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Research paper

Modern dinoflagellate cyst assemblages in surface sediments of Nunatsiavut fjords (Labrador, Canada)

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ABSTRACT

In order to document long-term climate cycles and predict future climate trends for the Arctic, geological records archived in ocean sediments can help establish the link between historical and pre-historical sea-surface parameters. Dinoflagellate cysts (dinocysts) are used as proxy indicators of sea-surface parameters (temperature, salinity, sea-ice cover, primary productivity) jointly with transfer functions and a modern dinocyst reference database, to reconstruct the evolution of sea-surface conditions at decadal and millennial timescales. Here we present the surface distribution of recent dinocyst assemblages in 13 surface samples collected in four Nunatsiavut fjords (northern Labrador, Canada) along a latitudinal gradient, and their relationship with various environmental and biological parameters. Dinocyst concentrations in surface sediments increased from the inner to the outer part of each fjord and also from the northernmost to the southernmost fjords. There was also a southward increase in the species diversity with an occurrence and a dominance of cysts from autotrophic dinoflagellates. The presence of cysts of the calcareous dinoflagellate species *Scrippsiella* cf. *S. crystallina* in Anaktalak Fjord, where mining activities are underway, appears to be an indicator of human-related pollution within the fjord.

1. Introduction

Labrador Inuit depend on the ocean and sea ice for their hunting and harvesting activities. They are concerned about the ecological integrity of the marine environment of northern Labrador, especially with respect to the impacts of climate change, industrialization (maritime navigation, mining) and contamination of their traditional foods. These natural resources are very important to native cultures and peoples. The peculiarities of Arctic ecosystem conditions (ice cover, photoperiod etc.) have determined their way of life for millennia. However, rapid changes with numerous ecosystem disruptions that are of natural or anthropogenic origin will result in significant disturbances in these fragile northern communities. As part of the Network of Centres of Excellence ArcticNet project "*Nunatsiavut Nuluak: Understanding the effects of climate change and modernization in a northern marine environment*" addresses these concerns. Since then, several oceanographic campaigns aboard the Canadian Coast Guard Ship (CCGS) *Amundsen* have been conducted along the Labrador coast, specifically inside four fjords, some with environmental disturbances and stresses caused by human activities (Fig. 1).

Dinoflagellates are microscopic unicellular biflagellate protists (Taylor et al., 2008), that occasionally form massive bloom events known as red tides. Some dinoflagellate species can be toxic. The life cycle of some species comprises a dormancy phase during which the vegetative stages form cysts. The cyst's membrane is composed of a highly resistant polymer called dinosporin, allowing the cyst to be preserved in sediments (Richerol et al., 2008b). Dinocysts have been used as proxy indicators to compare past and modern assemblages and link them with environmental parameters (sea-surface temperature and salinity, sea-ice cover duration, productivity) through the use of transfer functions (Rochon et al., 1999; Devillers and de Vernal, 2000; Boessenkool et al., 2001; de Vernal et al., 2001, 2006; Grøsfjeld and Harland, 2001; Kunz-Pirrung, 2001; Mudie and Rochon, 2001; Radi et al., 2001; Voronina et al., 2001; Richerol et al., 2008a, 2008b). In November 2009 and October 2010, the Nunatsiavut fjords were sampled to document modern assemblages of dinoflagellate cysts (dinocysts) and their relationship with various environmental parameters including summer sea-surface temperature and salinity, sea-ice cover duration, photosynthetically available radiation (PAR), nutrients (nitrites, nitrates, silicates and phosphates) and diatom abundance.

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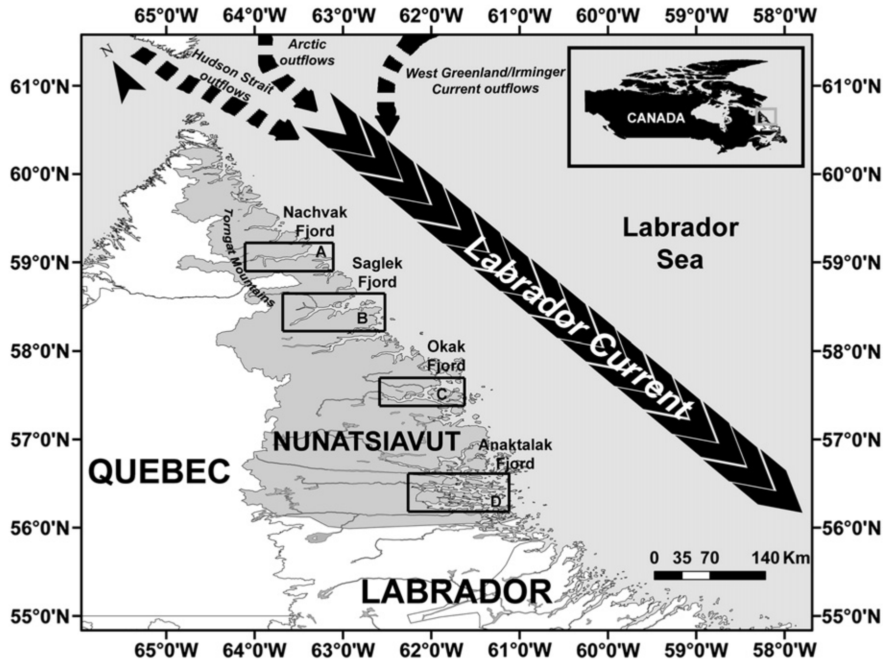

Fig. 1. Map of the Nunatsiavut (North Labrador, Canada) illustrating the location of the four fjords involved in this study: A. Nachvak Fjord; B. Saglek Fjord; C. Okak Fjord and D. Anaktalak Fjord.

Dinocysts in fjords from arctic and subarctic regions have already been the subject of previous studies. In Norwegian fjords, the dynamics of the formation, sedimentation and preservation of dinocysts have been studied in Trondheimsfjord (Dale, 1976), whereas they served as pollution and past climate indicators in Nordåsvannet and Grimstadfjord (Thorsen and Dale, 1997) and as indicators of cultural eutrophication in Oslofjord (Dale et al., 1999). Dinocysts were also part of a multi-proxy study on Holocene climate in the subarctic fjord Malangen (Hald et al., 2003). In Gullmar Fjord (Sweden) the relationship between the abundance of planktonic dinoflagellates, the abundance of dinocysts recovered from sediment traps and environmental factors have been studied (Godhe et al., 2001). In Igaliku Fjord (southern Greenland) dinocysts have been used to document the palynofacies of the late Holocene in relation to the paleohydrography of the fjord (Roncaglia and Kuijpers, 2004). The assemblages of dinocysts from Svalbard fjords have been documented in relation to the modern oceanographic conditions (Kongsfjorden, Krossfjorden, Sassenfjorden, Van Mijenfjorden and Storfjorden) (Grøsfjeld et al., 2009) and the influence of Atlantic water circulation (Kongsfjorden and Rijpfjorden) (Howe et al., 2010). On the Canadian west coast, the anoxic fjord Effingham Inlet (Vancouver Island, BC) has been studied for the modern assemblages of dinocysts (Kumar and Patterson, 2002) and paleoceanographic conditions (Patterson et al., 2011).

This study is the first to document the modern dinocyst assemblages in the fjords of Nunatsiavut (northern Labrador, Canada) with the aim of providing a better understanding of the ecological status of these fjord ecosystems, thereby allowing us to predict their response to future anthropogenic changes. A better knowledge of the natural background conditions will help develop appropriate mitigation measures for the effective management and sustainable development and preservation of the ecological and cultural integrity and diversity of the North. The dinocyst assemblages from this study (n = 12 sites; Fig. 2) will be integrated into the regularly updated reference database of modern dinocyst assemblages from the Northern Hemisphere (n = 1429 sites), managed by GEOTOP (de Vernal et al., 2001; Radi and de Vernal, 2008), for subsequent use in paleoceanographic reconstructions. This is a prerequisite for a better understanding of the impacts of present-day and future changes on these fjord ecosystems.

2. Environmental settings

Labrador is a region located on the eastern seaboard of Canada and extends between 46 and 60°N, along the Labrador Sea (Fig. 1). It is underlain mostly by granitic–gneissic Precambrian rocks of the Canadian Shield (De Blij, 2005). Our study region is located in the northern part of the province called Nunatsiavut ("Our Beautiful Land") that belongs to the Inuits.

During the last glaciation (between 110 and 10 ka BP), the Laurentide Ice Sheet covered the entire region, except for some nunataks (high ice-free peaks extending above the ice dome of the ice sheet) in the Torngat Mountains. The southeastern part of Labrador was free of ice ca. 11,000 years BP (Dyke and Prest, 1987; Dyke et al., 2002). Between 11 and 6 ka BP, the retreat of the ice sheet exposed the northern part of Labrador while wasting ice persisted in the central high plateau area of Labrador-Ungava until about 6 ka BP (Lamb, 1980; Engstrom and Hansen, 1985). Large parts of Labrador are located between 450 m and 750 m above sea level. However, in the northeastern part there are mountain ranges (Torngat, Kaumajet) that rise to 1600 m and 1800 m above present-day sea level (Short and Nichols, 1977). The western and central regions of Labrador are characterized by broad flat till plains that are covered with lakes and peatlands. Closer to the coast, bedrock-controlled hills dissected by large rivers dominate the landscape (Engstrom and Hansen, 1985).

The climate of Labrador is characterized by long cold winters and short cool and moist summers. The temperature and moisture regimes are dominated by north–south transgressions of cold dry Arctic air and warm moist Atlantic air masses (Hare and Hay, 1974). There is a strong climatic contrast between the coastal and the interior Labrador. The cold Labrador Current (Fig. 1), which flows southward from the Arctic through Nares Strait and Baffin Bay, has a significant influence on the local climate (Engstrom and Hansen, 1985). In July and August, the mean temperature along the coast is around 10 °C, while inland the mean temperature can reach 16 °C, with occasional peaks as high as 38 °C. These conditions are reversed during the winter when mean temperatures are around 3 °C along the coast and warmer than inland temperatures (Short and Nichols, 1977; Ullah et al., 1992). The mean annual precipitation in Labrador varies from 750 mm in the north to 960 mm in the south. Precipitation is fairly