LATE QUATERNARY CHANGES IN SEDIMENT COMPOSITION IN THE CENTRAL ARCTIC OCEAN: PRELIMINARY RESULTS OF THE ARCTIC ´91 EXPEDITION

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ABSTRACT

Preliminary results of detailed sedimentological investigations of late Quaternary sediments from the central Arctic Ocean indicate that distinct changes in depositional environment occurred through space and time. Sedimentation processes in the major Arctic Basins are mainly controlled by turbidity currents. Stratigraphic variations of biogenic and siliciclastic sediments on oceanic ridges and plateaus probably reflect glacial/interglacial changes in surface-water productivity, sea-ice cover, and/or oceanic circulation patterns. The reduced abundance of biogenic calcareous and siliceous components during oxygen-isotope-stage 2 (- 4?) suggests a decreased glacial productivity presumably due to a more continuous sea-ice cover. During the Holocene, productivity increased. In general, temporal increases in organic carbon contents are attributed to increased supply of terrigenous organic matter. Marine organic matter is present only in minor amounts throughout the sedimentary sequences, reflecting the low productivity of the central Arctic Ocean throughout the late Quaternary.

INTRODUCTION

The Arctic Ocean system holds the key for understanding the global climate system of the past and predicting the possible changes of the world´s future climate (for overviews, see ARCSS Workshop Steering Committee, 1990; NAD Science Committee, 1992; and further references therein). Comprehensive summaries about the present knowledge on Arctic Ocean geology, paleoceanography, and paleoclimate are published in Herman (1989), Bleil and Thiede (1990), and Grantz et al. (1990). In order to extend this knowledge and to study the paleoclimatic history of the Arctic Ocean region, the international and multidisciplinary ARCTIC ´91 Expedition was carried out into the east-central Arctic Ocean (Fig.1; Anderson and Carlsson, 1991; Fütterer, 1992). The main goal of the ARCTIC ´91 marine geology program is the reconstruction of the long-term as well as short-term glacial/interglacial changes in the lithogenic and biogenic sediment supply and deposition in relation to changes in global climate, paleoceanic circulation, sea-ice cover, and paleoproductivity. In this context, we present preliminary

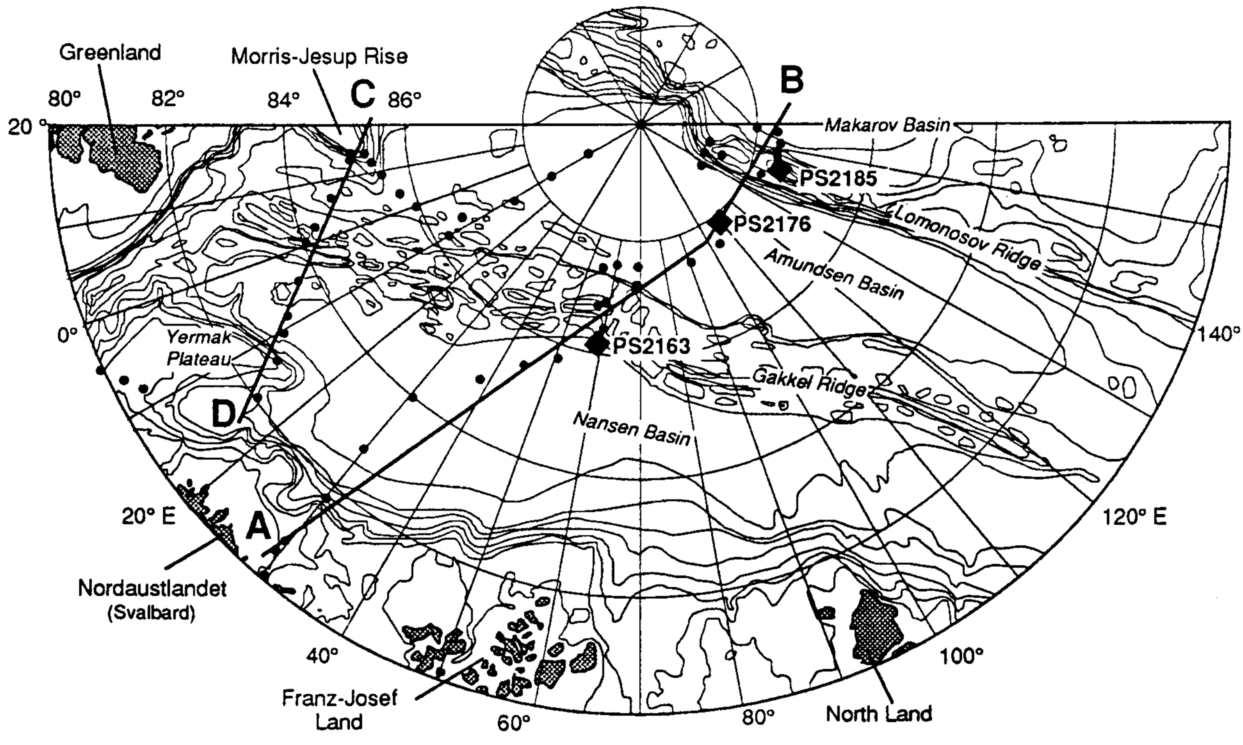

Fig.1. Position of ARCTIC ´91 geological stations with profiles A-B and C-D (cf. Fig.2). Position of cores PS2163, PS2176, and PS2185 are marked by asterisks (cf. Figs.3 and 4).

interpretations of the shipboard core description, analyses of smear slides and coarse fraction, and shorebased measurements of carbonate and total organic carbon. Further results including stable isotope and clay mineral data will be published in more comprehensive papers elsewhere (Stein et al., 1994a,b).

Methods of Shipboard and Shorebased Studies

To reach the above objectives of the ARCTIC ´91 Expedition, a comprehensive geological sampling program was performed at 60 stations, and unique, undisturbed near-surface and long-sediment core samples were obtained from major basins, ridges, and plateaus of the eastern Arctic Ocean (Fig.1). Most of the sediment cores were opened, described, and sampled onboard the RV *Polarstern*. Furthermore, first microscopic investigations of smear slides and coarse fractions and determinations of physical properties (water content, porosity, wet bulk density, and acoustic compressional wave velocity), magnetic susceptibility, and calcareous nannofossil abundances also were performed during the cruise. This allowed a preliminary description and interpretation of the depositional environment and its change through time and space. Details of the results obtained by the Shipboard Scientific Party during the ARCTIC ´91 Expedition are described in Fütterer (1992).

For our high-resolution study on stable isotope composition, organic geochemistry, and bulk and clay mineralogy, multicorer and kastenlot cores were sampled in detail. Total carbon and organic carbon contents were measured on ground bulk samples and HCl-treated carbonate-free samples, respectively, using an elemental CHN analyser. The accuracy of the method is 0.02-percent carbon absolute, as checked with standard and double measurments. Carbonate contents were calculated using the formula

(total carbon - total organic carbon) $*$ 8.333.

To obtain information on the possible source of organic matter (Tissot and Welte, 1984), hydrogen index (HI) values were determined on the ground bulk samples with a Rock-Eval-pyrolysis instrument. The chronostratigraphic framework is based on AMS ^{14}C dating and oxygen stable isotope and carbonate data. Further detailed description of the methods will be published elsewhere (Stein et al., 1994a,b).

RESULTS

Figures 2 though 4 present the first results of the investigation of ARCTIC ´91 sediments from the Barents Sea-Nansen Basin-Gakkel Ridge-Amundsen Basin-Lomonosov Ridge-Makarov Basin profile and the Morris Jesup Rise-Amundsen Basin-Gakkel Ridge-Nansen Basin-Yermak Plateau profile (Fig.1, A-B and C-D).

Core-Description, Smear-Slide, and Coarse-Fraction Data

Prominent changes in composition, texture, color, and grain size occur in the late Quaternary sediment sequences from different locations (cf. Fütterer, 1992). In general, sediments from deep-sea basins of the study area are characterized by fine-grained siliciclastic components with some fining-upwards sequences, silt/clay alternations, and occasional cross-bedding. Gray to dark gray sediments (colors according to the GSA Munsell Color Chart) dominate. Sediments from the oceanic ridges and plateaus display distinct cyclic changes in color, grain size, and sediment composition. Dark brown, brown, and beige colors, with occasional intercalation of gray intervals, are typical in the latter areas.

At almost all locations in the basins and on the ridges, the upper 40 cm of the sedimentary sequences can be divided into two different lithologies (Fütterer, 1992). The uppermost 5- to 15-cm-thick (depending on the sedimentation rate) sediments are characterized by dark brown to brown clay with rare occurrence of nannofossils and a coarse fraction dominated by planktonic foraminifera. In this section, benthic foraminifera and biogenic opal (mainly sponge spicules) only occur in minor amounts in the coarse fraction. At shallower ridge and plateau positions, bivalves, ostracodes, and echinoderms may additionally occur. The 15- to 40-cm-thick sequence underlying the surficial section generally consists of olive-gray to grayish-brown clay/silty clay with no nannofossils. In the coarse fraction, high amounts of quartz and rock fragments are typical, and biogenic components such as planktonic foraminifera are present in very minor amounts. Some of the siliciclastic particles are very coarse-grained ($>>1$ mm). At the Gakkel Ridge (Core PS2163-3, Fig.3), the two lithological units are underlain by a third unit that is similar to the uppermost one.

Carbonate and Total Organic Carbon

In the surface sediments (Fig.2), carbonate contents are relatively low, ranging from 0 to 17 percent, with higher values more typical for the oceanic ridges and lower values more typical for the basins. At the Morris Jesup Rise, carbonate values increase to almost 30 percent. In general, the coarse-grained carbonate is biogenic (i.e., foraminifers, ostracodes, bivalves, nannofossils). Only in the Morris Jesup Rise area, significant amounts of detrital carbonate (calcite and dolomite) occur (Vogt and Stein, in prep.).

In the sediment cores, maximum carbonate values generally are recorded in the uppermost part of the Holocene sequences, whereas the underlying grayish unit corresponding to the pre-Holocene to glacial stage 2 (-4?) interval, generally has significantly lower carbonate

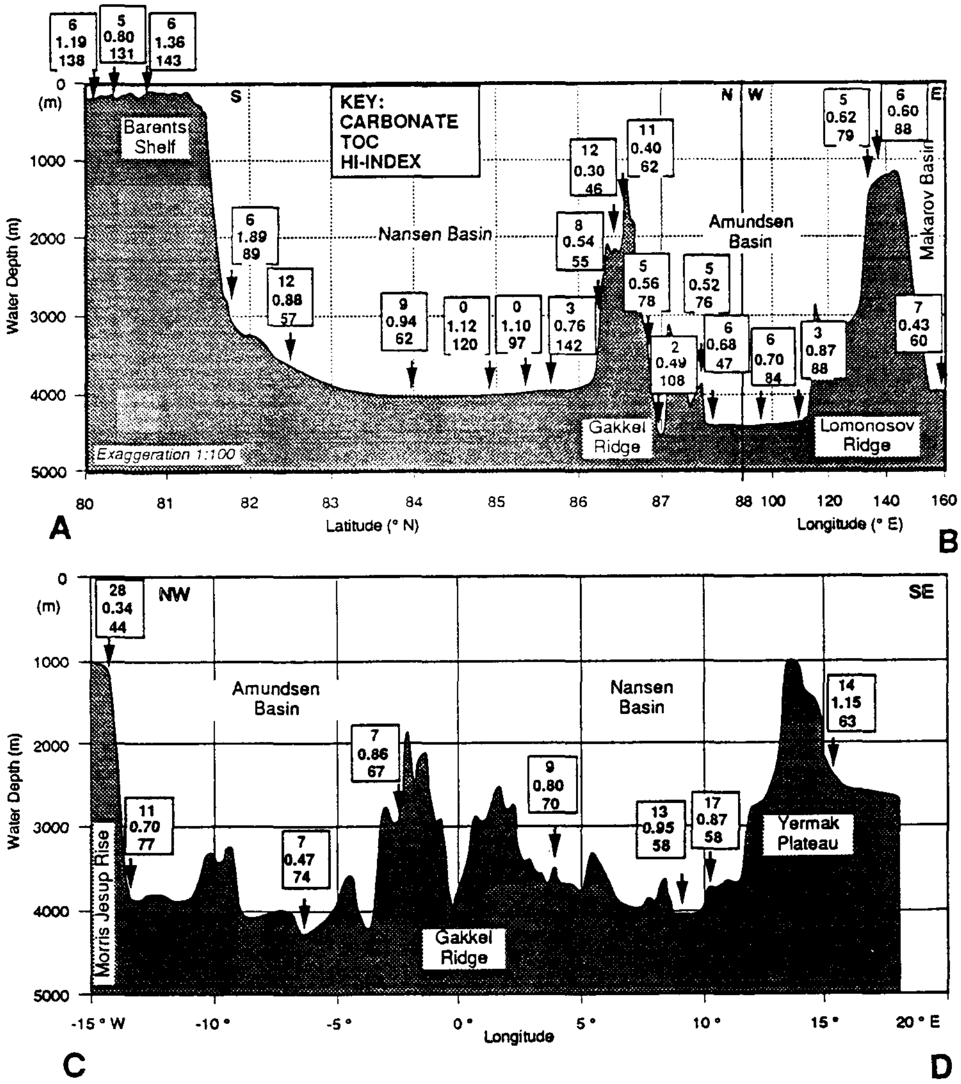

Fig.2. Profiles A-B and C-D (see Fig.1 for position) with carbonate and total organic carbon (TOC) contents (%) and hydrogen index (HI) values (mgHC/gC). See Fig.3 for further explanations.

contents (Figs.3 and 4; Stein et al., 1994b). Carbonate contents may again increase during isotope stage 3 (or 5?) (Fig.3).

In the long kastenlot cores from the Lomonosov Ridge as well as the Amundsen Basin, carbonate contents generally are <1 percent (Fig.4). The few intervals with higher carbonate values presumably correspond to interglacial stages, as proven, for example, for the carbonate maxima in the uppermost interval and between about 200 and 230 cm below seafloor (cmbsf) in Core PS2185-6. These carbonate peaks correlate with oxygen isotope stages 1 and 5, respectively, as indicated by stable isotope (Stein and Spielhagen, unpubl. data) and nannofossil (Gard, 1993) stratigraphies.

In general, total organic carbon (TOC) contents in surface sediments are higher in the basins (0.7-1.1 %) than on the ridges and plateaus (0.3-0.6 %) (Fig.2). Maximum values of 1.2 to 1.9 percent are at the Barents Sea Continental Margin and the Yermak Plateau, and hydrogen index values of <100 mgHC/gC are dominant there. Only in the Barents Sea Continental Margin area and in two samples from the deep Nansen Basin, HI values of 120 to 200 mgHC/gC were measured (Fig.2; Stein et al., 1994a). In the multicorer cores, TOC increases from low values around 0.2 percent in the lower part to values of 0.5 to 0.7 percent in the uppermost 5 to 10 cm (Fig.3; Stein et al., 1994b). This increase partly coincides with increasing carbonate values and corresponds to the Pleistocene/Holocene transition. In Core PS2163-3 from the Gakkel Ridge, HI values are mainly <100 mgHC/gC during oxygen isotope stages 1 and 3 (?), whereas in stage 2 higher HI values of 150 to 200 mgHC/gC are typical (Fig.3).

The two long-term sedimentary records presented in Figure 4 show distinct regional and/or environmental differences. The TOC record at the Lomonosov Ridge (Core PS2185-6) is characterized by generally very low values of 0.1 to 0.3 percent (only the Holocene interval displays higher values of up to 0.6 percent), whereas high TOC values of 0.5 to 1.5 percent are typical for the Amundsen Basin (Core PS2176-3; Fig.4). Maximum values around 1.5 percent are concentrated in the lower 4.5 m of the record. At Core PS2185, HI values generally are between 100 and 300 mgHC/gC. At Core

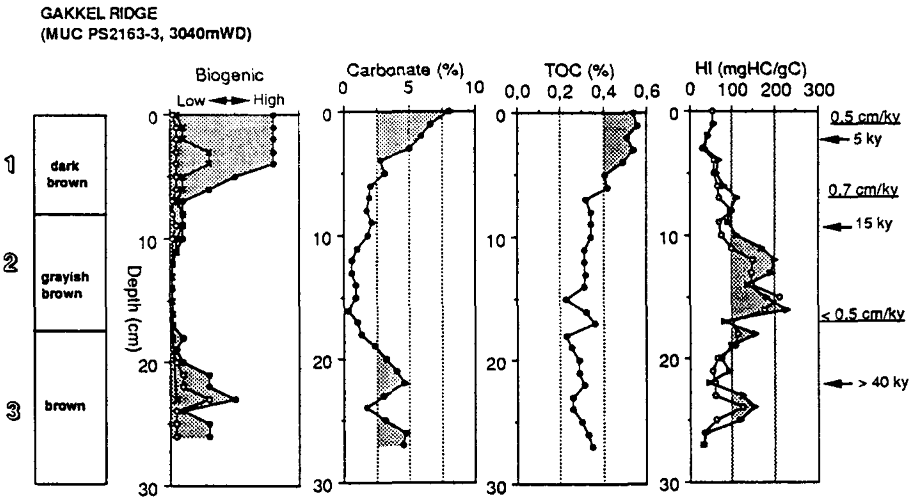

Fig.3. Data of Core PS2163-3 at the Gakkel Ridge: Composition of biogenic coarse fraction (solid dots: planktonic foraminifera; open dots: benthic foraminifera; crosses: biogenic opal), as based on rough smear-slide estimates performed onboard POLARSTERN; carbonate and total organic carbon contents; and HI values (mgHC/gC). Because of the low TOC values, HI values have been determined twice (open circles and solid triangles). High HI values of > >100 mg hydrocarbon / g organic carbon (mgHC/gC) suggest significant quantities of marine organic matter whereas HI values <100 mgHC/gC indicate a terrigenous source of the organic matter (cf., Tissot and Welte, 1984). HI values from the organic-carbon-poor (<0.4 %) intervals, however, have to be interpreted with caution. Lithologic units 1, 2, and 3 approximately correspond to oxygen stable isotope stages 1, 2 (or 2-4?), and 3 (or 5?), respectively. Absolute ages (ky BP) and sedimentation rates (cm/ky) are based on AMS ^{14}C dating (Stein et al., 1994b).

PS2176, most of the HI values are around 50; higher values of 150 to 400 mgHC/gC occur only between 420 and 600 mgHC/gC (Fig.4).

DISCUSSION AND CONCLUSIONS

Late Quaternary Geochronology in the Central Arctic Ocean

For a detailed paleoenvironmental interpretation of the sedimentological and geochemical data of the ARCTIC ´91 material and its change through time, a precise chronostratigraphy is necessary. For the Holocene to late Weichselian interval, AMS ^{14}C datings and isotope records are available (Stein et al., 1994b; Fig.3), whereas for the older sedimentary sections, isotope-, bio-, and magneto-stratigraphy are used (Gard, 1993; Cronin et al., 1994; Nowaczyck et al., 1994; Stein and Spielhagen, unpubl. data). The generally very low carbonate content of the central Arctic Ocean sediments, however, makes it difficult to establish a stratigraphic framework. Dating problems especially occur in the almost carbonate-free basin cores (such as, for example, Core PS2176-3; Fig. 4). At the Lomonosov Ridge Core PS2185-6, it was at least possible to establish an oxygen stable isotope stratigraphy on planktonic foraminifera *Neogloboquadrina pachyderma sin.* for the upper 5 m probably representing oxygen isotope stages 1 to 7 (Stein and Spielhagen, unpubl.). Below 5 m, however, the number counts of planktonic foraminifera *N. pachyderma sin.* are too low for isotope measurements. Other dating techniques (e.g., ^{230}Th and ^{10}Be; Bohrmann, 1991) may help to better establish time controls in the future (Eisenhauer and Mangini, in prep.). At the present time, precise reconstructions of the late Quaternary depositional history in the central Arctic Ocean (except for the last 30 kyBP) is therefore still quite constrained.

Surface Sediment Characteristics and the Modern Environment

Due to an extended sea-ice cover, the modern central Arctic Ocean is a low primary-productivity environment (Subba Rao and Platt, 1984), resulting in a very low flux of marine organic matter to the ocean floor. Despite this low carbon flux, TOC contents of surface sediments reach values of more than 1 percent (Fig.2), which is significantly higher than values from the modern ice-free open-ocean environment (about 0.3 %; McIver, 1975). This as well as the increase of organic carbon with increasing water depth (Fig.2) (a correlation that is just the opposite of that recorded in normal marine pelagic environments, e.g., Suess, 1980) suggests that factors other than primary productivity must have caused the enrichment of organic matter. In the central Arctic Ocean, the relatively high organic carbon contents

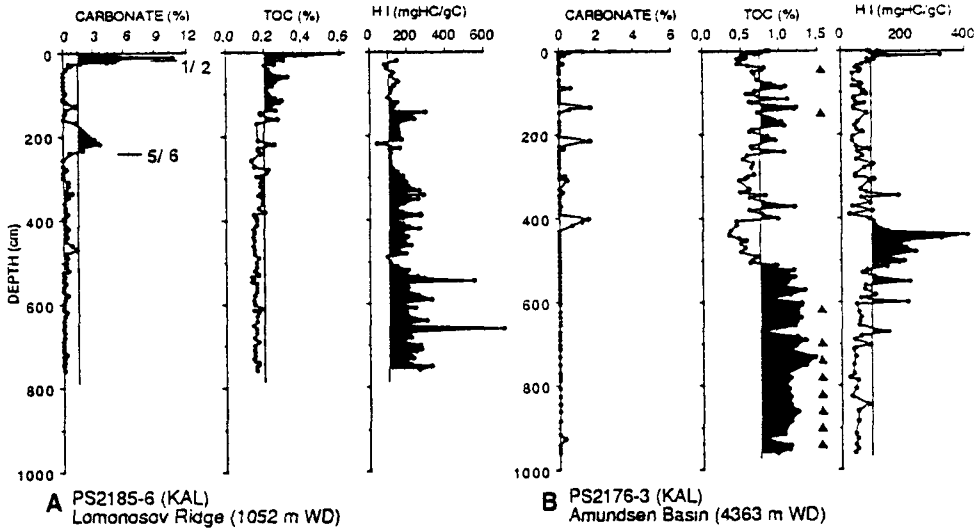

Fig.4. Carbonate and total organic carbon records and HI values (mgHC/gC) of Lomonosov Ridge Core PS2185-6 (A) and Amundsen Basin Core PS2176-3 (B). Oxygen stable isotope stage boundaries 1/2 and 5/6 in Core PS2185-6 are based on an oxygen stable isotope record determined on planktonic foraminifera *N. pachyderma sin.* (Stein and Spielhagen, unpubl.). Solid triangles mark occurrence of turbidites at Core PS2176-3. For HI values see also Fig.3.

probably are the result of increased supply of terrigenous organic matter, as suggested from low hydrogen-index values (Fig.2) and high carbon/nitrogen ratios (Stein et al., 1994a). Part of this terrigenous material is very likely derived from the Eurasian shelf areas and transported by sea ice via the Transpolar Drift, the dominant surface-current system in the eastern central Arctic Ocean (e.g., Pfirman et al., 1989; Bischof et al., 1990). The occurrence of significant amounts of displaced, shallow-water benthic foraminifera on the Lomonosov Ridge supports possible sea-ice transport of coarse-grained material from shallow-water environments (J. Wollenburg, pers. commun., 1993). In the central Nansen Basin, high TOC values also occur within turbidites (Stein et al., 1994a).

The maximum TOC values close to the Barents Sea Continental Margin correspond to high hydrogen indices (Fig.2). This indicates increased contents of marine organic matter, probably reflecting an increased surface-water productivity controlled by the inflow of warm Atlantic waters and/or increased nutrient availability at the ice edge (Stein et al., 1994a).

Late Quaternary Changes in Depositional Environment

The late Quaternary sediments from the Nansen and Amundsen Basins commonly consist of fine-grained siliciclastic components, with grading-upwards sequences and occasional silt/clay alternations (Fütterer, 1992). These deposits are interpreted as distal turbidites. In several cases, the surrounding Eurasian shelf edges are probably the source area of these sediments as suggested from the associated shallow-water benthic foraminifera and bivalves. This is consistent with some of the turbidites characterized by high terrigenous organic carbon contents (1.1 to 1.5 %) and HI values around 100 mgHC/gC (Fig.4).

On the other hand, the (hemi-) pelagic sediments from the oceanic ridges and plateaus are characterized by (cyclic) changes in color and sedimentary facies (Fütterer, 1992). The differences in biogenic and siliciclastic sediment composition suggest major paleoenvironmental changes in the central Arctic Ocean during (glacial/interglacial) Quaternary times. These changes could be changes in surface-water productivity, sea-ice cover, and mode of transport of sediments via sea ice or ocean currents. The common presence of planktonic foraminifers as well as coccoliths (Gard, 1993) in near-surface sediments and between 200 and 230 cmbsf in Core PS2185-6, suggests increased carbonate productivity during interglacial stages 1 and 5 when probably at least seasonal open-ice conditions prevailed (Fig.4). Very low organic carbon and carbonate contents in the pelagic sedimentary sequence from the Lomonosov Ridge, however, indicate, with the exception during stage 5, generally low productivity throughout the late Quaternary. The interpretation of the carbonate records in terms of productivity changes appears to be realistic because changes in carbonate dissolution can be neglected. This has been shown by carbonate dissolution studies on planktonic foraminifera from the Nansen Basin and Gakkel Ridge areas across the glacial/interglacial transition (Pagels, 1991).

Because of a more precise stratigraphic time control within the upper 40 cm of the cores, a somewhat more detailed interpretation of the depositional history is possible. Based on AMS ^{14}C dating and stable isotope and carbonate stratigraphy (Stein et al., 1994b) as well as nannofossil abundances (Gard, 1993), the upper 40 cm of the core probably represent the late Weichselian and Holocene (i.e., mainly oxygen isotope stages 1 and 2). As shown in Figure 3, the glacial interval is characterized by low contents of carbonate, organic carbon, and biogenic coarse fraction (i.e., planktonic and benthic foraminifera, ostracodes, and biogenic opal). The coarse fraction is dominated by quartz grains. Furthermore, calcareous nannofossils are absent in this interval (Gard, 1993). The low abundance of biogenic calcareous components and biogenic opal during the pre-Holocene (stage 2?) probably indicate a reduced glacial productivity due to an extented sea-ice cover. In contrast, within the Holocene, all major biogenic components and carbonate contents distinctly increase, indicating increased productivity. Increased Holocene productivity is also suggested from ostracode assemblages (Cronin et al., 1994).

Although the increase in biogenic components towards the Holocene is paralleled by an increase in organic carbon, the latter is probably not a productivity signal, because hydrogen-index values are low, indicating that major proportions of the organic matter are of terrigenous origin. Nevertheless, the flux of marine organic matter might have been increased during the Holocene. But due to the oxic deep-water conditions (inferred from the homogenous brown sediments) and low sedimentation rates of about 0.5 cm/ky (Fig.3), almost nothing of the marine organic material is preserved in the sediments. On the other hand, during stage 2 (?) the marine organic carbon production probably was significantly reduced due to the extended sea-ice cover. Nevertheless, some quantities of marine organic matter seem to be preserved as suggested from the increased hydrogen index values. This increased preservation of hydrogen-rich organic matter during the last glacial interval may have been caused by a reduced ventilation of deep-water masses, which probably is reflected in the olive-gray to grayish colors of glacial sediments and the absence of benthic foraminifera. Because of the low TOC content, however, the interpretation of the hydrogen index values is still preliminary. We suggest that a more detailed organic geochemical study using gaschromatography and kerogen microscopy will help to resolve some of the enigma (Schubert and Stein, in prep.). The change from olive-gray and grayish-brown late Weichselian to dark brown to brown Holocene sediments probably suggests progressively increased oxygenation of deep waters from glacial to interglacial. This is supported by a distinct change in ostracode assemblages, which is also explained by increased inflow of well-oxygenated Atlantic water masses near the stage 1/2 transition (Cronin et al., 1994).

Finally, it should be mentioned that more precise paleoenvironmental interpretations of the ARCTIC '91 core records will have to wait until a detailed data base is established on absolute ages, stratigraphy, organic and inorganic geochemistry, paleontology, and sedimentology. Plans call for generating these data under the auspices of major international multidisciplinary projects.

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