High-resolution paleomagnetic secular variation and relative paleointensity records from the western Canadian Arctic: implication for Holocene stratigraphy and geomagnetic field behaviour\textsuperscript{1,2}

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Abstract: Two piston cores recovered from the Chukchi and the Beaufort seas document Arctic Holocene geomagnetic field behaviour and highlight the potential of secular variation and relative paleointensity as a regional chronostratigraphic tool. Several centennial- to millennial-scale Holocene declination and inclination features can be correlated in both cores, with other high-resolution western North American lacustrine and volcanic paleomagnetic records and with records of changes in Earth’s dipole moment, supporting the geomagnetic origin of these features and implying that they are associated with changes in Earth’s dipole moment.


Introduction

Our knowledge of historical secular variation in the Arctic is only limited to the last 200 years (Jackson et al. 2000; Jonkers et al. 2002). The Arctic geomagnetic field, as revealed by recent satellite data as well as ground-based measurements, is characterized by secular variation at a much higher rate than for the rest of the Earth (Olson and Aurnou 1999; Hulot et al. 2002). One of the most evident expressions of this behaviour can be seen in changes of the north magnetic pole (NMP) position. The first direct reading placed the NMP at Cape Adelaide (Canadian Arctic) in 1831. Successive determinations performed during the last century depicted a clear migration of the NMP towards the Arctic Ocean (Olsen and Mandea 2007). Recent observations from the Resolute Bay Geomagnetic Observatory (Cornwallis Island, Northwest Territories) have detected a strong increase in NMP velocity since the 1970s, from 9 to 41 km/year and to \textasciitilde{} 60 km/year in 2003 (Olsen and Mandea 2007), and the rate of change of the intensity has increased from 10 to \textasciitilde{} 70 nT/year during the last 50 years (Geological Survey of Canada, unpublished data). These recent changes suggest that the Arctic may be a vantage point to record rapid changes in Earth’s magnetic field behaviour and help determine the high frequency dynamics of Earth’s magnetic field during the Holocene.

Spherical harmonic models of the geomagnetic field, based on global historical measurements, have estimated the position of the NMP over the last 400 years (e.g., Jackson et al. 2000), revealing that changes in the NMP position are consistent with the observations of the last century, whereas a new generation of time-varying spherical harmonic models, constrained by Holocene paleomagnetic data, have revealed that the rate of change of the dipole intensity could vary at the centennial timescale (Korte and Constable 2006). Nevertheless, the lack of directional as well as intensity measurements in the Arctic is an important limitation to accurately assess if the current accelerated Arctic secular variation is a persistent feature of the geomagnetic field.
The reconstruction of Earth’s magnetic field behaviour beyond historical records can be achieved by the study of geological materials like volcanic rocks and fired archaeological artefacts (e.g., Gallet et al. 2002; Hagstrum and Champion 2002; Genevey and Gallet 2003). The thermoremanent magnetization acquired by this type of material has the advantage of yielding absolute intensities (e.g., Dunlop and Özdemir 1997). However, due to the nature (lavas or artefacts) of these records, they are not continuous, often of low temporal resolution, and more or less absent in the Arctic. In contrast, the study of well-dated sedimentary sequences has proven to provide reliable, continuous and high-resolution records of geomagnetic field variation during the Holocene at high latitudes (e.g., Snowball and Sandgren 2002, 2004; St-Onge et al. 2003; Snowball et al. 2007; Stoner et al. 2007). In this paper, we present two high-resolution, continuous Holocene paleomagnetic records from the western Canadian Arctic, discuss the potential of Arctic secular variation (direction and relative paleointensity) as a chronostratigraphic tool, and assess geomagnetic field behaviour in the Arctic during the Holocene.

**Geological setting**

This study is based on the analysis of sediment cores collected on the slope of the continental shelf of the Chukchi Sea (410 m) and on the Mackenzie Shelf in the Beaufort Sea (218 m) (Fig. 1). Holocene postglacial sediments from the western Canadian continental shelf are characterized by much higher sedimentation rates than in the Arctic central basins (Darby et al. 2006). Since the Bering Strait was flooded by marine waters at ~12 ka, Holocene sedimentation rates in the Hope Valley (southern Chukchi Sea, 53 m) have varied from 60 up to 200 cm/ka and postglacial sediments are mainly composed of clays and silts (Keigwin et al. 2006).

Similar high sediment accumulation areas are also found on the Mackenzie Shelf. Modern sedimentation rates for the shelf sediments are estimated between 10 and 300 cm/ka with higher sedimentation rates in the Mackenzie Trough (water depths between 50 and 500 m; MacDonald et al. 1998). Holocene sediment inputs in the Mackenzie Delta and on the shelf are mainly derived from the Mackenzie River. Most of the shelf is covered by Holocene marine mud predominantly in the clay-size range (Hill et al. 1991). Similarly, in the upper part of two piston cores collected in the Beaufort Sea and Amundsen Gulf, Scott et al. (in press) described fine-grained sediments with a mean grain size <6 μm, whereas Andrews and Dunhill (2004) described four Holocene sedimentary facies ranging from laminated olive-grey mud containing dark grey laminations at the base to faintly bioturbated mud and similar but more bioturbated mud with greyish-black laminations at the top of a core collected on the Beaufort Sea slope, west of the Mackenzie River delta. This core revealed an average sedimentation rate of 135 cm/ka during the Holocene (Andrews and Dunhill 2004). Lastly, the onset of deglaciation in the Beaufort Sea and Amundsen Gulf was estimated at 12.5 ka by the dating of a sedimentary unit rich in ice-rafted debris (IRD) (Scott et al. in press). Because of the high sedimentation rates recently observed in cores from both the Chukchi and...
sampling and methods

Piston core HLY0501-05JPC (hereinafter referred to as core 05) was collected on board the US Coast Guard Cutter (USCGC) Healy with a companion trigger weight core in the Chukchi Sea margin at a water depth of 410 m as part of the 2005 Healy-Oden Trans-Arctic Expedition (HO-TRAX) expedition (Table 1). Piston core 2004-804-803 (hereinafter referred to as core 803) and its companion trigger weight core were collected on board the Canadian Coast Guard Icebreaker (CCGS) Amundsen in the Beaufort Sea on the Mackenzie Shelf area at a water depth of 218 m during the 2004 Canadian Arctic Shelf Exchange Study (CASES) expedition (Table 1).

The core sections were cut and split on board. The core sections were described and sampled with U channels (rigid U-shaped plastic liners with a square 2 cm cross section and a length of 1.5 m). The first 95 cm of core 05 (section 1) was not sampled because the sediment was too soupy. The magnetic measurements were performed in a magnetically shielded laboratory at the University of Florida (Gainesville, Florida).

Magnetic susceptibility

The low-field volumetric magnetic susceptibility ($k_{LF}$) was measured at 1 cm intervals using a Sapphire Instruments susceptibility bridge installed on a track for the measurement of U channels. The response function of magnetic susceptibility measurements is similar to that of the cryogenic magnetometer used for remanence measurements (4.5 cm; Thomas et al. 2003). The values of $k_{LF}$ essentially reflect the concentration of ferrimagnetic minerals such as magnetite but is also strongly grain-size dependent (e.g., Dunlop and Özdemir 1997).

Magnetic remanences

The natural remanent magnetization (NRM) was measured on U-channel samples using a 2-G Enterprises Model 760R cryogenic magnetometer at 1 cm intervals. However, due to the finite spatial resolution of the pick-up coils (half width of the response function = 4.5 cm), some smoothing occurs (Weeks et al. 1993). The data from the upper and lower 4 cm of each U channel were thus excluded because they are affected by an edge effect (i.e., the integration of “no sediment” at the end and beginning of each U channel). To isolate the characteristic remanent magnetization (ChRM), the NRM was measured and progressively demagnetized using stepwise peak alternating fields (AFs) of 10–60 mT in 5 mT steps, 70, and 80 mT. Magnetic declination and inclination of the ChRM (labelled ChRM D and ChRM I, respectively) were calculated at 1 cm intervals using a least-square line-fitting procedure (Kirschvink 1980). Since the cores were not azimuthally oriented, the ChRM D profiles are relative. The ChRM D profiles were also corrected by rotating the mean declination of the entire core to North. The precision of the best-fit procedure was estimated by the maximum angular deviation (MAD; Kirschvink 1980). MAD values <5° were recently suggested for high-quality marine U-channel data. Lastly, the median destructive field of the NRM (MDFNRM, the value of the peak AF necessary to reduce the NRM intensity to half of its initial value) was calculated using the software developed by Mazaud (2005).

Table 1. Coordinates of the sampling sites.

<table>
<thead>
<tr>
<th>Core</th>
<th>Latitude (°N)</th>
<th>Longitude (°W)</th>
<th>Water depth (m)</th>
<th>Length (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HLY0501-05JPC</td>
<td>72°51.618’</td>
<td>158°25.26’</td>
<td>410</td>
<td>1648</td>
</tr>
<tr>
<td>2004-804-803</td>
<td>70°37.976’</td>
<td>135°52.815’</td>
<td>218</td>
<td>598</td>
</tr>
</tbody>
</table>

Table 2. Radiocarbon dates.

<table>
<thead>
<tr>
<th>Core</th>
<th>Depth (cm)</th>
<th>Corrected depth (cm)$a$</th>
<th>Age (year BP)$b$</th>
<th>Calibrated age (cal BP)$c$</th>
<th>Dated material</th>
<th>Lab number$^{d}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>803</td>
<td>50</td>
<td>108</td>
<td>1530±40</td>
<td>693 (621–765)</td>
<td>Yoldia myalis</td>
<td>Beta-201958</td>
</tr>
<tr>
<td>803</td>
<td>274</td>
<td>332</td>
<td>3000±40</td>
<td>2249 (2140–2358)</td>
<td>Buccinum sp.</td>
<td>Beta-201959</td>
</tr>
<tr>
<td>803</td>
<td>360</td>
<td>418</td>
<td>3540±40</td>
<td>2928 (2800–3056)</td>
<td>Shell fragments</td>
<td>Beta-201960</td>
</tr>
<tr>
<td>803</td>
<td>550</td>
<td>608</td>
<td>4560±40</td>
<td>4242 (4105–4378)</td>
<td>Shell fragments</td>
<td>Beta-201961</td>
</tr>
<tr>
<td>05</td>
<td>37</td>
<td>112</td>
<td>1930±40</td>
<td>1477 (1358–1595)</td>
<td>Thyasira sp.</td>
<td>CAMS-128414</td>
</tr>
<tr>
<td>05</td>
<td>484</td>
<td>559</td>
<td>4465±40</td>
<td>4656 (4522–4789)</td>
<td>Yoldia sp.</td>
<td>CAMS-128415</td>
</tr>
<tr>
<td>05</td>
<td>589</td>
<td>664</td>
<td>4820±70</td>
<td>5091 (4891–5290)</td>
<td>Thyasira sp.</td>
<td>CAMS-128416</td>
</tr>
<tr>
<td>05</td>
<td>689</td>
<td>764</td>
<td>5220±40</td>
<td>5569 (5471–5667)</td>
<td>Yoldia sp.</td>
<td>CAMS-128417</td>
</tr>
<tr>
<td>05</td>
<td>800</td>
<td>875</td>
<td>5885±40</td>
<td>6303 (6212–6393)</td>
<td>Portlandia sp.</td>
<td>CAMS-128418</td>
</tr>
<tr>
<td>05</td>
<td>880</td>
<td>955</td>
<td>6395±45</td>
<td>6867 (6740–6993)</td>
<td>Portlandia sp. + Thyasira sp.</td>
<td>CAMS-128419</td>
</tr>
</tbody>
</table>

$^{a}$Depth corrected for the missing sediment (see text for details).

$^{b}$All ages were measured by the AMS method using Libby’s half life (5568 year) and corrected for natural and sputtering fractionation ($\delta^{13}C = –25%$ versus VPDB). The statistical uncertainty of the age determination is given as one standard deviation (Stuiver and Polach 1977).

$^{c}$Calibrated using the on-line CALIB version 5.0.2 software (Stuiver et al. 2005) and the Hughen et al. (2004) marine dataset. Regional reservoir correction (AR) for cores 05 and 803 is 0 and 400 year, respectively. The ages in parentheses represent the 2σ cal age range.

$^{d}$Beta, Beta Analytic Inc., Miami, Florida; CAMS, Lawrence Livermore National Laboratory, Livermore, California.

Beaufort seas, these two areas thus present a unique opportunity for the study of centennial- to millennial-scale geomagnetic field variations in the Arctic.
The MDF$_{NRM}$ is a coercivity and grain-size dependent parameter useful to estimate magnetic mineralogy.

An anhysteretic remanent magnetization (ARM) was imparted using a 100 mT AF field with a 50 $\mu$T direct current (DC) biasing field. The ARM was measured and demagnetized at peak fields of 20, 25, 30, 35, 40, 45, 50, 55, 60 mT and 10, 20, 25, 30, 35, 40, 50, 60, 80 mT for cores 05 and 803, respectively. The ARM was also expressed as anhysteretic susceptibility ($k_{ARM}$) by normalizing the ARM with the biasing field. If magnetic mineralogy is principally controlled by pseudo-single domain magnetite, $k_{ARM}/k_{LF}$ varies inversely with magnetic grain size (e.g., King et al. 1982). Two isothermal remanent magnetizations (IRMs) were imparted to the $z$ axis of the U channels with a DC pulse field of 0.3 T (IRM$_{0.3T}$) and 0.95 T (saturated IRM (SIRM)) using a 2-G Enterprises pulse magnetizer. Each IRM was then demagnetized and measured at peak AF of 0, 10, 20, 25, 30, 35, 40, 50, 60, 70, 80 mT and 0, 10, 20, 25, 30, 35, 40, 50, 60, 80 mT for cores 05 and 803, respectively. These IRMs were used to construct a pseudo S ratio by dividing the IRM$_{0.3T}$ by the SIRM. Pseudo S-ratio values close to 1 are indicative of low coercivity minerals such as magnetite, while lower values are indicative of the presence of high coercivity minerals such as hematite. Lastly, magnetite grain size was estimated by the $k_{LF}$ versus SIRM diagram (Thompson and Oldfield 1986). Even though the later diagram is based on the use of pure magnetite for calibration, it is often used in paleomagnetism for the estimation of grain size (e.g., Sager and Hall 1990; Gogorza et al. 2004).

Hysteresis measurements

Hysteresis loops were performed on core 05 on small quantity of sediment taken at the base of each U channel and in some selected intervals using a vibrating sample magnetometer system from Princeton Measurements Corporation. Hysteresis parameters including magnetization saturation (Ms), coercive force (Hc), saturation remanence (Mrs), and coercivity of remanence (Hcr) were extracted from the hysteresis data to characterize the magnetic mineralogy and grain size (Day et al. 1977).

Radiocarbon dating

The chronology of both cores were determined using accelerator mass spectrometry (AMS) $^{14}$C measurements on six and four calcareous pelecypod shells for cores 05 and 803, respectively (Table 2). All radiocarbon ages were calculated using Libby’s half life (5568 year) and corrected for natural and sputtering fractionation ($\delta^{13}$C = –25‰ versus Vienna Pee-Dee Belemnite (VPDB); Stuiver and Polach 1977). The conventional $^{14}$C ages were calibrated using the on-line CALIB version 5.0.2 software (Stuiver et al. 2005) and the Hughen et al. (2004) marine dataset. A regional reservoir correction ($\Delta R$) of 400 years was applied to core 803 based on the average $\Delta R$ value derived from five dates real-
ized on pelecypod shells collected prior to nuclear testing from the Amundsen Gulf (McNeely et al. 2006). In contrast, no regional reservoir correction was applied to core 05, as that core was raised from the slope in intermediate Atlantic-derived waters.

The two age models were constructed using a linear fit between the available calibrated ages on a composite depth scale corrected for missing sediments due to the piston coring process (Fig. 2). For core 05, the comparison of the attenuated γ-ray count measurements from the piston and

Fig. 3. Core top correlation. (A) Correlation of γ-ray attenuation counts between core 05 piston (PC) and trigger weight (TWC) cores (red thick and blue broken curves are smoothed data). The correlation between the piston and trigger weight cores indicates that the first 75 and 58 cm are missing from cores 05 and 803, respectively. (B) Correlation of wet bulk density (left graphs) and whole core low-field volumetric magnetic susceptibility ($k_{LF}$) profiles (right graphs) from core 803 piston (PC) and trigger weight (TWC) cores. Core 803 data was acquired on board the icebreaker CGCS Amundsen using a GEOTEK’s multi-sensor core logger (MSCL). The density data were not properly calibrated on board and, therefore, represent only relative changes.
trigger weight cores reveals that about 75 cm of sediment was lost during piston coring (Fig. 3A). An analogous estimate was made for core 803 using both the magnetic susceptibility and wet bulk density profiles, revealing that about 58 cm of sediments was missing in the piston core (Fig. 3B). For core 05, the age model was only constructed for unit 1 (see the following section), as the sedimentation rates in the sediments of unit 2 are currently unknown and could be much higher, as unit 1 was deposited in a glacial–deglacial environmental setting (see the following section).

**Results**

**Core 05**

**Lithology**

From 0 to 1315 cm (lithological unit 1; Fig. 4A), core 05 consists of olive-grey (5Y 4/2) to dark olive-grey mud (5Y 3/2) with the presence of iron sulphides (speckles, diffuse laminae). From 1315 to 1723 cm (lithological unit 2), the sediment is characterized by a succession of dark olive-grey
(5Y 3/2) to very dark-grey (2.5Y 3/2) – greyish-brown (2.5Y 4/2) mud with disseminated sand layers and IRD. The available \(^{14}\text{C}\) dates and the presence of IRD in unit 2 indicate that units 1 and 2 correspond to postglacial and glacial–deglacial sediments, respectively.

**Magnetic properties**

The values of \(k_{LF}\) of core 05 range from 200 to 250 \(\times 10^{-6}\) SI within lithologic unit 1 (Fig. 4A). In lithological unit 2, \(k_{LF}\) values reveal more variations and range from 80 to 350 \(\times 10^{-6}\) SI, consistent with mineralogical and grain-size variations observed during visual description of the core. Aside from the first 800 cm, where NRM is relatively constant (about 0.03 Am\(^{-1}\) after the 30 mT demagnetization step), a long-term downcore decreasing trend is observed. The same long-term downcore decreasing trend is observed in the ARM and IRM profiles, consistent with a diminution of the ferrimagnetic concentration downcore (Fig. 4A).

Vector end-point orthogonal projection diagrams (Zijderveld 1967) reveal that the measured NRM is characterized by two magnetic components (Fig. 5A): a soft magnetic component (viscous magnetization) with a coercivity spectrum in the 0–20 mT AF range and a stable, well-defined, magnetic component in the 25–80 mT AF range. The ChRM was isolated using 10 demagnetization steps between 25 and 80 mT. The ChRM Is fluctuate around the expected inclination \((I_{GAD})\) calculated at the sampling site using a geocentric axial dipole (GAD) model (Fig. 6A). Aside from lithologic unit 2, where the ChRM is poorly defined, downcore MAD values are lower than 2\(^\circ\), indicative of very well-defined ChRM.

The values of MDF\(_{NRM}\) fluctuate between 13.7 and

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**Fig. 5.** Typical vector end-point orthogonal projection diagrams for cores (A) 05 and (B) 803. One division on the intensity scales corresponds to 0.01 Am\(^{-1}\).
56 mT, with an average of 29.40 ± 8.03 mT (Fig. 7A). Such an average and range are typical of magnetite. The $k_{LF}$ versus SIRM diagram is compatible with the presence of magnetite in the 1–16 μm grain-size range (Fig. 8A). Downcore variations of the grain-size dependent ratio $k_{ARM}/k_{LF}$ depict a decreasing trend compatible with an increasing magnetite grain size (Fig. 7A). A submicron magnetite grain size from 319 to 1215 cm, as well as multi domain (MD) magnetite grain size (>16 μm) below 1605 cm is observed (Fig. 8A).

Coarse MD magnetite grains are inefficient carriers of a stable detrital remanent magnetization (DRM) (e.g., Dunlop and Özdemir 1997).

All the studied samples fall in the pseudo-single domain (PSD) region for magnetite (Fig. 9A; Day et al. 1977). Aside from lithologic unit 2, pseudo S-ratio values are close to 1, indicative of low coercivity minerals such as magnetite (Fig. 7A). In summary, the magnetic mineralogy and grain size of lithologic unit 1 is compatible with the presence of...
PSD magnetite, whereas the magnetic mineralogy and grain size of lithologic unit 2 is compatible with coarse MD magnetite.

The hysteresis loops indicate saturation fields well below 200 mT and coercivities typical of magnetite (Fig. 9A). In addition, all loops are characterized by a paramagnetic com-
ponent. However, an almost linear relationship between the measured magnetic moment \( M \) and the applied magnetic field \( H \) with no hysteresis loop is observed in some intervals of lithological unit 2, indicating that the magnetic behaviour of such samples is dominated by the paramagnetic fraction. For this reason, we will now only focus on the upper unit (postglacial sediments) of core 05 (unit 1).

Core 803

**Lithology**

The top 88 cm consists of faintly bioturbated olive-grey mud (5Y 4/1). From 88 to 113 cm, an alternation of dark olive-grey (5Y 3/2) to olive-grey (5Y 4/1) mud is observed, whereas the rest of the core (113–658 cm) is characterized by olive-grey mud (5Y 4/1) with a variable degree of bioturbation. Occasional black horizons and laminations are also observed along the entire core. The available \(^{14}\)C dates and very similar sedimentary facies below 113 cm indicate that the entire core is composed of postglacial sediments (lithological unit 1; Fig. 4B).

**Magnetic properties**

The values of \( k_{LF} \) of core 803 are relatively constant (~150 \( \times 10^{-6} \) SI) along the entire core (Fig. 4B). Variations of magnetic concentration-dependent parameters like NRM, ARM, and IRM are below one order of magnitude along the entire core (Fig. 4B).

The NRM of core 803 is characterized by a viscous, low-coercivity magnetization easily removed by the application of a 20 mT peak AF (Fig. 5B). A stable, well-defined ChRM was isolated using 11 magnetization steps from 20 to 80 mT. The characteristic component inclinations fluctuate around the calculated \( I_{GAD} \) and MAD values are lower than 2\(^\circ\) (Fig. 6B), again indicative of a very well-defined ChRM (e.g., Kirschvink 1980). The MDF\(_{NRM}\) values are between 31.5 and 41.9 mT with an average of 34.35 \( \pm \) 1.22 mT, whereas pseudo S ratios vary close to 1 (Fig. 7B). These results are compatible with the presence of magnetite as the principal carrier of the ChRM.

As revealed from the \( k_{LF} \) versus SIRM diagram, the magnetic mineralogy is characterized by PSD magnetite in the 8–16 \( \mu \)m grain-size range (Fig. 8B). Downcore variations of \( k_{ARM}/k_{LF} \) depict uniform grain-size variations (Fig. 7B).

**Relative paleointensity (RPI) determination**

The standard technique employed to derive a RPI proxy record is to normalize the measured NRM by a magnetic concentration-dependent parameter like ARM, IRM, or \( k_{LF} \) to compensate for the variable ferrimagnetic concentration (Tauxe 1993). The use of ARM as a normalizer has been justified both on an empirical and theoretical basis by King et al. (1983) and has been successfully used in numerous studies (e.g., Channell 2006; Stoner et al. 2003), whereas the use of IRM and \( k_{LF} \) as a normalizer necessitates careful evaluation (e.g., Valet 2003). To assess the reliability of a RPI proxy, some pre-established criteria must be satisfied (Tauxe 1993). According to Tauxe (1993) and more recently by Stoner and St-Onge (2007), the NRM must be characterized by a strong, stable, single component magnetization with MAD values <5\(^\circ\), whereas the measured NRM must be a DRM carried by magnetite in the PSD (1–15 \( \mu \)m) grain-size range. In addition, magnetite concentration variations of more than one order of magnitude should be avoided (Tauxe 1993).

The previous sections have shown that the postglacial sediments of both cores are characterized by a strong, stable, and single component magnetizations with MAD values generally <5\(^\circ\). Variations of concentration-dependent parameters like \( k_{LF} \) and ARM of both cores are well below one order of magnitude (Figs. 10B, 10D). The magnetic data of the postglacial sediments also indicate that the NRM is primarily carried by low coercivity minerals such as magnetite in the PSD size range, thus respecting the previous set of criteria. To construct a relative paleointensity proxy, we first calculated the average of NRM/ARM and NRM/IRM over the 30–45 mT AF range and then divided each mean by the standard deviation. As revealed from the orthogonal projections (Fig. 5), this AF window falls inside the AF range of the isolated and stable ChRM. The two calculated RPI proxy records display very similar pattern (\( r^2 = 0.80 \) and 0.93 for
cores 803 and 05, respectively), suggesting that the ARM and IRM activate the same magnetic assemblages (Figs. 10A, 10C). The standard deviation of each proxy is comparable. Although the two methods of normalization yield essentially the same intensity records, we have chosen ARM as the preferred normalizer. According to Levi and Banerjee (1976), the use of ARM as a normalizer offers the advantage of dealing with single or PSD grains of magnetite, whereas IRM can also activate a large fraction of magnetic grains that do not carry the NRM.

Discussion

Western North American comparison

The Holocene paleomagnetic inclination records of cores 803 and 05 show similar features with one and the other, as well as with several Holocene paleomagnetic secular variation (PSV) records from the western North America (Fig. 11). The different nature of these records (marine: cores 803 and 05; lacustrine: Fish Lake (Verosub et al. 1986) and Grandfather Lake (Geiss and Banerjee 2003); volcanic rocks: paleomagnetic secular variation record from lava flows (PSVL) compilation (Hagstrum and Champion 2002) further corroborates the geomagnetic origin of the signal in cores 803 and 05, as well as the $\Delta R$ used for both cores. The two most prominent magnetic inclination minima are observed at $\sim 1000$ (magnetic feature I-1) and 2500 cal BP (magnetic feature I-2) in all examined records. Similarly, a magnetic inclination minimum is observed $\sim 8500$ cal BP (magnetic feature I-3) in three high-latitude western North American records: Grandfather Lake (Alaska), Fish Lake (Oregon), and core 05 (Chukchi Sea).

The most striking feature in the declination record is the abrupt one observed in core 803 $\sim 1850$ cal BP (Fig. 11), although the steep inclination at this level means that the shift in declination in less dramatic than it appears in the declination plot. This feature does not occur at a section break and does not result from a sampling artefact (e.g., hole in the U channel, etc.) or a major lithological change. On the other hand, it is not apparent in core 05 and should thus be treated with caution at this stage. Excluding this sharp declination change, comparison of cores 803 and 05 declination records depicts millennial- to centennial-scale variability from 2000 to 4500 cal BP, where the two records can be directly compared (Fig. 12). In addition, some common centennial-scale declination features can also be clearly detected from 2000 to 2500 cal BP (magnetic features D-1, D-2, D-3, Fig. 13).

The RPI records of cores 05 and 803 reveal similar millennial-scale features for the last 4500 cal BP, as well as...
Fig. 10. Relative paleointensity proxies of cores (A) 05 and (C) 803. Note the strong similarities of both proxies (NRM/ARM and NRM/IRM). Also illustrated are changes in concentration-dependent magnetic susceptibility ($k_{LF}$) and anhysteretic remanent magnetization (ARM) for cores (B) 05 and (D) 803. Arrows indicate the maximum variability.

(A) Core HLY0501-05JPC

(B) Core 2004-804-803

higher frequency centennial-scale fluctuations (Fig. 14). Unfortunately, no high-resolution continuous Holocene RPI records from the Arctic are currently available for comparison purposes. Nonetheless, between 3500 and 8500 cal BP, the RPI proxy records of cores 05 and 803 are consistent with the global dipole moment compilations of Ohno and Hamano (1993) and McElhinny and Senanayake (1982) although, as suggested by Dunai (2001), very high dipole moment values for the earliest part of the Ohno and Hamano (1993) synthetic record may be an artefact of poor data replication. Discrepancies are nonetheless observed between the RPI records and the global dipole moment estimate of McElhinny and Senanayake (1982) for the last 3500 cal BP but could be the result of an important European bias in the database used for the reconstruction. For example and as pointed out by Ohno and Hamano (1993), this bias seems particularly true between 2500 and 3500 cal BP when the dipole axis was tilted towards the European region. Consequently, the millennial-scale relative paleointensity features of cores 05 and 803 may reflect global dipole moment variations. Because of the paucity of Arctic RPI records, it is impossible to assess the dipolar nature of the centennial-
Fig. 11. Western North American inclination (left graphs) and declination (right graphs) comparison for the last 9000 cal BP. Correlative inclination features I-1, I-2, and I-3 are presented (see text for details). Illustrated are cores 05 and 803 (this study), the western United States PSVL volcanic compilation (Hagstrum and Champion 2002), Grandfather Lake (Alaska; Geiss and Banerjee 2003), and Fish Lake (Oregon; Verosub et al. 1986). Fish Lake data were calibrated using the Stuiver et al. (1998) radiocarbon calibration curve (K. Verosub, personal communication, 2008). The continuous curves (red in the web version) in the inclination figures represent weighted functions. Note that the inclination and declination scales are not identical.
scale features although recent geomagnetic models have implied that changes in the intensity of the dipole moment can occur at the centennial timescale (Korte and Constable 2006).

Comparison with geomagnetic model output

The inclination records calculated for the sampling site of both cores using the time-varying paleomagnetic model CALS7K.2 (Korte et al. 2005) are very consistent with cores 05 and 803 inclination records, notably for the last 3000 cal BP (Fig. 11). Several large centennial to millennial-scale features are clearly recognizable and further support the reliability of both inclination records as well as the age models. Nevertheless, the paleointensity and the declination records calculated with CALS7K.2 model show more discrepancies with the variations recorded in the sedimentary records (Figs. 12, 13). The paleointensity records used in the model are mainly distributed in central Europe (Korte and Constable 2005a). Model-derived paleointensity records are thus strongly biased towards the central Europe dataset. Overestimates of the nondipole components of the geomagnetic field for prehistoric times, as discussed by Valet et al. (2008), could explain the observed discrepancies between magnetic declination record and CALS7K.2 prediction. In addition, only five declination datasets were used to constrain the model for North America, with none of them being >50°N (Korte et al. 2005).

Implications for Arctic chronostratigraphy

Distinctive magnetic inclination and declination features...
of cores 05 and 803 can be correlated >3000 km to the western North American volcanic secular variation compilation of Hagstrum and Champion (2002) to the sedimentary record from Fish Lake, Oregon (Verosub et al. 1986), and the RPI records of both cores are consistent with changes in Earth’s dipole moment. These results also highlight the potential use of both Holocene PSV and RPI records for chronostratigraphy purposes in the western Canadian Arctic.

Conclusions

Cores 003 and 005 provide the first continuous Holocene high-resolution PSV and RPI records for the western Canadian Arctic. Similar centennial- to millennial-scale Holocene magnetic declination and inclination features can be correlated in both cores and with other high-resolution western North American lacustrine and volcanic records. In addition, the RPI records of cores 003 and 005 reveal consistent millennial-scale fluctuations compatible with changes in Earth’s dipole moment. These results also highlight the potential use of both Holocene PSV and RPI records for chronostratigraphy purposes in the western Canadian Arctic.

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