Comparison between two sediment X-ray Fluorescence records of the Late Holocene from Disko Bugt, West Greenland; Paleoclimatic and methodological implications

Oskar Jäckel

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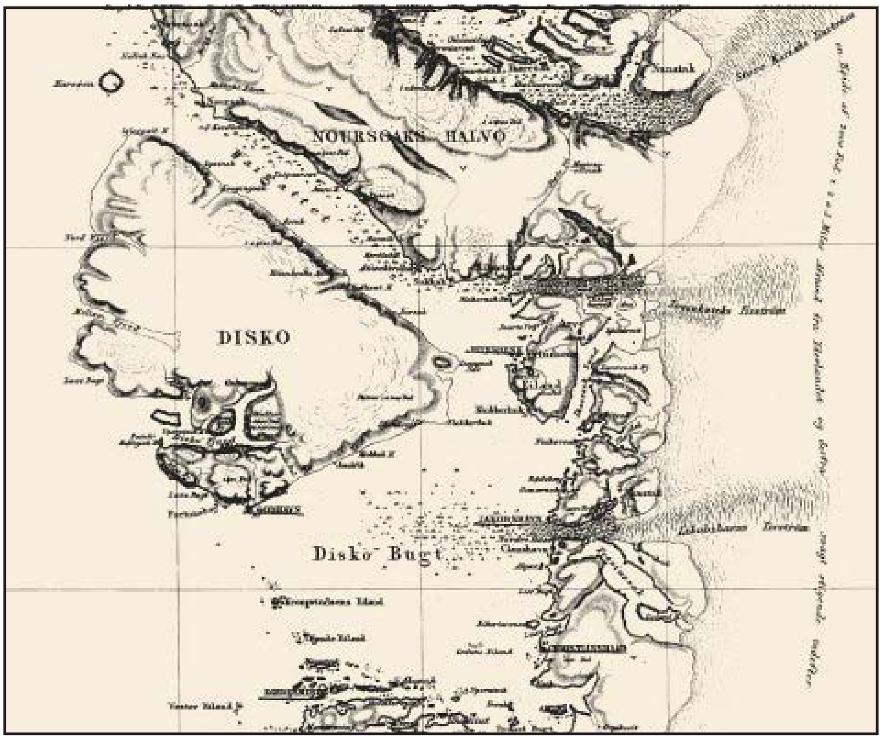

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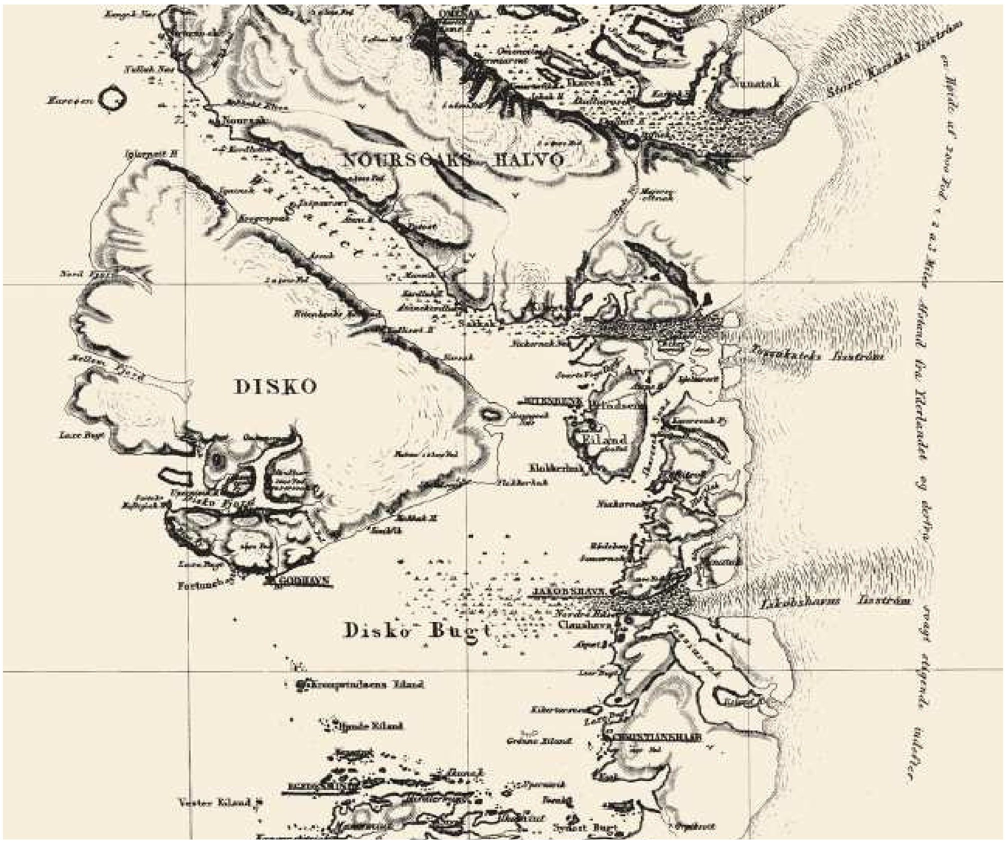

Master's thesis

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Department of Geology
Lund University

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Contents

Cover picture: Reproduction of part of H.J. Rink's map of the Disko Bugt region, published in 1853, adapted from Weidick & Bennike, 2007.

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Abstract: Two parallel sediment cores were retrieved from the Inner Egedesminde Dyb marine trench at Disko Bugt, West Greenland. Disko Bugt is the most northern point along the Western Greenland coast where relatively warm Atlantic water penetrates through the West Greenland Current. Both cores were subjected to X-ray fluorescence spectrometry (XRF) scanning to obtain the elemental composition of the sediment. The first core, labeled 343310-5-1, was scanned on board the research vessel Maria S. Merian using an Avaatech XRF scanner. The second, labeled 343310-6-1, was scanned at Stockholm University with an Cox Analytical Itrax core scanner. In addition magnetic susceptibility and mineral magnetism were measured on both cores. Subsamples from core 343310-6-1 were also subjected to thermogravimetric analysis, so that the weight loss on ignition could be determined. In order to establish an age model, two samples from 343310-5-1 where radiocarbon dated, and paleomagnetism was measured on subsamples from core 343310-6-1.The datings resulted in an age model, which indicated that the cores covered at least the last 3000 years.

The downcore mineral magnetic profiles of both cores are practically identical, but the XRF data showed some significant differences between the cores. It was assumed that one or both of the used scanners might have produced erroneous measurements. Not many opportunities to independently verify the outcomes of the XRF data were available, but the good correlation between the bromine record from core 6-1 and the loss on ignition at 550 degrees (LOI_{550}) from the same core suggested that the XRF analysis by the Itrax core scanner was probably not to be blamed.

It was hypothesized that there might be a correlation between the various magnetic properties and certain elements, but no significant correlations were found. Overall the mineral magnetic data proved hard to interpret, but it was useful for correlating the cores, as the mineral magnetic signals of the two parallel cores were close to identical. Of the XRF data the most interesting record was provided by bromine from core 6-1. Bromine has been suggested as a proxy for paleoproductivity, and its correlation with LOI_{550}, which represents the percentage of organic carbon in the sediment, seemed to confirm this. The bromine record showed variations that could be correlated with results from other studies, and could be interpreted as evidence for changing oceanographic conditions in Disko Bugt resulting in enhanced and reduced primary productivity in the surface waters. It appeared that primary productivity was strongest in the so-called Medieval Warm Period, of which it is still debated if it was actually relatively warm or cold in West Greenland. During the Roman Warm Period there were also phases of enhanced productivity, but they were periodically alternated by productivity lows. The iron and titanium records both showed a declining trend over the studied period, with cyclic variations superimposed on it. Both elements are thought to be of terrestrial origin in the marine sediment, and might be linked to the activity of calving glaciers around Disko Bugt such as Jakobshavn Isbrae.

Keywords: Disko Bugt, X-ray fluorescence, mineral magnetism, magnetic susceptibility, paleomagnetism, bromine, productivity, Medieval Warm Period

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1 Introduction

The Holocene climate of the North Atlantic region in general, and West Greenland in particular, is known from recent studies to be highly variable (Moros et al., 2004; Seidenkrantz et al., 2008). These variations are thought to be linked to oceanographic changes that occurred in the North Atlantic (Moros et al., 2006; Lloyd et al., 2007; Seidenkrantz et al., 2008). In this study relatively new and untested methods were applied to two sediment cores from Disko Bugt, to obtain new data. Furthermore the applied methods, ranging from X-Ray Fluorescence spectrometry (XRF) to mineral magnetism were tested, and their usefulness is evaluated in this study.

1.1 Research aims

The main goal of this study was to use methods such as XRF scanning and mineral magnetism to refine the current understanding of the oceanographic and climatic development in Disko Bugt over the time interval recorded in the two parallel sediment cores 343310-5-1 and 343310-6-1. In addition to that, it was needed to test the applicability and reliability of the used methods, and to explore the possible correlations between the methods.

1.2 Setting

Disko Bugt (known as Qeqertasuup Tunua by the native population) is a large embayment in central West Greenland (figure 2). To the northwest it is confined by Disko Island, to the east and south it is bordered by mainland Greenland. The bottom topography of Disko Bugt is markedly rugged, and characterized by various glacially carved channels. The most prominent of these is the 350 km long Egdesminde Dyb, which is up to 990 meters deep (Moros et al., 2006). At the time of the last glacial maximum a prominent ice stream advanced though this channel, the present day remainder of this ice stream is the Jakobshavn Isbrae (also known as Ilulissat Icefjord) which is located near the town of Ilulisat (Jakobshavn), 40 km into Disko Bugt (Lloyd et al., 2007). The Jakobshavn Isbrae is fed by 6% of the Greenland Ice Sheet area, and has a discharge of 35 km^3 per year, making it the largest outlet glacier of West Greenland (Weidick & Bennike, 2007). The sediment cores analyzed in this study (343310-5-1 and 343310-6-1) were taken in the Inner Egdesminde Dyb (figure 3) (Dietrich et al. 2007).

1.2.1 Geology

Disko Island mainly consists of Paleogene basalts, while the mainland of Greenland is predominantly built up of Precambrian basement. In the bedrock of Disko Bugt these two units are present as well, together with Upper Cretaceous and Paleogene sediments in the inner sector of the bay (figure 1; Weidick & Bennike, 2007).

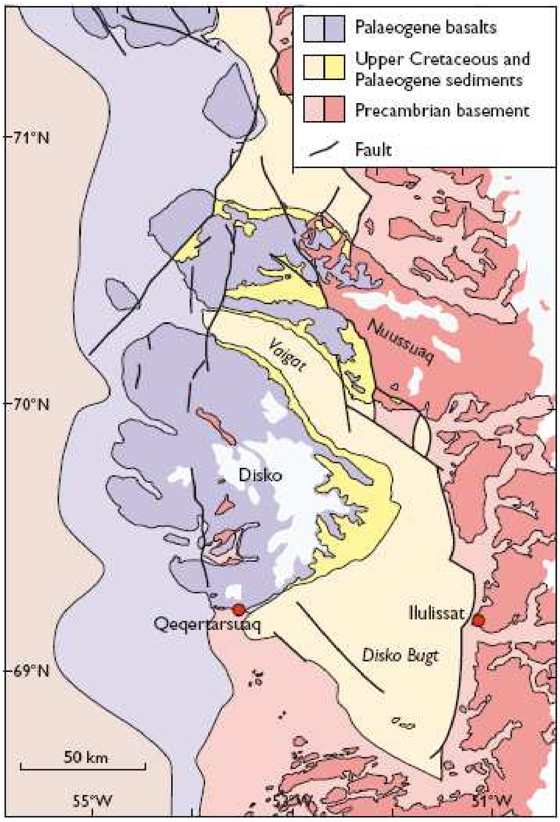

Figure 1. Geological map of the Disko Bugt region (from Weidick & Bennike, 2007)

1.2.2 Present day oceanography

The West Greenland Current (WGC) flows from the southern cape of Greenland along the western shore in northern direction through the Davis Straight into Baffin Bay. The WGC is a relatively warm arm of the Irminger Current (IC) that originates in the North Atlantic, and therefore its waters have a composition typical of the North Atlantic (figure 2) The East Greenland Current (EGC) is a cold arctic current, which meets the IC at southeastern Greenland. The Baffin Current (BC) flows at western edge of Baffin Bay along Baffin Island through Davis Strait into the Labrador Sea, where it meets the IC/WGC to form the relatively cold Labrador Current (LC).
The current system around Greenland is especially interesting because its flow pattern is in apparent contradiction with the Coriolis effect, and therefore the currents do not represent geostrophic currents. This is caused by the need for water masses to flow around obstacles, which in the case of these currents is more important than wind direction or the Coriolis effect (Garrison, 2005).

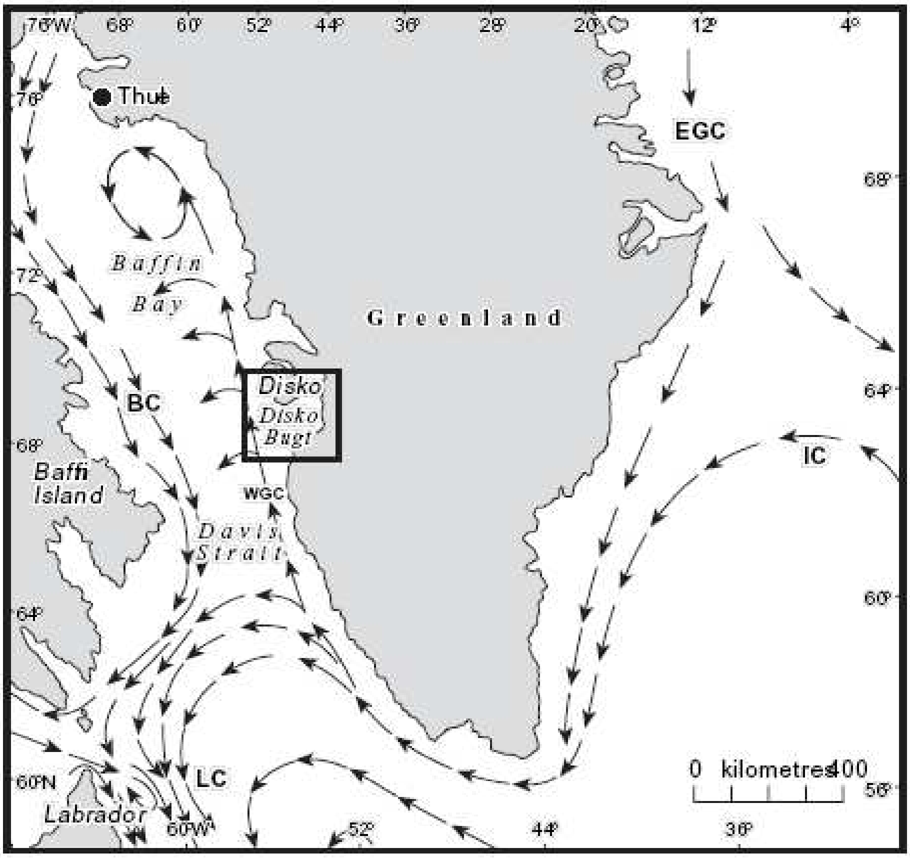

Figure 2. Ocean currents around Greenland, with the square indicating Disko Bugt. BC: Baffin Current, WGC: West Greenland Current, LC: Labrador Current, EGC: East Greenland Current, IC: Irminger Current (from Lloyd, 2006).

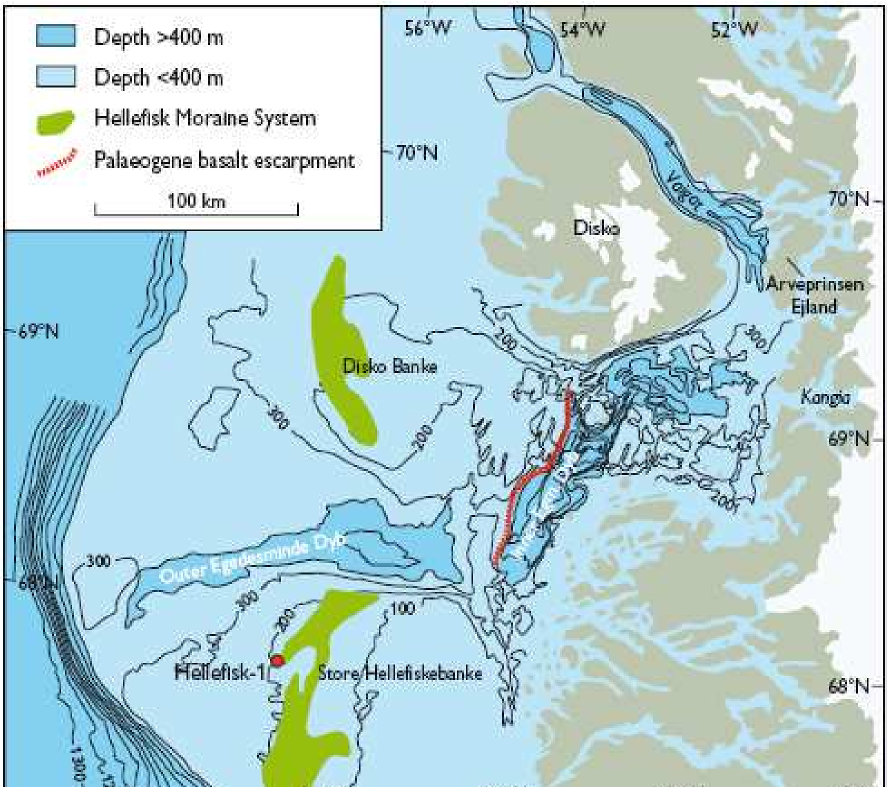

Figure 3. Continental shelf topography offshore Disko and Disko Bugt (from Weidick & Bennike, 2007).

The WGC current flows into Disko Bugt as a saline deepwater current. The surface waters are generally dominated by the meltwater outflow of the various outlet glaciers of the Greenland Ice Sheet that discharge into Disko Bugt (Desloges et al., 2002). Stratification of the water column is most prominent during summer, in winter it is more mixed. The majority of icebergs calving from the glaciers are currently transported north and west through the Vaigat fjord (Dietrich et al., 2007) and then surface currents move them to the south.

1.2.3 Present day climate

The climate around Disko Bugt is presently polar maritime. The annual average temperature at Ilulissat (at 69° North) is -3.9°C, and precipitation is relatively high. In most winters Disko Bugt is covered with land-fast sea ice from November till April, while it is ice-free during the summer months (Lloyd et al., 2007; Weidick & Bennike, 2007). Local residents have noticed a reduction in the length and thickness of ice cover over the last decade or two (Ian Snowball, personal communication).

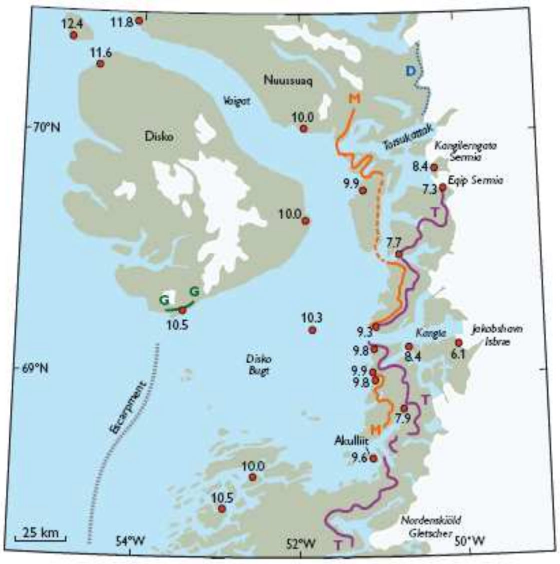

Figure 4. Dates in cal. kyr BP indicate the time at which the indicated locations became ice-free. The colored lines indicate important moraine systems (from Weidick & Bennike, 2007).

1.3 Regional history

West Greenland has long been a focus point for climate studies. People have been fascinated by the variability of the climate in the area since the disappearance of the Norse settlements in the 15thcentury and its speculated relation to climate change (Dugmore et al., 2007). Ice coring programs on the inland ice sheet of Greenland (see, e.g., Johnsen et al., 2001; North Greenland Ice Core Project members, 2004) have attracted a lot of attention from both the scientific community and the general public. In order to correlate the ice-core records to marine and coastal sections, special interest in the coastal area of Greenland has been sparked. Disko Bugt is one of the most northerly areas of the Labrador Sea region, where relatively warm Atlantic water regularly penetrates, and it also receives the output of one of the world's fastest flowing ice streams (Lloyd, 2006).The climate of this region is known to be highly variable and it offers interesting opportunities to study changes in glacier advances, ocean circulation, and biotic processes.

1.3.1 Climatic history

During the last glacial maximum the Disko Bugt region was covered by the Greenland Ice Sheet. The ice sheet expanded almost up to the edge of the continental shelf, where it formed the Hellefisk Moraine System (figure 3). After the termination of the last glacial, the ice sheet rapidly retreated (figure 4), and climatic warming culminated in the Holocene thermal maximum (HTM) which began around 8000 cal. yr BP in West Greenland (Kaufman et al., 2004).

Around 4000cal. yr BP the climate became colder again, leading to a period known as the neoglaciation the onset of which has been determined to about 3200 cal. yr BP (Kaufman et al., 2004; Seidenkrantz et al., 2008). The generally cold Late Holocene was interrupted by a warm phase from circa 2200 to 1400 cal. yr BP, which could be analogous with the Roman Warm Period in Europe (Lloyd et al., 2007).

The exact climatic history of West Greenland during the most recent part of the neoglaciation period is not yet fully understood. There is no agreement about the regional climate during the Medieval Warm Period (MWP) and the Little Ice Age, with different authors providing different scenarios for those climate zones (e.g. Lloyd, 2006; Seidenkrantz et al., 2008). It has been claimed that the Little Ice Age was the coldest period during the neoglaciation, but recent studies show that, at least for Greenland, this was probably not the case (Forman et al., 2007).

1.3.2 Paleoceanography

Various studies have suggested that the ocean currents in the North Atlantic were subject to variation over the Holocene (e.g. Bond et al., 1997; Bond et al., 2001; Andersen et al., 2004; Solignac et al., 2004). In the Disko Bugt area these variations are mostly related to changes in the strength of the WGC, and the importance of Atlantic water masses from the Irminger Current relative to those of the East Greenland Current in the WGC (Lloyd, 2006).

Up to 3500 cal. yr BP strong WGC inflow caused high melt rates at the margins of calving glaciers (figure 5d; Lloyd et al., 2007). Between 3500 and 2700 cal. yr BP the influence of Atlantic water in Disko Bugt weakened stepwise (figure 5b), leading to a cooling of the surface waters (Seidenkrantz et al., 2008). Between 2200 and 1664 cal. yr BP there was increased influence of relatively warm and saline Atlantic water masses (figure 5a), which are interpreted as increased prominence of the IC relatively to EGC in the WGC (Lloyd, 2006). In Disko Bugt this warming seemed to have peaked between 2000 and 1800 cal. yr BP (Moros et al., 2006).

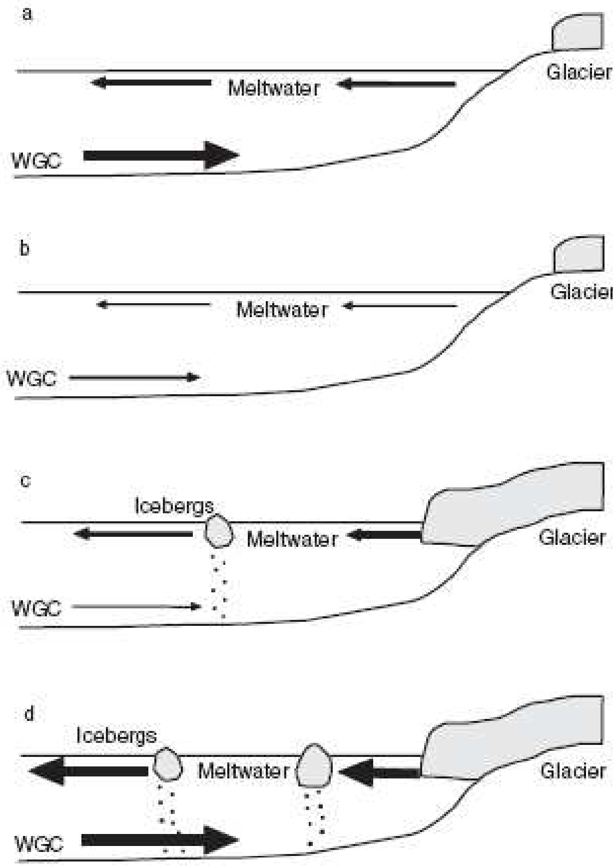

Figure 5. Schematic representation of different hydrographic conditions in a fjord in Disko Bugt:(a) moderate to low meltwater influx, glaciers most likely land based and strong WGC inflow at depth; (b) relatively weak circulation in the fjord, moderate meltwater flux with glaciers land based and weak inflow of WGC; (c) moderate meltwater flux from tidewater glaciers supplying some coarse-grained sediment and weak WGC inflow; (d) strong meltwater and sediment flux from tidewater glaciers and strong WGC inflow (from Lloyd et al., 2007).

According to Lloyd (2006), who studied two sediment cores from the eastern part of Disko Bugt close to Jakobshavn Isbrae, the EGC continued to decrease its input into the WGC until 474 cal. yr BP, as could be denoted from the continuing inflow of warm and saline water into Disko Bugt. This inflow of Atlantic water might have only warmed the subsurface waters during the MWP, as sea-surface temperatures in central Disko Bugt were low (Moros et al., 2006), and there the period from 1300 till 300 cal. yr BP was possibly the coldest of the Holocene (Seidenkrantz et al., 2008).

According to Lloyd (2006) conditions became colder after 474 cal. yr BP, pointing to an increase in the EGC component of the WGC, while Seidenkrantz et al (2008) argue that warmer surface waters characterized the period after 400 cal. yr BP.

1.3.3 North Atlantic climatic seesaw

Applying the terminology of the various historical climatic zones in the Late Holocene (such as the Little Ice Age or the Roman Warm Period) to Greenland can lead to some confusion. This is because the names of these zones originate in Europe, but a climatic discrepancy between Europe and Greenland is apparent.

This discrepancy was already recognized by Danish settlers in the late 18th century, who noticed that mild winters in Greenland coincided with cold winters in Europe, and vice versa (Van Loon & Rogers, 1978). This relation is currently known as the North Atlantic climatic seesaw (Van Loon & Rogers, 1978; Dawson et al., 2003; Seidenkrantz et al., 2008). The seesaw has been related to the North Atlantic Oscillation (NAO) and associated variations in storminess over the North Atlantic (Dawson et al., 2003).

An example of the supposed effect of this seesaw mechanism is the geographic variation in the climate of the MWP, which has recently been considered to be a relatively cold episode in the climatic history of Greenland (Moros et al., 2006; Seidenkrantz et al., 2008). Although this notion is opposed by some earlier publications, in which it is proposed that the MWP was indeed warm in Greenland, and even recognizable on a global scale (Dahl-Jensen et al., 1998; Broecker, 2001; Lloyd, 2006).

Even if the MWP was warm in Greenland, it might still have been diachronous compared with the European MWP, as Huang et al. (2008) propose that the warmest phase of the MWP was between 950 and 1100 AD, while in Europe it was between 1150 and 1300 AD.

1.3.4 Cultural history

The area around Disko Bugt has been inhabited by people for more than 4 millennia, although not continuously. At times the region was probably relatively densely populated, while there are also long intervals without any evidence for human presence. These uninhabited periods have been explained by climatic factors and the overexploitation of resources (Moros et al., 2004; Weidick & Bennike, 2007).

Archeological sites of Paleo-Eskimo cultures are abundant in the area (Kuijpers et al., 2001). In general three phases of Paleo-Eskimo and Neo-Eskimo cultures can be distinguished (figure 6). The oldest is the Saqqaq culture, ranging from circa 4500 BP till 2800 BP. The subsequent Greenlandic Dorset culture (or Early Dorset) was present from 2800 BP till 2000 BP. The Thule culture settled in the Disko Bugt region 800 BP, when there were probably also contacts with the Norse settlements further south (Weidick & Bennike, 2007).

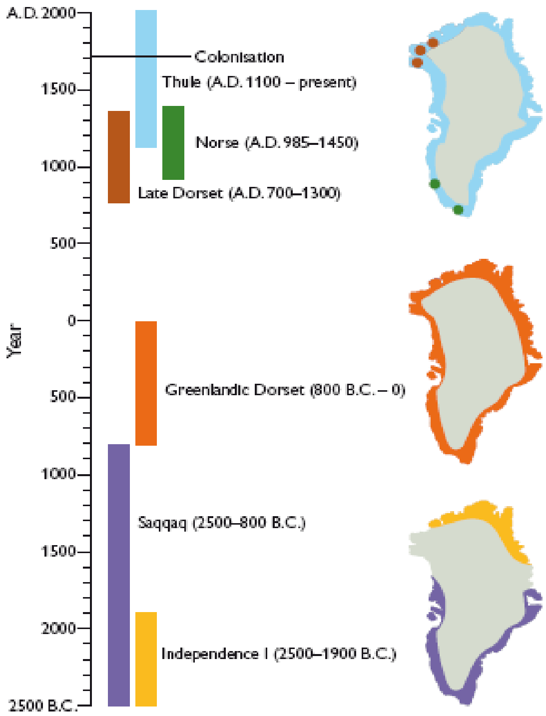

Figure 6. Chronology of the different archeological cultures that have colonized Greenland (from Weidick & Bennike, 2007).

1.4 Methodological overview

In this study both X-Ray Fluorescence spectrometry (XRF) scanning and mineral magnetism have been applied on relatively deep marine core sediments. In addition thermogravimetric analysis has been used as a supporting method, and both paleomagnetism and radiocarbon dating have been used in order to set up an age model for the main core.

1.4.1 X-ray fluorescence (XRF) scanning

X-Ray Fluorescence spectrometry (XRF) is a method by which the concentration of certain elements in materials can be detected. It works according to the principles of the photoelectric effect. X-rays penetrate an atom, and the high energy of the waves causes inner orbit electrons to be emitted from their orbit. This only occurs if the energy of the wave is higher than the energy by which electron is bound in its orbit. An electron coming from an outer orbit can now fill the place left in the inner orbit. This change of orbits leads to an energy surplus, which is emitted in the form of an X-ray (figure 7). The wavelength of the X-ray thus emitted is unique for each element, and when this wavelength is detected, the element can therefore be identified (Janssens, 2004).

XRF surface scanning is a relatively new method by which the elemental composition of sediment cores can be measured continuously. Its advantages are the speed at which the analysis can take place, the high resolution that can be obtained and the non-destructiveness of the method. A disadvantage is that no absolute concentrations can be acquired; instead data are acquired as relative number of 'counts' per element, most often reported as counts per second (cps). Recently, data derived from XRF scanning have increasingly been used in studies dealing with paleoceanography. However, the reliability of these measurements has only been tested in a handful of studies. The results of these studies often showed that the reliability of XRF scans cannot always be established firmly enough to be applied as a robust scientific method (Jäckel, 2007).

1.4.2 Mineral magnetism

Mineral magnetism or environmental magnetism is a method in which various magnetic properties of natural materials are studied in order to be able to relate changes in these properties to environmental change. This can be done because minerals commonly present in, for example, sediments have specific magnetic properties, and variations in the occurrence of these minerals could be affected by environmental conditions (Thompson & Oldfield, 1986). Mineral magnetism has most widely been applied to lake sediments and soils, but is has also proved to be a successful method in the marine realm (e.g. Snowball & Moros, 2003).

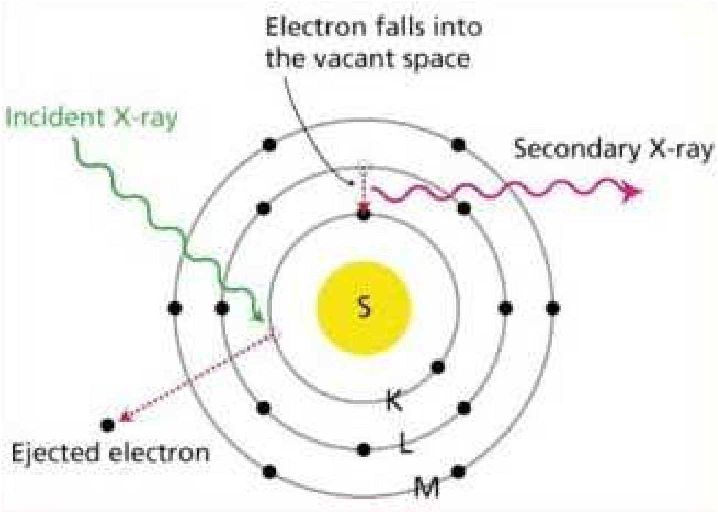

Figure 7. Schematic overview of X-Ray Fluorescence, adapted from www.oxford-instruments.com. See section 1.4.2 for details

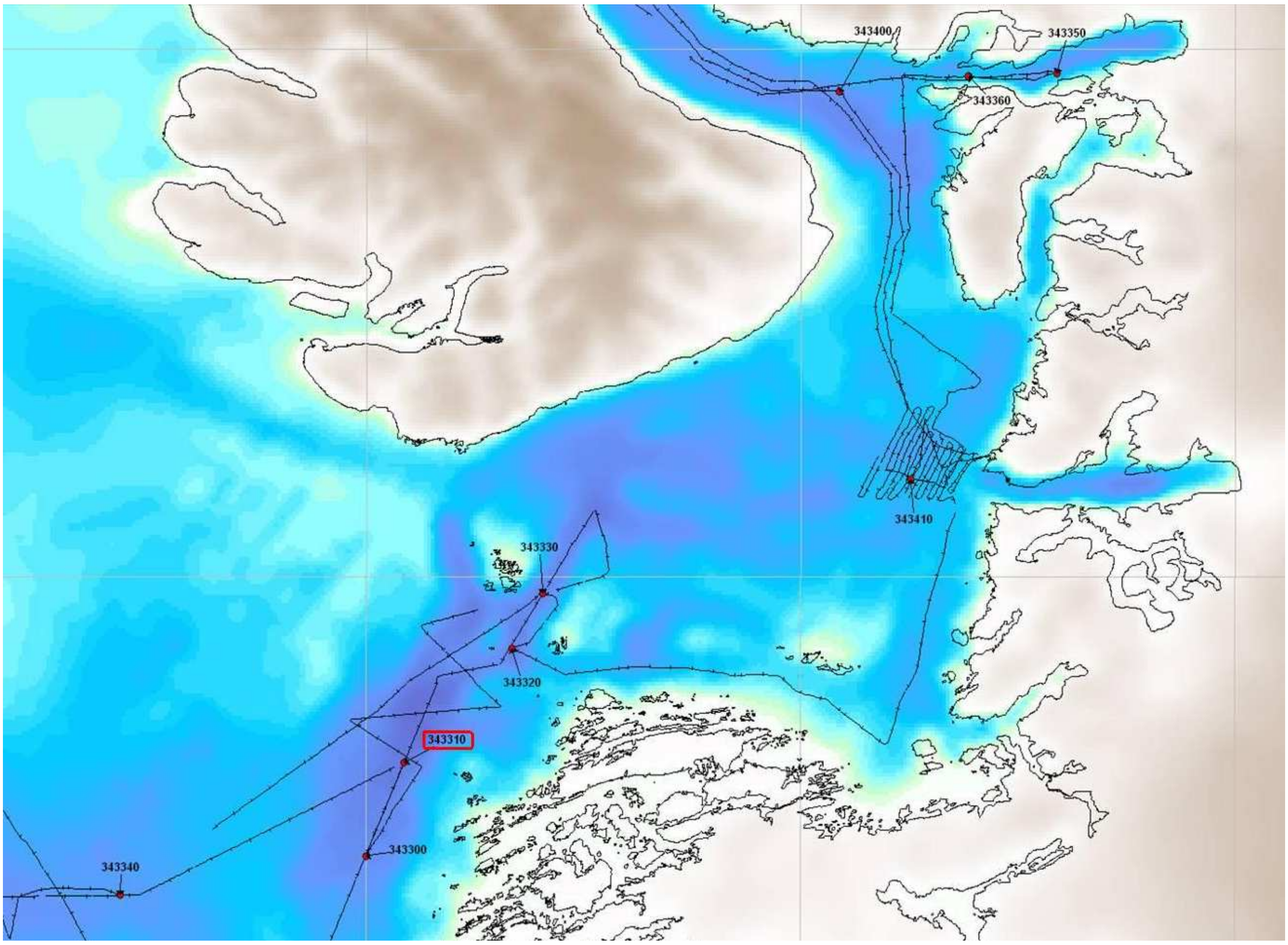

Figure 8. Location of coring site 343310 in Disko Bugt indicated in red. The black lines show part of the RV Maria S. Merian cruise route in 2007.

2 Material and methods

2.1 Sediment cores

During Cruise MSM 05/03 in West Greenland a number of sediment cores were retrieved using a 12 m gravity corer. The two cores that are dealt with in this study, originate from the Inner Egedesminde Dyb at Disko Bugt (figure 8). Core 343310-5-1 was taken at 68°38,861' N; 53°49,493'W at a water depth of 855.8 m, core 343310-6-1 was taken at 68°38,859' N; 53°49,496' S at a water depth of 856.3 m. Both cores were retrieved on June 19 2007. A seismic profile of the coring site was made as well (appendix 1).

Core 343310-5-1 was sampled and scanned on board of the research vessel Maria S. Merian, while core 343310-6-1 was kept in cold storage.

Core 343310-6-1 was opened and split in Lund. The core breaks of this core were at the following depths (in cm.): 28, 126, 221, 323, 425, 526, 627, 728 and 828. The total length of the core is 910 cm.

One half was put in cold storage (labeled OOO), while the other half (XXX) was scanned for magnetic susceptibility and subsampled for mineral magnetism. The subsampling was done by pressing plastic cubes with a volume of 7 cc into the sediment surface at an interval of 2.5 to 3 cm. On these subsamples magnetic susceptibility, Anhysteretic Remanent Magnetization (ARM) and Saturation Isothermal Remanent Magnetisation (SIRM) was measured (see section 2.5).

The core-half in cold storage was later used for XRF-scanning, and subsequently subsampled for paleomagnetic measurements. Here the same type of cubes was used, and a sampling interval of 3 cm was maintained.

2.2 Dating

Two samples of benthic foraminifera taken from core 343310-5-1 were radiocarbon dated in the Poznań Radiocarbon Laboratory using accelerator mass spectroscopy (AMS). AMS radiocarbon dating (or ^{14}C dating) is a radiometric dating method where the ratio between the stable ^{12}C and the unstable ^{14}C isotopes of a sample is measured. From that ratio the ^{14}C age can be calculated, as the half-life of ^{14}C is known (Walker, 2005).

The acquired ^{14}C ages were corrected for the marine reservoir effect, which is responsible for too high ages of marine samples as contemporary sea water has an apparent ^{14}C age (Walker, 2005). Then the corrected ages were calibrated to calendar years. Calibration is necessary as the production of ^{14}C has not been constant over time (Walker, 2005).

These radiocarbon datings were combined with available paleomagnetic data of core 343310-6-1 to establish an age model. By using magnetic susceptibility and mineral magnetic data of both cores, the two parallel cores could be correlated.

2.3 XRF scanning

XRF-scanning of core 5-1 was conducted on board the R/V Maria S. Merian using an Avaatech XRF core scanner, with a measurement interval of 10 mm. Core 6-1 was scanned at Stockholm University using an Itrax XRF core scanner with the measurement interval set to 5 mm. Both the Avaatech and the Itrax operate according to the same basic principle, but their operating mechanisms are of a different design. The detection range and the calibration of the raw data differ as well. Considering the setups used in this study, the Itrax detects a wider range of heavier elements compared to the Avaatech machine.

The raw XRF-data of core 343310-6-1 was calibrated by an algorithm-based calibration program. As the different core sections were calibrated separately, the obtained values sometimes showed an abrupt shift in the cps at the core-break. Each element was calibrated individually, so the data sets of some elements had these core-break shifts, while others had a more continuous record. In records where these shifts at core breaks were apparent, they have been corrected by subtracting or adding the value of the shift at the core break. This did not disrupt the data set, as the XRF-data does not represent absolute concentration of elements, but just gives a relative indication of the change in abundance of a certain element throughout the core.

Outlying values at the core breaks were deleted from the record as they obviously represented erroneous measurements. A smoothed trend-line was calculated by taking a 40-point running average for element data from core 6-1, and a 20-point running average for the data of core 5-1. The different average windows were used to take into account the different measurement increments.

2.4 Magnetic susceptibility

Both core 343310-5-1 and 6-1 were scanned for magnetic susceptibility. Susceptibility is the degree to which material can be magnetized (Thompson & Oldfield, 1986). Core 5-1 was scanned onboard of the R/V Maria S. Merian, and core 6-1 was scanned in the Palaeomagnetic and Mineral Magnetic Laboratory (PMML) at Lund University. The scanning of the core-halves was done with a Bartington Instruments MS2E1 high-resolution surface scanning sensor, which was coupled to a TAMISCAN-TS1 automatic logging conveyor, which moves the core-halves during the operation. The scanning was conducted at a measurement interval of 5 millimeter to comply with similar measurements conducted onboard Maria S. Merian.

Subsequently the magnetic susceptibility of the subsamples of both cores was measured in the PMML using a Geofyzika Brno Kappabridge KLY-2 magnetic susceptibility meter. After all the measurements were conducted on the subsamples, they were weighed, dried, and weighed again. This way their net dry weight could be calculated. By dividing the magnetic susceptibility with the net dry, the mass specific magnetic susceptibility (χ) was obtained.

2.5 Mineral magnetism

The mineral magnetic measurements were conducted in the Palaeomagnetic and Mineral Magnetic Laboratory (PMML) at Lund University. The samples were first measured for ARM by magnetizing them with a 2G-Enterprises alternating field coils 100 milliTesla (mT) in the presence of a DC bias field of 0.1 mT. Then they were subjected to a positive 1 Tesla DC field in a Redcliffe BSM700 pulse magnetizer. The ARM and SIRM of each sample was measured with a Molspin Minispin magnetometer. The samples were subsequently subjected to negative (back) fields of -100 and -300 mT and the resulting remanences measured with the Minispin. S-ratios were calculated using the SIRM and -100 and -300 mT fields.

2.6 Paleomagnetism

The core-half labeled “OOO” had been subsampled for paleomagnetism at intervals of 3 cm. The subsamples were demagnetized along three axes in an automatic sequence ranging from 0 to 40 mT at steps of 5 mT. The Normal Remanent Magnetisation´s (NRM’s) were measured after each demagnetization step using a 2G-Enterprises model 755R DC SQUID magnetometer and the results used to determine the characteristic natural remanent magnetization (cNRM) using principal component analysis (PC software written by A. Nilsson).

2.7 Thermogravimetric analysis

To establish the organic carbon and carbonate content of the sediment thermogravimetric analysis (TGA) was used. The analysis was performed in the Geolab at Utrecht University using a LECO TGA701.

With TGA the samples are heated in 5 predetermined steps up to 1000 degrees Celsius. The samples are weighed continuously during heating. At each temperature step all samples are held at a constant temperature until a stable weight is reached. Then the TGA warms up to the next temperature step. The temperatures used in this study were 105, 450, 550, 800, and 1000 degrees Celsius.

Dry samples of approximately 3 grams were used for this analysis, except for the interval 910 till 854 cm depth and 796.5 till 758 cm depth. In those two intervals slightly bigger samples weighing up to 4.8 grams were used. This was a mistake, which in theory could have lead to slight errors in data from these intervals (Heiri et al., 2001).

All organic carbon present in a sample burns when the sediment is heated at 550 degrees Celsius. To obtain the amount of organic carbon in a sample, the loss on ignition at 550 degrees Celsius (LOI_{550}) could be calculated using the formula:

$$LOI_{550} = ((DW_{105} – DW_{550})/DW_{105})*100$$

Where DW_{105} is the weight of the sample at 105 degrees Celsius and DW_{550} the weight of the sample at 550 degrees Celsius (Heiri et al., 2001).

The carbonate content of the sediment could be determined in a similar way, considering that carbonate decomposes at 950 degrees Celsius. Here the LOI at 1000 degrees Celsius (LOI_{1000}) was applied, which was calculated with the following equation:

$$LOI_{1000} = ((DW_{550} – DW_{1000})/DW_{105})*100$$

Where DW_{1000} represents the dry weight of the sample at 1000 degrees Celsius (Heiri et al., 2001).

3 Results

3.1 Lithology

Core 343310-6-1 consists mainly of grey-greenish clay. The lithology was quite homogenous; no layering or sedimentary structures were macroscopically visible (figure 9). Furthermore no gradation, or graded beds were encountered. At the top the sediment was close to being liquid, while it was quite firm at lower levels. Various clasts, ranging up to 2 cm in diameter, could be found throughout the core. They were interpreted as being ice rafted debris. There were no intervals where their abundance was significantly higher or lower than the average.

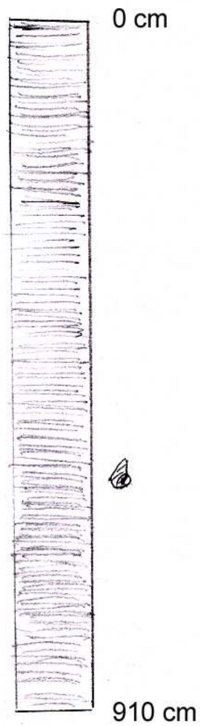

Figure 9. Simplified lithological column of core 343310-6-1**,** with the position of the gastropod at 606 cm depth indicated.

Microfossils and mollusks were also observed along the whole core. At 606 cm a particular large (6 cm long) gastropod of the species *Buccinum hydrophanum* was retrieved from the sediment (figure 10).

Figure 10. Buccinum hydrophanum Hancock, 1846

3.2 Dating and age model

The ^{14}C-ages from radiocarbon dating (Table 1.) were corrected for the 500 years reservoir effect in Disko Bugt. The resulting ages were then calibrated using CalPal Online (at http://www.calpal-online.de). This calibration resulted in an age of 153 ± 122 cal. yr BP (Before Present, where Present is 1950 AD) for the sample taken at a depth of 18-19 cm. The age for the sample from a depth of 402-401 cm was found out to be 1438 ± 53 cal. yr BP.

Sample depth (cm)	^{14}C age	minus reservoir effect (500 yr)*	cal. ^{14}C age^
18-19	685 ± 35 BP	185 ± 35 BP	**153 ± 122 BP**
401-402	2030 ± 30 BP	1530 ± 30 BP	**1438 ± 53 BP**
		*source: Marine reservoir database	^source: CalPal-Online

Table 1. ^{14}C-dating results of core 343310-5-1

As only two radiometric dates were available, constructing a crude age model was not complicated. The paleomagnetic data from core 6-1 were noisy but a declination swing around 800 cm depth might correspond to feature "f" (figure 14), which has been dated to 2670 cal. yr BP in Fennoscandia (Snowball et al., 2007). For the age model a constant sedimentation rate was assumed, and the standard errors of datings were not taken into further consideration. 18.5 cm was set at 153 cal. yr BP, and 401.5 cm was set at 1438 cal. yr BP, and from these starting points an age model for the whole core could be calculated (figure 11). This resulted in the following equation:

Age = 3.355 * Depth + 90.93

The depth should here be given in centimeters. The equation results in an age of 91 cal. yr BP for the top of both cores, and an age for the bottom of 5-1 (938 cm) of 3238 cal. yr BP, and for the bottom of 6-1 (910 cm) 3144 cal. yr BP.

From the correlation in the paleomagnetic data of cores 343310-6-1 and MD99-2269 could be inferred that the age models of both cores were in reasonable agreement with each other (see section 3.5).

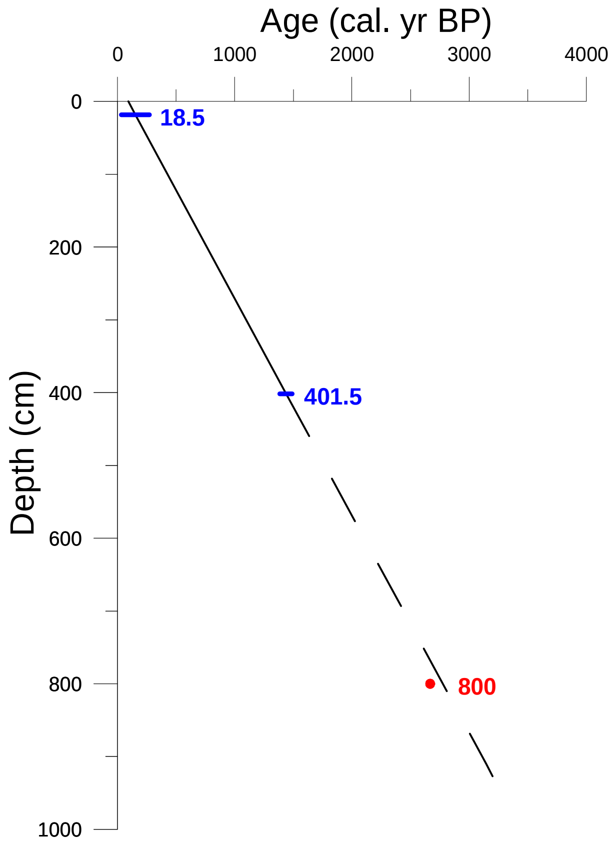

Figure 11. Age-depth diagram, with the ^{14}C datings indicated by blue lines and feature “f” indicated by the red dot.

3.3 XRF scanning

Core 343310-5-1 analyzed on board with the Avaatech machine yielded data for 9 elements. Core 343310-6-1 analyzed in Stockholm with the Itrax machine yielded 26 elements (Table 2, figure 12 and appendix 2).

343310-5-1	343310-6-1	Atomic number
aluminum (Al)	aluminum (Al)	13
silicon (Si)	**silicon (Si)**	**14**
	phosphorous (P)	15
sulfur (S)	**sulfur (S)**	**16**
chlorine (Cl)	**chlorine (Cl)**	**17**
	argon (Ar)	18
potassium (K)	**potassium (K)**	**19**
calcium (Ca)	**calcium (Ca)**	**20**
titanium (Ti)	**titanium (Ti)**	**22**
	vanadium (V)	23
	chromium (Cr)	24
manganese (Mn)	**manganese (Mn)**	**25**
iron (Fe)	**iron (Fe)**	**26**
	cobalt (Co)	27
	nickel (Ni)	28
	copper (Cu)	29
	zinc (Zn)	30
	arsenic (As)	33
	selenium (Se)	34
	bromine (Br)	35
	rubidium (Rb)	37
	strontium (Sr)	38
	yttrium (Y)	39
	zirconium (Zr)	40
	barium (Ba)	56
	lead (Pb)	82

Table 2. Elements analyzed in cores 5-1 and 6-1. Elements in bold are shown in figure 11. Elements in italics are shown in appendix 2.

The concentrations of some of the measured elements were, in practice, below the detection limit of the instruments, and no useful data were retrieved for them. In core 6-1 aluminum, phosphorous, arsenic, selenium, yttrium and lead were for most part at, or below the detection limit, leading to discontinuous and noisy data.

The elements silicon, potassium, iron, and titanium are thought to be mainly land-derived. While the presence of bromine might point either to high primary productivity rates (Pherodin et al., 2000), or to marine influence (Møller et al., 2006), which in this study would represent enhanced influx of Atlantic water through the West Greenland Current. In any further overview of the XRF-results and their interpretation, there will only be referred to the Itrax-data from core 6-1, as only that record encompasses all the elements that are of the main interest.

Overall the records of Si, K, Ti, and Fe show a declining trend from the bottom to the top. The record of Br shows a slightly increasing trend, although the overall increase of Br is considerably less than the decrease of the aforementioned elements.

Between 300 and 310 cm depth there is a pronounced shift in the measured values of both bromine and iron. At this interval bromine increases, andiron decreases. The same negative shift is to a lesser extent present in the silicon, potassium and titanium records.

Lower down in the interval between 500 and 800 cm depth there is a cyclicity visible with a period of roughly 200 to 300 years. The cycles are present in the records from quite a diverse number of elements such as Ti, Fe, Zr, Br, Sr, and maybe K, Ca, and Mn. Striking is that the records of Fe, Ti, Zr, and Sr seem to be in antiphase with the Br-record.

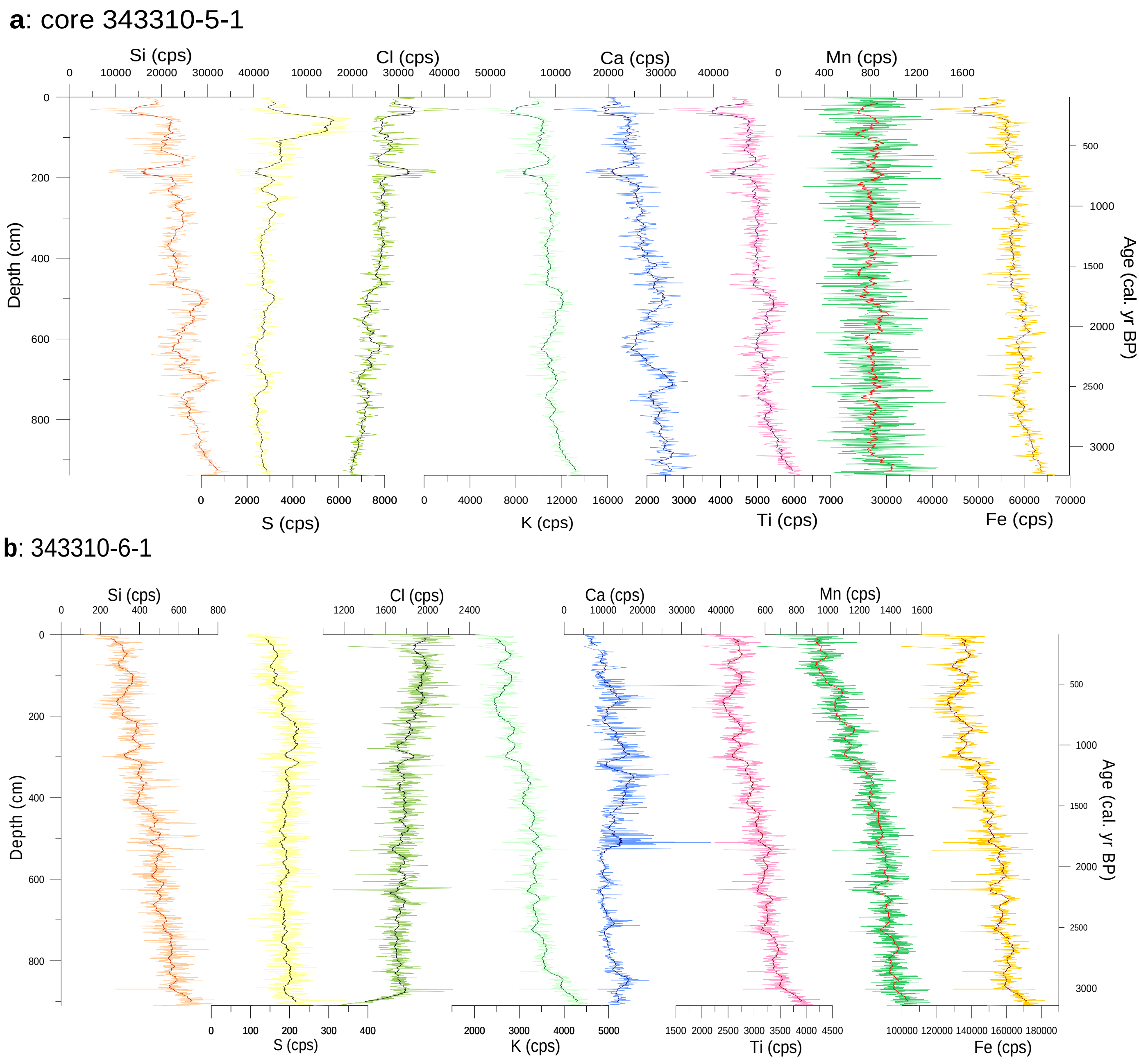

Figure 12. XRF results for elements scanned in both core 343310-5-1 (**a**) and in core 343310-6-1 (**b**). The clear lines are the smoothed trend lines based on a running average (see section 2.3), while the quite scattered lines represent the raw data.

3.4 Mineral magnetic data

Susceptibility ranges between 8 and 66 10^{-5} SI for the scanning measurements and between 0.228 and 1.225 10^{-5} m^3kg^{-1} for the mass specific measurements.

The magnetic susceptibility record of both cores generally shows good correlation between the two records (figure 13). At some intervals there is a slight depth shift apparent, but overall the cores contain identical trends and the same decimeter-scale changes.

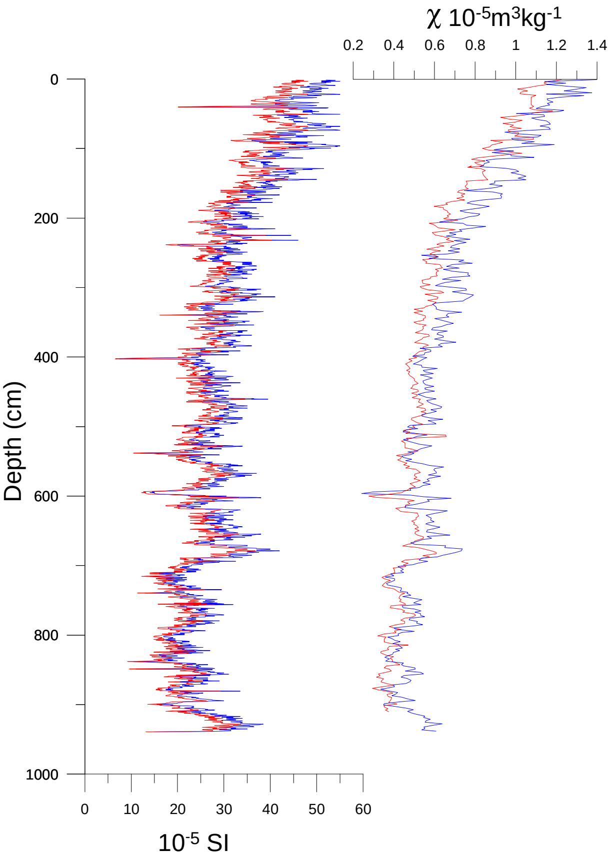

Figure 13. Magnetic susceptibility of both cores, with core 6-1 in red, and core 5-1 in blue. The left hand graph represents the scanning results, while the right hand graph shows the mass specific magnetic susceptibility (χ) derived from the subsamples.

In general there is an increasing trend in the measured values from the bottom to the top of the cores, with the most prominent increase in the upper 2 meters.

The mineral magnetic results from cores 343310-5-1 and 343310-6-1 are close to identical. All parameters measured showed quite low values, sometimes close to the lowest sensitivity of the of the Molspin magnetometer.

The SIRM record shows an almost exponential decline from top to bottom (appendix 3 and 4) with values ranging from 69 till 563 $10^{-3}Am^2$ kg^{-1}.

The ARM record of 5-1 has slightly lower values (ranging from 1 till 7 $10^{-3}Am^2$ kg^{-1}), and is noisier than the record from 6-1 (appendix 5). Both cores have low ARM values and show a weak, gradual decline in values from top to bottom.

3.5 Paleomagnetism

The paleomagnetic measurements were conducted at different times. The first batch of samples (325-555) was measured in spring 2008, and the second and final batch (558-908) was done in autumn 2008. Because some of the samples were taken before summer, but only measured after summer (555-725), they were stored under cool conditions. Nonetheless these samples did dry out due to a malfunction in the cool room humidifier. These samples are characterized by lower intensity values. This was especially true for samples 558 till 629, which were not kept in a closed box, but only under some plastic foil. This probably led to a deterioration of their magnetic properties.

In general the paleomagnetic record is noisy and not very clear. This was probably because the sediment did not favor good conservation of the paleomagnetic properties due to the low concentration of magnetic minerals in sediments that have accumulated in the Disko Bugt (Dietrich et al., 2007). The fact that the core was not sampled and analyzed in one shift might also have influenced the results negatively.

Although the quality of the data was not very promising, they were compared with another paleomagnetic record from core MD99-2269 from the North Iceland Shelf (Kristjánsdóttir et al., 2007) (figure 14). There was a reasonable correspondence between both the inclinations and the declinations of both cores. The dates indicated by the age model of MD99-2269 seem to be in good agreement with the ages for the corresponding depths in core 343310-6-1, based on the age model provided in paragraph 3.2.

The so-called feature “f” is a declination swing at an interval with steep inclination. It has been dated at 2670 cal. yr BP in Fennoscandia using varve chronologies (Snowball et al., 2007). This feature “f” could be present in the paleomagnetic data from core 343310-6-1 (figure 14), where it would be located at 800 cm depth.

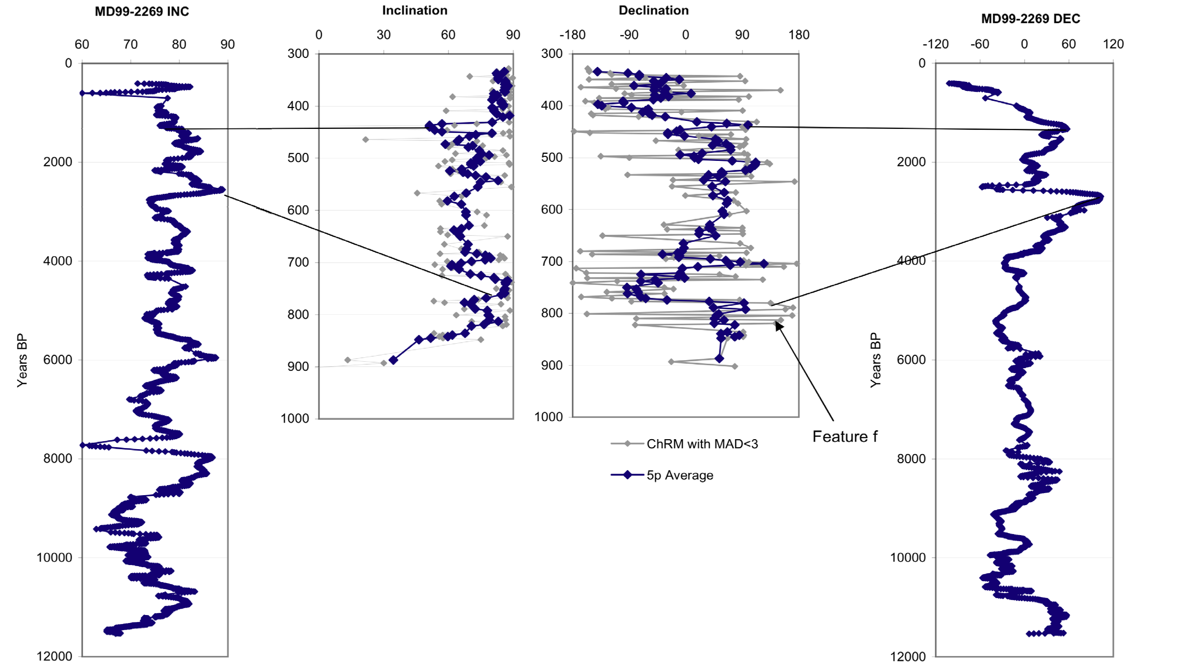

Figure 14. Comparison of paleomagnetic data from core 343310-6-1 (center) and MD99-2269 (Kristjánsdóttir et al., 2007). Feature "f" is indicated in the declination of 343310-6-1.

3.6 Thermogravimetric analysis

The results from the thermogravimetric analysis are presented in figure 15, where LOI_{550} and the LOI_{1000} are plotted against depth.

For the LOI_{550} there is a marked cyclicity between 900 and 500 cm. From 325 till 210 cm a significant rise in the LOI_{550} is recorded. The upper 200 cm of the core show a cyclic variation of quite short periodicity. Overall the weight percentage of organic carbon in core 343310-6-1 fluctuates between 5.7 and 7.5.

The lowermost 4 meters of the core show a similar pattern for LOI_{1000} as they do for the LOI_{550}. The upper 5 meters are less comparable, with no prominent trends or cycles discernable in LOI_{1000} record. The weight percentage of carbonate varies in core 343310-6-1 between 2.0 and 3.7.

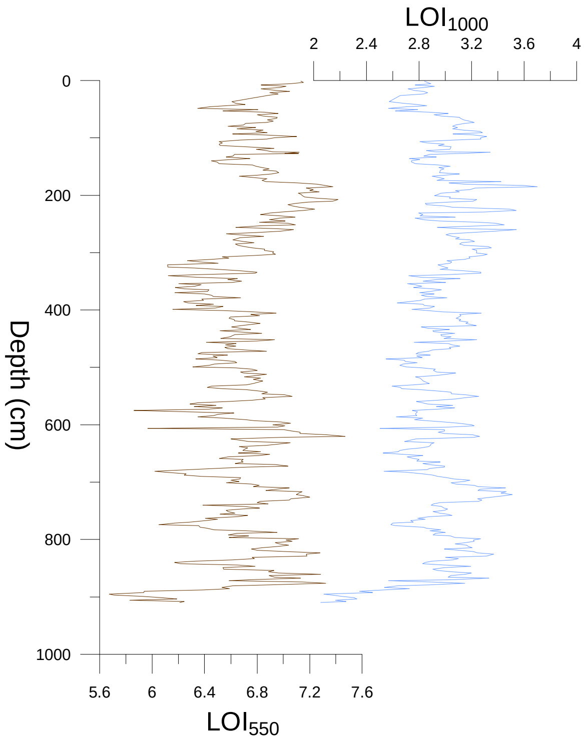

Figure 15. LOI_{550} (brown) and LOI_{1000} (blue) from core 343310-6-1

4 Discussion

4.1 Age model

The age model presented in this study is inherently flawed, as it is based on just two ^{14}C-datings and one paleomagnetic age based on correlation. The assumption that the sedimentation rate was constant is probably too simplistic, given the various dynamic processes active during the studied interval.

A comparison with the study of Seidenkrantz et al. (2007), which has a more thorough age control (see Møller et al., 2006 for more detailed information about their age model) is possible, if it is assumed that similar processes influenced both study sites more or less synchronously. The pronounced shift in iron and bromine values between 310 and 300 cm in core 343310-6-1 is dated to 1130 – 1100 cal. yr BP. In the data from Seidenkrantz et al (2007) that shift is also well represented and dated at 1400 -1300 cal. yr BP, and represents more or less the onset to the Medieval Warm Period. No firm conclusions can be drawn from this comparison, as it is uncertain if the variations were really synchronous. But if that would be the case, it might indicate that for this time interval the age model for core 343310-6-1 gives slightly too young ages.

From the correlation in the paleomagnetic data of cores 343310-6-1 and MD99-2269 could be inferred that the age models of both cores were in reasonable agreement with each other. This strengthens the reliability of the here presented age model. On the other hand, one should not assume that the paleomagnetic feature “f” was synchronous in Fennoscandia and western Greenland, but at the moment there are no independent ages of this feature west of Iceland (MD99-2269).

4.2 Core comparison

As the magnetic data for both core 5-1 and 6-1 are practically identical it would be expected that the XRF-data of both cores would also be more or less the same. This is not the case, as the results clearly show. As different types of XRF scanners were used to obtain the data, the difference in methodology or a fault in one of the two instruments might have caused the discrepancy. The problem with interpreting the XRF data is that it is hard to establish which of two instruments represents the most reliable and robust method.

4.2.1. XRF data

The XRF records of both cores do not seem to be in agreement with each other. Some elements such as silicon, potassium, titanium, and iron show the same general declining trend in both cores, but the decline is more pronounced in core 6-1 and smaller scale variations are quite dissimilar. For sulfur and manganese even the general trend is not the same between the two cores, and the manganese record of 5-1 is too noisy to use. The aluminum and calcium records differ partly because of the noise in the data from core 6-1.

4.2.2. Magnetic data

The magnetic susceptibility and mineral magnetic records of both cores are quite similar (figure 13, appendix3, and 4). These data suggests that the two cores represent essentially the same geological archive.

The magnetic susceptibility data show a few minor depth shifts between the cores, but the overall trend and details are identical. The ARM data from core 5-1 shows a bit weaker and noisier signal than that of core 6-1, but could be an effect of the fact the subsamples of 5-1 were longer in storage before they were measured and a magnetic mineral might have oxidized (e.g. Snowball & Thompson 1990).

4.3 Methodological synthesis

Overall the comparison between the Avaatech and Itrax XRF machines favors the Itrax. As results from the Avaatech generally have higher noise levels and show strange shifts (such as in the potassium and sulfur records) which cannot be explained otherwise than by errors.

For elements such as aluminum, the Itrax record is not reliable as it was below the detection limit of that machine. For other elements it cannot be said with certainty which machine is ‘right’, as there were no independent standard measurements available with which the results of both machines could be compared. Previous studies in which such a standard was available have already pointed towards the limitations of the Avaatech XRF scanner (Jäckel, 2007). The errors could be due to incorrect setup for the measured core.

The Itrax is also not free of potential errors, as the calcium record shows. This record has some strange interval full of outliers, which are best interpreted as noise, and maybe were caused by an insufficiently clean or flat core surface.
But when for instance the bromine record is considered (which is discussed more in-depth in paragraph 4.3.1), its good correspondence with the LOI_{550} record speaks in favor of the reliability of the Itrax machine.

The greater quantity of elements analyzed with the Itrax also offers a wider range of possible applications compared to the Avaatech. A disadvantage of the used setup of the Itrax is that some elements that can provide valuable paleoceanographic data such as aluminum and barium (Dymond et al., 1992; Reichart et al., 1997), could not be detected very well. The Avaatech did provide a better record for at least aluminum with regard to noise levels, but its reliability remains in doubt.

The application of several magnetic methods in this study did not meet the expectations, as paragraph 4.4 will show. In an appropriate sedimentary environment mineral magnetism can be useful. In a relatively deep marine setting with a high sedimentation rate of “non-magnetic” biogenic matter, but hardly any influx of ferrimagnetic minerals, mineral magnetism is probably not the method of choice.

4.4 XRF interpretation core 6-1

With the interpretation of the XRF-data from core 343310-6-1 the focus will be on those elements for which the available data are believed to be sufficiently reliable. Data from elements with a low number of counts are probably less reliable, as they are close to the detection limit.

The peak values for some elements (Ca, Br, Sr, Ba) around 850 cm depth are considered to be erroneous artifacts of the presence of some erratic plastic parts in that zone. The same kind of phenomenon can probably explain the extremely low or high values for some elements close to the bottom of the core, where the errors were most likely caused by the polystyrene foam plugging the last decimeters of the core.

No statistical analysis was executed on the XRF data, so the significance of the observed trends and variations is not firmly supported.

4.4.1 Bromine

Organic compounds with bromine found in marine sediment are primarily built by marine organisms. Particularly $CHBr_3$ produced by marine algae is a significant source for organic bromine (Gribble, 1999). Therefore an abundance of bromine in marine sediment has been considered to represent enhanced marine primary production (Mayer et al., 2007). And bromine has previously been applied as a proxy for paleoproductivity in marine sediment (Pheridon et al., 2000).

When the bromine data of core 6-1 are compared to the loss on ignition at 550 degrees (LOI_{550}) the correlation is quite striking (figure 16). The LOI_{550} is a good indicator of the amount organic carbon in the sediment (Heiri et al., 2001). Organic carbon in marine sediments is predominantly derived from planktonic primary producers in the photic zone, when the influx of terrestrial organic material is negligible (Mayer et al., 2007), as is the case in an arctic environment as Disko Bugt. This strengthens the theory that bromine can be successfully applied as a proxy for marine primary productivity in the studied core.

The bromine record shows a clear signal that can be interpreted as variations in primary production in the surface waters of Disko Bugt, as is argued above. These variations are probably due to the variable oceanographic and climatic conditions, which have affected the Disko Bugt area for the last 3000 years (Seidenkrantz et al., 2008).It should be noted that the magnitude of the variations cannot be deduced from the bromine record, but the fact that there is a clear signal suggests that the changes were significant.

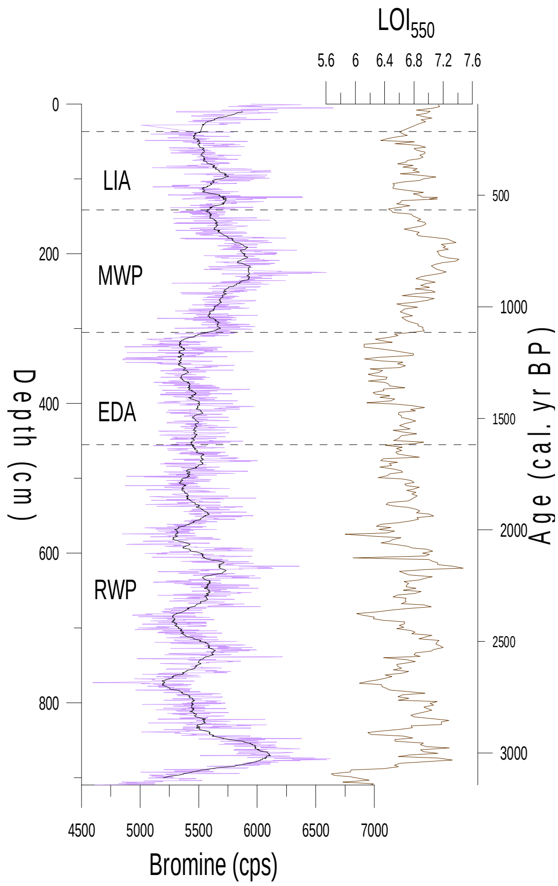

Figure 16. Bromine record (purple) from core 6-1 compared with the LOI_{550} record (brown) from the same core. LIA: Little Ice Age, MWP: Medieval Warm Period, EDA: Early Dark Ages, RWP: Roman Warm Period. The climatic zonation is based on Seidenkrantz et al., 2007.

In a study by Seidenkrantz et al. (2007), conducted in southwest Greenland, a bromine record was retrieved as well. There a quite similar pattern could be observed in the bromine data (appendix 6).This indicates that both the fjord systems in southwestern Greenland and the Disko Bugt area are influenced by the same ocean and climate systems. Holland et al. (2008) put forward evidence for the strong interlinkage of the whole oceanographic system along the western Greenland continental shelf. This could mean that oceanographic changes affecting southwestern Greenland will have a similar and almost synchronous effect in Disko Bugt. If that is really the case, and conditions were indeed similar and synchronous, then the bromine record of the two studies could be used for correlation and comparison.

If the same climatic zonation from Seidenkrantz et al. (2007) is applied to the bromine data from this study (figure 16), then the high bromine levels in the Medieval Warm Period are striking. This could imply that for some reason primary productivity was enhanced in that particular period. The apparently periodic variation of bromine in the Roman Warm Period is conspicuous as well.

4.4.2 Iron and titanium

The iron and titanium can generally be regarded as terrestrial influences in the sediment record of coastal settings in West Greenland (Møller et al., 2006). While titanium can also partly represent eolian dust input (Reichart et al., 1997).

Both records show a similar decreasing trend with a weak cyclicity superimposed on it (figure 17). The decrease in Fe and Ti could be interpreted as a general decline in the terrestrial influx over time. It could also be an artifact of the lower density of the sediment in the top compared to the bottom. The cyclic features are most prominent in the titanium record, where they are quite evident but do not seem to have a regular periodicity. In the iron record there is a marked decline between 310 and 300 cm, which is the same interval when the bromine record shows a clear increase. This interval could signify a changing environment, where biological productivity increased and terrestrial input decreased.

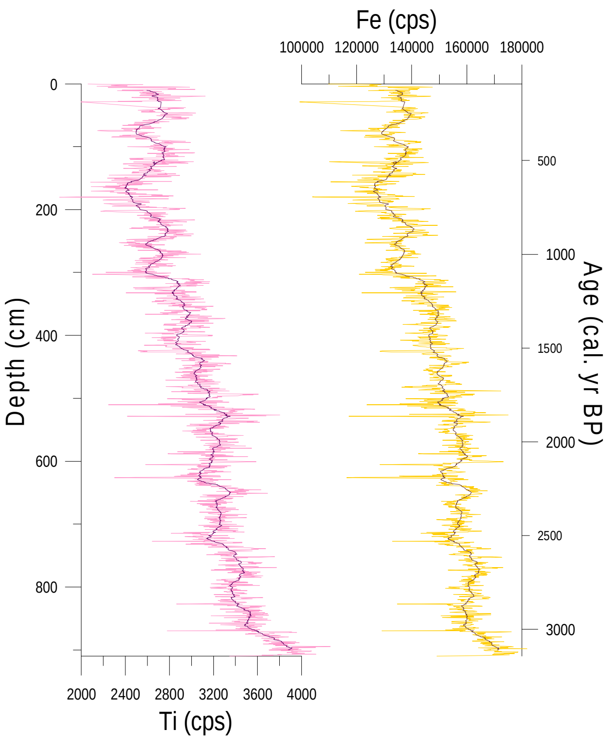

Figure 17. Iron and titanium logs from core 343310-6-1.

Dietrich et al. (2007) suggest that a relationship between the titanium and the magnetic susceptibility record should be expected, as both parameters are thought to be related to glacially eroded material from the mainland. In this study no such relation was found, indeed Ti and MS show opposite trends. This could be explained by the relatively distal position of the coring site from the tongues of the current glaciers, but more likely is that the relationship is invalid for at least the Late Holocene and that it rests on false assumptions. The negative relationship between Ti (and Fe) and MS suggests alternative sources have contributed to the sediments over time.

4.4.3 Strontium

The strontium record from core 343310-6-1 is interesting as it provides a clear signal, with acceptable noise levels (figure 18). The high number of counts also points towards a good reliability. But interpretation of the record proved to be problematic, as no information on the use of strontium as a proxy over short time scales was available in the studied literature.

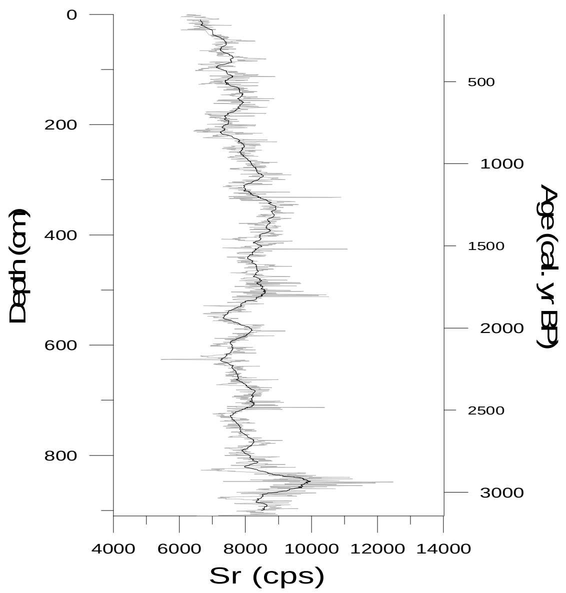

Figure 18. Strontium data from core 343310-6-1.

4.5 Interpretation of the mineral magnetic and paleomagnetic record

Overall not much could be deduced from the mineral magnetic data. The paleomagnetic signal was weak, but could be compared to the paleomagnetic data from core MD99-2269. The mineral magnetic record was useful to show the similarity between core 343310-6-1 and core 343310-5-1 (appendix 3, and 4), but did not yield a lot of information otherwise.

The SIRM record shows an increasing trend similar to the magnetic susceptibility, probably reflecting an increase in the magnetic mineral concentration in the sediment. If it is assumed that the magnetic susceptibility record can be interpreted as a "*signal produced by high concentration of terrestrially sourced glacial detritus*" (Dietrich et al., 2007), and that observed increasing trend in the MS is significant, then glacial activity should have generally increased over the studied interval, and especially over the last 800 years where the increase is most prominent. This increase in glacial activity would also have lead to a higher rate of iceberg calving and more melt water runoff, when the aforementioned assumptions are correct. The MS and SIRM signals from the cores were relatively weak, and the study site was almost 100 km removed from the nearest glaciers, so not too many firm conclusions should be drawn from this data. The negative trend between Ti (Fe) and MS suggests a more complex cause of the increasing mineral magnetic concentrations towards the top of the sediment sequence.

4.6 Paleoceanographic and paleoclimatic synthesis

The study by Holland et al. (2008) showed the pronounced effect ocean currents have on calving glaciers such as the present day Jakobshavn Isbræ. As the environment in Disko Bugt is also strongly influenced by the dynamics of calving glaciers, this probably means that variations in the strength of the West Greenland Current was also in the past one of the main forces driving environmental changes in the marine and glacial environments of Disko Bugt.

In the record presented here, which cover roughly the last three millennia of the Holocene, the shift at the beginning of Medieval Warm Period seems to have been the most pronounced of the various variations. This is evident when the bromine/iron-ratio is considered (figure 19), which could probably act as a more normalized proxy for productivity as it compensates for the dilution effect by terrestrial input. One can speculate on what caused this rise in productivity 1200 cal. yr BP. Variations in the phytoplankton productivity in Disko Bugt have been related to nutrient availability, water column stratification, and sea ice coverage, where less sea ice should lead to more productivity (Heide-Jørgensen et al., 2007). This view is opposite to the assumption of Seidenkrantz et al. (2007) that more sea ice induces higher productivity.

Model studies point out that increased primary production in the photic zone due to decreased sea ice cover does not necessarily have to lead to higher sediment accumulation rates of organic carbon (Hansen et al., 2003), but it is still often assumed that productivity and organic sedimentation are directly linked.

Enhanced input of nutrients by oceanographical changes is a plausible explanation for increased productivity, but what changes exactly caused episodes of higher primary productivity is not clear yet in the case of Disko Bugt.

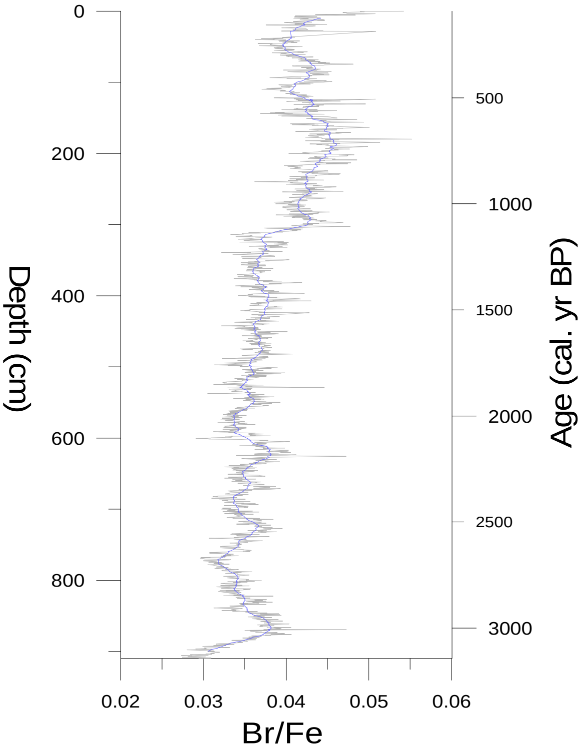

Figure 19. Bromine-iron ratio from core 343310-6-1.

If the theory that bromine can also be used as a proxy for the inflow of oceanic water (Seidenkrantz et al., 2007) is correct, then the data presented here are in conflict with the hypothesis that the Medieval Warm Period was characterized by a reduced inflow of Atlantic water (Seidenkrantz et al. 2008). Rejecting one of these conflicting hypotheses will solve this paradox. The statement that the Medieval Warm Period was cold in West Greenland is contradicted by Lloyd (2006), who argues that it was in fact "a culmination in peak warm" conditions due to reduced influence of the EGC in the WGC. The use of bromine as a general proxy for oceanic water inflow is also slightly questionable, as an inflow of relatively warm oceanic water with a low-nutrient content would not necessarily lead to higher biological production. Only if the inflowing Atlantic water would be rich in nutrients, an effect on the bromine content in the sediment would be expected.

If the surface waters of Disko Bugt indeed cooled at the onset of the MWP around 1200 cal. yr BP, and sea-ice cover increased accordingly (Moros et al., 2006; Seidenkrantz et al., 2008), then the here reported high primary productivity in the same period was not caused by the inflow of warm Atlantic surface water. It could be that the sea-ice cover induced more phytoplankton blooms, or that the cold water contained more nutrients.

The cyclicity observed in the bromine data in the interval that probably corresponds with the Roman

Warm Period has not yet been discussed in any of the other papers. This might be an interesting pattern that could suggest a linkage to century or millennial scale cyclic variations in the circulation of the North Atlantic.

The overall decline in the iron and titanium record could be interpreted as evidence for a declining trend in glacial activity which would have resulted in less terrestrial sediment brought into Disko Bugt. The lower glacial activity could be explained by a reduced inflow of the WGC. But the low iron and titanium concentrations could also be an effect of dilution as marine sediment is brought in by stronger WGC. It is hard to point out direct causes in relation to these elements. The fact that the magnetic susceptibility record shows an opposite trend only makes matters more confusing, as that is not what would be expected in a simple model. There are clearly more factors at play.

4.7 Archeological implications

From the here presented data no firm conclusions can be made regarding the influence of past environmental dynamics on the cultural history in de Disko Bugt area. It can be said though that the factors influencing the lives of people, such as temperature and sea ice cover, were probably not quite stable over the last 3000 years. If the Medieval Warm Period was cold in West Greenland, then the warming at the end of the period might have inhibited the foundation of the Thule culture. But the notion of a cold MWP is opposed to the popular notion that Norse settlers were initially greeted by a lush green landscape, which turned into a harsh environment at the onset of the Little Ice Age. But the high productivity rates during the possibly cold MWP might have supported a high marine biomass, which could have served as a food source for settlers. More research is focusing to provide more insight in the relationship between environmental change and human settlement.

4.8 Recommendations

To improve future projects using XRF as their prime method, more attention should be directed to the use of elements as proxies. As in this study several elements showed intriguing signals, but literature on how to interpret these signals was insufficiently available.

The data resulting from XRF is not always without errors, and it is unacceptable that different XRF scanners give different results when analyzing essentially the same material. So more attention should be directed to the reliability of the machines and potentially to the setup of the machines when they are used to measure sediment cores with an unknown element composition.

5 Conclusions

- The sediment record of both cores used in this study spans roughly the last 3000 years. The age model, based on two radiocarbon dates, is supported by paleomagnetic data.

- The XRF data retrieved with the Avaatech scanner from core 343310-5-1 has too many apparent errors to be of any use. Only the XRF data from core 343310-6-1, scanned by the Itrax, were used for interpretation.

- No clear correlations could be made between mineral magnetic properties and XRF data, partly because mineral magnetic signals were too weak.

- Of the elements analyzed in core 343310-6-1, bromine offered the most straightforward interpretation, as it directly relates to marine paleoproductivity. The clear signal that the bromine record presents can be related to environmental change in the Disko Bugt region, with particularly enhanced productivity during the Medieval Warm Period. Based on the bromine record it can be concluded that variations in the marine biological productivity were common in Disko Bugt over last 3000 years. Although the exact causes, timing and impact of these variations is not yet fully understood.

- Iron and titanium presumably represent terrestrial mineral influx, and they both show a general declining trend over the whole with periodic fluctuations superimposed. The decline in iron between 310 and 300 cm depth is notable, as it coincides with an increase in bromine, and is dated at 1130 – 1100 cal. yr BP, roughly corresponding to the beginning of the Medieval Warm Period.

- The observed variations in the XRF record of core 343310-6-1 are most likely caused by changes in the strength and composition of the West Greenland Current.

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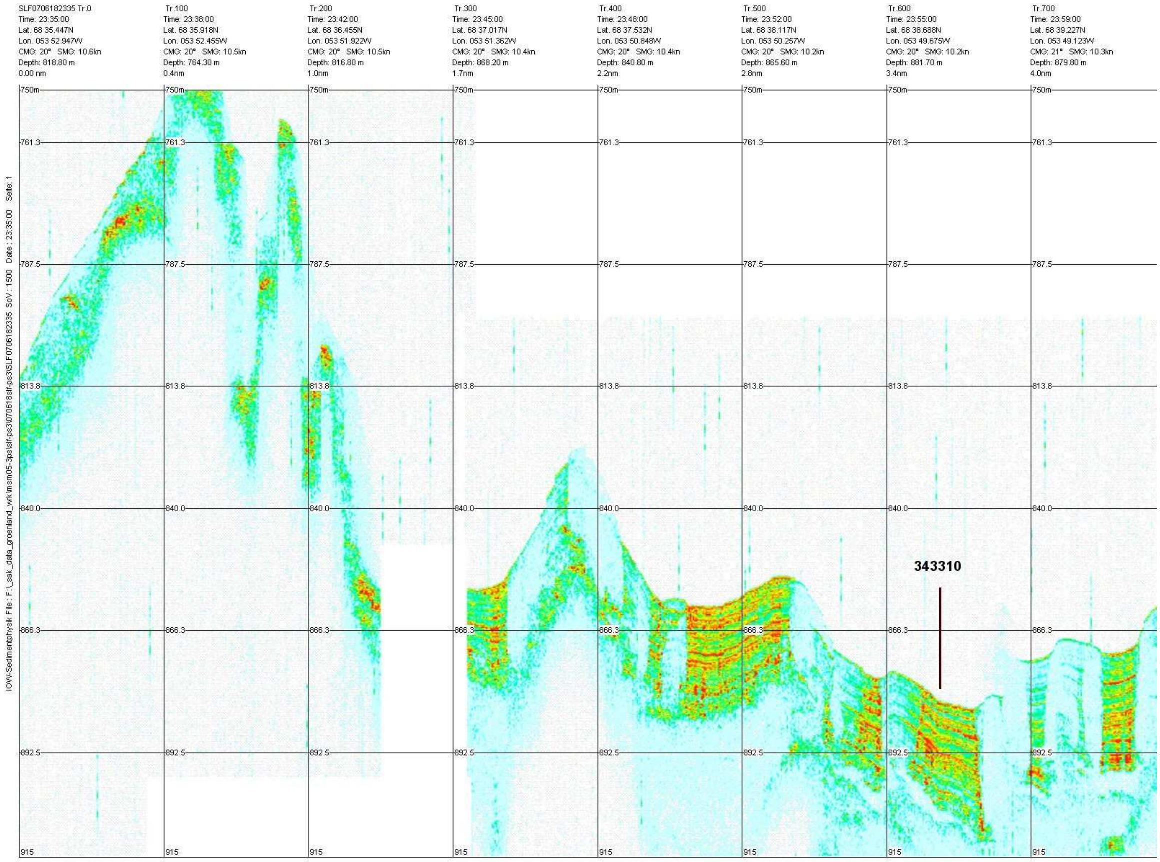
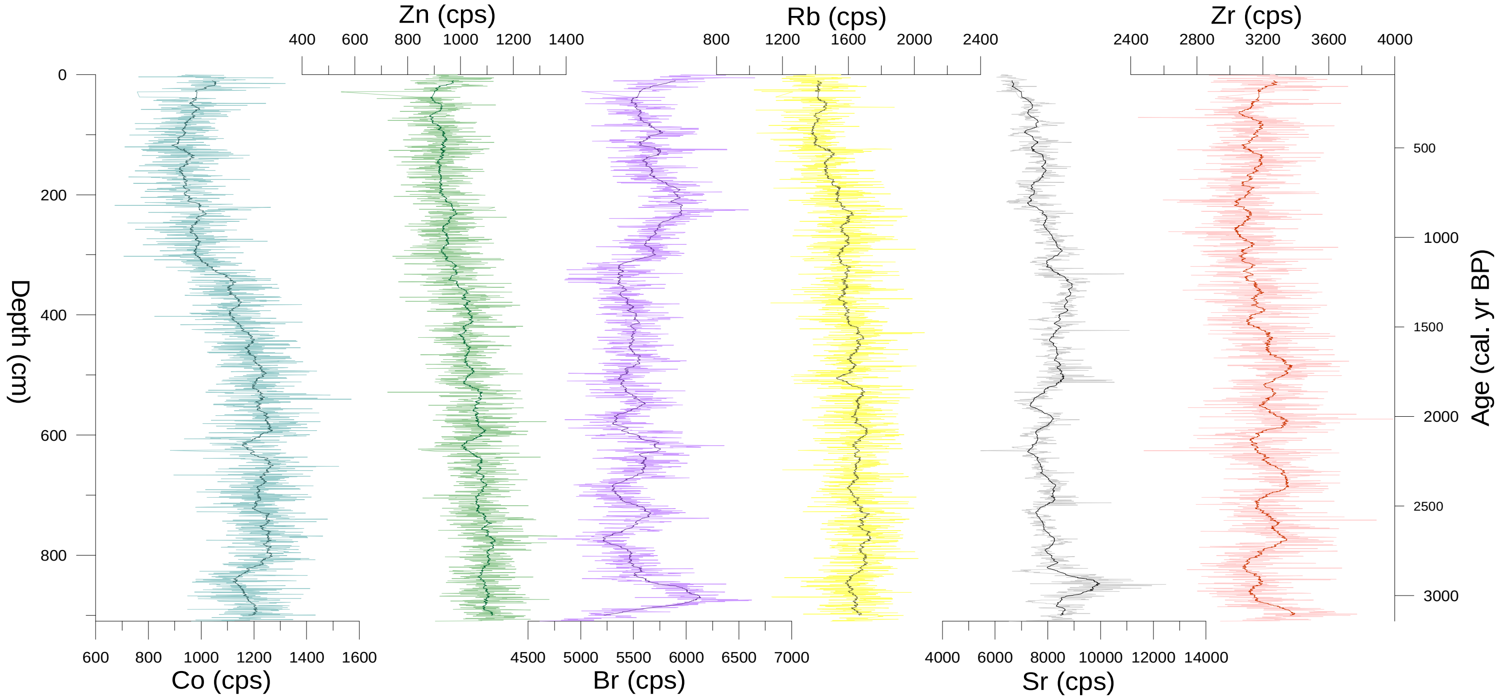
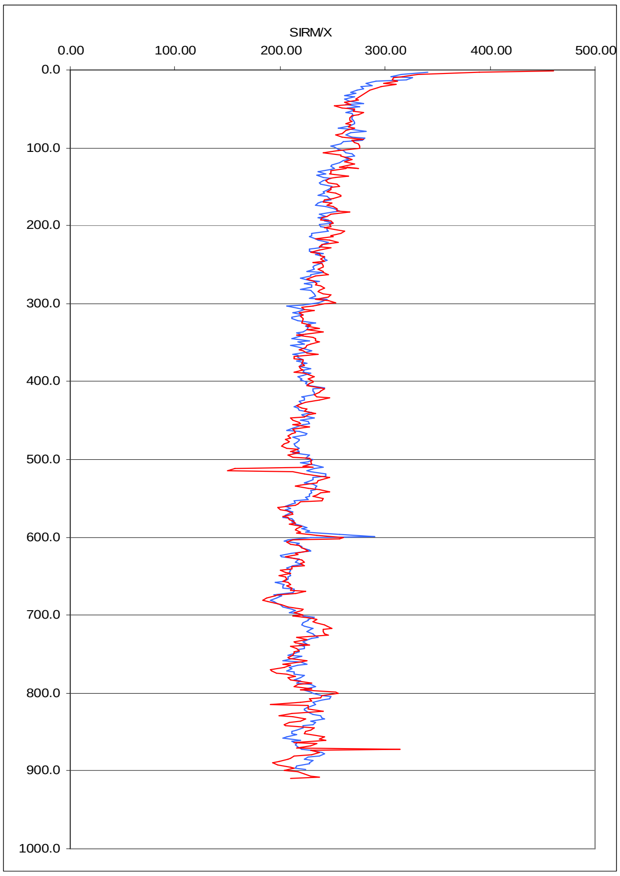
Appendices



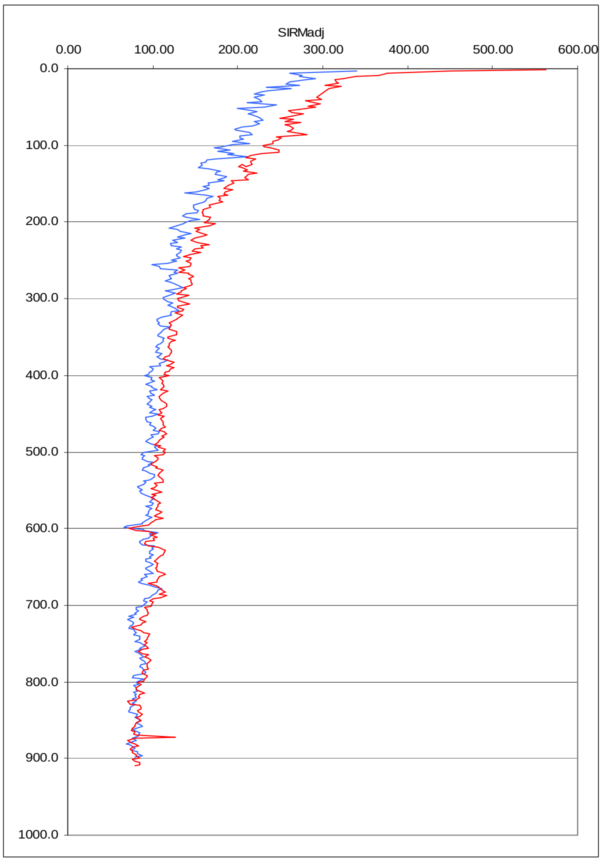
Appendix 1. Seismic profile of coring site 343310



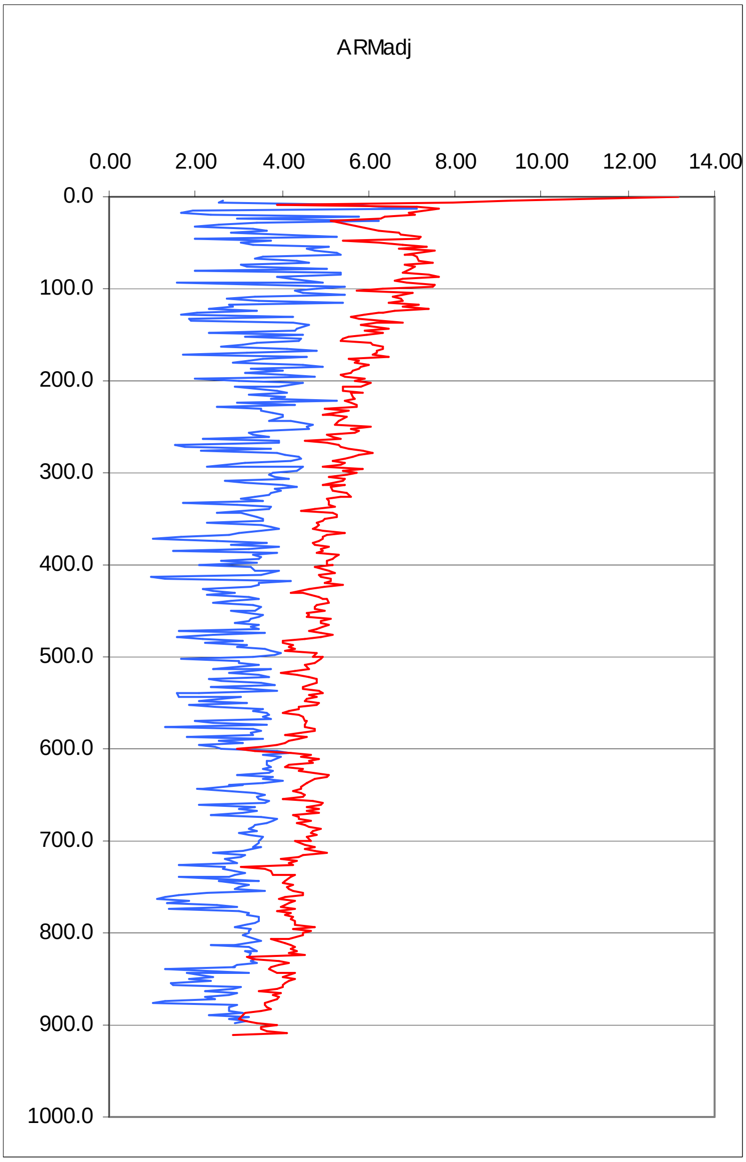
Appendix 2. XRF results for all elements scanned in core 343310-5-1 (*top*), and for selected elements in core 343310-6-1 (*middle and bottom*). The clear lines are the smoothed trend lines based on a running average (see section 2.3), while the quite scattered lines represent the raw data.



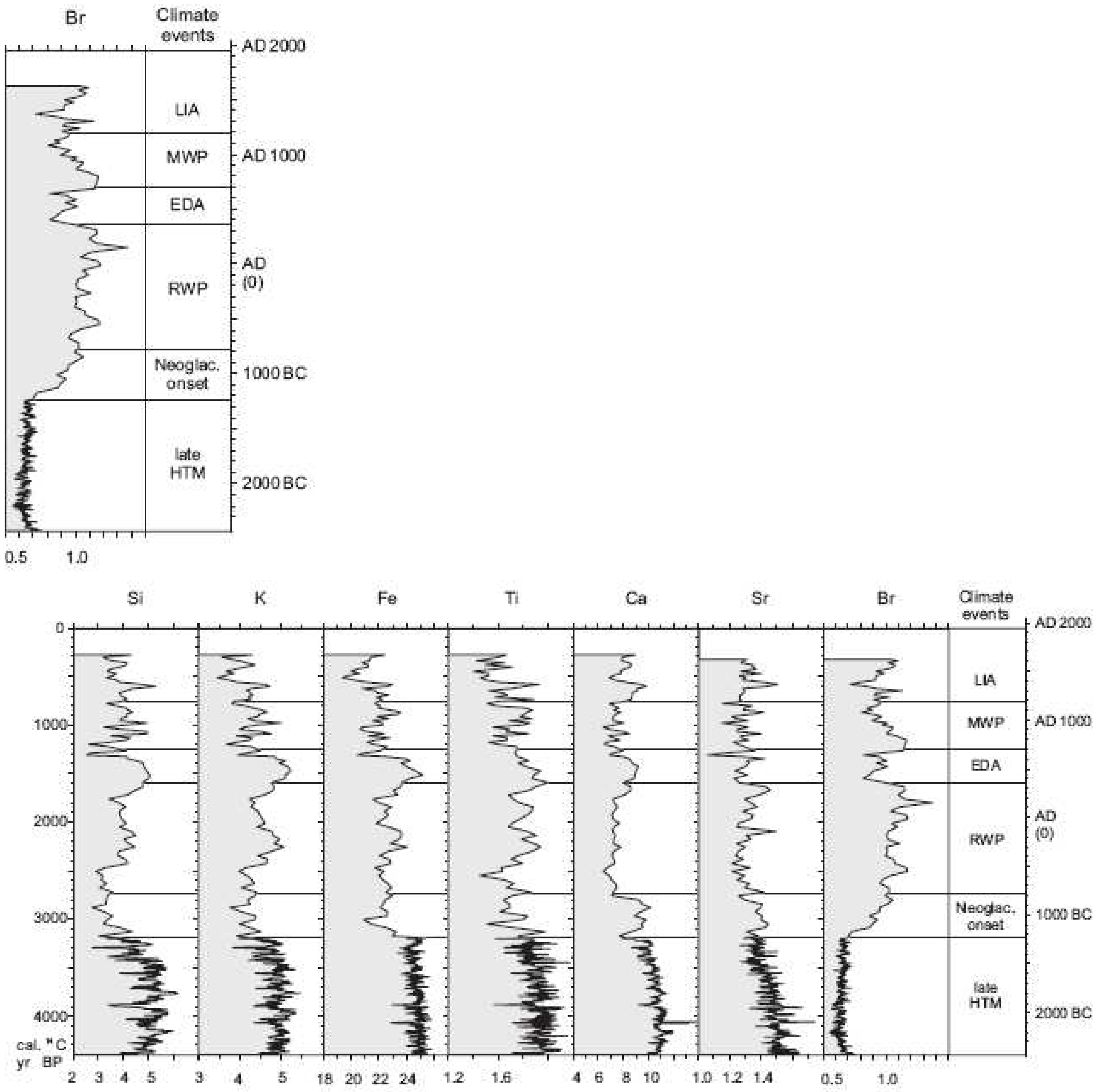
Appendix 3. SIRM/χ for core 343310-5-1 (blue), and 343310-6-1 (red)



Appendix 4. SIRMadj for core 343310-5-1 (blue), and 343310-6-1 (red)



Appendix 5. ARMadj for core 343310-5-1 (blue), and 343310-6-1 (red)



Appendix 6. XRF-data from Seidenkrantz et al. 2007

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