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1 **The variability of Baffin Bay seafloor sediment mineralogy: the identification of**
2 **discrete glacial sediment sources and application to Late Quaternary**
3 **downcore analysis**

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Abstract

Quantitative X-ray diffraction (qXRD) mineralogy of bedrock, ice-rafted and fluvial clasts, 239 seafloor samples (< 2 mm), and samples from two long piston cores are used to define: 1) regional patterns and sources within Baffin Bay, 2) evaluate two areas from W Greenland and E Baffin Is. in more detail, and 3) apply these findings to the interpretation of downcore variations in sediment sources. A sediment-unmixing program (SedUnMix) is used to define surface regional mineral assemblages and to examine changes in sediment sources in cores HU2013029-77PC (southern Baffin Island slope) and HU2008029-8PC (Davis Strait) during Marine Isotope Stages (MIS) 1 through 3. Distinct regional patterns are observed in the association between the mineralogy of surface sediments and carbonate and basalt bedrock outcrops. Detailed analysis of seafloor samples from the west Greenland troughs and Baffin Island fiords show regional differences in mineralogy, with sediments derived from the Foxe Fold Belt (N central Baffin Island) being mineralogically distinct from sediments to the north and south. Grain-size spectra from the west Greenland troughs suggested an association between grain-size spectra and mineral assemblages. Sediment unmixing of qXRD data from the two piston cores shows discrete intervals where one or more mineral sources were dominant. However, chronological control is such that it is unclear whether the various ice streams draining into Baffin Bay behaved synchronously.

Key words: Baffin Bay; seafloor mineralogy; regional variations; Late Quaternary events; Detrital carbonate sources

Introduction

The Quaternary sequences in Baffin Bay (Aksu, 1981; Hiscott et al., 1989; Srivastava et al., 1987) represent a mosaic of sediments delivered by the numerous ice streams that drained into the bay from the Greenland (GIS), Innuitian (IIS), and Laurentide ice sheets (LIS) (Dyke et al., 2002; Margold et al., 2015; Marshall et al., 2000; Stokes et al., 2016). During the last glaciation the deep troughs and channels that head into Baffin Bay (Fig. 1A) were the loci of fast-flowing tidewater glacial outlets. The distinct detrital carbonate (DC) signature originating from glacial erosion of Paleozoic dolomite-rich bedrock on the islands and channels north of Baffin Bay (Fig. 2B) has been recognized for some time in the Baffin Bay Quaternary stratigraphy, (Aksu, 1981; Aksu and Mudie, 1984; Andrews et al., 1998, 2014; Jennings et al., 2017b; Li et al., 2011; Marlowe, 1966; Parnell et al., 2007; Piper, 1973; Simon et al., 2014), and have been termed “Baffin Bay detrital carbonate events” (BBDC events) (Andrews et al., 1998). More recently, sediment mineralogy has been used to differentiate sediments delivered from the Uummannaq and Disko ice streams (Fig. 1B) (Andrews et al., 2014; Simon et al., 2014) and the extent of glacial erosion and transport from the west Greenland (WG) basalt outcrop was also evaluated (Andrews et al., 2015),

In the present paper we expand the earlier coverage (Andrews and Eberl, 2011) of surface samples from Baffin Bay from 82 to 239 (Fig. 1A). The goals of this paper are to: 1) examine whether it might be possible to distinguish discrete glacial source based on sediment mineralogy; 2) report on surface samples collected during cruise HU70037 to the WG shelf, and the 1982 and 1983 Sedimentology of Arctic Fjords Experiment (SAFE) cruises to several Baffin Island fjords (Syvitski and Blakeney, 1983; Syvitski,

1984); and 3) apply the information gained from steps 1 and 2 to document changes in glacial sediment sources in piston cores (Fig. 1B). Mineral data from the surface samples and the cores presented here are available in (http://ed.gdr.nrcan.gc.ca/index_e.php). The mineral wt% data for the surface samples, the estimated percentages of the bedrock sources, and other data will be deposited in the Pangaea data base (www.pangea.de).

Bedrock Geology: Greenland and Baffin Island were once were contiguous but were rifted apart by sea-floor spreading during the Cretaceous (Kerr, 1967). The bedrock of the Baffin Bay margins and hinterlands varies in age from Archean to early Tertiary (Henriksen, 2008; Jackson and Berman, 2000; St-Onge et al., 2009) (Fig. 2A), with the last major event being the emplacement of flood basalts on the rift margins of west Greenland and east Baffin Island (Clarke, 1966; Clarke and Upton, 1971; Larsen and Pedersen, 2009). Extending SW-NE across Baffin Island and onto west Greenland is an extensive outcrop of siliclastic and carbonate rocks that constitute the Foxe and Rinkian Fold Belts (Grocott and McCaffrey, 2017; Jackson and Berman, 2000). Extensive Paleozoic carbonates outcrop on land and on the floors of the main channels leading to northern Baffin Bay (Douglas, 1970; Parnell et al., 2007) and overlie Archean and Paleoproterozoic bedrock (Fig. 2B).

In the last three decades onshore geological mapping has been complemented by offshore geophysical surveys including bedrock coring (Balkwill et al., 1990; Bennett et al., 2014; MacLean, 1985; MacLean et al., 2011, 2014; Pedersen et al., 1997; Pedersen and Pulvertaft, 1992; Skaarup et al., 2006). Radiogenic isotopes have been used in some studies of Quaternary sediments in Baffin Bay to highlight provenance (Andrews et al., 2015; Farmer et al., 2003; Nuttin and Hillaire-Marcel, 2015; White et al., 2016),

however, the basic geologic units continue on either side of Baffin Bay (Jackson and Berman, 2000), hence the interpretation of radiogenic ages can be ambiguous in terms of a Baffin versus a Greenland source.

Oceanography and sea ice conditions: Ocean circulation in Baffin Bay is cyclonic (Fig. 1B), involving the northward flowing West Greenland Current (WGC) with a strong Atlantic Water component, and the south flowing Baffin Current (BC) comprised of Arctic Surface Water (ASW) that enters Baffin Bay through the channels in the Canadian Arctic Archipelago (CAA) (Münchow et al., 2015; 2006; Tang et al., 2004) (Fig. 1B). The present day depths of the channels govern the composition of inflowing ASW. The Arctic outflow joins the Baffin Current and forms the upper 100 to 300 m of surface water in Baffin Bay, except where the WGC dominates in the SE part of the bay (Tang et al., 2004). Sea ice covers nearly all of Baffin Bay in winter (Figs. 1B, 3A), except in the SE, due to the warmth and salinity of the WGC. Sea ice begins to form in September, reaches maximum coverage in March and is thickest and most persistent along the Baffin Island coast where the ASW flow is concentrated (Tang et al., 2004).

Sediment processes: glaciological and oceanographic constraints: There is an obvious and fundamental difference in modern-day sediment supply and mode of transportation and deposition on either side of Baffin Bay (Fig. 3A) (Andrews, 1990). West Greenland is dominated by the Greenland Ice Sheet, which contributes sediment to the west Greenland shelf via iceberg rafting and sediment-laden meltwater plumes (Chauche et al., 2014; Hudson et al., 2014). Seafloor sediment can also be reworked and transported by iceberg scouring, sediment gravity flows and bottom currents. Seasonal sea ice is restricted on the WG shelf due to the West Greenland Current (Figs. 1B and

3A) and this allows icebergs to drift northward along the shelf, and eventually drift south once they reach the northern end of Baffin Bay and are influenced by the Baffin Current (Fig. 1B). Individual iceberg exports onto the WG shelf and the Baffin shelf (Fig. 3A) can total between 1-17 km³/yr (Chauche et al., 2014) and the total output into Baffin Bay may be ~100 km³/yr (Bigg, 1999), including large inputs from NW Greenland ice streams (Kravitz, 1982; Kravitz and Sorensen, 1970).

On the Baffin Island side the modern sediment transport is dominated by fluvial and meltwater transport in the fjords (Gilbert, 1983; Syvitski, 1993; Syvitski et al., 1988; Syvitski and Hein, 1991) (Fig. 3A), but on the Baffin Island shelf both IRD and suspended sediment transport in meltwater plumes are involved (Andrews and Syvitski, 1994) (Fig. 3A). However, a variety of other processes occur locally (Gilbert, 1982, 1990).

Under present day conditions (Fig. 3A) we define areas (Fig. 1A) in terms of probable sediment processes and environments: 1) West Greenland shelf: 1 to 8 months of sea ice cover, extensive iceberg numbers, northward flowing surface water, limited suspended sediment plumes from tidewater glaciers; 2) West Greenland slope: limited iceberg numbers; 3) Baffin Island fjords: extensive sea ice cover (7-10 months), very few icebergs, sediment plumes from rivers; 4) Baffin Island shelf: heavy and persistent sea ice, large number of icebergs from W and NW Greenland; 5) N Baffin Bay: extensive and pervasive sea ice, numerous icebergs, and 6) Baffin Bay basin: sea ice coverage for 7-10 months, some icebergs. During the Last Glacial Maximum (LGM) both the Greenland and Laurentide Ice Sheets extended onto the shelf, and probably to the shelf break (Jennings et al., 2017a)(Fig. 3A, lower panel).

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142 **Methods**

143 Glacial marine sediments potentially consist of mixtures of different source bedrocks;
144 this is especially true if icebergs are free to drift from the tidewater glacier fronts and are
145 not restricted by landfast sea ice/ice shelf (Reeh et al., 1999; Reeh et al., 2001). Indeed,
146 the lack of diversity in mineral composition is one criterion for the presence of an ice
147 shelf (Anderson et al., 1980). A variety of methods have been used to detect changes in
148 sediment provenance (e.g. Farmer et al., 2003; Licht and Hemming, 2017; Weltje and
149 von Eynatten, 2004; White et al., 2016). Clay and sand mineralogy of Baffin Bay
150 Quaternary sediments has been employed by several researchers to develop models of
151 sediment provenance associated with the glacial history (Aksu, 1981; Andrews et al.,
152 1989; Hiscott et al., 1989; Piper and Slatt, 1977), although the main and visually obvious
153 markers were the recurrent intervals of detrital carbonate (Aksu, 1981, 1985; Aksu and
154 Piper, 1987; Andrews et al., 1998; Li et al., 2011; Marlowe, 1966; Piper, 1973; Simon et
155 al., 2012). Figure 3B schematically illustrates our approach, showing the linkages
156 between original bedrock source regions, the identification of mineral assemblages by
157 qXRD, and then estimates of the percentages of sources based on the program
158 “SedUnMix” (Andrews and Eberl, 2012). In the last stage note that there is an unknown
159 or unresolved component that might indicate the presence of another source, or it could
160 also be “noise”. Seventy-two bedrock, stream, and large IRD clasts, representing
161 bedrock from the region were pulverized and processed for their mineral compositions.
162 These samples were obtained on an *ad hoc* basis and do not fully represent all regional
163 bedrock compositions (Fig. 2). Note that the “bedrock” data base does not contain any

samples from Baffin Island other than the Ordovician shales, although we can assume some similarities on either side of Baffin Bay based on bedrock mapping (Fig. 2). Nevertheless, the bedrock source samples include carbonate, igneous and metamorphic clasts (the suite of samples from SW Greenland (Colville et al., 2011) representing the early Proterozoic Ketilidian Mobile Belt, the stable Archean Block, and the Nagssugtoqidian Mobile Belt. Sediments from these southerly sources could enter Baffin Bay via iceberg drift or sediment plumes in the northerly trending WGC. Other bedrock sources include Greenland basalts, west Greenland Cretaceous sandstones, Cretaceous mudstone, and highly weathered Achaean bedrock from west Greenland (Bonow, 2005). Source areas for Cretaceous shales are located off Disko Island, and Home Bay, Baffin Island, where a Cretaceous outcrop was detected on the seabed during seismic surveys (MacLean et al., 2011). Samples of Ordovician shale from the Paleozoic outcrop on Baffin Island are also included (Zhang, 2008, 2012; Zhang and Pell, 2014). Although far from a complete sampling of the bedrock surrounding Baffin Bay, the glacial marine sediments in this study are probably mixtures of these bedrock sources.

The Baffin Bay surface samples were processed for quantitative X-ray diffraction analysis on the < 2 mm sediment fraction. The method was developed by the USGS (Eberl, 2003) and used on the initial analysis of surface sediments from Baffin Bay (Andrews and Eberl, 2011). The Excel macro-program Rockjock v6 was used to determine the weight% of 33 non-clay and clay minerals, which were then normalized to sum to 100%. In the initial analysis a suite of 9 feldspars, and several carbonate and illite minerals are identified (Eberl, 2003) but these can be grouped for example into alkali-feldspars, plagioclase, and dolomite (Table 1) to reduce the species list (Andrews and

Vogt, 2014a, b). This qXRD method placed 3rd in the international Reynolds Cup (McCarty, 2002) and we routinely test our results against artificial known mineral mixtures. For example, ten runs during the 2017 summer indicated that the average bias on a mixture of 11 common minerals (bias = abs [Measured wt% - Estimated qXRD wt%]) was 0.9%.

To further an understanding of sediment composition we use the program SedUnMixMC (Andrews and Eberl, 2012; Eberl, 2004) to ascertain the agreement (or not) between our bedrock samples and the seafloor surface samples from Baffin Bay. The program uses a Monte Carlo approach to randomly sample (n = 100) the available source samples and calculate a standard deviation on the estimates.

Grain-size analysis of the surface samples is a strong indicator of sediment transport. We use the Malvern Model 2000 laser diffraction analyzer to determine the grain-size spectra of the < 2 mm fraction and the program “Gradistat” (Blott and Pye, 2001) to determine the grain-size statistics and sediment classification.

Mass magnetic susceptibility (mass MS) of many samples was measured using a Bartington Meter and a 10 cc cup (Walden et al., 1999). The meter was repeatedly calibrated against a laboratory standard. Mass MS is a complex measure of sediment attributes that includes mineralogy and grain-size (Stoner and Andrews, 1999; Thompson and Oldfield, 1986). It is especially affected by the competing influences of diamagnetic versus ferromagnetic minerals. These data are not discussed but will be included in the Pangaea data.

The determination of geochemical assemblages consists of two broad alternative methodologies that entail Factor Analysis (Pisias et al., 2013; Reimann et al., 2002) or

cluster analysis (Minansy, 2010; Reimann et al., 2002). Ding and He (2004) have shown a relationship between k-mean clustering and Principal Component Analysis (PCA). Analysis is complicated by the impact of the “closed array” problem, that is, both the qXRD and grain-size data sum to 100% (Aitchison, 1986; Reyment and Savazzi, 1999). We use k-means cluster analysis (Kanungo et al., 2002) to identify samples that possess similar mineral compositions and to provide a simplification of changes in sediment provenance; the algorithm used is that of Hartigan and Wong (1979), using euclidean distance as a measure of similarity between samples. We standardized the variables (i.e. mean = 0 ± 1) so that each mineral has equal weight. The goal is to iteratively seek the optimal partitioning of a matrix with m variables by n objects into k -clusters so that each sample is assigned to the cluster with the nearest mean, thus allowing a reduction in the number of variables that need to be evaluated (m variables reduced to k -clusters). The number of clusters, k , is chosen *a priori*, but the efficiency of the choice can be tested by analysis-of-variance (Anova) (Aabel, 2015), or by examination of indexes that have been developed to evaluate the most efficient number of clusters (Charrad et al., 2014). We stress that there is no accepted “best” approach to determining the number of clusters. There is no intrinsic importance in the naming or ordering of clusters. We use the non-parametric Contingency Analysis (Dixon and Massey, 1957; Miller and Kahn, 1962) to examine associations between categorical data---such as whether there is a statistically significant association between broad geographic regions (e.g. west Greenland shelf, Baffin Shelf) and the results of the k-mean clustering. Aabel (2015) (see later) also includes an assessment of the importance of each variable on the resulting k -clusters. We use single variable Analysis of Variance (Dixon and Massey, 1957) to test for the

significance between clusters and individual mineral wt%, and employed the Scheffe test (Aabel, 2016) to evaluate the probability of a significant difference ($p > 0.05$). The Scheffe test is a *post-hoc* test for differences in means of unequal numbers of samples employed over multiple comparisons; it assumes that the variances are similar.

Results

We first outline the mineral composition of six bedrock sample groups and then discuss the variations in the surface sediment compositions.

Bedrock/clast samples: The Bedrock/IRD clast samples can be grouped into 6 bedrock types based on their lithology and mineralogy (Table 1, Fig. 4). The significance of the differences in their mineralogy was tested by Stepwise Discriminant Function Analysis (SDFA) (Davis, 1986), which resulted in a 100% correct classification with plagioclase, dolomite, muscovite, and kaolinite being the 1st four selected minerals. SDFA testing of the combined bedrock and surface samples indicated, not unsurprisingly, that ~87% of the Baffin Bay surface samples were grouped with the Precambrian bedrock samples (Figs. 2 and 4).

Surface samples: Mineral Comparisons: There is a matrix of 237 (including some replicate) samples and 14 minerals; these are designated as being from select areas (Fig. 1A; Table 3). Our interest is not in the mineralogy of an individual sample but rather ascertaining whether there are discrete geographic clusters of samples. A k-means solution of 6 clusters with between 12 and 63 sites per cluster was selected (Figure 5--- the data are plotted without the ocean/land information for clarity). For identification

purposes we will identify them as Baffin Bay Mineral Clusters BBMC#1, BBMC#2 etc. The Contingency test of the association between the Baffin Bay Mineral Clusters and their geographic location (West Greenland shelf etc.) resulted in a strong rejection of the null hypothesis (i.e. no association) with a Chi-square value of 318 ($p < .0001$)(Fig. 5). Figure 5 indicates that the Baffin fiords are primarily associated with BBMC#6, whereas on the West Greenland margin the dominant associations are with #1,2, and 4. The Nares Strait (carbonate-rich) BBMC#3 can be tracked southward into northern Baffin Bay and into Baffin Bay. BBMC #5 appears to be primarily located on the Baffin shelf and central Baffin Bay. Note that there is only one BBMC #6 site on the West Greenland margin, despite what might be expected from the bedrock geology (Fig. 2). The values of the minerals associated with each BBMC (Table 2) clearly demonstrate that BBMC#1 is linked to mafic-rich sediment input (Andrews et al., 2015) with values of 8.5% for pyroxene and 4.19 for iron oxides, and the other BBMCs' have one or more minerals with characteristically high wt%s and the analysis-of-variance (Anova) (Table 2) indicates important differences between the BBMC#s and the minerals (note the comments at the bottom of the table).

Single variable Anova (Dixon and Massey, 1957) and the Scheffe *post-hoc* test (Table 3) indicates that with 6 clusters the most extreme differences (as calculated by: % significant differences/total comparisons) was ~66%. The minerals that were the most useful in discriminating between regions were plagioclase, dolomite, smectite and illite. This admittedly crude index of the regional differences (Table 3) indicates that the most extreme differences between our regions are: Baffin fiords

278 versus Nares Strait and West Greenland Slope, the Baffin fiords versus West
279 Greenland shelf, and Nares Strait versus West Greenland shelf.

280 **Baffin Bay Sediment Mixtures:** It is important to note that in our “source”
281 groups (Fig. 4) both the carbonate and the kaolinite sources include transported
282 Precambrian Shield bedrock minerals. To gain an understanding of the robustness of the
283 unmixing method (i.e. Andrews and Eberl, 2012) we ran the 72 “bedrock” sources
284 against themselves (Table 1). As expected this gave excellent results for the basalt,
285 carbonate, and kaolinite-rich sources but the distinction between SW and W Greenland
286 sources was less absolute; indeed some of the large clasts that were used from JR175-
287 VC23 on the West Greenland Shelf may have originated as IRD from icebergs calved
288 south of 66°N which drifted north in the WGC. Kaolinite-rich sediments are an indicator
289 for Cretaceous sediments derived from erosion of weathered Precambrian outcrop;
290 however, moderate amount of kaolinite and smectite were also measured in Ordovician
291 shales on Baffin Island. The average total fraction of sediment assigned to the bedrock
292 sources was 0.83 ± 0.17 indicating that average unidentified fraction was ~ 0.17 with a
293 range between 0.52 and 0. This discrepancy could be due to the introduction of another
294 bedrock source, or changes in apparent source mineralogy caused by sediment transport
295 (Syvitski and Macdonald, 1982).

296 Ocean Data View (ODV) (Schlitzer, 2011) was used to plot the estimates of
297 bedrock sources. The spatial distribution of the unresolved fraction (Fig. 6B) is
298 concentrated in Smith Sound northward into Nares Strait and on the Baffin Island shelf
299 and adjacent deep sea at $\sim 70^\circ\text{N}$. The plot of the basalt sources (Fig. 6A) shows a strong
300 concentration that highlights the West Greenland early Tertiary basalt outcrops around

Disko Island (Fig. 1B, DI), although the signature does not extend very far from the outcrop (Andrews et al., 2015). This is obviously associated with BBMC#1 (Fig. 5) and the associated high values of pyroxene and iron-bearing minerals (Table 2). Carbonate-rich sediments extend from source areas in NW Greenland (Jennings et al., 2011a; Jennings et al., 2011b; Kravitz, 1982) and the Canadian Arctic islands and channels (Parnell et al., 2007), as an intermittent plume along the Baffin Island shelf and in Baffin Bay, but with virtually no record on the West Greenland shelf (Fig. 6C).

It was initially uncertain whether there was any clear distinction between the mineral composition of the IRD clasts from West Greenland and the sediments collected from SW Greenland (Colville et al., 2011) (Fig. 6 D, E). The estimates of a West Greenland source shows one “hot spot” just south of 75°N on West Greenland and a N-S elongated signal along the outer NW/W Greenland shelf/slope (Fig. 6C). A SW Greenland source is marked by an area of high values in Melville Bugt (north of 75°N) and moderate values along the Baffin Fjords and inner Baffin Island shelf.

West Greenland Shelf ---HU70037 mineralogy and grain-size: The approach adopted covers a large area (Fig. 1), thus the regional results could hide important nuances in more focused sediment. The grab samples from HU70037 (n = 57) track along many of the major cross-shelf troughs on the West Greenland shelf (Fig. 7A)(Slabon and al., 2016) and thus enables a more focused enquiry than that carried out in the previous section.

Four grain-size modes (WGGSM) were identified by the k-mean clustering (Andrews et al., 2016; Lucchi and Rebesco, 2007; Perner et al., 2016). The grain-size clusters (Fig. 8A) are classified on their average grain-size as sandy muds to muddy

sands (Blott and Pye, 2001; Folk, 1964). By far the dominant WGGSM was #3 (n=33), coarse silt with little evidence for coarse IRD (Fig. 8A). WGGSM #4 only has 4 samples and #1 and #2 have mean grain-sizes that fall in the very coarse silt and very fine sand categories.

The *m* variable mineral assemblages were reduced to 4 mineral clusters based on k-mean clustering. A map of the 4-part qXRD West Greenland Mineral Clusters (WGMCs) (Fig. 7B) shows distinct patterns. WGMC #2 is restricted to the area of the early Tertiary basalt outcrop (GEUS 1:2,500,000 map series #6), and WGMC#1 is present along the outer shelf but also is seen as a series of sites leading from a “source” near Upernavik. Melville Bugt is dominated by a combination of WGMC #3 and #4 but these are also seen intermittently south of Disko Island (Fig. 7B). Boxplots of the mineralogy of the 4 clusters (Fig. 8B) indicate that WGMC #1 has high wt% of plagioclase and pyroxene, whereas WGMC #4 (Melville Bugt) is dominated by quartz, feldspars, and little to no weathering minerals. The Scheffe test for the significance of the difference between the 4 WGMCs indicated that WGMC #1 and #3 and WGMC #3 and #4 were the most different whereas WGMC #1 and #2, and #2 and #4 were the most similar (Table 4). WGMC #1, being distant from the ice sheet margin and aligned along the outer shelf, probably represents a mixture of sediment sources associated with iceberg rafting, iceberg scouring of the seafloor, and the rainout of suspended sediment (Fig. 3B).

A key question is to what degree is mineralogy a function of grain-size (Weltje and Prins, 2003; Weltje and Prins, 2007)? Both the mineral and grain-size data were transformed to their logratio to mitigate the closed array problem (Aitchison, 1986). The question of the association between mineralogy and grain-size was tackled by using

Contingency Analysis to see whether the resulting nominal (cluster) data are associated or not (Table 4). This indicated a significant association between the clustering of grain-size and mineralogy with the dominant WGGSM #3 being associated with WGMCM #3 with relatively low wt% of quartz and high values of smectite (Fig. 8).

Baffin Fiord Mineralogy: S.A.F.E. cruises in 1982 and 1983 (Syvitski and Blakeney, 1983; Syvitski, 1984) conducted in-depth research on the sedimentary environments in a suite of Baffin Island fjords (Fig. 9A). Grain-size data for the 1982 grabs are available from a combination of settling tube and Sedigraph analyses (Clattenberg and al., 1983) but are not considered here. Fifty-eight grab samples were processed from three areas (Fig. 9): 1) cores on the northern flank of the Cumberland batholith (Fig. 2A), including one fjord within the early Tertiary outcrop; 2) cores from the area of Home Bay north to Clyde Fjord, which lie within Mesoproterozoic siliclastic and carbonate outcrop of the Foxe Fold Belt; and 3) the northern fjords of Cambridge and Clark within the Rae Craton consisting of variable granitoid rocks and gneisses (St-Onge et al., 2009) (Fig. 2A).

We hypothesize that the seafloor mineral data will be associated with the source bedrock; hence 3 clusters might be present. This hypothesis was tested with a Contingency Test, which resulted in a relatively weak rejection of the null hypothesis. However, a k-mean cluster analysis of the qXRD data suggested two basic clusters, one strongly linked to the fjords in the Foxe Fold Belt and the second cluster linked to the fjords both to the south and the north (Fig. 9B---table insert). The association between the two-cluster mineral assemblages and the broad geographic locations was significant ($p < 0.0001$) with the mid-Baffin Island sites nearly exclusively (29/30) in Cluster 2 (Fig.

9B). Figure 9C shows the distinct separation of the two clusters based on the wt% of the two feldspar groups, with Group 1 having on average greater wt% of the alkali feldspars.

Discussion and application of mineral assemblages to downcore source analysis

Detailed discussion of the late Quaternary history of the Baffin Bay is not an objective of this paper, rather the data are used to indicate how a knowledge of the bedrock and seafloor sediment mineralogy can be useful in understanding the Quaternary history of Baffin Bay and the phasing of the responses of the three surrounding ice sheets (Jennings et al., 2017b). Therefore, we apply our surface mineral data (Figs. 1A) to investigate downcore source variations in two marine sediment cores. HU2013029-77PC (Campbell, 2014; Klein, 2016; Klein et al., 2016) is from 1153 m water depth on the slope off Home Bay; and core HU2008029-8PC from 857 m water depth in Davis Strait (Andrews et al., 2014; Campbell and de Vernal, 2009) (Fig. 1A). Both cores recovered sediments that included the Last Glacial Maximum (LGM) (Dyke et al., 2002; Jennings et al., 2017a, 2017b) and extended into Marine Isotope Stage 3 (Simon et al., 2014). During this time the ice sheets extended onto their respective shelves (Fig. 3A, lower panel)

Generally, glacial marine sediments consist of a mixture of bedrock sources (Jaeger and Koppes, 2016) (Fig. 3B) and the question is whether there are systematic changes that can be recognized, or is there only one sediment source involved? The program “SedUnMix” (Andrews and Eberl, 2012) (Fig. 3B) is used with six sources (Table 5), including samples from the Foxe Fold Belt fiords and other Baffin Island fiords, as well as carbonate-, kaolinite-, and shale-rich samples (Fig. 4). To investigate the sensitivity of our “source” samples these were processed through SedUnMix to

evaluate whether the sources were indeed distinct from each other (Andrews et al., 2014). The samples assigned to the Foxe Fold Belt had an average correct assignment of $77 \pm 15\%$ with consistent inputs (average 10%) from the broader Baffin Island granitoid compositions (Suppl. Fig.a). Thus the “sources” have some limited internal variability that will affect the unmixing and source recognition, and this uncertainty will be reflected in the error calculation (Andrews and Eberl, 2012).

Core HU2013029-77: The inner slopes of Home Bay are littered with large carbonate clasts (Andrews et al., 1970); this was later shown to be the result of an ice stream that carried carbonate-rich (largely dolomitic) sediment ENE from Foxe Basin (Dredge, 2004; Tippet, 1985)(Fig. 1B). The Home Bay Ice Stream is a major ice stream draining the Foxe Basin Dome of the LIS (Margold et al., 2015; Margold et al., 2014; Stokes et al., 2016). Paleozoic and Cretaceous sediments outcrop upstream from the HU2013029-77 site (MacLean et al., 2011, 2014). Estimates of the annual export from this ice stream were $\sim 18 \text{ km}^3/\text{yr}$ (Stokes et al., 2016), thus similar to the East Greenland Kangerlussuaq Glacier (Andrews et al., 1994).

The downcore plots of grain-size and estimated source fractions (Klein, 2016; Klein et al., 2016) indicate that this site received sediment from three major sources, with major pulses in delivery (Fig. 10A). The sum of all sources is close to 100% indicating that there are few intervals with large unresolved sources, and the Degree of Fit (DOF) (Andrews and Eberl, 2012) demonstrates relatively small residuals between the observed and calculated mineral %. However, note that the closed array constraint must be factored in to any interpretation of the results, so a positive correlation between sources is of more interest than a negative correlation (Chayes, 1971). Thus, the correlation ($r =$

0.62) between the Foxe Fold Belt and Ordovician shale source inputs (Fig. 10A) is worth noting and may indicate erosion of Paleozoic shale units on the floor of Home Bay (MacLean et al., 2014). As noted earlier SedUnMixMC generates an estimate of the standard deviations on each sample, and Supplemental Figure 2 illustrates this for the HU2013029-77 data.

Figure 10A and Suppl. Figure 2 imply a degree of mixing between sources, and we seek to identify major units by standardizing the six source % data and deriving k-mean groups. Four combined source groups were identified that were different at the $p \leq 0.0001$ probability (Aabel, 2016))(Fig. 10B). This allows us to define specific downcore intervals (A to G Fig. 10A) and their major source and mineral constituents (Fig. 10B and C). Unit A has a calibrated basal date of $\sim 41.46 \pm 1.6$ ka BP (Campbell et al., 2017) indicating that this core includes the regional LGM (Jennings et al., 2017a). The core primarily records sediment inputs from N & S Baffin Island fiords (e.g. Fig. 9) with high wt% of alkali feldspars (Figs. 10B & C). Units B and F reflect intervals of enhanced carbonate input whereas Unit D is dominated by sediments derived from the Foxe Fold Belt with high wt% of plagioclase, and there are pulses of Foxe Fold Belt sources in unit A (Fig. 10A & C). These data indicate that the supply of sediment to HU2013-77 did not consist of input from a single source, but reflect significant re-organizations in sediment sources. In a similar manner the grain-size data indicate that the influx of coarse iceberg-rafted debris (IRD) was spasmodic (Fig. 10A) although a dominant signal between ~ 14 and 12 cal ka BP occurs when deglaciation of northern Baffin Bay was underway (Jackson et al., 2017; Jennings et al., 2017b; Li et al., 2011; O'Cofaigh et al., 2013).

Do sediment mineralogy and sources correlate with lithofacies and other measured parameters, such as XRF scans (Ca/Ti), spectrophotometer colour, or magnetic susceptibility (Campbell et al., 2017)? Figure 11 shows striking associations between these proxies and the derived source units. For example, the strongest peaks associated with Foxe Fold Belt mineralogy (578-548 cm, 450-425 and 319-274 cm) correspond to a distinct olive and grey mud suggesting that this lithofacies is locally sourced from Foxe Basin via Home Bay. There is also a lesser but distinct correlation between this same lithofacies and “shale”, which could be sourced in Home Bay (MacLean, 2014), or derived from the Paleozoic outcrop, further suggesting a Home Bay source for the grey and olive muds. The strongest carbonate peak at 150 cm corresponds to BBDC #1 of Andrews et al. (1998), whereas lesser-defined carbonate peaks at ~200, 260, 390 and 500 cm all correspond to distinctive gold brown mud events in core.

HU2008029-8: This core is located on the Davis Strait sill at a present depth of 863 m (Fig. 1). The core description (Campbell and de Vernal, 2009) indicates that the sediments are primarily dark olive gray to grayish red silty clays with variable coarse IRD including large pebbles. There are numerous sand and mud clasts, and occasional shell fragments were noted. An earlier discussion of the mineral assemblages and age constraints are discussed in Andrews et al. (2014). The chronology of this core is not simple, and Andrews et al. (2014) suggested that the basal unit with high calcite wt% probably originated from Hudson Strait during Heinrich (H-) event 4 (ca 38 cal ka BP) (Hesse, 2016; Hesse and Khodabakhsh, 2016), whereas the upper DC event represents the widespread Baffin Bay Detrital Carbonate unit 1 (BBDC 1) (Jennings et al., 2017b; Simon et al., 2014), which is also present in HU2013029-77 (Fig. 10A) as unit F. The

peaks in calcite wt% may indicate recirculation of calcite-rich sediment plumes associated with the Hudson Strait ice stream and which may correlate with H-1 and H-2. However, the purpose of this paper is to illustrate the downcore variations in sediment sources without a detailed discussion of the chronology.

We use the same set of sediment sources as noted for HU2013029-077, but with the addition of calcite-rich sediments from Hudson Strait (Table 5) to “carbonate sources” (Andrews et al., 2012). The results (Fig. 12A) suggest that there were significant changes in sediment provenance over roughly ~40 cal ka BP. To simplify the changes in sources we again standardized the % source and used k-mean cluster to group the data into units with similar compositions. Grouping into 4 clusters resulted in good discrimination between each cluster. When plotted (Fig. 12A) this exercise showed systematic changes in the dominance of a particular source group, which results in the recognition of 5 major intervals---although unit A could be divided into 2 sub-units dominated by sources 2 or 3 (Fig. 12A). Boxplots of the association between minerals, sources, and the 4 k-mean sources (Fig. 12B & C) clarifies the nature of some of the critical changes. Units A and D represent DC events with high dolomite wt% whereas Unit B represents a continuous supply of sediment from either W Greenland or the N & S Baffin Is. sources. The Foxe Fold Belt mineralogy is most evident in Cluster 4, which occurs primarily in Unit C.

Summary: Core HU2008029-8 is located at the exit from Baffin Bay to the Labrador Sea and would have potentially received sediments from a broader range of sources (Fig. 1) than HU2013029-77, which lay at the terminus of the HBIS. Although deposition of the DC units appears synchronous within Baffin Bay (Andrews et al., 2014;

Jennings et al., 2017a; Simon et al., 2014) our chronological controls are such that we cannot confirm or deny whether there was synchronous or asynchronous behavior of the ice streams heading into Baffin Bay (e.g. Dowdeswell et al., 1999; Stokes et al., 2014). It is difficult to determine, for example, if the pulses of sediment in the two cores (Figs. 10 and 12) associated with the Foxe Fold Belt were synchronous or not. There are 3 distinct peaks of this source in HU2013029-77 that occurred > 14.2 and < 42 cal ka BP (labeled *FFB 1* etc.), and it is tempting to correlate these with peaks farther south on Davis Strait (labeled *FFB 1?* etc.). These might reflect activities associated with the HBIS (Fig. 1). Other sources are marked by discrete peaks, implying that the various ice streams and outlet glaciers surrounding Baffin Bay contributed sediments into the Bay. It is still uncertain whether sediments from the ice sheets surrounding Baffin Bay were exported across Davis Strait into the Labrador Sea (Andrews et al., 2012, 2014) and multi-proxy provenance studies (e.g. Licht and Hemming, 2017) will be required to answer such a question.

Conclusions

An understanding of the provenance of glacial marine sediment plumes is potentially more complex than their land-based counterparts (Hooke et al., 2013) because of the dilution and addition of far-travelled water-transported (i.e. icebergs, meltwater plumes) sediments. Studies suggest that the half-life transport distance of glacially eroded sediments on land is $\sim 10^1$ km (Clark, 1987), although individual erratics can be carried $\sim 10^3$ km (Prest, 1990; Prest and Nielsen, 1985). The approach adopted here (the present is the key to the past, Figs. 10 and 12) assumes that the signature of sediment delivery into Baffin Bay did not change as the large late Quaternary ice sheets expanded and

contracted (Dyke et al., 2002). Recent reviews of provenance methods (Weltje and von Eynatten, 2004; Licht and Hemming, 2017) did not mention XRD, but quantitative XRD analysis of surface (seafloor) sediments from Baffin Bay (Fig. 1) indicate that there are discrete regional variations that can be described by six mineral clusters (Fig. 5 and 6), and possibly with differences in the dominance of sediment transport modes (Fig. 3A) (Syvitski and Macdonald, 1982). In addition to the broad regional survey, two embedded data sets were evaluated in more detail in order to ascertain if there were discrete compositional clusters along the West Greenland shelf, and within the Baffin Island fjords. These studies also suggested that the mineralogy of the glacial marine surface sediments were not homogeneous but rather showed distinct regional affiliations. The qXRD data were then applied to describing the downcore variations in sediment sources in cores HU2013029-77 from the entrance to Home Bay and HU2008029-8 from Davis Strait.

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University, provided the grain-size data for the HU70-37 samples. Drs C. Stokes and M. Margold kindly provided the ice flux estimates for the Home Bay Ice Stream. Data used to produce Figures 10 and 12 will be archived in www.Pangea.de. We thank the Associated Editor and two reviewers for their comments and insights, which have led to an improved final paper.

Tables

Table 1: A) Table of minerals recognized by qXRD using Rockjock v6 (Eberl, 2003); B) Consolidated minerals; C) Average wt% of the six bedrock types (Fig. 4)

Table 2: A) Number of samples in the six BB clusters. B) Mineral departures at k-mean centers for the six BBCLs---the mean value of all minerals is set to 0 ± 1 . C) Mean wt% for the minerals in each cluster.

Table 3: A) Results of the Scheffe *post-hoc* test for the minerals versus of the six BBMC (Fig. 5). B) Results of the Scheffe *post-hoc* test for the minerals versus of the four WGMC (Fig. 7B)

Table 4: Contingency Table for comparison between the XRD and grain-size clusters for HU70-027 data

Table 5: Average mineral values for the six sediment sources used in SedUnMix for cores HU2013029-77 and HU2008029-8.

551 **Figure captions**

552 Figure 1: A) Location of the seafloor or core top samples used in this study. Latitude and
 553 longitude of the sites are listed in data deposited to the Pangaea data base. Abbreviations
 554 refer to regional groupings (see text) BF = Baffin fiords, BS = Baffin Shelf, BSc = Baffin
 555 Slope, BB = Baffin Bay, NBB = North Baffin Bay, NS = Nares Strait, WGS = West
 556 Greenland Shelf, Wags' = West Greenland Slope. B) Surface ocean circulation in Baffin
 557 Bay and the late spring extent of sea ice. Filled stars indicate major ice stream calving
 558 areas; the location of the Baffin Island Home Bay Ice Stream (HMIS) is shown, as is the
 559 location of cores HU2013029-077 and HU2008029-8. Abbreviations (from bottom left
 560 clockwise) are: CP = Cumberland Peninsula, HBIS = Home Bay Ice Stream, HB = Home
 561 Bay, BC = Baffin Current, WGC=West Greenland Current, LS = Lancaster Sound, DV =
 562 Devon Island, JS = Jones Sound, SS = Smith Sound, KB = Kane Basin, NS = Nares
 563 Strait, MB = Melville Bugt, UT = Uummannaq Trough, DI = Disko Island, DT = Disko
 564 Trough.

565 Figure 2: A) Bedrock geology of the Baffin Bay margins (Jackson and Berman, 2000)
 566 Reprinted with permission of the *Canadian Mineralogical Society*. B) Paleozoic outcrops
 567 of NE Canada and NW Greenland

568 Figure 3A: Schematic East-West cross -section across Baffin Bay at present (Upper
 569 Panel) and during the LGM (Lower panel) B) Schematic flow diagram of the approach
 570 adopted in this paper. The lower bars represent changes in the 3 sediment sources with
 571 time (T).

572 Figure 4: Pie diagrams of the average weight% (Table 1B) of the six different
 573 bedrock/clast samples derived from this study---Precambrian sites are from W/NW

Greenland. Key: amphib = amphibolite, pyrox = pyroxene, FeO = sum (magnetite + hematite + pyrite + magnetite), SiO = sum (amorphous silica and chert), bio & chlor = biotite and chlorite. .

Figure 5: Geographic distribution of the six k-mean clusters (BBMC#). The Contingency Table shows the highly significant association ($p < 0.001$) between the Baffin Bay Mineral Clusters (BBMC#) and the geographic areas (Fig. 1), indicating that there are indeed regional differences in mineral assemblages.

Figure 6: Maps of the seafloor sediments and their affiliation with the sources (Fig. 4): A) unresolved B) basalt; C) carbonate; D) Precambrian (W/NW Greenland fractions); E) SW Greenland (Precambrian).

Figure 7: A) Location of the seafloor samples collected on HU70037 and B) distribution of the 4-part k-mean cluster results. The color bar to the right shows the 4 WGMs that are plotted as infilled circles.

Figure 8: A) Grain-size cluster modes for the seafloor sample collected on cruise HU70037. B) Boxplot of the mineral composition of the 4-fold clusters determined for samples from HU70037. The inserted table shows the results of comparing the grain-size and mineral clusters.

Figure 9: A) Location of the seafloor samples used for this study collected in 1982 and 1983 as part of the SAFE Project (Syvitski and Schafer, 1985; Syvitski, 1984). ClF = Clyde Fiord; CaF = Cambridge Fiord; B) Location of Mineral Clusters 1 and 2; C) Plot of the weight% of alkali feldspars versus plagioclase feldspars for the two groups in Fig. 9B. Inserted Contingency Table shows the association between the two mineral clusters and geographic area.

Figure 10: A) HU2013029-77: Downcore plot of coarse > 2 mm IRD counts, % of coarse sand, bedrock source %, k-mean cluster group (see text), major sediment source input units (A-G), and lithofacies. BBDC1 = Baffin Bay Detrital Unit 1. *FFB 1* etc. refer to the distinct peaks in material from the Foxe Fold Belt. B) Boxplots of the bedrock source %s associated with the 4 clusters (note Fig. 10A, Source 1 = N & S Baffin fiords, 2 = Carbonate, etc.); C) Boxplots of the major mineral assemblage associated with the 4 cluster types.

Figure 11: Lithology of core HU2013-77 compared to the XRD-derived source clusters (Fig. 10A) showing the XRF Ca/Ti scans and departures from mean values for colour (L* whiteness, a* green to red, b* blue to yellow) attributes and magnetic mass susceptibility. The aqua shaded zones represent intervals with below average “redness” and above average magnetic susceptibility. The mauve interval has above average “whiteness” and is an IRD interval with an increase in carbonate (Fig. 10A).

Figure 12: A) Plot of the estimated percentages of 6 sources and selected mineralogy from sediments in HU2008029-0008PC in Davis Strait (Fig. 1A) showing the lithology (right-most column) and derived source units (see B & C this figure)(black filled objects represent IRD). BBDC1 = Baffin Bay Detrital Unit 1. H-1? possible Heinrich event. *FFB 1?* etc. refers to discrete peaks in material from the Foxe Fold Belt. B) Box plot of the association between sediment sources and the 4 derived sediment units (see text). C) Box plots of the association between mineralogy (wt%) and the 4 derived sediment units. Estimated chronology (see Andrews et al., 2014) is listed on the far right in cal ka BP.

620 cjes-2017-0223suppla: Fraction and standard deviation of each of the 6 sources
621 associated with themselves on analysis in SedUnMix.
622 cjes-2017-0223supplb: Downcore plot of sources for HU2013029-77 showing the
623 calculated standard deviations.
624
625

Draft

626 **References**

- 627 Aabel, 2016. Aabel NG software package, p. <http://www.gigawiz.com/>.
- 628 Aitchison, J., 1986. The statistical analysis of compositional data. Chapman and Hall,
629 London.
- 630 Aksu, A.E., 1981. Late Quaternary stratigraphy, paleoenvironmentology, and
631 sedimentation history of Baffin Bay and Davis Strait. Dalhousie University, Halifax, N.S.
- 632 Aksu, A.E., 1985. Climatic and oceanographic changes over the past 400,000 years:
633 Evidence from deep-sea cores on Baffin Bay and Davis Strait, in: Andrews, J.T. (Ed.),
634 Quaternary Environments: Eastern Canadian Arctic, Baffin Bay and Western Greenland.
635 Allen and Unwin, Boston, pp. 181-209.
- 636 Aksu, A.E., Mudie, P.J., 1984. Palaeoclimate of Baffin Bay from 300,000-year record of
637 foraminifera, dinoflagellates and pollen. *Nature* 312, 630-634.
- 638 Aksu, A.E., Piper, D.J.W., 1987. Late Quaternary sedimentation in Baffin Bay. *Canadian*
639 *Journal Earth Sciences* 24, 1833-1846.
- 640 Anderson, J.B., Kurtz, D.D., Domack, E.W., Balshaw, K.M., 1980. Glacial and Glacial
641 Marine Sediments of the Antarctic Continental Shelf. *Journal of Geology* 88, 399-414.
- 642 Andrews, J.T. 1990. Fiord to Deep-Sea sediment transfers along the Northeastern Canadian
643 Continental Margin: Models and Data. *Géographie Physique et Quaternaire* 44: 55-70.
- 644 Andrews, J.T., Barber, D.C., Jennings, A.E., Eberl, D.D., Maclean, B., Kirby, M.E.,
645 Stoner, J.S., 2012. Varying sediment sources (Hudson Strait, Cumberland Sound, Baffin
646 Bay) to the NW Labrador Sea slope between and during Heinrich events 0 to 4. *Journal*
647 *of Quaternary Science* 27, 475-484.
- 648 Andrews, J.T., Bjork, A.A., Eberl, D.D., Jennings, A.E., Verplanck, E.P., 2015.
649 Significant differences in late Quaternary bedrock erosion and transportation: East versus
650 West Greenland ~ 70°N and the evolution of glacial landscapes. *Journal of Quaternary*
651 *Science* 30, 452-463.
- 652 Andrews, J.T., Buckley, J.T., England, J.H., 1970. Late-glacial chronology and glacio-
653 isostatic recovery, Home Bay, East Baffin Island, Canada. *Geological Society of America*
654 *Bulletin* 81, 1123-1148.

- 655 Andrews, J.T., Eberl, D.D., 2011. Surface (sea floor) and near-surface (box core)
656 sediment mineralogy in Baffin Bay as a key to sediment provenance and ice sheet
657 variations. *Canadian Journal of Earth Science* 48, 1307-1328.
- 658 Andrews, J.T., Eberl, D.D., 2012. Determination of sediment provenance by unmixing
659 the mineralogy of source-area sediments: The "SedUnMix" program. *Marine Geology*
660 291, 24-33.
- 661 Andrews, J.T., Geirsdottir, A., Jennings, A.E., 1989. Spatial and temporal variations in
662 clay- and silt-size mineralogies of shelf and fiord cores, Baffin Island. *Continental Shelf*
663 *Research* 9, 445-463.
- 664 Andrews, J.T., Gibb, O.T., Jennings, A.E., Simon, Q., 2014. Variations in the provenance
665 of sediment from ice sheets surrounding Baffin Bay during MIS 2 and 3 and export to the
666 Labrador Shelf Sea: site HU2008029-0008 Davis Strait. *Journal of Quaternary Science*
667 29, 3-13.
- 668 Andrews, J.T., Kirby, M.E., Aksu, A., Barber, D.C., Meese, D., 1998. Late Quaternary
669 Detrital Carbonate (DC-) events in Baffin Bay (67° - 74° N): Do they correlate with and
670 contribute to Heinrich Events in the North Atlantic? *Quaternary Science Reviews* 17,
671 1125-1137.
- 672 Andrews, J.T., Milliman, J.D., Jennings, A.E., Rynes, N., Dwyer, J., 1994. Sediment
673 thicknesses and Holocene Glacial Marine Sedimentation Rates in Three East Greenland
674 Fjords (ca. 68°N). *Journal of Geology* 102, 669-683.
- 675 Andrews, J.T., Stein, R., Moros, M., Perner, K., 2016. Late Quaternary changes in
676 sediment composition on the NE Greenland margin (~ 73 degrees N) with a focus on the
677 fjords and shelf. *Boreas* 45, 381-397.
- 678 Andrews, J.T., Syvitski, J.P.M., 1994. Sediment fluxes along high latitude continental
679 margins (NE Canada and E. Greenland), in: Hay, W. (Ed.), *Material fluxes on the surface*
680 *of the Earth*. National Academy Press, Washington, D.C., pp. 99-115.
- 681 Andrews, J.T., Vogt, C., 2014a. Results of Bulk Sediment X-ray Diffraction Analysis and
682 Quantification of Mineral Phases Based on the RockJock and on the QUAX Quantita-
683 tive Analysis. <http://dx.doi.org/10.1594/PANGAEA.830397>.
684 doi:10.1594/PANGAEA.830395.

- 685 Andrews, J.T., Vogt, C., 2014b. Source to Sink: Statistical identification of regional
686 variations in the mineralogy of surface sediments in the western Nordic Seas (58°N –
687 75°N; 10° W -- 40°W). *Marine Geology* 357, 151-162.
- 688 Balkwill, H.R., McMillan, N.J., MacLean, B., Williams, G.L., Srivastava, S.P., 1990.
689 Geology of the Labrador Shelf, Baffin Bay, and Davis Strait, Chapter 7, in: Keen, M.J.,
690 Williams, G.L. (Eds.), *Geology of the Continental Margin of Eastern Canada*.
691 Geological Survey of Canada, Queens Printer, Ottawa, pp. 293-348.
- 692 Bennett, R., Campbell, D.C., Furze, M.F.A., Haggart, J.W., 2014. The shallow
693 stratigraphy and geohazards of the Northeast Baffin Shelf and Lancaster Sound. *Bulletin*
694 *of Canadian Petroleum Geology* 62, 217-231.
- 695 Bigg, G.R., 1999. An estimate of the flux of iceberg calving from Greenland. *Arctic*,
696 *Antarctic, and Alpine Research* 31, 174-178.
- 697 Blott, S.J., Pye, K., 2001. GRADISTAT: A grain size distribution and statistics package
698 for the analysis of unconsolidated sediments. *Earth Surface Processes and Landforms* 26,
699 1237-1248.
- 700 Bonow, J.M., 2005. Re-exposed basement landforms in the Disko region, West
701 Greenland - disregarded data for estimation of glacial erosion and uplift modelling.
702 *Geomorphology* 72, 106-127.
- 703 Campbell, D.C., 2014. CCGS Hudson Expedition 22013-029, Geological Hazard
704 Assessment of Baffin Bay and Biodiversity Assessment of Hatton Basin, August 14-
705 September 16, 2013. Geological Survey of Canada OpenFile 7594, p. 124.
- 706 Campbell, D.C., de Vernal, A., 2009. CCGS Hudson Expedition 2008029. Marine
707 geology and paleoceanography of Baffin Bay and adjacent areas, Nain, NL to Halifax,
708 NS, August 29-September 23.
- 709 Campbell, D.C., Jenner, K.A., Higgins, J., Piper, D.J.W., 2017. Analysis of piston cores
710 and high-resolution sub-bottom profiler data, Baffin Bay slope, Nunavut. *Geological*
711 *Survey of Canada, Open File* 8135, p. 179.
- 712 Charrad, M., Ghazzali, N., Boiteau, V., Niknafs, A., 2014. Nbclust: An R Package for
713 Determining the Relevant Number of Clusters in a Data Set. *Journal of Statistical*
714 *Software* 61, 1-36.

- 715 Chauche, N., Hubbard, A., Gascard, J.C., Box, J.E., Bates, R., Koppes, M., Sole, A.,
716 Christoffersen, P., Patton, H., 2014. Ice-ocean interaction and calving front morphology
717 at two west Greenland tidewater outlet glaciers. *Cryosphere* 8, 1457-1468.
- 718 Chayes, F., 1971. Ratio correlation. University of Chicago Press, Chicago.
- 719 Clark, P.U., 1987. Subglacial sediment dispersal and till composition. *J. Geol.* 95, 527-
720 541.
- 721 Clarke, D.B., 1966. Tertiary basalts from Baffin Island and West Greenland, Volcanic
722 Studies Group Meeting.
- 723 Clarke, D.B., Upton, B.G.J., 1971. Tertiary Basalts of Baffin Island: Field Relations and
724 Tectonic Settings. *Canadian Journal of Earth Sciences* 8.
- 725 Clattenberg, D., al., e., 1983. SAFE: 1982 Bottom grab samples, in: Syvitski, J.P.M.,
726 Blakeney, C.P. (Eds.). Geological Survey of Canada Bedford Institute of Oceanography,
727 Dartmouth, NS, Canada, pp. 8-1 to 8-94.
- 728 Colville, E.J., Carlson, A.E., Beard, B.L., Hatfield, R.G., Stoner, J.S., Reyes, A.V.,
729 Ullman, D.J., 2011. Sr-Nd-Pb Isotope Evidence for Ice-Sheet Presence on Southern
730 Greenland During the Last Interglacial. *Science* 333, 620-623.
- 731 Davis, J.C., 1986. Statistics and data analysis in Geology. John Wiley & Sons, New
732 York.
- 733 Dixon, W.J., Massey, F.J.J., 1957. Introduction to Statistical Analysis, 2nd ed. McGraw-
734 Hill Book Company, Inc., New York.
- 735 Douglas, R.J.W., 1970. Geology and Economic Minerals of Canada, Economic Geology
736 Report No. 1. Queen's printer, Geological Survey of Canada, Ottawa, Ont.
- 737 Dowdeswell, J.A., Elverhoi, A., Andrews, J.T., Hebbeln, D., 1999. Asynchronous
738 deposition of ice-rafted layers in the Nordic seas and North Atlantic Ocean. *Nature* 400,
739 348-351.
- 740 Dredge, L.A., 2004. Till geochemistry results, central Baffin Island, Nunavut (NTS 37A,
741 37D, 27B, 27C). Geological Survey of Canada Open File 4543, p. 222.
- 742 Dyke, A.S., Andrews, J.T., Clark, P.U., England, J.H., Miller, G.H., Shaw, J., Veillette,
743 J.J., 2002. The Laurentide and Innuitian ice sheets during the Last Glacial Maximum.
744 *Quaternary Science Reviews* 21, 9-31.

- 745 Eberl, D.D., 2003. User guide to RockJock: A program for determining quantitative
746 mineralogy from X-ray diffraction data. United States Geological Survey, Open File
747 Report 03-78, 40 pp, Washington, DC.
- 748 Eberl, D.D., 2004. Quantitative mineralogy of the Yukon River system: Variations with
749 reach and season, and determining sediment provenance. *American Mineralogist* 89,
750 1784-1794.
- 751 Farmer, G.L., Barber, D.C., Andrews, J.T., 2003. Provenance of Late Quaternary ice-
752 proximal sediments in the North Atlantic: Nd, Sr and Pd isotopic evidence. *Earth and*
753 *Planetary Science Letters* 209, 227-243.
- 754 Folk, R.L., 1964. A Review of Grain-Size Parameters. *Sedimentology* 6, 73-93.
- 755 Gilbert, R., 1982. Contemporary sedimentary environments on Baffin Island, N.W.T.,
756 Canada: Glaciomarine processes in fiords of eastern Cumberland Peninsula. 14, 1-12.
- 757 Gilbert, R., 1983. Sedimentary processes of Canadian Arctic Fiords. *Sedimentary*
758 *Geology* 36, 147-175.
- 759 Gilbert, R., 1990. Rafting in glaciomarine environments, in: Dowdeswell, J.A., Scourse,
760 J.D. (Eds.), *Glaciomarine Environments: processes and Sediments*. The Geological
761 Society, London, pp. 105-120.
- 762 Grocott, J., McCaffrey, K.J.W., 2017. Basin evolution and destruction in an Early
763 Proterozoic continental margin: the Rinkian fold-thrust belt of central West Greenland.
764 *Journal of the Geological Society* 174, 453-467.
- 765 Hartigan, J.A., Wong, M.A., 1979. Algorithm 136: A K-means clustering algorithm.
766 *Journal of the Royal Statistical Society (Applied Statistics)* 28, 100-108.
- 767 Heinrich, R., 1990. Cycles, Rythmns, and Events in Quaternary Arctic and Antarctic
768 Glaciomarine Deposits, in: Bleil, U., Thiede, J. (Eds.), *Geological History of the Polar*
769 *Oceans: Arctic versus Antarctic*. Kluwer Academic Publishes, Boston, pp. 213-244.
- 770 Henriksen, H., 2008. Geological history of Greenland. Geological Survey of Denmark
771 and Greenland, Copenhagen.
- 772 Hesse, R., 2016. Ice-proximal Labrador Sea Heinrich layers: a sedimentological
773 approach. *Canadian Journal of Earth Sciences* 53, 71-100.
- 774 Hesse, R., Khodabakhsh, S., 2016. Anatomy of Labrador Sea Heinrich layers. *Marine*
775 *Geology* 380, 44-66.

- 776 Hiscott, R.N., Aksu, A.E., Nielsen, O.B., 1989. Provenance and dispersal patterns,
777 Pliocene-Pleistocene section at Site 645, Baffin Bay, in: Stewart, S.K.e. (Ed.),
778 Proceedings ODP, Scientific Results, 105. Ocean Drilling Program, College Station, TX,
779 pp. 31-52.
- 780 Hooke, R.L., Cummings, D.I., Lesemann, J.E., Sharpe, D.R., 2013. Genesis of dispersal
781 plumes in till. *Canadian Journal of Earth Sciences* 50, 847-855.
- 782 Hudson, B., Overeem, I., McGrath, D., Syvitski, J.P.M., Mikkelsen, A., Hasholt, B.,
783 2014. MODIS observed increase in duration and spatial extent of sediment plumes in
784 Greenland fjord. *Cryosphere* 8, 1161-1176.
- 785 Jackson, G.D., Berman, R.G., 2000. Precambrian metamorphic and tectonic evolution of
786 northern Baffin Island, Nunavut, Canada. *The Canadian Mineralogist* 38, 399-421.
- 787 Jackson, R., Carlson, A.E., Hillaire-Marcel, C., Wacker, L., Vogt, C., Kucera, M., 2017.
788 Asynchronous instability of the North American-Arctic and Greenland ice sheets during
789 the last deglaciation. *Quaternary Science Reviews* 164, 140-153.
- 790 Jaeger, J.M., Koppes, M.N., 2016. The role of the cryosphere in source-to-sink systems.
791 *Earth-Science Reviews* 153, 43-76.
- 792 Jennings, A.E., Andrews, J.T., al., e., 2017a. Baffin Bay paleoenvironments in the LGM
793 and HS1: Resolving the ice-shelf question. *Marine Geology*.
- 794 Jennings, A.E., Andrews, J.T., ÓCfoaigh, C., St. Onge, G., Sheldon, S., Belt, S.T.,
795 Cabedo-Sanz, P., Hillaire-Marcel, C., 2017b. Ocean forcing of Ice Sheet Retreat in
796 Central West Greenland from LGM through Deglaciation. *Earth and Planetary Science*
797 *Letters* 472, 1-13.
- 798 Jennings, A.E., Sheldon, C., Cronin, T.M., Francus, P., Stoner, J., Andrews, J., 2011a.
799 THE HOLOCENE HISTORY OF NARES STRAIT: Transition from Glacial Bay to
800 Arctic-Atlantic Throughflow. *Oceanography* 24, 26-41.
- 801 Jennings, A.E., Sheldon, C., Cronin, T.M., Francus, P., Stoner, J., Andrews, J.T., 2011b.
802 Nares Strait HLY03-05GC Holocene Sediment Data. NOAA Paleoclimatology.
- 803 Kanungo, T., Mount, D.M., Netanyahu, N.S., Piatko, C.D., Silverman, R., Wu, A.Y.,
804 2002. An efficient k-means clustering algorithm: Analysis and implementation. *Ieee*
805 *Transactions on Pattern Analysis and Machine Intelligence* 24, 881-892.

- 806 Kerr, J.W., 1967. Nares Submarine Rift Valley and the Relative Rotation of North
807 Greenland. *Bulletin of Canadian Petroleum Geology* 15, 483-520.
- 808 Klein, A.J., 2016. Lateral variations in sediment provenance and grain-size along the
809 Baffin Island slope, Geological Sciences. University of Colorado Boulder, p. 48.
- 810 Klein, A.J., Andrews, J.T., Jenner, K., Jennings, A.E., Campbell, D.C., 2016. Late
811 Quaternary variations in sediment mineralogy and grain-size on the northern Baffin
812 Island slope: insights into the glacial history of Baffin Bay. *Geological Society of
813 America Abstract vol.*
- 814 Kravitz, J.H., 1982. Sediments and sediment processes in Kane Basin, a high arctic
815 glacial marine basin. INSTAAR, University of Colorado.
- 816 Kravitz, J.H., Sorensen, F.H., 1970. Sedimentological Reconnaissance Survey of Kane
817 Basin. *Maritime Sediments* 6, 17-20.
- 818 Larsen, L.M., Pedersen, A.K., 2009. Petrology of the Paleocene Picrites and Flood
819 Basalts on Disko and Nuussuaq, West Greenland. *Journal of Petrology* 50, 1667-1711.
- 820 Li, G., Piper, D.J.W., Campbell, D.C., 2011. The Quaternary Lancaster Sound trough-
821 mouth fan, NW Baffin Bay. *Journal of Quaternary Science* 26, 511-522.
- 822 Licht, K.J., Hemming, S.R., 2017. Analysis of Antarctic glacigenic sediment provenance
823 through geochemical and petrologic applications. *Quaternary Science Reviews* 164, 1-24.
- 824 Lucchi, R.G., Rebesco, M., 2007. Glacial contourites on the Antarctic Peninsula margin:
825 insight for palaeoenvironmental and palaeoclimatic conditions, in: Viana, A.R., Rebesco,
826 M. (Eds.), *Economic and Palaeoceanographic Significance of Contourite Deposits*, pp.
827 111-127.
- 828 MacLean, B., 1985. Geology of the Baffin Island Shelf, in: Andrews, J.T. (Ed.),
829 Quaternary environments. Eastern Canadian Arctic, Baffin Bay, and Western
830 Greenland. Allen and Unwin, London, pp. 154-177.
- 831 MacLean, B., Williams, G., Zang, S., 2011. Cretaceous strata on the Baffin Island Shelf,
832 3P Arctic-Polar Petroleum Potential Conference and Exhibition. American Association of
833 Petroleum Geologists, Halifax, NS.
- 834 MacLean, B., Williams, G., Zhang, S., 2014. New insights into the stratigraphy and
835 petroleum potential of the Baffin shelf's Cretaceous rocks. *Bulletin of Canadian
836 Petroleum Geology* 62, 289-310.

- 837 Margold, M., Stokes, C.R., Clark, C.D., 2015. Ice streams in the Laurentide Ice Sheet:
838 Identification, characteristics and comparison to modern ice sheets. *Earth-Science*
839 *Reviews* 143, 117-146.
- 840 Margold, M., Stokes, C.R., Clark, C.D., Kleman, J., 2014. Ice streams in the Laurentide
841 Ice Sheet: a new mapping inventory. *Journal of Maps*, 1-17.
- 842 Marlowe, J.I., 1966. Mineralogy as an indicator of long-term current fluctuations in
843 Baffin Bay. *Canadian Journal of Earth Sciences* 3, 191-201.
- 844 Marshall, S., J., Tarasov, L., Clarke, G.K.C., Peltier, W.R., 2000. Glaciological
845 reconstruction of the Laurentide Ice Sheet: physical processes and modelling challenges.
846 *Canadian Journal of Earth Sciences* 37, 769-793.
- 847 McCarty, D.K., 2002. Quantitative mineral analysis of clay-bearing mixtures: The
848 "Reynolds Cup" contest. *International Union of Crystallography, Newsletter No. 27*, 12-
849 16.
- 850 Miller, R.L., Kahn, J.S., 1962. *Statistical analysis in the Geological Sciences*. John Wiley
851 and Sons, Inc., New York.
- 852 Minansy, B., 2010. Fuzzy k means extragrades, performance measures & fuzzy linear
853 discriminant analysis. The University of Sydney, Australia, p. 28 pp.
- 854 Nuttin, L., Hillaire-Marcel, C., 2015. U- and Th-series isotopes in deep Baffin Bay
855 sediments: Tracers of detrital sources and of contrasted glacial/interglacial sedimentary
856 processes. *Marine Geology* 361, 1-10.
- 857 O'Cofaigh, C., Andrews, J.T., Jennings, A.E., Dowdeswell, J.A., Hogan, K.A.,
858 Killfeather, A.A., Sheldon, C., 2013. Glacimarine lithofacies, provenance, and
859 depositional processes on a West Greenland trough-mouth fan. *Journal of Quaternary*
860 *Science* 28, 13-26.
- 861 Parnell, J., Bowden, S., Taylor, C., Andrews, J.T., 2007. Biomarker determination as a
862 provenance tool for detrital carbonate events (Heinrich events?): Fingerprinting
863 Quaternary glacial sources in Baffin Bay. *Earth and Planetary Science Letters* 257, 71-82.
- 864 Pedersen, A.K., Watt, M., Watt, W.S., Larsen, L.M., 1997. Structure and stratigraphy of
865 the Early Tertiary basalts of the Blosseville Kyst, East Greenland. *Journal of the*
866 *Geological Society* 154, 565-570.

- 867 Pedersen, G.K., Pulvertaft, T.C.R., 1992. THE NONMARINE CRETACEOUS OF THE
868 WEST GREENLAND BASIN, ONSHORE WEST GREENLAND. *Cretaceous Research*
869 13, 263-272.
- 870 Perner, K., Jennings, A.E., Moros, M., Andrews, J.T., Wacker, L., 2016. Interaction
871 between warm Atlantic-sourced waters and the East Greenland Current in northern
872 Denmark Strait (68 degrees N) during the last 10 600 cal a BP. *Journal of Quaternary*
873 *Science* 31, 472-483.
- 874 Piper, D.J.W., 1973. A Late Quaternary Stratigraphic Marker in the Central Basin of
875 Baffin Bay. *Maritime Sediments* 9, 62-63.
- 876 Piper, D.J.W., Slatt, R.M., 1977. Late Quaternary clay mineral distribution on the eastern
877 continental margin of Canada. *Geological Society of America Bulletin* 88, 267-272.
- 878 Pisiias, N.G., Murray, R.W., Scudder, R.P., 2013. Multivariate statistical analysis and
879 partitioning of sedimentary geochemical data sets : General principles and specific
880 MATLAB scripts. *Geochemistry Geophysics Geosystems* 14, 4015-4020.
- 881 Prest, V.K., 1990. Laurentide Ice-Flow Patterns: A Historial Review, and Implications of
882 the Dispersal of Belcher Island Erratics. *Geographie physique et Quaternaire* 44, 113-
883 136.
- 884 Prest, V.K., Nielsen, E., 1985. The Laurentide Ice Sheet and Long-Distance Transport,
885 in: Kujansuu, R., Saarnisto, M. (Eds.), *INQUA Till Symposium*, Finland, pp. 91-101.
- 886 Reeh, N., Mayer, C., Miller, H., Thomsen, H.H., Weidick, A., 1999. Present and past
887 climate control on fjord glaciations in Greenland: Implications for IRD-deposition in the
888 sea. *Geophysical Research Letters* 26, 1039-1042.
- 889 Reeh, N., Thomsen, H.H., Higgins, A.K., Weidick, A., 2001. Sea ice and the stability of
890 north and northeast Greenland floating glaciers, in: Jeffries, M.O., Eicken, H. (Eds.),
891 *Annals of Glaciology*, Vol 33, pp. 474-480.
- 892 Reimann, C., Filzmoser, P., Garrett, R.G., 2002. Factor analysis applied to regional
893 geochemical data: problems and possibilities. *Applied Geochemistry* 17, 185-206.
- 894 Reyment, R.A., Savazzi, E., 1999. Aspects of multivariate statistical analysis in Geology.
895 Elsevier, New York.
- 896 Schlitzer, R., 2011. Ocean Data View, <http://odv.awi.de>, 2011.
- 897 .

- 898 Simon, Q., Hillaire-Marcel, C., St-Onge, G., Andrews, J.T., 2014. North-eastern
899 Laurentide, western Greenland and southern Innuitian ice stream dynamics during the last
900 glacial cycle. *Journal of Quaternary Science* 29, 14-26.
- 901 Simon, Q., St-Onge, G., Hillaire-Marcel, C., 2012. Late Quaternary chronostratigraphic
902 framework of deep Baffin Bay glaciomarine sedimentts from high-resolution
903 paleomagnetic data. *Geochemistry, Geophysics, Geosystems*,
904 doi:10.1029/2012GC004272, .
- 905 Skaarup, N., Jackson, H.R., Oakey, G., 2006. Margin segmentation of Baffin Bay/Davis
906 Strait, eastern Canada based on seismic reflection and potential field data. *Marine and*
907 *Petroleum Geology* 23, 127-144.
- 908 Slabon, P., al., e., 2016. Greenland ice sheet retreat history. *Quaternary Science Reviews*
909 154, 182-198.
- 910 Srivastava, S.P., Arthur, M., Clement, B., al., e., 1987. Part A-Initial Reports Sites 645-
911 647 Baffin Bay and Labrador Sea. Ocean Drilling Program Texas A & M University,
912 Washington, D.C.
- 913 St-Onge, M.R., van Gool, J.A.M., Garde, A.A., Scott, D.J., 2009. Correlation of
914 Archaean and Palaeoproterozoic units between northeastern Canada and western
915 Greenland: constraining the pre-collisional upper plate accretionary history of the Trans-
916 Hudson orogen. *Earth Accretionary Systems in Space and Time* 318, 193-235.
- 917 Stokes, C.R., Corner, G.D., Winsborrow, M.C.M., Husum, K., Andreassen, K., 2014.
918 Asynchronous response of marine-terminating outlet glaciers during deglaciation of the
919 Fennoscandian Ice Sheet. *Geology* 42, 455-458.
- 920 Stokes, C.R., Margold, M., Clark, C.D., Tarasov, L., 2016. Ice stream activity scaled to
921 ice sheet volume during Laurentide Ice Sheet deglaciation. *Nature* 530, 322-+.
- 922 Stoner, J.S., Andrews, J.T., 1999. The North Atlantic as a Quaternary magnetic archive,
923 in: Maher, B., Thompson, R. (Eds.), *Quaternary Climates, Environments and Magnetism*.
924 Cambridge University Press, Cambridge, UK, pp. 49-80.
- 925 Syvitski, J.P.M., 1993. Glaciomarine environments in Canada: an overview. *Canadian*
926 *Journal Earth Sciences* 30, 354-371.
- 927 Syvitski, J.P.M., Blakeney, C.c., 1983. Sedimentology of Arctic Fjords Experiment:
928 HU82-031. Canadian Data Report on Hydrography and Ocean Sciences.

- 929 Syvitski, J.P.M., Boudreau, B.P., Calabrese, E.A., Smith, J.N., 1988. Basin
930 Sedimentation and the Growth of Prograding Deltas. *Journal of Geophysical Research*
931 93, 6895-6908.
- 932 Syvitski, J.P.M., Hein, F.J., 1991. Sedimentology of an Arctic basin: Itirbilung Fiord,
933 Baffin Island, Northwest Territories. *Geological Survey of Canada*.
- 934 Syvitski, J.P.M., Macdonald, R.D., 1982. Sediment character and provenance in a
935 complex fjord; Howe Sound, British Columbia. *Canadian Journal of Earth Sciences* 19,
936 1025-1044.
- 937 Syvitski, J.P.M., Schafer, C., 1985. Sedimentology of Arctic Fjords Experiment
938 (S.A.F.E.) Project: Project Introduction. *Arctic* 38, 264-270.
- 939 Syvitski, J.P.M.c., 1984. Sedimentology of Arctic Fjords Experiment. HU83-024 Data
940 Report. Bedford Institute of Oceanography.
- 941 Thompson, R., Oldfield, F., 1986. *Environmental Magnetism*. Allen & Unwin,
942 Winchester, Mass.
- 943 Tippet, C.R., 1985. Glacial dispersal train of Paleozoic erratics, central Baffin Island,
944 N.W.T., Canada. *Can. J. Earth Sci.* 22, 1818-1826.
- 945 Walden, J., Oldfield, F., Smith, J., 1999. *Environmental Magnetism. A Practical Guide*,
946 Technical Guide No. 6. Quaternary Research Association, London, p. 243.
- 947 Weltje, G.J., Prins, M.A., 2003. Muddled or mixed? Inferring palaeoclimate from size
948 distributions of deep-sea clastics. *Sedimentary Geology* 162, 39-62.
- 949 Weltje, G.J., Prins, M.A., 2007. Genetically meaningful decomposition of grain-size
950 distributions. *Sedimentary Geology* 202, 409-424.
- 951 Weltje, G.J., von Eynatten, H., 2004. Quantitative provenance analysis of sediments:
952 review and outlook. *Sedimentary Geology* 171, 1-11.
- 953 White, L.F., Bailey, I., Foster, G.L., Allen, G., Kelley, S.P., Andrews, J.T., Hogan, K.,
954 Dowdeswell, J.A., Storey, C.D., 2016. Tracking the provenance of Greenland-sourced,
955 Holocene aged, individual sand-sized ice-rafted debris using the Pb-isotope compositions
956 of feldspars and Ar-40/Ar-39 ages of hornblendes. *Earth and Planetary Science Letters*
957 433, 192-203.

- 958 Zhang, S., 2008. New insights into Ordovician oil shales in Hudson Bay basin: their
959 number, stratigraphic position, and petroleum potential. *Bulletin of Canadian Petroleum*
960 *Geology* 56, 300-324.
- 961 Zhang, S., 2012. Ordovician stratigraphy and and soil shale, southern Baffin Island,
962 Nunavut---preliminary field and post-field data. *Geological Survey of Canada Open File*
963 *Report 7199*, p. 26 p.
- 964 Zhang, S., Pell, J., 2014. Conodonts recovered from the carbonate xenoliths in the
965 kimberlites confirm the Paleozoic cover on the Hall Peninsula, Nunavut. *Canadian*
966 *Journal of Earth Sciences* 51, 142-155.
- 967
- 968

Draft

PALEOPROTEROZOIC

- Dextery Granulite Belt (1.825 Ga); reworked Archean and some Paleoproterozoic rocks
 - Granite-tonalite, charnockite-enderbite plutons (1.87- 1.81 Ga, c= Cumberland Batholith)
 - Thelon Tectonic Zone; reworked Archean, 2.0 - 1.9 Ga granitic, and charnockitic intrusions, supracrustal rocks of uncertain age
 - Supracrustal rocks and derived gneisses (2.2 - 1.8 Ga); includes some small Paleoproterozoic granitic plutons, and reworked Archean rocks; Nagssugtoqidian Mobile Belt is shown by stippling
- ### ARCHEAN
- Granite - tonalite, charnockite - enderbite (~2.54 Ga)
 - Committee Belt; 2.9-2.5 Ga granite-greenstone terranes with some older and younger rocks, and Paleoproterozoic reworking
 - Undifferentiated Archean (3.8-2.5 Ga); local Paleoproterozoic reworking
- NP = Nain Province, SP = Superior Province, and QM = Queen Maud Block

Two-Way Contingency Table (Observed)

Cluster_ID_6:	1	2	3	4	5	6
region id						
WGS	17	33	0	18	2	0
BS	3	7	10	4	31	0
BF	5	4	0	6	3	36
BB	1	1	2	2	11	0
WGSL	0	4	1	3	5	1
NBB	0	1	0	4	2	0
NS	0	0	7	0	0	0
BSL	0	0	0	1	2	0
$df = 35$ $X^2 = 318.209$						
$X^2_{0.05} = 49.8018$ $X^2_{0.01} = 57.3421$ $p = < 0.0001$

WGGSM#1 very coarse silt
mean μm = 34.1 μm

WGGSM#2 very fine sand
mean μm = 73.76

WGGSM#3 coarse silt
mean μm = 18.72

WGGSM#4 fine sand
mean μm = 155.6

Two-Way Contingency Table (Observed)

WG GSM#	1	2	3	4
WG MC#				
1	4	1	13	0
2	2	3	3	0
3	3	0	17	0
4	2	6	0	3

df = 9 Chi-sq = 38.46
Chi-sq 0.05; : Chi-sq 0.01 = p = < 0.0001

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A)

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Table 1

Average and standard deviation wt% of the six bedrock types (Fig. 4)

wt% sources	Basalt		Carbonate		n =10 W/W Grn'Ind		n = 8
Minerals pres	average	st deviation	average	st deviation	average	st deviation	
Quartz	0.3	0.23	14.86	1.47	21.4		6.78
Alkali feldspa	9.0	1.32	17.88	2.82	14.9		14.06
Plagiclase	39.6	3.12	6.91	2.12	32.8		8.01
Calcite	1.0	0.31	10.62	2.01	0.7		0.92
Dolomite	1.2	1.56	25.89	4.18	0.5		0.41
Amphibole	0.6	0.15	0.68	0.15	3.0		5.50
Pyroxene	23.5	3.76	1.22	0.32	0.2		0.24
FeO	11.0	2.11	1.82	1.71	1.6		2.31
SiO	0.3	0.52	8.15	2.27	14.0		2.95
Kaolinite	0.0	0.06	0.19	0.53	0.3		0.38
Smecitites	7.5	2.04	1.82	1.71	0.9		1.17
Illites	0.7	0.82	4.63	1.67	2.0		3.10
Biotite&chlor	1.1	0.26	4.68	0.74	3.7		4.01

	SW Grn'Ind		19 Wx & Cret. n = 18		Ordov. Shale n = 9	
	average	st deviation	average	st deviation	average	st deviation
Quartz	19.7	6.9	18.5	9.6	6.5	3.5
Alkali feldspa	20.2	8.3	13.2	5.1	16.8	1.5
Plagiclase	32.1	10.3	2.0	3.1	4.4	0.8
Calcite	0.1	0.1	2.1	4.0	2.9	0.5
Dolomite	0.7	1.0	8.9	16.3	7.3	5.5
Amphibole	4.1	3.5	0.2	0.3	2.5	1.1
Pyroxene	1.1	1.0	0.1	0.2	0.0	0.1
FeO	3.2	3.6	6.1	5.9	0.5	0.5
SiO	7.4	3.0	13.2	3.5	1.4	0.6
Kaolinite	0.0	0.1	16.2	5.3	15.4	2.0
Smecitites	3.2	3.6	6.7	4.3	1.0	0.6
Illites	4.2	7.1	3.6	3.4	8.5	2.0
Biotite&chlor	3.9	2.5	7.3	4.2	8.8	1.3

Table 2A

A) Average weight% of the minerals at k-mean centers for the six BBCLs

K-Means Cluster Centers

Cluster centers transformed back to original units.

Variable	BBMC#1	BBMC#2	BBMC#3	BBMC#4	BBMC#5	BBMC#6
quartz	10.2	20.0	24.8	8.4	9.0	11.0
Alkalifelds	8.6	12.7	12.6	12.1	28.4	9.9
plagioclase	30.6	32.2	18.8	24.1	17.5	13.7
calcite	0.4	0.1	1.0	0.1	0.3	2.6
dolomite	0.6	1.6	7.9	1.8	0.6	8.1
amphibole	2.1	3.6	1.4	3.1	1.9	1.0
pyroxene	8.5	1.7	0.6	1.3	0.4	0.6
feoxides	4.2	1.3	1.4	2.0	1.3	1.3
egrained sio2	9.7	10.6	12.2	13.2	14.8	12.9
kaolinite	1.8	0.2	0.3	1.0	0.5	0.9
smectites	9.8	3.4	1.8	10.6	4.1	7.1
illites	4.4	4.2	8.3	8.0	4.7	17.1
biochlor	7.5	7.2	7.9	11.9	15.1	11.4

Table 2B results on the single variable Analysis of Variance (ANOVA)

MS = mean square, df = degrees of freedom, F = value of F Statistic,

p = probability of the differences being due chance

ANOVA						
Variable	MS Cluster	df	MS Error	df	F	p
quartz	27.1	5	0.41	221	66.42	< 0.0001
Alkalifelds	27.8	5	0.39	221	70.83	< 0.0001
plagioclase	32.8	5	0.28	221	117.41	< 0.0001
calcite	3.4	5	0.94	221	3.65	0.0034
dolomite	25.3	5	0.45	221	56.31	< 0.0001
amphibole	23.2	5	0.50	221	46.78	< 0.0001
pyroxene	28.3	5	0.38	221	73.95	< 0.0001
feoxides	16.9	5	0.64	221	26.42	< 0.0001
egrained sio2	7.8	5	0.85	221	9.24	< 0.0001
kaolinite	7.8	5	0.85	221	9.22	< 0.0001
smectites	24.1	5	0.48	221	50.52	< 0.0001
illites	31.2	5	0.32	221	98.07	< 0.0001
biochlor	22.9	5	0.51	221	45.28	< 0.0001

Number of Clusters: 6; Pre-Processing: Standardization

The cluster means are calculated in multivariate space;

tests are univariate, being conducted along each variable direction. Accordingly, the tests and the corresponding values should be used only for descriptive purposes.

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Table 3

A) Results of the Scheffe *post-hoc* test for the minerals versus the six BBMCs (Fig. 5).

BBMC	Quartz	Alkalifelds	Plagioclase	Dolomite	Pyroxene	FeO	Smectite	Illites	Biotite&Chlorite	% dissimilar
1 v 2	No	No	Yes	No	Yes	No	Yes	Yes	No	44.4
1 v 3	Yes	No	Yes	Yes	Yes	Yes	No	Yes	No	66.7
1 v 4	Yes	No	Yes	No	Yes	No	Yes	Yes	Yes	55.6
1 v 5	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	66.7
1 v 6	Yes	Yes	Yes	No	Yes	Yes	No	No	Yes	66.7
2 v 3	Yes	No	Yes	Yes	No	No	Yes	Yes	No	55.6
2 v 4	Yes	No	Yes	Yes	No	No	Yes	Yes	Yes	55.6
2 v 5	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	66.7
2 v 6	Yes	Yes	Yes	No	Yes	No	Yes	No	Yes	55.6
3 v 4	Yes	No	Yes	Yes	No	Yes	Yes	Yes	Yes	66.7
3 v 5	Yes	No	No	Yes	No	No	Yes	Yes	Yes	44.4
3 v 6	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	66.7
4 v 5	No	No	Yes	Yes	Yes	No	Yes	Yes	No	55.6
4 v 6	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	66.7
5 v 6	No	Yes	No	Yes	No	No	Yes	Yes	Yes	44.4
No sign. Diff	11	5	13	11	9	3	13	13	10	

Table 3B

Results of the Scheffe *post-hoc* test for the minerals versus of the four WGCIs (Fig. 7B)

Regions (Fig. 1A)	Quartz	Alkalifelds	Plagioclase	Dolomite	Pyroxene	FeO	Smectite	Illites	Biotite&Chlorite	% dissimilar
BB v BF	Yes	Yes	No	Yes	No	No	Yes	Yes	Yes	55.6
BB v BS	No	No	No	No	No	No	No	No	No	0.0
BB v Bsl	No	No	No	No	No	No	No	No	No	0.0
BB v NBB	No	No	No	No	No	No	No	No	No	0.0
BB v NS	No	No	Yes	Yes	No	Yes	Yes	Yes	No	55.6
BB v WGS	No	No	Yes	Yes	Yes	No	No	Yes	Yes	44.4
BB v WGS�	No	No	Yes	No	No	No	No	Yes	No	22.2
BF v BS	Yes	Yes	NO	Yes	No	No	No	Yes	Yes	55.6
BF v BSL	No	Yes	No	Yes	No	No	Yes	Yes	No	44.4

BF v NBB	No	Yes	Yes	Yes	No	No	No	Yes	Yes	55.6
BF v NS	Yes	Yes	Yes	Yes	No	Yes	No	Yes	Yes	66.7
BF v WGS	Yes	Yes	Yes	No	Yes	No	Yes	No	Yes	55.6
BF v WGSL	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	66.7
BS v BSL	No	No	No	No	No	No	No	No	No	0.0
BS v NBB	No	No	Yes	No	No	No	Yes	No	No	22.2
BS v NS	No	No	Yes	Yes	No	No	No	NO	No	22.2
BS v WGS	No	No	Yes	Yes	Yes	No	Yes	Yes	Yes	66.7
BS v WGSL	No	No	Yes	No	No	No	No	Yes	No	22.2
BSL v NBB	No	No	No	No	No	No	No	No	No	0.0
BSL v NS	No	No	Yes	Yes	No	No	Yes	No	No	33.3
BSL v WGS	No	No	Yes	Yes	No	No	No	Yes	No	33.3
BSL v WGSL	No	No	No	No	No	No	No	Yes	No	11.1
NBB v NS	No	No	Yes	Yes	No	No	Yes	No	No	33.3
NBB v WGS	No	No	Yes	Yes	Yes	No	No	Yes	No	44.4
NBB v WGSL	No	No	Yes	No	No	No	No	No	No	11.1
NS v WGS	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No	66.7
NS v WGSL	No	No	Yes	Yes	No	No	Yes	Yes	No	44.4
WGL v WGSL	No	No	Yes	Yes	Yes	Yes	No	Yes	No	55.6
No sign. Diff	4	5	19	16	6	3	10	16	7	

Table 4

Results of the Scheffe *post-hoc* test
on the four mineral clusters (WGMC) versus the four W Greenland
grain-size modes (WGGSM) (Fig. 8).

Two-Way Contingency Table (Observed)

WGGSM#:		1	2	3	4
WGMC#					
	2	9	1	9	0
	4	2	6	0	3
	3	0	1	24	0
	1	0	2	0	0

df = 9

Chi-sq 0.05 == 16.91

Chi-sq = 60.26

Chi-sq 0.0001 = 21.66

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Table 5
Average mineral values for the six sediment sources
used in SedUnMix for cores HU2013029-77 and HU2008029-8

Minerals present	N & S Baffin	Detrital carbonate	W Greenland	Ordov. shale	Cret & wx bedrock1	Foxe Fold Belt
Quartz	10.2	14.9	23.5	18.5	16.3	7.1
Alkali feldspa	41.2	18	9.8	21.5	11.1	21.4
Plagiclase	13.8	6.9	34.9	35.2	1.2	22.3
Calcite	0.3	10.7	0.8	0.1	0.2	0.2
Dolomite	0.8	26	0.7	0.4	19.9	0.6
Amphibole	1.3	0.7	5.6	4.4	0.3	3.8
Pyroxene	0.4	1.2	0.1	1.1	0.1	0.5
FeO	1.5	1.9	2.6	2.2	7.2	1.8
SiO	11.2	8.2	14.4	7.6	12.7	15
Kaolinite	0.3	0.3	0.3	0	13.6	0.9
Smecitites	3.6	1.8	1.3	2.1	5.4	5.5
Illites	3.7	4.6	3.4	2.8	3.7	3.8
Biotite&chlor	11.7	4.7	2.6	4.1	8.3	17.3