UNIVERSITÉ DU QUÉBEC À MONTRÉAL

POSTGLACIAL PALEOCEANOGRAPHY OF CENTRAL BAFFIN BAY FROM PALYNOLOGICAL TRACERS

THESIS

PRESENTED

IN PARTIAL REQUIREMENT

OF THE MASTERS IN EARTH SCIENCES

OF

SARAH STEINHAUER

FEBRUARY 2012

UNIVERSITÉ DU QUÉBEC À MONTRÉAL
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UNIVERSITÉ DU QUÉBEC À MONTRÉAL

PALÉOCÉANOGRAPHIE POSTGLACIAIRE DU CENTRE DE LA BAIE DE BAFFIN À PARTIR DE TRACEURS PALYNOLOGIQUES

MÉMOIRE

PRÉSENTÉ

COMME EXIGENCE PARTIELLE

DE LA MAÎTRISE EN SCIENCES DE LA TERRE

PAR

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FÉVRIER 2012

AVANT-PROPOS

Ce mémoire de maîtrise est présenté sous la forme d'un article scientifique qui sera soumis à la revue *Marine Micropaleontology*. Par conséquent, la mise en forme ainsi que l'utilisation de la langue anglaise respectent les exigences de *Marine Micropaleontology* et non celles de l'Université du Québec à Montréal.

REMERCIEMENTS

Je remercie ma directrice de recherche Mme Anne de Vernal pour son accueil au sein de son laboratoire ainsi que pour ses encouragements tout au long de ma maîtrise. Un grand merci également à tout le personnel du GEOTOP et surtout à l'équipe du laboratoire de micropaléontologie pour leur aide ainsi qu'à mon co-directeur M. Claude Hillaire-Marcel. Un énorme merci à Lisa, Carolyne, Nouha et Sophie pour leur soutien sans faille. Et enfin, un merci particulier à mes parents et ma soeur pour leurs encouragements et soutien à distance, sans lesquels ce travail n'aurait peut-être pas abouti.

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RÉSUMÉ

Deux carottes sédimentaires de la partie centrale de la baie de Baffin (HU2008029-14B et -16TWC ; 70.46°N 64.66°W; ~ 2060 m) ont été échantillonnées afin de reconstituer les conditions hydroclimatiques holocènes à partir de l'analyse des assemblages de dinokystes. Des mesures ^{14}C sur des carbonates biogéniques et des analyses de ^{210}Pb sur le sédiment révèlent de très faibles vitesses de sédimentation, inférieures à 4,5 cm/ka. Un changement dans les assemblages de dinokystes est enregistré à 16 cm dans la carotte 16TWC, ce qui correspondrait à la fin de l'Holocène moyen, i.e. vers 4000 ans BP, si on postule des vitesses de sédimentation uniformes au cours de l'Holocène. La transition est marquée par une diminution de pourcentage du taxon polaire *Impagidinium pallidum* et par l'augmentation des proportions du taxon ubiquiste *Operculodinium centrocarpum.* Elle correspondrait à un réchauffement des eaux de surface que l'on associe à une pénétration plus importante des eaux nord-atlantiques via le courant ouest groenlandais. Les reconstitutions quantitatives des conditions de surface avec la technique des meilleurs analogues indiquent des conditions optimales, plus chaudes que l'actuel avec un couvert de glace moins étendu pendant la plus grande partie de l'Holocène supérieur. De tels résultats sont compatibles avec l'hypothèse d'une opposition des changements océanographiques dans le nord-ouest de l'Atlantique Nord par rapport à ceux du secteur nord-est. Les données suggèrent également des changements récents dans la baie de Baffin qui semble être extrêmement sensible vis-à-vis des variations hydroclimatiques liées aux courants de la Terre de Baffin et ouest groenlandais.

Mots-clés : Holocène, baie de Baffin, dinokystes, paléocéanographie

INTRODUCTION GÉNÉRALE

L'objectif des travaux de recherche entrepris dans le cadre de ma maîtrise était d'améliorer la résolution des enregistrements des variations hydroclimatiques au cours de l'Holocène par rapport aux études antérieures menées dans cette région. Pour ce faire, ont été étudiés les sédiments de carottes prélevées lors de la mission du NGCC-*Hudson* en 2008 (Campbell et al., 2008). Il s'agit des carottes-boîtes HU2008-029-014BC (14BC dans le texte; 70.46°N 64.66°W, profondeur d'eau : 2060 m) et par gravité HU2008-029-016TWC (16TWC dans le texte ; 70.46°N 64.66°W, profondeur d'eau : 2063 m).

Située entre le Groenland et les Territoires du Nord canadien, la baie de Baffin est une zone de convergence entre les masses d'eau issues de l'Arctique et de l'Atlantique (Fig.1). Il est donc important de retracer les variations hydrographiques de la baie de Baffin car cela donne des informations sur l'historique des échanges entre ces deux océans. Des études ont été menées sur la paléocéanographie de cette région dans les années 1970 et 1980, notamment dans le cadre de la thèse de Aksu (1981) et suite à une expédition de l'*Ocean Drilling Program* (ODP; Arthur et al., 1985; Hillaire-Marcel et al., 1989). Toutefois, ces études n'ont pas livré de résultats probants en ce qui concerne les variations paléocéanographiques à l'Holocène. D'une part, le sous-échantillonnage des carottes étudiées a été fait selon un intervalle très large (tous les 10 à 20 cm dans la carotte HU85-027-016PC située à proximité du site d'étude; Figure 1) ce qui se traduit par une faible résolution chronologique des séries holocènes. D'autre part, les assemblages microfossiles dans cette partie de la baie de Baffin sont pauvres, notamment en raison d'une dissolution du carbonate de calcium et de la silice biogéniques (e g., Aksu, 1983). Par conséquent, l'amélioration des techniques d'analyse depuis les années 1980, et surtout une maille d'échantillonnage plus serrée, permettent d'espérer de meilleurs résultats.

Concrètement, la baie de Baffin est caractérisée par la rencontre des eaux froides et peu salées de l'Arctique entrant par le Nord (détroits de Smith, Jones et Lancaster) et longeant l'est de l'Ile de Baffin avec des eaux plus chaudes et salées provenant de l'Atlantique Nord. Celles-ci sont véhiculées du Sud vers le Nord de la baie par le courant ouest groenlandais. Ces deux masses d'eau forment une gyre cyclonique. La baie de Baffin est formée de trois masses d'eau distinctes sous une mince couche de surface d'environ 20 mètres qui enregistre d'importantes variations saisonnières. La couche supérieure s'étend de 20 à environ 200 mètres de profondeur, est très froide (-1,7°C) et serait originaire de l'Arctique. La couche intermédiaire est formée d'eau provenant de l'Atlantique et sa température atteint près de 2°C. Enfin, la couche profonde se caractérise par une température décroissante avec la profondeur qui peut atteindre un minimum de -0,4°C. Le couvert de glace de la baie de Baffin est à son maximum en mars et minimum en septembre. Au cours des 50 dernières années, le couvert de glace annuel moyen (concentration >50%) a été de 9 mois/an (NSIDC).

Les reconstitutions hydrographiques de surface (température, salinité, couvert de glace, productivité) sont effectuées à partir des assemblages de kystes de dinoflagellés ou dinokystes. Les dinokystes qui sont constitués de matière organique réfractaire se fossilisent dans les sédiments marins. Ils forment des assemblages caractérisés par une diversité taxonomique élevée dans les milieux de hautes latitudes (de Vernal et al., 1994, 2001). Les reconstitutions ont été effectuées à partir de la technique des meilleurs analogues modernes (MAT) (de Vernal et al., 2005). On aurait souhaité utiliser d'autres traceurs que les dinokystes. Toutefois, dans le contexte interglaciaire des milieux profonds de la baie de Baffin, une dissolution totale de la silice et des carbonates biogéniques limite la portée de la plupart des autres approches micropaléontologiques.

CHAPITRE 1

POSTGLACIAL PALEOCEANOGRAPHY OF CENTRAL BAFFIN BAY: PALYNOLOGICAL EVIDENCE

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Abstract

Two sediment cores from central Baffin Bay (HU2008029-014BC and -016TWC; 70.46°N 64.66°W, ~ 2060 m) were analysed in order to reconstruct variations in hydroclimatic conditions during the Holocene based on dinocyst assemblages. Measurements of ^{14}C in biogenic carbonate and ^{210}Pb data from the top 12 cm of sediment suggest very low sedimentation rates during the Holocene (< 4.5 cm/ky). An important change in dinocyst assemblages is recorded at 16 cm in core 16TWC, which corresponds to about 4000 cal years BP assuming constant sedimentation rates throughout the Holocene. The change is marked by a decrease in the relative abundances of the polar taxa *Impagidinium pallidum* relative to an increase of the ubiquitous taxa *Operculodinium centrocarpum.* This suggests warming of surface waters in response to enhanced contribution of the Atlantic waters flowing northward through the West Greenland Current. The quantitative reconstruction of sea-surface conditions from the modern analogue technique (MAT) indicates optimal conditions during the late Holocene, with summer sea-surface temperatures higher than today. The overall results are compatible with the hypothesis of opposite pattern of changes in the northwest vs. northeast North Atlantic. These data suggest that Baffin Bay sea-surface conditions are extremely sensitive to hydroclimatic variations linked to the Baffin Land Current and the West Greenland Current.

Keywords : Holocene, Baffin Bay, dinocyst, paleoceanography

1 Introduction

Baffin Bay is a large transitional basin that extends from the Arctic to the North Atlantic Ocean. It is also a discharge basin for ice, meltwater and sediment from the Innuitian and Greenland ice sheets. Freshwater, meltwater, and sea-ice flowing from the Arctic through Baffin Bay and Davis Strait control sea-surface salinity and temperature in the Labrador Sea, thus playing a determinant role on water mass stratification and intermediate to deep water formation (e.g., Rudels, 1986).

Several studies conducted in Baffin Bay have documented environmental changes that occurred during the Holocene. These studies include using proxies such as diatoms, benthic foraminifera and dinocysts (Levac et al., 2001; Hamel et al., 2002; Knudsen et al., 2008; Seidenkrantz et al., 2008; de Vernal, 1986; de Vernal and Hillaire-Marcel, 1987). However, most of these studies were performed in northernmost Baffin Bay or in the nearshore Disko Bugt area along the western Greenland coast, which are sites above the lysoclineand characterized by relatively high sedimentation rates. At these sites, the records mainly relate to local changes in environmental conditions. Hence, they cannot provide an integrated picture of the oceanographical conditions in Baffin Bay and do not permit assessments on freshwater export towards Labrador Sea. Central Baffin Bay would be a more suitable location for obtaining a regional picture of past oceanic changes in a major transitional basin. However calcium carbonate dissolution characterizes surface and Holocene sediments (Aksu, 1983; de Vernal et al., 1992), which makes it difficult to establish a chronostratigraphy. Moreover, the absence of calcareous and siliceous microfossils due to both carbonate and silica dissolution (Aksu, 1983) prevent the use of diatoms and foraminifers. By using dinocyst that are composed of highly resistant organic matter and usually very well preserved in marine sediments including those of Baffin Bay (de Vernal et al., 1987; de Vernal and Mudie, 1989), we aim to reconstruct the sea-surface conditions (temperature, salinity, sea-ice cover and productivity) during the Holocene. Here we report on palynological assemblages analysed in core HU2008029-016TWC, which were collected during the expedition HU2008029 of the CCGS *Hudson* near the Ocean Drilling Program (ODP) Site 645 (Arthur et al., 1985) and the site survey core HU85-027-016PC (70.27°N 64.39°W; Hillaire-Marcel et al., 1989; de Vernal et al., 1989; de Vernal, 1986; de Vernal and Hillaire-Marcel, 1987).

2 Oceanic settings

The surface circulation in Baffin Bay forms a counter-clockwise gyre consisting of two main components (Figure 1): (1) the West Greenland Current (WGC) which flows northwest along the west coast of Greenland to Nares Strait in summer but is diverted westward into Davis Strait in winter, (2) the Baffin Land Current (BLC) which is fed by water masses from the Arctic Ocean through Smith, Jones and Lancaster Sounds and flows southward along the east coast of Baffin Island (Rudels, 1986).

Baffin Bay is composed of three different water masses below a thin (approx. 20 meters) and low salinity (<33) layer that records large seasonal variations from 5°C in summer to freezing in winter (Figure 2). The upper layer extends down to 200 meters and originates from the Arctic. It is cold with a temperature close to freezing point and salinity of approximately 33-33.7 (Zweng and Münchow, 2006). The intermediate layer is of North Atlantic origin. It records maximum temperature of 2°C at 500 meters. Below the intermediate layer is the deep intermediate layer which records decreasing temperatures down to -0.4°C in bottom waters, where the salinity reaches 34.44.

Modern summer sea-surface temperature and salinity at the coring site are 3.23 ± 1.32°C and 29.6 ± 0.49 respectively (World Ocean Atlas, 2001). An increase in primary productivity generally occurs from May to September and is estimated at 70 gC/year from MODIS (http://daac.g fc.nasa.gov).

The low salinity in the surface water layer is due to the freshwater fluxes from the Canadian Arctic Archipelago. The flow is weaker in winter and stronger in summer (Dickson et al., 2007). Prinsenberg and Hamilton (2004, 2005) have calculated a freshwater flux of 48 mSv (liquid) plus 1.3 mSv (solid) through Lancaster Sound. Münchow et al. (2006) have estimated the freshwater flux through Nares Strait to be 25 ± 12 mSv. The Greenland ice sheet represents a large freshwater reservoir in the Northern Hemisphere. Its annual freshwater flux is estimated at 18 mSv, which is divided between Baffin Bay and the Greenland Sea. In Davis Strait, at the outlet of Baffin Bay, mean annual values of 72 to 130 mSv have been reported (Dickson and al., 2007). These values take into account large variations recorded since the 1980s. They may be underestimated in a perspective of climate warming (e.g., Seidenkrantz et al., 2008; Zweng and Münchow, 2006).

Sea ice extent reaches its maximum in March and minimum in September. In Baffin Bay, the sea-ice extent from 1972 to 1995 is 1.13×10^6 km^2 (Tang et al., 2004). Between 1953 and 2003, the seasonal extent of sea-ice cover at our study site averaged 9 months/year with a standard deviation of 1.1 (Figure 3; data compiled from the National Snow and Ice Data Center in Boulder).

3 Material and methods

3.1 Onboard measurements and core sampling

The trigger weight core HU2008029-016TWC (hereafter 16TWC; 70.46°N 64.66°W, 2063 m) and the companion Box core HU2008029-014BC (hereafter 14BC; 70.46°N 64.66°W, 2060 m) were collected during the HU2008029 expedition of the CCGS *Hudson*. The core 14BC was collected with a box-corer of 50 x 50 cm. Five push-cores were collected from the box using the vacuum backpressure technique to prevent compression (Campbell et al., 2008). The 34 cm long push-core selected for our study was subsampled by extrusion at 1 cm intervals. Here we report on ^{210}Pb analyses performed on the upper 12 cm of core 14BC. Palynological and geochemical results are reported by Steinhauer (2012).

The trigger weight core HU2008029-016TWC (hereafter 16TWC; 70.46°N 64.66°W, 2063 m) was split onboard and described visually. A working half was sampled for paleomagnetism (u-channel). It was subsampled every centimeter and we analysed the upper 64 cm of this 155 cm-long core (Figure 4).

3.2 Chronology

Analyses of ^{210}Pb were made in the upper 12 cm of cores 14BC and 16TWC to determine the sedimentation rate at the coring site. Analyses of ^{137}Cs were also conducted in the upper 5 cm to identify the 1967 peak (Ritchie and McHenry, 1990). All analyses were carried out at the GEOTOP research center.

The subsamples were dried at a temperature lower than 40°C in a drying chamber and crushed in an agate mortar. The ^{210}Pb activities were obtained by measuring the decay rate of its daughter isotope ^{210}Po ($t_{1/2}$=138.4 days; α=5.30 MeV) with an α-spectrometer and by adding ^{209}Po as a spike to determine the extraction and to count the efficiency. Chemical treatments with HCl, HNO_3, HF and H_2O_2 were done to extract and purify the polonium before making electro-depositions on silver disks (Flynn, 1968).

As for the ^{137}Cs, sediments were analyzed by gamma-spectrometry after preparation, which consisted of drying and crushing similarly to the ^{210}Pb analyses.

No calcareous microfossils was found in core 14BC and the uppermost occurrence of calcareous fauna in core 16TWC is at 52 cm. Foraminifer shells of both benthic and planktic taxa were sufficiently abundant at 56 cm to be hand-picked for radiocarbon dating. The conventional ^{14}C ages were calibrated using the Calib 6 software (Stuiver et al., 2005), which includes a correction of 400 years for the air vs. marine reservoir. No additional correction for regional air-sea reservoir effect (delta R) was applied.

3.3 Geochemical analyses

Samples have been dried out and crushed in an agate mortar before being analyzed with a Carlo Erba Elemental Analyser to determine total weight percent carbon and nitrogen contents.

The inorganic carbon content was measured with a coulometer on 20-40 mg of sediment. The organic carbon content was calculated by subtracting the inorganic carbon content from the total carbon content. Some tests which consisted of fumigating the samples with HCl allowed us to verify the accuracy of the method. According to Hélie (2009), coulometry is the most accurate method to determine inorganic carbon. The $\delta^{13}C_{org}$ has been measured using the Carlo Erba and reported vs. VPDB. Reproducibility tests indicate an accuracy of ± 0.1‰.

3.4 Microfaunal and palynological preparations and analyses

For each sample, about 5 cm^3 were processed following the protocol described in de Vernal et al. (1996). The samples were sieved at 106 μm and 10 μm in order to separate fine clays and coarse particles. During sieving, one tablet of *Lycopodium* spores was added in order to determine concentrations following the marker-grains method (Matthews, 1968). After the first sieving, the fraction between 106 µm and 10 µm was treated successively with HCl (10%) and HF (49%) in order to eliminate carbonate and silica particles, respectively.

The residue was mounted with glycerine gel between a slide and cover slide for examination by optical microscopy with transmitted light at 400X magnification. All palynomorphs were counted (Steinhauer, 2012). They include dinocysts, pollen grains, spores, reworked palynomorphs and organic linings from benthic foraminifera. The nomenclature of dinocysts was conformed to Rochon et al. (1999) and Head et al. (2001). Here we are only reporting the dinocysts. The occurence of other palynomorphs is very low.

The fraction greater than 106 µm was dried and examined with a binocular microscope in order to handpick foraminifera for radiocarbon dating. This fraction was then weighed since it provides an indication of the coarse sand content.

The past sea-surface conditions were reconstructed from dinocyst assemblages by using the modern analogue technique (MAT), which estimates past environmental conditions from the modern ones at sites containing similar modern assemblages (Guiot, 1990; Guiot and de Vernal 2007). We used the software R to perform MAT and an update of the Northern Hemisphere reference database of dinocyst assemblages (de Vernal et al., 2005; Radi and de Vernal, 2008; Bonnet et al, 2010) that comprises 1408 surface sediment sample sites and includes 64 from Baffin Bay.

4 Results

4.1 Chronology and stratigraphy

Previous work from central Baffin Bay at ODP Site 645 and in nearby cores suggested mean sedimentation rate of about 8-13 cm/ky during the Pleistocene (e.g., de Vernal et al., 1987; de Vernal and Mudie, 1989; Hillaire-Marcel et al., 1989). The two radiocarbon dates obtained from benthic and planktic foraminifera hand-picked at 56-57 cm in core 16TWC yielded ages of respectively 13 488 cal. years BP and 13 261 cal. years BP (Table 1). These ages indicate an average sedimentation rate of about 5 cm/ky during the postglacial interval, which is consistent with the paleomagnetic data that provided sedimentation rates of 4 to 8 cm/ky (Simon et al., 2010). Thus, those data suggest lower sediment accumulation rate during the present interglacial than during glacial stages. This is compatible with reduced detrital input from surrounding lands after the glacial retreat along the northeastern coasts of Canada (e.g., Dyke, 2002) and northwest Greenland (e.g., Long, 1994).

The ^{210}Pb analyses in cores 14BC and 16TWC provide complementary data about sedimentation rates, but the results show profiles that cannot be interpreted easily (see Figure 5). None of the profiles show an upper mixing zone. The asymptotic trend of ^{210}Pb activities downcore suggests supported ^{210}Pb of about 1 dpm/g, with excesses starting to increase above 7 cm in box core 14BC and close to 12 cm in gravity core 16TWC. Maximum values of 10.68 dpm/g and 7.32 dpm/g are obtained within the surface of cores 14BC and 16TWC, respectively. The ^{210}Pb profiles could be used to calculate sedimentation rates of 14 cm/ky and 12 cm/ky respectively. However, the profiles can also be related to biological mixing and diffusion in the sediment. This is likely the case in view of the ^{14}C ages and paleomagnetism data. Moreover, the samples do not contain detectable ^{137}Cs, which also confirms low sedimentation rates and biological mixing. Whereas the ^{210}Pb data are not conclusive in terms of sedimentation rate, they demonstrate compaction in the box core 14BC as compared to the gravity core 16TWC. Compaction may have occurred while sampling the push core in spite of the use of a vacuum pump. More likely, it occurred when sampling the push core by extrusion.

From available data, it seems clear that sedimentation rates are lower during postglacial than glacial stages or transitional periods. However one cannot assume constant sedimentation rates during the entire postglacial period. More abundant ice rafted debris (IRD) in the lower part of the core, below 10 cm (Figure 6), suggests higher detrital input and thus higher sedimentation rate during the early part of the postglacial. This would imply a decrease in sedimentation rate towards the top of the core.

The geochemical profiles ($CaCO_3$, C_{org}, $\delta^{13}C_{org}$) of the sediment records exhibit large amplitude variations (Figure 6). The C_{org} ranges from 0 to 1.95% (44-45 cm) with an average of 0.65%. The $CaCO_3$ content is variable reaching up to 6.44%. Considering the rarity of calcium carbonate microfossils in the section above 52 cm in core 16TWC, the $CaCO_3$ content likely relate to detrital inputs (Aksu, 1983). Abundant detrital $CaCO_3$ below 20 cm is thus compatible with abundant coarse sand debris (Figure 6). The $\delta^{13}C_{org}$ averages -25.23‰. However, the $\delta^{13}C_{org}$ in the upper 10 cm of the core increases to -21.67‰ (Figure 6). Such values are similar to those reported by Hillaire-Marcel et al. (1989) from nearby ODP site 645. The $\delta^{13}C_{org}$ suggest variations in the input of terrestrial vs. marine organic matter with a predominance of terrestrial organic matter in the lower part of the record. The higher $\delta^{13}C_{org}$ values in the upper part of the core suggest a slight increase in marine fluxes relative to terrestrial inputs.

4.2 Palynological content

The palynological content of core 16TWC is characterized by low concentrations of pollen grains, spores, reworked palynomorphs, organic linings of foraminifera (<100/g) and by moderately high concentrations of dinocysts (up to 1200 cysts/g). Dinocyst concentrations are higher in the upper 10 cm of the core (Figure 6) which indicates higher productivity. These results are consistent with the $\delta^{13}C_{org}$. The low concentration of terrestrial palynomorphs is due both to low pollen production in the Arctic tundra of adjacent lands and distance from land (cf. Rochon and de Vernal, 1994). The concentration of marine palynomorphs notably dinocysts is relatively low, yielding fluxes lower than 5 cysts.cm^{-2}.y^{-1}. This suggests low productivity in central Baffin Bay, which is consistent with the low chlorophyll content measured in the upper water column (Herman, 1983).

The dinocyst assemblages are dominated by *Impagidinium pallidum* from the base of the core to 18 cm and by *Operculodinium centrocarpum* above 18 cm (Figure 7). Thus, two main assemblage zones can be defined:

(1) The lower zone (base of the core to 18 cm), defined by the dominance of *Impagidinium pallidum*, also contains *Islandinium minutum* and *Islandinium*? *cezare.* This assemblage corresponds to cold polar conditions (e.g. de Vernal et al., 2001). *Impagidinium pallidum* is an oligotrophic taxon occurring in the open ocean settings of polar and subpolar seas (Matthiessen et al., 2005). High percentages of this taxon characterize the surface sediment of the Greenland Sea area where summer sea-surface temperature and salinity are 6°C and 34 respectively (de Vernal et al., 2005; Radi and de Vernal, 2008; Bonnet et al, 2010) (Figure 8).

(2) The upper zone (18 cm to surface) is characterized by the dominance of *Operculodinium centrocarpum*, the disappearance of *Islandinium* spp. and the presence of *Nematosphaeropsis*

labyrinthus, *Spiniferites elongatus* and *S. ramosus*. This assemblage is exclusively composed of Gonyaulacales, which suggests subpolar conditions and may reflect the influence of Atlantic waters. A transition zone between 18 and 10 cm is marked by an assemblage characterized by both *I. pallidum* and *O. centrocarpum*. This led to distinguish subzones 2a (18-10 cm) and 2b (10-0 cm).

In the upper part of the core, the absence of Protoperidiniales such as *Islandinium* might reflect poor preservation due to oxidation processes (e.g., Zonneveld 1997). However, there is no indication of alteration or poor preservation of other dinocysts. Moreover, when we consider Gonyaulacale taxa exclusively because they are less susceptible to degradation by oxidation (Zonneveld, 1997), the assemblages remain very different. In the Disko Bugt area, *P. dalei* is dominant (Andresen et al., 2010; Ribeiro et al., 2012) whereas it is rarely recorded in the central Baffin Bay. Similarly, in the northern Baffin Bay, Protoperidiniales dominate but *I. pallidum* occurs in much lesser percentages than *P. dalei*. Therefore, even when taking into account possible biases due to oxidation, assemblages from central Baffin Bay significantly differ from those of the western Greenland margin off Disko Bugt (cf. Andresen et al., 2010; Ribeiro et al., 2012) and northern Baffin Bay (cf. Levac et al., 2001; Ledu et al., 2008).

Dinocyst assemblages from central Baffin Bay thus appear specific to the area and correlations with the postglacial dinocyst stratigraphy of Disko Bugt and northern Baffin Bay cannot be made easily.

4.3 Reconstructions of sea-surface conditions

In order to reconstruct sea-surface conditions, we used the modern analogue technique (MAT) applied to dinocyst assemblages. In most of the samples, close analogues are identified. In the lower part of the record, which is characterized by high percentages of *I. pallidum*, the best analogues are mostly from offshore sites of the Greenland Sea, where cold water and low productivity are presently recorded. In the upper part of the record, the analogues are mostly found in the Baffin Bay area.

Results from core 16TWC show large amplitude variations in summer sea-surface temperature (SST) and salinity (SSS) as well as seasonal duration of the sea-ice cover (Figure 9). In the lower part of the sequence (below 18 cm), results indicate cold conditions and sea-ice cover up to 9 months/year, which is close to modern values. From 18 to 8 cm, data suggest a trend towards increased temperatures accompanied by a decrease of sea-ice cover towards values close to sea-ice free conditions. The upper 8 cm present maximum SSTs (4-9°C) and minimum sea-ice cover (<6 months/year). Oscillations are also recorded. However, due to poor time resolution of analyses, the data do not permit to identify a structure in the changes.

The coarse sand content of the core is high (> 0.10 g/cm^3) below 10 cm. This indicates abundant ice-rafted input which is compatible with dense sea-ice cover. Reconstructions at the top of the core yield conditions different than the modern. This can be due to the fact that the surface sediment sample integrates several hundred years, whereas the modern represent the last few decades only. In any case, overall the record indicates that optimal conditions in surface water established only during the second half of the Holocene. They also suggest that the modern conditions observed at the scale of the last decades are not representative of those recorded during the last millennia.

5 Discussion

The lack of precise chronology and the overall low sedimentation rates makes it difficult to interpret the record of core 16TWC in a regional to hemispheric perspective. Assuming constant sedimentation rates over the studied sequence, the main transition from cold to cool conditions that is recorded at 18 cm occurred after approximately 4000 years BP. However, this transition could have been earlier in the hypothesis of decreasing sedimentation rate towards the top of the core. Despite uncertainties with the exact age of the transition, the results suggest a late establishment of optimal interglacial conditions in central Baffin Bay. The data also point to dinocyst assemblages that were very different from those of the Labrador Sea during the early and mid-Holocene. Indeed, in the Holocene cores of the Labrador Sea, none of the dinocyst assemblages are dominated by *I. pallidum*, which never represents more than 5% of the assemblages. Holocene dinocyst assemblages of the Labrador Sea are rather dominated by *P. dalei* and *N. labyrinthus* (cores P13 and P21 in Figure 1; de Vernal et al., 2001; Solignac, 2004). The differences between Labrador Sea and Baffin Bay assemblages during the early mid-Holocene suggest isolation of the Baffin Bay basin and therefore a weak northward penetration of Atlantic water masses, at least in surface waters. The dinocyst assemblages, geochemical and sedimentological content of core 16TWC also suggest very harsh conditions in surface waters with low temperatures, dense sea-ice cover, ice calving and icebergs and low productivity during the early Holocene and probably until the late Holocene. High calving activity and melwater supply in northern Baffin Bay along the Canadian and Greenland ice sheet margins during the first part of the Holocene is compatible with the ice core record of the Agassiz ice cap that shows important melt layers until about 4000 years BP, (Fisher et al., 1995). Ice calving and meltwater discharges could well explain particularly strong stratification of surface water masses and dense sea-ice cover in the Baffin Bay during an interval also marked by high summer insolation in the Northern Hemisphere (Berger, 1978). The regional response of Baffin Bay we reconstruct here is compatible with some terrestrial records of northeastern Canada where a delayed establishment of the Holocene thermal optimum is observed (e.g. Kaufman et al., 2004; CAPE project members, 2001).

6 Conclusion

The record of core 16TWC provides unique data to document climate and ocean changes in central Baffin Bay during the Holocene. Despite uncertainties with respect to the chronology, the results show an important transition during the mid-Holocene, with a change from assemblages dominated by *I. pallidum* to assemblages dominated by *O. centrocarpum*. During the early part of the Holocene, the overall data point to the existence of harsh conditions in baffin Bay and the composition of dinocyst assemblages suggest very limited influence of the West Greenland Current and North Atlantic waters, at least in the surface water layer. This does not exclude the possibility of the penetration of subducting North Atlantic water below a low density surface layer, Actually, the data also indicate terrigenous and ice rafted inputs during the early Holocene, which seems to have been marked by intense ice calving activity and strong meltwater discharges along the Greenland and Canadian ice sheet margins in the Baffin Bay, possibly as a response to high summer insolation in the Northern Hemisphere. Therefore, the delayed establishment of Holocene thermal optimum in Baffin Bay would be a regional response forced by the presence of ice on surrounding lands.

During the mid-Holocene and possibly as late as 4000 years BP, reduced melting rates along the ice margins would have favoured higher surface salinity, the inflow of Atlantic water at the surface and the establishment of relatively warm conditions. The record from Baffin Bay thus illustrates the critical role of freshwater budget in the basin and point to complex regional response of epicontinental environments to global forcing.

7 Aknowledgments

This study was conducted using the material collected during the expedition HU2008-029 funded by the Canadian Foundation for Climate and Atmospheric Science (CFCAS) through the Polar Climate Stability Network (PCSN), the Geological Survey of Canada and the Natural Science and Engineering Research Council (NSERC) of Canada. This is a contribution to the project Past4Future.

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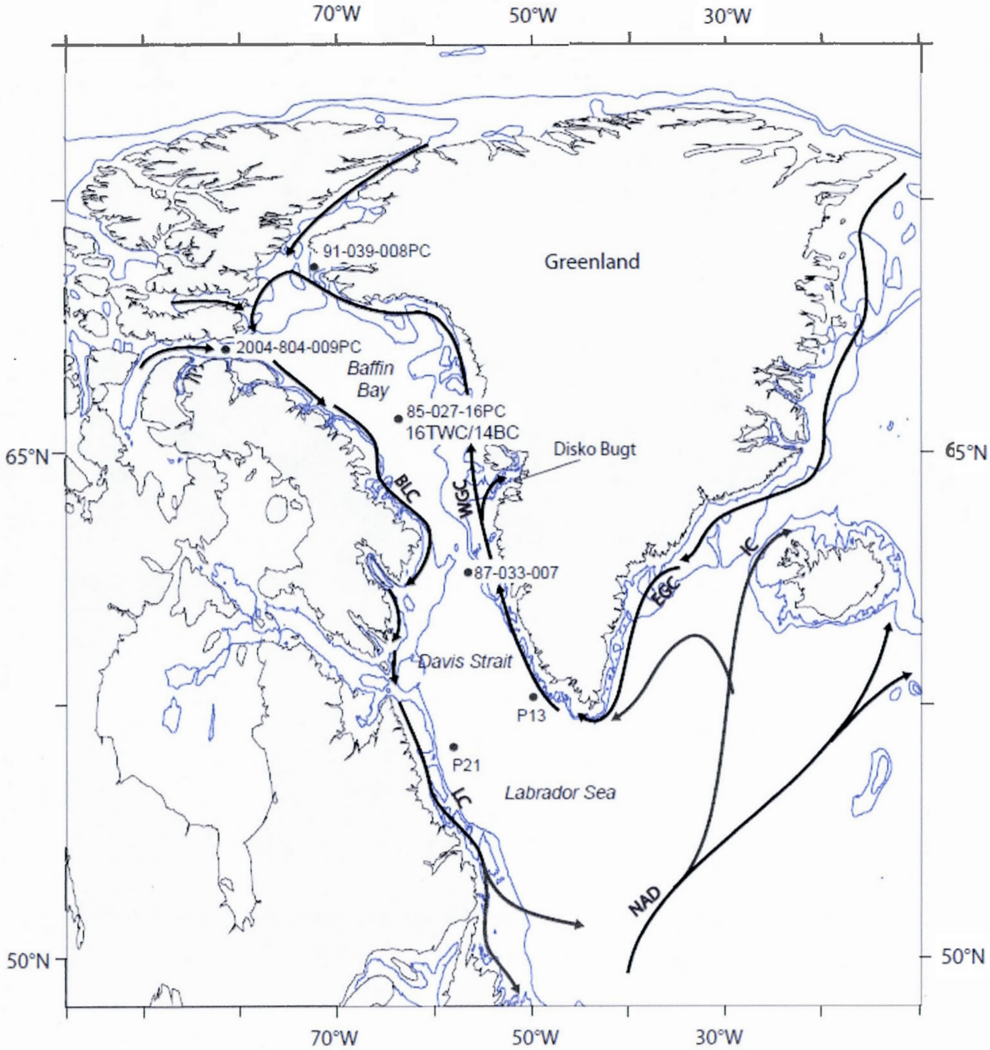

Figure 1. Location of cores HU2008-029-014BC (14BC) and HU2008-029-016TWC (16TWC) (70.46°N, 64.66°W, water depth: 2060 m and 2063 m) and trajectories of main ocean surface currents. Arrows illustrate the path of main currents. The location of cores referred to in the text is also illustrated (P21: see de Vernal et al., 2001; P13: see Solignac et al., 2004). Isobaths correspond to 200 and 500 m. WGC: West Greenland Current, EGC: East Greenland Current, BLC: Baffin Land Current, LC: Labrador Current, IC: Iceland Current, NAD: North Atlantic Drift.

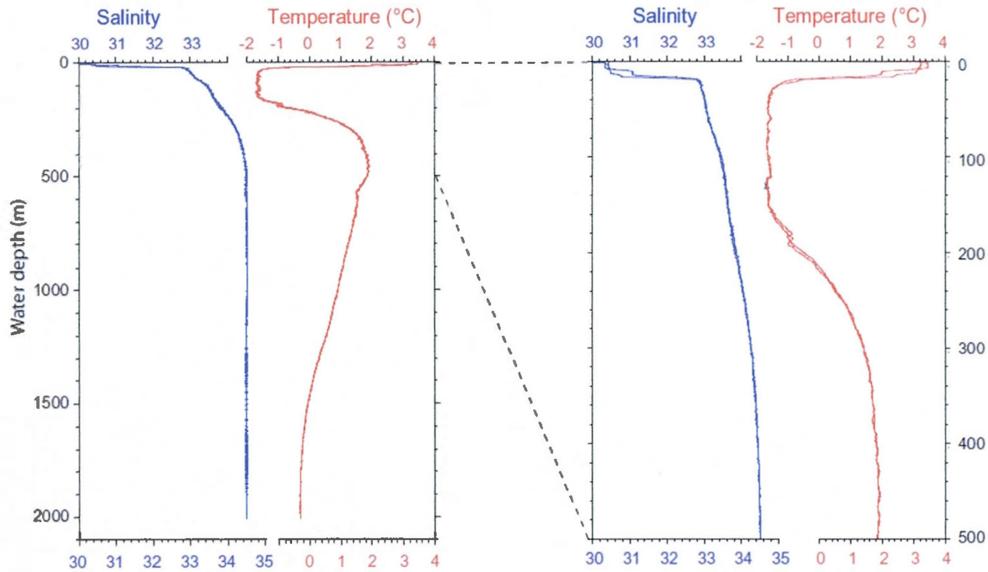

Figure 2. Temperature and salinity profiles at core site location (70.46°N, 64.66°W, water depth: 2060 m). The CTD (Conductivity, Temperature, Depth) cast was made in late August during expedition HU2008-029 (Campbell et al., 2008). The left diagram shows the profiles throughout the entire water column and the right diagram is a blow up of the upper 600 meters.

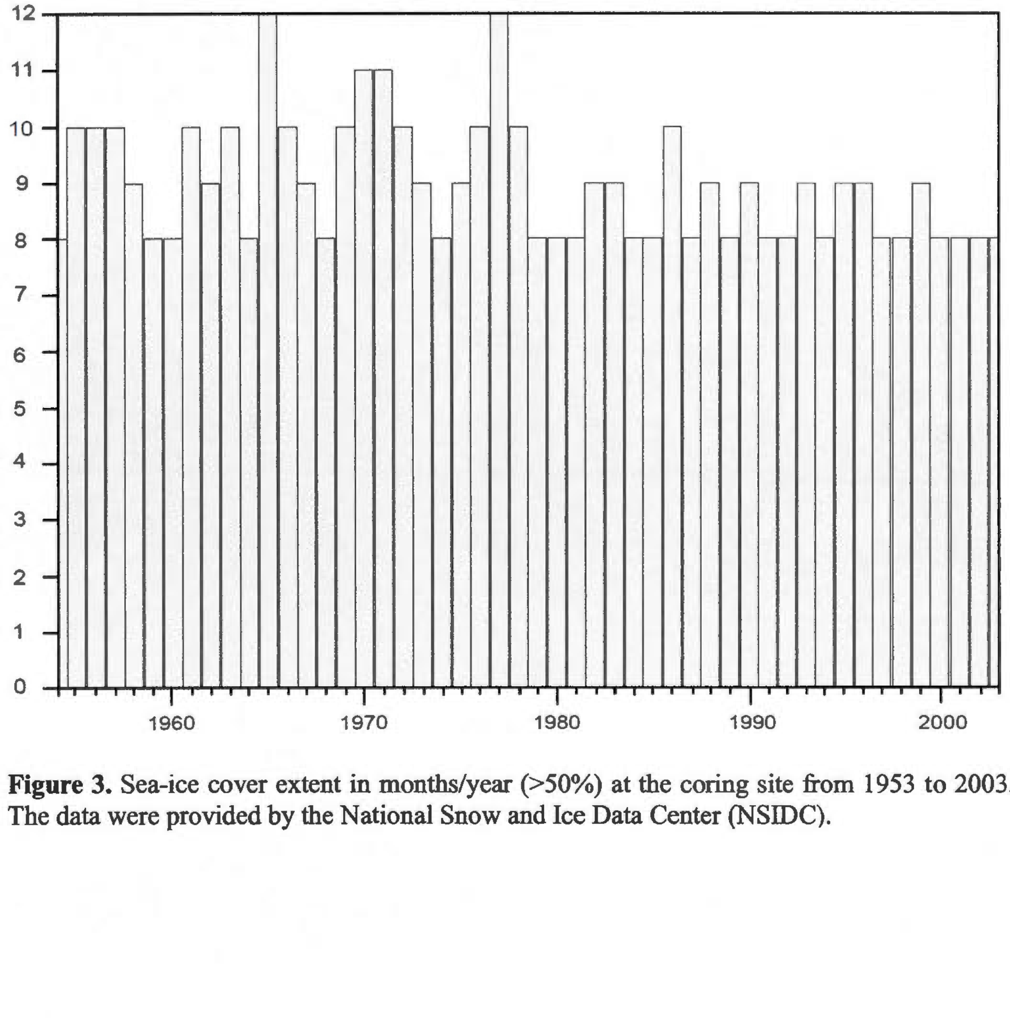

Figure 3. Sea-ice cover extent in months/year (>50%) at the coring site from 1953 to 2003. The data were provided by the National Snow and Ice Data Center (NSIDC).

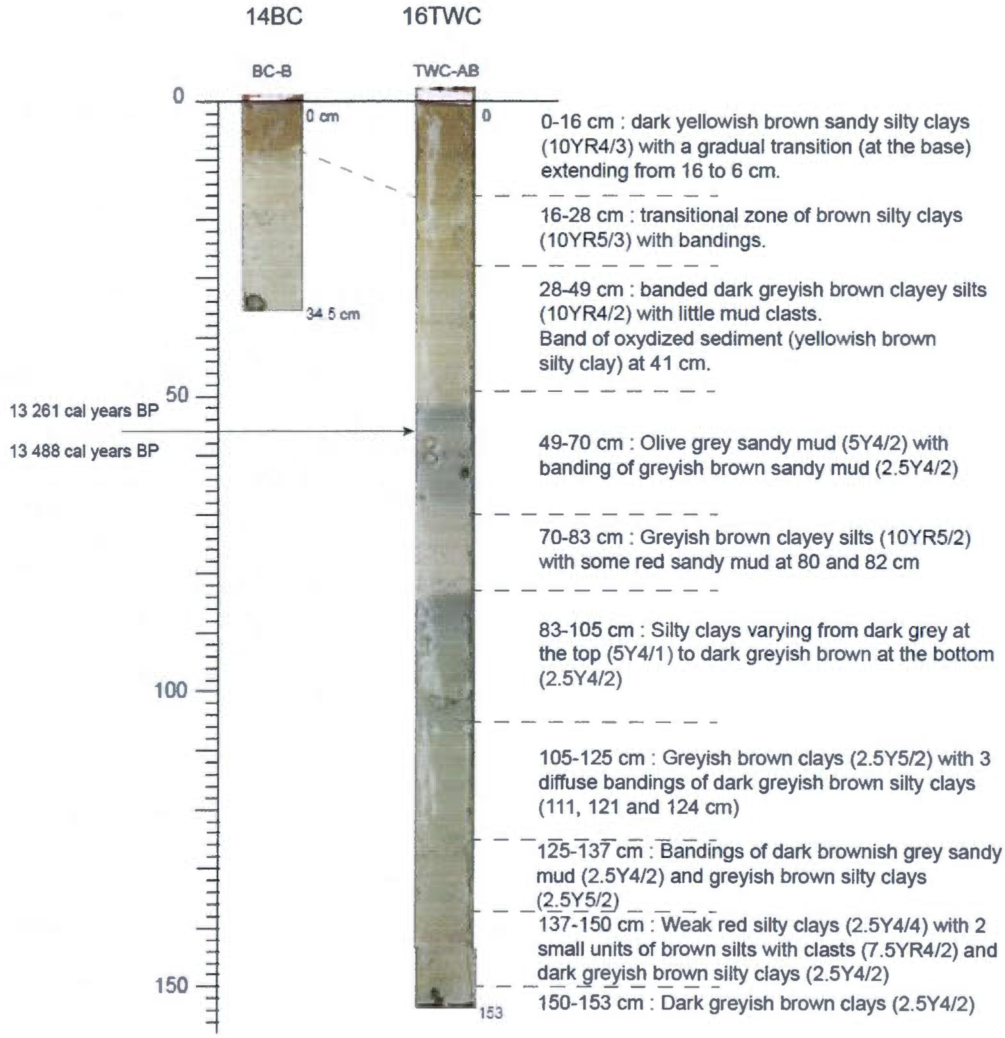

Figure 4. Photographs and summarised sediment core description of cores 14BC and 16TWC taken immediately after the opening of the cores on board. See Table 1 for information on ^{14}C ages. The analysed section corresponds to the upper 64 cm. The code in parenthesis refers to colors from the Munsell Chart.

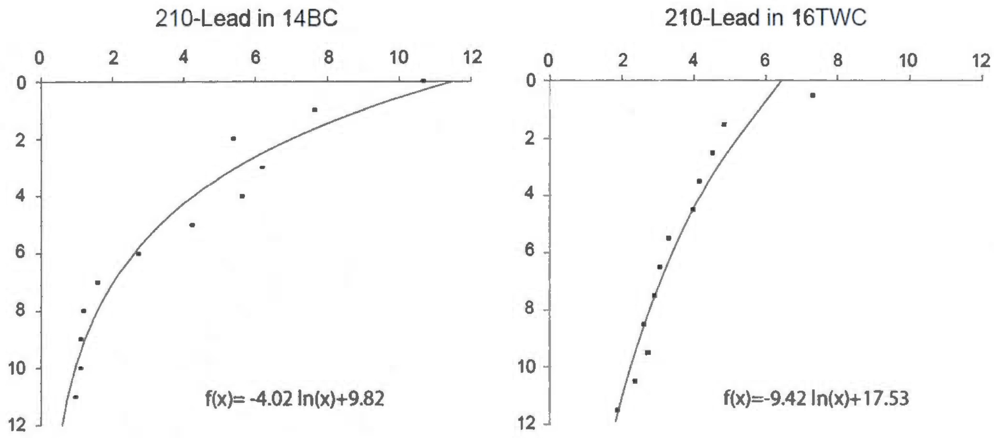

Figure 5. Lead-210 (in dpm/g) as a function of depth in cores 14BC and 16TWC. The lines correspond to the logarithmic equation that could be used to evaluate sedimentation rates.

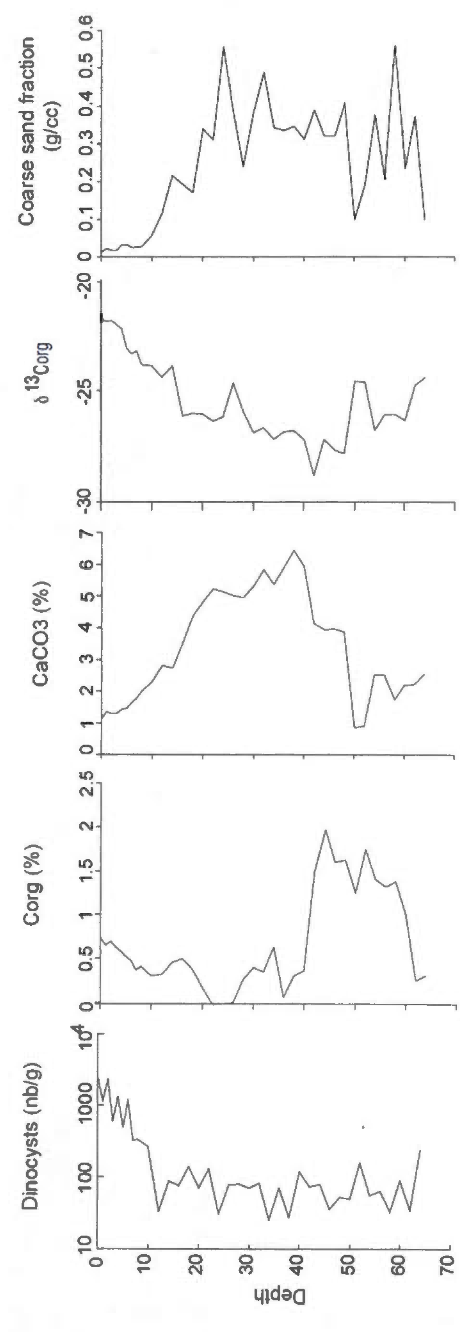

Figure 6. Diagram of palynomoph concentrations, $\delta^{13}C_{org}$ and coarse fraction as a function of depth in core 16TWC. Note that the results are expressed with a logarithmic scale.

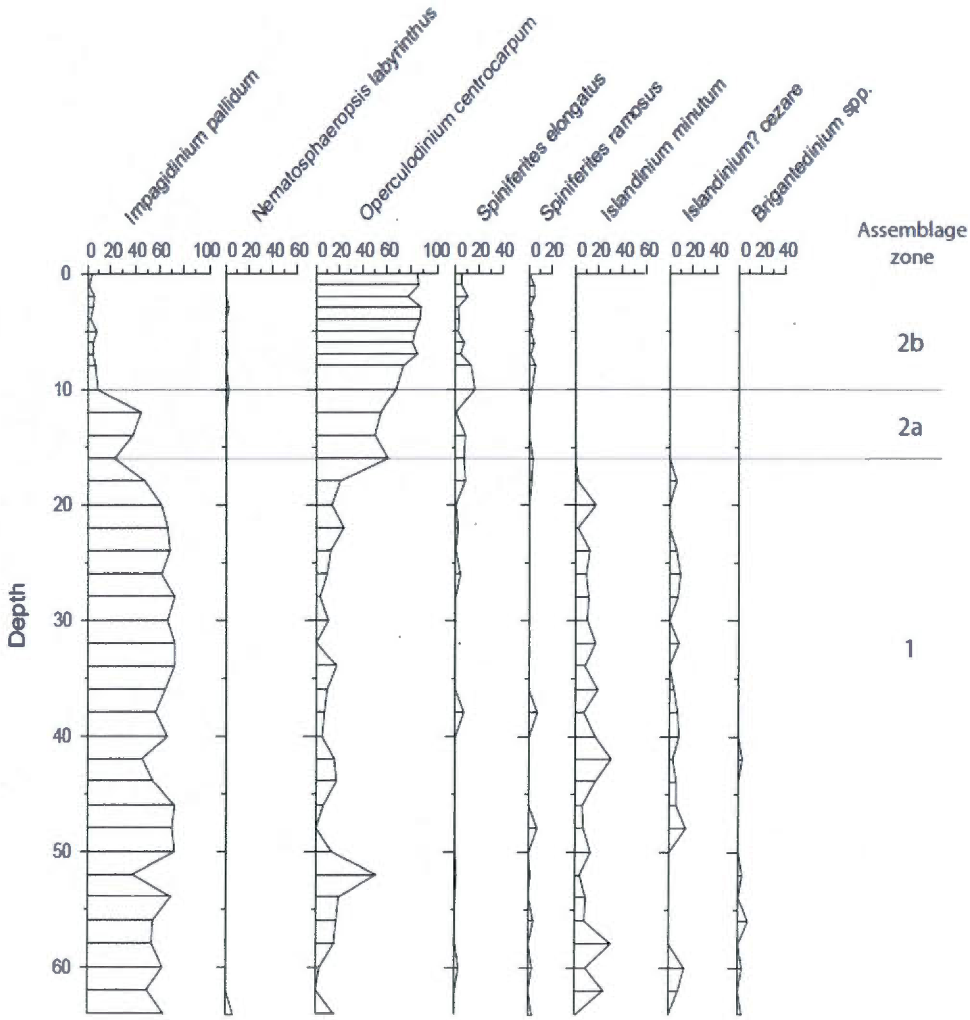

Figure 7. Diagram of dinocyst taxa percentages and assemblage zones as a function of depth in core 16TWC.

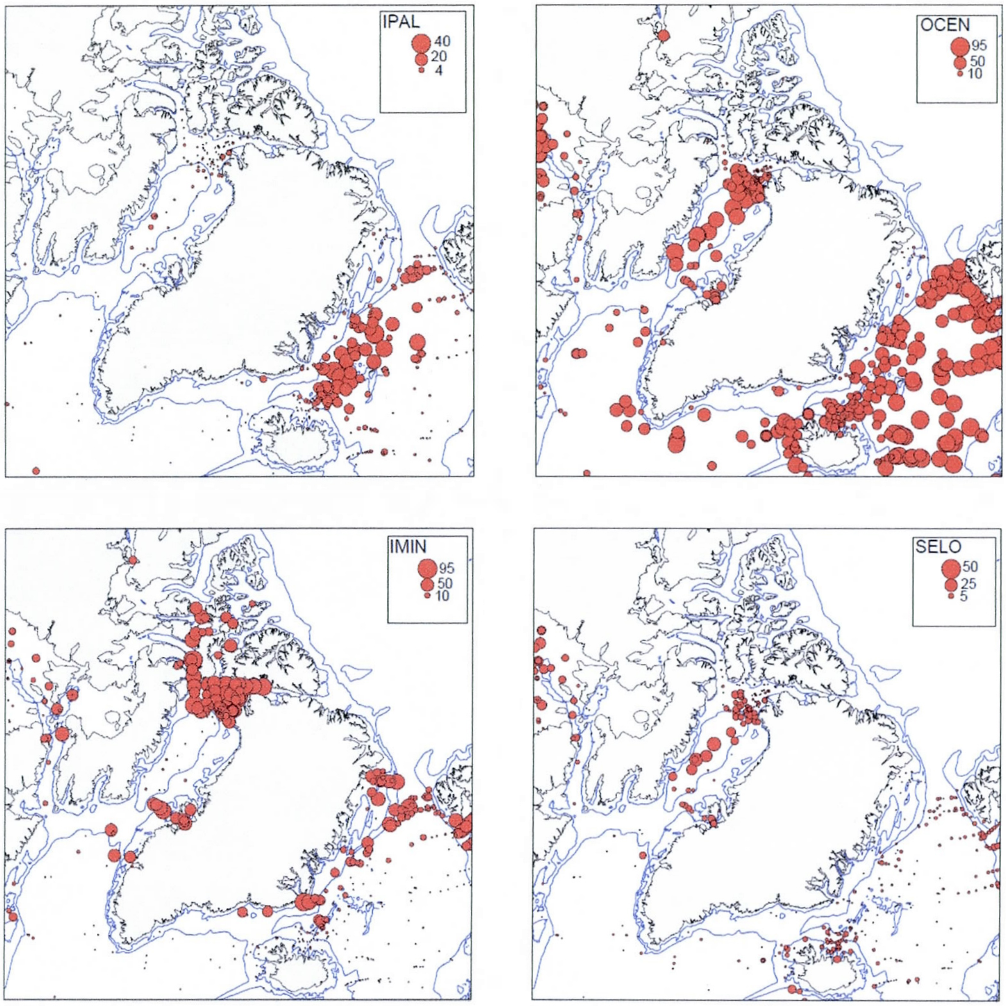

Figure 8. Maps of the distribution of the dinocyst taxa *I. pallidum* (IPAL), *O. centrocarpum* (OCEN), *I. minutum* (IMIN) and *S. elongatus* (SELO) in surface sediment samples (cf. data base available on the GEOTOP web site)

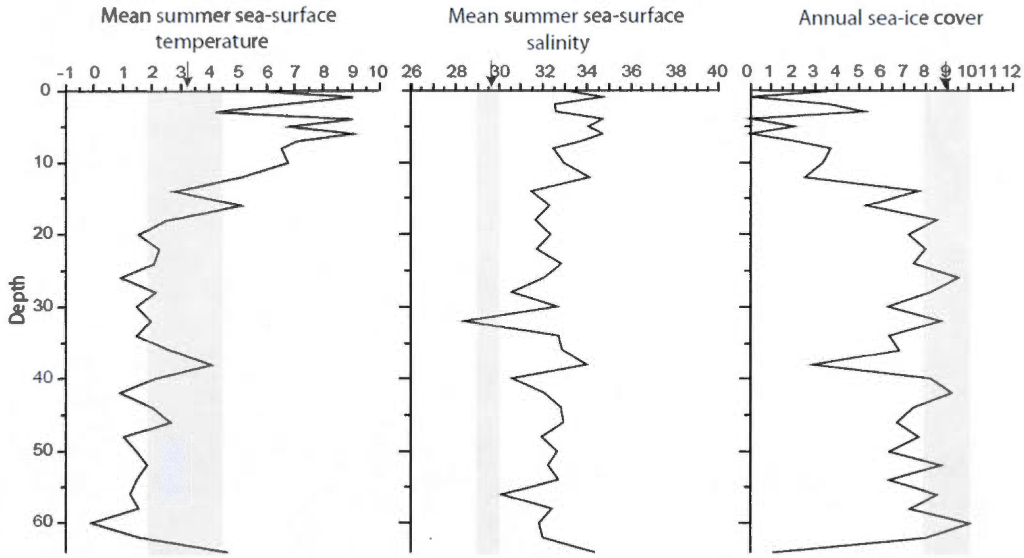

Figure 9. Reconstruction of sea-surface temperature, salinity and sea-ice cover from dinocyst assemblages as a function of depth, based on the Modern Analogue Technique (MAT). The modern values are represented by an arrow and their standard deviations by the grey areas.

^{14}C results									
CAMS #	**Sample Name**	**Material dated**	**Modern fraction**	±	**$D^{14}C$**	±	**^{14}C age**	±	**cal. ^{14}C age**
146826	HU2008 029-16TWC 56-57pl		0.2301	0.0011	-769.9	1.1	11800	40	13261
146827	HU2008 029-16TWC 56-57ben		0.2245	0.0029	-775.5	2.9	12000	110	13488

1) The quoted age is in radiocarbon years using the Libby half life of 5568 years and following the conventions of Stuiver and Polach (ibid.).

2) The uncertainty on CAMS# 146827 is larger due to the small size of the sample (~100μgC).

Table 1. Radiocarbon ages from core 16TWC. The software Calib 6 for marine samples was used for calibration (Stuiver et al., 2005). No additional age correction for regional air-sea difference (delta R) was made.

CONCLUSION GÉNÉRALE

La Baie de Baffin est une zone géographique importante à étudier de part sa localisation entre l'Océan Arctique et l'Océan Atlantique Nord. Par contre, peu d'enregistrements sont disponibles et ceux-ci ont une faible résolution qui ne permet pas une interprétation optimale. Grâce à cette étude et à des méthodes analytiques plus performantes, il a été possible de reconstituer des changements dans les conditions d'eau de surface de la Baie de Baffin.

Malgré une forte dissolution des carbonates et silice biogéniques, les assemblages de dinokystes illustrent des changements importants dans les masses d'eau.

L'absence de chronologie précise et les taux de sédimentation relativement faibles rendent l'interprétation de la carotte 16TWC difficile. Si l'on suppose des taux de sédimentation constants pour la séquence étudiée, la transition majeure entre des conditions froides et fraîches (18 cm) prendrait place vers 4000 ans BP si ce n'est plus tôt selon l'hypothèse d'un ralentissement du taux de sédimentation dans la partie supérieure de la carotte. Cela suggèrerait une mise en place tardive des conditions interglaciaires optimales au centre de la baie de Baffin. Jusqu'à environ 4000 ans BP ou plus tôt, les assemblages de dinokystes dominés par *I. pallidum* sont différents de ceux de la mer du Labrador ce qui impliquerait un isolement du bassin et une faible pénétration des eaux de surface dans la baie de Baffin. Les dinokystes et les données géochimiques et sédimentologiques de la carotte indiquent des conditions très rudes avec des températures basses, un couvert de glace dense incluant la présence d'icebergs, et une faible productivité jusqu'à la fin de l'Holocène.

Après 4000 ans BP, la dominance de *O. centrocarpum* dans les assemblages de dinokystes indique une pénétration des eaux de l'Atlantique et la mise en place de conditions plus clémentes avec une productivité plus élevée.

APPENDICE A

TABLEAUX DE COMPTAGES ET CONCENTRATIONS DES PALYNOMORPHES TERRESTRES ET MARINS DE LA CAROTTE HU2008-029-014BC

Profondeur (cm)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Impagidinium pallidum	21	7	27	27	40	39	6	8	4	3	2	8	4	3	2	1	1
Impagidinium sphaericum	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0
Lingulodinium machaerophorum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nematosphaeropsis labyrinthus	24	13	19	8	4	3	0	1	0	1	0	1	0	0	4	2	2
Operculodinium centrocarpum	273	93	212	121	213	175	37	43	13	17	4	6	9	3	7	10	7
Operculodinium centrocarpum short processes	4	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spiniferites elongatus	31	6	7	12	27	24	7	4	1	0	1	1	0	2	0	2	0
Spiniferies ramosus	8	1	7	1	7	8	1	4	1	0	0	0	1	0	0	0	0
Spiniferites spp.	11	1	10	4	1	4	0	0	0	0	0	1	0	0	0	0	0
Cyst of *Pentapharsodinium dalei*	2	0	2	0	2	0	0	0	0	2	1	2	1	0	1	0	1
Islandinium minutum	7	1	8	0	0	0	0	2	0	0	1	0	1	0	0	0	0
Brigantedinium spp.	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	0
Brigantedinium cariacoense	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Brigantedinium simplex	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyst of *Polykrikos schwartzii*	3	0	1	11	3	15	1	0	1	0	0	0	0	0	0	0	0
Total	384	125	295	184	297	275	52	62	20	24	9	19	16	8	15	17	11
Concentration (dinocysts/cm³)	532	275	454	358	379	798	208	137	44	87	29	46	30	15	20	24	21

Profondeur (cm)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Total pollen grains	7	9	12	14	9	3	11	12	8	0	0	0	1	0	2	1	0
Concentration (pollen grains/cm³)	10	20	18	25	11	9	44	26	18	0	0	0	2	0	3	1	0
Total spores	19	16	6	5	2	1	0	0	0	0	0	0	0	0	0	0	0
Concentration (spores/cm³)	26	35	9	10	3	3	0	0	0	0	0	0	0	0	0	0	0
Total reworked palynomorphs	0	2	9	12	29	21	7	10	5	6	7	6	8	4	4	24	11
Concentration (reworked palynomorphs/cm³)	0	4	14	23	37	61	28	22	9	22	23	15	15	8	5	34	21
Total organic linings	15	8	7	0	6	0	3	3	4	0	2	0	0	0	0	0	1
Concentration (organic linings/cm³)	21	18	11	0	8	0	12	7	9	0	6	0	0	0	0	0	2

APPENDICE A

TABLEAUX DE COMPTAGES ET CONCENTRATIONS DES PALYNOMORPHES TERRESTRES ET MARINS DE LA CAROTTE HU2008-029-014BC

Profondeur (cm)	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
Impagidinium pallidum	3	6	15	16	8	7	14	12	14	7	18	13	9	14	8	8	7
Impagidinium sphaericum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lingulodinium machaerophorum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Nematosphaeropsis labyrinthus	2	1	0	2	0	0	0	0	2	0	2	0	1	0	0	0	0
Operculodinium centrocarpum	2	2	3	2	2	3	3	3	3	3	7	5	3	3	4	1	3
Operculodinium centrocarpum short process	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spiniferites elongatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spiniferies ramosus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spiniferites spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyst of *Pentapharsodinium dalei*	0	0	0	0	1	0	0	0	0	0	0	0	0	1	2	2	0
Islandinium minutum	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0
Brigantedinium spp.	0	0	0	0	1	0	0	1	1	3	0	0	1	0	0	1	1
Brigantedinium cariacoense	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Brigantedinium simplex	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Cyst of *Polykrikos schwartzii*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	7	9	18	20	12	13	18	16	20	13	27	18	14	18	15	12	11
Concentration (dinocysts/cm³)	14	37	62	42	45	31	46	17	40	16	38	49	47	29	35	31	27

Profondeur (cm)	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
Total pollen grains	0	0	0	0	0	0	0	1	0	1	0	0	0	1	0	0	0
Concentration (pollen grains/cm³)	0	0	0	0	0	0	0	1	0	1	0	0	0	2	0	0	0
Total spores	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0
Concentration (spores/cm³)	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0
Total reworked palynomorphs	3	3	4	2	2	2	4	6	3	7	6	5	4	2	2	2	2
Concentration (reworked palynomorphs/c	6	12	14	4	8	5	10	6	6	8	8	14	13	3	5	5	5
Total organic linings	0	1	0	1	0	1	1	0	0	0	1	1	0	3	2	2	1
Concentration (organic linings/cm³)	0	4	0	2	0	2	3	0	0	0	1	3	0	5	5	5	2

APPENDICE B

TABLEAUX DE COMPTAGES ET CONCENTRATIONS DES PALYNOMORPHES TERRESTRES ET MARINS DE LA CAROTTE HU2008-029-016TWC

Profondeur (cm)	0	1	2	3	4	5	6	7	8	10	12	14	16	18	20	22	24	26	28
Impagidinium pallidum	13	4	13	6	8	12	16	4	4	4	5	9	6	21	18	23	11	13	19
Impagidinium sphaericum	5	1	3	1	0	5	0	2	0	0	0	0	0	0	0	0	0	0	0
Lingulodinium machaerophorum	0	0	0	0	0	0	0	0	0	0	0	0.	1	2	2	0	0	0	1
Nematosphaeropsis labyrinthus	1	1	0	3	1	1	2	1	0	1	0	0	0	0	0	0	0	0	0
Operculodinium centrocarpum	268	188	198	106	287	137	268	78	43	32	6	12	16	9	4	8	2	2	1
Operculodinium centrocarpum short processes	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0
Spiniferites elongatus	20	11	25	3	12	4	25	4	8	8	0	2	2	4	0	1	0	1	0
Spiniferites ramosus	2	9	11	0	12	2	14	1	3	1	0	0	1	1	0	0	0	0	0
Spiniferites spp.	6	3	4	1	7	3	4	1	1	2	0	1	0	0	0	0	0	1	0
Islandinium minutum	0	0	0	0	0	0	0	0	0	0	0	0	0	1	5	1	2	2	3
Islandinium ? Cezare	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	1	2	2
Brigantedinium spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Selenopemphix quanta	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyst of *Polykrikos schwartzii*	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Total	336	217	255	120	327	164	329	91	59	48	11	24	26	44	29	34	16	21	26
Concentration (dinocysts/cm³)	1260	508	1000	279	819	300	790	214	159	113	47	95	96	170	98	164	47	121	99

Profondeur (cm)	0	1	2	3	4	5	6	7	8	10	12	14	16	18	20	22	24	26	28
Total pollen grains	0	0	0	1	0	2	0	1	2	2	0	4	3	4	6	5	2	1	3
Concentration (pollen grains/cm³)	0	0	0	2	0	4	0	2	5	5	0	16	11	15	20	24	6	6	11
Total spores	0	1	0	1	0	0	0	1	0	0	0	1	0	1	0	1	1	1	0
Concentration (spores/cm³)	0	2	0	2	0	0	0	2	0	0	0	4	0	4	0	5	3	6	0
Total reworked palynomorphs	8	7	5	8	0	9	2	7	4	6	4	4	5	8	5	11	5	1	4
Concentration (reworked palynomorphs/cm³)	30	16	20	19	0	16	5	16	11	14	17	16	19	31	17	53	15	6	15
Total organic linings	0	2	1	1	0	0	0	0	0	0	0	2	1	4	0	2	0	0	0
Concentration (organic linings/cm³)	0	5	4	2	0	0	0	0	0	0	0	8	4	15	0	10	0	0	0

APPENDICE B

TABLEAUX DE COMPTAGES ET CONCENTRATIONS DES PALYNOMORPHES TERRESTRES ET MARINS DE LA CAROTTE HU2008-029-016TWC

Profondeur (cm)	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64
Impagidinium pallidum	6	16	8	13	8	22	12	16	11	10	11	24	7	12	7	19	6	40
Impagidinium sphaericum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lingulodinium machaerophorum	1	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	2	0
Nematosphaeropsis labyrinthus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
Operculodinium centrocarpum	1	0	2	2	1	2	4	5	1	0	2	32	2	4	2	1	0	10
Operculodinium centrocarpum short processes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spiniferites elongatus	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	1	0	0
Spiniferites ramosus	0	0	0	0	1	0	0	0	0	1	0	1	0	1	0	1	0	2
Spiniferites spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Islandinium minutum	1	4	1	4	1	6	8	5	1	1	2	3	1	2	4	3	3	1
Islandinium ? Cezare	0	2	0	1	1	3	1	2	1	2	0	0	0	0	0	4	1	0
Brigantedinium spp.	0	0	0	0	0	0	1	0	0	0	0	2	0	2	0	1	0	2
Selenopemphix quanta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyst of *Polykrikos schwartzii*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
Total	9	22	11	20	14	33	26	29	14	14	15	63	10	22	13	30	12	62
Concentration (dinocysts/cm^3)	121	138	40	94	48	179	123	122	53	77	43	142	71	67	48	95	45	208

Profondeur (cm)	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64
Total pollen grains	0	4	2	1	2	6	0	9	9	5	10	11	2	2	7	11	12	6
Concentration (pollen grains/cm^3)	0	25	7	5	7	33	0	38	34	27	28	25	14	6	26	35	45	20
Total spores	0	0	0	0	0	0	0	0	0	0	2	4	0	1	0	0	2	1
Concentration (spores/cm^3)	0	0	0	0	0	0	0	0	0	0	6	9	0	3	0	0	7	3
Total reworked palynomorphs	1	8	6	2	2	2	3	4	3	4	10	10	6	14	13	16	5	12
Concentration (reworked palynomorphs/cm^3)	13	50	22	9	7	11	14	17	11	22	28	23	42	43	48	50	19	40
Total organic linings	0	0	1	0	0	5	0	2	2	4	6	9	2	0	1	7	1	9
Concentration (organic linings/cm^3)	0	0	4	0	0	27	0	8	8	22	17	20	14	0	4	22	4	30

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