

Hydrological Changes in the White Sea during the Historical Period Inferred from Analysis of Dinocysts

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According to available historical evidence, colonization of the White Sea region began in the 9th–8th centuries B.C. [2]. This unique region with ancient residence sites experiences progressively increasing anthropogenic load against the background of natural climatic changes. The intense economic development of the region requires complex ecological and paleogeographic studies aimed at detailed reconstruction of past sedimentation settings.

The analysis of dinocysts, which makes it possible to reconstruct various parameters of water masses washing the Arctic shelf, has become a promising method in paleohydrological studies, widely used in recent years [10, 11]. Dinoflagellates, which represent one of the main phytoplankton groups in the Arctic Seas, the White Sea included, form cysts with biopolymer envelopes, which are preserved in sediments. Thus, information on glacial–hydrological conditions is recorded in marine sediments. In the White Sea, this method was first used for the study of bottom sediments only in 2003 [3, 15].

In this communication, we present the first results obtained during the thorough study of dinocysts in bottom sediment cores from the White Sea, which cover the last 250 years. The study of this microfossil group made it possible to reconstruct in detail changes in glacial–hydrological settings in the sea and reveal their relations with known climatic–hydrological events that occurred in neighboring regions during the historical period.

MATERIALS AND METHODS

Examined cores 4719 and 4706 were sampled by the Neimisto corer with an inner diameter of 53 mm during

Cruise 49 of the R/V *Professor Shtokman* (August 2001) by scientists from the Laboratory of Physical–Geological Studies of the Institute of Oceanology, Russian Academy of Sciences. Cores 68 and 20 cm long were taken in the open part of the Kandalaksha and Onezhskii bays at water depths of 277.0 and 65.6 m, respectively (Fig. 1a). According to ²¹⁰Pb and ¹³⁷Cs dating, their maximal age is 250 years [1]. The age of separate intervals is estimated based on calculated average sedimentation rates in this sea area: 2.2 mm/year under continuous sedimentation [1].

The sediment samples taken with a step of 1–4 cm for the dinocyst analysis were treated in line with the procedure used at the A. Wegener Institute in Potsdam [9]. For determining concentrations of dinocysts, a tablet with a fixed quantity of *Lycopodium clavatum* spores was added into the preliminarily weighted sample at its initial treatment stage [9]. Microfossils were studied under the light microscope Zeiss Axiostar+ with magnification of 400. At least 100 cysts were identified in each sample. The defined correlations of the composition of dinocyst assemblages and their distribution in bottom sediments of the White Sea with the main hydrological parameters of the sea photic layer served as a methodological base for paleoreconstructions [9].

RESULTS

The dinocyst assemblage in the examined cores numbers 12 species and their groups (table) characteristic also of surface waters in the present-day White Sea [3, 9, 15]. The sum concentrations of dinocysts range from 500 to 85 000 cysts/g varying usually from 2000 to 3000 cysts/g of sediment (Fig. 1b). Their maximal contents are registered for the upper part of Core 4719 from Kandalaksha Bay corresponding to the period of 1980 to 2000.

For paleohydrological reconstructions, the identified species of dinocysts were divided into two main ecological groups (autotrophic and heterotrophic) in accordance with published data on the geographic dis-

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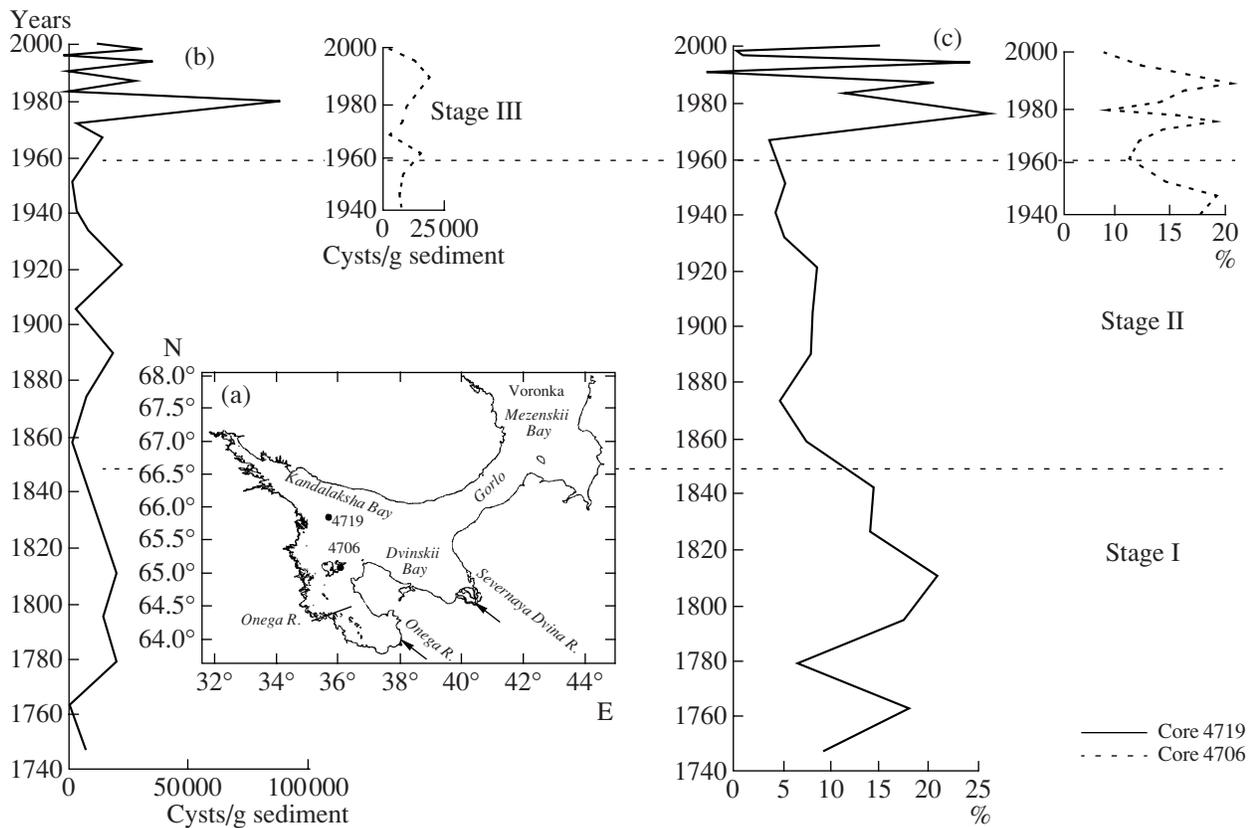


Fig. 1. The distribution of dinocysts in bottom sediment cores 4719 and 4706 from the White Sea and stages (I, II, and III) in glacial-hydrological development during the last 250 years: (a) location of examined cores; (b) changes in concentrations of dinocysts in cores; (c) changes in proportions of heterotrophic relatively cold-resistant dinoflagellate species in cores.

tribution of these species and their ecological tolerance [12] as well as with results of our previous studies in the White Sea (table, [9]). The autotrophic community consisting of five species is dominated by *Operculodinium centrocarpum*, which prevails also in Recent sediments of the White Sea [9]. In examined open areas of Kandalaksha and Onezhskii bays, its content varies from 70 to 95%, which is determined by minimal (0.2–0.5 mg/l) concentrations of suspended matter in waters and, correspondingly, favorable conditions for photosynthesis [9]. The occurrence of this species in dinocyst assemblages of the Arctic seas [7] is thought to be related to the distribution of warm Atlantic waters [10, 13]. In the examined cores, dinocysts of autotrophic species dominate and their integral share ranges from 75 to 95%.

The group of heterotrophic dinocysts is represented in both Recent and older examined sediments by species prevalent in the Arctic shelf seas (*Islandinium minutum* and close morphotypes *I. cesare*, *Echinidinium karaense*), which indicate significant duration of the ice cover (over six months annually) [10, 13]. In the present-day White Sea, the maximal content of heterotrophic dinoflagellate species (up to 47%) is distinctly confined to end areas of shallow bays with high

turbidity of waters that are strongly influenced by the Onega and Severnaya Dvina river discharge [9, 15].

The total content of heterotrophic species in both cores varies from 2 to 25% reaching maximal concentrations in the periods from 1760 to 1850 and from 1960 to 2000 (Fig. 1c).

The examined cores of bottom sediments were obtained from the open areas of the Kamdalakshskii and Onezhskii bays, where the influence of the river runoff is now insignificant [14]. Such a situation was also characteristic of the last 250 years. This is evident from practically complete lack of freshwater green algae in sediments, which reflect river runoff in the Arctic shelf seas [12]. The present-day hydrological situation in study areas is determined by the distribution of seasonally stratified White Sea waters with a low content of suspended matter [7, 14]. The average annual duration of the seasonal ice cover is approximately 6.5 months [8].

Based on established changes in the distribution of defined ecological groups of dinocysts and their abundances in sediments of the examined cores (4719 and 4706), three main stages are distinguished in development of glacial-hydrological conditions in the White

Composition of dinoflagellate cysts in sediments of cores 4719 and 4706 (White Sea), planktonic stages of cysts, and their ecological affinity

Planktonic stage of dinoflagellates	Dinocysts	Autotrophic species	Heterotrophic species
Gonualax digitalis (Pouchet) Kofoid	Bitectatodinium tepikiense Wilson	+	
Protoperidinium cf. avellanum (Meunier) Balech	Brigantedinium cariacense (Wall). Reid		+
Protoperidinium conicoides (Paulsen) Balech	Brigantedinium simplex (Wall). Reid		+
Protoperidiniaceae	Echinidinium karaense Head, Harland & Matthiessen		+
Protoperidiniaceae	Islandinium minutum Harland & Reid		+
Protoperidiniaceae	Islandinium? cezare de Vernal et al		+
Protoceratium reticulatum (Claparende & Lachmann) Diesing	Operculodinium centrocarpum Wall & Dale 1966	+	
Scrippsiella faeroense (Stein) Balech	Cysts of Pentapharsodinium dalei Indelicato & Loeblich	+	
Polykrikos sp. Kunz-Pirrung	Cysts of Polykrikos sp. Arctic morphotype Kunz-Pirrung		
Protoperidinium conicum (Gran) Balech	Selenopemphix quanta (Bradford) Matsuoka		+
Gonualax elongata (Reid) Ellegaard	Spiniferites elongatus Reid	+	
Gonualax spinifera (Claparende & Lachmann) Diesing	Spiniferites ramosus Mantell	+	

Sea during the last 250 years: 1740 to 1850 (I), 1850 to 1960 (II), and 1960 to 2000 (III).

I. The period of 1740 to 1850 (Core 4719, Solovetskie Islands, Fig. 1a) was characterized by a high share of polar and subpolar heterotrophic dinoflagellate species of the genus *Protoperidinium* (up to 23%, Fig. 1c) among dinocyst assemblages. This value exceeds significantly that in bottom sediments of the region, which indicates longer duration of the seasonal ice cover as compared with the present-day one. This period corresponds to the second half of the Little Ice Age that lasted in high latitudes of the Northern Hemisphere approximately from 1430 to 1850 [4, 5]. This entire epoch was marked by an increased distribution area of Arctic marine ice and from 1780 to 1820 the average annual air temperature over the North Atlantic (north of 50° N) being 1–3°C lower as compared to the present-day one [4, 5].

II. The subsequent stage of 1850 to 1960 was characterized by significant reduction of the seasonal ice cover, which is evident from the minimal (for the section of Core 4719) proportion of cold-water heterotrophic dinoflagellate species in their assemblages (Fig. 1c), which was lower as compared with the present-day one. The significant increase in the share of autotrophic species, primarily *Operculodinium centrocarpum* indicating the influx of Atlantic waters to the Arctic Ocean, might be explained by its increased vegetation period and growth of summer water temperatures.

In western Arctic seas and subarctic areas of the North Atlantic, the period under consideration was characterized by an unstable ice cover: Iceland waters were practically free of ice for 15 years after termination of the Little Ice Age [4, 5].

III. The period from 1960 until the present in the examined cores from the White Sea is marked by an increased share of cold-resistant heterotrophic dinoflagellate species in their assemblages (Fig. 1c). Significant repeated changes in both relative proportions of these species and abundance of dinocysts in sediments were likely determined by short-period climatic oscillations and fluctuations in glacial–hydrological conditions, which were established also in the neighboring Arctic area during the last decades of the last century [4, 5].

Thus, the analysis of the distribution of dinocysts in cores of bottom sediments from central areas of the White Sea reveals significant changes in glacial–hydrological conditions during the last 250 years. The defined stages in glacial–hydrological development of the sea (Figs. 1b, 1c) are generally synchronous with the known climatic and glacial–hydrological events in adjacent areas of the western Arctic and North Atlantic regions, which indicates the high potential of dinoflagellate analysis for study of the White Sea history.

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