The paleogeography of the Caspian Sea first of all is the history of fluctuations of its level. Historic and paleogeographical data give evidence to considerable level oscillations, whose amplitude was more than 100 m during Pleistocene and Holocene. The task of this lection is to find out a dependence of fluctuations of the Caspian Sea level during the Late Pleistocene (130-11.7 ky, the last climatic macrocycle) with the global climate changes. The second task is the correlation the paleogeographical events in the Caspian Sea with the Black Sea. The Caspian and Black Seas (Ponto-Caspian) represent a system of basins (Fig. 1), relicts of the East Paratethys that have their own unique environmental features and paleogeographical history.

The evolution of the basins natural system and changes in individual constituents depended of a number of factors including global climatic changes; glacial-interglacial rhythms on the Russian Plain and in mountains; neotectonic processes; volumes of groundwater and pore water inflow; deposition within the basin; etc. (Antipov et al., 1996; Chepalyga, 2006; Fedorov, 1978; Golubov, 1984; Golubov et al., 1998; Karpychev, 1992; Kvasov, 1977; Lavrushin et al., 2004; Mayev, 1994; Rychagov, 1997; Svitoch, 2007, 2014; Varushchenko et al., 1987; Yanina, 2012, 2014; a.o.). In the course of the geological history the impact of the listed factors varied in efficiency from one stage to another. In the Late Pleistocene the leading role belonged to the global climatic changes; those were manifested as alternating cold and warm epochs and resulted from variations in insolation due to changes in the Earth orbit elements (marine isotope stages MIS 5 to MIS 2) (Fig. 2).

The study of the Late Pleistocene development of the Ponto-Caspian basins, initiated at the end of the nineteenth century by the works of Andrusov (1888, etc.), was continued by many researchers (Arkhangelskiy and Strakhov, 1938; Zhukov, 1945; Fedorov, 1957, 1978; Vasiliev, 1961; Moskvitin, 1962; Nevesskaya, 1965; Goretskiy, 1966; Vronskiy, 1974; Kvasov, 1975; Ostrovskiy et al., 1977; Popov, 1983; Balabanov and Izmailov, 1988, 1989; Yanko, 1989; Svitoch, 1991, 2007; Maev, 1994; Chepalyga, 1997; Rychagov, 1997; Bezrodnykh et al., 2004; Yanina, 2005, 2012, 2013, 2014; Aksu et al., 2006; Badyukova, 2007; Yanina, 2012; Badyukova, 2007; Sorokin, 2011; Tudryn et al., 2013; and many others). Despite abundant data and insights, major questions about the paleogeographic development of the region are still being debated.
Caspian Sea

During the Late Pleistocene, several transgressive and regressive episodes developed, including the Late Khazar (Late Khazar and Girkan transgressive stages) and the Khvalynian (Early Khvalynian and Late Khvalynian transgressive stages) transgressive epochs, separated by the Atel regression. The Late Khazar transgression developed in two successive stages that are separated by a regression. Lake levels in the earlier Late Khazar basin, according to spatial distribution of the deposits, did not exceed -10 m, and its surface area was not much bigger than the modern Caspian Sea (Fig. 3). The mollusc fauna contained crassoidal-type *Didacna* and was characterized by the occurrence of *Didacna nalivkini* and *Didacna surachanica* (Fig. 4). The fauna is characterized by the large size and massive nature of shells, especially in the southern parts of the Caspian Basin. Abundant trigonoidal and catilloidal *Didacna* dominated faunas
occurred in the freshened areas of the Northern Caspian, influenced by the Volga River during Late Khazar times.

Common gigantism of shells, high carbonate content in the sediment, and the presence of oolites represent warm climate conditions during Late Khazar times. Salinities reached from 10 to 12‰ in the northern up to 14-15‰ in the southern part of the Caspian Basin, higher than today’s salinities. Data on foraminifera (Yanko, 1989) support this conclusion. The warm climatic phase is also shown in palynological analyses (Abramova, 1974; Yakhimovich et al., 1986). During early Late Khazar times, the Caspian Basin was occupied by an isolated lake-sea that lacked any connection with the Black Sea Basin.

Fig. 3. Late Khazarian transgression (Yanina, Makshaev, 2016)

Fig. 4. Late Khazarian mollusks
After the Early Late Khazar stage, a regression followed that is seen in hiatuses in the depositional sequences of Dagestan and erosion and soil formation in the Volga River valley (Yanina and Sviatoch, 1990; Sviatoch et al., 1993, 1997; Yanina, 2005). At present, there is no direct evidence to estimate the extent of the Late Khazarian regressive phase. As the composition of the mollusc fauna was not much altered, this probably was a minor regression. Traces of the second transgressive Late Khazar stage are not preserved along the Caspian coasts. Based on borehole material from the northwestern part of the Caspian region, Goretskiy (1957) and Popov (1955, 1967) indicated the presence of a brackish water basin which existed after the Late Khazarian transgression and before the Khvalynian transgression, the Girkanian (Hyrkanian) transgression. The Girkanian basin was inhabited by “Khvalynian-like” fauna, traces of which have not been recorded elsewhere. A number of researchers strongly objected to the Girkanian transgression concept (Shkatova, 1975; Fedorov, 1978; Vasiliev, 1982; Shkatova et al., 1991; Sviatoch, 1991; Sviatoch et al., 1993, 1997, 1998).

The stratigraphic succession in cores from the northern Caspian Sea (Fig. 5, Yanina et al., 2013) shows that between the Chernoyarsk and Atelian regressive phases, two intervals of brackish deposits exist. The lower interval is assigned to Late Khazarian transgressive interval. These deposits contain an admixture of warm species with a Pontocaspian nature (D. nalivkini and also rare D. surachanica, Didacna vulgaris and Didacna pallasi) as well as the fluvial Corbicula fluminalis. During late Khazarian times, the Caspian Basin was a brackish water shallow warm-water basin. The overlying marine sandy-clay sediments contain abundant Didacna subcatillus, the occurrence of Didacna cristata and species of Khazarian type D. pallasi, Didacna shuraosenica and Didacna subcrassa. According to Popov (1983), D. subcatillus in combination with D. cristata characterized the Girkanian fauna (Fig. 6). Thus, the interval identified in the boreholes can be attributed to the Girkanian transgression.

![Fig. 5. The seismoacoustic profile with boreholes displaying the structure of deposits in the Northern Caspian Sea](image)

Very crude and partially overlapping age estimates exist for the Late Khazarian epoch. U-Io techniques give age estimates of 114-76 ka (Leontiev et al., 1975; Rychagov, 1997); 115-81 ka (Arslanov et al., 1978), and 122-91 ka (Shkatova et al., 1991). Based on thermoluminescence (TL) analysis, age estimates are 144-90 ka (Geochronology, 1974), 130-91 ka (Leontiev et al., 1975), and 122-106 ka (Shakhovets, 1987; Shkatova et al., 1991). Results of electronic paramagnetic (spin) resonance (ESR) showages between 140 and 85 ka (Bolikhovskaya and
Molodkov, 1999, 2008; Molodkov and Bolikhovskaya, 2009). The wide range of age estimates as well as the improved understanding of the paleogeographic successions implies a longer duration for this period than is generally accepted (Fedorov, 1978). The Girkanian mollusk shells have been dated by radiocarbon using AMS in the Lawrence Livermore National Laboratory, the USA, within the range from 47 to >55 ka BP (Yanina et al., 2018). The estimated geological age of the Girkanian deposits lies beyond the $^{14}$C dating limits, so further geochronological investigations are required.

As a result of research performed as a part of the European Science Foundation research program, that is Quaternary Environments of the Eurasian North (QUEEN) project, there have been reconstructed the overflow of the West Siberian ice-dammed lake through the Turgai Hollow, Aral Sea, and Uzboy channel into the Caspian Sea that took place about 90 ka BP (Fig. 7, Mangerud et al., 2004).

![Fig. 6. Girkanian mollusks](image)

![Fig. 7. West Siberian ice-dammed lake](image)
As the timing of the conjectured overflow is roughly comparable with the Girkanian transgression of the Caspian Sea, it seems quite pertinent to suppose it to be one of the causes of the transgression. No convincing evidence (geological or paleontological) in favor of such an assumption has been found as yet.

The Khazarian epoch ended with the deep Atelian regression. During this time, vast areas of the Caspian shelf were exposed and river incision was very deep (Fedorov, 1978; Rychagov, 1997). Atel epoch deposits are found in many parts of the Caspian Region (Svitoch, 1991; Svitoch and Yanina, 1997). In the Lower Volga region, the base of the Atelian regressive unit is formed by the Akhtuba deposits, referred to by Goretzkiy (1958) as periglacial. These deposits represent a perfect marker horizon in the Lower Volga sections, often with sharp wedges penetrating the underlying sediments (Fig. 8-9).

These wedges and the co-occurring winter fractures in the base of Akhtuba sands form evidence of very cold climate conditions at the time of deposition that included the development of permafrost. Vegetation was represented by tundra-steppe associations (Grichuk, 1954). Formation of lublineite crystals in the Akhtuba sands indicate cold dry climate (Moskvitin, 1962). The Akhtuba deposits are conformably overlain by Atelian sandy loam and loam sediments (up to 20 m thick) of various origins, formed in continental environments in the Caspian region. Some shells of stunted freshwater and continental mollusks are found in these sediments. The deposits contain mammal remains of the upper Paleolithic faunal complex, including mammoth, horse, reindeer and other species that show the cold nature of the Atelian epoch. Palynological assemblages typical of taiga were found (Grichuk, 1954; Chiguryaeva and Khvalina, 1961; Moskvitin, 1962). The Atelian layer has up to four palaeosol horizons with different degrees of development, which implies a multiple change of climatic conditions in the region, with increasing warming and humidity. Towards the end of the Atelian epoch, the climate became warmer. In the vegetation, the share of arboreal pollen increased, along with birch, pine and spruce, newly introduced elm, oak and linden appeared. In the herbaceous associations the importance of xerophytes decreased, while Gramineae and herbaceous vegetation were introduced. Steppe and forest-steppe environments became dominant.

Based on seismic-acoustic profiling (Lokhin and Maev, 1990; Maev, 1994), during the maximum regression the water level of the basin was -120 to -140 m. The Caspian basin retreated into the middle and southern parts of the lake. There is no data on the shell fauna of this basin. A drastic faunal shift occurred, and the formerly abundant Khazarian Didacna of the crassa group and closely related taxa became almost completely extinct. The main components of the Khvalynian fauna with preference for lower salinity habitats were inherited from the Girkanian fauna. Based on the thickness of the Akhtuba-Atelian deposits, and the presence of at least three
paleosol horizons within them, the continental hiatus on the territory of the Northern Caspian Depression was long-term and multi-phase. It started with the water retreat from the Girkanian basin, which, most likely, happened after 76 ka.

In the Northern Caspian cores the deposits of the Girkanian transgressive basin are overlain with the Atelian regressive horizon. The regression is pronounced in the seismic-acoustic profiles by a number of distinct erosional incisions under the base of Khvalynian sediments (Fig. 10).

The series is variable in lithology, with alternating layers of clay loams, sandy loams and clays; they contain iron monoxide in the form of hydrotroilite. The deposits include plant detritus arranged along the layers. According to O. Uspenskaya, the organic remains are dominated by fragments of higher aquatic plants, mostly of hornwort and reedmace. Palynological data obtained by N. Bolikhovskaya (Bolikhovskaya et al., 2016) lent support to the conclusion on the Atelian deposits having been deposited in channels eroded in the older layers. They contain pollen of aquatic and littoral (near-shore) plants (Potamogeton, Sparganium, Lemna, Myriophyllum); remains of freshwater and brackish-water algae, and dinocysts (Pediastrum, Botryococcus, Spiniferites cruciformis, etc.). Some freshwater mollusks are found occasionally (Dreissena polymorpha polymorpha, Valvata piscinalis, Theodoxus pallasi, Limnea stagnalis), as well as terrestrial gastropods.

The organic remains suggest aquatic environments – freshwater (less common – brackish-water) shallow basins deficient in biogenic elements. Palynological data on the Atelian series point to considerable changes in environments during the series deposition (Bolikhovskaya et al., 2016). The radiocarbon dating was performed in the Institute of Geography, RAS and in the Lawrence Livermore National Laboratory (the USA) on humic acids extracted from Atelian deposits infilling paleo-channels. The ages thus obtained lie in the range of 36 680±850 to 40 830±100 14C yr BP, or 41 191±750 to 44 390±180 cal. yr BP. It should be noted that the results obtained in different laboratories are close enough to each other. We concluded that
Atelian regression took place during the Late Valdai (Kalinin, MIS 4) glacial period of Eastern Europe, and they fix its end during an epoch of interstadial warming (MIS 3).

The Atelian regression was followed by the “Great” Khvalynian transgression with the most extensive sea-level rise in the Late Pleistocene history of the Caspian Sea. During the Early Khvalynian transgressive stage, levels reached as high as 48-50 m a.s.l. (Fig. 11).

![Fig. 11](image1.png)

The basin was occupied by a low diversity fauna dominated by catilloid and trigonoid *Didacna* species, all characterized by thin and small shells (Fig. 12).

![Fig. 12](image2.png)
The structure of mollusc fauna is indicative of relatively low salinities for the basin as a whole, but regional variations existed. Salinities in the main water body of the northern Khvalynian Sea were slightly higher than modern salinities (3-4‰) whereas salinity of the middle and southern parts of the basin (about 11‰) was slightly lower than today (Yanina, 2012a). The small thin shells of mollusks indicate low water temperatures in comparison with ancient basins and the present Caspian Sea. The lower Khvalynian deposits are made up of very characteristic chocolate clays (Fig. 13, 14). According to Moskvitin (1962) and Goretskiy (1966), the clays were formed as a result of accumulation of fine sediments that derived from the periglacial landscapes of the hinterland. Palynological data confirm a cold climate.

According to the drilling material, in the Northern Caspian Sea the Atelian formations are overlain with Khvalynian series of complicated structure (Fig. 15).

![Fig. 13, 14. Khvalynian “chocolate clays”](image)

![Fig. 15. The thickness of the Khvalynian deposits in the N. Caspian Sea (Yanina et al., 2018)](image)
There is a layer of shell and sandy deposits 2.5 to 5.0 m thick at its base (Fig. 15, layer 1). The fauna is dominated by Didacna subcatillus, occasionally found are Didacna zhukovi, D. parallella, Monodacna caspia, Micromelania caspia, Clessiniola variabilis, Theodoxus pallasi; Dreissena shells are numerous. The shells recovered from that layer were dated by scintillation radiocarbon method and yielded the $^{14}$C age within the interval of 27 200±340 to 31 600±420 yr BP (33 860±1490 to 36 580±340 cal. yr BP). The deposits suggest a shallow-water basin – the initial stage of the Khvalynian transgression. Judging from the shell appearance (medium to large size, with thick valves) the water temperature was moderately warm. On top of the above-described shallow-water deposits attributed to Lower Khvalynian there are marine clays 8 to 10 m thick with sand interbeds varying in thickness (Fig. 15, layer 2). That part of the sequence may be interpreted as indicative of a continuing transgression. The series contains Early Khvalynian shells Didacna protracta protracta, D. protracta submedia, D. subcatillus, Dreissena rostriformis distincta, Dreissena rostriformis compressa. In the mollusk assemblage there are numerous subspecies known as dwellers of relatively deep water (D. protracta submedia, Dreissena rostriformis compressa); along with the sediment composition, their presence implies a deep-water stage of the Khvalynian transgression.

It is the first transgressive stage of the Khvalynian transgression, we don't see its sediments on the Caspian coasts. The first transgressive stages of the Khvalynian transgression took place during the warming of the MIS 3, in the interstadial epoch.

The clays are overlain with a predominantly sandy layer up to 8 m thick, which suggests a drop of the Khvalynian basin level. The lower boundary of the series is dated by radiocarbon to the interval of 22 to 20 ka BP (Fig. 15, layer 3). They correspond to LGM (Last Glacial Maximum) in the Eastern Europe. The sands are covered with a layer of sandy loam up to 2 m thick (Fig. 15, layer 4). Among shells occurring at its base there have been identified Didacna protracta protracta, D. subcatillus, Hypanis plicatus, Dreissena rostriformis distincta. A sample from the layer base was dated by $^{14}$C at 19 325±75 yr BP. The deposition of the layer was related to a short-term rise of the Khvalynian sea level.

The structure of the top part of this thickness (Fig. 15, layers 5-6) reflects events of the Khvalynian epoch which are expressed in a structure of coastal sections too. According to radiocarbon dating it was the epoch of the degradation of the last glaciations (MIS 2).

Caspian Sea researchers have shown stadial coastlines during an epoch of the Early Khvalynian basin: maximum, 34-36 m (Talginsk), 28-30 m, 20-22 m (Buinaks), 14-15 m (Turkmenian), and 4-6 m (Fedorov, 1957; Rychagov, 1970, 1974) (Fig. 16).
Chepalyga (2006, 2007) offered the “fantastic” concept according to which Early Khvalynian transgression was a catastrophic Great (Bible) Flood, and its transgressive phases were the “waves” of this flood developed at high speed. He even executed a Noah’s Ark reconstruction on waves of the Khvalynian Sea. His conclusions were contested by others, including Badyukova (2007), Svitoch (2007), Sorokin (2011) and Yanina (2012a). According to their reconstruction, development of the Khvalynian transgression was gradual and had no catastrophic character.

The Early Khvalynian ended with the Enotayevsk regression, with a maximum level estimated at -105 m (Maev, 1994). Terrestrial Enotayevsk deposits and numerous unconformities in the marine record are described on the coasts of the Caspian Sea (Leontiev and Fedorov, 1953; Vasiliev, 1961; Rychagov, 1974; Fedorov, 1978; Svitoch, 1991; Svitoch and Yanina, 1997). On the Caspian shelf, the Enotayevsk layers have been found in boreholes (Maev, 1994; Svitoch et al., 2008a). According to pollen data (Sorokin et al., 1983), arid cool climate conditions existed.

During the succeeding Late Khvalynian transgressive stage, sea levels reached about 0 m (Fig. 17). *Didacna praetrigonoides*, a rare species in the early Khvalynian, became dominant. Salinity of the main water body of Late Khvalynian basin was very similar to that of the Early Khvalynian basin, 11-12‰, although foraminifera faunas suggest salinities up to 12-14‰ (Yanko, 1989). In the northern Caspian coastal zone, salinities were as low as 3-4‰ (Yanina, 2012a).

![Fig. 17. Late Khvalynian transgression (Yanina, Makshaev, 2016)](https://example.com/fig17)

Relative abundance of the mollusks in the basin and their large and more massive shells (Fig. 18) are explained by favorable (warmer) conditions compared to those of the Early Khvalynian basin. Palynological data (Grichuk, 1954; Abramova, 1974; Sorokin et al., 1983) indicate general warming in the region. The regressive tendency of the Late Khvalynian Sea was characterized by a series of minor secondary transgressive phases (Leontiev and Fedorov, 1953; Leontiev and Foteeva, 1965; Rychagov, 1997) (Fig. 19). The Late Khvalynian regression coincided with increasing aridity in the Caspian region. This is shown in the change of pollen of
wood vegetation (pine, alder, birch, oak, hornbeam, willow) towards xerophilous grassy pollen typical of semi-desert and steppe vegetation (Abramova, 1974).

Fig. 18. Late Khvalynian mollusks

Fig. 19. The stages of the Late Khvalynian basin
The age of the Khvalynian epoch remains a subject of discussion (Kaplin et al., 1972, 1977a,b; Leontiev et al., 1975; Kvasov, 1975; Arslanov et al., 1978; Rychagov, 1997; Bezrodnykh et al., 2004; Badyukova, 2007, and others). Leontiev and Rychagov (Leontiev et al., 1975; Rychagov, 1997) based mostly on TL dates, estimated the age of the Early Khvalynian transgression as 70-40 ka, and the age of the Late Khvalynian transgression as 20-10 ka. An opposite point of view based on 14C and U-Th dating was proposed by Kvasov (1975) and Svitoch (1991). In recent years, on the age of the Khvalynian transgression of the Caspian Sea emerged (Leonov et al., 2002; Bezrodnykh et al., 2004; Svitoch, 2007; Arslanov and Yanina, 2008; Chepalyga et al., 2008, 2009; Svitoch et al., 2008a,b; Arslanov et al., 2013; Tudryn et al., 2013). Analyses on mollusks from boreholes show 30 to >30 ka for the lower part of the Khvalynian deposits (Bezrodnykh et al., 2004); 14C age 28.5-31.5 ka, calibrated age from 33.5 to 36.5 ka (Arslanov et al., 2013, 2017; Yanina et al., 2013). According to these data, the Khvalynian transgression began about 37 ka. Unfortunately, no radiocarbon age estimates exist for the maximum level of the Khvalynian transgression, and all existing estimates (Chepalyga, 2007; Svitoch, 2007; Dolukhanov et al., 2009, 2010) are based on indirect correlations and assumptions. Most are associated with the stadial level about 22-24 m, defining its age (calibrated) as 15-14 ka.

Such is paleogeography of the Caspian Sea during the Late Pleistocene.

What events took place in the Black Sea at this time?

Black Sea

The scheme of the Late Pleistocene events of the Pontian Basin includes the Karangat (Karangat and Tarkhankut stages), Surozh and New Euxinian transgressions, and intervening regressions. The Karangat transgression is the largest Pleistocene interglacial transgression with the highest salinities during the Pleistocene. The analysis of the Karangat fauna showed that transgression developed with two stages, Karangat and Tarkhankut. They were characterized by faunal complexes that contained stenohaline as well as euryhaline mollusc taxa. The Karangat transgression developed in two phases. During the early Tobechik phase (Nevesskaya, 1965), a mollusc fauna similar to the modern Black Sea fauna was established. Sea levels did not exceed the modern levels. Age estimates for this phase range from 121 to 127 ka (Dynamics, 2002).

With further development of the interglacial Mediterranean transgression, the penetration of marine waters in the Black Sea led to the second phase of the Karangat transgression. Stenohaline species (Acanthocardia tuberculatum, etc.), which are absent in the Black Sea today, flourished in the Karangat basin. They indicate salinities of about 30‰ in the open part of the sea. High salinity was characteristic for the southern part of the Sea of Azov, and the Manych and the Don estuary. The Karangat transgression was characterized by warm waters, as shown by the composition of the mollusc fauna, as well as the presence of warm-water subtropical types of diatoms (Zhuze et al., 1980). Spores and pollen ranges also indicate warm conditions in the region (Sherbakov et al., 1977; Koreneva, 1982; History of geological development, 1988).

In the second phase of the transgression, the Karangat Sea exceeded the limits of the present Black Sea and Sea of Azov. The sea ingressed into river valleys tens of kilometers upstream and even 70-80 km upstream in the Danube River system (Mikhaylesku, 1990). According to Popov (1983), the maximum extension of the Karangat Sea extended as far east as the Manych watershed. The age of the maximum transgressive stage is not well constrained: a series of thorium - uranium dates show a range between 140 and 70 ka (Arslanov et al., 1975; Balabanov and Izmailov, 1989; Dynamics, 2002).

After the maximum transgression, the Karangat Sea lowered. During this Tarkhanhut stage, the Karangat Sea had a similar outline as the modern Black Sea. It was the residual basin of the Karangat Sea, a final stage of its existence. The Mediterranean connection had ceased to exist at the time. Salinities did not exceed 14-15‰. The mollusc faunas were dominated by Mediterranean taxa but lacked stenohaline species. During the Tarkhanhut stage, Girkanian waters entered through the Manych passage, and Didacna species (D. cristata, D. subcatillus) invaded the basin margins on the northeast from the Caspian Basin. The Post-Karangat
regression lake level dropped to -110 m (Ostrovskiy et al., 1977; Balabanov and Izmailov, 1989). The marine environment was replaced by brackish-water, and then almost fresh-water conditions (History of geological development, 1988). Diatom species indicate cold water conditions. Palynological analyses also show very cold conditions at the time (Sherbakov et al., 1977).

According to Popov (1983), during the Post-Karangat epoch a single transgression occurred, the Surozh transgression. Surozh deposits have been identified on the shelf and in the deep-water depressions (History of geological development, 1988). During the Surozh transgression, sea levels reached -25 m. There was no connection with the Mediterranean Sea at the time. The mollusk fauna of the Surozh stage is not known. Palynological analyses indicate warming climate (Sherbakov et al., 1977). The epoch of the existence of this basin is estimated as 40-25 ka (Sherbakov, 1982).

After the Surozh epoch, a deep regression developed in the Black Sea (Pontian) Basin. Lake levels dropped to -80 m (Sherbakov et al., 1977; Fedorov, 1978) and possibly even to -140 to -150 m (Ryan et al., 1997). Deposits and faunas dominated by *Dreissena* found in depressions, on the lower part of the shelf, and on the continental slope show that the basin was occupied by an almost freshwater lake. The diatom flora indicated very cold conditions (Zabelina and Sherbakov, 1975; Zhuze et al., 1980). The Sea of Azov was a coastal plain crossed by the Don River whose mouth was located 50 km south of the Kerch Strait. The lower courses of the Dnepr, Dnestr, and Danube rivers merged, resulting in a formation of the “grand canyon” and a single delta (Kaplin and Sherbakov, 1986). Periglacial landscapes surrounded the northern coasts with cold and arid climate conditions as shown by palynological data (Vronskiy, 1974; History of geological development, 1988). An arctic fauna, including arctic foxes, white partridges, and reindeer roamed the coasts (Khrustalev and Sherbakov, 1974). The most severe cold conditions existed around 22-23 ka, coinciding with the onset of the New Euxinian regressive basin (23-16 ka: Balabanov and Izmailov, 1989; Sherbakov et al., 1977).

The New Euxinian transgressive stage was initiated ca 16 ka. Around 12.5 ka, its level reached -45 m. The New Euxinian basin was populated by a slightly brackish Pontocaspian fauna dominated by *Monodacna, Adacna*, and *Dreissena*, and lacked Mediterranean taxa. Rare occurrences of Khvalynian species such as *Didacna ebersini* and *Didacna moribunda* in the New Euxinian deposits indicate the overflow of Caspian waters during the Khvalynian transgression. Khvalynian ostracod and foraminifera species are also found in New Euxinian sediments (Popov, 1983; Yanko, 1989). Around 9.8 ka, New Euxinian lake levels reached about -30 m (Balabanov and Izmailov, 1989). The transgression impounded valleys of the rivers, and alluvial and lake deposits filled part of the Azov depression. With the warming climate and developing interglacial transgression of the Mediterranean Sea, the transition of the New Euxinian to the modern Black Sea initiated.

**Correlation**

During the Late Pleistocene, the Caspian Sea Basin and Black Sea (Pontian) Basin represented basins of different types. Timing and extent of sea level changes, hydrological parameters, paleogeographical evolution, and features of fauna were mostly independent (Fig. 20).

During most of the Late Pleistocene, the Caspian Basin was an enclosed basin. During the Girkanian transgression stage and twice in the Early Khvalynian transgression, overflow developed from the Caspian basin towards the Pontian Basin across the Manych Passage. In the Pontian basin endorheic conditions existed in the maximum stages of regressions. When the lake rose above the Bosphorus sill, lake waters drained into the Marmara Sea. The basins were overflowing at times when the Caspian Sea overflowed and the Black Sea Basin overfilled and connected to the Sea of Marmara through the Bosphorus. Development of marine transgressions in Pont Basin was caused by inflow of the Mediterranean waters. There was no bilateral water exchange with the Caspian Sea.
During maximum transgressions, the surface area of the Caspian Sea increased as much as 250% compared to the current sea, and water levels reached +50 m. The maximum level of the transgression was controlled by the height of the Manych threshold. Caspian Sea levels were as low as −140 m during maximum regressions, resulting in lake level variations of 190 m in the Late Pleistocene. During the maximum transgression of the Pontian basin, sea level was at most 7 m higher than today. The maximum level of the transgression was controlled by the level of the Mediterranean Sea. The lowest levels were 100 m below the current sea level of the Black Sea, resulting in sea level variations of 100-110 m in the Late Pleistocene.
Despite the large changes in sea level and water volumes, salinity fluctuations in the Caspian Sea were relatively small, no more than 6-7‰. During extensive transgression, the basin as a whole became slightly fresher, but during small transgressions salinities were notably high. Salinity maxima in the Pontian were much higher as a result of the marine ingressions during the Karangat, and the basin experienced marine, semi-marine, as well as enclosed brackish conditions. Late Pleistocene salinity fluctuations were possibly as high as 30‰.

The successive Caspian lake stages were inhabited by species and genera of the Caspian autochthonous brackish complex. *Didacna* species in the Caspian basin underwent very rapid speciation and high turnover rates. Species diversity increased with a diversification of habitat types in the Caspian subbasins. Different faunal types (Mediterranean as well impoverished Pontocaspian faunas) inhabited the Pontian Basin in successive stages. Faunal turnover was as profound as in the Caspian Sea, but the diversity and turnover in the Pontocaspian fauna of the Pontian basin was less dramatic owing to the more uniform character of the entire basin, that did not stimulate speciation.

The biodiversity of Caspian faunas was defined by variability of conditions in the basin. The shallow nature of the Northern Caspian and variation of Volga input created dynamic and very variable habitats. Biodiversity in the Pontian basin depended on either invasions of Caspian taxa or of Mediterranean marine taxa. The highest species richness occurred during the Karangat stage.

Within the Caspian Basin, transgressions occurred in cold climate conditions (such as the extensive Early Khvalynian transgression) and in warm climate conditions (such as the relatively small Late Khazarian transgression). In their late stages, climate of the cold transgressions became warmer and that of warm transgression became colder. Transgressions in warm episodes correspond to high salinities, whereas transgression in colder episodes produced lowered salinities. The marine transgressions in the Pontian Basin (Karangat in the Late Pleistocene and Black Sea in the Holocene) occurred in warm interglacial times. Caspian type of lake-seas in the Pontian Basin developed during cold climate intervals.

The most severe regressions occurred during the coldest episodes. The episodic Manych Passage between the Caspian and Pontian basins is a unique passageway influencing the paleogeography of the region. The elevation of this passageway set the upper boundary of transgressions in the Caspian Basin, especially in cold intervals. Intermittent overflow must have deprived the Caspian Sea of salt and depressed salinities and at the same time contributed to the salt balance in the Pontian lakes. The Manych area acted as a threshold for marine ingressions from the Pontian Basin during interglacial periods. The intake of the Caspian waters increased water volume in the Pontian Basin, modifying hydrological, hydrochemical, and ecological conditions. The paleogeographical conditions of the Caspian and Pontian basins were in many respects defined by the degree of their isolation. The influence of global climate change on their development is very different in both basins.

The global climatic events of the Late Pleistocene, caused by cyclic changes of the Earth orbital elements, in turn caused variations of insolation resulting in the warm interglacial epoch (MIS 5 or MIS 5e, according to representations of different researchers) and the complex cold glacial epoch (MIS 4-2 or MIS 5d-2). In different latitudes and regions, glacial and interglacial intervals were expressed differently. In the Ponto-Caspian region, they were reflected by an alternation of the transgressions and regressions. On the East-European plains and in adjacent mountain areas, they were expressed in the advance and retreat of glaciers that also impacted the evolution of the Ponto-Caspian basins.

The beginning of the Late Pleistocene was characterized by the warm epoch (MIS 5: Eemian or Mikulino interglacial in Eastern Europe). Debate exists about the age limits and duration of interglacial conditions. The age of the Mikulino interglacial is estimated at 100-70 ka (Zarrina and Krasnov, 1983), 128-116 ka (Spiridonova, 1991; Arslanov, 1992), 140-100 ka (Paleoclimates, 2009); and 140-70 ka (Bolikhovskaya and Molodkov, 1999). According to some researchers (Mangerud et al., 2004; Svendsen et al., 2004; Brauer et al., 2007; Brewer et al.,
truly interglacial conditions existed only briefly during isotope substage 5e with the warmest period about 125 ka. The Mikulino interglacial consists of three thermal maxima. The oldest corresponds to isotope substage 5e (Bolikhovskaya and Molodkov, 1999, 2008; Molodkov and Bolikhovskaya, 2009). The younger two correspond to substages MIS 5c and MIS 5a. The warm episodes were intervened by two cold periods (endothermals).

Reconstructions of the paleogeographical events in the Ponto-Caspian region (Fig. 21) shows that during the warm interglacial epoch at the beginning of the Late Pleistocene (cf MIS 5e) the Caspian Sea experienced regressive conditions. During the early endothermal (cf MIS 5d) the early stage of the Late Khazar transgression developed when climate conditions became somewhat colder and humid. The Late Khazarian lake was relatively warm and lake levels reached -10 m. In the Pontian Basin, MIS 5e corresponds to Karangat transgression when full marine conditions developed and sea levels were highest as a result of connection with the Mediterranean and world oceans. The transgression reached the Manych threshold.

Regression of the Early Late Khazarian lake developed under warm and dry conditions that possibly correspond to MIS 5c. During the second endothermal and climate cold interval (cf MIS 5b), the second Late Khazarian transgressive stage (Girkanian) developed. During that time the Girkanian lake penetrated deeply into the Manych area from the east, forming an extensive estuary in the Pre-Manych area. In the Pontian Basin, the Karangat transgression continued its development. The succession of Late Pleistocene deposits of the Manych depression with alternating deposits containing Karangat and Late Khazarian mollusc faunas indicates the synchronous existence but asynchronous development of both systems. The warm water Late Khazarian lake-sea and Karangat sea co-existed in the Ponto-Caspian region during the entire MIS 5 interglacial, showing that the Mikulino interglacial was a relatively long epoch with a complex structure.

At the beginning of MIS 4, the Karangat sea level dropped, coinciding with the global ocean level drops. The Caspian waters of the Girkanian transgression ingressed in the Manych valley and at the same time Karangat waters withdrew into the Pontian basin. The regressive trend of the Karangat Sea was complicated by overflow of Girkanian waters through the Tarkhankut basin. The nature, extent, and regional variability of the cold Weichselian or Valdai epoch (MIS 4-2 or MIS 5d-2) on the East European plains are debated. The epoch was predominantly characterized by cold continental climate and complex succession of climate conditions and regional variability. The number of glaciations and their extents are still not completely understood (Velichko, 1991; Velichko et al., 1999; Mangerud et al., 2004; Svendsen et al., 2004; Sudakova, 2005; Paleoclimates, 2009; Shik, 2010; Rychagov et al., 2012). Palynological data indicate the presence of two early Valdai and three middle Valdai interstadial intervals and five cold stadial intervals (Bolikhovskaya and Molodkov, 2008).

During the cold maximum of the interval MIS 4 when regional climate was cold and arid, a regression developed in lake Girkanian in the Caspian Basin, the Akhtuba-Atelian regression. The development of periglacial continental conditions is shown by deep ice wedges in the basis of the Akhtuba sediments and periglacial spores and pollen in these deposits. A succession of colder and warmer periods (a stadial-interstadial alternation) is shown by successive podzol horizons in the Atelian deposits. Synchronously with the Akhtuba-Atelian deposits in the Caspian Basin, thick lake deposits developed in the freshwater lake Burtass in the Manych depression. These lake deposits contain pollen of cold plant taxa, and four paleosol horizons are found. At the same time in the Pontian Basin, the very deep Post-Karangat regression developed and connection with the Mediterranean was completely lost.

The slightly warmer conditions of MIS 3 resulted in increasing precipitation and river activity in the East-European plain and simultaneous reduction of evaporation over the lake basins. The water balance became positive, resulting in transgressions in the Caspian Basin (the first phase of the Early Khvalynian transgression), and in the Pontian Basin (the Surozh moderately warm water basin). The upper part of the terrestrial Atelian deposits also corresponds to this time interval.
Fig. 21. Scheme of development of the Ponto-Caspian basins during the Late Pleistocene under global climate change.

A - Interglacial epoch (MIS 5, Mikulino interglacial on the East-European Plain): the Karangat transgression of the Pont (with ingress in the Manych valley) and the Late Khazarian transgressive stage of the Caspian (isolated basin).

B - Transitional epoch from interglacial (MIS 5) to glacial (MIS 4) epochs: beginning of the Karangat regression of the Pont and Girkorian transgressive stage of the Caspian; Girkorian passage of the Manych.

C - Early stage of the glacial epoch (MIS 4, Early Valdai glaciations on the East-European Plain); glacial maximum: Post-Karangat regression of the Pont and Atelian regression of the Caspian Sea.

D - Interstadial warming (MIS 3, Bryansk interstadial on the East-European Plain); glacial degradation: Surozh basin of the Pont and beginning of the Early Khvalynian transgression of the Caspian Sea.

E - Late stage of the glacial epoch (MIS 2, Late Valdai glaciations on the East-European Plain); glacial maximum: the New Euxinian regression of the Pont and regressive stage (Elton?) of the Early Khvalynian basin.

F - Degradation of glaciations (MIS 2); the New Euxinian transgression of the Pont and maximal stage of the Early Khvalynian transgression of the Caspian Sea.

G - Glacial degradation (MIS 2) - beginning of post-glacial epoch (MIS 1): the New Euxinian transgression of the Pont and Late Khvalynian transgression of the Caspian Sea.

During the ultimate glacial interval (MIS 2), the Late Valdai glaciation developed. During the Late Glacial Maximum (LGM), the deep New Euxinian regression developed. An almost freshwater lake occupied the Black Sea Basin. In the isolated Caspian Basin under cold conditions, the Early Khvalynian transgression further developed. The general transgressive trend was interrupted though during the LGM. Permafrost existed around the northern Caspian coasts. Average annual temperatures decreased to _10 to -5°C in the southern areas of Europe (Paleoclimates, 2009). The climate conditions resulted into a negative water balance of the Khvalynian Lake-Sea, causing sea level drop. Climate modeling shows similar negative water balance at the time (Kislov and Toropov, 2006, 2007; Kislov, 2010).

The Early Khvalynian transgression resumed during deglaciation after the LGM. Transgression of the Caspian type began in the New Euxinian basin: however, its levels remained low because of dumping of waters through the Bosporus passage towards the Marmara Sea and beyond. The Early Khvalynian transgression, having reached the level of the Manych threshold, developed an erosive valley and discharged into the New Euxinian basin. Erosion of the threshold resulted in a drop of the Early Khvalynian sea levels. Ingression in the Manych valley and the final stage of overflow of waters from the Early Khvalynian Basin into the New Euxinian Basin occurred at the Caspian level about -22 m. The Caspian inflow raised sea levels of the New Euxinian lake-sea. Its maximum coincided with the onset of the Mediterranean transgression (Yanko-Hombach et al., 2007).

After the final episode of overflow, the Khvalynian lake-sea underwent a series of smaller transgressive and regressive events, which reflected the pulsation of climatic conditions in the Caspian catchment. Cold dry conditions of the Middle Dryas resulted in the Enotayevsk regression. Increasingly continental climatic conditions during the Boreal period of the Holocene resulted in the Mangyshlak regression. In the Pontian Basin at the onset of the Holocene, the final transgression from the Mediterranean developed.

Global climate change in the late Pleistocene was driving transgressive-regressive cycles in the Ponto-Caspian basins as well as in their catchments through glacier development and retreat (Yanina, 2012a,b). In the Caspian Basin, two types of transgressions occurred: those under relatively warm and those under cold conditions, with different amplitudes. Grichuk (1969) distinguished warm and cold phases within glacial cycles on the East-European Plain, and in each phase, based on degree of humidity, he distinguished stages: in the warm e xerothermic and gyrothermic; and in the cold e cryogygrotic and cryoxerotic (Fig. 22). Moisture and heat supply curves on the East-European Plain shifted in relation to each other by half-phase, although in the Caspian region they shifted by three-quarters (Alisov and Poltoraus, 1962; Grichuk, 1969; Filippova, 1997). Southward, correlation between lowered temperatures decrease and increased humidity is more apparent (Yanina, 2012a,b). Analysis of temporal humidity changes in the studied region (the key factor for transgression development), indicates that “cold” transgressions occurred during cryogygrotic phases, with favorable conditions for glacial development on the East-European Plain. However, the moisture peak in the Caspian reached its maximum earlier than the glacial maximum (approximately by the middle of the preceding cryogygrotic phase). By the time of the glacial maximum on the East-European Plain (the end of the cryogygrotic phase) sea-level drop occurred, corresponding to the “cold” regression. Existence of a “pluvial belt” during global climate cooling is shown for the entire arid zone in Asia (Devyatkin, 1989, 1993). Reconstructions show increased humidity on the Caucasus coast with simultaneous temperature decrease (pluvial intervals) during glacial epochs and humidity decrease and temperature rise during interglacials (Markov et al., 1965; Abramova, 1974; Markov, 2005 and others).

An “idealized” scheme of transgressive-regressive Caspian cyclicity correlation with global climatic events is complicated by regional factors, such as glaciations on the East-European Plain (magnitude, outline, dynamics, reorganization of hydrographic system), introducing regional changes in climatic parameters and in the magnitude of water inflow. Retreating glaciers and increased melt water inflow caused several rises on small temporal
scales. According to the scheme, regression maxima corresponded to xerothermic interglacial phases. Such “warm” transgressions apparently developed at the onset of cooling at the end of interglacials with increasing moisture. Geological factors (neotectonic movements, sedimentation in the basin) also played a role in the dynamics of basins. Reorganization of hydrographic system impacted development of the Caspian basins. The height of the Manych threshold provided the upper limit of the maximum sea-lake levels of the cold Caspian transgressions. Further sea level rise resulted in overflow of the Caspian waters to the Pontian Basin. In the Pontian Basin, two types of transgressions occurred: marine transgressions (those driven by the ingression of marine Mediterranean waters) and transgressions of the Caspian type (when the Pontian basin was in the lake phase, and those driven by the overflow of brackish waters from the Caspian Basin). The marine high stands are unambiguously correlated with interglacial episodes when transgressions of the World Ocean occurred, and are correlated with the interglacial epochs of the East-European Plain as well. Transgressions of the Caspian type developed synchronously with the cold transgressions in the Caspian Sea, but with different results. If lake or sea levels in the isolated Caspian Basin rose above the Manych threshold, its waters would overflow, driving transgressions in the Pontian Basin and eventually resulted into an overflow over the Bosporus towards the Sea of Marmara and the Mediterranean that experienced low stands at the time.

The cold extensive transgressions of the Caspian Sea and the transgressions of the Caspian type of the Pontian Basin, not exceeding its modern level, developed synchronously in the cold (glacial) climatic epochs. The maximum height of level of the Caspian transgressions was limited by the height of the Manych threshold, and the transgressions of the Caspian type in the Pontian Basin by the height of the Bosporus threshold. The warm small transgressions of the Caspian Sea and the marine (Mediterranean type) transgressions of the Pont with maximum level developed during the warm interglacial epochs. However, if the existence of the interglacial endothermals was the main factor for the warm Caspian transgressions, for development of the Pontian Basin it was the interglacial marine transgressions of the World Ocean. The cold

Fig. 22. The “idealized” scheme of transgressive-regressive Caspian cycles correlation with global climatic events (out of regional factors influence). 1 - temporal humidity changes in the Russian Plain; 2 - heat supply curve; 3 - temporal humidity changes in the Caspian Region; 4 - transgression of the Caspian Sea; 5 - glaciation on the Russian Plain (the materials of Alisov and Poltoraus, 1962; Grichuk, 1969; Filippova, 1997 are applied).
transgressions of the Caspian Sea and the Caspian type transgressions of the Pontian Basin developed asynchronously with the transgressions of the World Ocean.

The Pontian transgressions of the Caspian type developed synchronously with cold transgressions of the Caspian Sea, but their sea/lake levels were low due to dumping of waters in the regressing Mediterranean Sea. The Pontian marine transgressions of the Mediterranean type unambiguously are correlated with the interglacial epochs of the East-European Plain.

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