Foraminiferal and dinocyst associations as indicators of the Holocene environmental changes at the Cambridge Strait, Franz Josef Land

E V Ivanova, E A Novichkova and D A Kozhanova
Shirshov Institute of Oceanology, Russian Academy of Sciences, 117997 Moscow, Russia

E-mail: e_v_ivanova@ocean.ru

Abstract. Herein we report the first decadal to centennial–scale resolution data on foraminiferal and dinocyst assemblages from core AMK-5454 collected in the hard-to-reach Cambridge Strait, Franz Josef Land, and on corresponding paleoenvironments over the last 9.2 ka. The dinocyst and foraminiferal assemblages from the core are rather diverse through the Holocene and represented by 24 and 33 taxa, respectively. The most active hydrodynamics and probably Atlantic Water (AW) inflow are suggested by the enhanced values of autotrophic dinocysts and epibenthic species, as well as Melonis barleeanus, from 9.2 to 6.3 cal ka BP. Specific benthic assemblages indicate high-productivity frontal conditions at site location from 6.3 to 4.1 cal ka BP. AW influx from the Franz Victoria Trough to the Cambridge Strait in subsurface to bottom layer, below the very cold Arctic Water and dense sea ice, is documented by enhanced \% Cassidulina teretis over the last 4.5 ka.

1. Introduction

The Cambridge Strait between the Prince George Land and Alexandra Land in the Franz Josef Archipelago (FJA), Eastern Barents Sea, is a glacial fjord with almost year-round sea ice conditions and poorly investigated surface and bottom environments. Today, a relatively warm subsurface Atlantic Water (AW) transporting heat to the Arctic along the Eurasian margin penetrates into the Barents Sea below the surface Arctic Water (ArW) through the troughs. The AW inflow to the Franz Victoria Trough westward of the FJA (figure 1) during the Holocene is reported by some authors [1−4]. However, little is known about the Cambridge Strait surface and bottom conditions. In this study, we investigate the associations of dinocysts (i.e., cysts of dinoflagellate algae living in the surface waters) and benthic foraminifers (inhabiting the sea floor or burrowing into the sediments) from the sediment core AMK-5454 (figure 1) in order to document changes in species diversity, composition and abundance, and to reconstruct surface and bottom paleoenvironments through the Holocene. Special attention is paid to the issue of whether the chilled AW penetrated into the Cambridge Strait at any time during the Holocene.

2. Material and Methods

The gravity core (80° 35.54′N, 47°41.53′E) and multi-core (80° 35.5′N, 47°42.13′E) AMK-5454
were collected from the deepest part of the strait at water depth 639 m during Cruise 67 of R/V Akademik Mstyslav Keldysh in 2016.

Figure 1. Overview map (a) of AW flow along the Barents Sea continental margin, and (b) studied core location in the Cambridge Strait. Surface currents from [5]: Atlantic Water, Arctic Water and coastal water are marked by red, blue and green arrows, respectively. FVT – Franz Victoria Trough.

2.1. Chronology and sedimentation rates
Thirteen AMS-\(^{14}\)C dates on mollusk and gastropod shells were obtained from core and multi-core AMK-5454 (table 1) and calibrated to calendar ages using the CALIB 7.1 software and Marine 13 calibration data set with a standard reservoir correction of 405 yr [6] and \(\Delta R\) of -124 \(\pm\) 22 yr accounting for local reservoir effect estimated in [7] for selected locations in the area. 12 dates were included in the combined (core and MUC) age-depth model, and one date (from 329 cm) was considered as outlier and excluded (table 1). The ages are given hereafter in cal ka BP (thousands of calendar years before AD 1950). The depth-age scale was estimated by a linear interpolated between the dates.

2.2. Foraminiferal study
Planktic foraminifers (PF) and benthic foraminifers (BF) were identified to a species level and counted from 63 washed and dried sample aliquots >0.1 mm from the core AMK-5454 as described in [8]. BF species percentages were calculated from the samples containing at least 100 specimens while rare PF occurrences prevented any quantitative assessment.
Table 1. AMS-14C dates and calibrated ages from core and multi-core (MUC) AMK-5454. The calibration is based on the CALIB 7.10 with Marine13 calibration curve [6] and Delta R = -124±22 [7]. The dates which are not used in the final depth-age model are indicated in italics. Lab codes: Poz – Poznań Radiocarbon Laboratory.

| Lab ID     | Sample depth | Dated material     | 14C date  | Calibrated age range ±1σ | Age, cal years BP (median probability) |
|------------|--------------|--------------------|-----------|--------------------------|---------------------------------------|
| Poz-102490 | MUC 9−10     | Bivalvia shell     | 575 ± 30  | 296−390                  | 349                                   |
| Poz-90975  | MUC 12−13    | mixed Bivalvia shells | 580 ± 30  | 300−395                  | 353                                   |
| Poz-102491 | MUC 20−21    | Bivalvia shell     | 795 ± 30  | 472−610                  | 524                                   |
| Poz-102492 | 68−69        | Bivalvia shell     | 1635 ± 30 | 1270−1339                | 1307                                  |
| Poz-90976  | 79−80        | Bivalvia shell     | 1690 ± 30 | 1303−1388                | 1353                                  |
| Poz-94843  | 101−102      | Bivalvia shell     | 2530 ± 30 | 2296−2388                | 2342                                  |
| Poz-94844  | 191−192      | Bivalvia shell     | 3030 ± 35 | 2867−2997                | 2939                                  |
| Poz-90977  | 225−226      | Bivalvia shell     | 3580 ± 35 | 3563−3678                | 3621                                  |
| Poz-90978  | 271−272      | Bivalvia shell     | 3955 ± 35 | 4060−4201                | 4119                                  |
| Poz-90979  | 305−306      | Gastropoda         | 6030 ± 40 | 6526−6649                | 6587                                  |
| Poz-97985  | 310−311      | Bivalvia shell     | 6160 ± 40 | 6668−6790                | 6739                                  |
| Poz-94845  | 329−330      | Bivalvia shell     | 13900 ± 1200 | 14,790−17,955 | 16,287                               |
| Poz-102493 | 337−338      | Bivalvia shell     | 7375 ± 30  | 7921−7995                | 7957                                  |

2.3. Dinocyst study
Marine dinoflagellate cysts (dinocysts) and other palynomorphs (freshwater green algae, acritarchs, foraminiferal linings, pollen and spores etc.) were treated from 36 samples using a standard palynological technique [9]. Generally, about 100–250 specimens were identified in each slide following the nomenclature provided in [10−12], except for 7 samples with low cyst number. To estimate river runoff, the CD criterion [13, 14] representing freshwater Chlorophyceae algae to marine dinocyst ratio [9] was applied. The AH criterion (a ratio of autotrophic to heterotrophic dinocyst species), commonly considered as an indicator of the North Atlantic water influx in the Arctic seas [9], was also used.

2.4. Total organic carbon
The total organic carbon (TOC) contents were measured by L. Demina using the express carbon analyzer AN 7529 (with a reproducibility of 0.005% of carbon).

3. Results and discussions
In core AMK-5454, the sediments are represented by homogeneous greenish olive gray clayey mud of various shades typical of the Holocene sediments in the Barents Sea [8] with TOC content ranging from 1 to 1.4% (figure 2). The constructed depth-age model shows that the core recovered the last ~ 9.2 ka, and the sedimentation rates varied significantly through time which is also characteristic of the Barents Sea fjords and troughs. Due to this variability, the time resolution for studied samples ranges from 40 to 460 years.

The downcore dinocyst concentrations vary considerably demonstrating the maximum values (up to 86 thous. cyst/g) during the last 4.3 cal ka BP (figure 2). Other palynomorphs are mainly represented by freshwater green algae (0–3.3 thous. specimens/g), acritarch (0–7.7 thous. specimens/g), remains of foraminiferal linings (up to 34.6 thous. specimens/g) and pollen & spores (up to 27.8 thous. specimens/g). Besides, a significant amount of reworked Mesozoic pollen grains (1.5–72.6 thous. pollen/g) is documented throughout the core.
In total, 24 taxa of dinoflagellate cysts typical of the Barents Sea today are identified in the core AMK-5454. The dinocyst assemblages are dominated by Islandinium minutum, Echinidinium karaense and Islandinium (?) cezare. In the Arctic seas, these heterotrophic cysts as well as Brigantedinium spp. species are associated with cold and strong sea-ice hydrological conditions [15]. In the Barents Sea, similar associations are found in or nearby the fjords of Novaya Zemlya affected by glacier meltwater [15]. The autotrophic dinocyst assemblages dominated by Operculodinium centrocarpum (and their morphotypes), Nematosphaeropsis labyrinthus, Spiniferites group, as well as by the cyst of Pentapharsodinium dalei are associated with reduced ice cover and relatively warm and saline surface waters [10, 12, 15–17].

In general, the dinocyst records from core AMK-5454 indicate cold conditions with dense sea ice during the last 9.2 kyr. However, the rare occurrences of the autotrophic species (O. centrocarpum, N. laburinthus, and Spiniferites group) might suggest an Atlantic influence and/or increased hydrodynamic activity in the Cambridge Straight from 9.2 to 6.3 cal. ka BP. The AH ratio 4.7 also reflects a dominance of relatively warm-water autotrophic species. At ~ 6.3 cal. ka BP, the CD ratio rises to 0.4 indicating the occurrence of green algae and freshwater acritarch Halodinium sp. in the Cambridge Strait.

The interval from 6.3 to 4.1 cal. ka BP is characterized by a sharp increase in dinocyst concentrations up to 51 thousand cysts/g. Heterotrophic species Echinidinium karaense and Islandinium minutum associated with cold ArW in the Barents Sea dominate in the associations.

During the last 4.1 cal. ka BP, short-term peaks in dinocyst concentrations up to 86 thous. cysts/g (maxima at 4, 2.4, 1.6 cal. ka BP) were alternated with periods of low values of 10−13 thous. cysts/g (minima at 2.7, 3.7 cal. ka BP). Relatively cold-water heterotrophic species prevailed in the dinocyst associations over this stage.

Benthic foraminifers are represented by 33 species, ranging 9−22 species per sample throughout the core. The typical Arctic taxa Elphidium clavatum, Cassidulina reniforme, Nonion labradoricum, Nonionellina auricula, Islandiella spp., Buccella spp. dominate the assemblages while the other species occur in lower numbers. An upward increase in percentage of the most opportunistic E. clavatum and decrease in % C. reniforme (figure 2) is typical of the Northern Barents Sea [3] and suggests an overall intensification of polar conditions with the dense sea ice cover till the last 500−300 years. In the early Holocene, the maximum abundance of an epibenthic Cibicides lobatus indicates active bottom-water environments. If an assumption on Melonis barleeanus association to the Atlantic-derived water [1] is true, a relatively high (up to 10%) faunal portion of the species might indicate an influx of chilled AW into the fjord at 9.2−8.5 cal ka BP. In the mid-Holocene, enhanced % N. labradoricum and N. auricula (up to 25) likely mirrors an increase in bioproductivity productivity [3, 18] due to frontal or polynya conditions. In the late Holocene, the Atlantic-affiliated Cassidulina teretis [2, 3] occurs in low numbers (up to 10%) providing an evidence of the AW influx to the Cambridge Strait since ~4.5 cal ka BP while variations in % Islandiella spp. and % Buccella spp. document a highly variable surface sea ice conditions and bioproductivity. The maximum % E. clavatum (up to 80) reports the most severe sea ice conditions from~ 1.3 to 0.4 cal ka BP.

Along with abundant BF rare subsurface dwelling planktic foraminifers, notably subpolar Neogloboquadrina pachyderma sin., as well as single specimens of boreal species N. pachyderma dex. и Turborotalita quinqueloba are found downcore. The findings of single specimens of warm-water species Globigerinoides sp. и Globigerina rubescens at ~2.4 cal ka BP is especially noteworthy. They might be transported to the strait by relatively small AW rings.

A persistent occurrence of C. teretis over the last 4.5 ka is consistent with the data from cores ASV-880 [4] and JPC5/PG5 [2] thus suggesting an AW influx to the Cambridge Strait from the west via the Franz Victoria Trough (figure 1, 2).
Figure 2. Downcore distribution of TOC, pollen & spore, acritarch, indicative benthic foraminiferal species, dinocyst and green algae paleoindicators (AH and CD ratio see in text) and concentration.
4. Conclusion
The dinocyst and foraminiferal assemblages from the AMS-\textsuperscript{14}C-dated core AMK-5454 provide the first detailed information on surface and bottom water conditions and corresponding biotic changes the Cambridge Strait over the last 9.2 ka. From 9.2 to 6.3 cal ka BP, surface and bottom water currents were more vigorous than later on. An Atlantic influence on the fjord surface and bottom water layer is suggested which needs further investigation. The high-productivity frontal conditions are reported by indicative benthic species from 6.3 to 4.1 cal ka BP. A subsurface to bottom AW influx from the Franz Victoria Trough to the Cambridge Strait below the very cold ArW and dense sea ice is documented over the last 4.5 ka.

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