



Researchers look for links among paleoclimate events

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Unbalanced Budget

The discovery that the ocean is a significant sink for methyl bromide highlights a huge deficit in our knowledge about sources. As it turns out, estimated sinks for methyl bromide outweigh known global sources by about 70 Gg per year (see Table 1). With average methyl bromide concentrations of 10 ppt (parts per trillion) in the global atmosphere, increased removal in the ocean must be offset by unidentified sources, which could exceed the presently known industrial emissions.

"The problem is that we keep finding sinks," said Butler, who believes that "the most likely solution to the deficit [in methyl bromide sources] is a missing natural terrestrial source."

"We're not sure what's producing it," said King. Researchers have measured methyl bromide production by certain marine organ-

isms, including kelp and phytoplankton species. But attempts to extrapolate these numbers globally come up short. "All of the studies are looking at one set of species rather than at the whole ocean, and they are working from cultures, which are very different from the open ocean," King said.

By emitting methyl bromide into the air, Butler suggests, humans have shifted the global balance so that there is more degradation in the ocean. "If we stopped emitting methyl bromide, the industrial contribution would probably be gone from the atmosphere within 5 years," he said, noting that this chemical is not as persistent as CFCs are.

Butler believes that "policymakers need to make an informed decision about restricting emissions. In order to do that, we need to find and quantify the missing puzzle pieces: production and consumption in the ocean, missing methyl bromide sources, and new terrestrial sinks.

As knowledge increases, the human contribution may turn out to be a big piece—or a relatively small one—compared to other global sources such as forests, soils, and coastal upwellings. Regulators remain guarded. "If we're coming to understand the natural system, including production and consumption, we still have to look at anthropogenic contributions to stratospheric ozone depletion, since bromine is so active in the stratosphere," said Thomas. Until the puzzle is solved, our understanding of this and other global cycles is so fragmentary that we cannot determine whether our contribution puts the Earth's protective shield in jeopardy. But we do know that "lowly" marine bacteria are probably our allies, quietly consuming a compound that at certain levels, can break down the atmospheric shield protecting life on the planet from ultraviolet radiation.—*Elaine Friebele*

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Several peculiar features appear in climate-related records at about 8000 years BP and are occasionally referred to as the 8-ka events. For example, paleolake data from intertropical Africa show a drop in water levels [e.g., *Gasse and Van Campo*, 1994], and the Antarctic Byrd ice-core record reveals a decrease in atmospheric CO₂ of about 40 ppm [*Neftel et al.*, 1988]. Similarly, detailed paleoceanographic studies in the northwest North Atlantic reveal a decrease in primary productivity and burial rates of biogenic carbonates at precisely 8000 years BP [*Hillaire-Marcel et al.*, 1994], and the oxygen and deuterium values in Greenland ice show at least one sharp and short-lived decrease [*Johnsen et al.*, 1992].

In eastern Canada (Figure 1), this time interval is of particular interest since it post-dates a short-lived advance and retreat of ice from the Labrador dome and coincides with the final collapse of the Hudson Bay ice dome and the sudden drainage of the proglacial lakes Ojibway and Agassiz. Based on the idea that the global climate system—when forced by a single event—could produce non simultaneous climate signals, it was tempting to link the dramatic Laurentide ice decay and glacial lake drainage with the 8-ka BP climate changes. The cause could be a direct oceanographic effect or a reorganization of atmospheric circulation patterns.

To examine the origin and impact of these "8-ka events" and the possibility of errors or bias in geological ages during the interval, an informal workshop was held at

GÉOTOP in Montréal, as a side contribution to the Climate System History and Dynamics (CSHD) project. Prior to discussion, the participants set up a synopsis of the so-called 8-ka events outlined above. Evidence was given for an 8-ka climatic event in a high-resolution paleolimnic record from Germany, matching a drop in the ¹⁸O record of the Greenland Icecore Project (GRIP). Various

proxy records of environmental changes in the High Canadian Arctic coasts were examined, as well as those from small Arctic Island ice caps. The rapidly changing ice configurations in Hudson Strait and their influence on the Labrador shelf and slope were also addressed. Changes in oceanographic conditions were illustrated in the Labrador Sea and the eastern North Atlantic. Finally, floral, faunal, and isotopic evidence was presented for contemporaneous terrestrial conditions southeast of the southeastern Laurentide Ice margin.

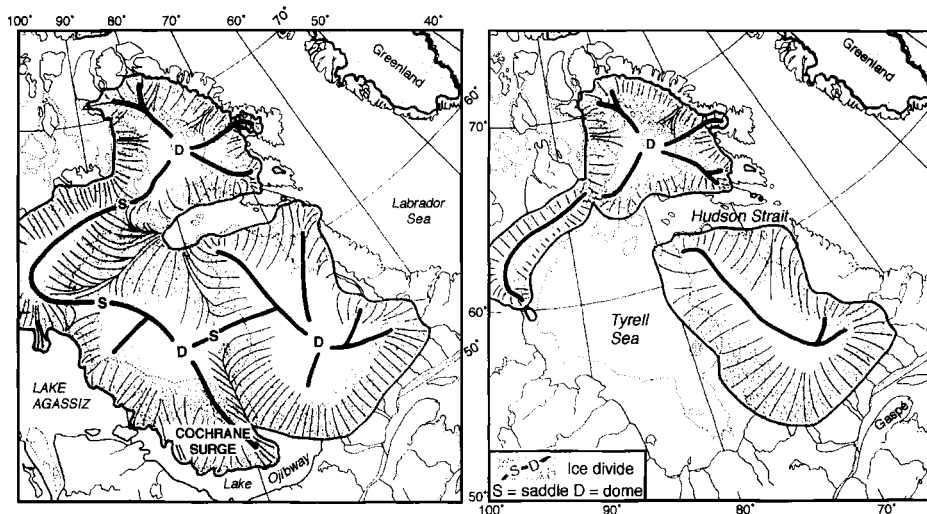


Fig. 1. Late glacial paleogeography in northeastern North America [Dyke and Prest, 1989] at 8400 years BP (left) and ~7900 years BP (right). Within a few hundred years, the Cochrane surged into Lake Ojibway and the Hudson Bay ice dome finally collapsed. The latter was accompanied by the northward drainage of $\sim 1.2 \times 10^5 \text{ km}^3$ of fresh water from the southern glacial Lakes Agassiz and Ojibway, which occurred at precisely 8–7.9 ka BP, as measured with the ¹⁴C-dating method. The collapse of the ice sheet and the opening of the Hudson Bay corridor was likely responsible for major reorganizations of atmospheric circulation; this in turn may have influenced nutrient supply in the northwestern North Atlantic.

The comparison of records and the critical examination of the chronologies, most of which were based on the ^{14}C dating method, led to the conclusion that there are likely independent, nonsynchronous changes of different magnitude and duration. In examining the ice-core and lake isotope event, we find that the paleolimnic record from Europe and the ^{18}O data from ice caps from both the Greenland and Agassiz ice caps show a correlative short-lived negative oscillation of 1–1.5% spanning less than 200 years centered on 8200 calendar years before present (that is, 7400 ^{14}C years BP).

Rapid Changes Related to Ice Dynamics in Eastern Canada

The onshore to offshore eastern Canadian records reveal a succession of major events occurring from ~8600 to ~7500 ^{14}C years. These changes thus pre-date the above ice-core and lake isotope event, forcing us to reject a simple causal link between them, if there is indeed any link. Based on ^{14}C ages, the succession of changes in ice dynamics in eastern Canada was pieced together. Throughout the Canadian Arctic Archipelago the occurrence of whale bones decreases from 8500 to 8000 years BP, and driftwood deposition begins at this time; this pattern reflects the onset of major Arctic sea-ice delivery to the High Arctic Canadian Islands. In the Hudson Strait, ice occupying the Eastern Basin of the Hudson Strait collapsed back into Ungava Bay at 8600–8400 years BP.

Following the deglaciation of the eastern Hudson Strait, the Hudson Bay Ice Dome surged into glacial Lake Ojibway in two phases. These were the Cochrane surges [Hardy, 1977], which moved the ice front possibly as much as 1500 km southward between 8300 and 8000 years BP. As a consequence, the Hudson Bay Ice Dome collapsed rapidly, and at precisely 8000–7900 years BP, Lakes Ojibway and Agassiz drained northward through Hudson Strait, allowing marine water to enter the bay. The Ojibway drainage event was recorded by traceable sediment units in the southeast Hudson Bay area [Hardy, 1977] as well as throughout Hudson Strait [Kerwin, 1996].

The eastern Hudson Strait ice collapse left behind an accumulation of detrital carbonates overlain by ice-rafted debris both on the shelf and on the continental rise. There, the sedimentological signature of the sequence dated between 8500 and 7500 years BP mimics that of most "Heinrich" layers in the Labrador Sea, which appear as sets of detrital carbonate and ice-rafted debris layers. Despite the distinct sedimentology of the event, changes in the offshore salinity and temperature are not recorded in the isotopic composition of benthic and planktonic foraminifera, nor are they present in the reconstruction of

sea surface conditions based on dinocyst transfer functions. Nevertheless, by 8000 years BP, a significant decrease in marine productivity in the northwest North Atlantic is recorded by a ^{13}C -depletion in planktonic foraminifera and by a drop in microfossil fluxes and organic and inorganic carbon burial rates.

In southeastern Quebec (Gaspé Peninsula), there are no changes in faunal assemblages that suggest climate deterioration precisely at the target time, but there is a sudden decrease in pollen influx at ~8000 years BP in two ecotonal, subalpine lakes. A synchronous major pollen influx decrease is also recorded in two coastal lakes of New England. At the same time, the isotopic composition of aquatic cellulose in Lac à Euloge sharply decreased. Together the faunal, pollen influx, and isotopic data suggest a change in the hydrological budget that likely resulted from altered atmospheric circulation patterns.

In spite of chronological uncertainties inherent to ^{14}C dating of marine fossils, the timing of the changes in ice dynamics in eastern Canada, spanning close to 1000 years, seems consistent on a regional scale. Although large changes in the northeastern Canadian ice configurations are clearly recorded, there is no indication of major variations in sea-surface and air temperatures. Actually, conditions as warm as present may have prevailed over eastern Canada at 8000 years BP.

There are two difficulties in attempting to relate the ice core and lake isotope event to changes in ice dynamics in eastern Canada. First, any short-lived, moderate amplitude climate oscillation (that would be associated with the isotopic shift recorded in the ice core) is unlikely to be detected in most marine records due to smoothing by bioturbations. Second, the time lag of at least 600 ^{14}C years between the two events is too long to support any cause-effect relationship.

The identification of the two distinct sets of 8-ka events leaves the door open to several questions that the informal working group plans to address next: Can we identify a causal link for the climate oscillation described in Greenland and Europe at 7400 ^{14}C years BP (Event A)? And, was there a change in North Atlantic air and sea temperatures that resulted from the major changes in Canadian ice configurations at precisely 8000–7900 ^{14}C years BP?

Another missing piece of information is the real atmosphere-sea surface ^{14}C gradient around 8000 ^{14}C years BP in the North Atlantic. What triggered the observed decrease in marine productivity at ~8000 ^{14}C years BP? Could it be associated with minor physical oceanographic changes, and/or with decreased eolian supply of nutrients that could have resulted from atmospheric circulation

reorganization? There may be a causal link—yet to be identified—between the ice dynamic events associated with the Laurentide ice decay and the long-term hydrometeorological changes of lower latitudes reflected in intertropical lake levels or in the CH_4 -decrease [Blunier *et al.*, 1995] for example.

At least, the participants of the Montreal meeting agreed on one conclusion: future attempts to compare the climate response to specific events in high-resolution records from ice, oceanic, and continental archives, as was done during the 8-ka event workshop, should coincide with major land- or marine-based international programs such as the polar-equator-polar continental paleoclimate programs (PEP I, II, III) or the international marine projects such as IMAGES (International Marine Global Change Study).

The site of this scientific forum will be the GÉOTOP web page (<http://www.unites.uqam.ca/geotop/wwwgeotop.html>). Those who are willing to contribute are invited to communicate through this channel.—Anne de Vernal and Claude Hillaire-Marcel, GÉOTOP, Université du Québec à Montréal, Canada; Uli von Grafenstein, Laboratoire de Modélisation du Climat et de l'Environnement, LMCE, Saclay, France; and Donny Barber, INSTAAR (Institute of Arctic and Alpine Research), University of Colorado, Boulder

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