Presence of laminated sediments in relation to depth: An evaluation of three fjord-like lakes in the Québec North Shore

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Introduction

In the Québec North Shore region, three lakes are under study for the possible occurrence of annually laminated (varved) sediments.

Objectives:
(i) Identify the sedimentary facies,
(ii) Gain understanding of paleolimnological conditions that influence the deposition of laminated sediments in the lakes, and
(iii) Evaluate the relationship between the presence of laminated sediments and lake morphometry through the application of morphological heuristics.

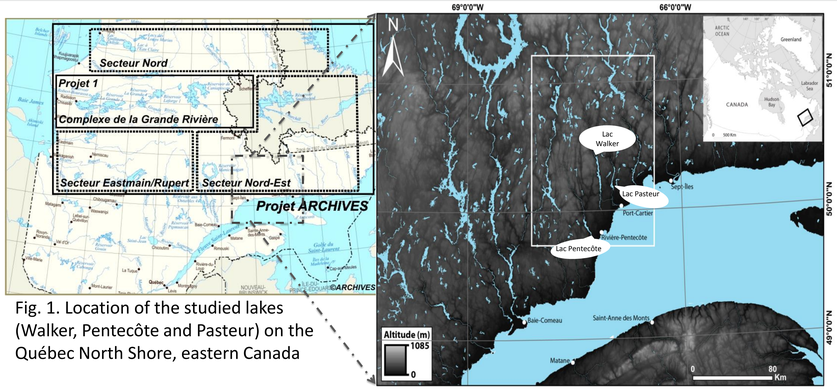


Fig. 1. Location of the studied lakes (Walker, Pentecôte and Pasteur) on the Québec North Shore, eastern Canada

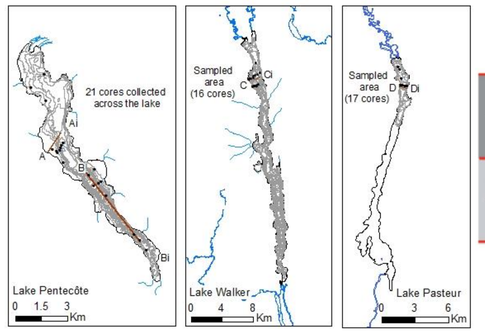


Fig. 2. Maps showing the sampled region in each lake

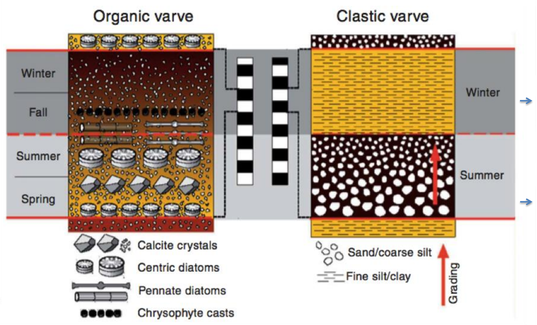
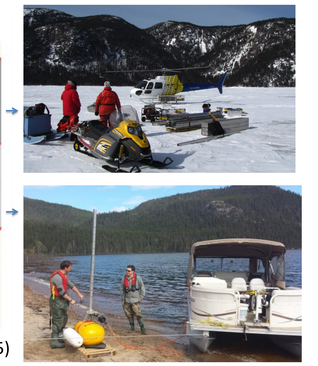


Fig. 3. Simplified model of varve formation (Zolitschka et al. 2015)



Methodology

- Bathymetric survey
- Seismic survey
- CT-scan

Photo: INRS-ETE

- Lithological description
- Multi-sensor core logging
- X-ray microfluorescence

Photo: INRS-ETE

- Radiocarbon dating
- Thin-section image analysis

Table 1. Some characteristics of the studied lakes

Lake	Latitude (°)	Longitude (°)	Basin area (km²)	Lake area (km²)	Maximum depth (m)	Altitude (m)
Pentecôte	49.867	-67.333	1748	18.9	130	88
Pasteur	50.217	-66.067	740	19.3	70	88
Walker	50.267	67.15	2187	41	280	119

Table 2. The potential for preservation of varved sediments and thermal condition in the studied lakes based on inference from heuristics

Lake	area (ha)	Zm	Z_r (%) Eqn. 1	Zm_1 Eqn. 2	Can lake preserve varves? Eqn. 2	Zm_m Eqn. 3	Can lake preserve varves? Eqn. 3	Zm_d Eqn. 4	Prevalent thermal condition Eqn. 4
Pentecôte	1890	130	2.7	71.5	Yes	27.6	Yes	25.4	Dimictic
Pasteur	1930	70	1.4	72.5	No	27.7	Yes	25.5	Dimictic
Walker	4100	280	3.9	89.8	Yes	34.6	Yes	30.8	Dimictic

Morphological heuristics

- Relative depth $Z_r = 50Z_{max}\sqrt{\pi}/\sqrt{}$ Eqn. 1 (Hutchinson, 1957)
- Critical boundary, $Zm_1 = 7.78A_0^{0.294}$ Eqn. 2 (Larsen & MacDonald, 1993)
- Maximum critical boundary, $Zm_m = 3.0\ A_0^{0.294}$ Eqn. 3 (Larsen & MacDonald, 1998)
- Critical depth, $Zm_d = 3.85\ A_0^{0.25}$ Eqn. 4 (Gorham & Boyce, 1989; Zolitschka et al. 2015)

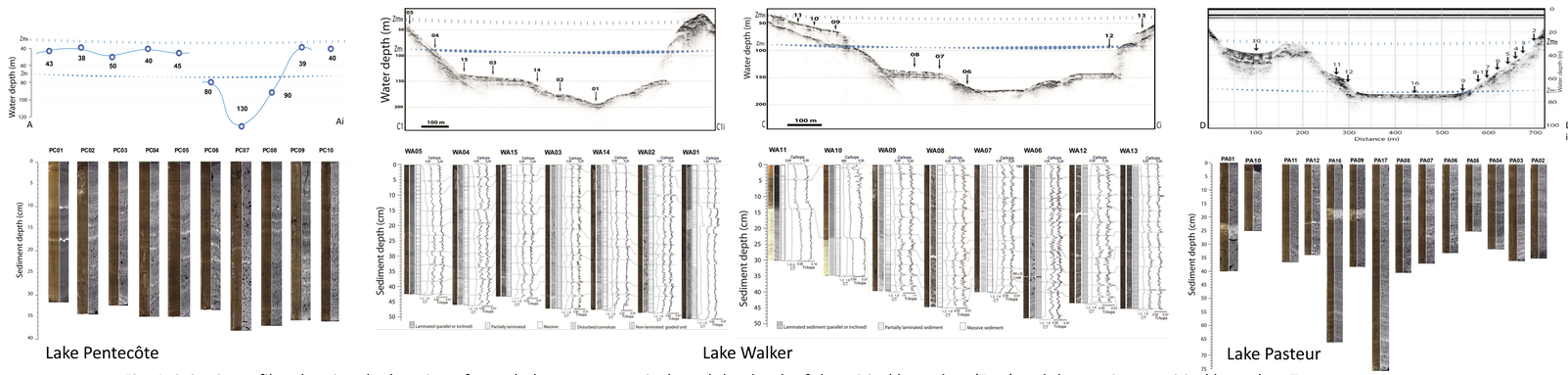
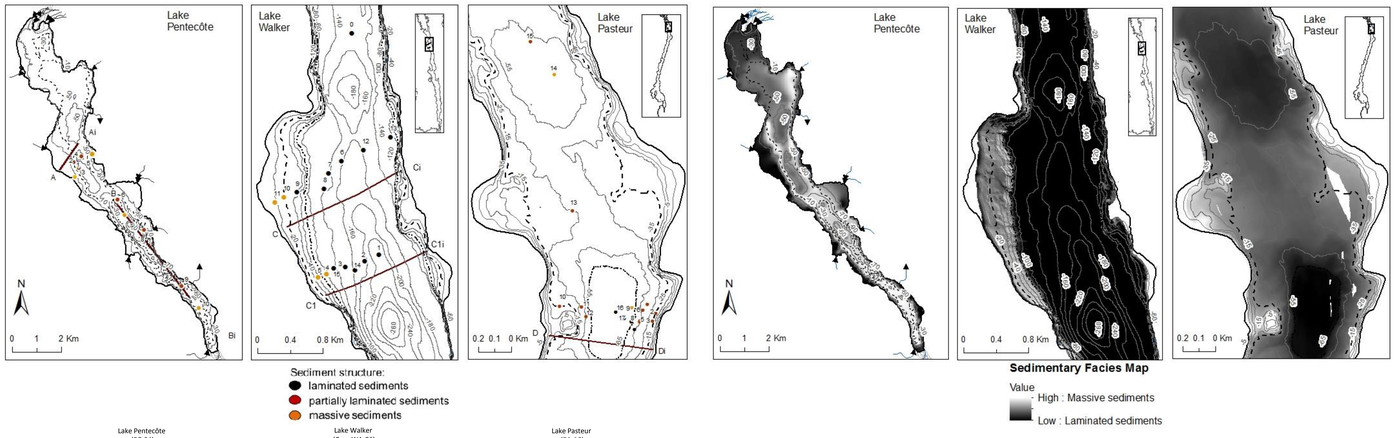
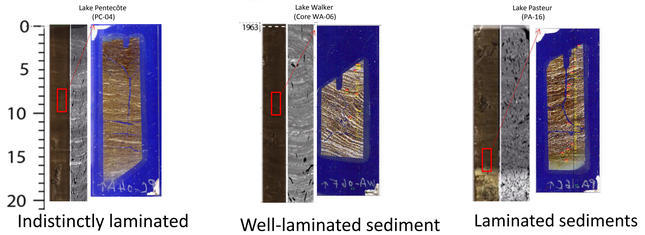


Fig. 4. Seismic profiles showing the location of sampled cores, respectively and the depth of the critical boundary (Zm_1) and the maximum critical boundary Zm_m . (Below) Digital photos, CT-scan images and profiles of geochemical data from X-ray microfluorescence

Results

Facies analysis





Indistinctly laminated homogenous mud facies

Well-laminated sediment facies, possibly varved

Laminated sediments and hemipelagic mud

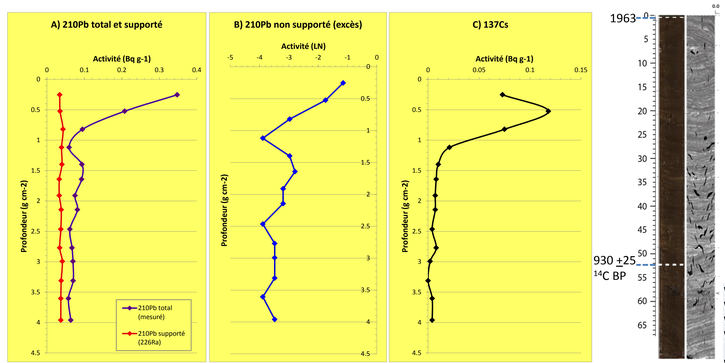
Summary: Factors affecting distribution of laminated sediment facies

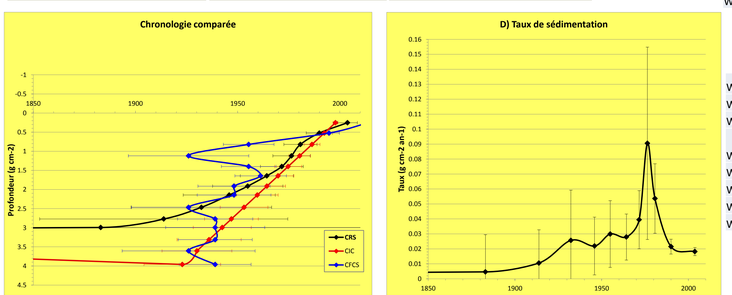
Lake Walker - Prevalence of deep basin appears to be the most favourable factor
- Seasonal or permanent axonia due to increasing in salinity with depth

Lake Pentecôte - Presence of gentle to flat lake bottom should be favourable but shows less influence likely due to concentric hydrological pattern

Lake Pasteur - Presence of gentle to flat lake bottom is favourable at relatively shallow depths likely due to prolonged absence of sediment-water mixing

Radiocarbon dating





Age-Depth Model of Lake Walker

Graph showing sedimentation rate

Varve counting by image analysis

Lamina no	Start	End	Thickness	Depth (mm)		
WA-06A-1	0	1,471	1,471		2013	
WA-06A-2	1,471	2,275	0,804	2,275	2012	
WA-06A-3	2,275	4,265	1,99	4,265	2011	
						Cs 137 peak supposed from
WA-06A-4	4,265	6,265	2	6,265	2010	depth vs Cs peak curve
WA-06A-5	6,265	6,922	0,656	6,921	2009	
WA-06A-6	6,922	8,594	1,672	8,593	2008	
WA-06A-7	8,594	9,038	0,445	9,038	2007	
WA-06A-8	9,038	9,419	0,381	9,419	2006	
WA-06A-9	9,419	9,895	0,476	9,895	2005	
						Age difference w.r.t. Cs peak: 2010 - 1963 = 47 years
WA-06A-47	38,756	38,978	0,222	38,978	1967	
WA-06A-48	38,978	39,91	0,931	39,909	1966	
WA-06A-49	39,91	40,301	0,392	40,301	1965	
WA-06A-50	40,301	41,074	0,773	41,074	1964	
						Cs 137 peak supposed from
WA-06A-51	41,074	42,016	0,942	42,016	1963	literature
WA-06H-2	0,804	1,619	0,815	363,152	1641	
WA-06H-3	1,619	2,593	0,974	364,126	1640	
WA-06H-4	2,593	3,63	1,037	365,163	1639	
						Supposed C14 date
WA-06H-5	3,63	4,096	0,466	365,629	1638	(36.5 cm from surface)
WA-06H-6	4,096	5,98	1,884	367,513	1637	
WA-06H-7	5,98	8,012	2,032	369,545	1636	
WA-06H-8	8,012	9,546	1,535	371,08	1635	
WA-06H-9	9,546	11,176	1,63	372,71	1634	

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