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Low oxygen events in the Laurentian Channel during the Holocene

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ABSTRACT

Geochemical and micropaleontological analyses were carried out on a 35 cm box core (CR06-TCE) spanning the last 6000 years in the Esquiman Channel, a northeast arm of the Laurentian Channel in the Gulf of St. Lawrence. A 0.6‰ decrease of $\delta^{18}O$ in benthic foraminifer *Globobulimina auriculata* shells characterizes the upper 10 cm of the core and suggests a warming of the bottom waters. This change is concomitant with increased percentages of the low-oxygen tolerant benthic foraminifer species *Brizalina subaenariensis* and the Atlantic water species *Oridorsalis umbonatus*. Although a precise timing cannot be established, notably because of the smoothing effect of bioturbation, the amplitude of the trend recorded in the Esquiman Channel is coherent with that of the regional warming observed in the bottom water of the main axis of the Laurentian Channel over the last century. Warm bottom water conditions, however, are not exclusive to the recent time interval as shown by data from the lower part of the core, which are also characterized by low $\delta^{18}O$ values in *G. auriculata* and occurrence of both *B. subaenariensis* and *O. umbonatus*. Such data suggest the existence of low-oxygen and relatively high temperature conditions in the bottom water of the Esquiman Channel about 4 to 6 kyrs ago likely related to enhanced inflow of Atlantic water in the Gulf of St. Lawrence through the Cabot Strait and the Laurentian Channel. These results highlight the sensitivity of bottom water properties in the Gulf of St. Lawrence to changes in the western North Atlantic circulation.

1. Introduction

Several studies suggest that oxygen levels are generally decreasing both in the coastal ocean (Diaz and Rosenberg, 2008) and in the deep ocean (Keeling and Garcia, 2002). However, a recent publication by Gilbert et al. (2010) highlights a significant difference between most oxygen trends described in the scientific literature and the trends calculated from the median of raw oxygen data. On this basis, Gilbert and colleagues suggest the existence of a bias in the literature in favor of negative trends of oxygen concentrations in the open ocean. Gilbert et al. (2010) also noticed that most publications on hypoxia report oxygen data only from one or two years and that the long-term perspective of oxygen level change is often missing. Consequently, some of the records reporting trends toward hypoxia are equivocal and the increasing number of known hypoxic areas might be the result of increased awareness, research and monitoring efforts. While there are O_2 measurements covering the last decades, none permits documenting the pre-industrial period (e.g., Fonselius and Valderrama, 2003; Whitney et al., 2007). It is therefore of primary importance to develop longer time series from the regions that are subject to changes in O_2 content. Hence, studies have been undertaken using sedimentary sequences to develop proxy-records of coastal eutrophication-induced hypoxia and paleo-O_2 trends (cf. Gooday et al., 2009).

In the Lower St. Lawrence Estuary (LSLE), an oxygen decline has been evidenced by instrumental data of oxygen concentration over the last 70 years (Gilbert et al., 2005). The O_2 concentration in the LSLE bottom water reflects the balance between O_2 supply from the surface through physical transport and O_2 consumption by respiration of organic material. The concentration of dissolved oxygen in the deep water is thus particularly sensitive to changes in both ocean circulation and biological activity (Joos et al., 2003). Whereas enhanced marine organic matter fluxes in the 1960s may have contributed to local oxygen consumption in the bottom water of the LSLE (Benoit et al., 2006; Thibodeau et al., 2006), a significant warming of about +1.7 °C in bottom waters during the last century has probably played a major role in the development of regional hypoxia (Gilbert et al., 2005; Thibodeau et al., 2010a). A warming of the same amplitude was reconstructed from a sediment core in the Gulf of St. Lawrence (Genovesi et al., 2011). These data suggest that the last century was marked by a warming of bottom waters throughout the Laurentian Channel from the Cabot Strait to the lower estuary. The warming could have been induced by a change in the proportion of the different water masses forming the Laurentian Channel Bottom Waters (LCBW; cf. Gilbert et al., 2005). A higher proportion of the low-oxygenated Atlantic temperate slope water (Pershing et al., 2001) compared to the well-oxygenated Labrador subarctic slope water would account for both the warming and a significant part of the O_2 depletion.

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The Esquiman Channel is located in the northern part of the Gulf of St. Lawrence. The bottom of the water column is occupied by the northeast branch of the LCBW (Fig. 1). It is remote from industrial or agricultural activities and unlike the LSLE, primary productivity in surface water of the Esquiman Channel does not seem to be affected by anthropogenic nitrate inputs (Thibodeau et al., 2010b). The Esquiman Channel is presently characterized by hemipelagic sedimentation with low detrital input. Hence, the postglacial sedimentation rate is low, around 0.01 cm a^{-1} or less (de Vernal et al., 1993). Therefore, sedimentary cores from this location are not suitable for the reconstruction of changes with a high temporal resolution, decadal or centennial. They nevertheless permit to estimate changes over the last millennia.

Here, we present benthic foraminifer and dinocyst assemblages along with geochemical and isotopic composition of the organic matter (C_{org}, C_{org}: N, $\delta^{13}C_{org}$ and δ^{15} N) and isotopic composition in calcareous shells of benthic foraminifer ($\delta^{18}O_c$ and $\delta^{13}C_c$) from core CR06-TCE collected in the Esquiman Channel (Fig. 1). The objectives of the study are to reconstruct primary productivity and changes in the properties of bottom waters, in order to verify the respective effects of organic matter fluxes and bottom water temperature on deep water oxygen content.

2. Regional setting

The Estuary and Gulf of St. Lawrence are part of the second largest freshwater system in the world (freshwater discharge of 10,900 m^3 s^{-1} (Bourgault and Koutitonsky, 1999)). The dominant topographic feature is the Laurentian Channel, a submarine valley (250–500 m deep) that extends over 1240 km landward from the continental shelf edge of the eastern Canadian coast to Tadoussac (Fig. 1). In the Gulf, the Laurentian Channel branches into the Estuary and the Anticosti Channel to the northwest and into the Esquiman Channel to the northeast. The Esquiman Channel follows the western Newfoundland coastline and extends toward the narrow and shallow Strait of Belle-Isle (16 km wide and 60 m deep).

The circulation in the Gulf is estuarine. It is characterized by three water layers: 1) a thin seaward-flowing surface layer (down to 50 m) of low salinity that originates from the mixing of seawater with freshwater runoff from the Great Lakes, the St. Lawrence River and the Northern Quebec drainage system, 2) a seasonal intermediate, cold and saline layer between 50 and 150 m, and 3) a warmer and saltier deep layer flowing landward that corresponds to a mixture of the Labrador Subarctic Slope Water and Temperate Atlantic Slope Water (Dickie and Trites, 1983). The LCBW is isolated from the atmosphere by a permanent 100–150 m deep pycnocline. Hence, the bottom waters gradually lose oxygen through respiration and remineralization of organic matter as the water mass flows landward from the mouth of the Cabot Strait to the head of the channels. At depths greater than 150 m, the oxygen consumed through respiration cannot be replenished by winter convection (Petrie et al., 1996). The oxygen balance is thus very sensitive not only to changes in the organic matter fluxes but also to changes in the rate of organic matter remineralization. Oxygen concentration within the LCBW at the head of Esquiman Channel is less than 100 µmol L^{-1}

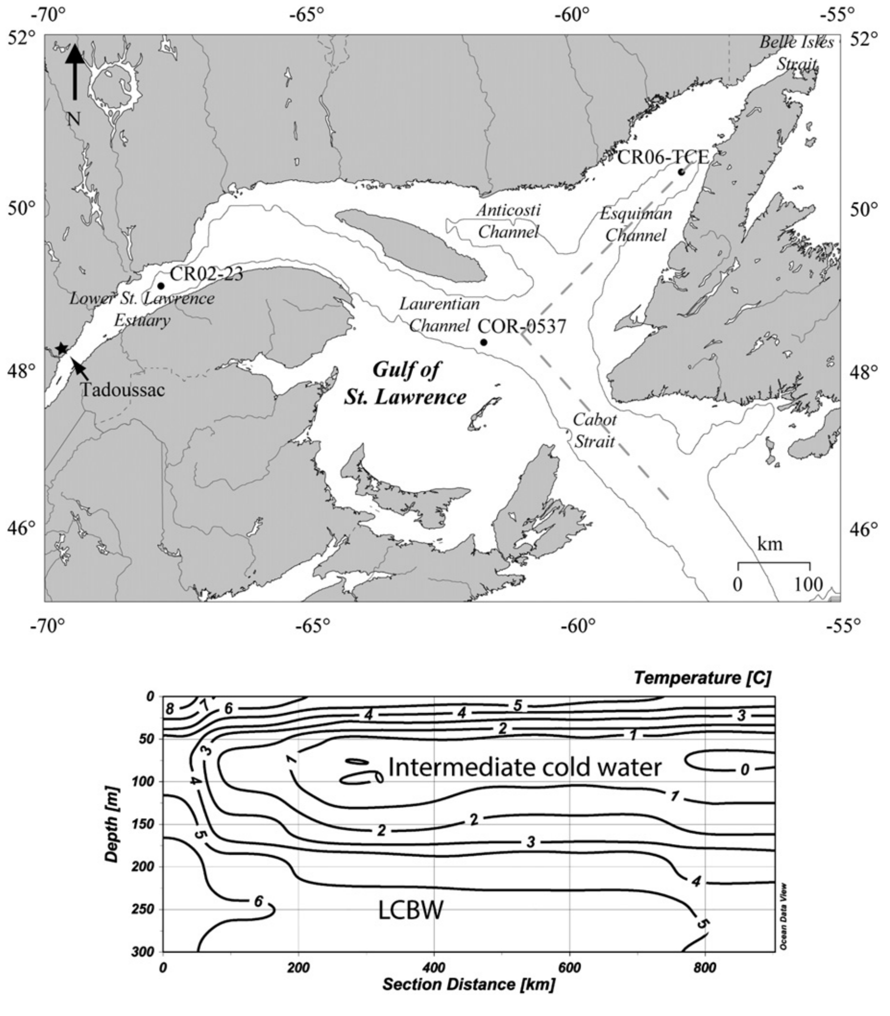

Fig. 1. Upper panel: Map of the St. Lawrence marine system with location of the sediment cores. Bottom panel: cross section (dashed gray line in the upper panel) of temperature (°C) from Cabot Strait (left side) to coring station CR06-TCE (World Ocean Database, 2009).