Sedimentary processes within the Canadian Arctic Archipelago: relationships among sedimentological, geochemical and magnetic sediment properties

Sarah Letaief\textsuperscript{1}, Jean-Carlos Montero-Serrano\textsuperscript{2}, and Guillaume St-Onge\textsuperscript{2}

\textsuperscript{1}University of Montpellier  \\ \textsuperscript{2}Université du Québec à Rimouski

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Abstract
The sedimentological, geochemical, physical and magnetic properties of 40 surface and basal sediment samples of box cores collected throughout the Canadian Arctic Archipelago (CAA) from the Canadian Beaufort Shelf to Lancaster Sound were analyzed to determine the sedimentary processes that operate within the CAA during the pre- and post-industrial periods. In addition, the chronology of seven selected regional cores was established using $^{210}$Pb measurements, where the base is dated between 1550 and 1820 CE. These cores provide an opportunity to robustly compare post-1900 sedimentary conditions with those of the colder Little Ice Age period (LIA; $\sim$1500-1900 CE). The different properties combined with multivariate statistical analyses result in the identification of three regional provinces with distinct sedimentary characteristics: (1) the West province (the Mackenzie Shelf/Slope, West Banks Island and the M’Clure Strait) typified by detrital associations (Fe-Rb-Ti-Zn), high organic matter inputs, dominance of magnetite and low-coercivity minerals and high aluminosilicate contents; (2) the Intermediate Zone (the Amundsen and Coronation Gulfs) distinguished by Si-Al-Zr-Sr-K associations, Fe-Mn oxyhydroxyde precipitation and a mixture between marine and terrigenous organic matter; and (3) the East Province (the Queen Maud Gulf, Victoria and Barrow Straits, and Lancaster and Eclipse Sounds) described by high detrital carbonate inputs, marine organic matter, and dominance of high-coercivity minerals. Our results confirm that the pre- and post-industrial sedimentary dynamics are controlled by sediment supplies from the river discharges in the West and Intermediate provinces, whereas the East province is more influenced by sea ice and coastal erosion.

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Sarah Letaïef\textsuperscript{1,2,4}, Jean-Carlos Montero-Serrano\textsuperscript{3,4} and Guillaume St-Onge\textsuperscript{1,4}

\textsuperscript{1}Canada Research Chair in Marine Geology, Institut des sciences de la mer de Rimouski, Université du Québec à Rimouski, Québec, Canada.
\textsuperscript{2}Géosciences Montpellier, Université de Montpellier, CNRS, 34090 Montpellier, France.
\textsuperscript{3}Institut des sciences de la mer de Rimouski, Université du Québec à Rimouski, Québec, Canada.
\textsuperscript{4}GEOTOP Research Center, Montréal, Québec, Canada

Corresponding author: Sarah Letaïef (Letaief-Sarah@laposte.net)

Key Points:

- Sedimentological, geochemical and magnetic baseline data are reported in the Canadian Arctic Archipelago.
- Sedimentary processes that operate within Canadian Arctic Archipelago during the pre- and post-industrial periods are documented.
- Regional \textsuperscript{210}Pb-dated box cores provide clues about the sedimentary dynamics that operated during the Little Ice Age.
Abstract

The sedimentological, geochemical, physical and magnetic properties of 40 surface and basal sediment samples of box cores collected throughout the Canadian Arctic Archipelago (CAA) from the Canadian Beaufort Shelf to Lancaster Sound were analyzed to determine the sedimentary processes that operate within the CAA during the pre- and post-industrial periods (i.e., before and after 1900 Common Era or CE). In addition, the chronology of seven selected regional cores was established using $^{210}\text{Pb}$ measurements, where the base is dated between 1550 and 1820 CE. These cores provide an opportunity to robustly compare post-1900 sedimentary conditions with those of the colder Little Ice Age period (LIA; ~1500-1900 CE). The different properties combined with multivariate statistical analyses result in the identification of three regional provinces with distinct sedimentary characteristics: (1) the West province (the Mackenzie Shelf/Slope, West Banks Island and the M’Clure Strait) typified by detrital associations (Fe-Rb-Ti-Zn), high organic matter inputs, dominance of magnetite and low-coercivity minerals and high aluminosilicate contents; (2) the Intermediate Zone (the Amundsen and Coronation Gulfs) distinguished by Si-Al-Zr-Sr-K associations, Fe-Mn oxyhydroxyde precipitation, constant high magnetic grain concentrations and a mixture between marine and terrigenous organic matter; and (3) the East Province (the Queen Maud Gulf, Victoria and Barrow Straits, and Lancaster and Eclipse Sounds) described by high detrital carbonate inputs, marine organic matter, a dominance of high-coercivity minerals and high magnetic concentrations in pre-industrial samples. Our results confirm that the pre- and post-industrial sedimentary dynamics are controlled by sediment supplies from the river discharges in the West and Intermediate provinces, whereas the East province is more influenced by sea ice and coastal erosion. Basal sediment samples from the seven $^{210}\text{Pb}$-dated cores suggest intensification of the Mackenzie, Coppermine and Ellice Rivers runoff, extensive sea-ice cover and consequently sediment transport by the latter during the LIA period.

1 Introduction

Polar regions act as the world’s thermostat by providing a strong albedo with their perennial or seasonal sea-ice cover. During the past decades, the Arctic region seems to be the most affected by climate warming, with a decrease of 12.4% per decade in summer sea-ice extent [Stroeve et al., 2011; Comiso et al., 2017] accompanied by a loss of ice older than five years. Recently, less than 5% of the Arctic Ocean ice observed is older than 5 years, compared to 20% in the 1980s [Serreze and Stroeve, 2015], responding to the increase in greenhouse gas emissions [Pachauri et al., 2014]. The rapid loss of sea-ice cover and thereby albedo has played a role in amplifying Arctic warming [Holland and Bitz, 2003; Serreze and Francis, 2006; Serreze et al., 2008; Cohen et al., 2014]. The magnitude of these changes around the Arctic shows regional patterns and generally results in an increases in temperature and precipitation due to enhanced evaporation [Bintanja and Selten, 2014; Kopec et al., 2016], northward transport of moisture [Zhang et al., 2013] and intensification of the hydrological cycle [Huntington, 2006; Peterson et al., 2006] depending on the region.

During the last decade, palaeoclimatic studies have become more frequent for the Arctic region (Fennoscandia, Arctic Canada, Alaska and Greenland) using numerous proxies from natural archives such as lakes [Gajewski, 2002; 2006; 2015], peat [Ruppel et al., 2013; Zhang et al., 2017], marine sediments [e.g., Stokes et al., 2005; Ledu et al., 2010; Durantou et al., 2012, Bringué and Rochon, 2012; Pienkowski et al., 2011; 2013; Deschamps et al., 2018; Caron et al., 2019, 2020; among others], ice cores [Paterson and Waddington, 1984; Mosley-
Thompson et al., 2001] and tree rings [Helama and Lindholm, 2003; Linderholm and Chen, 2005; Pisaric et al., 2009]. A recent review summarizes Arctic hydroclimate changes during the last two millennia [Linderholm et al., 2018], where hydroclimate simulations and proxies generally reveal that the Little Ice Age (LIA, 1500-1900 Common Era or CE; Jones and Mann, 2004) was drier [Ljungqvist et al., 2016] even if large regional differences are observed. During the last 2000 years, an increase in precipitation [Viau and Gajewski, 2009] and river runoff [Wagner et al., 2011] and general colder reconstructed summer sea surface temperatures [e.g., Bringué and Rochon, 2012] have been shown in the western Canadian Arctic Archipelago (CAA), whereas a decrease in precipitation [Viau and Gajewski, 2009], an increase in sea-ice cover and colder conditions have been described in the southwest [Pienkowski et al., 2011; 2017] and central CAA [e.g., Vare et al., 2009; Belt et al., 2010]. Comparisons between different Arctic areas allow the reconstruction of the climatic mosaic and the Arctic response to ongoing global warming, but the lack of spatiotemporal analyses makes comparisons difficult. Since the CAA provides a large area controlled by several sedimentary processes, the aims of this work are to reconstruct and compare sedimentary processes during the pre- and post-industrial periods (i.e., before and after 1900 Common Era or CE) as well as during the LIA within this Arctic region. To achieve these objectives, we use sedimentological, magnetic and geochemical proxies from box cores covering a large part of the CAA in order to compare the sediment properties from (1) the surface (post-1900) and basal (pre-1900) sediment samples of the cores and (2) the LIA interval of seven $^{210}$Pb-dated box cores.

1.1 Regional characteristics and hydrology

The CAA is a complex array of islands covering an area of 2.9 million km$^2$ that represents approximately 20% of the total shelf area in the Arctic [Jakobsson, 2002]. Narrow channels formed by glacial erosion during the Quaternary [England et al., 2006] are interconnected with larger basins. Furthermore, the Northwest Passage (NWP) connects the Eastern (Baffin Bay) and Western (Beaufort Sea) Canadian Arctic through the CAA and represents one of the three main routes connecting on a larger scale the Arctic Ocean to the Labrador Sea and North Atlantic. For this reason, the CAA is considered to be a key area for mass and heat exchanges between the Arctic and Atlantic Oceans [Melling et al., 2001, 2002; Michel et al., 2006; Dickson et al., 2007]. The export of water through the Nares and Fram Straits and the NWP influence the formation of Atlantic deep waters [Aagaard and Carmack, 1989, 1994] and thereby impact the global thermohaline circulation [Proshutinsky et al., 2002]. Because of the large freshwater inputs (including river discharges, summer sea-ice melting and precipitation), the Arctic water column is strongly stratified, creating advection from the relatively fresh upper layer [Aagaard and Carmack, 1989]. Typically, a cold and low-salinity surface layer named the Polar Mixed Layer (PML) is found in the upper 50 to 100 m depths and is mainly formed by summer meltwaters and river discharges. From depths of 100 to 300 m the PML (Figure 1A) is underlain by warmer and low-salinity Pacific waters (PW) added to a contribution from Mackenzie and Yukon river waters via the coastal Alaskan current [Jones et al., 2003]. Finally, a strong halocline separates the PW from the Atlantic waters (AW) until depths of 500 to 800 m which enters into the system through the west Spitsbergen and west Greenland currents [Woodgate et al., 2007]. Furthermore, the highly complex inter-island dynamics in the archipelago are mainly explained by the presence of shallow channels: in the West, water depths reach ~550 m except close to M’Clure Strait, where a sill causes a decrease in water depth of approximately 375 m. In the East, the limiting sill is in Barrow Strait, where the depth is ~125 m and increases gradually eastward to ~500 m in Lancaster Sound and then to over 2000 m in Baffin Bay [McLaughlin et al., 2004]. Consequently, the water column is predominantly composed of Pacific waters [Jones et al., 2003] that originate from the Canadian Basin via the M’Clure Strait and the Amundsen
Gulf. In the western part, the general water mass circulation (Figure 1A) in the CAA is strongly influenced by the anticyclonic Beaufort Gyre (BG), whereas the central CAA is driven by a net southeastward circulation [Ingram and Prinsenberg, 1998].

**Figure 1.** (A) Map of the CAA showing studied regions forming part of the study area. The generalized modern circulation: dashed arrows represent surface currents (BG: Beaufort Gyre and CAC: Coastal Alaskan Current) whereas solid black arrows indicate deepest Atlantic Water circulation (BC: Baffin Current and WGC: West Greenland Current). Some important rivers are also identified: A=Mackenzie River; B= Coppermine River; C= Ellice River; D= Back and Hayes Rivers and E= Cunningham River. (B) Map of the geological setting and collected dolomite cores. The red colored stations correspond to 210Pb dated cores. Simplified geological units map of the CAA inspired from Wheeler et al. [1996], Harrison et al [2011] and modified from Alkire et al [2017]. The color code represents the dominant facies: C*= dominant carbonate/evaporite; C = major carbonate unit; S = sedimentary facies; Ip = plutonic; M = metamorphic; SM = sedimentary and metamorphic, SV = sedimentary and volcanic; G = unknown deposit influenced by the ancient glacier coverage.

1.2 Climate and sea ice

In the CAA, the annual cycle of solar radiation is quite variable both regionally and temporally [McLaughlin et al., 2004]. During winter, recent mean air temperatures are close to -30°C, whereas the cool summers are characterized by mean temperatures of 4°C. In the western part of the CAA, recent meteorological conditions are driven by the fluctuations in the large-scale Arctic Oscillation [Barber and Hanesiak, 2004]. In the West, the semipermanent high-pressure system located over the Beaufort Sea during winter impacts the regional climate [Agnew and Silas., 1995], whereas in the East, the local climate is affected by wind forcing and specific topography [Ingram and Prinsenberg, 1989]. Presently, the CAA is covered by sea ice annually with a strong seasonality. The formation of sea ice begins mid-September, and sea ice starts to break up in late May, while the minimum sea-ice cover is observed late August [Canadian Ice Service, 2019].

Paleoreconstructions in the Northern Hemisphere show a general decrease in summer temperatures over the past 8 cal ka BP, reflecting the continuous insolation decrease resulting from the precession of the equinoxes [Wanner et al., 2011]. The changes in summer temperatures have been more significant in the Arctic than in other places [Kaufman et al., 2004; Vinther et al., 2009] and operated after medieval times. In addition, anomalously cold summers at century-scale intervals have been recorded by most glaciers and ice caps from the CAA, related to the colder LIA period [Jones and Mann, 2004]. Notwithstanding the variety of records defining climate change during the past millennium [Mann et al., 2008], there is no clear consensus about the timing and duration and what factors contributed to generating and...
maintaining LIA conditions. Globally, this cold time period within the CAA is included between 1500 and 1900 CE [Bradley et al., 1993; Jones and Mann, 2004] but also differ regionally: between 1500 and 1900 CE in Mackenzie Shelf/Slope [Richerol et al., 2008; Bringué and Rochon, 2012; Durantou et al., 2012]; ~1680-1940 CE in Coronation Gulf [Pieńkowski et al., 2011; 2017]; ~1500-1900 CE in Victoria Strait [Belt et al., 2010]; 1650-1900 CE in Lancaster Sound/Baffin Bay [Ledu et al., 2010a; 2010b]; and ~1550-1850 CE in Devon Ice Cap/Ellesmere [Koerner, 1974; 1977; 1990].

1.3 Surrounding geology

The Mackenzie River drains a basin of $1.78 \times 10^6$ km$^2$ [Aziz and Burn, 2006; Hill et al., 2001]. The basin is characterized in the western part by the North American Cordillera geological unit (Mackenzie and Rocky Mountain belts; Millot et al., 2003) composed of sedimentary and volcanic rocks (Figure 1B) and in the eastern part by the Canadian Shield in the Slave Province, which comprises Archean granites and gneisses [Millot et al., 2003]. In turn, Banks Island is mostly composed of Cretaceous to upper Paleozoic sedimentary rocks (Figure 1B) and Quaternary dolomite-rich tills [Bischof et al., 1996; Bischof and Darby, 2000]. Otherwise, most of the islands such as Victoria and Prince of Wales Islands, are typically underlain by Ordovician and Silurian detrital carbonates (Figure 1B; Stokes et al., 2009). Finally, eastern Lancaster Sound is defined by Cretaceous to Plio-Pleistocene geological units associated with rifting [MacLean et al., 1990; Li et al., 2011] and Bylot Island is characterized by plutonic igneous rocks belonging to the Canadian Shield.

1.4 Sediment dynamics

The mean annual discharge of the CAA rivers was recently estimated to be ~202 km$^3$/yr [Lammers et al., 2001; Alkire et al., 2017]. Although the Mackenzie River discharge in the system is significant (~420 km$^3$/yr; Wagner et al., 2011), many CAA small rivers exist, including the Coppermine River (~88 km$^3$/yr), the Ellice and Back Rivers (~2.82 km$^3$/yr and ~15.52 km$^3$/yr respectively; Déry, 2016) and the Cunningham River (~3.28 km$^3$/yr). Their cumulative discharge is large enough to significantly impact the freshwater flowing through the CAA and the local sedimentation.

The most important sediment entrainment in the Beaufort Sea, the Northwest Passage and globally in the Arctic Ocean is known as suspension freezing by frazil and anchor ice [Reimnitz et al., 1993; Darby et al., 2011]. During rapid ice formation in open and shallow water areas, frazil incorporates fine-gained suspended sediment that is disseminated along its way [Reimnitz and Barnes, 1987; Reimnitz et al., 1993]. Indeed, fine-grained sediments discharged from coastal erosion or river drainages within the first 25-30 m water depth are disseminated into the first-year ice during freezing storms. Then they are transported by ice until the ice motion is stopped for the duration of winter and finally deposited elsewhere during rapid summer melting [Reimnitz et al., 1993]. By using Fe-oxide fingerprinting grains, Darby et al. [2003] showed that western Canadian Arctic sea-ice floes drift west from the Laptev Sea to Beaufort Gyre via the Transpolar Drift. Aeolian transport in the CAA has been identified as insignificant and very localized [Darby et al., 1974; Reimnitz and Maurer, 1979]. In the context of current climate change, sea ice becomes more seasonal, and coasts have enhanced permafrost. Consequently, un lithified ice-bonded coasts in the West area and high cliffs in the East promote conditions for coastal erosion [Overduin et al., 2014]. For instance, the prograded beach morphology on Cape Charles Yorke (Baffin Bay) is an excellent case that shows a recent shift in sedimentary processes from deposition to erosion, resulting from a lower sediment supply, increased wave energy and sea level rise [St-Hilaire-Gravel, 2011].
2 Materials and Methods

2.1 Coring and sampling

In total, 40 box cores were collected at various depths in eight different regions (Figure 1B), including the Mackenzie Shelf/Slope, the Amundsen Gulf, the M’Clure Strait, the Coronation and the Queen Maud Gulfs, the Victoria Strait, the Barrow Strait, and the Eclipse Sound on board of the Canadian Coast Guard Ship (CCGS) Amundsen as part of the ArcticNet program in 2016 [Montero-Serrano et al., 2016; Table 1]. All coring sites were targeted using high-resolution seismic profiles that indicated high sediment accumulation not influenced by mass wasting events [Montero-Serrano et al., 2016]. In each box core, two push cores were subsampled. Using the results from digital X-ray and continuous multi-sensor core logger (MSCL) measurements processed in the lab, one replicate push core was selected for subsequent analyses based on the absence of coring disturbance/artifacts and the absence of compaction visually confirmed on deck during the sampling. To study the sediment-water interface, surface sediment samples were collected on board in the uppermost 1 cm of each box core using a spatula and stored in plastic bags. Furthermore, once split, the cores were sampled with 1 cm$^3$ cubes at the top (representing the first 1 cm) and the base (the lowest centimeter in each core; Table 1) for grain size, magnetic and sedimentological analyses.

Table 1. Coordinates of the studied cores.
2.2 Continuous physical and geochemical analyses

All the box cores were opened, described, photographed and analyzed with the GEOTEK MSCL in split core mode at 0.5 cm intervals. With this setting, the following parameters were determined: diffuse spectral reflectance (L* and a*) using a Konica Minolta CM2600d spectrophotometer, low-frequency magnetic susceptibility (kL) using a point source sensor and chemical composition (Ti, Mn, Fe, Al, Si, K, Ca, Zn, Rb, Sr, Zr) using a portable Olympus Delta Professional X-ray fluorescence (pXRF) sensor. The pXRF data enabled the calculation of geochemical ratios in order to derive more information about sedimentological processes, such as the Log (Al/Ca) and Log (Mn/Al) ratios, which have previously been used to reconstruct changes in sediment provenance and transport [Croudace et al., 2006; Croudace and Rothwell, 2015]. Log(Al/Ca) provides a straightforward proxy to reflect sediment sources where the aluminum can be associated with alluminosilicate inputs [Nizou et al., 2011] and calcium with...
detrital carbonates. Given that Mn is a highly insoluble oxyhydroxide when oxic conditions prevail [Burdige, 1993; Calvert and Pedersen, 2007], enrichment in Mn is associated with oxic conditions. Finally, Log (Mn/Al) is used as an indicator of bottom water ventilation [Gamboa et al., 2017].

2.3 Carbon and nitrogen analyses

Carbon and nitrogen analyses were performed for surface and basal sediments in order to determine the spatial variations in the sedimentary organic matter sources (terrestrial vs marine) and inorganic carbon (C_{inorg}) content [e.g., Meyers, 1994; St-Onge and Hilaire-Marcel, 2001]. The first aliquot of 6-10 mg of bulk sediment was dried, homogenized and encapsulated for total carbon (%C_{tot}) and total nitrogen (%N_{tot}) contents. A second aliquot of 8-12 mg of sediments was acidified with 0.2 ml HCl (1 M) to dissolve carbonates in order to measure organic carbon (%C_{org}) contents. Both aliquots were analyzed using the CF-IRMS (continuous flow isotope ratio mass spectrometry) coupled with a COSTECH 4010 (Costech Analytical) elemental analyzer. The δ^{13}C_{org} content was analyzed in the acidified aliquot portion, whereas the δ^{15}N_{tot} content was measured using the bulk samples with a gas chromatograph coupled to a ThermoScientific Deltaplus XP mass spectrometer where the analytical errors (n= 50) of measurement were 0.2‰ and 0.4‰, respectively. System suitability prior to analysis was evaluated using standards (caffeine, nannochloropsis and Mueller Hinton Broth). The C_{inorg} content was calculated by subtracting C_{org} from C_{tot} content. The C_{org}/N_{tot} ratio is expressed as an atomic C/N ratio and used to distinguish between marine and terrestrial sources for sedimentary organic matter [OM; Meyers, 1994; 1997].

2.4 Grain size measurements

Approximately 1 g of sediment was moistened with H₂O. Afterwards, 10 ml of hydrochloric acid (1 M HCl) and hydrogen peroxide (30% H₂O₂) was added to remove biogenic carbonates and organic material, respectively, in order to isolate the detrital fraction. Samples were then deflocculated by successive washing with distilled water and analyzed with a Beckman Coulter LS13320 laser diffraction grain-size analyzer, which had a detection range of 0.04-2000 μm. The statistical parameters (e.g., sorting and mean grain size) were computed with the GRADISTAT software [Blott and Pye., 2001] by using the method of moments on the logarithmic phi-scale.

2.5 Discrete magnetic analyses

The sampled cubes were analyzed with a 2G SRM-755 cryogenic magnetometer. The natural remanent magnetization (NRM) was measured and then demagnetized at a peak alternating field (AF) of 0 to 80 mT at 5 mT steps. The Anhysteretic remanent magnetization (ARM) was induced by an AF of 100 mT and a direct current (DC) biasing field of 0.05 mT. Isothermal remanent magnetization and saturated isothermal magnetization (IRM and SIRM, respectively) were acquired using a 2G-pulse magnetizer in DC fields of 300 and 950 mT. Both ARM and IRM were then demagnetized at the same AF steps as the NRM. In the case of SIRM, the demagnetization steps were operated at 0, 5, 10, 30, 50 and 80 mT. By dividing the IRM imparted at 300 mT by the SIRM (950 mT), we calculated the pseudo S-ratio in order to estimate the magnetic mineralogy. Values close to 1 indicate the presence of lower-coercivity ferrimagnetic minerals (e.g., magnetite), whereas lower values indicate the contribution from higher-coercivity minerals (e.g., hematite). The median destructive field (MDF) is the required field to remove half of the initial remanence and is influenced by magnetic grain size and mineralogy.
For all the samples, magnetic susceptibility was measured using a Bartington MS2E instrument. To determine the frequency dependence, magnetic susceptibility measurements were performed in a magnetic field created by two frequencies: a low frequency at 0.46 Hz and a high frequency at 4.6 Hz. The difference between these two measurements was used to detect the presence of superparamagnetic minerals [e.g., Dearing, 1999] characterized by slightly lower susceptibility values at high frequency. Ultrafine superparamagnetic crystals are smaller than ~0.03 μm and show rapid changes over time in their magnetic behavior [Dearing, 1999].

Finally, samples were measured using a Princeton Measurement Corporation alternating gradient force magnetometer (MicroMag 2900 AGM) to determine the coercivity force (Hc), the coercivity of remanence (Hcr), the saturation magnetization (Ms) and the saturation remanence (Mrs). The resulting coercivity (Hc/ Hc) and remanence (Mrs/Mr) ratios and the shape of the hysteresis loops are indicative of the magnetic mineralogy and grain size [Day et al., 1977; Dunlop, 2002].

2.6 Sediment dating

Recent sedimentation rates were calculated from seven cores representative of each part of the study area (05-BC, 165-BC, 304-BC, 316-BC, 408-BC, 535-BC and QMG4-BC) and based on 210Pb measurements at GEOTOP (Montréal). Approximately 2 g of dried and crushed sediment was sampled at 1 cm intervals until 15 cm and at every 5 cm thereafter until reaching the core bottom. The 210Pb measurements were made after chemical treatment purification and deposition on a silver disk following routine procedures and using an EGG ORTEC model 576 alpha spectrometer [Hamilton and Smith, 1986]. Excess 210Pb measurements were processed by counting the activity of the 210Po daughter isotope [Appleby and Oldfield, 1984; Zhang, 2000], and 209Po was used as the chemical yield. The counting error was evaluated at 1σ ~2-4%. To estimate the sedimentation rates, we first visually determined 210Pb supported and second calculated 210Pbexcess (210Pbexcess = 210Pb - 210Pb supported). Then, the CRS model (constant rate of 210Pb supply; Appleby and Oldfield, [1983]; Oldfield and Appleby, [1984]), the slope of the linear regression ln (210Pbex) and depth was used to calculate the average sedimentation rate (SR) = -ln (2)/(slope*22.3), where 22.3 is the half-life of 210Pb [e.g., Ghaleb, 2009]. This SR allowed us to estimate the age of the base of the measured cores.

Furthermore, we used the magnetic susceptibility variations measured along the cores to link the dated cores with the nearby undated ones for each region. Similar profiles between cores coming from the same part of the study area were correlated (Figures S1 to S4). In addition, sedimentation rates (cm/ka) data available within the CAA were compiled in an interpolated map (Figure S5). Based on this information, we assumed that surface sediments accumulated after 1900 CE, whereas basal sediments most likely accumulated prior to 1900 CE.

2.7 Statistical and spatial approach

Due to its large regional climatic and oceanographic variability, sedimentary processes operating across the CAA referenced in paleoenvironmental studies and actual descriptions vary from region to region. Indeed, this variability has been notably explained by the influence of the Mackenzie River and the small Canadian Arctic rivers in the western part of the CAA [Scott et al., 2009; Belt et al., 2010; Bringué and Rochon., 2011; Durantou et al., 2012; Wagner et al., 2011; Gamboa et al., 2017; Alkire et al., 2017] and the influence of sea ice in the eastern part of the study area [Pieńkowski et al., 2011, 2013; Ledu et al., 2010a, 2010b]. Considering the vastness of the study area, sedimentary provinces characterized by their own processes were statistically defined using cluster analysis. Therefore, sampling sites were arranged in a hierarchical cluster using the major surface geochemical elements (Ti-Mn-Fe-Al-Si-K-Ca) from the pXRF data set in order to identify different sedimentological provinces. In addition,
to gain information on the degree of mixing between the clusters, a fuzzy c-means (FCM) clustering analysis was also performed using the pXRF major elements data. The results from the FCM clustering are visualized in a silhouette plot [Kassambara, 2017]. The silhouette plot allows visualization of the robustness of clusters [Borcard et al., 2011], where each sample is represented by a bar (silhouette width) that ranges from 0 (no similarity) to 1 (identical). Both hierarchical and FCM analysis were performed using the Aitchison distance between the samples as a measure of dissimilarity and Ward’s method for agglomerative calculation purposes. To obtain a statistical link among several variables by detecting elemental associations with similar relative variation patterns that may be interpreted from a paleoenvironmental standpoint [e.g., von Eynatten et al., 2003, 2016; Montero-Serrano et al., 2010; Gamboa et al., 2017], principal component analysis (PCA) was performed on the pXRF data from surface and basal samples. Statistical analyses were conducted with R software (R Core Team, 2021) using the packages ‘compositions’ [van den Boogaart and Tolosana-Delgado, 2008, 2021], ‘factoextra’ [Kassambara and Mundt, 2020], and ‘cluster’ [Maechler et al., 2019].

The geochemical data are compositional, i.e. vectors of nonnegative values subjected to a constant-sum constraint (of 100%). This feature implies that relevant information is usually contained in the relative magnitudes and that the statistical analysis must focus on the ratios between components [Aitchison, 1986]. Prior to multivariate analysis, a log-centered (clr) transform is applied [Aitchison, 1990]. This transformation first divides the elemental concentration by the geometric mean of the compositions of the individual observations and then uses the logarithm. Note that all the geochemical element ratios are expressed as log-ratios in order to minimize the highest values and distribute the lowest one, which is most suitable for right-skewed distributions [van den Boogaart and Tolosana-Delgado, 2013].

Finally, physical and magnetic properties, grain size and carbon-nitrogen data, as well as the score from the first principal component (PC1) of the log-centered pXRF data, are used to produce interpolated maps using the Ocean Data View (ODV) software [Schlitzer, 2018]. The interpolated maps are generated using a weighted-average gridding algorithm with a quality limit of 1.2.

3 Results

3.1 Sedimentological and physical properties

3.1.1 Spatial delimitation based on elemental geochemistry

Hierarchical and FCM analysis reveal similar results and indicate that there are three geographical clusters within the CAA with distinct geochemical compositions (Figure 2A-C). Cluster 1 is mainly represented by samples from the western CAA (M’Clure Strait, West Banks Island, the Mackenzie Shelf/Slope) and also by samples from the mouth of Coppermine and Ellice Rivers. Cluster 2 is represented by samples mainly originating from the Amundsen Gulf, with some samples from the West Banks Island and Coronation and Queen Maud Gulfs (this cluster is hereafter referred as Intermediate Zone or IZ). Cluster 3 is mostly represented by samples from the eastern CAA (Queen Maud Gulf, Victoria and Barrow Straits, and Lancaster and Eclipse Sounds). The silhouette plot reveals that 100% of the sediment samples are correctly classified (Figure 2B). However, most of samples with below-average silhouette width values (<0.29) are samples from cluster 1 (West province), likely due to a greater mix of different sediment sources. PCA of pXRF data reveal two PC scores which explain 71.5% of the total variance (54.4% and 17.1% for PC1 and PC2 scores, respectively; Figure 2D). PC1 scores are positively associated with Ti-Fe-Rb-Zn and negatively associated with Ca. PC2 scores shows anti-correlation between Sr-Zr and Al-Si. It is also important to mention that Mn
is removed from the PCA because of its strong influence on geochemical variability. The spatial
distributions of the PC1-scores for surface and basal sediments depict large positive PC-1 scores
(Ti-Fe-Rb-Zn) in most of the West province stations and large negative PC-1 scores (Ca-Si) in
the East province stations (Figure 3A-B). Intermediate PC-1 scores (Al-Si-Sr-Zr) are observed
in most of the IZ stations.

The Log(Mn/Al) distribution map shows higher concentrations for surface sediments
especially south of Banks Island and in the Amundsen and Coronation Gulfs (Figure 3C-D).
Finally, Log(Al/Ca) is used as a sediment source and transport agent indicator. Indeed, higher
Log(Al/Ca) values are found in the West Province for surface and basal sediments
(Figure 3E-F), whereas lower Log(Al/Ca) values are mostly observed in the East Province in the surface
and basal sediments.

**Figure 2.** (A) Clustering dendrogram obtained by applying Ward clustering algorithm on the
pXRF major element data (Ti-Mn-Fe-Al-Si-K-Ca). (B) Silhouette plot resulting from the fuzzy
clustering analysis of the surface samples based on the pXRF major element data. 100% of the
sediment samples are correctly classified. However, cluster 1 (West province) is mostly
represented by samples with below-average silhouette width values (<0.29) likely suggesting
mixing of sediment provenance. (C) Map of the three clusters, which point out the three
geochemical provinces. The red rectangle on stations correspond to $^{210}$Pb dated cores. (D)
Biplot of the PC-1 versus PC-2 obtained on the pXRF data. Note that Mn is removed from the
PCA because of its strong influence on geochemical variability.
Figure 3. (A, B) Map of PC-1 scores derived from pXRF major elements data of surface (post-1900) and basal (pre-1900) sediment samples. Spatial distribution of Log(Mn/Al) (C, D) and Log(Al/Ca) (E, F) for surface (post-1900) and base (pre-1900) samples. High Mn concentrations are observed in surface samples located in the south of Banks Island, the
entrance of Amundsen Gulf and part of Coronation Gulf. Al concentrations are higher in the
Canadian Beaufort Shelf and Queen Maud Gulf, while Ca show higher concentrations in the
M’Clintock Channel. The red rectangle on stations correspond to $^{210}$Pb dated cores.

3.1.2 Grain size distribution

The mean surface and basal grain size in the study area do not depict great variability
and are mainly composed of silts. Indeed, the mean surface sediment grain size expressed on
the phi scale ranges from 9.0 (clay) to 7.0 (fine silt) whereas the minimum phi values are found
in the Coronation Gulf. The surface sample grain size distribution shows a general West-East
trend with finer grains (8-9 $\Phi$) in the western part and coarser grains ($< 8 \Phi$) in the eastern part
(Figure 4A). The basal sample grain size depicts a coarser grain size near to the Mackenzie
mouth (~8.5 $\Phi$), whereas the grain size in the rest of the western and eastern parts generally
become finer (7.5 $\Phi$) (Figure 4B).

Generally, sorting is better as the mean grain size decreases, especially in the West province
surface sediments (Figure 4C). The most poorly sorted sediments are found in the East province
and near the M’Clure Strait (545-BC and 20-BC).

Figure 4. Spatial distribution of mean grain size (A, B) and sorting (C, D) for surface (post-
1900) and basal (pre-1900) sediment samples from the CAA.

3.1.3 Sediment color

The presence of detrital carbonates in the eastern part of the CAA, more precisely in
the Coronation Gulf and Victoria Strait can be determined by a whiter sediment color expressed
by higher L* values (Figure 5A-B). L* values are higher at the base than at the surface for these
regions except for M’Clure Strait. In fact, higher L* values for basal sediment, especially those
found in the East province, appear to coincide with increases in the inorganic carbonate contents
(Figure 5G-H), as well as decreases in the Log(Al/Ca) ratios (Figure 4E-F) corresponding to
the presence of detrital carbonates. Furthermore, reddish sediments (Figure 5C-D) tend to be located mainly in Coronation and Queen Maud Gulfs both at the surface and the base.

3.1.4 Carbonate and inorganic carbon contents

Figure 5E-H illustrates the organic and inorganic carbon concentrations in the study area. In the surface samples, the organic carbon content distribution shows higher concentrations in the West and along the Lancaster Sound (Figure 5E), whereas the organic carbon of basal samples decreases in the Mackenzie Shelf/Slope area (Figure 5F). On the other hand, the eastern area is characterized by higher contents of inorganic carbon for surface and basal sediments (Figure 5G-H).
Figure 5. Spatial distributions of color indices $L^*$ (A, B) and $a^*$ (C, D) as well as of organic carbon (E, F) and inorganic carbon (C, D) contents for the surface (post-1900) and basal (pre-1900) sediment samples from the CAA. The red rectangle on stations correspond to $^{210}$Pb dated cores.
3.1.5 Organic carbon sources

The East province is first characterized by $\delta^{13}$C values ranging from -22 to -23‰ in surface sediments and from -24 to -26‰ at the base and second by C/N ratios between 5 and 10 in surface sediments and between 5 and 15 in basal sediments (Figure 6). The West province is characterized by more strongly negative $\delta^{13}$C values (from -24 to -26.5‰ at the surface and from -26 to -30.5‰ at the base) and higher C/N values (from ~7 to 14 in surface sediments and from 5 to > 20 at the base). Figure 6 reveals a west-east trend with more terrigenous OM in the West, more marine OM in the East and a mixing between marine and terrigenous OM in the intermediate zone. Finally, the data also reveal that $\delta^{13}$C values become less strongly positive whereas C/N ratio values are higher between the surface and the base of the sediment cores (Figure 6).

Figure 6. Relationship between C/N and $\delta^{13}$C values for the surface (post-1900) and basal (pre-1900) sediment samples. Three distinctive clusters of C/N and $\delta^{13}$C values are highlighted and correspond to the three geochemical provinces defined by clustering analysis: West, Intermediate Zone (IZ) and East. Amundsen = Amundsen Gulf; M’Clure= M’Clure Strait; Coronation= Coronation Gulf, Lancaster= Barrow Strait/Lancaster Sound; Mackenzie= Mackenzie Shelf/Slope; QMG= Queen Maud Gulf; Victoria= Victoria Strait and WBI= West Banks Island.

3.2 Magnetic properties

3.2.1 Magnetic concentration

To more closely examine the magnetic grain concentration, a concentration-dependent parameter is used: magnetic susceptibility ($k_{LF}$; Figure 7A-B). Generally, the intermediate zone surface samples show higher values in magnetic susceptibility ($k_{LF} > 25 \times 10^{-5}$ SI) than samples from anywhere else ($k_{LF}=5$ to $10 \times 10^{-5}$ SI). This feature suggests a higher concentration of ferrimagnetic material in the intermediate zone, whereas lower magnetic susceptibilities recorded in the Western and Eastern areas could be due to the higher organic matter contents in the West and the higher detrital carbonate concentration in the East. Finally, magnetic susceptibility is mainly lower in the base than in the surface sediment samples.
Figure 7. Spatial representations of magnetic properties from surface (post-1900) and basal (pre-1900) sediments from the CAA: (A) and (B) for magnetic susceptibilities ($k_{LF}$). (C and D) illustrate the pseudo S-ratio [Stoner and St-Onge, 2007]. The Median Destructive Field of the natural remanent magnetization ($MDF_{NRM}$) is represented in panels E and F. The red rectangle on stations correspond to $^{210}$Pb dated cores. Finally, Day plot [Day et al., 1977] for the surface and basal samples from the CAA is illustrated in panel G. The mixing reference lines for single and multi-domain (SD and MD) are from Dunlop (2002). Frequency dependence and magnetic mineralogy

Difference in the magnetic susceptibility values between the low and high frequencies is negligible, suggesting the absence of superparamagnetic grains (Table S1). In addition, the magnetic mineralogy in the CAA is mainly dominated by minerals with low coercivity, such as magnetite. This observation is particularly supported by the pseudo S-ratios, which are generally $>0.9$. Indeed, more magnetite seems to be present in Barrow Strait and Lancaster Sound for the surface samples (Figure 7C), whereas in the base samples, pseudo S-ratio data increase and almost all samples values close to 1, except for those from the southern Victoria Strait, Coronation Gulf and M’Clure Strait (Figure 7D).

On the other hand, the median destructive field of natural remanent magnetization ($MDF_{NRM}$) reveals higher values in the northern Victoria Strait for surface and base samples (Figure 7E-F). Otherwise, $MDF_{NRM}$ values tend to decrease from $\sim40$ mT to $\sim15$ mT between the surface and the base in samples from the rest of the study area.

3.2.2 Magnetic grain size

A coarsening magnetic grain size trend is mainly observed between the surface and basal sediments but also from West to East (Figure 7G). Most samples are included in the pseudo-single domain (PSD) range and seem to be aligned to the theoretical single and multi-
domain (SD + MD) mixing line. A larger contribution of coarser MD magnetite grains and other minerals is evident for the East basal sediments and one West basal sample (AMD 2016-805-20BC). Otherwise, the rest of the samples are dominated by finer PSD magnetite grains.

3.3 Relationships between magnetic properties, grain size and elemental geochemistry

The relationships between the different properties are established by using bivariate graphs (Figure 8). First, relation between the mean phi grain size and skewness shows that surface sediments from the East and IZ Provinces are mostly characterized by coarse detrital grain sizes with asymmetric distributions (Figure 8A). In turn, surface sediments from the West Province and the majority of base sediment samples show the opposite trend. In addition, the relationship between the magnetic grain size ($M_{rs}/M_s$) and the elemental geochemistry ratio (Figure 8B) reveals a west-east trend where surface samples from the East Province are mostly characterized by fine magnetic grains (high $M_{rs}/M_s$ ratios) and high contents of detrital carbonates [low Log(Al/Ca) ratios], whereas the West and IZ Provinces are influenced by high aluminosilicate concentrations.

![Figure 8. Relationship between: (A) sediment grain size characteristics such as mean grain size in phi-scale and skewness and (B) magnetic and geochemistry parameters as Log(Al/Ca) and magnetic grain size $M_{rs}/M_s$.](image)

3.4 Lead-210 dating

Clear radioactive decay is observed in $^{210}$Pb data of seven box cores and allows visual determination of the value of the supported $^{210}$Pb and excess $^{210}$Pb (Figure 9). The slope of the unsupported $^{210}$Pb decay is used to calculate the sedimentation rates (SR; Figure 9B). Generally, the sedimentation rates vary between ~82.3 and 370 cm/ka with basal ages from ~1550 to 1820 CE, providing an opportunity to compare post-1900 conditions with those of the LIA (~1500-1900 CE). These new sedimentation rate estimates are similar to and complement the different data already obtained (summarized in Figure S5) in the Mackenzie Shelf/Slope [Richerol et al., 2008; Bringué and Rochon, 2012; Durantou et al., 2012], the Coronation Gulf [Pieńkowski et al., 2011; 2017] and the Victoria and Barrow Straits [Vare et al., 2009; Ledu et al., 2010a; 2010b; Belt et al., 2010; Pieńkowski et al., 2013].
Figure 9. (A) $^{210}$Pb chronology of selected box cores from the CAA. Total activity of the $^{210}$Pb (dpm/g) and vertical dashed lines characterized supported $^{210}$Pb was represented in the first row. (B) Grey and black Ln (excess of $^{210}$Pb activity) plot symbols distinguish two slopes and thus different sedimentation rates which are both used to calculate the basal age for some core.

4 Discussion

4.1 Sedimentary provinces and processes

As a result of the statistical analysis, together with sedimentological, magnetic properties and the color of the surface and basal sediments, three main provinces and their distinct sedimentary compositions and dynamics are described below and summarized in Figure 10.

4.1.1 The West Province

The surface sediments (post-1900) of the West (Mackenzie Shelf/Slope, West Banks Island and the M’Clure Strait; cluster 1) are mainly characterized by: fine detrital grains, detrital element (Fe-Rb-Ti-Zn) associations and a dominance of aluminosilicates [high Log(Al/Ca) ratios], implying high detrital inputs delivered particularly by rivers. In this province, PSD magnetite and soft minerals suggesting the presence of low-coercivity minerals (Figure 7C,G) with a MDF$_{NRM}$ of 40mT are noted, but even if magnetite is present, the magnetic susceptibility (k$_{LF}$; Figure 7A) remains relatively weak. This feature may be explained by the dilution of magnetic minerals by the large terrestrial OM supply (Figure 5E-F) coming from the Mackenzie River discharge [Macdonald et al., 1998; Magen et al., 2010; Gamboa et al., 2017]. The heterogeneous sedimentary composition (i.e. mixture of sediments rich in aluminosilicates and detrital carbonates; Figure 2B-C) within the Mackenzie Shelf/Slope, the relatively symmetric and skewed grains and the constant mean grain size (Figure 4A) support the idea that the post-1900 sedimentation in this area is thus mainly dominated by the Mackenzie River discharge.
Detrital inputs from the Mackenzie River derive mainly from the Interior Platform, where Cambrian to Cretaceous shales, sandstones, and limestone are cropping out [Millot et al., 2003; Gamboa et al., 2017; Deschamps et al., 2018]. Moreover, differences in the sedimentary records observed within this province suggest that the Mackenzie plume influence is not strong enough to be the only common factor controlling the recent sedimentary processes in the West Banks Island and M’Clure Strait areas. Indeed, in addition to the high contents of organic carbon found in West Banks Island, confirming the influence of Mackenzie River discharge, poorly sorted fine silts and detrital carbonate contents are higher than those on the Mackenzie Shelf/Slope. This difference likely suggests a modern supply by coastal cliff erosion of Quaternary dolomite-rich tills, in agreement with other studies in this area [O’Brien et al., 2006; Belliveau, 2007; Gamboa et al., 2017; Lewkowicz and Way, 2019]. Finally, in the M’Clure Strait region, the high contents of carbonate and aluminosilicate minerals and the mixture of terrestrial and marine OM observed in surface sediments suggest sedimentation influenced by the mixing of sedimentary material produced locally (autochthonous) and that transported from outside the region (allochthonous) [Howell and Brady, 2019]. Indeed, we assume that coastal erosion of Banks and Prince Patrick Islands added to the presence of several Banks Island rivers (such as the Bernard, Big and Thomsen Rivers) promote inputs of such carbonate- and aluminosilicate-rich sediments, which are subsequently brought into the M’Clure Strait by sea-ice transport and coastal currents [e.g., Darby et al., 2003].

The main sedimentary properties within the West Province remain substantially similar for the basal samples, which describe the pre-1900 conditions. Indeed, this province remains characterized by a high Log(Al/Ca) ratio associated with a terrigenous OM inputs, the presence of SD/PSD magnetite and low-coercivity minerals, along with a constant weak magnetic susceptibility. Since the magnetic mineralogy is almost identical to that of the surface samples, the slight decrease in MDFRM (Figure 7F) may reflects changes in the magnetic grain size [Stoner and St-Onge., 2007; Özdemir and Dunlop, 1997] and is consistent with the Day plot (Figure 7G), which reveals coarser magnetic grain sizes. Nevertheless, some differences can also be observed involving changes in the sedimentary processes. The detrital grain size is coarser near the Mackenzie River mouth and becomes finer in surrounding areas and to the north of Banks Island in basal sediment samples (Figure 4B), together with coarsely skewed grains. These changes in pre-1900 sediments are also accompanied by an increase in aluminosilicate contents [higher Log(Al/Ca) ratios; Figure 3F] to the north of Banks Island as well as the slight % Ciorg decrease (Figure 5H) to the west of Banks Island. Based on previously published mineralogical, geochemical and palynological studies performed in the Mackenzie Shelf and Slope during the Late Holocene (e.g., Richerol et al., 2008; Durantou et al., 2012; Hanna et al., 2018; Deschamps et al., 2018a), we hypothesize that the sedimentological changes recorded in pre-1900 sediments in this province were likely driven by an increase and a wider influence of the Mackenzie River discharge along the Canadian Beaufort margin. On one hand, the results of the dated cores 408-BC and 535-BC from the LIA period show an increase than post-1900 sediment samples of the magnetic concentration (from 20 to 50.10^6 SI for 408-BC and from 50 to 70-80.10^6SI for 535-BC; Figure 7) as well as detrital grain size (Figure 4), Log(Al/Ca) values, a constant pseudo S-ratio (close to 1; Figure 7) and inorganic carbon content and finally, a decrease of OM content (Figure 5). These observations may indicate a dilution by organic matter which is more important in the West Province during the pre-1900 period. On the other hand, palynological studies all around the area suggest that colder sea surface conditions, higher-than-average sea-ice cover, and enhanced Alaskan Coastal Current (ACC) flow prevailed during the LIA period [e.g., Richerol et al., 2008; Durantou et al., 2012; Bringué and Rochon, 2012]. These features lead us to speculate that the climate and ocean conditions during the LIA likely fostered the recurrent incorporation of Mackenzie Shelf
seds rich in coarse-grained magnetite into the sea ice (a process known as suspension freezing; Reimnitz et al., 1990; 1993; Darby et al., 2003) and their subsequent entrainment towards the Amundsen Gulf entrance and north of Banks Island via the ACC (e.g., Lin et al., 2020). This hypothesis is also supported by the increase in asymmetric grain distribution and magnetic grain contents in basal samples from the core 535-BC, implying different depositional processes such as sea-ice transport and river discharges and the work of oceanic currents.

Figure 10. Summary of the sedimentary processes involved from each province during the pre- and post-industrial periods.

4.1.2 The Intermediate Province

The IZ (the Amundsen, Coronation and Queen Maud Gulfs; cluster 2) acts as a transitional zone between the West and East Provinces (Figures 2A-C and 10). The surface sediments are defined by common characteristics: Si-Al-Zr-Sr-K contents, high concentrations of manganese and aluminum (associated with aluminosilicates), SD/PSD magnetite, MDF\textsubscript{NRM} ~40mT and a mixture of terrigenous and marine OM. The lower pseudo S-ratios found in the Coronation and Queen Maud Gulfs (Figure 7C) than in the other areas suggest the presence of higher-coercivity magnetic minerals. The high concentrations of manganese observed in this region are correlated with high values of a* (reddish sediment color), indicating a geochemical relationship most likely similar to Fe-Mn oxyhydroxide phases [Macdonald and Gobeil, 2012]. In fact, a well-oxygenated water column sustained by vertical turbulent mixing (strong winds and recurrent ice-free conditions) and high terrestrial OM input foster ideal conditions for the settling of Fe-Mn oxyhydroxides onto the seafloor by reductive remobilization [Gamboa et al., 2017]. Furthermore, some differences between the Amundsen and the Coronation Gulfs are also noteworthy. The high contents of poorly sorted clay-size sediments (~8 Φ), relatively high concentrations in terrestrial OM contents and low magnetic susceptibility found in the Amundsen Gulf reflect a modern sedimentation dominated by the strong influence of the far-
reaching Mackenzie plume [Hill et al., 1991; Macdonald et al., 1998, Schell et al., 2008]. In addition, the relatively high content of detrital carbonates observed in the Amundsen Gulf demonstrates a further contribution from the coastal cliff erosion process [Bellido, 2007; Lewkowicz and Way, 2019] occurring to the south and west of Banks Island. The Coronation and Queen Maud Gulfs are in turn characterized by the predominance of detrital fine silts, asymmetric grain distributions, low concentrations of organic and inorganic carbon and high magnetic susceptibilities. On the other hand, the high Log(Al/Ca) values in the Coronation and Queen Maud Gulfs indicate aluminosilicate-enriched sediments (particularly feldspars; Belt et al., 2010; Deschamps et al., 2018a). These observations suggest that local sedimentation is mainly influenced by surrounding rivers (such as the Coppermine in Coronation Gulf and Back, Hayes, Perry, Armark, Simpson, Hayes and Ellice Rivers in Queen Maud Gulf; Alkire et al., 2017), draining the Canadian Shield. All these observations explain the presence of the sediment samples from the mouth of Coppermine and Ellice Rivers in the cluster 1 (West Province) instead in the IZ.

The basal sediments (pre-1900) display some similarities with those from the surface (post-1900): the elemental geochemistry is still dominated by the Si-Al-Sr-Zr-K association, the detrital grain size is generally finer, whereas the magnetic mineralogy shows decreases in magnetite contents based on the lower pseudo S-ratios (Figure 7D) as well as the considerable decreases in the MDF, which reveal coarser magnetic grain sizes. These similarities may suggest that the sediment sources remained the same and that some changes could be due to the contribution of different transport agents (such as sea-ice transport; Darby et al., 2003). Additionally, relatively high terrigenous OM contents and the absence of manganese precipitation [low Log(Mn/Al) ratios] suggest a less oxygenated water column during the pre-1900 period than during the post-1900 time, especially in the Coronation and Queen Maud Gulfs. In these latter areas, the higher Log(Al/Ca), magnetic susceptibilities, higher pseudo S-ratios and concentrations of reddish sediments in the LIA interval of the dated cores 05-BC, 316-BC, and QMG4-BC may indicate more continental inputs from the Canadian Shield during the LIA, supplied by an enhanced river discharges, coastal erosion and sea-ice transport. This hypothesis agrees with the studies of Pienkowski et al. [2011; 2017] and Belt et al. [2010], which reconstructed colder conditions during the LIA with wider sea-ice extents and a shorter open-water season in these areas.

4.1.3 The Eastern Province

Surface sediments (post-1900) of the Eastern Province mainly indicate the presence of fine silts (~7.5 Φ) and a chemical composition generally dominated by calcium and marine OM. In addition, the magnetic properties reveal weak magnetic susceptibilities that intensify slightly and gradually eastward. Counterintuitively, the important presence of soft minerals such as MD coarse magnetite (Figure 7C) increases gradually eastward as well as the MDF_NRM (Figure 7E). However, specific differences within this province can also be observed. The Victoria and Barrow Straits dominantly show detrital carbonates supported by low Log(Al/Ca) values and C_{more} > 5%, suggesting that modern sedimentary processes are dominated by coastal erosion of Ordovician-Silurian carbonate-bearing rocks cropping out in Victoria, Prince of Wales and Somerset Islands as well as in the Brodeur Peninsula before they are ultimately transported by sediment-laden sea ice [Reimnitz et al., 1993]. Moreover, the high contents of aluminosilicates and terrigenous OM inputs and the lower contents of detrital carbonate inputs in eastern Lancaster Sound can indicate that sediments are mainly transported by sea ice. The presence of glaciers on Devon Island and in Sirmilik National Park could have a local impact on settling by generating iceberg rafting and sediment-laden meltwater plume sediment supply.
The basal (pre-1900) sediment samples in this province are mainly characterized by a finer detrital grain size (~8.5 \( \Phi \)), poorer sorting, a dominant association of Ca-Si with relatively weak magnetic susceptibilities that increase in the northern Victoria Strait and more terrigenous sediment inputs than the surface sediments. Compared to the surface sediments (post-1900), the basal sediments have the magnetic mineralogy that is dominated by higher-coercivity minerals and a mixture of PSD/MD magnetite. On the other hand, considering the increase in magnetic susceptibilities in the northern Victoria Strait, the pseudo S-ratios close to one and the increase in magnetic grain sizes, we suggest the presence of a higher concentration of coarser magnetite during the pre-1900 period. Bischof and Darby [2000] observed higher magnetite concentrations (up to 36\%) in the Fe oxide fraction of tills samples from the northern Viscount Melville Sound (Figure 1A). Thus, we suggest that magnetite-rich sediments from the Viscount Melville Sound area are probably incorporated into the sea ice during its formation and subsequently transported by drifting ice to northern Victoria Strait. Furthermore, the relatively lower OM and higher detrital carbonate contents correlated with whiter sediments in Victoria Strait suggest more pronounced contributions of coastal erosion and sea-ice sediment transport during the pre-1900 conditions than under the post-1900 ones. In addition, the high \( C_{\text{org}} \) values (1.5-2\%) recorded in the Barrow Strait relative to the rest of the province in both surface and basal sediment samples suggest enhanced primary productivity probably related to the recurrent polynya formation in this area [e.g., Steffen, 1986; Hannah et al., 2009]. The occurrence of polynyas in Barrow Strait area seems to be connected with the location of a wintertime ice plug (fast-ice arch) in the south of Cornwallis Island [Steffen, 1986]. In this latter area, fine-grained and poorly sorted sediment samples from the LIA interval in the dated core 304-BC show low \( \log(\text{Al/Ca}) \) and high \( C_{\text{org}} \) (up to 4\%) values, similar to the post-1900 sediment samples, suggesting similar-to-modern sedimentary conditions during LIA in Barrow Strait area. Few variations in sedimentological and geochemical proxies since 1550 CE have also been reported in a nearby core from Barrow Strait (core 2005-804-004BC; Ledu et al., 2010a), consistent with our interpretations. Note that since no sediments were successfully dated using \( ^{210}\text{Pb} \) in Victoria Strait area, we are not able to conclude about the impact the cooler LIA conditions on the sedimentary dynamics in this region.

In Eclipse Sound (southern Bylot Island), LIA samples from the dated core 165-BC are characterized mainly by the association of Si-Al-Zr-Rb-Ti, high magnetic susceptibilities, and fine-grained and poorly sorted sediments. Previously palynological lake studies around Bylot Island [e.g., Gajewski et al., 1995; Gajewski and Frappier, 2001; Peros and Gajewski, 2008; Zabenskie and Gajewski, 2007] suggest that cold climate conditions prevailed during the LIA in this area. In this context and because Bylot Island glacier drains Archean gneiss from the Canadian Shield in the east part as well as Mesozoic-Cenozoic siliciclastic rocks in west part, we hypothesize that an enhanced glacier activity during the LIA period likely promoted an enhanced input of poorly sorted detrital sediments of mixed origin (i.e., from Archean gneiss and siliciclastic rocks).

4.2 Methodological and sediment dynamic implications

Methodologically, our study illustrates that by combining the magnetic, geochemical and sedimentological properties, together with cluster and spatial analyses, we can determine provenance and sedimentary processes that operate within the CAA. Given the challenges of dating marine sedimentary sequences in the Arctic Ocean, this study also allows the dating of seven new box cores from West Banks Island, the Lancaster and Eclipse Sounds, and the Amundsen, Coronation and Queen Maud Gulfs to improve the Arctic chronology mosaic. In addition, the high number of box cores used in this study considerably extends the spatial coverage of sedimentary records available across the marine CAA, allowing us to compare pre-
and post-1900 sedimentary conditions and provide clues with those of the LIA period. In terms of sedimentary dynamics, this study points out the variability of sedimentary processes in each part of the CAA taking place during the pre- and post-industrial periods. Post-1900 sedimentary processes are mainly influenced by the Mackenzie River discharge and its far-reaching plume in the Mackenzie Shelf/Slope and the Amundsen Gulf, small CAA rivers draining the Canadian Shield, coastal erosion and sediment-laden sea-ice in the Banks Island area, the M’Clure Strait and the East Province, whereas pre-1900 sedimentary processes suggest an intensification of the continental runoff in the West (Mackenzie River) and IZ (e.g., Coppermine and Ellice Rivers) and more intense sea-ice conditions along with sediment-laden sea ice and coastal erosion in the IZ and eastern CAA.

5 Conclusions

The regional heterogeneity in sedimentary processes that operate within CAA during the pre- and post-industrial periods was investigated through magnetic, geochemical and sedimentological analyses of 40 surface and basal sediments throughout the CAA. The following conclusions are detailed below:

1. The multiproxy analysis allows the identification of three sedimentary provinces: (1) the West province (the Mackenzie Shelf/Slope, west of Banks Island and M’Clure Strait) is typified by detrital associations (Fe-Rb-Ti-Zn), important terrestrial OM inputs and high aluminosilicate inputs; (2) the Intermediate Zone (the Amundsen, Coronation and Queen Maud Gulf’s) is distinguished by Si-Al-Zr-Sr-K associations, Fe-Mn oxyhydroxide precipitation (particularly in the recent period), high magnetic susceptibilities and a mixture between marine and terrestrial OM contents; and (3) the Eastern province (the Queen Maud Gulf, Victoria and Barrow Straits and Lancaster/Eclipse Sounds) is characterized by high detrital carbonate inputs, marine OM contents, and low magnetic grain concentrations.

2. Pre- and post-industrial sedimentary processes are mainly influenced by the Mackenzie River discharge and its far-reaching plume in the Mackenzie Shelf/Slope and the Amundsen Gulf areas and by small CAA rivers draining the Canadian Shield in the Coronation and Queen Maud Gulf’s, whereas the Banks Island area, the M’Clure Strait and the Barrow Strait/Lancaster Sound are mostly characterized by coastal erosion and sediment-laden sea ice. In Eclipse Sound, sedimentation is mainly driven by Bylot Island glacier dynamics.

3. Seven $^{210}$Pb-dated box cores from of three determined provinces suggest an intensification of the continental runoff in the West (Mackenzie River) and IZ (Coppermine and Ellice Rivers) and more intense sea-ice conditions along with sediment-laden sea ice and coastal erosion in the IZ and the eastern CAA during the LIA period.

4. Our geochemical proxy Log(Al/Ca) ratio derive from pXRF can be successfully used to track changes in the sedimentary sources within the CAA, where Al is associated with
aluminosilicate minerals discharged by rivers and Ca is linked to detrital carbonates, coastal erosion and sediment-laden sea ice.

Finally, this study provides a basis for using the sedimentological, geochemical and magnetic signatures of longer sediment records from the CAA to reconstruct variations in sediment dynamics related to late Quaternary climatic and oceanographic changes.

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Supporting Information for

Sedimentary processes within the Canadian Arctic Archipelago: relationships among sedimentological, geochemical and magnetic sediment properties

Sarah Letaïef¹,²,⁴*, Jean-Carlos Montero-Serrano³,⁴ and Guillaume St-Onge¹,⁴

¹Canada Research Chair in Marine Geology, Institut des sciences de la mer de Rimouski, Université du Québec à Rimouski, Québec, Canada.
²Géosciences Montpellier, University of Montpellier, CNRS, 34090 Montpellier, France.
³Institut des sciences de la mer de Rimouski, Université du Québec à Rimouski, Québec, Canada.
⁴GEOTOP Research Center, Montréal, Québec, Canada

*Corresponding author: Sarah Letaïef (Letaief-sarah@laposte.net)

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Introduction
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Figure S2. Correlation of cores located in the M’Clure Strait-West of Banks Island areas with the dated core 535-BC (in red color) by using the variations of magnetic susceptibility along the core.
Figure S3. Correlation of cores located in the Queen Maud Gulf and the Coronation Gulf areas with the dated cores QMG4-BC, 316-BC and 05-BC (in red color) by using the variations of magnetic susceptibility along the core.
**Figure S4.** Correlation of cores located in the Victoria, Barrow Strait and the Lancaster Sound areas with the dated cores 165-BC and 304-BC (in red color) by using the variations of magnetic susceptibility along the core.
Figure S5. Summary of sedimentation rates (cm/ka) within the Canadian Arctic Archipelago (CAA). The red squares on stations represent those calculated in this study while the remaining samples stations are derived from other studies in the CAA (Richerol et al., 2008; Ledu et al., 2008; 2010a; 2010b; Scott et al., 2009; Vare et al., 2009; Barletta et al., 2010; Belt et al., 2010; Pienkowski et al., 2011, 2017; Durantou et al., 2012; Kuzyck et al., 2013; Bringué & Rochon, 2012; Deschamps et al., 2018b; Wu et al., 2020).

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