiguryaeva and Voronina (1960) who also studied Khvalynian deposits including the chocolate clays in many places of northern Caspian region. They interpreted a considerable part of the coniferous pollen as well as Polypodiaceae, *Lycopodium* and some others to be redeposited. Based on those results they conclude that their pollen data do not confirm the existence of a taiga forest phase identified by V.P. Grichuk (1952) in the Early Khvalynian vegetation history.

In our opinion, all the disagreements in the palynological results obtained from chocolate clays or other Lower Khvalynian deposits may be attributed to the fact that only fragments of sequences have been studied by palynologists in various regions of the Northern Caspian territory. The studied fragments could be different in age or incompleteness of the exposed series and/or be deposited in different depositional environments and phytocoenoses (zonal or local ones).

The problem of conditions – both facies-genetic and landscape-climatic ones – of the chocolate clay formation in the Northern Caspian region is still debatable. That is why it is particularly important to study taphonomic characteristics of pollen and spores from those layers, as well as to specify the taxonomy of the most important constituents in palynoflora and their proportion in the pollen assemblages. For this purpose, N.S. Bolikhovskaya performed a detailed palynological analysis of the chocolate clays as well as f underlying and overlying layers from the Srednyaya Akhtuba section. The analysis included palynomorphological and palynotaphonomical studies along with the pollen and spore photography. There have been prepared a collection of electronic photographs of various pollen and spores. It includes pollen of arboreal plants, bush and shrubs, herbs, grasses and dwarf shrubs; spores of the higher spore plants (green mosses, sphagnum, ferns, clubmoss, horsetail), and other microfossils (algae, fungi, stomata, etc.) belonging to autochtonous and allochtonous complexes.

In this paper we present the main results of the performed investigation into the paleogeography and pollen morphology; the materials are illustrated with photographs of pollen belonging to the principal autochtonous taxa and, for comparison, to some redeposited palynomorphs, complemented with pollen diagram and the list of palynoflora recovered from the studied Lower Khvalynian sequences.

2. Synopsis of the previous investigations

To make clear a necessity of more detailed investigations of the composition and taphonomic characteristics of palynoflora recovered from the Lower Khvalynian deposits, we'll dwell on the most important results of the earlier works.

The first results the pollen analysis of the Lower Khvalynian sediments were obtained by V.P. Grichuk (1952) from several sections in the Lower Volga and Manych valleys. The most comprehensive materials were illustrated with the pollen diagram of the 2nd terrace sequence ~12 m thick at the Mordovskoye village (near Verkhniy Balykley settlement). The sequence is described from the top downward as follows (thickness of layers is indicated in brackets): loamy sand (2.20 m); chocolate clay (5.30 m); interbedded sandy loam, sand, and clay (0.25 m); loamy sand with interlayers of sand and clay and freshwater malacofauna at the base (3.05 m); sand attributed to the Khazarian or Atelian age (apparent thickness is 1.4 m). No pollen or spores redeposited from older Quaternary layers have been recorded (see Table 2 (Grichuk, 1952)). There were, however, microspores of pre-Quaternary forms found, locally in abundance. The lower part of the chocolate clays and the loamy sand layer ~3 m thick are noted for pollen assemblages of forest type (AP – up to 85%, spores – up to 30%). Spruce and pine (*Pinus sylvestris*) pollen occur in a considerable abundance (*Picea* – 29–56%), while the proportion of fir (*Abies*) and Siberian pine (*Pinus sibirica*) is insignificant. At the time of the considered sediment deposition, dominant were forests of pine and spruce (with some admixture of fir and Siberian pine); they occupied the entire valley of the Volga and extended onto the watersheds (Grichuk, 1952). Six analyzed samples taken from the overlying (main) part of the chocolate clays yielded assemblages of transitional type indicative (in the Grichuk's opinion) of a considerably reduced forest area in the Volga drainage basin, an expansion of birch groves with some pine, probably with Siberian pine and spruce, and – in small amounts – linden (*Tilia cordata*) and elm (*Ulmus laevis*).

Chiguryaeva and Voronina (1960) obtained representative data on pollen and spore assemblages having analyzed a great number of samples taken from Khvalynian deposits (including chocolate clays) studied in sections Enotayevsk, Sukhaya Mechetka, Cherny Yar, Pichuga. Those authors considered a considerable part of the coniferous pollen grains (*Abies*, *Picea, Pinus* s/g *Haploxylon*, *Pinus* s/g *Diploxylon*) and spores (Polypodiaceae, *Lycopodium*, *Sphagnum*) to be redeposited (see (Table 1 in Chiguryaeva and Voronina, 1960)). On the basis of the above, those authors stressed that "… the results obtained do not suggest the taiga existence at the time of the Lower Khvalynian layers and lower series of the chocolate clay deposition" (p. 1416).

Recently there have been published results of palynological analysis of the Lower Khvalynian sediments studied by E.A. Spiridonova in Srednyaya Akhtuba, Kolobovka, and Tsagan-Aman sections (Lavrushin et al., 2014) and Seroglazovka and Raygorod sections analyzed by T.F. Tregub (Svitoch et al., 2017). In the detailed list of species, genera and families identified in the palynoflora recovered from the chocolate clays T.F. Tregub includes some Neogene relicts (*Tsuga*, *Nyssa*, *Magnolia*, *Zelkova*, *Osmunda* and some other taxa) as found *in situ*. The conclusion calls for further considerations and hardly can be discussed here because of limited volume of the paper.

It may be noted, however, that the most detailed palynological analysis of the chocolate clays performed by E.A. Spiridonova, as well as the analysis of the overlying and underlying Lower Khvalynian sediments, have not identified the "taiga phase" at the time of their deposition either. A high proportion of *Picea* pollen (up to 40%) was found in the assemblages recovered from the upper half of the chocolate clay horizon exposed in the Kolobovka section. The palynological data obtained from three studied sections made possible reconstructions of the forest and forest-steppe vegetation during three Late Valday interstadials (namely Rauniss, Bølling and Allerød); steppe formations were dominant during the Late Ostashkov coolings (Younger, Older, and the Oldest Dryas). The Allerød optimum was marked by widely spread pine-spruce and spruce-pine forests with admixture of birch and – more rarely – of elm and linden trees. Regrettably, the author (E.A. Spiridonova) does not give the complete list of the palynoflora identified in the studied horizons (Lavrushin et al., 2014).

3. Materials and methods

The chocolate clays in the Srednyaya Akhtuba section have been palynologically studied in detail by N.S. Bolikhovskaya. The studies were aimed at making a more complete list of the Lower Khvalynian palynoflora and at reconstructing the climate-phytocoenotic successions at the maximum stage of the Early Khvalynian transgression.

The Srednyaya Akhtuba section (48°41′54.22″ N, 44°54′33.26″ E) is on the left bank of the Akhtuba River at the mouth of a large "balka" (flat-bottom valley) 0.5 km south of the settlement of the same name (Fig. 1). The section is situated on a second terrace of the Volga River Valley. The complete lithological description of the Srednyaya Akhtuba section supplemented with results of dating by optically stimulated luminescence (OSL) is given in the paper by T.A. Yanina (Yanina et al., 2017). The section displays ~17 m series of the Late Pleistocene marine, fluvial, and subaerial deposits crowned by modern chestnut soil and including several paleosol horizons dated (11 dates) to the interval of 112 630 ± 5400 to 720 ± 70 yr BP (Yanina et al., 2017). The OSL dates 15 020 ± 1000 and 13 060 ± 610 yr BP obtained on the chocolate clays agree well with the earlier published radiocarbon dates (Leonov et al., 2002; Lavrushin et al., 2014), the clay accumulation is correlatable with the degradation of Ostashkov stage of the Valday Ice Age on the East European Plain.

There have been performed a detailed pollen analysis of 12 samples taken from the chocolate clays and the underlying and overlying sediments (layers 3–8), from the depth interval 1.2–4.0 m (the upper part of the sequence) (Fig. 2). Radiocarbon ages of layer 6 are presented in Table 1. The top of the sequence is at an altitude of ~15 m a.s.l. The exposed layers are as follows (from the top downward):

1. (pdQ_4). The uppermost part of the modern soil horizon (chestnut soils), loamy in composition, win calcareous inclusions (Lebedeva et al., 2018). Thickness is ~40 cm.
2. (pdQ_{3-4}). Light brown loam, porous, - the lower part of the pedocomplex, ~80 cm thick.
3. (eQ_{3-4}). Sandy loam, brown, stratified, with thin lenses of sand. Thickness is ~25 cm.
4. (mQ_3hv_1). Chocolate clays, compact, thinly laminated, with silt and sand interlayers in the upper part. The layer is ~60 cm thick. An OSL data 13 060 ± 610 yr BP (Risø-150806) was obtained on quartz sample from that layer (Yanina et al., 2017).
5. (mQ_3hv_1). Chocolate clays, compact, massive, with thick platy parting, ~65 cm thick.
6. (mQ_3hv_1). Light brown sands, compact, fine-grained, with shells of *Didacna protracta, D. ebersini, Dreissena rostriformis, Dr. polymorpha.* The layer is ~15 cm thick. The shell material from the layer was dated by radiocarbon at 13 506 ± 134 cal yr BP (LU-7037) and 13 506 ± 134 cal yr BP (LU-8152).
7. (mQ_3hv_1). Chocolate clays, compact, massive, fissured, ~75 cm thick. The quartz sample from the layer yielded OSL date 15 020 ± 1000 yr BP (Risø-150807) (Yanina et al., 2017).

Table 1
Radiocarbon dates for the Srednyaya Akhtuba section. Radiocarbon ages were calibrated to calendar year BP using the CALIB7.1 (Stuiver et al., 2019) online program (http://calib.org/calib/calib.html) and using the IntCal13 calibration dataset (Reimer et al., 2013).

Lab code	Layer	Sample description	^{14}C yr BP	(±) yr	^{14}C cal BP 1σ	Median^{14}C cal BP	(±) yr
LU -7037	6	Mollusc shells: *Didacna protracta, D. ebersini, Dreissena rostriformis, Dr. polymorpha*	11680	150	13372 ± 13640	13506	134
LU -8152	6	Mollusc shells: *Didacna protracta, D. ebersini, Dreissena rostriformis, Dr. polymorpha*	11680	150	13372 ± 13640	13506	134

Table 2
Percentage of redeposited pollen and miospores in the studied sediments (the Srednyaya Akhtuba section).

Lithology	sandy loam	chocolate clays					sand	chocolate clays			sandy loam	
Number of layer	3	4		5			6	7			8	
Number of sample	7	8	9	10	11	12	13	14	15	16	17	18
Depth, m	1,30	1,50	1,75	2,05	2,35	2,65	2,75	2,95	3,20	3,50	3,70	4,00
Pre-Cenozoic pollen and miospores	1,1%	1,5%	6,9%	2,7%	2,1%	0%	1,4%	4,5%	0,5%	8,2%	0%	0%
Quaternary redeposited pollen	6,7%	8,3%	0,6%	16,7%	0,6%	1,7%	2,9%	5,4%	4,7%	6,0%	0%	2,1%
Total sum of redeposited palynomorphs	7,8%	9,8%	7,5%	19,4%	2,7%	1,7%	4,3%	9,9%	5,2%	14,2%	0%	2,1%

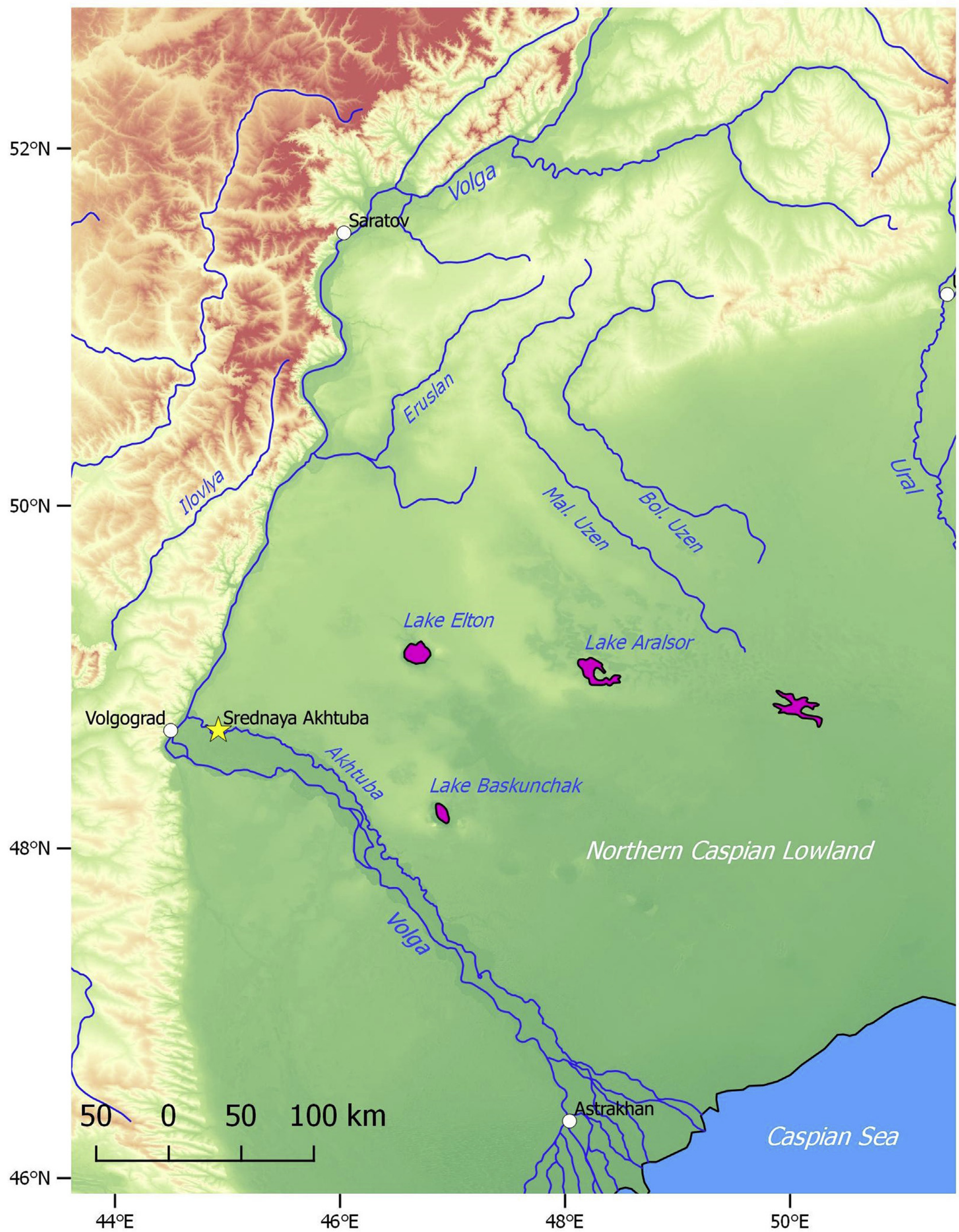

Fig. 1. Location scheme of Srednyaya Akhtuba section.

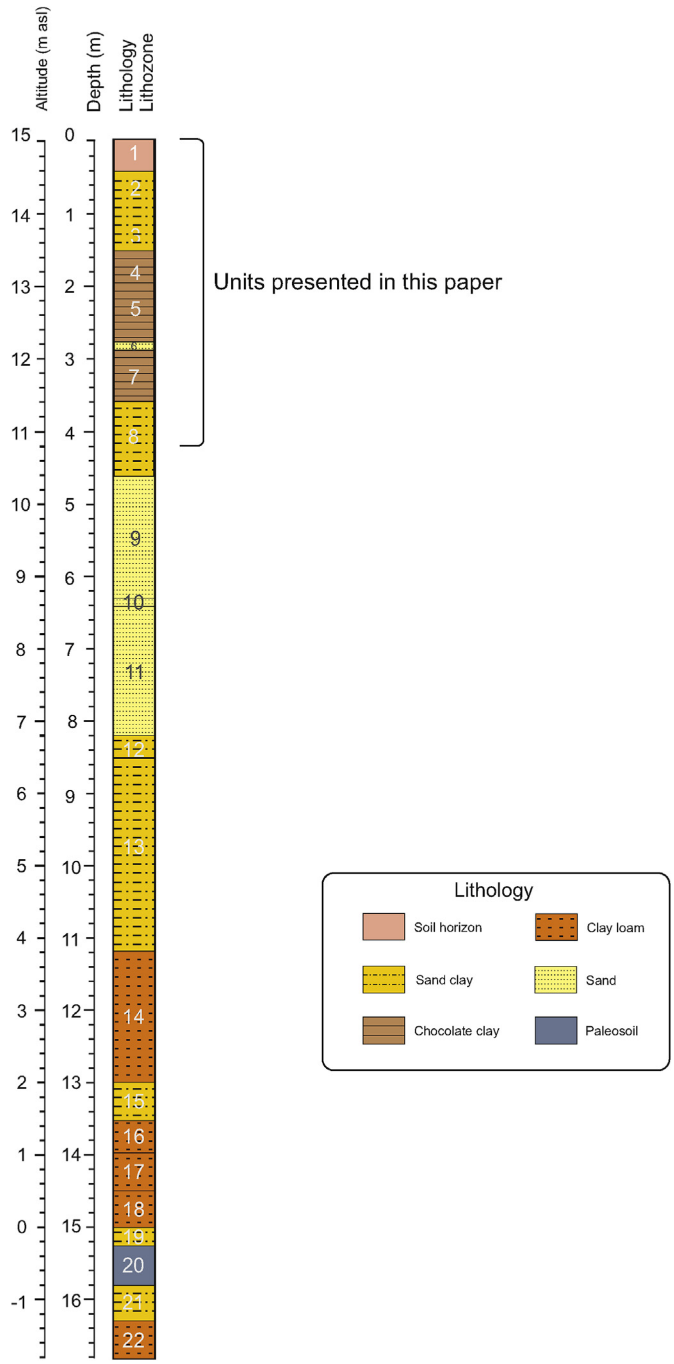

Fig. 2. Lithological structure of Srednyaya Akhtuba section.

8. (aQ_3hv_1). Sandy loam and sands light beige in color, alluvial, ~50 cm thick.

The palynological data obtained have been interpreted in the context of climate and phytocoenoses on the basis of literature and the authors' own materials on the subrecent assemblages recovered from the various facies of the present-day deposits in Northern Caspian region and from the benthic marine deposits (Mal'gina, 1952; Fedorova, 1952; Vronsky, 1976; Bolikhovskaya, 1995; Bolikhovskaya and Kasimov, 2008).

In the process of studying under microscope and determination of palynomorphs, our attention was centered on specific features of their taphonomic characteristics. The previously studied Atelian deposits sampled in a borehole in the north of the Caspian Sea (Bolikhovskaya et al., 2018) appeared to contain a sizable amount (up to 10% in a few samples) of redeposited pre-Cenozoic miospores together with considerably damaged or mineralized pollen grains and spores derived from Quaternary deposits. An analysis of the Lower Khvalynian sediments in the same core revealed an equally high proportion of allochtonous palynomorphs in a few samples. Considering the chocolate clays sampled in the Srednyaya Akhtuba section, the proportion of redeposited plant microfossils (pre-Cenozoic miospores plus Quaternary pollen) varies in the range of 1.7–19.4% of the total number of palynomorphs studied in each sample (Table 2). The redeposited from the Quaternary deposits pollen is characterized by destroyed (loose, thinned, torn, skeletal) or strongly mineralized sporoderm. Some examples of redeposited pollen grains of spruce (*Picea* sect. *Picea*, *Picea* cf. *abies*), Siberian pine (*Pinus sibirica*), Pre-Cenozoic miospores and *Sphagnum* spores are given in Fig. 3 together – for comparison – with the same microfossils occurring *in situ*. When studying the microfossils with the use of the AXIO IMAGER D1 microscope, particular attention had been given to recording their taphonomic characteristics in photographs. A collection of electronic microphotographs was produced for every sample including tree, shrub, and herb and grass pollen, as well as spores of the spore plants (sporophytes), such as green mosses, sphagnum mosses, ferns, club moss (*Lycopodium*), equisetum, and other micro-remains (algae, fungi, etc.) forming a part of a autochtonous and allochtonous complexes. A representative list of the studied autochtonous palynoflora has been compiled.

4. Results of the study and discussion

The representative palynoflora and pollen and spore and pollen assemblages (spectra) have been obtained for the following units exposed in the Srednyaya Akhtuba section: 1) loam of layer 3 overlying the chocolate clays; 2) chocolate clays (layers 4, 5, 7); 3) the sandy interbed (layer 6) abounding in Early Khvalynian mollusk shells within the clays; and 4) alluvial sandy loam and sands (layer 8) underlying the chocolate clays. According to Yanina et al. (2017), layers 3–7 were formed during the second (maximum) stage of the Early Khvalynian transgression while layer 8 corresponds to the end of the early stage of that transgression.

4.1. The composition of palynoflora

During the entire history of investigations into palynoflora of the time of maximum stage of the Early Khvalynian transgression it is for the first time that reliable data have been obtained on arcto-boreal and arcto-alpine taxa presence in considerable proportion in the majority of spore-pollen spectra (SPS) and their almost constant participation in palynoflora. Among the most typical representatives of those taxa are *Betula fruticosa*, *B. nana, Alnaster fruticosus, Juniperus communis*, *J.* sp., *Dryas octopetala*, *Botrychium boreale*, as well as Siberian pine (*Pinus sibirica*), characteristic of tundra, forest-tundra and northern taiga phytocoenoses. A series of photographs of the pollen grains illustrating palynomorphic and taphonomic characteristics of those taxa are given in Figs. 4 and 5.

As follows from the results of a thorough palynological analysis, the studied autochtonous Early Khvalynian palynoflora includes about 100 taxa of various ranks. The tree and shrub pollen group (AP – arboreal pollen) includes pollen of 34 taxa: fir (*Abies* sp.), spruce (*Picea* sect. *Omorica*, *Picea* sect. *Picea*, *Picea abies* (L.) Karst.), pine (Pinus s/g *Haploxylon* (sp. indet.), Siberian pine (*Pinus sibirica*), Siberian larch (*Larix sibirica*), Scots pine (*Pinus sylvestris*), birch (*Betula* sect. *Albae, Betula pendula*, *B. pubescens*), shrubby birch (*Betula* sect. *Fruticosae, B. fruticosa*), dwarf birch (*Betula* sect. *Nanae*, *B. nana*), shrubby alder (*Alnaster fruticosus* after S.K. Cherepanov (1973)), *Duschekia fruticosa* (Rupr.) Pouzar./), European alder (*Alnus glutinosa*), speckled alder (*A. incana*), hazel nut (*Corylus avellana*), linden (*Tilia* sp., *Tilia cordata*), oak (*Quercus* sp., *Quercus robur*), ash (*Fraxinus* sp.), elm (*Ulmus* sp., *Ulmus*

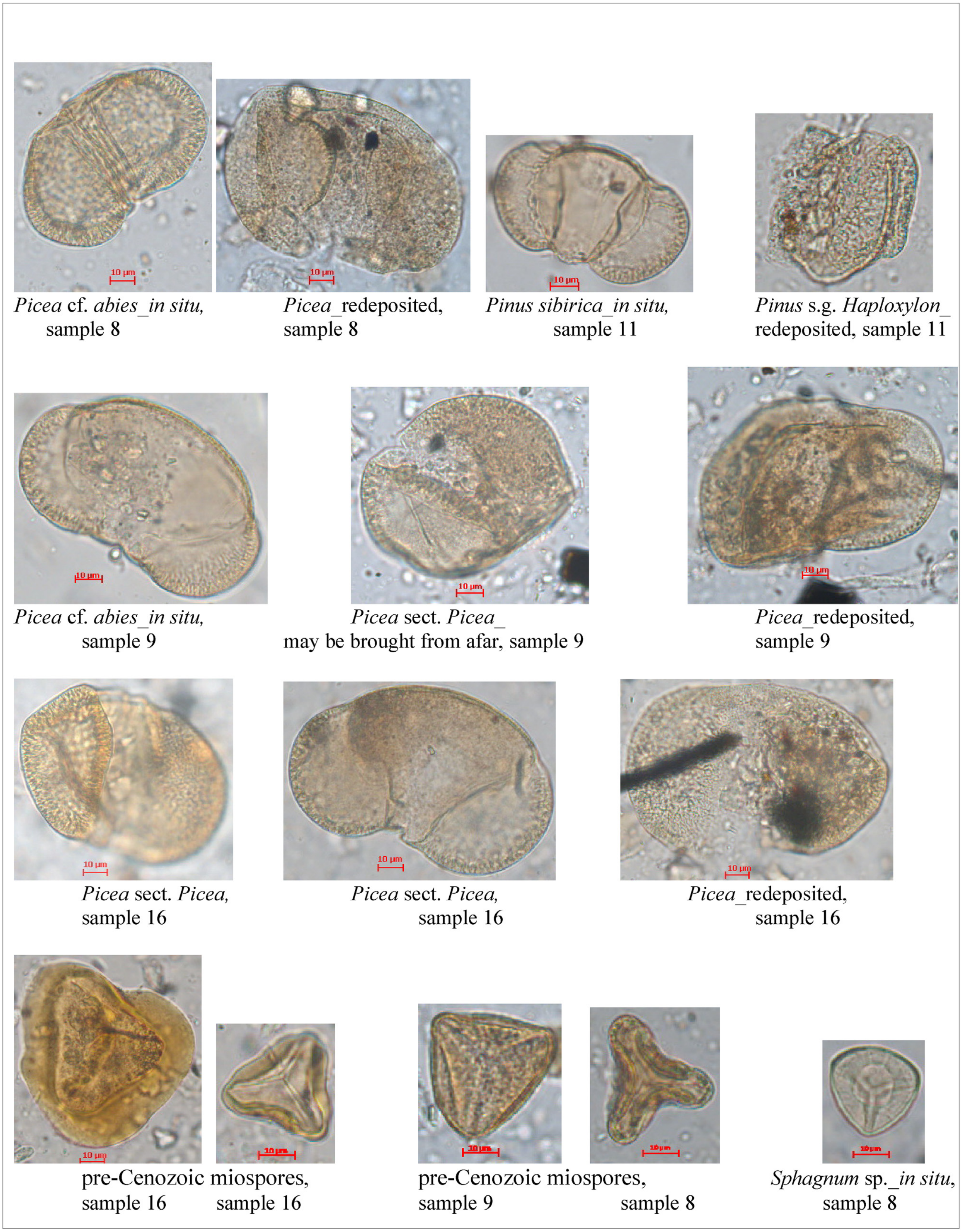

Fig. 3. Images of the pollen (*in situ* and redeposited), spores (*in situ*) and miospores detected in chocolate clays of the Srednayay Akhtuba section: pollen of spruce (*Picea* sect. *Picea*) and the Siberian stone pine (*Pinus sibirica*); spore of sphagnum moss (*Sphagnum*) and pre-Cenozoic miospores (zoom x400).

laevis, U. cf. *pumila*), oleaster (*Elaeagnus*), wild grape (*Vitis sylvestris* C.C.Gmel.), willow (*Salix* spp.), juniper (*Juniperus* sp., *J. communis* L.), red currant (*Ribes rubrum* L.), common hop (*Humulus lupulus*) and others.

The non-arboreal pollen group (NAP) includes more than 50 families, genera, and species of herbs, grasses and dwarf shrubs as

Fig. 4. Images of the pollen (*in situ*) detected in chocolate clays of the Srednaya Akhtuba section: the Siberian stone pine (*Pinus sibirica*), Scots pine (*Pinus sylvestris*) and the larch (*Larix* sp.) (zoom x400).

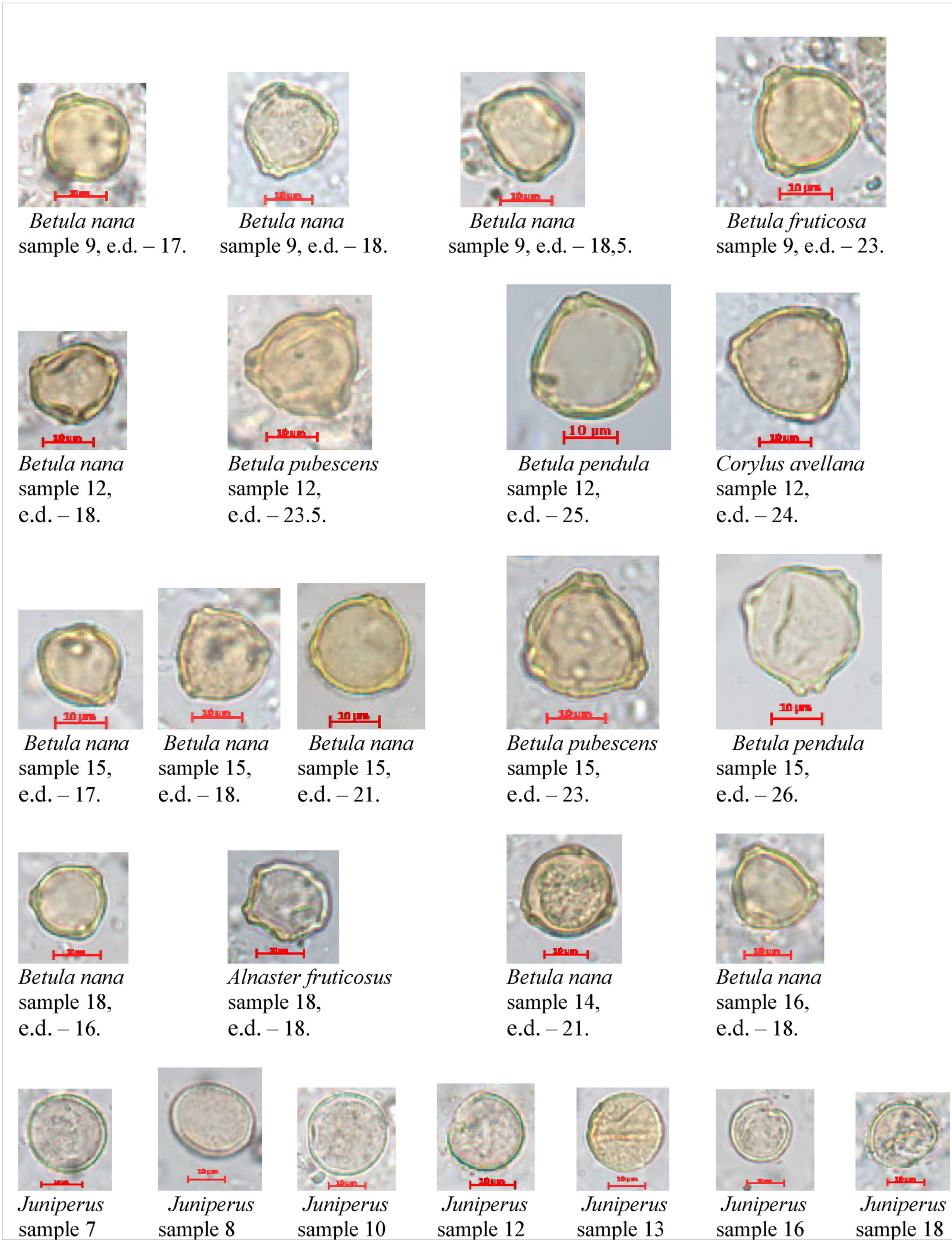

Fig. 5. Images of the pollen (*in situ*) detected in chocolate clays of the Srednaya Akhtuba section: the dwarf birch (*Betula nana* L.), the shrub birch (*Betula fruticosa* Pall.), the pubescent birch (*Betula pubescens* Ehrh.), the shrub alder (*Alnaster fruticosus* (Rupr.) Ledeb.) and the juniper (*Juniperus*) (zoom x400).

follows: Ericales, grasses (Poaceae), sedges (Cyperaceae), hemp (*Cannabis*), *Ephedra* sp., sagebrush, wormwood (*Artemisia* sp., *Artemisia* subgenera *Seriphidium*, *Artemisia* subgenera *Euartemisia*); families: pigweed (Chenopodiaceae, including *Atriplex cana* C.A.M., *A. litoralis* L., *A. verrucifera* M.B., *Halostachys capsica* (Pall.) C.A.M., *Kochia prostrata* (D.) Schrad. and others); Plumbaginaceae (including wide-leaved sea lavender *Limonium latifolium*/Smith./O.Kundze), Apiaceae, Fabaceae, Polygonaceae (*Polygonum, Fagopyrum*), Campanulaceae, Caryophyllaceae, Ranunculaceae, Scrophulariaceae, Rosaceae (including *Dryas octopetala*), Portulacaceae, Rubiaceae, Violaceae (among them wild pansy *Viola tricolor*), Plantaginaceae (*Plantago*), *Urtica,* Fabaceae, Linaceae, Iridaceae, Liliaceae (*Tulipa*), Alliaceae, Asteraceae, *Xanthium*, *Ambrosia*, Cichoriaceae, and others. There are present in the NAP group some pollen of aquatic and near-shore plants: watermilfoil (*Myriophyllum*), pondweed (*Potamogeton*), duckweed (*Lemna*), waterwort (*Elatine alsinastrum*), water-plantains (Alismataceae), cattail (*Typha*), and bur-reed (*Sparganium*).

In the group of higher spore (cryptogam) plants there were identified the following taxa: green mosses (Bryales), sphagnum moss (*Sphagnum*), ferns of Polypodiaceae family (including mountain bladder-fern (*Cystopteris montana* (Lam.) Desv.), ferns of Ophioglossaceae family (*Botrychium boreale* (Fr.) Milde, *B. virginianum* (L.) Sw., *Botrychium* sp.), club-mosses. (*Lycopodium clavatum*, L. sp.), horsetail (*Equisetum* sp.).

4.2. Reconstructions of the sediment genesis and the evolution of vegetation and climate

More than 600 pollen grains and spores have been identified in most samples of Lower Khvalynian sediments studied in the Srednyaya Akhtuba section; and somewhat lesser amount of samples yielded ~300 to 480 grains. The representative pollen assemblages are shown in the diagram (Fig. 6). A considerable number of SPS marked by a high proportion of shrub pollen necessitated a presentation of tree pollen separately from that of shrubs. In this way a relationship can be found between the areas of forests and shrub communities in the reconstructed paleo-landscapes. To estimate a significance of the temperate thermophilic dendroflora (characteristic of the warmings), the total amount of broadleaf tree pollen (Quercetum mixtum) is shown in a separate diagram preceding the data on the individual taxa. As the herb and grass taxa are extremely numerous, there are sums of their percentages given in every assemblage (as the Herbetum mixtum diagram).

The studied palynoflora and changes in species assortment and percentage in the obtained SPS, when being analyzed from the viewpoint of environmental requirements of the coenoses, allow a conclusion on the chocolate clay genesis and a reconstruction of the subsequent changes of environments and climate throughout the entire Lower Khvalynian series formation.

The series of chocolate clays was deposited in a shallow basin, as suggested by green algae *Botryococcus* and *Pediastrum* present in abundance in all the samples, as well as by a high proportion (up to

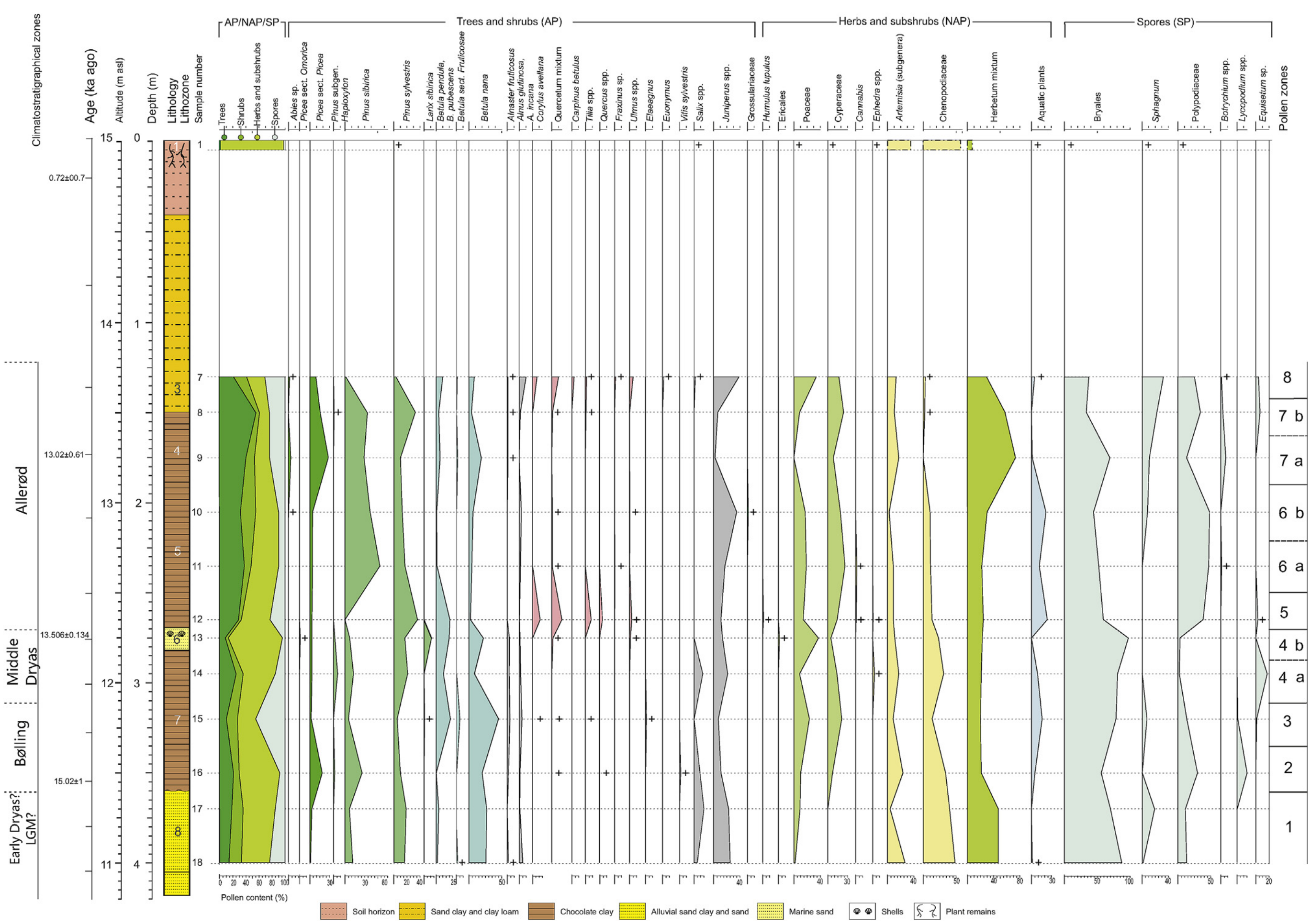

Fig. 6. Pollen and spore percentage diagram of the Lower Khvalynian sediments of the Srednaya Akhtuba section. Summary column of trees, shrubs, grasses and subshrubs and spores shown as percentages of total pollen and spore sum. The percentage of each taxon was calculated with respect to: trees and shrubs taxa as percentage of trees and shrubs sum, grasses and subshrubs taxa as percentage of grasses and subshrubs sum, spore taxa as percentage of spore sum. + – content less than < 3%.

24% in samples 10–12 and up to 16% in samples 14–16) of aquatic plant pollen (*Myriophyllum, Potamogeton*, *Lemna*) inhabiting limans, floodplains, lakes, marshes, and representatives of near-shore communities (Alismataceae, *Typha*, *Sparganium*, *Elatine alsinastrum*). Pollen indicators of brackish-water environments are rare. The marine environments of sedimentation are strongly suggested by typical marine dinocysts (*Cleistosphaeridium* sp.) recovered from the upper horizon of the chocolate clays (sample 9). 10 specimens of dinocysts (Cordosphaeridium gracile) have been recovered from sands with marine malacofauna (sample 13).

All the SPS obtained from the Lower Khvalynian sediments are typically periglacial. The palynological record of paleoclimatic events in the lower reaches of the Volga during the last 11 500 years was reconstructed by N.S. Bolikhovskaya (2011; Bolikhovskaya and Kasimov, 2011) based on pollen analysis and radiocarbon dating of lacustrine (oxbow lake) sediments of the Solenoye Zaimishche locality (130 km southeast of the Srednyaya Akhtuba section). The comparison of the palynological records and the reconstructed paleoclimatic events of the Holocene and the epoch of the Early Khvalynian transgression of the Paleo-Caspian Sea shows unambiguously that the deposition of the studied Lower Khvalynian sediments took place under climatic conditions of a glacial epoch.

The Lower Khvalynian layers are distinct for the joint presence of species typical of tundra, boreal forest, and desert-steppe floras in the SPS; that suggests the deposition in periglacial environments. Among the species identified there are *Betula nana*, *B. fruticosa, Alnaster fruticosus, Dryas octapetala*, *Botrychium boreale*, *Abies* sp., *Picea* sect. *Picea*, *Picea abies*, *Pinus sibirica*, *Larix sibirica*, *Pinus sylvestris*, *Betula pendula*, *B. pubescens, Ephedra* sp., *Artemisia* s.g. *Seriphidium*, *A.* s.g. *Euartemisia*, species of Chenopodiaceae family (*Atriplex cana*, *A. litoralis*, *A. verrucifera*, *Halostachys capsica*, *Kochia prostrate* and others). There are present pollen and spores of plants growing now in diversified ecological-coenotic and edaphic conditions (in forests, on steppe sites, in wetlands and meadow ecotopes, in places with disturbed or immature soils, on saline or perennially frozen substrates). The pollen spectra obtained suggest a complicated mosaic pattern of the Early Khvalynian vegetation and the periglacial landscapes of that time as a whole.

Near the upper margin of the pollen diagram (see Fig. 4) there is shown an SPS obtained from the surface of the modern chestnut soil that crowns the studied sequence in the Srednyaya Akhtuba locality. That is a subrecent pollen assemblage dominated by Artemisia, Chenopodiaceae, *Ephedra*, and various herbs and grass (with a rather scarce assortment of species belonging to Polygonaceae, Liliaceae, Asteraceae and Cichoriaceae families), while tree pollen (that of common pine and willow) are present sporadically. The pollen assemblage is an adequate reflection of the zonal vegetation of the semidesert and corresponds to the plant community growing at present on the 2nd terrace fragment.

A comparison of the SPS recovered from the chocolate clays with this subrecent spectrum and with those from the present-day subaqual deposits (Fedorova, 1952; Vronsky, 1976; Bolikhovskaya, 1995; Bolikhovskaya and Kasimov, 2008) has clearly shown that the moisture supply in the Northern Caspian region at the Early Khvalynian time was much greater than at present.

According to the palynological data, open landscapes of tundra-steppe, periglacial forest-steppe, and periglacial steppe (palynozones 1–4 in Fig. 4) were dominant during the entire period of deposition of layers 6, 7 and 8. Forest formations gained essentially in area at the time of layers 4 and 5 deposition. The forests were primarily of dark coniferous trees, Siberian pine and Norway spruce being dominant. Periglacial steppes were the dominant landscapes over the most part of the period. Periglacial dark coniferous forests and parklands spread onto the valley slopes and flat interfluves and probably acquired the significance of zonal landscapes in the region only at the final phase of the chocolate clay formation.

The climatic characteristics during the chocolate clay deposition (including the intermediate sand layer) are clearly indicated by changing proportions of pollen of cold-tolerant shrubs, coniferous and deciduous trees, spores of mosses and ferns in SPS (spores-pollen spectra) within every of three parts of the palynological record. Quite probably, the cryogenic processes occurred and permafrost developed sporadically, as suggested by SPS of palynozones 2–4 dominated by dwarf birch (*Betula nana*) pollen with a significant proportion of *Juniperus*, *Salix* and green moss spores; the *Alnaster fruticosus* and *Betula fruticosa* pollen is also present. The most conspicuous warming is recorded at the beginning of the upper horizon of chocolate clays and corresponds to palynozone 5; it is marked by a 15% maximum of linden, oak and elm pollen, a noticeable peak of hazel (up to 12%), along with a high percentage of the pollen of pine (*Pinus sylvestris*), birch (*Betula pendula*, *B. pubescens*) together with fern spores (Polypodiaceae), while the cryophytes are almost completely absent. The remainder (that is, the most part of the upper chocolate clay horizon, palynozones 6, 7) was accumulated under conditions of the increasing climate humidity (peaked at the time of layer 4 deposition), degrading sporadic permafrost, and a wide expansion of dark coniferous (Siberian pine *Pinus sibirica* and Norway, or European, spruce *Picea abies*), fir and Scots pine also present.

The obtained palynological record gave the climate-stratigraphic basis for subdivision of the studied sediments and for reconstruction of the climate and vegetation development over the ~2 to 2.5 millenia interval in the history of the Northern Caspian region. It permitted to identify several phases in the environmental evolution.

The period of the alluvial layer 8 deposition corresponds to the stadial cooling of the Oldest Dryas. It was marked by the wide occurrence of tundra-steppe (palynozone 1) dominated by open spaces with desert-steppe of Artemisia-Chenopodiaceae and grass-forb communities (dominant in the herb and forb group are Plumbaginaceae, Asteraceae, Liliaceae, Violaceae, Ranunculaceae, Polygonaceae, Fabaceae, Malvaceae) and dwarf shrub ("yernik") formation (*Betula nana*). The occurrence of dwarf shrubs and bushes of *Alnaster fruticosus*, *Betula fruticosa*, *B. nana, Juniperus*, *Salix* suggests the permafrost presence. A high proportion of green moss and sphagnum spores indicated, in all probability a wide occurrence of wetlands. Fragments of open forests of Siberian and Scots pines could occur in the most benign environments.

SPS of palynozones 2 and 3 corresponds to interstadial warming of climate (correlatable with Bølling), which resulted in an expansion of periglacial forest-steppes. The first phase of their advancement (palynozone 2) the shrub formations were reduced in area along with a decreased proportion of hypoarctic taxa. The automorphous landscapes were occupied by open forests of Scots pine, spruce, and Siberian pine, with ferns and club mosses in the ground layer. The composition of plant communities on steppe plots remain the same, though some areas of wet meadows were coming into being. At the 2nd phase (palynozone 3) the landscapes were dominated by wet meadow ecotopes with herb-sedge-grass communities, the moss bogs being gradually overgrown with dwarf birch. Small-size forest stands were dominated by birch (*Betula pendula*, *B. pubescens*) and alder (*Alnus glutinosa*, *A. incana*). A characteristic feature of the interstadial vegetation of that interval consisted in an appearance of broadleaf trees (*Quercus robur, Tilia cordata*) in the tree layer, the hazel in the understory, and the oleaster (*Elaeagnus*) and wild grape-vine (*Vitis sylvestris*) in the coastal ecotopes.

The next phase of the climate deterioration (the stadial correlatable with the Older Dryas) was marked by a wide expansion of periglacial steppe and disappearance of broadleaf trees under conditions the climate cooling and increasing continentality (palynozone 4). During the first sub-phase (4a) the vegetation of steppe units was dominated by Artemisia–Chenopodiacea associations with ephedra, while the forested areas presented open forests of birch, common pine and Siberian pine, with juniper and dwarf birch in the shrub layer. The coastal ecotopes featured, along with other xerophytes and halophytes, *Atriplex cana*, *A. litoralis*, *Kochia prostrata*. The 2nd subphase (4b) of that cold stage was noted for an expansion of the steppes, a reduced presence of the wormwood and Chenopodiacea and a predominance of herb and grass communities with some of Ericales. Both Siberian pine (*Pinus sibirica*) and Scots pine (*P. sylvestris*) lost in importance. Forested areas were mostly occupied by birch and larch groves with shrub birch and juniper in the understory. The moss layer was composed of green mosses at both subphases.

The obtained palynological record strongly suggests the geological record to be incomplete, with a break in sedimentation notable between layers 6 and 5.

The upper horizon of chocolate clays exposed in the Srednyaya Akhtuba was deposited during the longest interval within the studied part of the Late Glacial time correlatable with the Allerød Interstadial. The specific features of the climate-phytocoenotic successions of that time have been considered above. Here we discuss successive changes in the zonal types of vegetation (palynozones 5–7). At the initial phase of that interstadial (palynozone 5) periglacial forest-steppe were dominant. In the forest formations prevailed those of pine and birch (with an admixture of spruce) or of oak and linden with the hazel in the understory. The herb layer was dominated by grasses, herbs, and ferns (Polypodiaceae). The water and near-water coenoses included pondweed (*Potamogeton*), waterwort (*Elatine alsinastrum*), sedges, reeds, bur-reed (*Sparganium*).

The next phase (palynozone 6; the time of the deposition of the middle part of the upper chocolate clay horizon) corresponds to periglacial forest-steppe landscapes where forest habitats were dominated by pine (*Pinus sibirica* and *P. sylvestris*) with some spruce and fir, and juniper in the shrub layer. Among broadleaf trees there were ash and elm widely represented. The forest confined to river valleys included a considerable proportion of alder. The species composition of the herbs and dwarf shrubs in the steppe and forest ecotopes remained unchanged. The communities in aquatic and near-water phytocoenoses were dominated by watermilfoil (*Myriophyllum*), pondweed (*Potamogeton*), duckweed (*Lemna*), waterwort, water plantains (Alismataceae) and bur-reed (*Sparganium*).

The time interval of the chocolate clay (layer 4) deposition corresponds to the next stage of the considered interstadial; it was a humid phase (palynozone 7) when dominant were the periglacial forests of spruce and Siberian pine alternating with open woodlands with fir, pine and birch in the upper layer and *Betula fruticosa*, *B. nana* and (less common) *Juniperus* in the shrub layer. In the open habitats the herb layer was dominated by Liliaceae along with sedges and ferns (Polypodiaceae, *Botrychium boreale*, *B. virginianum* and others). Pollen of hydrophytes and hygrophytes were absent from the deposits of that phase. The ground layer is mostly represented by green and sphagnum mosses.

On the basis of the data at hand we cannot confidently draw a conclusion about the geological age of the upper-lying deposits of layer 3 (interbedded loam and sandy loam). Judging from the SPS recovered from sample 7 (palynozone 8), the species composition is consistent with an earlier phase of the vegetation evolution in the Holocene. It is strongly suggested by the diversified species composition and the proportion of broadleaf species (hornbeam, linden, elm, ash-tree, hazel) and associated species (*Alnus glutinosa*, *A. incana*, *Euonymus*). A more tenable conclusion would be possibly drawn after a series of representative SPS is obtained from layers 1 and 2 of the studied sequence.

Finally, considering the reconstructed climate-phytocoenotic record, it is pertinent to note that, according to the palynological data, there are no sediments of the last cold stage of the Ostashkov Late Glacial correlatable with Younger Dryas stadial present in the Srednyaya Akhtuba section.

5. Conclusions

- Palyno- and climate-stratigraphic reconstructions performed for the studied Lower Khvalynian sediments do not contradict the conclusion (based on absolute dating) on their accumulation at the final (Late Glacial) Ostashkov cold stage.
- The palynological data indicate a subaqueous (marine brackish-water and freshwater) deposition of the studied series in periglacial environments and mostly in a severe climate.
- The plant communities typical for a glacial climate – tundra-steppes, periglacial forest-steppes, periglacial steppes, periglacial parklands and periglacial forests – were widespread over the studied region throughout the period of the studied Lower Khvalynian series deposition.
- A wide occurrence of microthermic plants making a part of the periglacial vegetation in the region (dwarf birch formation of *Betula nana* and dwarf shrubs of *Betula fruticosa*, *B. nana, Alnaster fruticosus*, *Juniperus*) is indicative of severe climate and, possibly, of sporadic permafrost existence during the cold intervals (stadials) of the Ostashkov Late Glacial (the latter attribution is based on the absolute dating). The data obtained are in agreement with the views of earlier investigators (Moskvitin, 1962; Goretskiy, 1964; Chistyakova and Lavrushin, 2004), based on lithological studies of the chocolate clays.

Declaration of competing interest

We have no conflict of interest to declare.

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