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Evidence for large-amplitude biome and climate changes in Atlantic Canada during the last interglacial and mid-Wisconsinan periods

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ABSTRACT

Last interglacial and mid Wisconsinan pollen data from sedimentary sequences of Cape Breton Island in Atlantic Canada were analyzed to reconstruct biome and climate conditions. Our results show warm and humid climate with mean annual temperature 6–7°C higher than today, up to 15–20% more sunshine and significantly longer growing season that fostered growth of temperate trees during the optimum of the last interglacial. The northern limit of the deciduous forest biome was then about 500 km north of its modern limit. Towards the end of the interglacial the deciduous forest was replaced by conifer/hardwood forest and boreal forest. Climate was then similar to modern. The transition from interglacial to glacial was marked by a change towards coniferous forest related to colder and dryer conditions. During the mid Wisconsinan, the development of forest tundra to boreal forest reflects migration of the Arctic Front and significant cooling with mean annual temperature anomalies of −8 to −12°C. The overall time series reflect large amplitude climate changes that point to high sensitivity of the southeastern Canadian margins, likely as a response to latitudinal shifts of the Gulf Stream and variable strength of the Labrador Current together with changes in large-scale atmospheric circulation pattern.

Introduction

The Atlantic Provinces of Canada are situated in a transitional zone marked by the influence of the Gulf Stream originating from the south and the cold Labrador Current flowing from the north along the coastline. Hence, the sea-surface temperature (SST) gradient off Nova Scotia is particularly large, with typical temperature difference of 5–10°C across a few km (Young and Sikora, 2003). The vegetation of southeastern Canada is characterized by high diversity, with the boreal forest in the north being gradually replaced by deciduous-dominated forest southward. Today, the dominant vegetation in Atlantic Canada is a mixed conifer/hardwood forest, which is an ecotone between the deciduous forest and boreal forest biome (Goldblum and Rigg, 2010). Its spatial distribution in Atlantic Canada is related with the boundary between maritime and continental polar air masses (cf. LaFontaine et al., 1990).

The confluence of the warm and saline Atlantic waters with the cold and fresher Arctic waters carried through the Labrador Current drives the position of the Arctic Front, which corresponds to the maximum limit of sea-ice extent. Ocean–atmosphere interactions are exceptionally vigorous over oceanic frontal zones and the Gulf Stream position correlates with large-scale atmospheric circulation pattern (e.g., Nakamura et al., 2008; Kwon et al., 2010). A northward position of the Gulf Stream is generally observed together with anticyclonic atmospheric circulation and strong westerlies over Atlantic Canada. Such a situation corresponds to a decrease of the amount of cold freshwater carried by the Labrador Current along the southeastern Canadian coasts (Pickart et al., 1999; Rossby and Benway, 2000). The decrease in southward advection of cold freshwater masses may drive northward migration of the Arctic Front. Conversely, the increase in southward export of cold freshwater may cause a southward shift of the Arctic Front. Hence lateral shifts in the Arctic Front have the potential to affect large-scale atmospheric circulation (e.g., Masson-Delmotte et al., 2005; Wohlfarth et al., 2008).

During the last 130,000 yr, large-amplitude climate changes at mid to high latitudes of the Northern Hemisphere were accompanied by major shifts in the vegetation cover as documented from pollen records of western Europe (e.g., de Beaulieu and Reille, 1984, 1992; Allen et al., 2000; Allen and Huntley, 2009), southeastern United States (e.g., Watts, 1971; Grimm et al., 1993, 2006; Heusser and Oppo, 2003) and of western North America (e.g., Whitlock and Bartlein, 1997; Grigg and Whitlock, 2002; Woolfenden, 2003; Jiménez-Moreno et al., 2007). However, the current knowledge of vegetation and climate changes in northeastern North America is limited by the rarity of representative sedimentary sequences due to glacial erosion during the last ice age.

In southeastern Canada, at the margin of the former Laurentide Ice Sheet (e.g., Dyke, 2005), exceptionally well-preserved sedimentary sequences of the last interglaciation sensu lato (Marine Oxygen Isotope Stage 5 (MIS 5), ca. 130–75 ka BP) and the mid Wisconsinan (MIS 3, ca. 60–30 ka BP) periods permit the documentation of regional vegetation and climate changes (cf. de Vernal and Mott, 1986; de Vernal et al., 1986). This paper presents a reanalysis of the pollen record from Cape Breton Island in southeastern Canada, which permitted the quantification of regional vegetation and climate changes, including temperature, moisture availability and sunshine, throughout the last interglacial

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sensu lato and the mid Wisconsinan periods, prior to the last glacial maximum. Because of its geographical setting, close to the modern Arctic Front, Cape Breton Island is ideally located to study large-scale ocean circulation and air mass trajectory. Beyond the regional climate reconstructions, the originality of this paper is to present estimates of sunshine, hence cloud cover, and to document large-scale (or synoptic) atmospheric circulation patterns. Records of change in sunshine conditions developed from pollen-based climate reconstruction (cf. Fréchette et al., 2008) are important for paleoclimatology because the atmosphere responds more quickly than other components of the Earth system to climate change (Mayewski et al., 1997). Changes in the vegetation of Atlantic Canada in relationship with the migration of the Arctic Front, shifts in the Gulf Stream position and changes in atmospheric circulation patterns are the questions we address in this study.

Regional setting: climate and vegetation

East Bay (45°57′N, 60°32′W) and Castle Bay (45°55′N, 60°39′W) sections are located on Cape Breton Island along the northeast shore of Bras d'Or Lake, a body of brackish water (20–30 psu) confluent with the Atlantic Ocean (Fig. 1). Present-day climate on Cape Breton Island is typically Maritime Boreal with cool winters and summers (mean of −4.1°C and 16.0°C, respectively) and average precipitation of 1520 mm/yr (Environment Canada, 2011). Mean temperatures of the warmest month (MTWA) and coldest month (MTCO) are 17.5°C and −7.3°C respectively, and the seasonal temperature contrasts or seasonality (MTWA–MTCO) is 24.8°C (Table 1). The growing season defined from the period with daily mean temperature above 5°C ranges from 180 to 200 days and the mean growing-degree-days above 5°C (GDD5) is 1560°C-day (Environment Canada, 2011).

On Cape Breton Island, the coastal influence is important, notably because fog results in lesser sunshine than in continental areas further inland. In the study area (45–46°N, 60–61°W), summer sunshine values average 50% (sunshine is expressed as percent of bright sunshine from sunrise to sunset), whereas it is generally higher at inland locations of similar latitude (Environment Canada, 2011). On Cape Breton Island, winds are strongest in the colder months and blow most frequently from the west or northwest, whereas in summer dominant winds blow from the southeast along the coast following the Gulf Stream.

The present day vegetation of Cape Breton Island can be divided into three distinct zones, which are mostly determined by elevation. The lowlands are characterized by the Acadian Forest, composed of mixed woods (coniferous and temperate tree species) (Loo and Ives, 2003). On the highlands, the landscape is characterized by lesser tree species-diversity and is dominated by the Boreal Forest with pure stands of Balsam Fir (*Abies balsamea*). At even higher elevation (>450 m), the boreal forest is replaced by a transitional forest tundra or Taiga. The vegetation around the Bras d'Or Lake is part of the mixed hardwood–softwood Acadian Forest that covers from the Great Lakes to New England and Atlantic Canada. Sugar Maple (*Acer saccharum*), Yellow Birch (*Betula alleghaniensis*) and American Beech (*Fagus grandifolia*) grow on highlands and hill slopes. Coniferous trees (*Abies*, *Picea*, *Pinus*) occupy valleys and Hemlocks (*Tsuga*) occasionally occur on wet hill slopes.

Modern pollen assemblages of all Cape Breton Island sites (n = 9) are portrayed in Figure 2 (Livingstone, 1968; Railton, 1973), which shows a good representation of the mixed hardwood–softwood Acadian Forest around Bras d'Or Lake. *Betula*, *Acer* and *Fagus* are the dominant taxa with some coniferous taxa. The recent (last 3000 yr) pollen assemblages from McDougall Pond (47°00′N, 60°34′W) (Fig. 1), in Northern Cape Breton Island, are also shown for comparison (de Vernal et al., 1985). As in modern pollen assemblages, *Betula* and *Acer* are abundant.

Palynostratigraphy of the East Bay and Castle Bay Late Pleistocene sequences

The East Bay and Castle Bay sections contain non-glacial organic-rich deposits (Mott and Grant, 1985). Embedded fossil wood were dated from U/Th measurements (de Vernal et al., 1986). Both sections were analyzed for their pollen content and three palynostratigraphic units

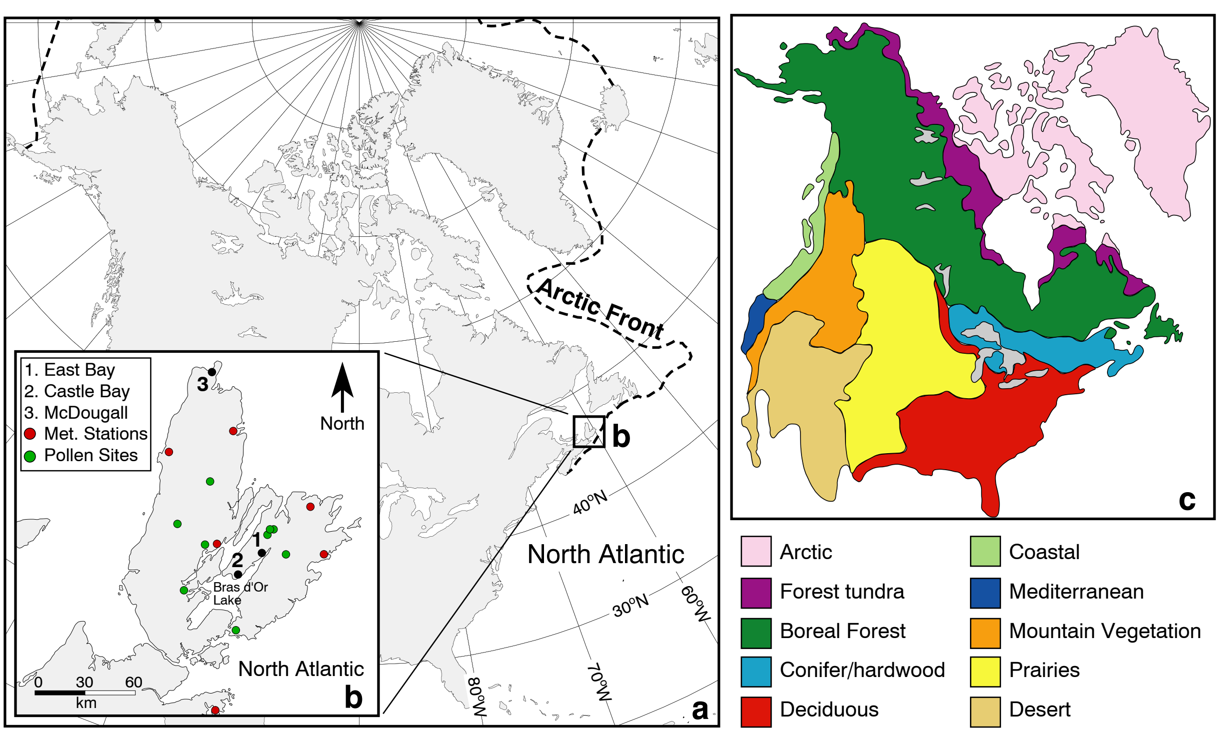

Figure 1. Map of the study area. a. North America and Greenland, and position of the Arctic Front in northern North Atlantic. The Arctic Front corresponds to the present day maximum sea-ice limit. b. Location map of East Bay (45°57′N, 60°32′W) and Castle Bay (45°55′N, 60°39′W) sections and McDougall Pond (47°00′N, 60°34′W) on Cape Breton Island, Nova Scotia, Atlantic Canada. The location of the 6 meteorological stations and the 9 modern pollen sites (see Table 1) on Cape Breton Island is also indicated. c. Major vegetation types (or biomes) of North America and Greenland as synthesized from Fedorova et al. (1994) (from Whitmore et al., 2005). Cape Breton Island is within the conifer/hardwood domain.