ISSN 1028-334X, Doklady Earth Sciences, 2009, Vol. 429, No. 8, pp. 1369–1372. © Pleiades Publishing, Ltd., 2009.
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OCEANOLOGY

New Data on the Sedimentation Rate in the Sea of Azov in the Late Holocene

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Received May 5, 2009

Abstract—The sedimentation rates in the Sea of Azov for the period of the last 2000 years (Late Azov stage) were studied by methods of absolute geochronology, lithology, and biostratigraphy. The average sedimentation rate of the Late Azov deposits varied from 0.4–0.8 to 1.5–2.0 mm per year. It reached as much as 4.0–6.0 mm per year in the areas close to the sharp coasts and was defined by the area geomorphology. The scheme of the lithological transects, sedimentation rates, and absolute age of the sediments is presented. The palaeoecology peculiarities of deposit accumulation during the Late Azov stage are described from the diatom and spore-pollen analyses.

Keywords: Sedimentation process, Holocene, geochronology, Late Azov deposits, Sea of Azov.
DOI: 10.1134/S1028334X09080285

Data on deposit accumulation rates may be obtained by a complex of different biological and geological approaches, including the methods of absolute geochronology. The ocean and sea shelf areas greatly differ in the sedimentation rates. Thus, estuaries are characterized by the highest rates of 0.3 to 3.0–4.0 mm per year and even more [4, 11]. The sedimentation rates reach 1.0 mm per year for the North Caspian shelf and even up to 6.0 mm per year for the Kura River estuary. Values about 0.03–0.1 mm per year are typical for the continental margins.

The Sea of Azov is one of the biggest estuaries; it has been well studied due to its economical value and inland geographical position [7]. Much attention was given to studying the sedimentation rates in the arid climate [13]. However, the geochronology data were obtained sporadically, and the pattern of the sedimentation process and deposit dating for the Late Holocene has remained unclear until now. The isolation of the Sea of Azov started from the Early Holocene (10 000 years ago). Two types of deposits were described, Early Azov and Late Azov. The age of the oldest Late Azov deposits was determined as 3100 ± 170 years from the radiocarbon analysis of fossil mollusk shells [12].

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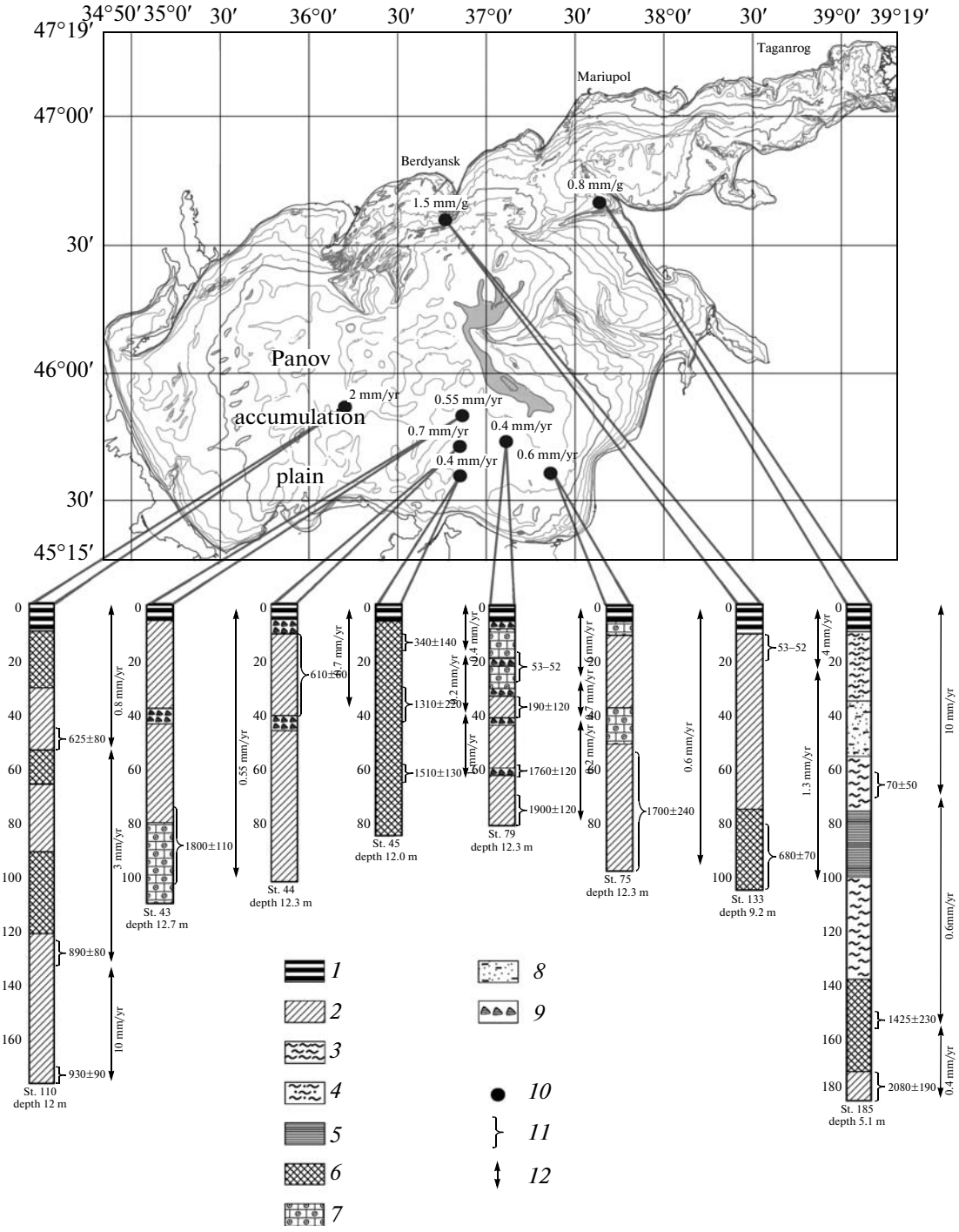
The present study aimed to assess the sedimentation rates and to reconstruct the typical environment on the sea shelf for the Late Azov stage, based on analyses of the sediment cores (1–2 m). The samples obtained in expeditions in 2004–2008 made a dataset for the current study. The sampling was performed onboard the seine boat *Primorets* (2004–2005), R/V *Deneb* (2007–2008) and R/V *Professor Panov* (seasonal sampling in Taganrog Bay). Core sampling was performed by means of a direct-flow tube with weighting material, leaf shutter, and changeable polythene film to prevent sample contamination.

The sample study included lithological analysis, diatom and spore-pollen analyses, and absolute age dating (Fig. 1). The radiocarbon measurements were performed in the Laboratory of Holocene Palaeography and Geochronology, Geography Institute, St. Petersburg State University, Russia (Fig. 1). The optical-stimulated luminescent dating (OSL-dating) was performed in the Laboratory of Luminescent Analysis, University of Wisconsin, Chicago, United States [14, 15].

The samples for the diatom analysis were prepared under the standard methods [2]. The diatom species were defined under a light microscope *Leika DME* (oil-immersion lens, total magnification 1000x) and under a scanning electron microscope *Carl Zeiss EVO 40 XVP*. The samples for the spore-pollen analyses were performed by Grichuk's method [1].

A significant dataset of the samples obtained in the expeditions by Southern Scientific Center and the Murmansk Marine Biological Institute in the years 1997–2008 is now available to analyze the geomorphology and stratigraphy of the Late Azov deposits and



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 ^{14}C radiocarbon-dating. (*1*) drowned clayey mud; (*2*) clayey mud; (*3*) aleurite-clayey mud; (*4*) sandy aleurite-clayey mud; (*5*) argillo-arenaceous fine aleurite 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.

to describe major patterns of the pollen and diatom distribution.

Silty argillaceous deposits are the main surface sediments; the fraction of 0.01 constitutes more than 70% (Fig. 1). They are found for 75% of the shelf area, mostly for the Panov accumulation plain [5, 7]. Gray and dark gray silts accumulate locally in the bottom depressions of the bays and firths and in the hollows between the banks.

Fine silts (fraction <0.01 mm constitutes more than 85%) are found in the Zhelezinskaya depression and some others bottom depressions for the depths of 12–

14 m (Fig. 1). All the silty deposits are characterized by a high content of organic compounds and by an expressed hydrogen sulfide odor; they contain a significant amount of shelly ground in the peripheral areas of the sea proper. The sand compound constitutes from 0.3 to 2.5%, reaching up to 7–17% close to the shores.

The stratified deposit structure formation intervened in the Late Azov stage. The seam thickness of these deposits is 0.5 to 2.5 m; they are typical for the shelf of the Sea of Azov. The maximal age of the lowest deposit layers (100–180 cm) is about 1500–2080 (±190) years, from radiocarbon and OSL-dating. Mostly aleurite, silt, and mixed sediments with fossil mollusk shells are found in numerous core samples. Interlayers of dirty sand with organic and detrital matter (20–40 cm) are usual, which are signs of their formation in the shore (littoral) environment.

Regional differentiation of the accumulation rates in the Late Holocene was governed by the local geomorphology, river discharge and its composition, wind activity, and bioproductivity of the Sea of Azov. The sedimentation rates and the deposit formation peculiarities were studied under analysis of two core samples obtained in the shore area at depths of 5–9 m (Fig. 1).

The sediment rate for the last 700 years constituted about 1.5 mm per year for the southern area off the Berdyanskaya Spit (Fig. 1). The two-meter deposits between the banks of Dolgaya and Yelenina spits (st. 185) were formed by complex alternation of different heterogeneous sediment types, from silts through aleurite-clayey mud to sandy aleurite-clayey mud. Eight layers were defined, which are different in the lithology origin and are of 10, 20, and 35 cm depth. This alternation is a significant sign of repeated change of the estuary regime for the last 2000 yrs. The upper 70-cm layer was formed in the last 70 ± 50 yrs with a sedimentation rate of more than 10 mm per year. Only the upper 60-cm deposit layer in Taganrog Bay contained the pollen of crop plants. We assume that this layer was forming in the Late Azov stage, taking into account that the era of crop production started only 2000–4000 years ago in the Azov region [8].

The average sedimentation rate in the Late Azov stage constituted 2 mm per year on the Panov accumulation plain, the open sea area, and depths of 12 m (Fig. 1). The sedimentation rate of clayey mud reached up to 10 mm per year during the Nymphean stage of advance of the sea (930 ± 90 yrs ago). The sedimentation rates constituted from 0.2 to 6.0 mm per year in the adjacent areas of Temryuk Bay, which was governed by shore attrition and the Kuban' River discharge.

The pollen biodiversity is similar for most of the core samples taken in different parts of the Sea of Azov, as the spore-pollen analyses show [8]. The impact of arborous pollen increases up to 40% in the lowest layers of the core samples. Therefore, the climate in the period of 1300–1800 years ago was less arid than nowadays. Arborous pollen was mostly represented by birch (*Betula* spp.) and pine-tree (*Pinus* spp.) pollen; the pollen of large-leaved trees, especially oak pollen (*Quercus* spp.), played a minor role. The presence of pollen of xerophyte and halophyte pigweeds (Chenopodiaceae) was a sign of the aridization of the climate during the period of the Late Azov deposit formation.

Only the upper layers of the sediments (20–35 cm) are characterized by high diatom biodiversity (more than 70 species) and contain the frustules of the diatom species that dominate in the Sea of Azov nowadays. The dominant species biodiversity varies for different areas of the Sea of Azov. The central part of the sea is characterized by planctonic diatom species dominating, *Chaetoceros* spp., *Sceletonema costatum* (Grev.) Cleve, *Cyclotella tuberculata* Makar. et Log., *Coscinodiscus, Thalassiosira* and some others. Benthic diatoms prevail in the upper layers of the core samples for the estuaries and near shore areas, e.g., *Amphora, Fragilaria, Cymatopleura, Cocconeis, Navicula, Pinnularia*, and some others.

The oldest (lowest) sediment layers are characterized by low diatom biodiversity. Only two species dominate, *Actinocyclus octonarius* Ehr. and *Actinoptychus senarius* (Ehr.)Ehr. Inspite of their occurrence in the present-day diatomic flora of the Sea of Azov, these species are not so widely distributed as indicated by valves in deeper (15–20 cm) layers. These two species, *A. octonarius* and *A. senarius*, usually inhabit mesothermal brackish waters [2, 10]; thus, we assume that the ancient Sea of Azov (~1500–1900 yrs ago) was characterized by shallow waters.

High abundance of *Actinocyclus octonarius* Ehr. and *Actinoptychus senarius* (Ehr.)Ehr. and their subvarieties [3] is characteristic of a specific hydrodynamics of the near shore shallow waters, which was stable for quite a long period of time. The eroding of the sediments might occur as a result of processes of both regression and advance of the sea [9]. These processes might cause significant differences in the diatom biodiversity in the core samples (upper layers, 30–35 cm) obtained in different parts of the Sea of Azov. A similar pattern was described under the acoustic measurements [6], which stated discretions in the sedimentation process during the Fanagorian regression (2500–3000 years ago).

Accordingly, the upper 2-m sediment layer and contemporary bottom relief of the Sea of Azov formed over the last 2000 years (the Late Azov stage), as the results of both lithology and absolute geochronology analyses of eight core samples show. The average sedi-

mentation rate for this period varied from 0.4–0.8 to 1.5–2.0 mm per year (Fig. 1). Similar values of 0.25–0.50 mm per year for the late period of the Fanagorian regression were obtained by acoustic measurements of the bottom sediments of the Sea of Azov [6]. However, the highest rates of 4–6 mm per year were found in the areas close to the abrupt coasts and were defined by the area geomorphology.

ACKNOWLEDGMENTS

This work was supported by the Program no. 15 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."

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