Magnetic properties of deep-sea sediments off southwest Greenland: Evidence for major differences between the last two deglaciations

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ABSTRACT

High-resolution rock magnetic data, atomic mass spectroscopy ^{14}C dates, δ^{18}O, and grain-size analyses from a piston core (HU90-013-013) located off southwest Greenland provide a record of the last two deglaciations. During Termination I, a well-defined interval having high volumetric magnetic susceptibility (k) and a low ratio of anhysteretic susceptibility to volumetric magnetic susceptibility (k_{ARM}/k) postdates the Younger Dryas and the δ^{18}O change marking the stage 2/1 boundary and correlates with sedimentological and geomorphological evidence for Greenland ice-sheet retreat from the coastline to the continental interior. During Termination II, a very similar magnetic signal coincides with the δ^{18}O shift marking the stage 6/5 glacial-interglacial transition and continues throughout substage 5e. We suggest that this magnetic signal, during both Termination I and Termination II, marks continental meltwater–carried detritus from Greenland. If so, the synchronous changes in magnetic and oxygen isotopic records at Termination II indicate very early and rapid deglaciation of Greenland, in contrast to the relatively late deglaciation observed for Termination I. Distinct fluctuations in k and k_{ARM}/k occur below the onset of the δ^{18}O change at Termination I (where they occur at ~16 900 yr B.P.) and at Termination II. These fluctuations are interpreted as due to sudden influxes of detritus into the basin caused by unpinning of ice from the continental shelf at the inception of deglaciation.

INTRODUCTION

Piston core HU90-013-013 (P-013) was taken from the Labrador Sea, on the Greenland rise, northwest of the of the Eirik Ridge (lat 58°13'N, long 48°22'W, present water depth: 3380 m), at approximately the same location as Ocean Drilling Program Site 646 (Leg 105) (Fig. 1). The *N. pachyderma* (left coiled)–derived planktonic δ^{18}O record for this 17.4 m core indicates that the base was deposited during an interstadial period in isotopic stage 6 or in stage 7 (Hillaire-Marcel et al., 1994). Late Pleistocene sedimentation in the deep Labrador Sea was largely detrital. The coarse sediment fraction (>125 μm) primarily reflects ice-rafted debris (IRD), which was almost exclusively deposited during glacial isotopic stages 6 and 4 to 2 and was at a maximum during the Heinrich events. During interglacial periods, deposition was primarily from hemipelagic suspension with much higher sedimentation rates during the Holocene (32–54 cm/ka) than during the preceding glacial interval (10–15 cm/ka) (Hillaire-Marcel et al., 1994).

Magnetic measurements were carried out on 7 cm^3 cubic samples collected back-to-back downcore, each sample representing ~2.0 cm of core length. Although a wide range of magnetic measurements has been carried out on this core (see Stoner et al., 1994), we restrict our discussion to the records at Termination I and Termination II of two parameters: volumetric magnetic susceptibility (k) and anhysteretic remanent magnetization expressed as anhysteretic susceptibility (k_{ARM}). Numerous magnetic hysteresis loops from these intervals indicate that magnetite is the only magnetic mineral present in detectable quantity. Hysteresis ratios lie in the pseudo–single domain field of the Day et al. (1977) plot and display a grain-size mixing trend (Fig. 2). In this core, k is therefore primarily a measure of the concentration of magnetite, and variations in the ratio k_{ARM}/k are inversely related to changes in the grain size of fine (~0.1–20 μm) magnetite (see King et al., 1982; Bloemendal et al., 1992, 1993). We document changes in magnetic parameters during Termination I (stage 2/1) and Termination II (stage 6/5) and compare these changes with δ^{18}O, atomic mass spectroscopy (AMS) ^{14}C dates, percentage of carbonate, laser microgranulometer–determined mean grain size (in micrometres) of the <160 μm fraction, and percentage of the

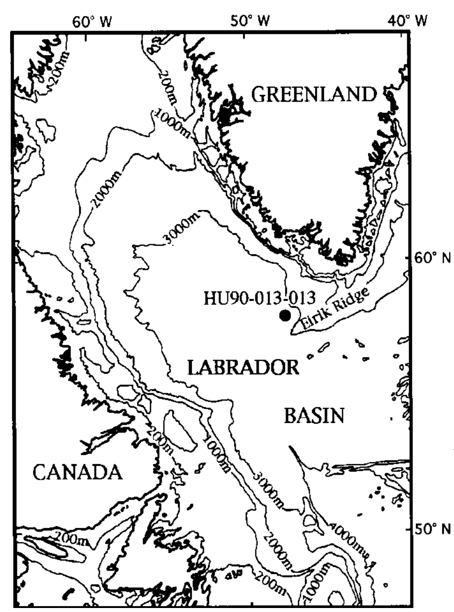

Figure 1. Location map, showing site of piston core HU90-013-013 (P-013).

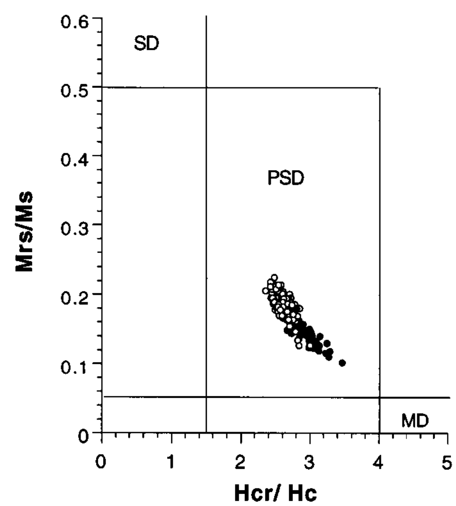

Figure 2. Hysteresis ratios of 187 samples from upper 500 cm and from 1200 to 1600 cm of P-013. Solid circles = data from ME events and shaded core intervals shown in Figures 3 and 4; open circles = data from background sediment (outside shaded intervals in Figs. 3 and 4). Mrs—saturation remanence, Ms—saturation magnetization, Hcr—remanent coercivity, Hc—coercive force. Single-domain (SD), psuedo–single-domain (PSD), and multidomain (MD) fields after Day et al. (1977).

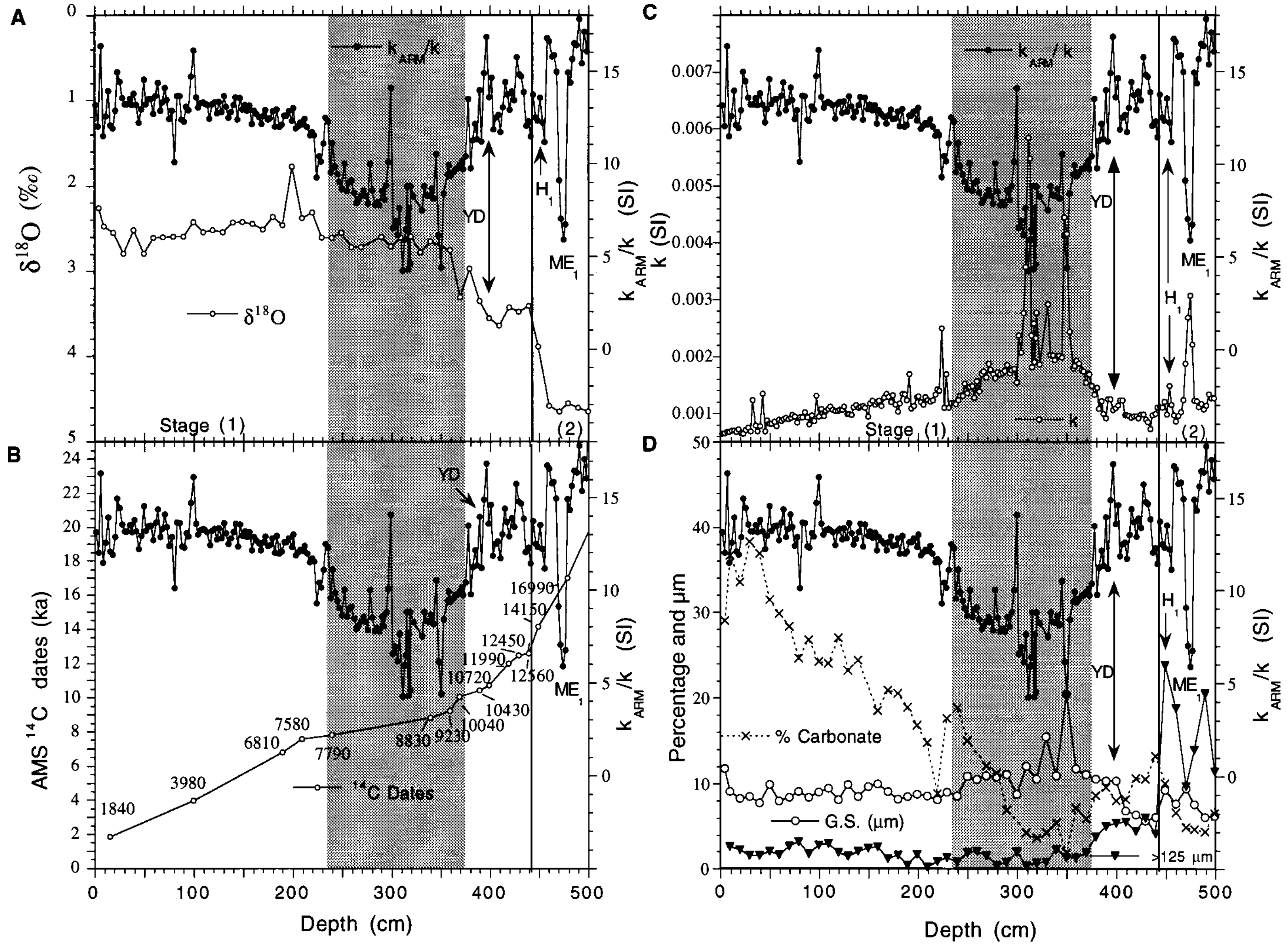

Figure 3. A: Magnetic grain-size–dependent parameter k_{ARM}/k (solid circles) (increased magnetic grain size indicated by smaller values) compared with planktonic $\delta^{18}O$ record from *N. pachyderma* (left coiled) (open circles) for upper 500 cm of P-013. Shaded area delineates interval of increased magnetite concentration and grain size interpreted as continental-meltwater–derived detrital flux from southern Greenland; vertical line at 440 cm marks isotopic stage 2/1 boundary. YD—Younger Dryas, H_1—Heinrich event 1, ME_1—magnetic event attributed to beginning of deglaciation prior to Termination I. B: Diagram of k_{ARM}/k (solid circles) compared with corrected (−400 yr for reservoir effect) atomic mass spectroscopy ^{14}C dates. C: Diagrams of k_{ARM}/k (solid circles) compared with magnetic concentration–dependent parameter k (open circles). D: k_{ARM}/k (solid circles) compared with percentage of carbonate (CO_3) (×), mean grain size (G.S.; in µm) for <160 µm fraction (open circles), and percentage of coarse fraction >125 µm (solid triangles).

coarse fraction >125 µm (Hillaire-Marcel et al., 1994). The magnetic parameters at this location appear to be particularly sensitive to environmental changes during the last two deglaciations, providing a link between ice-sheet behavior and the marine-sediment record.

TERMINATION I

The dominant feature of the magnetic record at Termination I is a broad low in k_{ARM}/k (between 235 and 375 cm below the sea floor) coinciding with a high in k (Fig. 3). These changes in magnetic parameters, indicating an increase in magnetite (fine-fraction) grain size and concentration, postdate the $\delta^{18}O$ change defining the stage 2/1 transition (~440 cm). The onset of the change in magnetic properties coincides with (1) the end of a distinct fluctuation in k_{ARM}/k, which is coeval with the Younger Dryas (Fig. 3); (2) a marked decrease in IRD indicated by the percentage of the coarse fraction >125 µm (Fig. 3D); (3) an increase in the mean grain size of the <160 µm fraction (Fig. 3D); (4) low percentage of carbonate (Fig. 3D); and (5) the highest sedimentation rates in the core (Fig. 3B). The AMS ^{14}C dates bracket this broad change in magnetic properties within the 10–7.7 ka interval (Fig. 3B).

Three short-lived fluctuations in k_{ARM}/k precede the broad change in magnetic properties mentioned above. (1) Increased k_{ARM}/k (with little change in k) at ~11 to 10.4 ka is correlated to the Younger Dryas as defined by $\delta^{18}O$, the Vedde ash, and AMS ^{14}C dates (Hillaire-Marcel et al. 1994) (Fig. 3, B and C). (2) Decreased k_{ARM}/k at ~14 ka is correlated to Heinrich Event 1 (Fig. 3, A and B). This fluctuation occurs just prior to the change in $\delta^{18}O$ marking the stage 2/1 boundary (Fig. 3A) and is associated with an increase in IRD (Fig. 3D). (3) A distinct fluctuation in k_{ARM}/k and k (ME_1 in Fig. 3) after 16 990 yr B.P. (^{14}C dating), and prior to the $\delta^{18}O$ shift at the stage 2/1 transition, correlates with a decrease in IRD and carbonate and an increase in the mean grain size (Fig. 3D).

The geologic record of deglaciation in this region indicates two distinct stages, disintegration of marine ice and melting of continental ice (Funder, 1989). The onset of deglaciation is poorly determined; however, radiocarbon dates indicate that the ice margin in all parts of Greenland was located near the present coastline by 10–11 ka (Funder, 1989). The second stage in the retreat of the Greenland ice sheet involved melting of land-based ice, which retreated to approximately its present position in southwestern Greenland by 8 ka (Kelly, 1985) and continued to retreat to inside its present position until ~7 ka (Funder, 1989).

The magnetic interval of high k and low k_{ARM}/k at 10–7.7 ka (Fig. 3) is interpreted to be caused by the transfer of large amounts of glacially eroded detritus to the deep sea by meltwater as the Greenland ice sheet retreated from the coast into the continental interior. According to this hypothesis, the increased magnetic grain size and concentration are due to a proximal meltwater source carrying detritus from the crystalline bedrock of Greenland. Because the interval coincides with the highest sedimentation rates in the core, the record cannot be an artifact of sediment winnowing. The interpretation is supported by high silicate flux during this interval (Hillaire-Marcel et al., 1994) and by a distinct change in the solid-phase Fe, Mn, and P, which has been attributed to a shift from a distal to a proximal detrital source (Lucotte et al., 1994). The lack of a large magnetic response to the first (marine) stage of deglaciation (characterized by high IRD) indicates that k and k_{ARM}/k (at this location) were relatively insensitive to IRD deposition associated with marine deglaciation, possibly because of different sources for some of this detrital material. The end of the magnetic interval at ~7.7 ka occurred at approximately the time of maximum ice retreat on Greenland (Funder, 1989) and a return to relatively stable ice-sheet conditions.

TERMINATION II

A broad change in k_{ARM}/k and k is associated with the isotopic substage 5e (Fig. 4). As with Termination I, the change in magnetic properties indicates an increase in magnetite grain size and concentration which coincides with a marked decrease in IRD and carbonate and an increase in the mean grain size (in micrometres) of the <160 μm fraction (Fig. 4C). As for Termination I, we interpret this magnetic signal to be due to an influx of continental meltwater detritus. For Termination II, however, the onset of the change in magnetic properties coincides with the $\delta^{18}O$ shift defining the stage 6/5 glacial-interglacial transition (Fig. 4A). The magnetic signal continues throughout substage 5e, implying a source of land-derived detrital input until just prior to the 5e/5d boundary (Fig. 4A).

An additional distinct fluctuation in k_{ARM}/k and k (ME_2 in Fig. 4) precedes the $\delta^{18}O$ shift of the stage 6/5 boundary. This fluctuation is similar in all respects to ME_1 prior to Termination I (Fig. 3). However, at Termination II, the magnetic event coincides with a light peak in the $\delta^{18}O$ record (Fig. 4A).

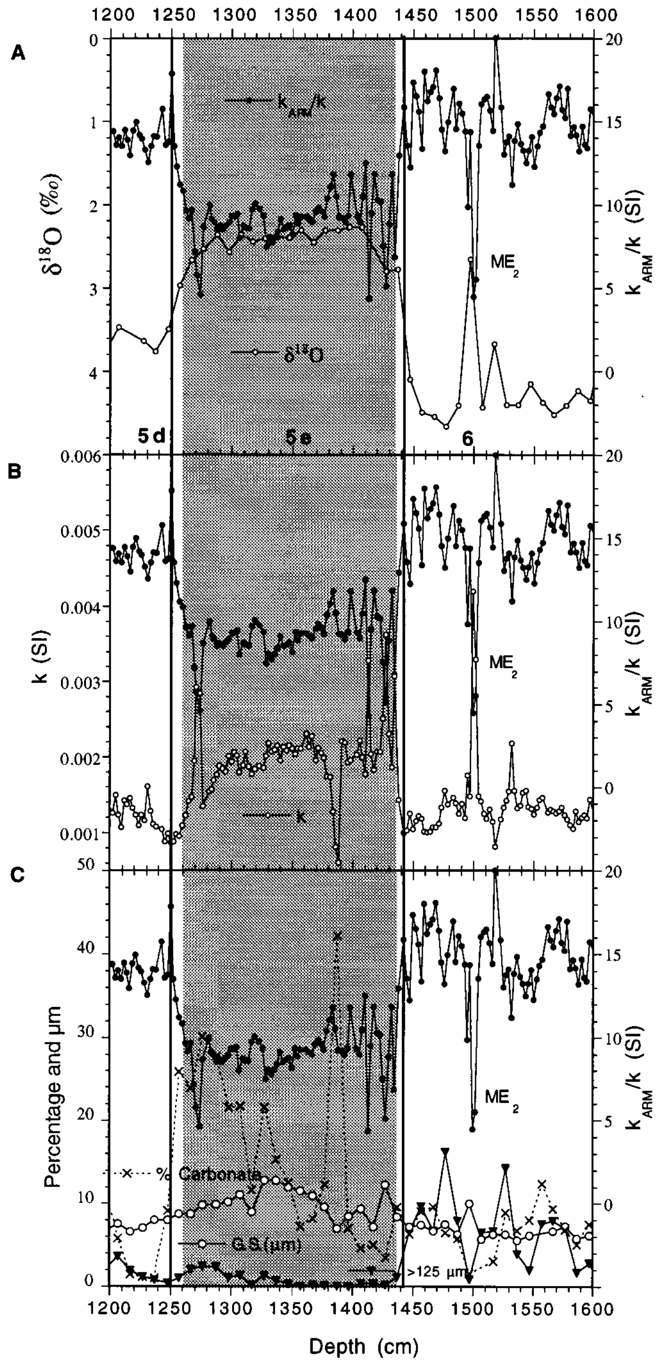

Figure 4. A: Magnetic grain-size–dependent parameter k_{ARM}/k (solid circles) (increased magnetic grain size indicated by smaller values) compared with planktonic $\delta^{18}O$ record from *N. pachyderma* (left coiled) (open circles) for interval from 1200 to 1600 cm of P-013. Shaded area delineates interval of increased magnetite concentration and grain size interpreted as continental-meltwater–derived detrital flux from southern Greenland; vertical lines at 1250 and 1440 cm mark isotopic substage 5e/d and stage 6/5 boundaries, respectively. ME_2 = magnetic event attributed to beginning of deglaciation prior to Termination II. B: Diagram of k_{ARM}/k (solid circles) compared with magnetic concentration–dependent parameter k (open circles). C: Diagram of k_{ARM}/k (solid circles) compared with percentage of carbonate (×), mean grain size (G.S.) for <160 μm fraction (open circles), and percentage of coarse fraction >125 μm (solid triangles). Note: large carbonate spike at 1390 cm is of detrital origin.

DISCUSSION

The coincidence of the onset of the change in k and k_{ARM}/k with an almost complete cessation in IRD deposition and, for Termination I, with the time at which the Greenland ice sheet reached the present coastline is consistent with the interpretation that the onset of the change in magnetic properties marks the disappearance of marine-based ice and the beginning of continental-derived meltwater flux. The change in magnetic parameters is associated with an increased contribution from a proximal, highly magnetic detrital source as compared to a more distal and less magnetic source associated with much of the IRD (i.e., Hudson Straits for the Heinrich events). The return to background magnetic properties at ~7.7 ka is consistent with the time at which the ice sheet was stabilized.

The AMS ^{14}C stratigraphy indicates that the temporary increase in magnetite grain size and concentration at Termination I occurred between 10 and 7.7 ka (Fig. 3B). Peak values occurred between 9.2 and 8.5 ka, correlating with the later part of the Fairbanks (1989) meltwater pulse Ib, whereas the entire magnetic episode occurs during Termination Ib (Duplessy et al., 1981, 1986).

No corresponding magnetic signal is associated with the Fairbanks (1989) meltwater pulse Ia or Termination Ia (Duplessy et al., 1981, 1986).

In contrast to the two-step deglaciation associated with Termination I, Termination II is generally characterized in the marine record by a fairly sudden and simple $\delta^{18}O$ decrease (e.g., Broecker and Van Donk, 1970; Martinson et al., 1987). In our record of Termination II (Fig. 4), a $\delta^{18}O$ shift of 2.4‰ occurs over an interval of 70 cm from glacial maximum values of 4.7‰ at 1477 cm to full interglacial $\delta^{18}O$ values of 2.3‰ at 1407 cm. The change in $\delta^{18}O$ from 4.1‰ to 2.8‰ in 10 cm coincides with a factor of two increase in k and a 50% decrease in k_{ARM}/k (Fig. 4A). This large and rapid increase in magnetite grain size and concentration coincides with an almost complete disappearance of IRD, an increase in mean grain size, and low carbonate percentage (Fig. 4C). If, as postulated, this magnetic signal is due to land-derived meltwater detritus, then substantial ice retreat must have occurred extremely early in Termination II. Because the Greenland ice sheet is believed to have been more extensive during isotopic stage 6 than during the last glacial maximum (Kelly, 1985; Funder, 1989), an extremely high rate of Greenland margin deglaciation is required to explain the synchroneity of the magnetic and $\delta^{18}O$ records. Alternatively, significant deglaciation of the marine-based Greenland ice margin prior to the decrease in $\delta^{18}O$ (see Crowley, 1994) could also explain the synchroneity of the records. The early deglaciation of the Greenland continent, independent of the deglaciation rate, suggests a much greater sensitivity of the Greenland ice sheet to initial deglacial forcing during Termination II than is observed for Termination I. This implies that initial stages of deglaciation had a different geographical distribution for the two terminations.

Distinct fluctuations in k_{ARM}/k and k prior to Termination I (ME_1; Fig. 3) and Termination II (ME_2; Fig. 4) are interpreted to have been due to a sudden pulse of detritus into the basin. Both events correlate with an increase in mean grain size and a decrease in IRD and carbonate and are characterized by laminated sediments; ME_2 also correlates with a large decrease in $\delta^{18}O$ indicative of a meltwater pulse. These events are interpreted to signify the beginning of deglaciation, marking the unpinning of grounded ice from the continental shelf, leading to a short-term depositional event at this site. ME_1 during stage 2 occurs just above an AMS ^{14}C date of 16 990 yr B.P., which places this event at the time of the beginning of eustatic sea-level rise (Fairbanks 1989) and with established melt events in the Davis Strait and the Labrador Sea (Hillaire-Marcel and de Vernal, 1989; Andrews et al., 1994). During isotopic stage 6, light $\delta^{18}O$ events have also been observed in the Labrador Sea (Fillon, 1985) and Norwegian Sea (Kellogg et al., 1978). Therefore the ME events may be equivalent to the Imbrie et al. (1993) "Major Nordic" deglaciation events postulated to indicate early response to insolation changes.

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