Correlation of the Late Pleistocene paleogeographical events of the Caspian Sea and Russian Plain

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ABSTRACT

The present work shows the author’s concept of paleogeographic development of the Caspian Sea in the Late Pleistocene, based on the comprehensive analysis of the Caspian deposits and their relation and synchronization with glacial–interglacial cycles on the Russian Plain, based on published materials. Global climate changes were fundamental for both the transgressive-regressive state of the Caspian basins, as well as for glacier formation and retreat on the Russian Plain. At the same time, glaciers influenced the Caspian basin development on a regional level. The long-term low Caspian Sea level, complicated by the double-stage “minor” Late Khazar transgression, corresponded to the Mikulino (Eemian) interglacial with two endothermals. This warm stage in the Caspian history encompassed the interval corresponding to Marine Isotope Stage (MIS) 5. This is in agreement with the point of view of researchers who correlate the Mikulino interglacial with the entire MIS 5. The “cold” vast Khvalynian transgression and preceding to it the Atel regression developed during the Valday glaciation (MIS 4–2). The Atel regression corresponds to cold MIS 2 and the beginning of MIS 3. Its lower boundary in the Lower Volga region is marked with ice wedges. A transgressive tendency began to show in the second half of the interstadial (second half of MIS 3) and continued into early stages of the Late Valdai cooling, but it was interrupted during the dry and cold Glacial Maximum (peak of MIS 2) by the regressive stage. Further transgression development occurred during the degradation of the glaciation. Its course was impacted by transgressive-regressive events of lower magnitude linked to oscillations of climatic parameters: i.e., cold dry conditions of the Middle Dryas by the Enotaevka regression, and the continentalization of the Boreal period of the Holocene by the Mangyshlak regression.

1. Introduction

The problem of correlation between Pleistocene transgressive-regressive oscillations in the Caspian and glacial events on the Russian Plain (Fig. 1) is of great importance and complexity in Pleistocene paleogeography. It has been previously thoroughly studied by a number of researchers (Milanovskiy, 1932; Mirchink, 1936; Nikolaev, 1953; Fedorov, 1957, 1978; Vasiliev, 1961, 1982; Moskvitin, 1962; Markov et al., 1965; Kozevnikov, 1971; Zubakov, 1986; Rychagov, 1997; Dynamics ...., 2002). It is a widespread point of view that the Caspian transgressions are caused by the melting of the Russian Plain and surrounding mountain glaciers (Kovalewskiy, 1952 and others). The timing of glaciations on the Russian Plain was compared with transgressions (Vasiliev, 1961; Moskvitin, 1962). According to Markov (2005), the most favorable conditions for transgressions development occurred during time intervals when glaciers did not melt, but were intensively growing. Velichko (1973, 1991) and Kvasov (1975) considered the second half of glacial stages to have very unfavorable climatic conditions for transgression development. Conclusion about development of transgressions at the end of interglacial — beginning of glacial stages was drawn by Rychagov (1997). A similar point of view was stated by Abramova (1974) and Filippova (1997). Chepalyga (2006) linked development of the Khvalynian transgression to the “epoch of the extreme inundation”. At the present moment there is no unequivocal opinion on the correlation of the Caspian events with glacial–interglacial changes on the Russian Plain (Table 1). The same is true for the event stratigraphic schemes of these regions in the Pleistocene.

Today, the climate concept prevails in the problem regarding the causes of Caspian Sea transgressions, although some researchers have questioned it. Tectonic or other geological factors as causes of Caspian transgressions are cited in the works (Gerasimov, 1937; Kolesnikov, 1939; Vardanyants, 1948; Zektser et al., 1994; Lavrushin et al., 2002, 2004). Relationship of the waters of the sea with the
underground hydrosphere is viewed as the reason for rise by a number of authors (Golubov, 1984, 1995; Golubov et al., 1998).

According to the view of the author, many reasons (neotectonic movements, sedimentation in the basin, the restructuring of the hydrographic network, etc) affected the transgressive-regressive rhythmic of the Caspian Sea, chief of which is the global climate rhythm. This work presents the author's view of the paleogeographical development of the Caspian Sea in the Late Pleistocene and its relation and synchronization with glacial—interglacial cycles on the Russian Plain.

2. Materials and methods

The author has carried out thorough analyses of virtually all known sites with Caspian fauna on the Lenkoran coast, in the Kura Depression, on the Apsheron Peninsula, Azerbaijan and Dagestan coasts of the Caucasus, Manych Depression, Lower Volga Region and Volga Delta; on the Volga-Ural interfluve, in the Ural River valley, on the Mangyshlak Peninsula and Iranian coast (Yanina, 2005). This included the revision of a large collection of mollusc shells together with analyses of their spatial and stratigraphical distribution in sediments of Late Pleistocene age of the Caspian Region. Research examined the taxonomic composition, taphonomy, biostratigraphical distribution, evolution, phylogeny and biogeography of molluscs. The main focus was on the brackish water species of genus Didacna Eichw. Members of this genus are index species for the Caspian Sea and are endemic for the Pontian-Caspian Region. This genus is known for its high evolutionary rates at the species and subspecies levels, which highlight its significance for the stratification of the marine Pleistocene of the Caspian and for paleogeographic reconstructions of the Caspian basins.

Analysis of shells of Didacna Eichwald from the Upper Pleistocene deposits of the Caspian Region revealed that they represent 26 species and subspecies (Table 2). Representatives of another families and genus are accompanying species with wide-ranging chronological distribution. In the distribution of Didacna, the Late Khazar and Khvalynian faunas were singled out. Each of the faunas is characterized by a particular ratio of major Didacna groups (“crassa”, “trigonoides” and “catillus”), as well as by taxonomic composition of each faunal group with its own index-species and affiliation to a particular interval in Caspian sediments, separated from under- and overlying sediments by traces of unconformity or
erosion. The faunas characterize transgressive epochs in the Caspian history.

Each fauna is represented by faunal assemblages, closely interrelated between each other, and characterizing sediment members of different age, corresponding to separate stages in the transgression development. Assemblages have particular taxonomic composition of Didacna with characteristic species. Late Khazar fauna is represented by two assemblages: Late Khazar and Gircan, which characterize marine deposits of the Caspian terraces with different altitudes, or marine deposits with terrestrial sediments/ traces of non-conformity between them. Khvalynian fauna is represented by two assemblages, Early Khvalynian and Late Khvalynian. They characterize Caspian terraces with different altitudes or deposits divided by terrestrial Enotaevka sediments.

The distinguished faunal assemblages at different taxonomic levels are used as a base for the stratigraphic and event schemes of the Late Pleistocene of the Caspian Region (Table 2) (Yanina, 2009). To verify the results of the malacological analysis, microfaunal studies (Foraminifera and Ostracoda) were additionally used. The coupled method was used, implying the use of the geomorphological, lithological, facies, spore and pollen, geochronological and other types of analyses used for the study of recent sediments, which supplement each other. Paleogeographical evidence on glacial—interglacial events on the Russian Plain is based on published sources.

3. Results and discussion

The event stratigraphic scheme of the Caspian Late Pleistocene includes Late Khazar (Late Khazar and Gircan transgressive stages) and Khvalynian (Early Khvalynian and Late Khvalynian transgressive stages) transgressive epochs, separated by the Atel regression. The Late Pleistocene history of the Russian Plain is represented by the Mikulino (Eemian) interglacial and Valday (Wurm) (Early Valday and Late Valdai stages) glacial epochs.

3.1. Late Khazar transgression

The Late Khazar transgression developed in two independent stages, separated with a regression. Sea-level of the earlier Late
Khazar basin, according to sediment spatial distribution, did not exceed –10 m, and its area was much bigger than the modern Caspian. Malacologic fauna represent a faunal assemblage with crassoidal Didacna and characteristic species Didacna nalivkinii and Didacna surachanica. Its distinguishing feature is large dimensions and massiveness of shells, especially common for the southern parts of the Caspian. Significant distribution of trigonoidal and cattiloidal Didacna in the Late Khazar basin was recorded only in the freshened areas of the northern Caspian, influenced by the Volga River. Common gigantism of shells, high carbonate content in the sediment and presence of oolites indicate the warm climate of the Late Khazar. Warm waters of the basin had higher salinity than in the modern Caspian: between 10 and 12‰ for the northern and up to 14–15‰ for the southern Caspian Sea. Data on foraminifera (Yanko, 1989) support this conclusion.

The site of Vetyanka has limnic deposits with multiple large shells of Corbicula, assigned (Moskvitin, 1962) to the Late Khazar. The morphology of warm-water shells indicates high water temperature. Warm climate of that epoch is supported by palynologic data. Palynologic spectra, obtained by Abramova (1974), reflect a climatic phase with warm enough temperature for some of the forest vegetation, but not humid and cool enough for developing typical forest formations. The Lower Ural area was characterized by warm and arid steppes (Dorofoev, 1960; Yakhimovich et al., 1986). The absence of distal pebbles in the sediments indicates low water level in the catchment area and dry climate. The basin held an isolated saltwater lake, which was not connected to the Euxinian basin.

Early Late Khazar transgression stage was followed by a regression. It was indicated by hiatuses in marine sedimentation (Dagestan), and erosion and soil formation (Volga River valley) (Yanina and Svitoch, 1990; Svitoch et al., 1995, 1997; Yanina, 2005). Stratigraphic hiatuses were recorded by Fedorov (1957), Rychagov (1997), and Popov (1983). At present, there is no direct evidence to estimate the extent of the Late Khazar regressive phase. According to changes in malacologic fauna, it was not significant.

Traces of the second transgressive Late Khazar stage are not preserved on all coasts. Its deposits were recorded in Dagestan (Yanina and Svitoch, 1990; Svitoch and Yanina, 1997) and on the Krasnovodsk Peninsula (Fedorov, 1957). The composition of the malacologic fauna is only slightly different from the earlier one. It was also dominated by crassoidal Didacna with predominance of D. surachanica and D. nalivkinii. Based on drill sites materials from the north-western part of the Caspian region, Goretškiy (1957, 1966) and Popov (1967, 1983) reconstructed a strongly freshened brackish-water basin. These researchers defined it as an independent Girkan transgression of the Caspian, which took place after the Late Khazar transgression and was separated from the Khvalynian transgression by the Atel regression. The basin was inhabited by “Khvalynian-like” fauna, which is why it was initially considered as the earliest stage of the Khvalynian transgression (Popov, 1955). The presence of a thick layer of subaerial sediments of the Atel regression, separating Girkan deposits from the Khvalynian, led Popov (1967, 1983) to recognize an independent large-scale transgression of the Caspian, traces of which have not been recorded elsewhere.

A number of researchers strongly objected to this concept (Vasiliev and Fedorov, 1965; Shkatova, 1975; Fedorov, 1978; Svitoch et al., 1997). The main criticism was that the Girkan layers in the Lower Volga represent merely the freshened facies of the Upper Khazar deposits, where the Didacna trigonoides group is dominant. In the author’s opinion, the Girkan freshened basin, described by Popov in the north-western Caspian Depression, represents a vast lagoon (liman), limited by the Late Khazar transgressive stage of the Caspian on one side and the Karangat regression into the Kuma–Manych Depression on the other side. Freshwater influence of the Volga and Terek and other minor rivers and freshwater streams led to its significant freshening and settling of abundant Caspian limnic species of genera Monodacna, Hpypanis, Adacna, with a large admixture of freshwater molluscs. Among Didacna, only species tolerant to significant freshening (trigonoidal group) and soft substrate with relatively low dissolved oxygen (cattiloidal group) remained. Such taxonomic composition resulted in the “Khvalynian-like” malacologic fauna. The typical freshwater form is Corbicula fluminalis, which implies warm water. Deposits with Didacna cf. praetrigonoides, Didacna aff. parallella, known from the Terek-Kuma as “transitional between Khazar and Khvalynian stages”, also belong to this basin (Ilyinskyi, 1947). These are also characterized by abundant Dreissena and by the presence of C. fluminalis.

It is likely that the late Late Khazar (Girkan) transgressive stage developed during a humid epoch with stronger river runoff compared to the earlier basin. The Girkan basin formed a deep embayment in the Manych valley, in which waters of the Karangat transgression penetrated deeply from the side of the Azov-Black Sea basin. Complex correlation of the Girkan and Karangat deposits in the Manych valley (Popov, 1983) indicates their synchronicity. According to a correlation analysis (Yakhimovich et al., 1986), at the end of the Late Khazar the flora was the typical Khazar variety, but diversity of herbaceous vegetation decreased, with the Chenopodiaceae becoming more abundant. Forest groups show decreasing admixture and species diversity of broadleaf taxa, all of which implies progressive cooling. In many sections from the Lower Volga River area, a distinct paleosol of estimated Mikulino age (Moskvitin, 1962) is observed and represents a sharp boundary between the Upper Khazar and the younger deposits.

According to uranium—ionium dating, the age of the Late Khazar transgressive stage is 114–76 ka (Leontiev et al., 1975; Rychagov, 1997); 115–81 ka (Arslanov et al., 1988), and 122–91 ka (Shkatova et al., 1991). Based on thermoluminescence (TL) analysis it is 144–90 ka (Geochronology, 1974), 130–91 ka (Leontiev et al., 1975), and 122–106 ka (Shakhovets, 1987; Shkatova et al., 1991). Results of electron paramagnetic resonance (EPR) show an age between 140 and 85 ka (Bolikhovskaya and Molodkov, 2008; Molodkov and Bolikhovskaya, 2009). Both the geochronological results and the paleogeography of the Late Khazar transgressive stage indicate its longer duration than is generally accepted by researchers (Fedorov, 1978 and others).

The beginning of the Late Pleistocene on the Russian Plain was characterized by the warm Mikulino interglacial. Age estimations of the boundaries and duration of the Mikulino interglacial differ. A summary of various views on this subject was published by Bolikhovskaya and Molodkov (2008). The age of the Mikulino interglacial was estimated at 100–70 ka (Zarrina and Krasnov, 1983), 128–116 ka (Spirdonova, 1991; Arslanov, 1992), 140–100 ka (Paleoclimates..., 2009); and 140–70 ka (Bolikhovskaya and Molodkov, 1999). For the territory of Belarus it is 130–115(90) ka (Yelovicheva and Sanko, 1999), for Ukraine 130–107 ka (Gerasimenko, 2001). Many researchers consider that the interglacial was short-term in duration, comparable only with MIS 5e based on SPECMAP, with the warmest peak at around 125 ka. According to Bolikhovskaya and Molodkov (1999, 2008; Molodkov and Bolikhovskaya, 2009), MIS 5e corresponds only to the first of the three thermal peaks of the Mikulino interglacial. Within the interglacial with a complex structure, which encompasses in their opinion the entire MIS 5, two cooling intervals called endothermals were also distinguished.

Paleogeographical reconstruction of the Caspian region with the warm interglacial stage in the beginning of the Late Pleistocene including a “minor” Late Khazar transgression, which correspond to
the entire MIS 5 reflect the concept of Bolikhovskaya and Molodkov on the paleogeography of the Mikulino interglacial. Two endo-
thermals in the structure of the interglacial, characterized by temperature decrease and humidity rise, correspond to the two transgressive stages of the Caspian, caused by the increase in water inflow in its water budget system.

A number of authors (Spiridonova, 1991; Arslanov, 1992; Velichko et al., 2000; Sudakova, 2005; Paleoclimates... 2009, and others) believe that at around 110 ka the Valday glacial epoch had already commenced. The Caspian Sea paleogeographical data disprove this opinion, since at that time the Caspian basin was warm and in its freshened parts, in particular in the north-western region, its malacologic fauna was characterized by C. fluminalis, a southern warm water species. Additional confirmation of the interglacial type of environment was its simultaneity with the interglacial Karangat transgression of the Black Sea, indicated by the pattern of sediment deposition in two basins in the Manych depression (Popov, 1983).

3.2. Atel regression

The end of the Khazar stage of the Caspian development was marked by the deep Atel regression. During this time, vast areas of the Caspian shelf were exposed and rivers intensively carved into it (Rychagov, 1997). Out of all continental formations of regressive Caspian epochs, sediments of this one are the most widespread and are found at all Caspian coasts (Svitoch, 1991; Svitoch and Yanina, 1997).

In the Lower Volga region in the base of the regressive layer there are Akhtuba deposits, first distinguished by Goresetskij (1958) and referred to as a periglacial formation. They represent a perfect marking horizon in the Lower Volga sections, often with sharp wedges penetrating the underlying sediments. These wedges and winterkill fractures in the base of Akhtuba sands are syngenetic, and represent evidence of the severe climatic conditions at the time of deposition and permafrost development. According to Grichek (1954), vegetation was represented by tundra–steppe associations. The formation of films of lublinite crystals in the Akhtuba sands indicates a cold dry climate (Moskvitin, 1962).

The Akhtuba deposits are conformably overlain by Atel sandy loam and loam sediments (up to 20 m thick) of various genesis, formed in continental environments in the Caspian Depression. Shells of freshwater and continental ecological groups of mollusks are found in these sediments, both with suppressed morphology. Mammal skeletal remains of the upper Paleolitich fauna complex are found, including a mammoth, a horse, a reindeer and other animals, giving evidence for the cold climate of the Atel epoch. The same is indicated by the taiga spore and pollen spectra from the Atel deposits (Grichek, 1954; Chiguryaeva and Khvalina, 1961; Moskvitin, 1962).

The Atel layer has several (up to 4) paleosols of different degrees of development, which implies a multiple change of climatic conditions in the region with warming and increased humidity. By the end of the Atel 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 level of the basin went down to ~120 to ~140 m. The Caspian basin retreated into the middle and southern parts of the basin. There is no data on the malacologic fauna of this basin. A drastic faunal shift occurred: formerly abundant Khazar 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 Girkan fauna. Based on the thickness of the Akhtuba-Atel deposits, and the presence of at least three horizons of paleosols within them, it was concluded that 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 Late Khazar (Girkan) basin, which, most likely, happened after 76 ka. Radiocarbon dating of the regressive sediments, exposed in the drill core (Svitoch et al., 2008), is 34,640 ± 1000 BP (LU-5951), calibrated age 40,230 ± 1070 cal. BP.

Views of scientists on the Valday glaciation, as well as on the Mikulino interglacial, vary. Different ages have been assigned to the paleogeographic events of the Valday epoch based on different approach to estimate the duration of the Mikulino interglacial. Material on this subject was summarized by Bolikhovskaya and Molodkov (2008). The present author has already expressed an opinion on the duration of the Mikulino interglacial (equivalent to MIS 5), based on paleoconstructions in the Caspian region. The Valday glacial epoch is considered by the author to correspond to MIS 4–2.

This epoch was predominantly characterized by cold continental climate and complex inner structure. The question of the number and extent of glaciations on the Russian Plain is debatable (Sudakova, 2005; Paleoclimates... 2009; Shik, 2010 and many others). At present most researchers agree that there was no (or insignificant) ice cover in Early Valday time. According to palyno-

data (Bolikhovskaya and Molodkov, 2008), within the Val-
day glacial climatic cycle there were two early and three middle Valday interstadials and five cold stadials. In the Late Valday there were one interstadiiial, three interphases and five cold stadials. Starting with the second early Valday cooling and lasting up to the Holocene, the center of the Russian Plain was occupied by a variety of periglacial landscapes.

At the beginning of the early Valday cooling maximum, the transgressive development of the Caspian was disrupted by the Atel regression that reached the lowest level at the peak of cooling conditions, under a cold and dry climate. Deep ice wedges in the base of Akhtuba deposits and periglacial spore and pollen spectra throughout the entire sediment layer indicate the regressive stage of the Caspian. Heterogeneity of climatic conditions, expressed as an alternation of stadials and interstadials, was reflected in the Atel deposits by the (rather weak) development of paleosol horizons.

3.3. Khvalynian transgression

The Atel regression was followed by the “Great” Khvalynian transgression, with the most significant sea-level rise in the Pleistocene history of the Caspian. Unlike earlier transgressions, traces of Khvalynian Sea development are found on all Caspian coasts. The maximum sea-level can be easily traced by the distinct marked relief found with rare exceptions, at levels of 46–50 m asl throughout the entire perimeter of the paleobasin. Almost all researchers who studied the Caspian history agree that there are two Khvalynian transgressions, Early and Late Khvalynian, separated by the Enotaevka regression (Fedorov, 1957, 1978; Rychagov, 1997 and others). Biotstratigraphical analysis (Svitoch and Yanina, 1997; Yanina, 2005 and others) showed that both the Early and Late Khvalynian “transgression” are transgressive stages of development of the Khvalynian transgression.

The Early Khvalynian transgressive stage at its peak reached a sea-level of 48–50 m. The basin was inhabited by relatively poor fauna, originating from the Girkan basin; the most common species are D. parallella, Didacna protracta, and Didacna ebersini, and less
common are Didacna cristata, Didacna zhukovi, Didacna subcatillus, Didacna vulgaris, and D. praetrigonoides. The core facia composition does not include crassoidal Didacna. It is distinguished by thin shells, often of smaller size. Taxonomic composition of malacologic fauna generally indicates lower salinity compared to earlier Pleistocene basins. However, salinity distribution on the basin area and its temporal variations in different environments were not the same (Yanina, 2005, 2009). Yanko (1989) suggested strong freshening of the entire Early Khvalynian Sea (down to \( P_{50}\)). Presence of thin shells, most likely, implies low temperatures compared to older basins and the modern Caspian.

Low temperature in the basin inferred from the malacological fauna at the final stages of basin development, are additionally confirmed by palynological data. Thus, in the Ural River basin the Early Khvalynian epoch is marked by the maximum development of Late Pleistocene forest areas (Yakhimovich et al., 1986). In the beginning of the Early Khvalynian, spruce dominated the coniferous forests, but their role decreased in the second part of this period. On the western Caspian coast, the Lower Khvlynian deposits in the base of the section contain abundant pollen of arboreal vegetation (oak, elm, alder, birch, maple, hornbeam, linden, pine, and spruce) (Abramova, 1974). Up-section, horizons are characterized by predominance of herbaceous pollen (Cheno-podiaceae dominate) and shrubs. Among pollen of arboreal vegetation, pine, spruce, birch, oak, alder, and wingnut tree are found. By the end of the Early Khvalynian epoch, the climate became milder.

Most researchers accept the fact that coastlines were changing, corresponding to different stadials of the Early Khvalynian basin. Besides the maximum coastline level on the Caspian coast, there are several coastlines at levels of 34–36 (“Talgin-skaia” (Rychagov, 1970)), 28–30, 20–22 (“Buina-skaia” (Fedorov, 1957)), 14–15 (“Turkmen-skaia” (Fedorov, 1957)), 4–6 m. Their formation is believed to have been caused either by transgressive phases, separated with regressions (Leontiev and Foteeva, 1965; Rychagov, 1970; Chepalyga, 2006), or as a result of level stabilization caused by regression (Fedorov, 1957; Myakokin, 1963; Vasiliev and Fedorov, 1965). Besides the above described Early Khvalynian terraces on the Dagestan coast, Rychagov (1997) described the formation of terraces by either stabilization of the regressive sea at the certain level or caused by insignificant positive sea-level changes as a result of a regression. Their characteristic feature is their spatial inconsistency. Kovda (1950), Britsina (1954), and Vasiliev (1961), based on analysis of Lower Khvalynian deposits of the northern Caspian Depression, concluded that there were two Early Khvalynian transgressions, separated by a regression, which Vasiliev (1961) named Elton. This point of view is currently being developed by A.L. Chepalyga. The analysis of the drill core obtained in the northern Caspian Depression (Svitoch et al., 2008) showed that in the recovered Lower Khvalynian deposits there are distinct traces of sea regressions, as indicated by interlayers of coarse sediments within the clay layer. Five transgressive-regressive stages were recorded within the section, which confirms the complexity of development of the Early Khvalynian transgression.

The age of the early Khvalynian epoch has always been and still remains a subject of debates (Kaplin et al., 1972, 1977a, b; Geochronology of the USSR, 1974; Arslanov et al., 1978, 1988; Mamedov and Aleskerov, 1988, 1989; Svitoch, 1991, 2007; Rychagov, 1997; Leonov et al., 2002; Bezrodnikh et al., 2004; Chepalyga, 2006; Badyukova, 2007; Chepalyga et al., 2008; and others). The present author also participated in this discussion, standing up for the “young” age of the Khvalynian transgression (Svitoch and Yanina, 1983, 1997; Svitoch et al., 1994, 1998). In recent years there was a number of publications (Bezrodnikh et al., 2004; Arslanov and Yanina, 2008; Chepalyga et al., 2008; Svitoch et al., 2008) with new age data for the Khvalynian transgression of the Caspian that included a number of radiocarbon dates.

Drilling material and dates obtained from shells and organic matter from sediment cores, are of great interest (Bezrodnikh et al., 2004). The radiocarbon age of Khvalynian deposits lies in the range of 30 (>30) – 9 ka. Radiocarbon dating of shells from the Lower Khvalynian core material, that had been previously studied by us (Svitoch et al., 2008), resulted in a dating of 29,200 ± 1220 BP (LU-5953), corresponding to 33,860 ± 1490 cal. BP. Taking into consideration the complex structure of the Khvalynian deposits, recovered within the core, together with the age of Aтел deposits from the same core, estimated as 40,230 ± 1070 BP, it was assumed that the transgressive tendency of the Caspian started to develop at around 35 ka. Evidently, the first transgressive phases of the Early Khvalynian transgression took place in the second half of the Valday interstadial.

The Late Valday glacial maximum dated at 24–17 ka BP (Paleoclimates ... , 2009) was distinguished by a very cold and dry climate, the most severe climate of the Pleistocene (Velichko, 1973). On the Russian Plain the continuous coverage of the permafrost is
reconstructed to $57-58^\circ$ N; locally, it was found to spread down to the coasts of the Caspian Sea. Mean annual temperatures decreased to $-10$ to $-5^\circ$C in the southern regions of Europe (Paleoclimates .., 2009). Such climatic conditions obviously affected the water budget of the Caspian, causing sea-level to decrease.

Analysis of the dated coastal sediments showed that, unfortunately, at present time there are no radiocarbon dates of the maximum stage of the transgression. Most dates come from the stadial level of about 22 m, defining its age as $15-14$ ka. That was the time when the Late Valday glaciation started to recede, accompanied by considerable river water increase on the Russian Plain and consequently river runoff increase into the Caspian (Panin et al., 2005). From the lithological point of view, the Lower Khvalynian deposits are characterized by presence of "chocolate" clays. According to Moskvitin (1962) and Goretskiy (1966), their accumulation resulted from the abundant inflow of fine suspended material from the continent under periglacial conditions. The banded structure of clay additionally confirms periglacial conditions (Moskvitin, 1962). The absence of malacologic fauna in "chocolate" clay apparently implies high turbidity in the basin.

Radiocarbon dates in the interval of $11-12$ ka, obtained from the Lower Khvalynian deposits in the Manych Depression (Arslanov and Yanina, 2008; Svitoch et al., 2008), also point to the existence of the Manych Strait at the time interval when the Caspian Sea level was at about 22 m. At present there are no dates from the first stage when the water flowed through the Manych Strait after the sea level reached up to 50 m.

The end of the Early Khvalynian time was marked by the Enotaevka regression. Its level was estimated by Leontiev (1968) and Rychagov (1997) as $-43$ to $-45$ m. Varuschenko et al. (1987) suggested that the sea-level dropped down to $-64$ or $-84$ m. Even a greater level decrease down to $-105-110$ m was recorded by Lokhin and Maev (1990). Data from the core indicate a sea-level drop to at least $-51$ m.

The Caspian coasts lack continental Enotaevka deposits, although there are multiple traces of hiatuses in the marine sedimentation (Svitoch and Yanina, 1997) with Enotaevka layers in the core section (Svitoch et al., 2008). Enotaevka deposits were recorded on the east of the Middle Caspian (Maev, 1994). These are fine aeoluroelite silt with predominance of Dreissena rostriformis, and rare D. protracta, usually characteristic for the Early Khvalynian basin. According to pollen data (Sorokin et al., 1983), that was an epoch of dry cool climate. Presumably it may correspond to the Middle Dryas on the Russian Plain, characterized by arid and cold conditions.

The Enotaevka regression was followed by the Late Khvalynian transgression which reached a water level of 0 m at its peak. Taxonomic composition of Didacna that settled in the basin was not much different from the Early Khvalynian. The main distinguishing feature of this complex was the predominance of D. praetrigonoides, which in the Early Khvalynian basin occupied only minor biotopes. Water parameters in the Late Khvalynian basin were more stable and homogenous compared to the Early Khvalynian. Salinity in the Late Khvalynian basin in general was slightly higher than in the Early Khvalynian, $11-12^\circ$Cl, in the coastal areas of the northern Caspian it decreased to $3-4^\circ$Cl.

More favorable conditions for mollusc habitats, in particular higher water temperature as compared to the Early Khvalynian basin, explain their relatively high abundance. This is additionally confirmed by the large and more massive shells of the Late Khvalynian species. Presumably, such favorable conditions resulted from efficient vertical water circulation. Grayish-brown and yellow-brown Khvalynian deposits suggest conditions favorable for oxidation. Taxonomic composition of foraminifers (Yanko, 1989) indicates a higher salinity than in the Early Khvalynian basin, which reached $12-14^\circ$Cl. Spore and pollen data (Abramova, 1974; Vronsikiy, 1974; Yakhimovich et al., 1986) implies general warming in the region.

The Late Khvalynian sea-level drop occurred irregularly, complicated by intervals of sea-level stabilization and secondary transgressive level rise (Leontiev and Fedorov, 1953; Rychagov, 1997; and others). A regressive tendency started under conditions of aridity increase in the region. For instance, based on the data of Abramova (1974) in the lower part of the Upper Khvalynian deposits, there is abundant and diverse pollen of arboreal vegetation (pine, alder, birch, oak, hazel, hornbeam, wingnut, and willow) and spores (green moss and fern). Up-section, the type of spectra changes significantly and herbaceous (with up to 30% xerophytes) and shrub pollen become dominant, while arboreal pollen is scattered. Spore and pollen spectra of the end of Late Khvalynian time are characterized by the predominance of pollen of herbaceous xerophytes, among them sagebrush and Chenopodiaceae, reflecting semi-desert — steppe type of vegetation.

Sea-level decrease in the Late Khvalynian basin terminated with the Mangyshlak regression. Based on the palynological data from the sections in the Volga-Akhtuba flood land, the climate was becoming more continental (Bolikhovskaya, 2011). This, together with radiocarbon dating (Rychagov, 1997), imply that the Mangyshlak regression occurred in the Boreal time of the Holocene.

4. Conclusions

Global climate change in the Late Pleistocene was of crucial importance for transgressive-regressive state of the Caspian basins, and influenced glacier formation and recession on the Russian Plain. The latter also regionally governed the Caspian basin's development.

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**Fig. 3.** The scheme of correlation of the transgressive-regressive events of the Caspian Sea with glacial—interglacial events on the Russian Plain.
Analysis of malacologic data, additionally verified by the results of the micropaleontological and palynological analyses, revealed that the most significant Late Pleistocene Caspian transgression was the Khvalynian, developed in cold climatic conditions. Along with it, in the warm climate, transgressive sea-level rises of a minor scale (“minor transgressions”; Yanina, 2009) occurred corresponding to the Late Khazar transgression. Together with “cold” and “warm” transgressions, “cold” and “warm” regressions, separating them, were recorded in the Caspian history.

In the Pleistocene cyclicity for the Russian Plain, Grichuk (1969) distinguished warm and cold phases, and in each phase, based on degree of humidity, he distinguished stages: in the warm, xero- and gyrothermic; and in the cold, cryogrycotic and cry-oexotic (Fig. 2). Although the moisture and heat supply curves on the Russian Plain are shifted in relation to each other by a half-phase, in the Caspian region they are shifted more (Alisov and Poltoraus, 1962; Grichuk, 1969; Filippova, 1997) and the correlation between temperature decrease and humidity rise increases southward.

Analysis of temporal humidity changes in the studied region (the key factor for transgression development) indicates that “cold” transgressions occurred during cryogrygrotic phases, with favorable conditions for glaciations development on the Russian Plain. However, the moisture peak in the Khvalynian reached its maximum earlier than the glacial maximum (approximately by the middle of the cryogrygrotic phase). By the time of the glacial maximum on the Russian Plain (the end of the cryogrygrotic phase), the sea-level drop corresponded to the “cold” regression.

Existence of the “pluvial belt” during global climate cooling is evident for the entire arid zone in Asia (Devyatkin, 1989, 1993). Reconstructions showed increased humidity on the Caucasus coast with simultaneous temperature decrease (pluvials) during glacial epochs and humidity decrease and temperature rise during interglacial (Shnitnikov, 1956; Markov et al., 1965; Abramova, 1974; Markov, 2005 and others).

The given (“idealized”) scheme of transgressive-regressive Caspian cyclicity correlation with global climatic events is superimposed by regional factors (Fig. 2). They are caused by glaciations on the Russian Plain (its magnitude, outline, dynamics, reorganization of hydrographic system), introducing regional changes in climatic parameters and in the magnitude of water inflow. Degradation of glaciations and inflow increase cause new transgressive sea-level rise and is reflected in its dynamics with smaller-scale cyclicity. The reorganization of hydrographic system impacts development of the Caspian basins. For example, Kvasov (1975) considered it to be the main factor in the history of the Khvalynian transgression.

According to the scheme, regression maximum corresponded to the xerothetic phase of the interglacial. “Warm” transgressions were apparently taking place during cooling phases with moisture increase within the long-term complex interglacials. The extensive epoch of low Caspian Sea level, complicated with the double-stage “minor” Late Khazar transgression corresponded to the Mikulino interglacial with two endothermals in its structure. This warm epoch in the Caspian history covered the time interval corresponding to the MIS 5 (Fig. 3), which agrees with the point of view of researchers who compare the Mikulino interglacial with the entire MIS 5, unlike those who only compare it to MIS 5e.

The “Cold” vast Khvalynian transgression and the preceding Atel regression were developing during the Valday glacial epoch (MIS 4–2). The Atel regression corresponds to cold MIS 2 and, seemingly, beginning of MIS 3. Its lower boundary in the Lower Volga region is marked with ice wedges. Transgression started in the second half of the interstadial (second half of MIS 3) and continued into the beginning stages of the Late Valday cooling. During the dry epoch of the Last Glacial Maximum (peak of MIS 2) it was interrupted with a regression. Further development of the transgression occurred during deglaciation. Its course was impacted by transgressive-regressive events of lower magnitude linked to oscillations of climatic parameters: i.e., cold dry conditions of the Middle Dryas by the Enotaevka regression, and the continentalization of the Boreal period of the Holocene by the Mangyshlak regression.

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References


