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On the age of the Mangyshlakian deposits of the northern Caspian Sea

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ABSTRACT

The distribution, sedimentology, and age of early Holocene Mangyshlakian deposits beneath the northern Caspian Sea are studied. Analyses and interpretations derive from high-resolution sub-bottom profiling, lithological analysis of core sections and boreholes, biostratigraphic analysis of mollusc shells, and radiocarbon dating. We show that the Mangyshlakian deposits overlie Upper Pleistocene Khvalynian deposits, filling valleys and depressions that formed during lower water levels, similar to present lacustrine water bodies (ilmeni) of the Volga Delta. Transgressive marine Holocene Neo-Caspian sediments that are filling facies overlie the Mangyshlakian deposits. The deposits are composed of both organogenous and terrigenous materials. The flora and fauna in the sediment indicate deposition into freshwater, differing from marine biota in the underlying and overlying sediments. Eighteen radiocarbon ages indicate that the Mangyshlakian deposits accumulated between 9 and 12 ka.

Introduction

The Caspian Sea is the largest inland body of water on Earth and is an isolated basin, with outflow through the Manych valley into the Black Sea (Fig. 1A) only during extensive transgressions (Arkhangelsky and Strakhov, 1938; Ross and Degens, 1974; Kvasov, 1975; Shimkus et al., 1975; Fedorov, 1978; Ross et al., 1978; Popov, 1983; Arslanov, 1993; Ryan et al., 1997, 2007; Svitoch and Yanina, 1997; Svitoch et al., 1998; Aksu et al., 2002; Major et al., 2002, 2006; Chepalyga, 2007; Sorokin and Kuprin, 2007; Yanina, 2012). The late Quaternary record of the Caspian Sea differs, yet complements, that of the Black Sea, that is connected to global sea level via the Bosporus Strait and the Mediterranean Sea during interglacials.

The late Quaternary, starting from the time of the last Pleistocene interglacial (Eemian–Riss–Würm–Mikulino), is the best-investigated period in the history for the Black and Caspian seas. Four vast transgressions and three deep regressions have been identified for the Caspian Sea during the late Quaternary. These include the Late Khazarian interglacial transgression, simultaneous with the Karangatian transgression of the Black Sea, the Late Pleistocene Early Khvalynian and Late Khvalynian transgressions, and the Holocene Neo-Caspian transgression. These episodes of high lake levels are separated in time by the Atelian, Enotaevkian, and Mangyshlakian regressions (Leontyev, 1961; Lebedev et al., 1973; Kvasov, 1975; Fedorov, 1978; Popov, 1983; Sorokin et al., 1983; Varushchenko et al., 1987; Arslanov et al., 1988; Arslanov, 1993; Rychagov, 1997; Svitoch and Yanina, 1997; Svitoch et al., 1998; Leonov et al., 2002; Bezrodnykh et al., 2004; Maev, 2006, 2009; Vronskii, 2006; Badyukova, 2007; Chepalyga, 2007; Bolikhovskaya, 2011; Yanina, 2012; Leroy et al., 2013). The timing of these lake-level changes remains uncertain, as are their correlation with glacial events (Table 1). The uncertainty is due to different dating methods (U/Io, ^{14}C, thermoluminescence) and to ambiguity concerning the causes of the Caspian transgressions. For example, the Early Khvalynian transgression may have occurred during the Kalinin stadial (Rychagov, 1997; Vronskii, 2006; Badyukova, 2007), Mid-Valdai interstadial (Fedorov, 1978; Popov, 1983), or the first half of the Ostashkov stadial (Svitoch and Yanina, 1997; Yanina, 2012). Similarly, the Late Khvalynian transgression may have occurred during the Ostashkov stade, at the end of the Ostashkov stadial, or at the end of the late glacial and post-glacial. According to Bezrodnykh et al. (2004), on the basis of ^{14}C age determinations, the Early Khvalynian transgression occurred during 36,000–20,000 cal yr BP (31,000–17,000 ^{14}C yr BP), while the Late Khvalynian was 18,000–12,000 cal yr BP (16,000–11,000 ^{14}C yr BP). The same uncertainty characterizes the position of the Mangyshlakian deposits, formed during the last regression. The uncertainty of the timing of Caspian sea-level changes challenges correlations between the Black and Caspian seas.

The Mangyshlakian regression of the Caspian Sea is associated with a decline of sea level by about 80 m below present-day global sea level (gsl), about 50 m lower than its present level at −28 m gsl (Lebedev et al., 1973; Fedorov, 1978; Rychagov, 1997; Svitoch and Yanina, 1997; Bezrodnykh et al., 2004; Maev, 2006, 2009; Yanina, 2012). This was the last major regression prior to transgression to Holocene lake levels. Previous understanding of the Mangyshlakian regression is based mainly on landforms and data acquired as a result of investigating of sediment cores taken mostly in the deep-water parts of the sea. By contrast, data from shelf environments is scarce and fragmented; thus,

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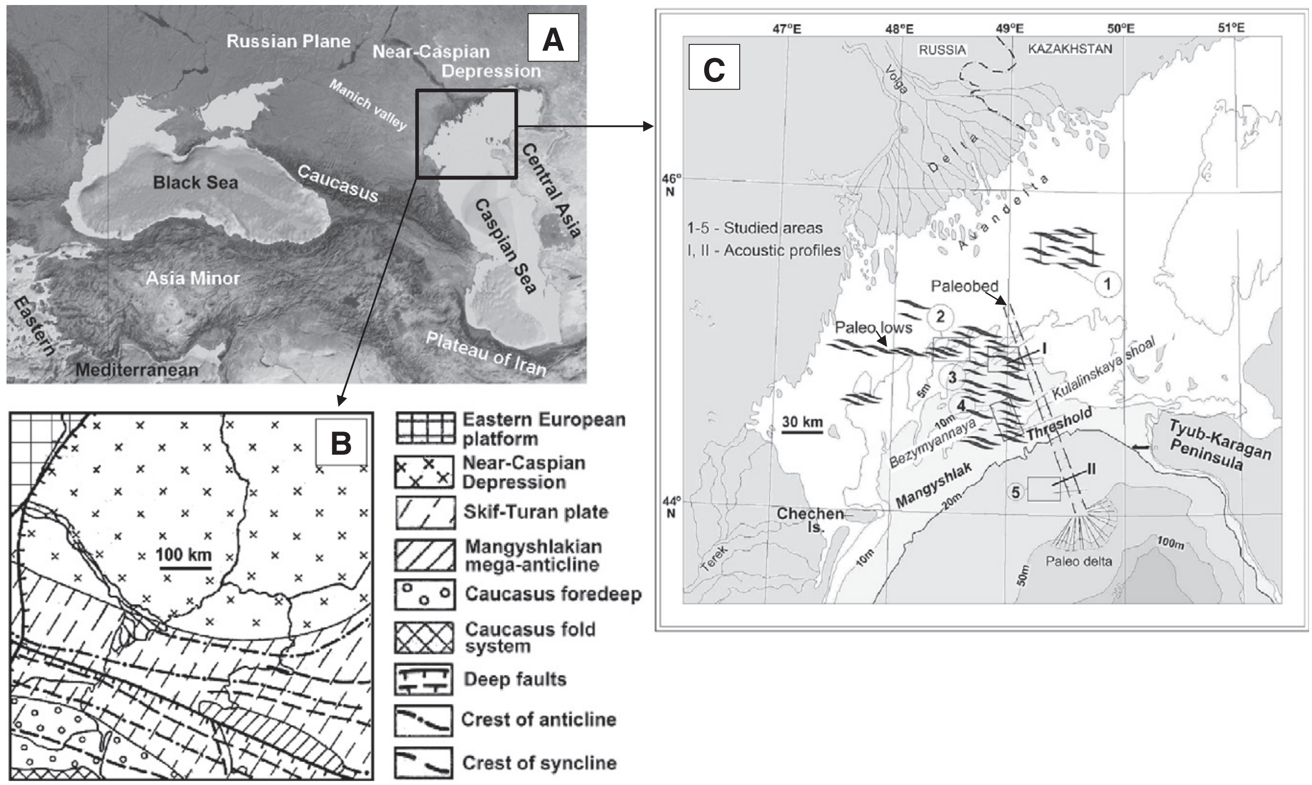

Figure 1. Topography, geology, and detailed locations of the study area. A) Caspian and Black seas shown on part of the GEBCO world map; B) geology of the Northern and Middle Caspian Sea (Khain, 1958); C) detailed study areas.

notions of conditions of sedimentation and distribution of the Mangyshlakian deposits are limited. Our new data on the age of the Mangyshlakian regression better defines the timing of the Late Khvalynian transgression and the start of the Neo-Caspian transgression. Based on the available data, the Mangyshlakian regression is coincident with the final stages of the Neo-Euxinian lacustrine transgression of the Black Sea, which was interrupted several times by considerable short-time reductions of its rise (Balabanov, 2009). Thus, it is possible to identify either synchronous or asynchronous character of the relevant variations of the sea levels, which is one of the problems of the Late Quaternary paleogeography of this region.

Mangyshlakian deposits occur only within the limits of the existing sea area. They lie between the Khvalynian and the Neo-Caspian strata in the stratigraphic sections. Available numerical ages bracketing deposits are ambiguous (Arslanov et al., 1988; Rychagov, 1997; Svitoch and Yanina, 1997; Leonov et al., 2002; Bezrodnykh et al., 2004; Leroy et al., 2013). For example, the age of the youngest Khvalynian deposits investigated onshore is 8500–8000 cal yr BP (7700–7300 ^{14}C yr BP), and that of the oldest Neo-Caspian deposits 8800–7600 cal yr B (8000–6800 ^{14}C yr BP) (Rychagov, 1997). Radiocarbon dating of Mangyshlakian sediments sampled on the eastern shelf of the Caspian Sea at depths of 90–105 m (−60 to −75 gsl) yield ages of 17,000–

Table 1
Correlations of Upper Quaternary deposits of the Caspian Sea and glacial events on the Russian plain.

Authors	Mikulino Interglacial	Valdai glaciation			Holocene	
	MIS-5	Kalinin stade MIS 4	Interstadial MIS 3	Ostashkov stade MIS 2	MIS 1	
Rychagov (1997)	Upper Khazarian	Lower Khvalynian	Enotaevkian	Upper Khvalynian →	Mangyshlakian	Neo-Caspian
Vronsky (2006)						
Badyukova (2007)						
Popov (1983)	Girkanian	Gudilo-Atelian	Lower Khvalynian	Enotaevkian ← Upper		
Fedorov (1978)	Upper Khazarian	Atelian	Lower Khvalynian →	Khvalynian		
Svitoch and Yanina (1997)	Upper Khazarian	← Atelian	→	Lower Khvalynian, Enotaevkian, Upper Khvalynian	Mangyshlakia	
Yanina (2012)	Girkanian →	Akhtubinsk -Atelian →		Lower Khvalynian		

10,500 cal yr BP (13,800–9300 ^{14}C yr BP) (Maev, 2006, 2009). This seems inconsistent with the 8500–8000 cal yr BP age for the youngest Khvalynian deposits. Thus, there is a considerable ambiguity for the published ages of the accumulation of the Mangyshlakian strata and the associated regression of the Caspian Sea.

Geotechnical drilling during the recent years has enabled analysis of the widespread Mangyshlakian sediments lying between the faunally characterized Upper Khvalynian and Neo-Caspian formations in different parts of the shelf of the northern Caspian Sea. The borehole sections, investigated using the biostratigraphy and radiocarbon dating, are correlated by numerous high-resolution sub-bottom lines, which also enable mapping the distribution of deposits over a large area of the Caspian seabed.

These analyses and results provide better information on the timing and distribution of sediments associated with the Mangyshlakian regression. This age information in turn provides constraints on the bracketing the ages for the Upper Khvalynian and Neo-Caspian sediments. Timing of these events also enables consideration of correlation with contemporaneous deposits and sea-level changes in the Black Sea.

Study area

The northern part of the Caspian Sea is a shallow-water area, separated from the Middle Caspian by the Mangyshlakian Step, stretching from the Tyub–Karagan Cape at the Mangyshlakian Peninsula in the east to the “Chechen' Island” on the Dagestan coast in the west. The water depth is mostly <10 m, increasing to 30–40 m only in the southern part of the step (Fig. 1C). The seabed in the northern and northeastern parts of the northern Caspian Sea occupies a part of the Near–Caspian Syneclise of the East European Precambrian Platform, filled by a thick cover of Palaeozoic and younger sedimentary rocks (Fig. 1B). The region is a lowland plain onshore, mainly below sea level. The epi-Hercynian Skif–Turan plate lies to the south under the Caspian Sea.

The seabed is depositional plain, that receives sediment from the Volga, Ural, Emba, the Kuma, Sulak, and Terek rivers. The Volga delta, buried riverbeds, islands, and shoals (Kulalinskaya, Bezymyannaya) are highlighted in Figure 1C. Due to the inflow of freshwater from rivers, the salinity in the northern Caspian Sea does not exceed 5–10‰, leading to the development of brackish-water fauna and flora. Presently, the lake level of the Caspian Sea is −28 m gsl. Lake level has varied considerably throughout the Quaternary, from ~+50 m gsl during the transgression maximums to ~−80 m gsl during the regressive stages (Supplementary Fig. 1; Fedorov, 1995).

Materials and methods

We studied the region located in the central part of the northern part of the Caspian Sea between the mouth of the Volga, the Tyub–Karagan peninsula, and the Dagestan coast at the water depth up to 50 m. The study areas are shown in Figure 1C. Acquired data include data of high-frequency high-resolution sub-bottom profiles (Boomer modification), lithological descriptions of numerous core sections and those acquired during the drilling of geotechnical boreholes, biostratigraphic analysis of molluscs recovered from cores, radiocarbon dating of mollusc shells, and organic matter using the standard liquid scintillation methods.

The laboratory lithological study of the structure and composition of deposits include grain-size analysis, gasometric determination of $CaCO_3$ content, microscopic study on the polarizing microscope and SEM, X-ray analysis.

A composition of pollen and spores in two samples of organic deposits (peat and sapropel) from Area 3 was searched using a standard technique. We also studied a microscopic composition of six samples of biological material from peat and sapropel deposits from Areas 2–4, selected sieving method.

The radiocarbon dating was undertaken at the laboratories of the M. V. Lomonosov Moscow State University and the St. Petersburg State University. Radiocarbon ages were calibrated using Calib7.0.2 (Stuiver et al., 2014). We used the calibration database marine13.14c (the correction $\Delta R = 74 \pm 23$; Kuzmin et al., 2007) for shell samples and database intcall13.14c for organic matter.

Results

The structure and distribution of deposits

Mangyshlakian deposits lie on lithologically heterogeneous Khvalynian sediments and are overlain by the Neo-Caspian sediments (predominantly sand with varying amounts of shell material; Fig. 2). Mangyshlakian sediments are preserved in two distinct environments: i) valleys formed by river incision during periods of low lake stands; and ii) closed, mostly elongated subparallel depressions of different size, representing relict lows in the relief of draining past deltas. Deltaic deposits of the same age occur along the southern edge of the shelf zone, while a vast alluvial fan formed at the edge of the northwestern flank of the Middle Caspian depression in depth interval 45–60 m below the present Caspian sea level (see Fig. 1C).

The paleo-valley of the Volga is the largest area of deposition during the Mangyshlakian regression, stretching southeast to the large alluvial fan flanking the Middle Caspian depression. The incised valley is evident in seven seismic acoustic lines crossing it over a longitudinal distance of ~90 km. The total paleo-valley width varies between 6 and 8 km (Fig. 3). The valley is not reflected in the seabed relief over a large distance. The features of a paleo-valley appear as a gently sloping hollow to the south from latitude 44.25°N. Seismic acoustic records show that the river incision is filled with sediments containing major accumulations of “free” gas, probably biogenic CH_4 (Fig. 3). Gas saturation sings are i) “flame” (cone-shaped) surface configuration of the gas front (high amplitude reflections), discordant reflections from geological layers and intersecting them; ii) increased amplitude reflections, showing a sharp increase in the reflectance; iii) the termination of the correlation of reflections below the surface of the gas front due to the increased absorption of seismic energy in the gas-saturated sediments. Seismic line II shows that the maximum depth of sediment is 35–40 m in the southern part of the study Area 5 (Fig. 4). The bottom of the deepest parts of the incised valley is about 103–108 m below gsl. The fill is unformable on the Khvalynian and the Upper Khazarian deposits. Features of the structure and spatial arrangement of reflectors on the sub-bottom profiles show a heterogenous structure to the succession of sediments that completely fill the paleo-valley (see Fig. 3). These include internal incisions and hollows with an amplitude up to several meters, presence of the sedimentary structures such as multi-directional large-scale cross-bedding up to few meters and various types of horizontal bedding up to several tens of centimeters. These structures reflect a dynamic sedimentary environments and facies changes during paleo-valley aggradation. Thin-layered deposits lie in the upper part of the succession, probably, of the lagoon type, accumulated with the ingressive flooding of the valley during the initial stage of the Neo-Caspian transgression. Their heterogenous structure reflects a composition of clayey and silty–clayey weakly consolidated deposits. Smaller cut-fills of the pre-Neocaspian age are rare, but where present, they are a few hundred meters wide and a few meters deep.

Closed paleo-lows (depressions), filled with the Mangyshlakian sediments, are also evident at most of the investigated sites (sea Fig. 1C). They are widespread to the west and to the east from the Volga paleo-valley at the water depth up to 20 m below present Caspain sea level.

These depressions are predominantly elongated, stretching in the east-west direction, occasionally stretching for a few kilometers almost parallel to each other, and are typically 300–500 m wide and 6–8 m deep, locally attaining 12–13 m deep within the largest depressions (Area 4, Fig. 5, Supplementary Fig. 2). These depressions are similar in

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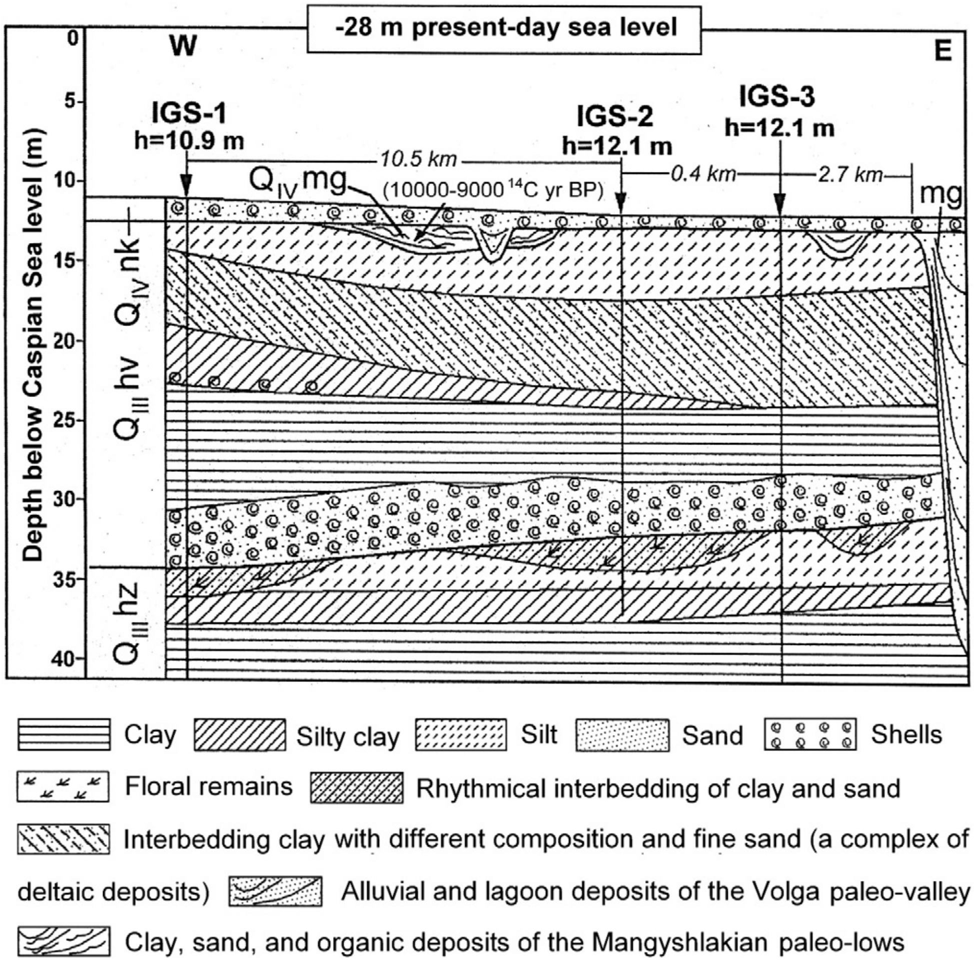

Figure 2. The structure and composition of the late Quaternary deposits and correlation of the borehole sections, using the data of seismic acoustic profiling in the Area. Stratigraphic horizons: Q_{III}hz—Khazarian, Q_{III}hv—Khvalynian, Q_{IV}mg—Mangyshlakian, Q_{IV}nk—Neo-Caspian.

morphology, mutual positions, and orientation to the modern near-steppe ilmeni—lakes in numerous depressions of land to the west of the Volga delta (Supplementary Fig. 3). The thin-layered structure of the filling type is very evident on the high-frequency seismic acoustic sections within paleo-lows. There are replacements of thin-layered, usually clayey sediments by sandy sediments without any signs of layering (Supplementary Fig. 4). Based on the lithological analyses, clay predominates among the deposits filling paleo-lows, but they also include plant detritus and freshwater shells (Fig. 6). Clayey-carbonaceous sapropel and peat are present at the bottom of the lows. Fine sand and peat layers occur in some places at the slopes of paleo-lows and in their central parts above the clay. The $CaCO_3$ content in

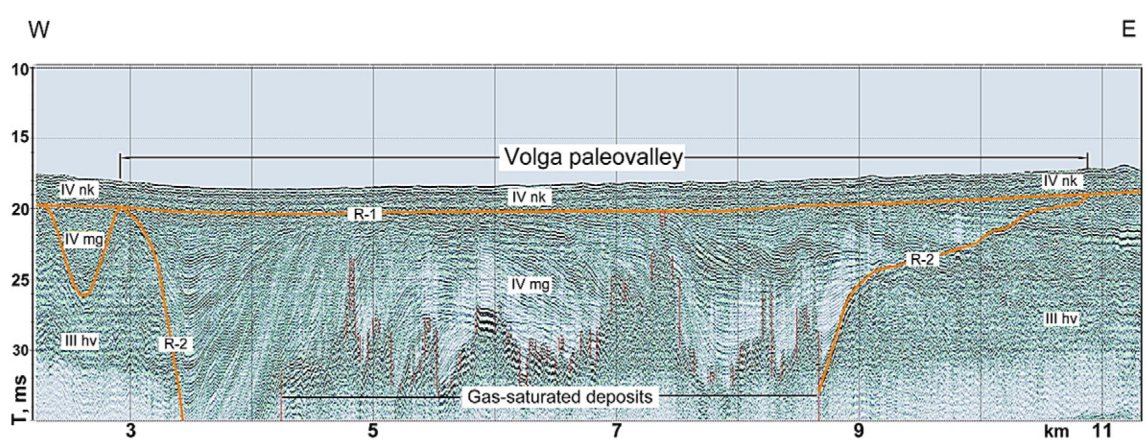

Figure 3. A high-frequency seismic acoustic profile crossing the Volga paleo-valley (center) and a shallow river incision (left) along the line I in the Area 3 (see Fig. 1C). In the valley bounded by the regional reflectors R-1 (the bottom of the Neo-Caspian horizon) and R-2 (the bottom of the Mangyshlakian horizon), the heterogeneous structure of its filling is evident. The stratigraphic horizons: Neo-Caspian (IVnk), Mangyshlakian (IVmg), Khvalynian (IIIhv).

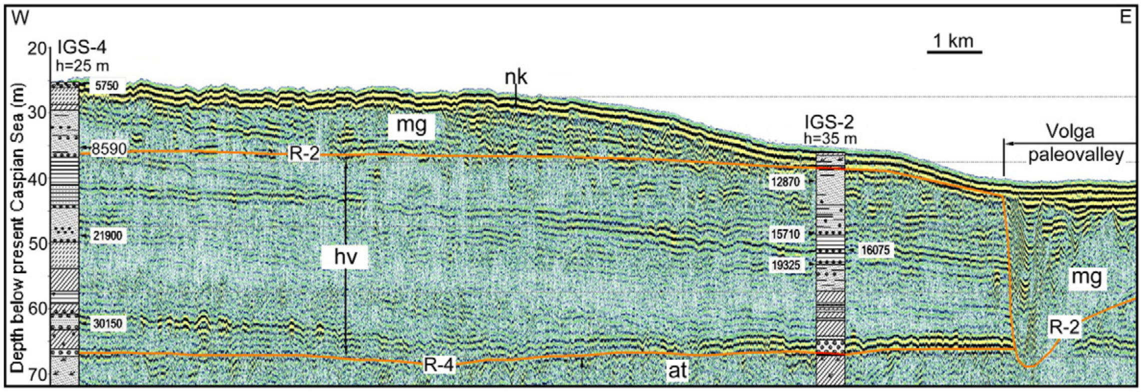

Figure 4. A seismic acoustic profile, combined with borehole sections, along the line II in the Area 5 (see Fig. 1C), crossing the Mangyshlakian deltaic–avant-deltaic complex and the western part of the Volga paleo-delta. R-2, R-4—reflectors at the bottom of the Mangyshlakian and the Khvalynian horizons. See captions to the borehole sections in Fig. 2. The numbers in the rectangles—^{14}C BP.

sapropels reaches 63%. The carbonate material is mostly high-magnesium calcite (up to 6% $MgCO_3$ in the calcite lattice; X-ray data), present as rounded silt-sized oblate inclusions, poorly defined crystals of the pelitic grain size, filling pores and caverns, and as globular formations with the diameter of separate globules up to 0.2 μm.

A vast cover of Mangyshlakian deltaic deposits age but with a different composition was identified in the southernmost area, at the sea depth in the interval 25–33 m below the present Caspian Sea. These deposits overlie a leveled surface situated at 35–37 m below present Caspian Sea, and overlie a series of incisions, which are much shallower than the Volga paleo-valley. According to the seismic acoustic data, the cover and the paleo-valleys contain sediment with a variety of cross-bedding, sinuous-bedding, and horizontal-bedding structures (see Fig. 4). The top part on the seismic acoustic records is a sub-horizontal horizon with thin-bedded strata (Fig. 3, 4; Supplementary Fig. 4). On the low-frequency records (using the Sparker source), larger layers are singled out, manifested in the lines of the latitudinal direction as wedge-shaped formations, inclined in the eastern direction. On the high-frequency records (using the Boomer source), the bedding is quite fragmented, and numerous diffracted waves are observed, probably associated with the presence of steep inclined thin layers. The cover of the deltaic deposits is 8–10 m thick, and fills small valleys incised as deep as 8 m. In our opinion, these deltaic sediments were deposited during initial sea-level rise after the maximum of the Mangyshlakian regression.

Biostratigraphy and composition of the organic material

The Mangyshlakian deposits have few fossils compared to the underlying Khvalynian and the overlying Neocaspian sediments. In the Upper Khvalynian horizon, along with the representatives of the gastropods, of the *Dreissena*, *Monodacna*, *Adacna* genera, there are several species of *Didacna* including *Didacna praetrigonoides*, *D. parallella*, and *D. cristata*. In addition, *D. barbotdemarnyi*, *D. baeri*, *D. crassa*, *D. trigonoides*, *D. longipes*, *Cerastoderma glaucum* are present in the Neocaspian deposits. *Didacna* is practically absent in the Mangyshlakian sediments, except in the adjacent to Upper Khvalynian and Neocaspian intervals. The following freshwater species characterize the Mangyshlakian sediments: *Dreissena polymorpha polymorpha*, *Unio pictorum*, *Viviparus viviparous*. While brackish water fauna include *Dreissena*, *Monodacna*, some Gastropoda (Table 2). Freshwater species of diatom algae are abundant in the organic sediments.

The presence among freshwater species of single *Didacna* shells, which are more characteristic of marine environments, in some places in sand at the bottom and top of the deposits filling the lows, is noteworthy. So *D. barbotdemarnyi* and *D. parallella* mark the transition upwards

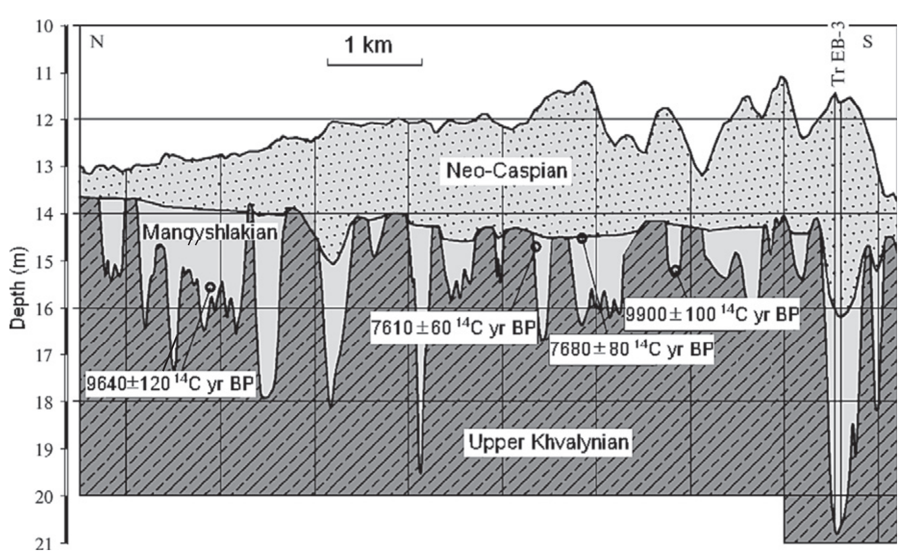

Figure 5. A geological section across paleo-lows in Area 4, produced on the results of interpretation of a high-frequency seismic acoustic profile and boreholes. EB-3 is the research borehole.

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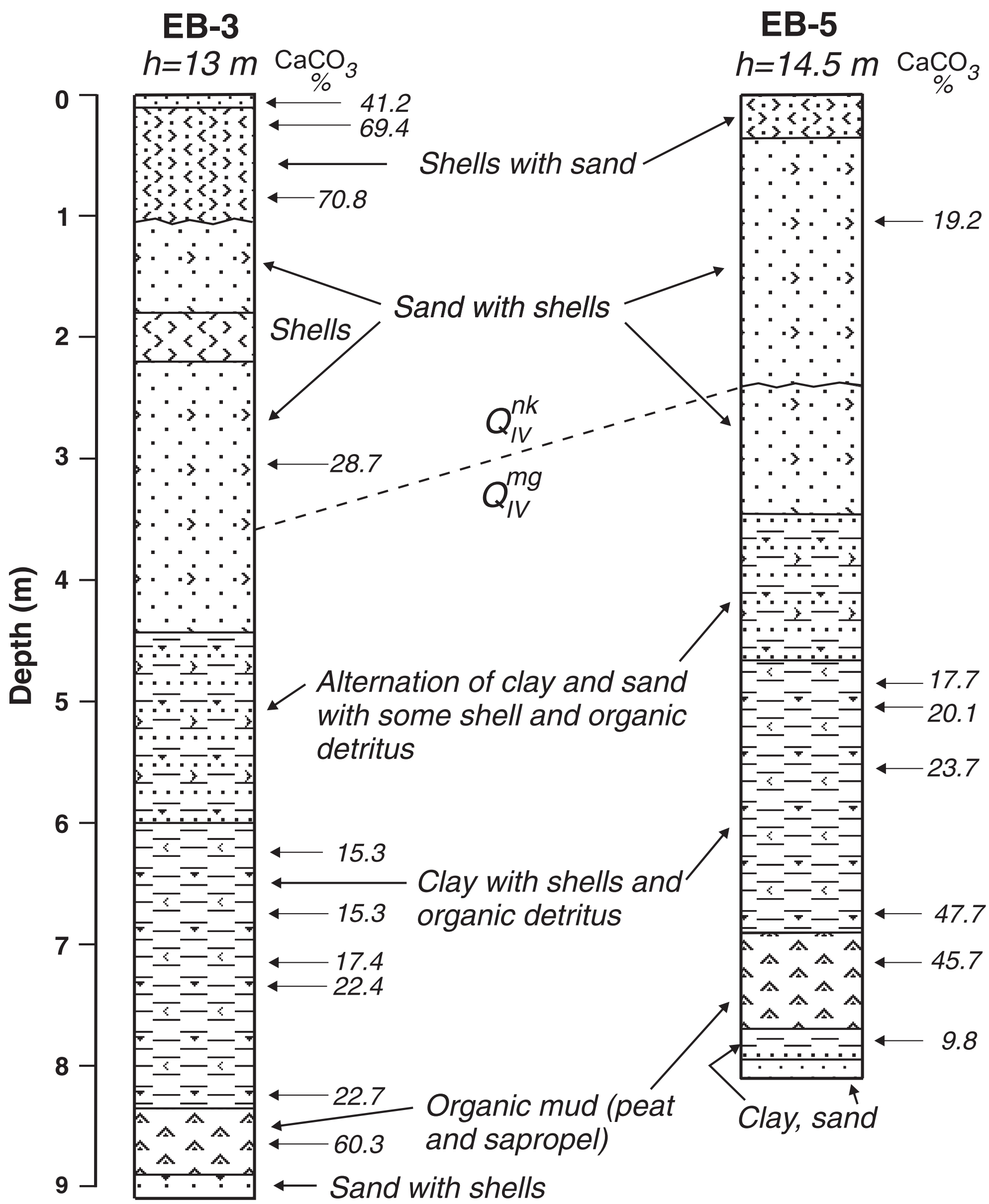

Figure 6. The lithological borehole profiles from the paleo-lows of the Area 4. See stratigraphic indexes and the position of the borehole EB-3 in Fig. 2 and 5.

to the Neocaspian marine sediments in Area 4. Occurrence of *Hypanis caspia*, *Dr. polymorpha caspia*, *D. cf. barbotdemarnyi* together with *D. praetrigonoides* at the bottom of the Mangyshlakian deposits marks the transition downwards to Upper Khvalynian marine deposits in Area 5.

To determine paleoenvironments of the clayey Mangyshlakian sediments, we analyzed the composition of spore-pollen complexes in two samples from Area 3 (Table 3). In the sample N 1 (peat), containing abundant cells and fragments of plant tissue, remains of fossil fungi etc., among 120 palynoforms, 56.7% represented the grass and shrub pollen, spores—42.5%, pollen of arboreal species—0.8%. In the sample N 2 (sapropel), out of 510 palynoforms, the pollen of xerophyte grass (78.2%) and spores (20%) predominates.

The biological composition of the peat and sapropel was also analyzed (Table 4). It is evident that higher plants predominate in the peat, mostly dried pieces ("mummified" material), reed fragments, and other aquatic plants. Also present were algae remains (5.7–54.2%), mostly diatoms. Algae remains predominate in the organic material of sapropels (up to 86.0–95.3%), among which diatom dominates; the remains of blue-green and other algae were also present. Among the material of higher plants, composing 4.5–26.0% of the plant fragments, Ceratophyllum—an herbaceous plant submerged in water—was most abundant. The organic material also contained the remains of sponges, bryozoans, small crustaceans, molluscs, and insects.

Radiocarbon ages

We obtained 18 radiocarbon ages for the Mangyshlakian sediments within the offshore area of the northern Caspian Sea. Resulting ages range between ~12,000 and 7500 cal yr BP (9900 and 7300 ^{14}C yr BP; Table 2). Eleven ages were on humic acids, extracted from sapropel and peat, and seven were based on the shell material. Age inversions occur in Area 2 (see Table 2). For instance, for station no. 18 2.0–2.15 cm (MSU-1601), the analyses gave an older age for shells (8530 ± 90 ^{14}C yr BP) compared to the underlying interval (2.15–2.30) based on humic acids (7420 ± 130 ^{14}C yr BP). This is probably due to the rejuvenation of the radiocarbon age of the plant material. The result for the station no. 47 (MSU-1611a, b) was different: the higher interval based on humic acids gave a younger age than the lower interval based on shells. Several ages based on shells (LU-6133,

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Table 2
Results of the age dating of the Mangyshlakian deposits.

No.	Laboratory number	Cores, interval (m)	Complex of molluscs	Stratigraphic index	Material	Age of sediments	
						^{14}C yr BP	Cal yr BP (2σ)
Area 1 (sea depth 3–5 m)							
1	MSU-1660	9 1.8–2.0	*Dr, polymorpha polymorpha, Lithoglyphus caspius, Monodacna caspia, Unio pictorum, Viviparus viviparus, Theodoxus pallasi*	Q_{IV} nk	Shell	7330 ± 70	7570–7880 (1)
2	MSU-1659	48 2.0–2.2	*Dr. polymorpha polymorpha, V. viviparus, L. caspius, Th. pallasi*	Q_{IV} mg-nk	Shell	8060 ± 70	8300–8600 (1)
3	MSU-1645	54 2.66–2.76	*Unfossiliferous*	Q_{IV} mg	Humic acid	9220 ± 100	10220–10610 (0.97)
Area 2 (sea depth 5–9 m)							
4	MSU-1601	18 2.0–2.15	*Dr. polymorpha polymorpha, M. caspia, U. pictorum, Th. pallasi, Radix pereger*	Q_{IV} mg	Shell	8530 ± 90	8770–9330 (1)
5	MSU-1618	18 2.15–2.30	*Unfossiliferous*	Q_{IV} mg-nk	Humic acid	7420 ± 130	7970–8440 (1)
6	MSU-1611a	47 2.45–2.60	*Unfossiliferous*	Q_{IV} mg-nk	Humic acid	8100 ± 300	8330–9690 (1)
7	MSU-1611b	47 2.15–2.45	*Dr. polymorpha polymorpha, Th.pallasi*	Q_{IV} nk	Shell	7300 ± 100	7510–7910 (1)
8	MSU-1620	52 2.27–2.78	*Unfossiliferous*	Q_{IV} mg	Humic acid	9290 ± 500	9270–12100 (1)
Area 3 (sea depth 10–13 m)							
9	MSU-1493	70 1.15–1.65	*Dr. polymorpha polymorpha*	Q_{IV} mg	Humic acid	9420 ± 60	10500 – 10790 (0.96)
10	MSU-1494	49 3.38–3.55	*Unfossiliferous*	Q_{IV} mg	Humic acid	9860 ± 240	10580 – 12150 (1)
11	MSU-1495	19 2.3–2.45	*Dr. polymorpha polymorpha*	Q_{IV} mg	Humic acid	9860 ± 330	10420 – 12420 (0.99)
12	MSU-1496	68 2.4–2.5	*Unfossiliferous*	Q_{IV} mg	Humic acid	9300 ± 110	10230 – 10770 (1)
13	MSU-1561	3 1.68–1.77	*Unfossiliferous*	Q_{IV} mg	Humic acid	7630 ± 440	7660 – 9490 (0.99)
Area 4 (sea depth 12–17 m)							
14	LU-6137	21 2.9–3.0	*Unfossiliferous*	Q_{IV} mg	Humic acid	9640 ± 20	11070 – 11170 (0.56)
15	LU-6138	61 2.22–2.44	*Dr. polymorpha polymorpha*	Q_{IV} mg	Humic acid	8870 ± 150	9550 – 10250 (1)
16	LU-6133	25A 2.88–2.9	*Pyrgula variabilis, Dr. polymorpha caspia, Th. pallasi, M. caspia, Dr. polymorpha polymorpha, Adacna leviuscula, Didacna parallella*	Q_{IV} nk	Shell	7610 ± 60	7870 – 8150 (1)
17	LU-6134	26 2.8–3.3	*Dr. polymorpha caspia, M. caspia, A. levius-cula, A. vitrea, Dr. polymorpha polymorpha, P. caspia, P. variabilis, T. pallasi, D. barbotdemarnyi*	Q_{IV} nk	Shell	7680 ± 80	7910 – 8270 (1)
Area 5 (sea depth 28–30 m)							
18	MSU-1558	IGS-2 7.7-7.8	*D. barbotdemarnyi, D. praetrigonoides, D. cristata, M. caspia, A. vitrea, A. leviuscula, Dr. polymorpha caspia, P. caspia*	Q_{IV} mg	Shell	8590 ± 70	8980 – 9360 (1)

LU-6134, MSU-1660) and one based on humic acids (MSU-1561) yield ages for sediment transitional from the Mangyshlakian horizon to the Neo-Caspian one (an early stage of the Neo-Caspian transgression), as the faunal composition contains more saline species with an admixture of *Didacna* (see above).

Discussion

Timing and paleoenvironment of the Mangyshlakian regression

From the stratigraphy and sedimentology, we infer the Mangyshlakian deposits in the northern Caspian Sea were deposited in the continental environment in the region crossed by the Volga River during ~12,000–8000 cal yr BP. The composition of the biogenic material in the lower parts of the sections suggest that there were two stages of the development of the water bodies filling paleo-lows in the Upper Khvalynian formation during the Mangyshlakian regression. During the early (sapropel) stage, sediment was deposited in either freshwater or brackish water bodies with vegetated substrates, meso- and eutrophic, with mobile (flowing?) water, rich in carbonates and sulfates, and oxygenated. The saturation of water with carbonates under dry climate conditions led to a massive deposition of high-magnesium calcite and accumulation of calcareous microalgal silt. During the subsequent stage of peat deposition, these shallow-water and freshwater or almost freshwater oligo-mesotrophic water bodies were overgrown almost completely with bottom higher plants (*Phragmites*, *Typha*, *Ceratophyllum*, and *Butomus*) with stagnant or weakly flowing water, and with an little influx of the terrigenous material.

Table 3
Result of spore-pollen analysis of the Mangyshlakian deposits from paleo-lows in Area 3.

Palynoforms	Sample N 1 (peat), %	Sample N 2 (sapropel), %
Arboreal	**0.8**	**1.8**
Birch	0.8	0.8
Pine	-	0.8
Oak	-	0.2
Grass and shrub	**56.7**	**78.2**
Chenopodiaceae	18.3	42.0
Artemisia	12.5	7.0
Gramineae	17.5	13.0
Liliaceae	1.8	2.2
Umbelliferae	1.8	0.4
Ranunculaceae	0.8	0.6
Sparganiaceae	1.6	-
Cruciferae	-	0.6
Compositae	-	9.6
Ephedra	-	0.8
Other	2.4	1.2
Spores	**42.5**	**20**
Bryales	41.7	19.4
Polypodiaceae	0.8	0.6

The composition of pollen and spores within the Mangyshlakian deposits suggest landscape with few or no arboreal species and the predominance of the steppe or semi-desert xerophyte associations. The climate was arid and probably cold compared to previous conditions. We obtained the spectra of a similar composition for the Mangyshlakian sediments from a deep-water depression in the Middle Caspian (Sorokin and Chernyshova, 1983): grass pollen dominates including single birch grains represent the arboreal flora.

Our study defines the timing of the Mangyshlakian regression that is more ancient than what previous researchers defined (as early Holocene; Varushchenko et al. (1987); Bolikhovskaya (2011). We obtained the oldest ages from Area 3 (12,420–10,420 cal yr BP, see Table 2). The water depth in that area is 10–13 m beneath the present Caspian Sea. The maximum level of the Late Khvalynian transgression reached 0 m gsl, (~28 m higher than present Caspian Sea) according to Svitoch and Yanina (1997). Consequently, the Caspian Sea water-level dropped by 40–44 m during the regression in Area 3. At the

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Table 4
Biological composition (%) of the Mangyshlakian organic sediments from paleo-lows (position Areas 2–4 see on Fig. 1C).

Biological composition	Area 2		Area 3		Area 4	
	Peat	Sapropel	Peat	Sapropel	Peat	Sapropel
Algae	6.1–23.0	50.4–86.0	12.8–54.2	76.5–87.3	5.7–37.6	66.8–95.3
Diatomeae	1.8–18.6	45.1–81.4	0.3–43.5	54.2–72.4	0–27.2	41.7–90.0
Chrysophyta	1.8–3.6	1.7–4.2	0.3–5.6	1–5.0	0.1–7.9	0.1–7.8
Charophyta	0	0	0	0	0–1.5	0
Chlorophyta	0	0	0–1.5	4.7–26.3	0–0.2	0
Cyanophyta	0.7	0.2–4.2	0–14.0	1–1.8	0–25	0–25
Desmidiaceae	0–1.3	1.5–13.9	0–0.3	0	0–9	0–0.6
Volvocaceae	0	0	0	0	0–0.1	0–0.2
Euglenophyta	0–0.4	0–0.2	0	0	0	0
Chlorococcophyceae	0–0.2	0	0–5.1	0	0–0.1	0
Higher plants	54.4–92.8	9.8–37.1	45.5–80.7	9–19.5	54.5–91.5	4.4–15.6
Phragmites communis	15	0–5	14.5–95.0	4.5–22.5	15–65	–
Typha	10	0	0–1.0	0.5–1.5	0–5	–
Ceratophyllum	0	15–55	0.5–10.0	0–93.5	0–70	–
Butomus umbellatus	0	0	0–5.0	0–0.7	0–10	–
Mummified remains	75	5–40	5–75	0–52.5	10–40	–
Grass remains	0	0	0.9	4.8–24.5	0	–
Pollen and spores	–	–	0–1.6	0–1.4	0.1–2.9	–
Animal remains (*Spongia. Ostracoda. Mollusca. Cladocera. Insecta. Bryozoa*)	0.2–19	4.8–10.4	0.3–1.6	3.7–5.2	0.3–11.8	0.3–24.9

historical rates of sea-level drop of 4–6 cm/yr (1880–1990; Varushchenko et al., 1987), the 44 m decline in Area 3 would have required 700–1000 yr. Adding this figure to the corresponding values of the calibrated age (MSU-1494 and MSU-1495, Table 2) with associated uncertainties, we suggest that the Mangyshlakian regression started 12,500–12,000 cal yr BP during the latter part of the Younger Dryas stadial based on the Blytt–Sernander scale (Schrøder et al., 2004). The coastline reached Area 3 during the late Pre-Boreal–the early Boreal under the conditions of arid climate, when chemogenic calcite with a high content of magnesium accumulated in the lacustrine water bodies. From our analyses, the age of the Upper Khvalynian deposits in Area 5 is 15,010–14,100 cal yr BP (12880 ± 100 ^{14}C yr BP) (Bezrodnykh et al., 2004). This is 1500–2000 yr older than the age of the start of the Mangyshlakian regression as calculated above, although some of this discrepancy is associated with the fact that the above age was not obtained from the very top of the Upper Khvalynian deposits.

For the deeper Area 5, the cover of deltaic deposits includes *Didacna*, which we infer marks the Neo-Caspian. These shells yield ages of 9360–8980 cal yr BP (MSU-1558, Table 2), indicating the time of transition to the Neo-Caspian transgression. This timing correlates to the second half of the Boreal stade. As these delta deposits overlie an paleo-topography incised 10–15 m below, we infer that the Mangyshlakian regression reached its lowest level by 500 yr earlier than the time fixed earlier for Area 5 (MSU-1558), during the late Pre-Boreal–early Boreal. All younger ages between 9000 and 7500 cal yr BP (MSU-1660, MSU-1618, MSU-1611b, MSU-1561, LU-6133, and LU-6134) pertain to the Neo-Caspian time and mark the early stages of the development of that transgression. A complete replacement of slightly brackish water mollusk complexes occurred ~8500–8000 cal yr BP (~7000 ^{14}C yr BP), based on our earlier analyses (Bezrodnykh et al., 2004).

From these ages (~12,500 cal yr BP), we conclude that the Mangyshlakian regression started during the second half of the Younger Dryas and ended during the first half of the Boreal stadial. If so, then the preceding Late Khvalynian transgression developed during the end of the Late Pleistocene from the global last glacial maximum, while the Neo-Caspian transgression started during the second half of the Boreal.

The ages from the Mangyshlakian deposits define the ages of the Khvalynian and the Neo-Caspian horizons. Based on the oldest Mangyshlakian ages, the Khvalynian deposits cannot be younger than 12,000 cal yr BP, the post-Khvalynian Mangyshlakian regression had apparently started by that time. While, the age of the Neo-Caspian deposits cannot be older than 10,000 cal yr BP. This timing is consistent with our previous results (Bezrodnykh et al., 2004).

Comparison of the Caspian Sea to the Black Sea

The Black Sea has also been subject to analysis of late Quaternary sea-level conditions. Ryan et al. (2007) investigated cores from the northwestern shelf, concluding that there was a large regression in the Black Sea during ~12,000–9000 cal yr BP (9500–8500 ^{14}C yr BP), with a drop nearly 150 m relative to its present sea-level elevation. This regression was manifest as an unconformity in the section of the Neo-Euxinian sediments. Balabanov (2009) investigated the coastal-marine and shallow-water deposits of the shelf of the Caucasus, concluding that there were also episodes of regression during the Neo-Euxinian transgression: 18 m in the interval ~10,800–10,000 cal yr BP and by 17 m in the interval 9600–9300 cal yr BP, indicating drawdown rates of ~6 cm/yr. A highly carbonaceous horizon is present in the top part of the Neo-Euxinian horizon of the deep-sea sediments of the Black Sea; its thickness is up to 15–20 cm and the $CaCO_3$ content reaches 60–65% (Sorokin et al., 1987; Bahr et al., 2005; Major et al., 2006). This horizon apparently formed 11,600–9400 cal yr BP (Major et al., 2006) in the conditions of arid post-glacial climate (Komarov et al., 1978; Sorokin et al., 1983; Chernyshova and Sorokin, 1984; Kuprin et al., 1984). From these relations, we infer that there was a considerable lowering of the level of the Black Sea during the Pre-Boreal and the Boreal periods under the conditions of arid climate, leading to oversaturation of the water with carbonate and its chemogenic deposition. This lowering manifested itself in the shallow water area as 2 phases of the lowering of the level, by almost 20 m each.

Comparing the records for the Caspian and the Black seas indicates similar short-term regressions at the close of the global last glacial maximum; the Mangyshlakian regression interrupted the post-glacial late Khvalynian transgression in the Caspian Sea, and the deep regressions during the Neo-Euxinian transgression in the Black Sea. These regressions were during the Pre-Boreal and the first half of the Boreal ~12,000–9000 cal yr BP in the Black Sea under arid climate conditions, which were warmer compared to the last glacial maximum, as indicated by the predominance of the grass pollen and a certain increase in the proportion of the tree pollen. For the Caspian Sea, the Mangyshlakian regression started earlier (during the Younger Dryas Stade), ~12,500 cal yr BP, and ended during the first half of the Boreal, ~9500 cal yr BP, under an arid climate. The arid climate conditions are indicated in the composition of sediments of both seas in the form of an almost simultaneous accumulation of chemogenic carbonates. The lake-level lowering was also similar at 4–6 cm/yr.

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Conclusions

Seismo-acoustic data show that the Mangyshlakian deposits fill paleo-lows in the strata of the Khvalynian deposits to a depth of 3–33 m below the present-day Caspian sea. The depositional environments include i) small depressions similar to the modern ilmeni water bodies of the delta of the Volga; ii) the paleo-Volga valley and the cover of paleo-deltaic deposits in the southern part of the northern Caspian Sea. Organogenous sediments are widespread in the composition of the freshwater Mangyshlakian deposits, represented by high-carbonate sapropel and low-carbonate peats.

The Mangyshlakian deposits were formed during arid conditions in the shallow-water lacustrine water bodies with flowing and stagnant regimes. The saturation of water with carbonates during the accumulation of sapropel led to the deposition of chemogenic carbonates.

The Mangyshlakian deposits contain few faunal remains compared to the overlying and underlying transgressive sequence but include freshwater and weakly brackish water bivalve molluscs, gastropods, and diatom algae. The absence of the *Didacna* genus is its characteristic feature. Radiocarbon dating defines the age of the Mangyshlakian deposits to be between 11,900 and 10,500 cal yr BP (~10,000–8500 ^{14}C yr BP).

The Mangyshlakian regression developed from the middle of the Younger Dryas until the middle of the Boreal period. The more precise age estimates allow inference of the timing of the maximum level of the late Khvalynian transgression—not later than 12,500 cal yr BP, and the start of the Neo-Caspian transgression as 9500 cal yr BP.

Comparing the timing and paleoenvironmental record of the Caspian Sea with the Black Sea indicates that the Mangyshlakian regression, which completed the Late Khvalynian stage of the development of the Caspian Sea, coincides with a deep regression in the Black Sea during the Neo-Euxinian transgression. Consequently, we conclude that both the Black and the Caspian seas developed practically synchronously after the global last glacial maximum.

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References

Aksu, A.E., Hiscott, R.N., Kaminski, M.A., Mudia, P.J., Gillespie, H., Adrajano, T., Yaşar, D., 2002. Last glacial–Holocene paleoceanography of the Black Sea and Marmara Sea: stable isotopic, foraminiferal and coccolith evidence. Marine Geology 190 (1-2), 119–149.
Arkhangelsky, A.D., Strakhov, N.M., 1938. Geological structure and history of development of the Black Sea. Nauka Press, Moscow (in Russian).
Arslanov, Kh.A., 1993. Late Pleistocene Geochronology of European Russia. Radiocarbon 35, 421–427.
Arslanov, Kh.A., Lokshin, N.V., Mamedov, A.V., 1988. On the age of Khazarian, Khvalynian, and New Caspian deposits of the Caspian Sea. Bulletin of the Quaternary Commission 57, 45–58 (in Russian).
Badyukova, E.N., 2007. Age of Khvalynian Transgressions in the Caspian Sea Region. Oceanology 47, 400–405.
Bahr, A., Lami, F., Arz, H., Kuhlmann, H., Wefer, G., 2005. Late Glacial to Holocene climate and sedimentation history in the NW Black Sea. Marine Geology 214, 309–322.
Balabanov, I.P., 2009. Paleogeographical background to formation of modern natural conditions of the Caucasus littoral Holocene terraces and their long-term development forecast. Dalnauka Press, Moscow-Vladivostok (in Russian).
Bezrodnykh, Yu.P., Romanyuk, B.F., Deliya, S.V., Magomedov, R.D., Sorokin, V.M., Parunin, O.B., Babak, E.V., 2004. Biostratigraphy and structure of the Upper Quaternary deposits and some paleogeographic features of the north Caspian region. StratigraphyGeological Correlation 12. Pleiades Publishing, Ltd, pp. 102–120.
Bolikhovskaya, N.S., 2011. Features of environmental and climatic changes in the Northern Caspian sea region and Caspian Sea level fluctuations controlled by climate during the Holocene. Proceeding of the VII All-Russian Quaternary Conference. The Quaternary in all of its variety. Basic issues, results, and major trends of further research. Apatity. Saint-Peterburg. V.1, pp. 74–77 (in Russian).
Chepalyga, A.L., 2007. The Late Glacial great flood in the Ponto-Caspian basin. In: Yanro-Hombach, V., Gilbert, A.S., Panin, N., Dolukhanov, P.M. (Eds.), The Black sea flood Question: Changes in Coastline, Climate, and Human Settlement. Springer, pp. 119–148.
Chernyshova, M.B., Sorokin, V.M., 1984. Comparison of palynological characteristics of Late Quaternary sediments from the Mediterranean and Black Seas, Izvestiya Vysshih Uchebnih. Zavedeniy. Geologiya i Razvedka 2, 118–120 (in Russian).
Fedorov, P.V., 1978. Pleistocene of the Ponto Caspian. Nauka Press, Moscow (in Russian).
Fedorov, P.V., 1995. Modern geology of the Caspian Sea. Herald of the Academy of Sciences. 65 (7), 622–625 (in Russian).
Khain, V.E., 1958. On the problem of the tectonics of Caspian depression and structural bounds between Caucasus and Trans Caspian region. Oil and Gas Geology 9, 11–18 (in Russian).
Komarov, A.V., Bozhilova, E.D., Filipova, M.V., Udintseva, O.G., 1978. Palynological spectra and their stratigraphic interpretation. Geology and Hydrology of the Western Black SeaSofia: Bulgar. Acad. Sci. pp. 85–91 (in Russian).
Kuprin, P.N., Sorokin, V.M., Babak, E.V., Chernyshova, M.B., 1984. Correlation of Quaternary sections in the western part of the Black Sea. The Study of the Geological History and Recent Sedimentation in the Black and Baltic Seas. Kiev, Naukova dumka, pp. 116–122 (in Russian).
Kuzmin, Y.V., Nevesskaya, L.A., Krivonogov, S.K., Burr, G.S., 2007. Apparent 14C ages of the 'pre-bomb' shells and correction values (R, ΔR) for Caspian and Aral seas (Central Asia). Nuclear Instruments and Methods in Physics Research B 259, 463–466.
Kvasov, D.D., 1975. Late Quaternary history of large lakes and inland seas of Eastern Europe. Nauka Press, Leningrad (in Russian).
Lebedev, L.I., Bordovskiy, O.K., Maev, E.G., 1973. Sediments of the Caspian Sea. Science Press, Moscow (in Russian).
Leonov, Yu.G., Lavrushin, Yu.A., Antipov, M.N., Spiridonova, E.A., Kuzmin, Ya.V., Jail, E., Burr, S., Jelinovsky, A., Shali, F., 2002. New data on the age transgressive phase Early Khvalynskaya transgression of the Caspian Sea. Doklady Akademii Nauk 386, 229–233 (in Russian).
Leontyev, O.K., 1961. The ancient shorelines of Quaternary transgressions of the Caspian Sea. Trudy Instituta Geografii. Akademii. Nauk SSSR. 8 pp. 45–64 (in Russian).
Leroy, S.A.G., Tudryn, A., Chalié, F., López-Merino, L., Gasse, F., 2013. From the Allerød to the mid-Holocene: palynological evidence from the south basin of the Caspian Sea. Quaternary Science Reviews 78, 77–97.
Maev, E.G., 2006. Extreme regression of the Caspian Sea during early Holocene. Proceedings of the international science conference. Extreme and hydrogeological events in Aral-Caspian seas, Moscow, pp. 62–66 (in Russian).
Maev, E.G., 2009. Phases of mangishlak regression in the Caspian Sea. Vestnik Moskovskogo universiteta. Seria Geografia 1, 15–20 (in Russian).
Major, C., Ryan, W., Lericolais, G., Hajdas, I., 2002. Constraints on Black Sea outflow to the Sea of Marmara during the last glacial interglacial transition. Marine Geology 190, 19–34.
Major, C.O., Goldstein, S.L., Ryan, W.B.F., Lericolais, G., Piotrovski, A.M., Haidas, I., 2006. The co-evolution of Black Sea level and composition through the last deglaciation and its paleoclimatic significance. Quaternary Science Reviews 25, 2031–2047.
Popov, G.I., 1983. Pleistocene of the Black Sea–Caspian Seaways. Nauka Press, Moscow (in Russian).
Ross, D.A., Degens, E.T., 1974. Recent Sediments of Black Sea. In: Ross, D.A., Degens, E.T. (Eds.), The Black Sea, Geology, Chemistry and Biology. Tulsa, Oklahoma. Am. Assoc. Petrol. Geol.
Ross, D.A., Neprochnov, Y.P., Hsű, K.J., Stoffers, P., Supko, P., Trimonis, E.S., Percival, S.F., Erickson, A.J., Degens, E.T., Hunt, J.M., et al., 1978. Initial Report of the Deep Sea Drilling Project 42, pt. 2. U.S. Government Printing Office, Washington.
Ryan, W.B.F., Pitman III, W.C., Major, C.O., Shimkus, K., Moskalenko, V., Jones, G.A., Dimitrov, P., Görür, N., Sakinç, M., Yüce, H., 1997. An abrupt drowning of the Black Sea shelf. Marine Geology 138, 119–126.
Ryan, W.B.F., Panin, N., Dolukhanov, P.M., 2007. Status of the Black sea flood hypothesis. In: Yanro-Hombach, V., Gilbert, A.S. (Eds.), The Black sea flood Question: Changes in Coastline, Climate, and Human Settlement. Springer, pp. 63–88.
Rychagov, G.I., 1997. Pleistocene History of the Caspian Sea. Moscow State University Press, Moscow (in Russian).
Schrøder, N., Højlund Pedersen, L., Juel Bitsch, R., 2004. 10,000 Years of climate change and human impact on the environment in the area surrounding Lejre. The Journal of Transdisciplinary Environmental Studies 3 (1), 1–27.
Shimkus, K.M., Emel'yanov, E.M., Trimonis, E.S., 1975. Black Sea bottom sediments and features of the Late Quaternary History. The Earth's Crust and Evolution of the Black Sea Depression. Nauka Press, Moscow, pp. 138–161 (in Russian).
Sorokin, V.M., Chernyshova, M.B., 1983. Late Quaternary climatic fluctuations by data of sediment studies in the Caspian Sea. Izvestiya Vysshih Uchebnih. Zavedeniy. Geologiya i Razvedka 6, 24–29 (in Russian).
Sorokin, V.M., Kuprin, P.N., 2007. On the character of Black Sea level rise during the Holocene. Moscow University Geology Bulletin 62. © Allerton Press, Inc., pp. 334–341.
Sorokin, V.M., Kuprin, P.N., Chernyshova, M.B., 1983. Late Quaternary comparative paleogeography of the Black and Caspian Seas. Paleogeography of the Caspian and Aral Seas in the Cenozoic. Moskovski Gosudarstvenniy Universitet, Moscow, pp. 42–52 (in Russian).
Sorokin, V.M., Sokolov, V.N., Shlykov, V.G., 1987. Genetic types of carbonates from the Late Quaternary sediments of the Black sea. Litologiya I poleznie iskopaemie 1, 24–30 (in Russian).
Stuiver, M., Reimer, P.J., Reimer, R., 2014. Calib radiocarbon calibration. html. www.calib.qub.ac.uk/calib/ (Execute version 7.0).
Svitoch, A.A., Yanina, T.A., 1997. Quaternary sediments of the Caspian Sea coasts. RASHN Press, Moscow (in Russian).

Svitoch, A.A., Selivanov, A.O., Yanina, T.A., 1998. Pleistocene paleogeographic events in the Ponto-Caspian and Mediterranean regions. Moskovskiy Gosudarstvenniy Universitet, Moscow (in Russian).
Varushchenko, S.I., Varushchenko, A.I., Klige, R.K., 1987. The change of the regime of the Caspian Sea and closed water basins during Paleotimem, Moscow. Nauka Press, Moscow (in Russian).
Vronskii, V.A., 2006. Ecological and geographical problems of the Caspian Sea. Geografiya i Prirodnie Resursi 1, 31–35.
Yanina, T.A., 2012. Correlation of the Late Pleistocene paleogeographical events of the Caspian Sea and Russian Plain. Quaternary International 271, 120–129.