Paleogeography of the Sea of Azov region in the Late Holocene (reconstruction by diatom and pollen data from marine sediments)

Gennady Matishova, Galina Kovalevc, Elena Novenko, Kristina Krasnorutskayac, Vladimir Pol’shin

Southern Scientifi c Center, Russian Academy of Science, Chekhov Av. 41, 344006 Rostov-on-Don, Russia
Murmansk Marine Biological Institute, Kola Scientifi c Center, Russian Academy of Sciences, Vladimirskaya St. 17, 183010 Murmansk, Russia
Institute of Arid Zones of the Southern Scientifi c Centre RAS, Chekhov Av. 41, 344006 Rostov-on-Don, Russia
Institute of Geography, Russian Academy of Science, Staromonetny 29, 119017 Moscow, Russia
M.V. Lomonosov Moscow State University, Faculty of Geography, Leninskie Gory 1, 119991 Moscow, Russia

A R T I C L E   I N F O

Article history:
Available online 4 June 2012

A B S T R A C T

This paper presents new available high-resolution pollen and diatom evidences, relief and sedimentation processes during the New-Azov stage of the sea development, as well as the reconstruction of environmental changes in the Late Holocene. According to data obtained from the southern steppe landscapes that are similar to the modern ones, were widespread in the area adjacent to the sea of Azov during the formation of the New Azov layers (the last three thousand years). However, the Late Holocene trend to climate aridization was interrupted by three phases of cool and more humid conditions: late Subboreal (3000–2300 cal. calendar years BP), middle Subatlantic (2000–1700 cal. BP), and the Little Ice Age (600–150 cal. BP). Diatom data suggest that during the fi rst and second phases of cooling, the Sea of Azov was characterized by conditions of shallow waters with relatively high salinity and specific hydrodynamics.

1. Introduction

Pollen and diatom analysis are applied widely in paleoecological studies of marine paleoenvironments. As reliable bio-indicators of the Holocene and Pleistocene climate, pollen and diatoms constitute a high quality tools for reconstructing past conditions and improvement of Quaternary stratigraphy in the region of the Sea of Azov (Matishov, 1986). Apart from the terrigenous factor, salt water organisms play an important role in sedimentogenesis of the sea basin (Khrustalev, 1999; Matishov et al., 2006).

The Sea of Azov has been intensively studied during the last several decades due to its economical value and inland geographical position (Modern Development..., 1999). Much attention was given to studying sedimentation rates in the arid climate (Khrustalev, 1989). However, the geochronology, pollen and diatom data were obtained sporadically, and the pattern of the sedimentation process and deposits dating for the Late Holocene (the New Azov Layers in the regional stratigraphic sequence) has remained unclear until now. The stratigraphic scheme of Quaternary deposits of the Sea of Azov is based mainly on data of fossil mollusc shells (Nevesskaya and Nevessky, 1960; Nevesskaya, 1963; Barg and Yatsenko, 2001) and results of pollen analysis (Vronsky, 1976, 1984; Isagulova, 1978). Rarely have the occurrences of few common diatom species been mentioned (Vronsky et al., 1974). The distribution of diatom assemblages in the Late Holocene deposits was not studied in detail until recently. The New Azov Layers lack high-resolution palynological characteristics.

The New Azov Layers have increasingly attracted the attention of researchers because of their importance for a better understanding of modern environmental processes. The recent bottom relief of the Sea of Azov and 2-m uppermost part of marine deposits were formed mainly during the New-Azov stages of the sea development. Regular and frequent tectonic movements in the adjacent territory to the marine basin and climatic fl uctuation have signifi cant in fl uence on rates of sedimentation, relief morphology and denudation-accumulative processes (Matishov, 2007; Matishov et al., 2009). This paper discusses the newly available high-resolution pollen and diatom evidence, relief and sedimentation processes during the New Azov stage of the sea development, as well as the reconstruction of environmental changes in the Late Holocene.
2. Study area

The Sea of Azov has one of the largest estuaries located in the south of the East European Plain. The relief of seabed includes extensive and relatively flat plain (Panov accumulation plain), numerous linear accumulative forms (spits), underwater sand-shell ridges caused by wind drifts and erosive depressions (Matishov et al., 2009). The thickness of marine sediments varies in the different part of the sea basin and reaches 30–40 m.

The isolation of the Sea of Azov started from the Early Holocene (about 10,000 years ago). The Holocene deposits of the Sea of Azov consist of two stratigraphical units: the Early Azov and New Azov Layers. The age of the lower boundary of the New Azov Layers was determined as about 3000 cal. BP using radiocarbon dating of mollusc shells (Stratigraphy USSR, 1984; Matishov et al., 2009) and corresponds to the late Subboreal and Subatlantic climatic periods of the Holocene according to the Blytt–Sernander classification modified for the East European Plain by Khotinski (1977). Two main phases of regional sea level movement in the Late Holocene have been determined: Fanagorian regression (2500–3000 cal. BP) and Nymphean transgression (during the last 2500 years). During the Fanagorian regression the sea level descended up to 5–6 m below its modern position (Matishov, 2007; Matishov et al., 2009), and gaps in sedimentation were recorded in a number of sediment sequences.

Climate of the Azov region is temperate-contontental. The mean January temperature is −5 °C in the northern part of the seashore and about 0 °C in the south. The mean July temperature is 22–24 °C. The mean annual precipitation changes from 400 to 600 mm.

Vegetation of the northern and eastern shores of the Sea of Azov is south steppe with stipa (Stipa ucrainica, Stipa lessingiana, Stipa capillata) and sheep fescue (Festuca valesiaca) as dominant species. However, the natural plant cover was greatly changed by human impact over the past 300 years. The present-day landscape is almost entirely anthropogenically modified, and native herbaceous communities have been replaced by agricultural land that is either in use or has been abandoned.

3. Materials and methods

The sedimentation rates and reconstructions of the typical environment on the sea shelf for the New-Azov stage are based on complex analyses of marine deposits (Fig. 1). The series of sediment cores were obtained during the cruises of the dredging boat Pri-morets (2004–2005), and R/V Deneb (2007–2008) Core sampling was performed by means of a direct flow tube with weighting device, material, leaf shutter, and changeable polythene film to prevent sample contamination.

Two sediment cores (up to 2 m in depth) obtained during the cruise of the R/V Deneb in 2007–2008 provided the material for the high resolution diatom and pollen studies. The first core (st. (station) 86, see Fig. 1) was taken from the south-eastern area of the Sea of Azov (the central part of Temryuk Bay); the seabed sediments were described according to lithological composition and subsampled for pollen and diatom analyses with intervals 1–3 cm. The samples were placed into sealed packages. To obtain additional information about regional vegetation dynamics palynological studies were carried out for the second core (st. 185, see Fig. 1) drilled in the north-eastern part of the Sea of Azov (Dolgaja Spit). Sediment samples were sliced for pollen analysis at 1–2-cm intervals throughout the core.

The age–depth relationship was constructed using radiocarbon and optical-stimulated luminescent (OSL) dating (Matishov et al., 2009). The radiocarbon measurements were performed in the Laboratory of Holocene Palaeography and Geochronology (Geography Institute, St. Petersburg State University, Russia) using technique, published by Arslanov (1987). Material for radiocarbon measurements were clamshells. The OSL-dating was carried out in the Luminescence Dating Research Laboratory of the Department of Earth and Environmental Sciences of the University of Illinois at Chicago, United States (Fig. 1). Materials for OSL-dating were whole core specimens, which were obtained and kept without light admission.

The samples for the diatom analysis were prepared under the standard methods (Diatom analysis..., 1949a). The diatom species were determined under a light microscope Leica DME (oil-immersion lens, total magnification 1000×) and under a scanning electron microscope Carl Zeiss EVO 40 XV, at least 500 valves were counted per sample. Fragments of valves belonging to species these can be reliably identified by a part of a diatom frustule (for example, species Actinocyclus octonarius, Actinoptychus senarius) were counted separately. In the analysis it was considered the fragments of valves the size of which was not less than 1/3 from the sizes of the whole frustule. Identification of diatom species was based on special books and atlases (Diatom analysis..., 1949a,b, 1950; Kranner and Lange-Bertalot, 1986, 1988, 1991a,b; Diatoms of the USSR..., 1988, 1992; Witkowski et al., 2000; Diatoms of Europe, 2002, 2002, 2003; Diatoms of Russia..., 2002, 2006, 2008).

Samples for pollen analysis were processed using the pollen extraction procedure developed by Grichuk (1940). The treatment included separation by heavy liquid (cadmium iodide) with a density of 2.2 g/cm3. In each sample, ~500 terrestrial pollen grains were counted. Pollen diagrams were compiled using Tilia and Tilia Graph programs (Grimm, 1990).

4. Geological setting

The current relief of the Sea of Azov formed during the Holocene as the result of complicated interrelation of endogenous and exogenous processes. In that time, the linear accumulative forms of relief (spits), numerous underwater sand-shell ridges caused by wind drifts, and erosive flat hollows of the bottom were formed. Among flat forms of relief, occupying the larger part of water area, erosional and erosional-accumulative terraces (located at the depth of 4–9 m) and accumulative plains linked to the maximum bathymetric points of the sea bottom are specified (Matishov, 2006, 2007). The accumulative morphology of plains comprises the system of ancient valleys of paleorivers, with the largest one being the valley of Paleo-Don (Shnyukov et al., 1974; Matishov, 2006). The outlines of paleoriver valleys in the bottom relief are smoothed by the covering thickness of marine sediments formed in the Early-Azov and the New-Azov stages of the sea development.

The differentiated character of tectonic movements within the borders of marine basin determined the conditions and rates of sedimentation, as well as morphology and development of relief (Khristalyev and Scherbakov, 1974). Frequent changes of the sea level, which took place during the New-Azov stage of the sea development, predetermined the rhythmic character of sedimentary mass composition (see Fig. 1). The thickness of these deposits is 0.5–2.5 m, typical for the shelf of the Sea of Azov. The age of the lowest deposit layers (100–180 cm) is about 1500–2080 (±190) cal. BP, from radiocarbon and OSL-dating. The oldest radiocarbon date (3110 ± 170 cal. BP) was obtained in the lowermost horizon of the core in the southeastern part of the Sea of Azov (the central part of Temryuk Bay, st. 86, see Fig. 1).

The terrigenous sediments, which are basically clay and silt (aleurite)-clay silts, prevail in the central part of the sea. The most common types of deposits (fine-silt silts and fine-grained sands) are registered in the sediment cores sampled along the periphery of marine basin, not far away from the coast and situated locally.
Fig. 1. Bathymetric map of the Sea of Azov with position of studied sediment cores (simplified after Matishov et al., 2009). Average sedimentation rate, mm per year, in the Sea of Azov in the New Azov period: lithological transects and absolute age of the deposits. Columns 110 and 185 were analyzed by OSL-dating; stations 43, 44, 45, 75, 79, 133, by 14C radiocarbon dating. (1) drowned clayey mud; (2) clayey mud; (3) silt-clayey mud; (4) sandy silt-clayey mud; (5) argillo-arenaceous fine silt; (6) calcareous loam; (7) silty shelly ground; (8) fine dirty sand; (9) shelly ground; (10) sampling sites, (11) sampling period with deposit age; (12) average sedimentation rate for the period.
Carbonaceous sediments are shells and products of their destruction (organic-detritus sand). The presence of horizons with heavily carbonaceous (shell) silts and silt-sized shell fragments is typical of the Sea of Azov. The thickness and quantity of inter-layers enriched with shell material generally increase in the cores sampled closer to the coast as the sea depth decrease.

In the total sedimentation balance, the role of terrigenous material formed in the result of coast and bottom abrasion while the sea level rose. Because of the lithological composition of rocks experiencing destruction, mainly fine silt-clay material entered the water area, and was distributed over the bottom under the influence of rough waves and currents. The major part of that material was deposited in the central part of the sea within the borders of a wide accumulative plain. The average rate of sedimentation in the New-Azov period was 2 mm/year, reaching a maximum of 10 mm/year during the Nymphean transgression. Sedimentation rates in the part of the accumulative plain close to the Temryuk Bay were 0.2–6 mm/year. The abrasion of the coasts and the outflow volume of the Kuban River loads apparently conditioned this regime. In some cases, depending on geomorphologic situation and closeness to the coastal bluffs, the accumulation rate reached 4–6 mm/year (Matishov et al., 2009).

5. Results

5.1. Diatoms

The distributions of diatom assemblages in the New Azov Layers were intensively investigated during the last decade (Kovaleva and Pol’shin, 2006; Kovaleva, 2007, 2008; Matishov et al., 2009). These studies have shown that irrespective of location of sampling sites, A. octonarius Ehr. and A. senarius (Ehr.) Ehr. (Fig. 2) are the most abundant species in the lower layers of sediments.

Despite several suggestions concerning ecology and requirements for water salinity of A. octonarius in the publications, it is assumed that A. octonarius is a mesohalobic planktonic species (Proshkina-Lavrenko, 1963; Cooper, 1995), occurring mostly in shallow estuaries of mesothermal seas, and specific for diatom assemblages of basins with abundant aquatic vegetation and low hydrodynamic activity (Diatoms of Russia..., 2008; Radionova and Golovina, 2008). A. senarius is typical for sublittoral zones and found in planktonic assemblages sporadically (Proshkina-Lavrenko, 1963). Nowadays, both species are registered in the Sea of Azov separately. Bearing in mind bionomics of these species, they can be considered as indicators of shallow waters.

Hydrological and climatic changes, which took place during the New-Azov stage, caused the rhythmic character of marine deposits. In the studied core (st. 86, see Fig. 1), 165 cm in depth, silt deposits interrupted by layers of shell detritus are exposed (Fig. 3). The results of high resolution diatom analyses have shown that specific diatom assemblages correspond to lithological compositions of the sediment column. For instance, the intervals with high concentration of A. octonarius are linked with horizons of mollusc shells. In contrast, an increase of Chaetoceros spores (Fig. 4) has been observed only in the strata without interlayers of shell detritus.

Six diatom assemblage zones were identified in the core based on the species composition and relative abundance of various species...
diatom taxa and ecological groups (see Fig. 3). The diatom assemblages of zone 1 (100–165 cm) are characterized by high content of *A. octonarius* shell detritus.

The diatom assemblages of zone 2 (83–100 cm) are marked by increase of *Thalassiosira parva* and *Chaetoceros* spore content. Changes of cells and spores numbers of *Chaetoceros* genus in diatom assemblages is a reliable indicator of waters mixing in the zone, where hydrological fronts combine and the sea level increases (Sancetta, 1981, 1982; Crosta et al., 1997). A high quantity of plankton frustules of *T. parva* and *Chaetoceros* spores in

---

**Fig. 3.** Diatom successions in the sediments of the core in the south-eastern part of the Sea of Azov (st. 86). Lithology: 1 – argillaceous silt, 2 – silt shell detritus.
5.2. Pollen analysis

Pollen analyses of marine sediments in the arid regions are characterized by some specific features. The previous studies of several cores and recent pollen assemblages in the Sea of Azov (Isagulova, 1978; Matishov and Novenko, 2008) allowed determination of three sources of pollen and spores in marine deposits: regional vegetation of the coastal area (mainly herb pollen); arboreal pollen (AP) and spores transported primary by rivers; and Pre-Quaternary microfossils reworked as result of coastal and bottom erosion. Therefore in the present paper the relative frequency of components in assemblages were calculated based upon the sum of autochthonous non arboreal pollen (NAP). Percentages of the trees, shrubs, and spores were also calculated in relation to this sum (NAP = 100%).

On the base of pollen analysis of more than hundred surface pollen samples of seabed deposits of the Sea of Azov, the relationship between the composition of the main components of pollen spectra and climate humidity was determined (Vronskiy, 1976; Isagulova, 1978). Two types of pollen assemblages were clearly defined: xerophytic (steppe) and mesophytic (forest-steppe) types (Isagulova, 1978). This distinction of pollen spectra has been traced as spatial and temporal patterns (Matishov and Novenko, 2008).

5.2.1. Sediment core st. 86

Pollen analysis of sediment cores st. 86 (see location on Fig. 1) have shown that herbaceous pollen (up to 80% in some intervals) mainly by Chenopodiaceae and Artemisia is dominated in pollen assemblages of investigated marine sediments (see Fig. 5). The participation of Poaceae pollen is relatively high; Apiaceae, Fabaceae, Rosaceae, Lamiaceae, Cichoreaceae are constantly occurring. Pollen of the typical steppe plants (Ephedra, Echinops, Plumbaginaceae, Dipsacaceae) are also permanent components of the spectra. These plants are very typical both in vegetation cover of the coastal area and pollen assemblages in surface samples of seabed deposits. Arboreal pollen are represented by Pinus, Betula, Alnus and broad-leaved trees such as Quercus, Ulmus, Tilia, Carpinus, Fagus and Juglans. Among spores, Polyopodiaceae and Sphagnum were identified. Pollen of aquatic plants was registered in sediments: Sparganium (abundant), Typha latifolia and Potamogeton (rare). Neogene microfossils are present in amount of 5—7%.

Despite the monotonous pollen diagram of the st. 86, local pollen assemblage zones have been identified (see Fig. 5). Pollen spectra of zones 1, 3 and 5 (155—160 cm, 75—125 cm, 0—45 cm) are attributed to xerophytic (steppe) type (after Isagulova, 1978). The share of AP is not more than 30—40%, and steppe herbs are significantly abundant.

In pollen assemblages of zones 2 and 4 (125—155 cm, 45—75 cm), the arboreal pollen increased to 60—70%, mainly Alnus, Quercus, Carpinus, Pinus and Betula. The content of Artemisia pollen decreased while pollen values of meadow herbs grew. The proportions of the main components of pollen spectra allow attribution of these pollen assemblages to mesophytic (forest-steppe) type.

5.2.2. Sediment core st. 185

The floristic composition and proportion of the components in pollen assemblages in sediment core st. 185 (Fig. 6) are similar to the pollen sequence in core st. 86. The typical feature of pollen assemblages of marine sediments from st. 185 is a high amount of reworked Neogene pollen and spores, especially in the interval 80—120 cm of the sediment column. The content of reworked pollen grows to 200—500% in relation to the Holocene ones. An increase of their values in the middle part of the core 185 could indicate active processes of bottom erosion. Pollen diagram of the st. 185 has been divided into 5 local pollen zones (see Fig. 6).

Pollen spectra in zones 1, 3 and 5 (162—180 cm, 118—140 cm, 16—80 cm) are referred to xerophytic (steppe) type. Herb pollen is the main component; the share of Artemisia is 50—60%, Chenopodiaceae – 30—40% and Poaceae – up to 10%. The proportion of trees and shrubs does not exceed 20—25% (from AP + NAP). Pollen of
aquatic plants is relatively abundant. Rare grains of Myriophyllum, an aquatic species growing only in fresh water, were found.

Pollen assemblages of zones 2 and 4 (140–162 cm, 80–115 cm), are defined as forest-steppe types characterized by high tree pollen values (50–60% AP + NAP). The frequencies of pollen of Alnus, Betula, Tilia, Corylus, Carpinus, Pinus increased. The proportion of dominant taxa in the NAP group (Artemisia, Chenopodiaceae, Poaceae) was reduced, the pollen content and diversity of mesophytic herbs (Asteraceae, Rosaceae, Apiaceae, Geraniaceae) raised, and pollen of Sanquisorba, Valeriana, Thalictrum were recorded.

Fig. 5. Pollen diagram of the core in the south-eastern part of the Sea of Azov (st. 86). Lithology: 1 – argillaceous silt, 2 – silt shell detritus.

Fig. 6. Pollen diagram of the core in the north-eastern part of the Sea of Azov (st. 185). Lithology: 1 – clayey mud, 2 – calcareous loam, 3 – silt-clayey mud, 4 – fine dirty sand, 5 – argillo-arenaceous fine silt.
6. Discussion

Pollen and diatom study of the Azov marine deposits provides information about the hydrodynamics of the sea basin and regional vegetation history in the south part of the East European Plain during the New-Azov phase of sea development (Late Holocene). According to radiocarbon data, the accumulation period of the sediments revealed in the core 86 span the late Subboreal and early Subatlantic phases of the Holocene. The results of high resolution diatom analysis of this core show that the oldest (lowest) sediment layers (diatom zone 1, see Fig. 3) are marked by low diatom biodiversity. Only two species dominate, A. octonarius and A. senarius, indicating shallow water in the ancient Sea of Azov (~2500–3000 cal. BP). High abundance of A. octonarius and A. senarius and their subvarieties (Kovaleva, 2007) and a high amount of macrophytes (pollen of Sparganium, Potamogeton, T. latifolia) suggest that these sediments were formed in a shallow-water gulf or bay with rich aquatic vegetation.

According to pollen records revealed from core st. 86, a high content of steppe plants (species of genera Chenopodiaceae, Poaceae and genus Artemisia) and permanent presence of Plumbaginaceae end Ephedra are characteristic for pollen assemblages that suggest an area of dry steppe vegetation in the Azov region during the last 3000 cal. However, several phases of vegetation dynamics were reconstructed. The parts of diagram at depths 155–170 cm (pollen zone 1; 3500–3000 cal. BP), 70–130 cm (pollen zone 2; 2400–2000 cal. BP) and 10–45 cm (pollen zone 5; 1700–600 cal. BP) are characterized by very high non arboreal pollen content, and they probably reflect very warm and arid conditions. The depth interval 125–150 cm (pollen zone 2, 2300–3000 cal. BP) is marked by increased tree pollen concentration (up to 60%), mainly due to birch and alder. Curves of Quercus, Tilia, Corylus and Carpinus pollen formed noticeable peaks. These changes in pollen assemblages in these periods could be caused by increased forest areas in the valleys of large rivers or by bay with rich aquatic vegetation.

Vegetation development of the Sea of Azov region in the Late Holocene was also strongly influenced by human impact, especially during the last 100 years. Pollen of cereals and other anthropogenic indicators (Brassicaceae, Cichoriaceae, Centaurea, Rumex, Polygonum aviculare) was recorded during the whole period under consideration, but their content increased notably in the last century (see st. 185, pollen zone 5, Fig. 6). Pinus pollen is abundant in assemblages of the last 70 years from sediments in the northern part of the sea that can be connected with pine plantations to stabilize sandy soil in the middle part of the Don River basin. A conspicuous increase of Asteraceae pollen value in assemblages of the last hundred years could be connected with plant communities on disturbed areas and or cultivation of Helianthus annuus.

7. Conclusions

The investigations of geochronology and lithostratigraphy of marine sediments of the Sea of Azov have emphasized the importance of detailed studies of marine deposits formed during the New-Azov stages of the sea development (Late Holocene) and environment conditions during their accumulation. The current relief of the Sea of Azov and the uppermost marine deposits were formed during the period as a result of complicated interrelation between tectonic movements in the adjacent territory and climatic fluctuation.

The pollen study of the key sequences of marine sediments indicated the evolution of landscapes in the Sea of Azov region over the last 3 thousand years. South steppe landscapes similar to the modern ones were in existence during the formation of the New Azov layers. However, the Late Holocene trend to climate aridization was interrupted by three phases of cool and more humid conditions: late Subboreal (3000–2300 cal. BP), middle Subatlantic (2000–1700 cal. BP) and the Little Ice Age (600–150 cal. BP). Diatom data suggest that during the first and second phases of
cooling reconstructed by pollen records, the Sea of Azov was characterized by conditions of shallow waters with relatively high salinity and specific hydrodynamics.

Acknowledgments

This work was supported by the Program of Basic Research of the RAS Presidium "Origin of Biosphere and Evolution of Geobiological Systems" within the project "Paleoclimatic and Biogeocenosis Changes in Internal Seas Basins as a Reflection of Global Events in Pleistocene and Holocene". Our sincere thanks go to Anna Ulanova and Graham Gary Wife for help with English language.

References


Cooper, Sh.R., 1995. Diatoms in sediments cores from the mesohaline Chesapeake Bay. Diatom Research 10 (1), 39–89.


