1750 YEARS OF LARGE RAINFALL EVENTS INFERRED FROM PARTICLE SIZE AT EAST LAKE, CAPE BOUNTY, MELVILLE ISLAND, CANADA

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Introduction

Major changes occurred in Arctic climate during the 20th century, including an important increase of surface air temperature particularly between 1970 and 2000 (Moritz et al. 2002). To better understand these changes beyond the available short instrumental record, there is a need to obtain long-term proxy climate records across a wide geographical area. In the western Canadian High Arctic, annually laminated sediments from lakes are the only available records with precise chronological control in an area that lacks tree-ring and ice core records. However, caution is needed when calibrating instrumental data with varve thickness (VT), since sediment accumulation can result from different hydroclimatic and geomorphic processes, such as snowmelt, rain events and landslides. In addition to VT, grain size measured at the annual scale is a sedimentary parameter that may be used as a potential variable to reconstruct paleo-hydroclimatic condition. Here, we use the methods pioneered by Francus (1998) together with a new image acquisition and analysis software developed at INRS (Francus and Nobert 2007), to obtain grain size measurements within each varve in a long Arctic lake sequence in order to demonstrate its potential for paleoenvironmental reconstructions.

Materials and methods

Study site

Melville Island

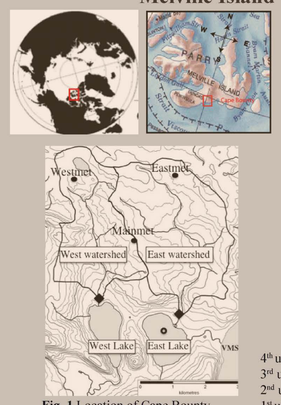
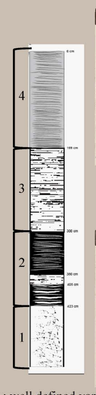
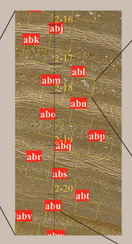


Fig. 1 Location of Cape Bounty



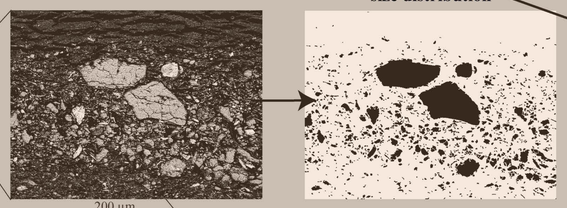
4th unit : well defined varves with coarse events and turbidites
3rd unit : Fine laminae with turbidites and debris low
2nd unit : Glacio-isostatic uplift : lake isolation
1st unit : Marine

86 thin sections overlapping each other from top to the bottom of the laminated section (first 423 cm)



Software calculates varve thickness

Image Analysis
B&W transformation and manual editing



A total of 6148 BSE images were treated for the last 2845 years

Measurements for particle size distribution

Images acquired at the scanning electron microscope in backscattered electron (BSE) mode

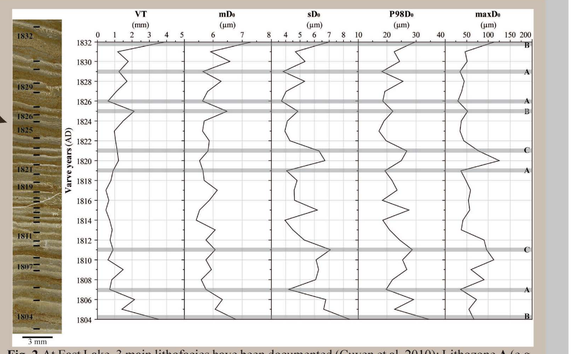


Fig. 2 At East Lake, 3 main lithofacies have been documented (Cuven et al. 2010): Lithozone **A** (e.g. AD 1826 and Fig. 4 : 1688;C), is composed of a fine silt layer deposited by nival melt runoff; Lithozone **B** (e.g. AD 1832 and Fig. 4 : 1689;B) is graded and likely deposited by a turbidity current caused by runoff of higher intensity than the regular spring melt; Lithozone **C** (e.g. AD 1821 and Fig. 4 : 1687 C;D) is composed of poorly sorted sand layers occurring systematically above the initial snowmelt silt layer and below the clay cap, it is interpreted to be produced by high discharge events which are triggered by high intensity rainfalls during summer.

Results and discussion : PSD and VT

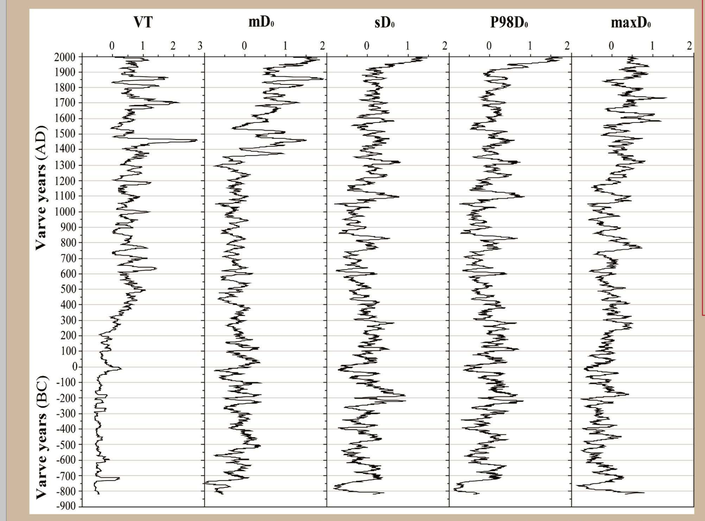


Fig. 3 East Lake varve thickness (VT) and four particle size indices for the last 2,845 years. Data are standardized relative to the mean and standard deviation. A 20-year running mean is applied on the series

Main observations

- The long-term evolution of VT and PSD indices at Cape Bounty is strikingly different.

- $P98D_0$ and sD_0 vary similarly through time and they are strongly correlated ($r = 0.83$, $p < 0.0001$). They increase to maximum at the beginning of the 20th century with highest values during the 1990s.

- The clear step change of mD_0 around AD 1350 does not correspond to a detected change in known boundary conditions in the watershed.

Table 1 : the Pearson's (r), Spearman's (ρ), and Kendall's (τ) correlations between varve thickness and annually resolved particle-size distribution indices for the raw (top half) and decorrelated (bottom half) time series, and their significance (p-values).

	mD_0	sD_0	$P98D_0$	$maxD_0$
Methods	Original time series			
r	0.5343 (< 0.0001)	0.2153 (< 0.0001)	0.2999 (< 0.0001)	0.0426 (0.0753)
ρ	0.3228 (< 0.0001)	0.1790 (< 0.0001)	0.2618 (< 0.0001)	0.1186 (< 0.0001)
τ	0.2238 (< 0.0001)	0.1217 (< 0.0001)	0.1784 (< 0.0001)	0.0792 (< 0.0001)
Methods	Decorrelated time series			
r	0.5503 (< 0.0001)	0.2092 (< 0.0001)	0.3149 (< 0.0001)	0.0166 (0.4879)
ρ	0.3967 (< 0.0001)	0.1765 (< 0.0001)	0.2745 (< 0.0001)	0.0724 (0.0025)
τ	0.2745 (< 0.0001)	0.1194 (< 0.0001)	0.1868 (< 0.0001)	0.0483 (0.0025)

High-energy facies can be found inside relatively thin laminae

The strenght of correlations between varve thickness and particle size distribution is weak

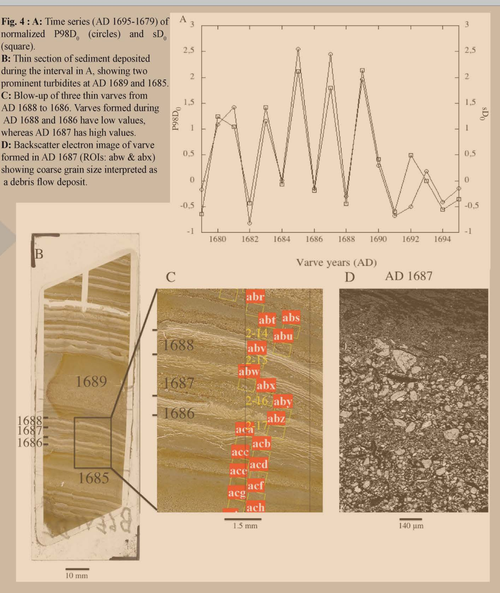


Fig. 4 : A: Time series (AD 1695-1679) of normalized $P98D_0$ (circles) and sD_0 (square). **B:** Thin section of sediment deposited during the interval in A, showing two prominent turbidites at AD 1689 and 1685. **C:** Blow-up of three thin varves from AD 1688 to 1686. Varves formed during AD 1688 and 1686 have low values, whereas AD 1687 has high values. **D:** Backscatter electron image of varve formed in AD 1687 (ROIs: abw & abx) showing coarse grain size interpreted as a debris flow deposit.

Nearby meteorological stations

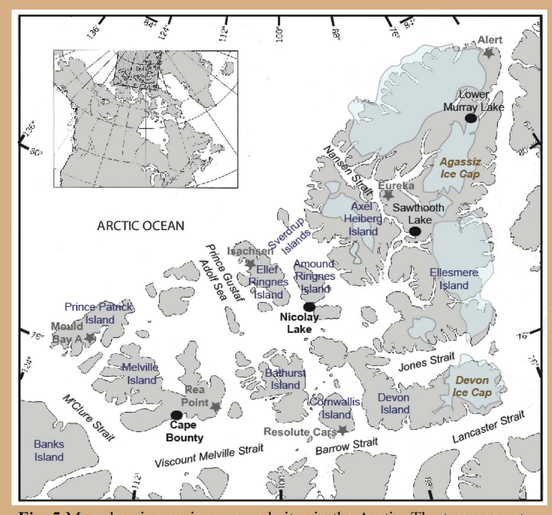


Fig. 5 Map showing various varved sites in the Arctic. The two nearest meteorological stations from Cape Bounty are **Rea Point** (100 km east) and **Mould Bay** (300 km north west).

Calibration with meteorological data

Table 2 : Pearson's (P), Spearman's (S), and Kendall's (K) correlations between particle-size distribution index $P98D_0$ and instrumental data from Rea Point and Mould Bay and their significance (p-values).

	Rea Point (1985–1971)			Mould Bay (1996–1971)		
Variables	P	S	K	P	S	K
June temp. (°C)	0.3961 (0.1439)	0.3214 (0.2424)	0.2000 (0.3282)	**0.4907 (0.0109)**	**0.5165 (0.0069)**	**0.3608 (0.0111)**
July temp. (°C)	0.3788 (0.1638)	0.3679 (0.1779)	0.2762 (0.1686)	0.2459 (0.2260)	0.2113 (0.3000)	0.1373 (0.3420)
MDD (May-July)	**0.5087 (0.0528)**	**0.5893 (0.0232)**	**0.4286 (0.0275)**	**0.4536 (0.0199)**	**0.3737 (0.0609)**	**0.2492 (0.0777)**
Largest rainfall (mm)	**0.8479 (0.0001)**	**0.7668 (0.0009)**	**0.5742 (0.0035)**	0.1046 (0.6110)	-0.0041 (0.9841)	0.0123 (0.9473)
Annual snowfall (cm)	-0.3186 (0.2471)	-0.2214 (0.4266)	-0.1238 (0.5590)	0.0337 (0.8729)	0.1246 (0.5513)	0.0867 (0.5631)

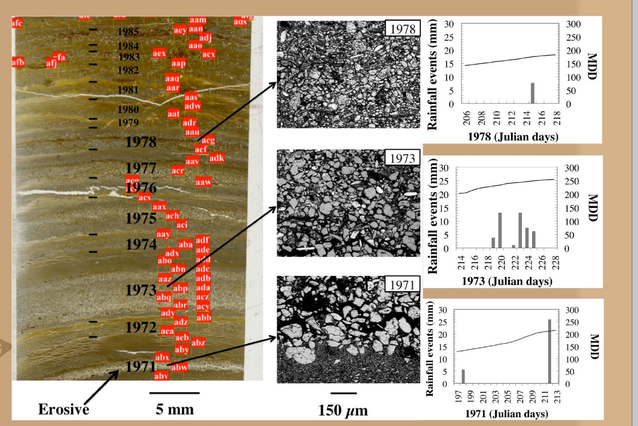


Fig. 6 Thin section (right) with regions of interest and varve boundaries.The right panel shows backscatter electron (BSE) images of sediment deposited during years AD 1971, 1973, and 1978 (ROIs abx, aaz, and aau respectively) that contain coarse grain size. Beside each BSE image is the corresponding year with rainfall events and the melting degree days above 0°C (MDD). In those years, warm conditions prevail before the precipitation events, especially for AD 1971 and 1973, where coarsest particle are observed. Maximum temperatures reached uncommun values during the 4 days (> 13°C) before the major rainfall event that occurred on July 30 (212 Julian day), 1971, the year with the coarsest particle size during the calibration record.

Climatic reconstruction

$\log(\text{rainfall} + 1) = -9.5337 + 3.2706 \log P98D_0$

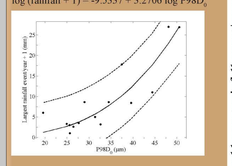


Fig. 7 Linear regression between log-transformed (Box and Cox 1964) $P98D_0$ and largest rainfall event/year at Rea Point using robust estimation (Maronna et al. 2006), and the 90% confidence interval (dotted lines).

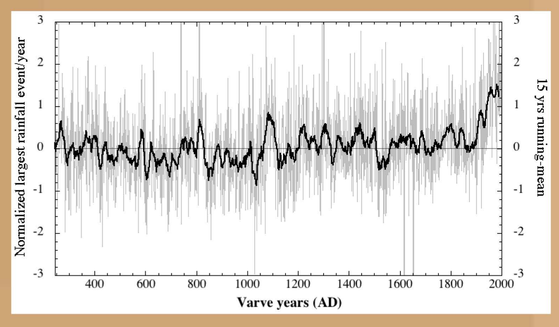


Fig. 8 Large rainfall events increase at ~AD 1920 with highest levels after ~ AD 1950. This increase is similar to the increase of temperatures documented by Kaufman et al. (2009). The peak at ~AD 1100 appears to be a strong anomaly similar to what is seen at the beginning of the 20th century. This could also be linked to warmer temperatures recorded in the Northern Hemisphere according to Moberg et al. (2005).

Conclusion

Grain size signal is different compared to thickness signal.

Our sedimentary record is sensitive to large rainfall events, particulraly when warm conditions predate the rain events. This is supported by process work at Cape Bounty (Dugan et al. 2009; Lewis et al. 2011)

Rain events at East Lake increased to unprecedented levels in the 20th century compared to the last 1,750 years.

Lapointe F, Francus P, Lamoureux F S, Saïd M, Cuven S. (2012) 1,750 years of large rainfall events inferred from particle size at East Lake, Cape Bount, Melville Island, Canada. Journal of paleolimnology: 47 (4) doi: 10.1007/s10933-01209611-8