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Identification and dating of a key Late Pleistocene stratigraphic unit in the St. Lawrence Estuary and Gulf (Eastern Canada)

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A B S T R A C T

A recently acquired ~8 m-long sediment core along with high-resolution seismic reflection and sub-bottom profiler sections allowed the identification, characterization and dating of a widespread seismic unit extending from the head of the Laurentian Channel (Lower St. Lawrence Estuary) to Honguedo Strait (Gulf of St. Lawrence), Eastern Canada. This seismic unit (labelled unit 2) is characterized by a series of parallel high-amplitude reflections with thicknesses ranging from 68 m near the head of the Laurentian Channel to <5 m in Honguedo Strait. This seismic unit is generally observed below a very thick sequence of postglacial sediments that can reach >250 m in the St. Lawrence Estuary, leaving it very difficult to be reached by conventional coring operations. Here, we reveal how we were able to trace and core this seismic unit in an area where it lays closer to the seafloor near the southern wall of the Laurentian Channel in the Lower St. Lawrence Estuary. This seismic unit consists of two sedimentary facies: sandy mud including ice-rafted debris (IRD) underlying faintly laminated to homogenous and plastic silty clays. Based on the sedimentary facies, we interpret the upper clays as ice-distal glaciomarine sediments and the lower sandier sediments as ice-proximal glaciomarine sediments. This interpretation is further supported by the fact that no seismic nor sediment facies present above seismic unit 2 throughout the Estuary and Gulf of St. Lawrence can be linked to glacial (i.e., ice-contact sediments such as till, moraines, esker, etc) sediments. Seismic unit 2 is highly disturbed by iceberg scouring in the Gulf of St. Lawrence where it is found at shallower depths, indicating that it was deposited during deglaciation. The available AMS ^{14}C dates obtained in the ice-proximal glaciomarine sediments indicate that the lower part of seismic unit 2 was deposited during local re-advances or stillstands of the Laurentide Ice Sheet margins in the Goldthwait Sea that began at or before the Younger Dryas cold event (11 100–10 000 yr BP) and that seismic unit 2 can be used as a chronostratigraphic marker throughout the St. Lawrence Estuary and northwestern Gulf of St Lawrence.

1. Introduction

The St. Lawrence Estuary and Gulf (Fig. 1) are characterized by a sedimentary sequence more than 400 m thick in certain areas (Syvitski and Praeg, 1989; Duchesne et al., 2007), where recent sedimentation rates are >1 m/ka (e.g., Smith and Schafer, 1999) and reached >30 m/ka (St-Onge et al., 2003) during the late deglaciation as the Laurentide Ice Sheet was retreating rapidly towards the hinterland. These very high-sedimentation rates in combination with the presence of >400 m of unconsolidated sediments suggest the preservation of a very detailed Quaternary sequence. However, only the first upper 51 m of sediments have been cored so far (St-Onge et al., 2003), leaving interpretation of much of the Quaternary stratigraphy below open for speculation.

The compilation and recent acquisition of seismic lines from the St. Lawrence Estuary and Gulf reveal a widespread seismic unit extending from the head of the Laurentian Channel (Lower St. Lawrence Estuary) to Honguedo Strait (Gulf of St. Lawrence) (Figs. 2 and 4). This seismic unit is generally observed below a very thick sequence of postglacial sediments that can reach >250 m in thickness, leaving it very difficult or impossible to be reached by conventional piston coring operations. Here, we show how we trace, core and date this seismic unit in the Lower St. Lawrence Estuary and reveal that this unit consists of ice-proximal and ice-distal glaciomarine sediments deposited during deglaciation. This discovery has implications for understanding the thick Quaternary

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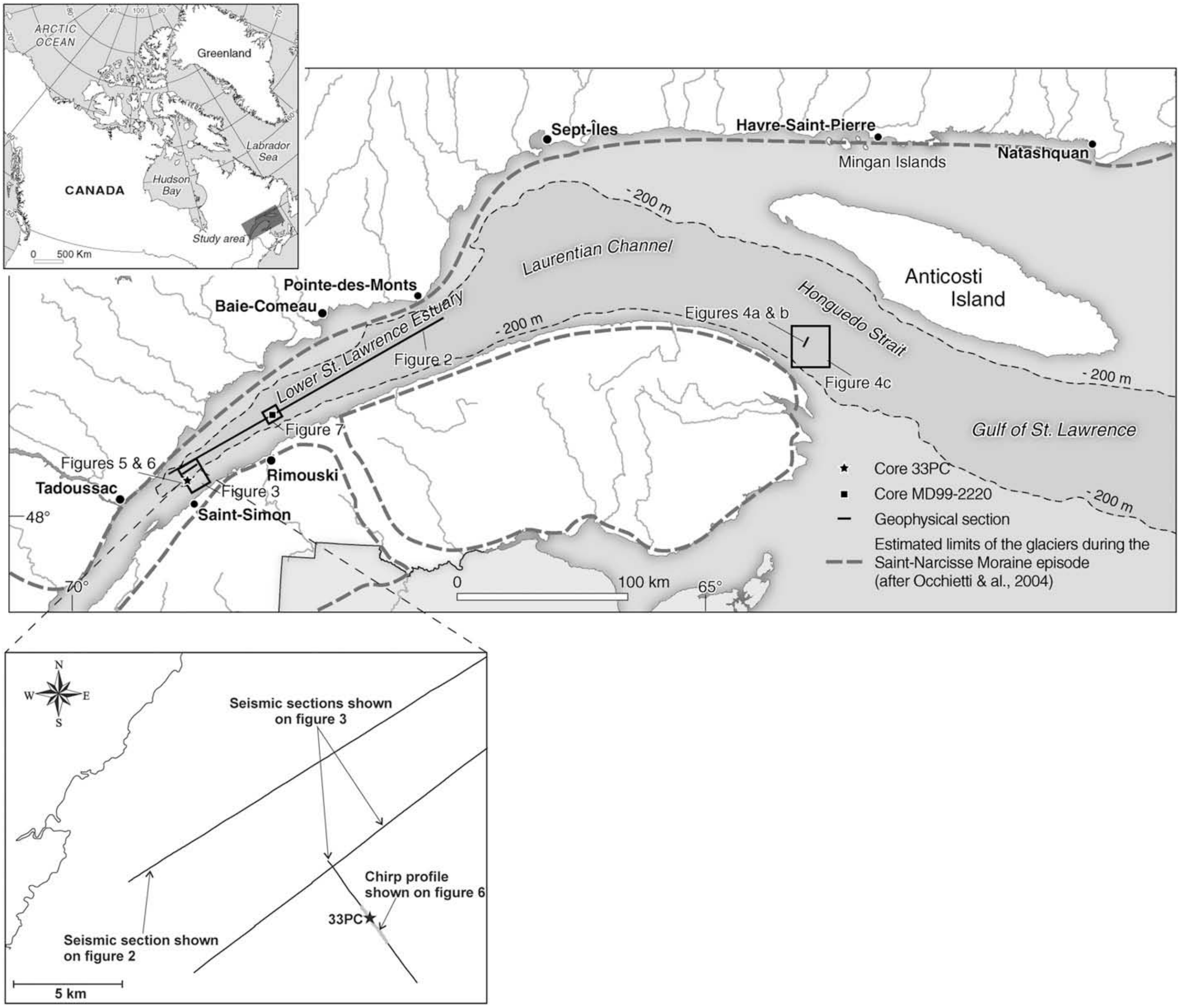

Fig. 1. Location of the seismic sections, cores and localities mentioned in the text. Also illustrated are the estimated limits of glaciers during the St. Narcisse Moraine (correlative with the Younger Dryas) episode (Occhietti et al., 2004), as well as the Laurentian Channel delimitated by the −200 m isobath. Inset figure: location and orientation of the seismic lines presented in Figs. 2, 3 and 6.

sequence observed in the St. Lawrence Estuary and Gulf and for its potential use as a widespread deglacial chronostratigraphic marker.

2. Stratigraphic background

Previous work (Syvitski and Praeg, 1989) based mostly on high-resolution seismic stratigraphy allowed the identification of five regional seismic stratigraphic units in the St. Lawrence Estuary that were interpreted as, from the base to the top: 1) ice-contact sediments deposited by grounded glacial ice; 2) ice-proximal glaciomarine sediments deposited in a high-energy environment located near the ice margin; 3) ice-distal glaciomarine sediments deposited by rain-out of suspended sediments; 4) paraglacial deltaic and prodeltaic sediments; 5) postglacial sediments deposited under modern hemipelagic conditions (Table 1). The longest piston core retrieved (51 m) in the St. Lawrence Estuary confirms the presence of the ice-distal glaciomarine and postglacial sediment units reported by Syvitski and Praeg (1989). However, the lower seismic units interpreted by these authors as ice-contact and ice-proximal glaciomarine deposits were not reached by the coring operations (St-Onge et al., 2003; Table 1). In addition, a detailed sedimentological and palynological record drilled onshore at Île-aux-Coudres (Occhietti et al., 1995), in the middle of the St. Lawrence Estuary, revealed the presence of glacial Illinoian and interglacial Sangamonian sediments (Marine Isotopic Stage 6–5e, 130–80 ka; Occhietti et al., 1995). This later study led Massé (2001) to hypothesize that, among the seven seismic stratigraphic units they recognized in the St. Lawrence Estuary, the three lowermost units consist of deltaic sediments deposited during the last three interglacial episodes (Table 1), while the four uppermost units are related to Late Pleistocene and Holocene deltaic sedimentation. In the Gulf of St. Lawrence, previous work based on high-resolution seismic stratigraphy and piston coring has allowed, from the Late Pleistocene to the Holocene, the identification of till, glaciomarine sediments and postglacial muds (Josenhans and Lehman, 1999; Table 1).

More recently, high-resolution seismic-reflection surveys were conducted in the Lower St. Lawrence Estuary to study the

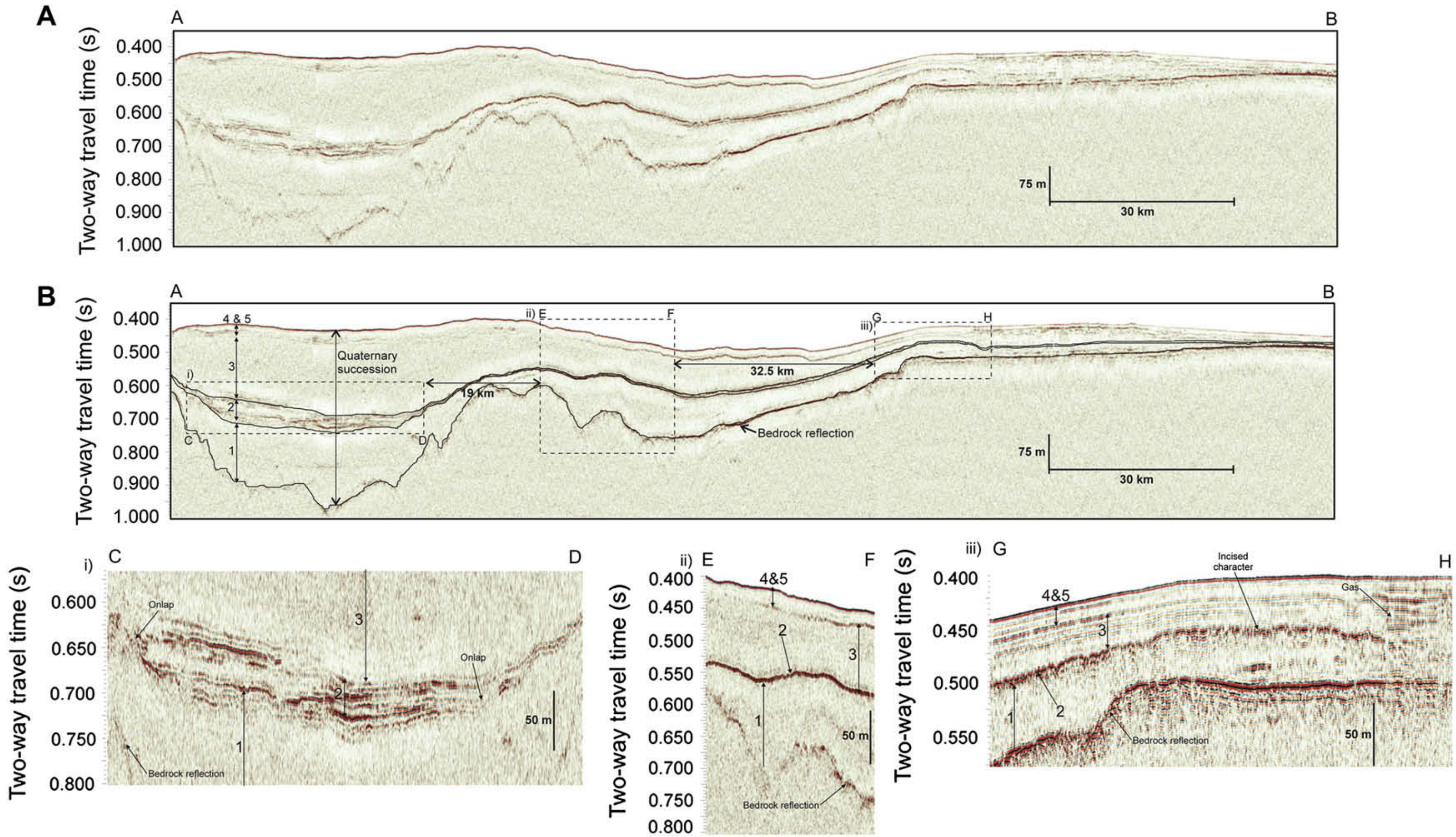

Fig. 2. Seismic unit 2 within the Lower St. Lawrence Estuary Quaternary succession. (A) Uninterpreted and (B) interpreted seismic sections. Note the change of depth, thickness and seismic character (imaged on i, ii and iii) of the unit along the basin. See Fig. 1 for location. Note the absence of a seismic signature typical of till.

Table 1
Previous seismic and lithological units from the St. Lawrence Estuary and Gulf and their chronostratigraphic interpretation

Syvitski and Praeg (1989)	Josenhans and Lehman (1999)	Massé and Long (2001)	St-Onge et al. (2003)	Duchesne et al. (2007)
Seismo-stratigraphic units: St. Lawrence Estuary	*Seismo-stratigraphic units: Gulf of St. Lawrence*	*Seismic sequences: St. Lawrence Estuary*	*Lithological units: St. Lawrence Estuary*	*Seismo-stratigraphic units: St. Lawrence Estuary*
1: Ice-contact sediments, last glaciation/deglaciation	1: Till, last glaciation	4: Interglacial sediments, Aftonian[a]		1: No chronostratigraphic interpretation
		3: Interglacial sediments, Yarmouthian[b]		
2: Ice-proximal sediments (glaciomarine), last deglaciation	2: Glaciomarine sediments, last deglaciation includes ice-proximal and ice-distal sediments	2: Interglacial sediments, Sangamonian, (MIS 5)		2: No chronostratigraphic interpretation
3: Ice-distal sediments (glaciomarine), last deglaciation			1: Glaciomarine sediments, last deglaciation	3: Holocene sediments, correlated to St-Onge et al. (2003) unit 1
4: Paraglacial deltaic sediments, last deglaciation				
5: Postglacial sediments	3: Postglacial sediments	1: Late Pleistocene to Holocene sediments, comprises units 1–5 of Syvitski and Praeg (1989), 1–3 of Josenhans and Lehman (1999), 1–2 of St-Onge et al. (2003) and 3–8 of Duchesne et al. (2007)	2: Postglacial sediments	4: Postglacial sediments, correlated to St-Onge et al. (2003) unit 2 5: Postglacial sediments, correlated to St-Onge et al. (2003) unit
				6: Local fan deposits 7: Mass wasting deposits 8: Local contourite: units 6–8 are local units with various stratigraphic positions

MIS, Marine Isotopic Stage. Note: In this paper, we use the seismic units as defined by Duchesne et al. (2007).
[a] North American equivalent of the Günz–Mindel Interglacial.
[b] North American equivalent of the Mindel–Riss Interglacial.

geometrical relationships between the bedrock topography and eight recognized seismic units (Duchesne et al., 2007; Table 1). Units 1 and 2 have a highly variable thickness and fill most of the two major bedrock depressions that exist in the Lower St. Lawrence Estuary. Unit 3 is present over the entire Lower St. Lawrence Estuary basin, partly infilling ponded-basins found on the bordering shelves of the estuary. Units 4 and 5 have a constant thickness, suggesting that they were deposited in a hemipelagic setting. Units 6, 7 and 8 were deposited by local sedimentary processes associated with submarine fans, mass wasting, and contourites along the flanks of the Laurentian Channel. Due to the lack of long sediment cores, Duchesne et al. (2007) restricted their interpretation to the upper units (3–8), where groundtruthing by piston cores was available. In their interpretation, seismic units 1 and 2 are of unknown age, whereas units 3 and 4 can be respectively correlated with glaciomarine clays ($\geq$7.7 ka BP or $\sim$8500 cal BP) and postglacial sediments ($\leq$7.7 ka BP or $\sim$8500 cal BP) identified and dated by St-Onge et al. (2003). For the rest of the paper, we will use the seismo-stratigraphy reported by Duchesne et al. (2007).

3. Methods

3.1. Geophysical surveys and data processing

Seismic-reflection and subbottom profiler sections were collected between 2003 and 2007 during five different cruises onboard the R/V Coriolis II. During these surveys, $\sim$3300 km of high-resolution (vertical resolution: $\sim$3 m), $\sim$1700 km of very high-resolution (vertical resolution: $\sim$0.6 m) seismic data and $\sim$1000 km of subbottom profiles (vertical resolution: $\sim$0.3 m) data were collected (Bellefleur et al., 2006; Campbell, 2007; Cauchon-Voyer et al., 2007; Bolduc, 2008). High-resolution seismic-reflection system consisted of a EG&G (9 electrodes) sparker array operated at an output energy of 2–8 kJ with a peak frequency of 200 Hz, one 12 m-long single-channel streamer containing 23 elements and one 260 m-long multichannel streamer including 48 receivers (2 elements each). The Huntec Deep-Tow-System (DTS) was used to collect very high-resolution sections. This system incorporates a boomer plate, an energy supply and two receiving hydrophones housed in an underwater towfish (McKeown, 1975). The Huntec DTS was towed at a depth of $\sim$100 m beneath the sea surface. Output energy was set to 540 J and peak frequency was 1500 Hz. In addition to the internal receivers, a 7.3 m-long single-channel streamer counting 24 elements was used to record the reflections. Subbottom profiles were gathered with a 3×3 hull-mounted chirp array (EdgeTech X-Star) which has output energy of 2 kJ and a peak frequency of 4500 Hz.

Processing of the high-resolution data included band-pass filtering, time-variant spectrum balancing, source signature deconvolution, time-variant predictive deconvolution, FX-prediction noise filtering and automatic gain control, whereas band-pass and swell filtering, source signature deconvolution and automatic gain control were applied to the very high-resolution data (Bellefleur et al., 2006; Duchesne and Bellefleur, 2007; Duchesne et al., 2007). For the chirp data, band-pass filtering, trace mixing, FX-prediction noise filtering and automatic gain control were part of the processing routine. In addition and for a first order approximation, we also converted the travel time into meters by using the average seismic velocity (1520 m/s) determined in the Quaternary sediments by stacking velocity analysis (Bellefleur et al., 2006).

In the Honguedo Strait, $\sim$2200 km^2 of multibeam bathymetry data were collected using a Simrad EM1002 system (Bolduc et al., 2008). This multibeam echosounder is a short to medium range high-resolution system with 111 narrow beams of 2×2 degrees and an operating frequency of 95 kHz. Soundings were located with a Pos/MV (position and orientation system for marine vessels) that uses differential corrections from the Canadian Coast Guard DGPS network. Processing steps included the removal of spikes from heave,

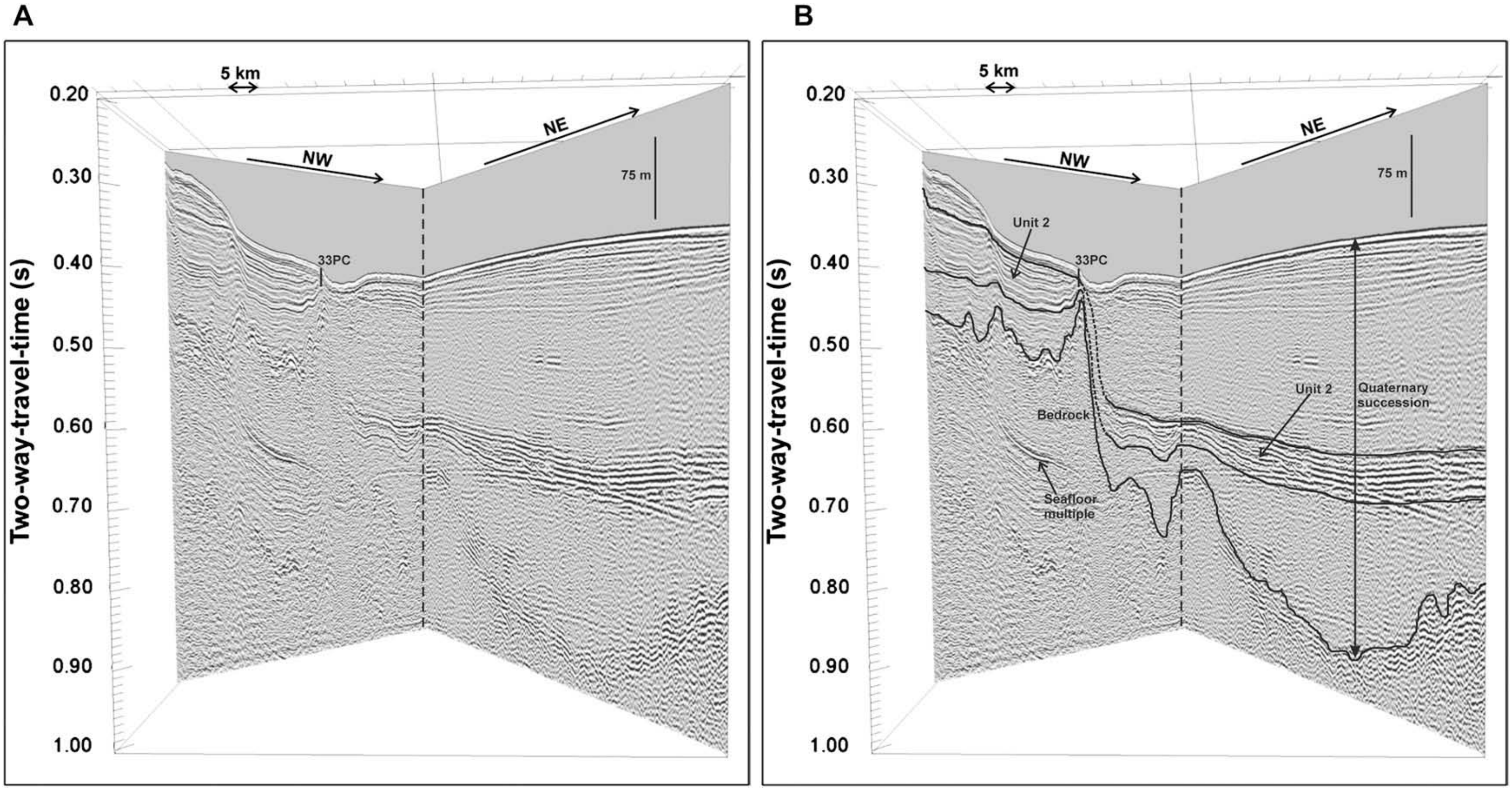

Fig. 3. Core 33PC displayed on a fence diagram. This seismic section is tied to a SW–NE trending section which runs along the entire basin (see Fig. 1 for location.). The depth of the bedrock controls the position of unit 2 within the seismic stratigraphy of the basin. (A) Uninterpreted and (B) interpreted seismic sections.

Table 2
Radiocarbon dates

Core	Depth (cm)	Lithological unit	Material	Conv. age (yr BP)	Corr. conv. age (yr BP), −400 years	Corr. conv. age (yr BP), −800 years	Lab #
33PC	323	Glaciomarine ice distal (L2)	Shell fragment	10 020 ± 80	9620 ± 80	9220 ± 80	TO-13656
33PC	574	Glaciomarine ice distal (L2)	Shell fragment	10 510 ± 80	10 110 ± 80	9710 ± 80	TO-13657
33PC	775	Glaciomarine ice proximal (L1)	Shell fragment	10 990 ± 60	10 590 ± 60	10 190 ± 60	Beta-239882
33PC	794	Glaciomarine ice-proximal (L1)	Shell fragment	10 785 ± 25	10 385 ± 25	9985 ± 25	UCIAMS-40610

Conv. age, ^{14}C conventional age; Corr. conv. age (yr BP), ^{14}C conventional age corrected by −400 years or −800 years to account for the marine reservoir effect (see text for details). For both dates in the ice-proximal sediments (L1), the ages fall in the Younger Dryas time interval (11 100–10 000 yr BP; Broecker, 2006) regardless of the correction applied.

pitch, roll and GPS tide data, merging of tide data with the soundings, integration of water column velocity profiles with the soundings for refraction corrections and exclusion of anomalous soundings.

3.2. Core sampling and processing

Core COR0703-33PC (hereinafter referred to as 33PC) was collected near the southern wall of the Laurentian Channel in the

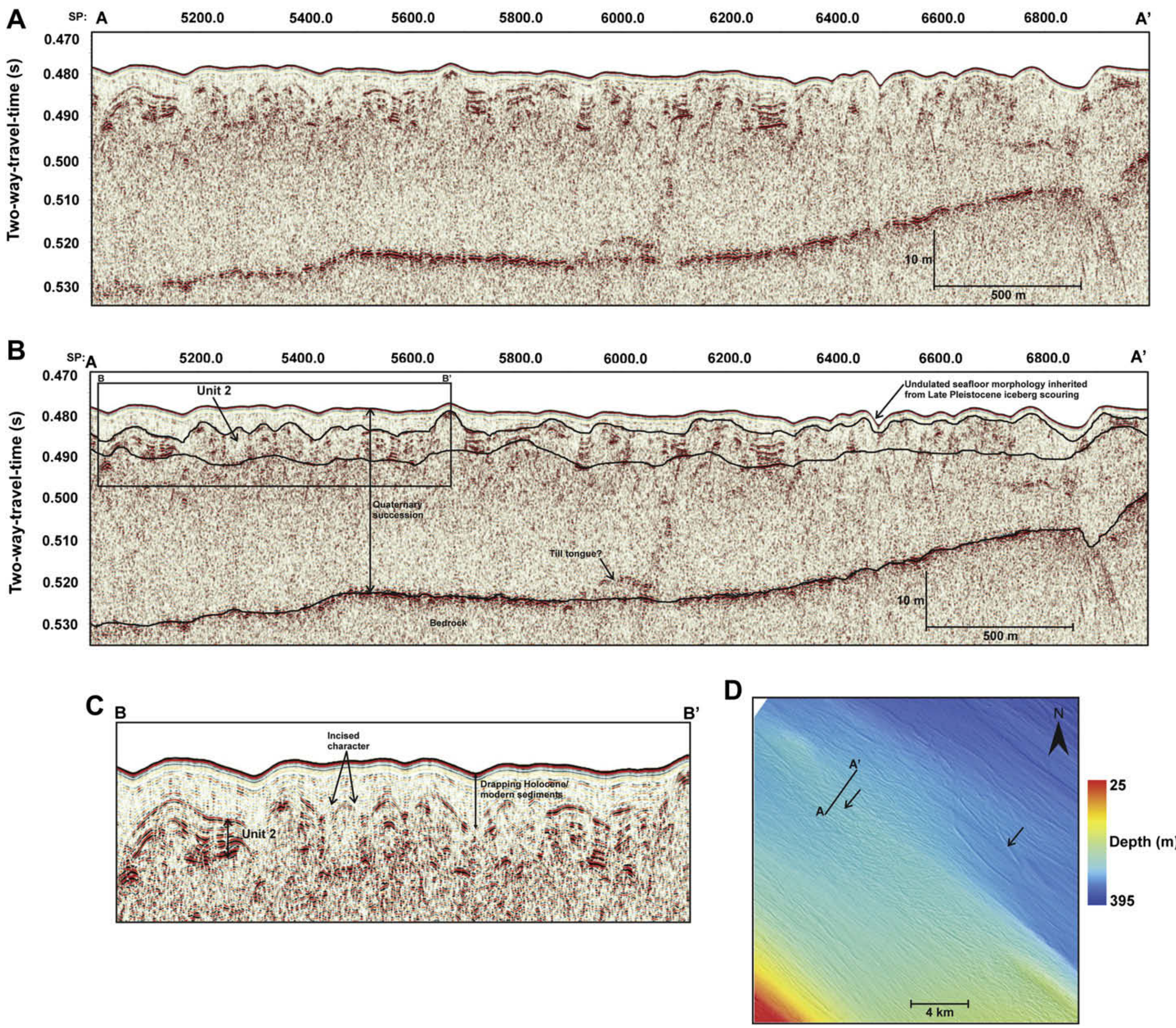

Fig. 4. Seismic section collected in Honguedo Strait showing the relationship with the bedrock, Quaternary seismic stratigraphy and seafloor morphology. (A) Uninterpreted and (B) interpreted seismic sections. Note the relatively thin unit of Holocene sediments draped on unit 2 compared to what is observed in the Lower St. Lawrence Estuary. (C) Enlargement of a portion of (B) illustrating the internal geometry of seismic unit 2. (D) Multibeam bathymetry of a portion of Honguedo Strait on which the seismic section displayed in (A) is located. Arrows point out examples of seafloor morphology inherited from buried iceberg scours. See Fig. 1 for location.

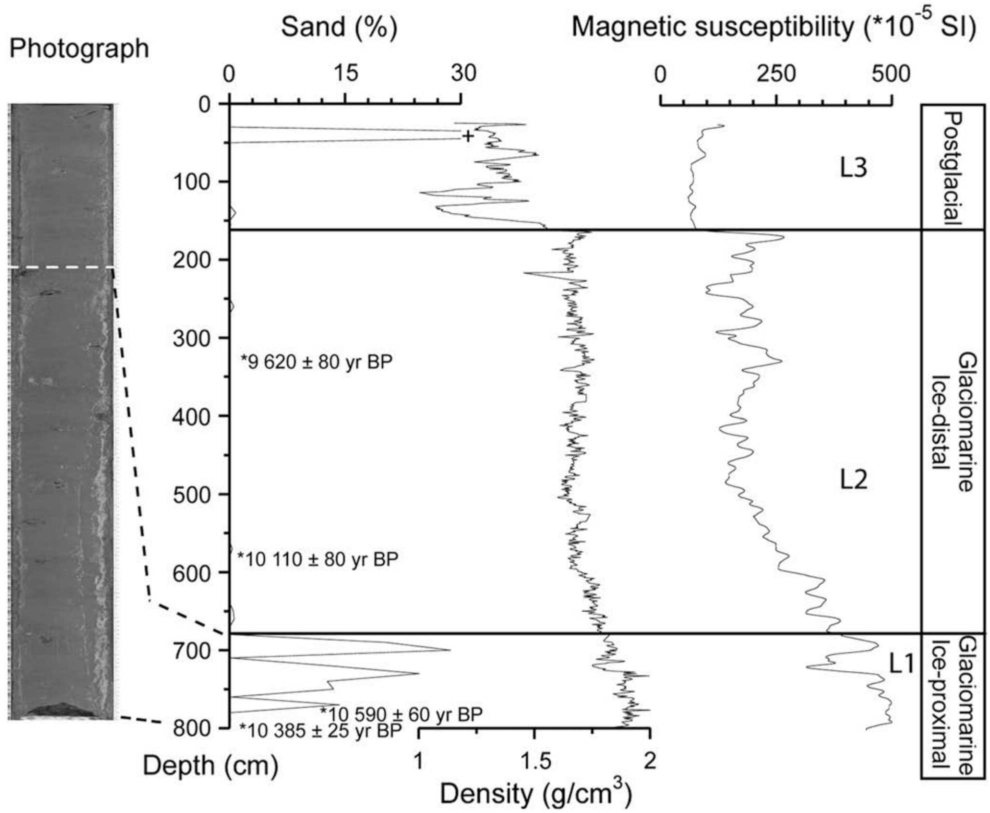

Fig. 5. Lithology and interpretation of the depositional environment of core 33PC. Also highlighted is the transition from lithological unit L1 (ice proximal) to L2 (ice distal) and the available ^{14}C AMS dates. The ^{14}C dates are illustrated as conventional radiocarbon dates corrected by −400 years. The photograph was obtained on the 148-cm long basal core section.

St-Simon area (Figs. 1 and 3) by piston coring onboard the R/V Coriolis II in 2007. The ~8 m-long core 33PC was analyzed for wet bulk density and volumetric whole core magnetic susceptibility using a GEOTEK Multi Sensor Core Logger. It was then split, photographed, described and sub-sampled for grain size measurements. Grain size analyses were performed at the *Institut des sciences de la mer de Rimouski* (ISMER) at 10 cm intervals. Prior to grain size analyses, the samples were added to a Calgon electrolytic solution (sodium hexametaphosphate) and rotated for about 3 h using an in-house rotator. The samples were then sieved (2 mm) and disaggregated in an ultrasonic bath for 90 s prior to their analysis. Disaggregated samples were then analyzed with a Beckman-Coulter LS-13320 (0.04–2000 μm). The results of at least two runs were averaged. The average continuous disaggregated particle size distribution output was processed using the Gradistat software for sediment parameters (Blott and Pye, 2001).

3.3. Radiocarbon dating

Four shell fragments from core 33PC were sampled and dated by accelerator mass spectrometry (AMS) ^{14}C at the Keck-Carbon Cycle AMS facility (University of California, Irvine), Beta Analytics and IsoTrace laboratories (Table 2). The dates are reported using Libby's half-life and corrected for natural and sputtering fractionation ($\delta^{13}C = -25‰$ vs. VPDB). To account for the apparent age of the dissolved inorganic carbon reservoir, a correction of −400 years was applied. This correction was shown to be appropriate for the St. Lawrence Estuary during the last 7.7 ka BP (St-Onge et al., 2003). However, during the Younger Dryas (YD) episode, a prominent cold interval between 11 100 and 10 000 yr BP associated with a weakening of the thermohaline circulation (e.g., Clark et al., 2001; Broecker, 2006), this correction may have varied between 300 and 800 years (Bard et al., 1994; Austin et al., 1995; Bondevik et al., 2006). Because no clear regional correction is currently available for the St. Lawrence Estuary during the YD (e.g., Occhietti et al., 2004), the dates are also reported using a maximum reservoir correction of −800 years. Finally, for comparison with previous studies and because the Younger Dryas interval is complex in terms of ^{14}C atmospheric concentrations and reservoir corrections (e.g., Muscheler et al., 2008), all ages are reported in radiocarbon rather than calibrated years.

4. Seismic unit 2

Seismic unit 2 is characterized by a series of parallel high-amplitude reflections (Duchesne et al., 2007). The character of the seismic reflections changes along the strike of the Lower St. Lawrence Estuary, from flat in the upstream part to wavy and even discontinuous in the downstream part. Seismic unit 2 has a wedge shape with a maximum thickness of 68 m in the upstream region of the Lower St. Lawrence Estuary, before diminishing downstream to <8 m in the Pointe-des-Monts area and <5 m in Honguedo Strait (Figs. 2 and 4). Unit 2 generally drapes unit 1, including major escarpments. Unit 2 is observed under a thick sediment sequence reaching >250 m in the Lower St. Lawrence Estuary and thinning out to <5 m in the Honguedo Strait (see Fig. 4). Nevertheless, unit 2 can be identified and traced to a depth of ~3 m below the seabed (see Fig. 3) in the Lower St. Lawrence Estuary, near the southern wall of the Laurentian Channel in the St-Simon area (see Fig. 1). Seismic unit 2 is found at great depths in the Laurentian Channel, reaching >470 m below the water surface at the sampling site of core MD99-2220 (St-Onge et al., 2003). Unit 2 is very disturbed in the Gulf of St. Lawrence. In this sector, it is characterized by discontinuous

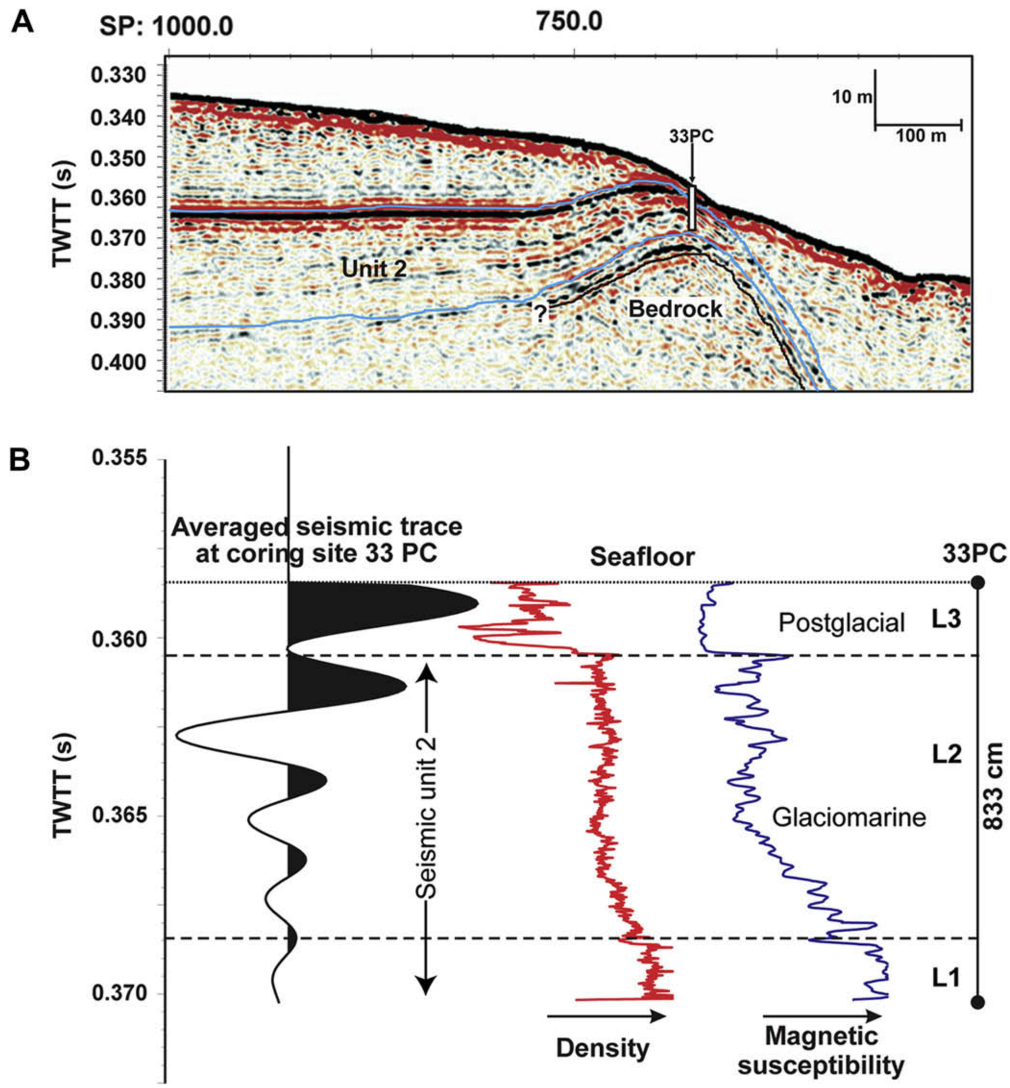

Fig. 6. (A) Location of core 33PC on a subbottom profiler section. (B) Correlation of the density and magnetic susceptibility profiles of core 33PC with the average seismic trace recorded at the coring site. Note the clear shift at the top of seismic unit 2. This sudden increase of density is tied with the second peak of the subbottom profiler trace denoting a change of the elastic properties of the geological medium controlling the reflection of the seismic energy. See Fig. 1 for location.

undulating parallel reflections, hyperbolae and a chaotic surface morphology, and is conformably draped by ~3 m of sediments (see Fig. 4). Multibeam bathymetry coverage reveals several furrows correlated with the undulating reflection pattern of this unit, suggesting that this disturbance is associated with iceberg scouring (see Fig. 4C). The absence of icebergs in the region today and the water depth (~400 m) of the area indicate that the disturbance was produced during deglaciation. It is the much weaker recent sedimentation rates in this area compared to the Lower St. Lawrence Estuary (Smith and Schafer, 1999) that allowed to preserve the signature of these features on the seafloor.

5. Sedimentary facies

Core 33PC was collected near St-Simon (see Fig. 1), where seismic unit 2 can be identified near the seafloor. Three main lithological units are present within core 33PC, from the base to the top (Fig. 5): L1) sandy mud including polished and subangular to subrounded clasts corresponding to ice-rafted debris (IRD); L2) faintly laminated or homogenous and plastic silty clay; and L3) bioturbated silty clay. These three lithostratigraphic units are clearly defined in the density, magnetic susceptibility and percent sand profiles (see Fig. 5). These profiles illustrate that the transition from unit L1 to unit L2 is relatively sharp and occurs between 680 and 690 cm. From the visual description of the core, pebble-size IRD and shell fragments are present below 687 cm (see Fig. 5). Similarly, the transition from L2 to L3 is very sharp and observed at 157 cm. Based on the sedimentary facies, we interpret unit L1 as ice-proximal glaciomarine sediments, unit L2 as ice-distal glaciomarine sediments, and unit L3 as postglacial sediments. This interpretation is consistent with previous studies of sediments from the Laurentian Channel (e.g., Josenhans and Lehman, 1999; St-Onge et al., 2003). The presence of IRD within unit L1 indicates the occurrence of marine-based ice margins in the St. Lawrence Estuary and Gulf during its deposition.

6. Seismic to core correlation

Fig. 6 compares the density and magnetic susceptibility profiles of core 33PC with a subbottom profiler section collected at the sampling location. This comparison highlights the sharp transition from unit L2 to unit L3 and therefore indicates that seismic unit 2 is composed of glaciomarine sediments.

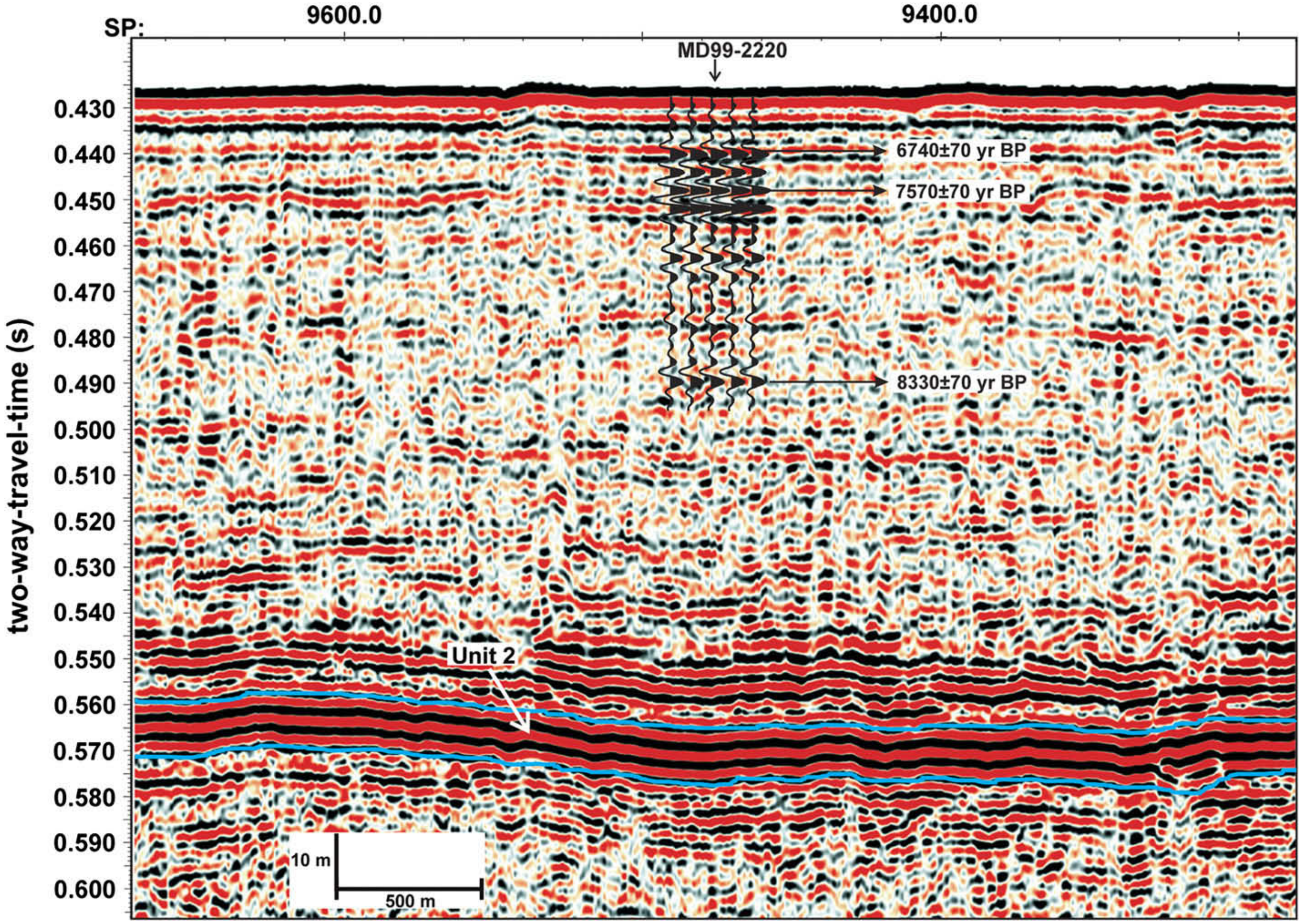

Fig. 7. Synthetic seismogram derived from velocity and density profiles of core MD99-2220 tied to a seismic section. Note the considerable thickness of sediments between seismic unit 2 and the oldest ^{14}C AMS date obtained on the core. See Fig. 1 for location.

7. Age of seismic unit 2

The available AMS ^{14}C dates obtained in units L1 and L2 indicate that most of seismic unit 2 was deposited between ~9600 and 10 600 yr BP. This range confirms that the sediments of units L1 and L2 and thus of seismic unit 2 were indeed deposited in a glaciomarine environment, as the newly deglaciated Lower St. Lawrence Estuary was invaded by the Goldthwait Sea during this period (e.g., Dionne, 1977; Dionne, 2001). The glaciomarine origin of seismic unit 2 is further supported by the absence of seismic and sediment facies above seismic unit 2 that can be associated with ice-contact glacial deposits throughout the St. Lawrence Estuary and Gulf (Mosher and Moran, 2001; Todd et al., 2008). Finally, the disturbed character of seismic unit 2 in the Gulf of St. Lawrence indicates that it represents the last deglacial sediments deposited prior to the iceberg scouring phase and thus eliminates the possibility that seismic unit 2 could be of Sangamonian age (Marine Isotopic Stage 5; see Massé, 2001).

8. Discussion

The sedimentary facies and available AMS ^{14}C dates in L1 indicate that a portion of the lower part of seismic unit 2 was deposited ~10 500 yr BP in an ice-proximal glaciomarine environment. This part of seismic unit 2 thus lies within the YD episode (11 100–10 000 yr BP; Broecker, 2006), suggesting that it was deposited during local re-advances or stillstands of the Laurentide Ice Sheet (LIS) margins in the Goldthwait Sea. This phase began at or before the YD, regardless of the marine reservoir correction applied (Table 2). Similarly, Lajeunesse et al. (2008) recently revealed the presence of ice-proximal glaciomarine deposits, morainal banks and ice-contact submarine fans offshore the city of Sept-Îles and the Mingan Islands, in the northwestern Gulf of St. Lawrence (see Fig. 1 for location). Based on the dates of 10.6 and 10.5 ka BP (conventional ages corrected by −400 years) obtained on pelecypod shells sampled in ice-proximal glaciomarine sediments south of the morainal banks and submarine fans, these authors attributed the later features to the eastward continuation of the St. Narcisse Moraine system (e.g., LaSalle and Elson, 1975; Occhietti et al., 2004), a major morphological feature in southern Québec constructed at the beginning of the YD cooling episode (Occhietti et al., 2004). The position of these ice-contact sediments and landforms south of the ~9.7–9.5 ka BP North-Shore moraine (Dubois and Dionne, 1985) also suggests that they were deposited during the YD. These glacial features and ice-proximal sediments can be observed along the northern shore of the Gulf of St. Lawrence because of the much lower sedimentation rates compared to the St. Lawrence Estuary, where the postglacial sedimentation rates are several times higher (e.g., Smith and Schafer, 1999; St-Onge et al., 2003) and ice-distal glaciomarine sedimentation was more than one order of magnitude higher (Josenhans and Lehman, 1999; St-Onge et al., 2003). For example, in the Lower St. Lawrence Estuary, the top of seismic unit 2 is still more than 100 m below the base of the 51 m-long core MD99-2220 (Fig. 7), whereas in the northern Gulf of St. Lawrence (core HU90-028-020; Josenhans and Lehman, 1999), ice-proximal sediments are observed at ~3.35 m below the seafloor surface.

Onshore, the presence of ice-contact deltas dated between 12.4 and 12.0 ka BP overlying marine clays in the Rimouski area (see Fig. 1) was interpreted by Hétu (1998) to represent an ice re-advance into the Goldthwait Sea, while Dionne and Occhietti (1996) dated fluvioglacial sediments near Tadoussac (see Fig. 1) between 11 and 10.6 ka BP and associated them with the St. Narcisse moraine system. Taken together, all these lines of evidence indicate that the deposition of ice-proximal glaciomarine sediments at or before the YD is observed throughout the St. Lawrence Estuary and Gulf and that the lower part of seismic unit 2 is correlative of these re-advance and stabilisation phases. We propose that seismic unit 2 represents a deglacial chronostratigraphic marker throughout the St. Lawrence Estuary and northern Gulf of St. Lawrence because of: 1) its widespread distribution in the Laurentian Channel from its head to Honguedo Strait, 2) its deposition during and slightly prior to the YD and 3) its correlation with other ice-proximal glaciomarine sediments deposited at or prior to the YD observed either onshore or offshore. Furthermore, the possibility that seismic unit 2 represents pre-Wisconsinan (i.e., Marine Isotopic Stages ≥ 5) sediments as proposed by Massé (2001) and Massé and Long (2001) is now excluded because the lower part of seismic unit 2 is of YD age. Nevertheless, over 150 m of sediments are present below seismic unit 2 in some areas. According to Duchesne et al. (2007), the main characteristics of seismic unit 1 are that it a) unconformably overlies and onlaps the bedrock mostly filling two bedrock troughs located in the upstream part of the study area, b) is preserved as a few discontinuous patches downstream and c) is generally seismically transparent (although it contains a few low amplitude reflections). In addition, in the relatively deep Laurentian Channel of the Lower St. Lawrence Estuary (see Fig. 2), the seismic signature of seismic unit 1 is not typical of ice-contact or sub-glacial sediments (e.g., Syvitski, 1991; Josenhans and Lehman, 1999; Mosher and Moran, 2001; Todd et al., 2008), suggesting that the sediments below the deglacial seismic unit 2 are either a very thick sequence (with very high-sediment accumulation rates) of slightly older deglacial sediments or pre-Wisconsinan sediments (i.e., Marine Isotopic Stages ≥ 5). The presence of pre-Wisconsinan sediments in the St. Lawrence Estuary was also proposed by Syvitski and Praeg (1989) for a regional basin-fill seismic facies observed in the Laurentian Channel in the Lower St. Lawrence Estuary characterized by the lack of stratification representing distinct and different geometries and acoustic patterns from the overlying units. Nonetheless, without further evidence, we cannot rule out either one of these alternatives, highlighting the potential of the St. Lawrence Estuary for the recovery of a very detailed sequence of possibly at least the Last Interglacial/Glacial cycle.

9. Conclusions

This paper reports on the identification of a widespread seismic unit (seismic unit 2) in the St. Lawrence Estuary and Gulf that extends over at least 400 km from the head of the Laurentian Channel (Lower St. Lawrence Estuary) to Honguedo Strait (Gulf of St. Lawrence). This unit is characterized by a series of parallel high-amplitude reflections with thicknesses ranging from 68 m near the head of the Laurentian Channel to <5 m in Honguedo Strait. It is generally observed below a very thick sequence of postglacial sediments, especially in the St. Lawrence Estuary. However, the presence of seismic unit 2 near the surface of the seafloor in the St-Simon area (Lower St. Lawrence Estuary) allowed its sampling for the first time. This seismic unit consists of two sedimentary facies: sandy mud enclosing IRD underlying faintly laminated or homogenous and plastic silty clays. Based on the sedimentary facies and radiocarbon dating, we interpret the upper clays as ice-distal glaciomarine sediments and the lower sandier sediments as ice-proximal glaciomarine sediments. The available AMS ^{14}C dates obtained in ice-proximal glaciomarine sediments indicate that the lower part of seismic unit 2 was deposited during a phase of stabilisation marked by local re-advances of the LIS margin in the Goldthwait Sea that began at or before the YD. This interpretation is supported by terrestrial and marine evidence of the concomitant deposition of ice-proximal glaciomarine sediments, indicating local ice re-advances or stillstands in the Rimouski, Tadoussac, Sept-Îles and Mingan areas. Consequently, seismic unit 2 can be seen as a widespread deglacial chronostratigraphic marker.

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