The last Glacial Period: rapid changes in air temperature and ocean hydrology

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Understanding the role of the ocean regarding the large amplitude climatic variability between 75 and 15 kyr B.P. recorded in the Greenland ice cores (Dansgaard-Oeschger cycles, Dansgaard et al, 1993) has been one of the great challenges in the last few years for the paleoceanographic community within and around IMAGES (International Marine Global Change Study).

The abundance records of the polar planktic foraminifera *Neogloboquadrina pachyderma* left coiling in North Atlantic Ocean sediment (cores ODP609, V23-81) exhibits the same large amplitude oscillations as those observed in the Greenland ice records (Bond et al., 1993).

These results have two immediate implications:

1) open ocean sediments appear to record the century scale variability of the climate system,

2) the climate system may be reorganized significantly within a few decades to a few centuries.

This increases drastically the importance of the oceanic paleoclimatic records for understanding the causes and consequences of climatic changes both in the past and the future.

The major coolings evidenced by the polar foraminifera records correspond to large inputs of Ice Rafted Detritus (IRD) over a wide latitudinal belt (40° to 55°N). They occured at 5 to 10 kyr interval, during the last glacial period (Broecker et al, 1992 called them "Heinrich events" after Heinrich, 1988). These iceberg discharges induced cooling by 2 to 5°C of sea surface temperatures associated with a strong decrease of sea surface salinity ranging from 1 to 3‰ (Cortijo et al, 1997).

Using the similarity of the ocean and ice records, Bond et al (1993, 95) proposed a common chronostratigraphic framework in which the Heinrich events appear to be linked to the largest coolings in the GRIP/GISP2 ice records and in which the smaller IRD inputs are synchronous with the other cold oscillations in the Dansgaard-Oeschger cycles.

The aim of the study presented here is to contribute to the understanding of the climate system variability and the relationships between the ice and the ocean. To reach this goal, we applied a multi-tracer approach to different sediment cores from the North Atlantic Ocean for which high sedimentation rates made it possible to reconstruct climatic oscillations with a centennial temporal resolution. The figure shows the results obtained in two different areas: the Faeroes-Scotland ridge documented by a stack of cores ENAM93-21 and IMAGES MD95-2009 located at 62°N and 3°W; and the Rockall plateau documented by core NA87-22 located at 54°N and 15°W.

The chronology of the ice $\delta^{18}O$ record at GRIP was constructed by counting the ice layers in the first part of the core and using an ice accumulation model where the ice layers are not visible. The sediment cores are AMS ^{14}C dated, with an error bar increasing from 50 years in surface samples to 1000 years at about 40 kyr B.P. The chronologies of the ice and ocean records are independant.

The stacked magnetic susceptibility record from ENAM-IMAGES cores bears a noticeable resemblance to the $\delta^{18}O$ of the ice at GRIP (Rasmussen et al, 1995). Each of the Dansgaard-Oeschger events between 10 and 50 kyr is identified in the magnetic susceptiblity record of the Faeroes sediment cores (curves A and B). The lowest magnetic susceptibility values are associated with cold temperatures of the air above Greenland and, conversely, the highest values are associated with warmer air temperatures. This magnetic susceptibility record is characteristic of the whole Northern Atlantic Ocean deep water system from the Faeroes to the Southern Greenland Sea. This parameter appears to trace the variations in the size and concentration of magnetic minerals from the northern area and thus the activity of the bottom water circulation.

The different oscillations are correlated to a decrease in the $\delta^{18}O$ of the planktic foraminifera, interpreted as a lowering of the surface water salinity of the North Atlantic and Southern Norwegian Sea (curve C). Based on the isotopic composition of the carbon of the benthic foraminifera *Cibicides wuellerstorfi* picked from the North Atlantic core NA87-22, Vidal et al, 1997, showed that reductions in deep water ventilation occurred during the largest Heinrich events (curve D), and were therefore, synchronous with sea surface drops in salinity and temperature, and reduced transport of magnetic particles by bottom currents. These $\delta^{13}C$ lowerings are recorded in other North Atlantic cores but not in Norwegian Sea cores because of the absence of *C. wuellerstorfi* in sediments from this area.

All these different parameters point towards a strong sensitivity of deep water properties (and probably the associated thermohaline circulation) to surface salinity changes. Thus, a decrease in the conveyor belt activity would induce a high latitude atmospheric cooling.

Simple box model experiments indicate that Laurentide ice sheet internal instabilities (following the binge and purge model from McAyeal, 1994) could control such strong cold Heinrich events and the warm oscillations which follow them (Paillard and Labeyrie, 1994). The cool phase of the smaller Dansgaard-Oeschger events are also associated with IRD and surface water $\delta^{18}O$ anomalies, but there is too much analytical noise to know if there is a corresponding deep water $\delta^{13}C$ decrease for these low amplitude cooling events. Would they correspond to the rapid oscillations of the marine-based ice sheets around the northern Atlantic (the Fennoscandian, Iceland and Greenland ice sheets)?

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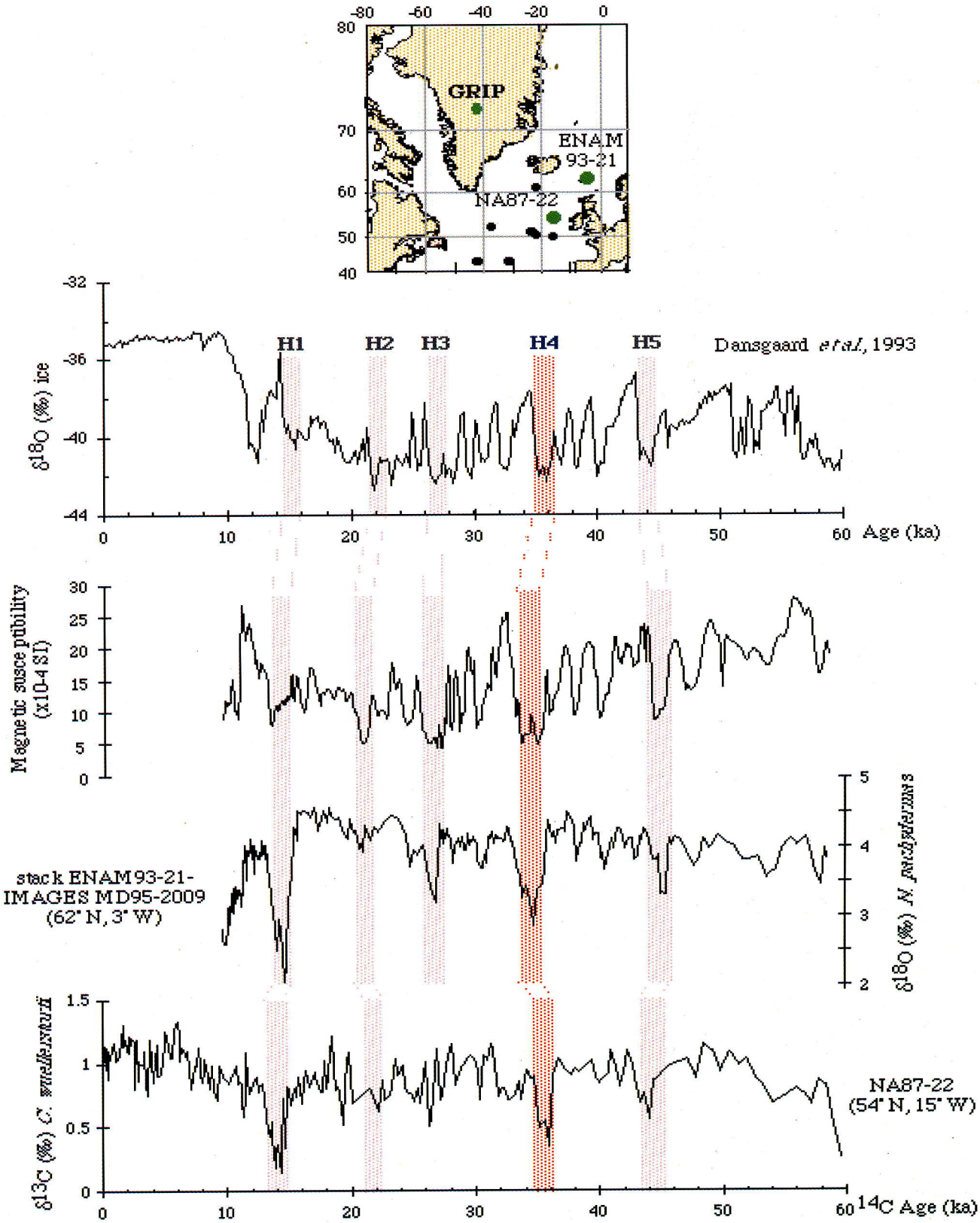

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