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The Allerød–Younger Dryas–Holocene sequence in the west-central Champlain Sea, eastern Ontario: a record of glacial, oceanographic, and climatic changes

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Abstract

The aragonite mineralogy and geochemistry of the mollusc faunas preserved at Navan and Bearbrook, Ontario, serve as proxies of original seawater chemistry. The composite section spanning 12,980–10,980 cal yr BP includes the Younger Dryas (YD) paleoclimatic oscillation. Oxygen isotopes demonstrate the onset of cooling with the YD event, in addition to the lowering of marine values by the influx of isotopically light glacial meltwater from Lake Agassiz. Impact of cooling and dilution is reduced or eliminated with the start of the Holocene, when water temperatures and salinities for Champlain Sea (CS) seawater were 8–16 °C and 27–34 ppt, respectively. Overall, oxygen isotope values deceased to −3.5% during the YD mainly due to freshening by glacial meltwater. Carbon isotopes confirm the rise in atmospheric CO_2 concentration at the YD–Holocene transition. Marine strontium isotope values for the Allerød–YD–earliest Holocene range from 0.709151 (16,210 cal yr BP) to 0.709145 (12,980 cal yr BP) and 0.709142 (10,950 cal yr BP). The oceanographic changes recorded for the CS are in agreement with the evolutionary phases of Lake Agassiz and deglaciation dynamics of the Laurentide Ice Sheet. The volume and direction of meltwater discharge from Lake Agassiz alternated between the Gulf of Mexico during the Allerød, via the Great Lakes through the CS to the North Atlantic during the YD, and back to the Gulf of Mexico during the early Holocene, but with diminished impact.
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1. Introduction

The glacial, oceanographic, and climatic history of the last deglaciation has been extensively documented on a nearly global scale and extent in numerous papers (e.g., Peteet, 1995). Circumstances surrounding this event are well documented in the North Atlantic region (Lowe et al., 1994). Fewer and less definitive studies document its existence in the southern hemisphere, but the database is gradually increasing (Rutter et al., 2000). The abrupt start and termination of this event have been clearly recognized by the oxygen isotope trends in ice cores from Greenland (Johnsen et al., 1992; Dansgaard et al., 1993; Grootes et al., 1993; Stuiver et al., 1995) and Antarctica (Neftel et al., 1988). The use of the ice cores as stratotypes for the last deglaciation, required that the relationship and necessary discrepancies between radiocarbon and calibrated ages have been adequately addressed (Stuiver et al., 1995, 1998). The chronologies of the major ice cores (GRIP and GISP2) have been reconciled by the work of Southon (2002), among others. Furthermore, because of intercontinental correlation problems between terrestrial and non-terrestrial sequences of the Younger Dryas (YD) event, a new sequence stratigraphy has been proposed by the INTIMATE Group based on the oxygen isotope signals and trends of the GRIP ice core from Greenland (Björck et al., 1998). Several stadial episodes have been recognized such as the Greenland Interstadial (GI-1) and Greenland Stadial (GS-1), where the GS-1 episode

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corresponds to the YD event. This event is based on numerous studies and has been dated from 12,790 to 11,450 cal yr BP (BP = 1950 AD).

The YD event is well documented in North America from the Atlantic to the Arctic to the Pacific (e.g., Mott et al., 1986; Wright, 1989; Yu and Eicher, 1998; Rutter et al., 2000; Friele and Clague, 2002; Shuman et al., 2002). The last deglaciation, which includes the YD, had a significant impact on the waters of the Gulf of Mexico and North Atlantic. These oceanographic and climatic impacts differed greatly depending on the direction and volume of the meltwater discharge derived from the Laurentide Ice Sheet (Teller, 1988; Broecker et al., 1989; Duplessy et al., 1992; Teller et al., 2002). Atmospheric CO_2 impacts measured directly from ice-trapped gas, or from proxies such as carbon isotopes in foraminifera and stomatal frequency of leaves suggest that concentrations were lower during glacial and deglaciation stages than today (Neftel et al., 1988; Monnin et al., 2001; McElwain et al., 2002).

The Champlain Sea, a marine extension of the North Atlantic Ocean, inundated the Ottawa, St. Lawrence and Lake Champlain Lowlands from about 12,490 to 10,950 cal yr BP (11,000–10,000 ^{14}C yr BP; e.g., Elson, 1969; Richard, 1974; Cronin, 1979; Terasmae, 1980). Sediments deposited during the incursion contain an abundant marine invertebrate fauna (Wagner, 1970). Marine bivalves dominate the invertebrate fauna found at Navan and Bearbrook, Ontario (Fig. 1), the dominant species being *Hiatella arctica* and *Macoma balthica* (Wassenaar et al., 1988). As these species are extant quantitative ecological comparisons can be made between Champlain Sea (CS) bivalves and their modern counterparts.

Several phases in the history of the CS have been recognized in littoral deposits on the basis of elevations above sea level, radiocarbon dates, and faunal assemblages. Elson (1969) distinguished an early "*Hiatella arctica*" phase, characterized by cold subarctic water that lasted from about 13,180 to 12,210 cal yr BP (11,800–10,800 ^{14}C yr BP). The second period, the "*Mya arenaria*" phase, was characterized by warm boreal water, which lasted from about (10,800 to 10,200 ^{14}C yr BP) in the eastern CS Basin. Cronin (1979) identified a "Transitional Phase" from about 14,070 to 13,080 cal yr BP (12,500 to 11,600 ^{14}C yr BP), characterized by the mixed association of fresh water ostracodes with euryhaline marine ostracodes and molluscs.

In a study of CS deposits in Quebec, Hillaire-Marcel (1980) established six bivalve communities on the basis of substrate and physicochemical properties of the ambient water. In the Ottawa–St. Lawrence Lowlands, Rodrigues and Richard (1983) described seven marine bivalve and cirriped communities. These studies suggest that normal marine conditions persisted during the "*Hiatella arctica*" phase of the Champlain Sea, and that salinity subsequently decreased and temperature increased as the sea freshened in the Lowlands (Hillaire-Marcel, 1980; Rodrigues and Richard, 1983, 1986). Wassenaar et al. (1988) concluded that after emergence of the sediments and ~13,000 yr of burial in the diagenetic environment saturated with meteoric water, the aragonitic fossils were still preserved in their original mineralogy, microstructures, and geochemistry. It was further assumed that glacial meltwater from the Laurentide ice sheet had a $\delta^{18}O$ composition of −15 to –30‰ (SMOW; Hillaire-Marcel, 1988). Based on these estimates, shallow-water *Macoma balthica* probably lived in waters with a salinity of 10–30 ppt, whereas deeper-water *Hiatella arctica* preferred waters with salinity of 20–35 ppt. However, in many CS deposits the two species occur together in the sediments implying (Wassenaar et al., 1988) no analogue or that at least one of the taxa is not in situ. It is believed from the attitude of the shells and their disarticulation that the specimens of *Macoma* most likely transported into the sedimentary horizons at Navan and Bearbrook.

The purpose of this study is to evaluate the geochemistry of a well-preserved macroinvertebrate fauna at Navan and Bearbrook, Ontario. The material at these two localities provides the opportunity to assess environmental influences on the trace element and stable isotope compositions of CS bivalves. Specifically we hope to comment on the paleoenvironmental conditions at these two localities in the larger framework of the isotopic history of Champlain seawater, and we consider deglaciation of the western CS with respect to glacial, oceanographic, and climatic events of the YD. The oceanographic connection of the CS to the Gulf of Mexico and the North Atlantic are to be assessed on the basis of stable isotope trends during the Allerød–YD–Holocene sequence.

2. Sedimentology

Sixty-four samples of *Hiatella arctica* and *Macoma balthica* were collected from two stratigraphic sections of Champlain sediments at Navan and Bearbrook (Figs. 1 and 2), and this database was supplemented by data of others (Table 1). The marine sediments at Navan represent an upward-fining sequence of sandy gravel to silty clay (Fig. 2). Shell material generally occurs in layers or lenses with concentrations greater than in the surrounding sediments (cf. Rodrigues and Richard, 1986). The marine sediments in the section at Bearbrook are silty clays except for the fine sand at the top of the unit (Fig. 2). Shell material is found in distinct lenses/layers here as well. The majority of the material (*Hiatella*) was collected from horizons throughout the

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