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Seismic stratigraphy of the lower St. Lawrence River estuary (Quebec) Quaternary deposits and seismic signature of the underlying geological domains

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Abstract: The lower St. Lawrence River estuary is a narrow Quaternary basin filled with several stacked sedimentary units. Recently, high-resolution seismic-reflection surveys conducted in the lower St. Lawrence River estuary permitted identification of eight seismic units overlying three lithotectonic domains with different seismic signatures. Units 1 and 2 have highly variable thickness and fill most of two major bedrock depressions that exist in the study area. Unit 3 is present over the entire lower St. Lawrence River estuary basin, partly infilling ponded basins found on the shoulders of the estuary. Units 4 and 5 have a more constant thickness, suggesting that they were deposited in a hemipelagic setting. Units 6, 7, and 8 result from local processes like the sedimentation of submarine fans, mass-wasting deposits, and contourite drifts occurring along the flanks of the Laurentian Channel. The thickness of the Quaternary succession shows a strong correlation with the bedrock topography, indicating that the lower St. Lawrence River estuary was an effective sediment trap.

Résumé : L'estuaire maritime du Saint-Laurent est un étroit bassin quaternaire où plusieurs unités sédimentaires sont empilées. Récemment, des levés de sismique-réflexion haute résolution effectués à cet endroit ont permis d'identifier huit unités sismiques recouvrant trois domaines lithotectoniques possédant des signatures sismiques distinctes. Les unités 1 et 2 ont une épaisseur très variable et remplissent le plus gros de deux dépressions majeures dans le substratum rocheux présentes au sein de la région d'étude. L'unité 3 couvre la totalité de l'estuaire maritime du Saint-Laurent, occupant une partie des bassins perchés présents au pourtour de l'estuaire. L'épaisseur plus constante des unités 4 et 5 suggère qu'elles ont été déposées dans un environnement hémipélagique. Les unités 6, 7 et 8 résultent de processus locaux comme la sédimentation de cônes sous-marins, de masses glissées et de contourites le long des flancs du chenal Laurentien. L'épaisseur des dépôts quaternaires montre une forte corrélation avec la topographie du substratum rocheux, indiquant ainsi que l'estuaire maritime du Saint-Laurent a été un piège efficace pour les sédiments.

INTRODUCTION

The geology of the St. Lawrence River estuary is a major gap in the current geological understanding of eastern Canada. Due to the poor quality of seismic lines acquired in the late 1970s for the petroleum industry (Société Québécoise d'Initiatives Pétrolières, 1987), the boundaries of Late Proterozoic to Paleozoic lithotectonic domains defined on land are still imprecisely located and their internal architecture is not well documented. Moreover, the correlation between the Quaternary sedimentary succession of the estuary (Syvitski and Praeg, 1989; Massé, 2001) and Quaternary deposits described on land (Fulton, 1989) is still controversial as the succession imaged in the marine domain is thicker by one order of magnitude or more compared to its counterpart on land.

This present study uses high-resolution, single-channel, seismic-reflection sections collected in 2003 and 2004 to improve the understanding of the regional geology of the St. Lawrence River estuary. The main objective of this study is to describe, in a preliminary way, the seismic architecture of the Quaternary sedimentary succession of the St. Lawrence River estuary. This issue is indirectly related to the bedrock geology as the present-day St. Lawrence River sedimentary basin geometry is controlled by inherited geological features. Among them, fault-controlled topographic features recognized on land (Kumarapelli and Saull, 1966; Tremblay et al., 2003) clearly extend into the estuary where they form major depocentre-bounding scarps. Previous studies by Syvitski and Praeg (1989) and Massé (2001) linked geological processes to reflection patterns of the various seismic units. This study aims to analyze the geometrical relationships between the seismic units identified and the bedrock topography.

GEOLOGICAL BACKGROUND

The lower St. Lawrence River estuary is 230 km long, extending from Tadoussac to Pointe-des-Monts in water depths ranging from a few tens of metres on the shelves to more than 350 m in the middle of the Laurentian Channel. The lower St. Lawrence River estuary is roughly parallel with both the Appalachian deformation front and with structures associated with the St. Lawrence rift system (Tremblay et al., 2003), a long-lived system that formed during a Neoproterozoic to Cambrian rifting period (Kumarapelli and Saull, 1966). The north shore of the lower St. Lawrence River estuary consists of Late Proterozoic Grenvillian metamorphic rocks with few outliers of Ordovician autochthonous, carbonate and siliciclastic rocks of the St. Lawrence Platform. The south shore is formed by Early Paleozoic sedimentary rocks belonging to the Appalachian tectonic wedge.

The greater resistance to erosional processes of the Grenvillian metamorphic rocks compared to surrounding domains (St. Lawrence Platform and Appalachian) have been classically advocated to explain the higher relief on the north shore of the lower St. Lawrence River estuary and the general parallelism of the estuary with the Appalachian structural grain.

PREVIOUS STUDIES

Previous geophysical information pertaining to the interpretation of the lower St. Lawrence River estuary Quaternary succession consists of irregularly distributed, high-resolution, single-channel, seismic-reflection profiles (Syvitski and Praeg, 1989; Massé, 2001) that image the Quaternary deposits and the topmost part of the bedrock. Seismic lines discussed in Syvitski and Praeg (1989) and Massé (2001) have variable orientation and spacing. Sampling of the Quaternary sediments provides stratigraphic control for the upper part of the sedimentary succession only and consists of one drill hole (onshore–middle estuary; Occhietti et al. (1995)), two Calypso piston cores (lower estuary; St-Onge et al. (2003)), several piston cores (gulf and lower estuary; Josenhans and Lehman (1999); G. Cauchon-Voyer, M. Henry, G. Desrosiers, P. Lajeunesse, J. Locat, A. Rochon, and G. St-Onge, internal report, Université Laval (2005); ; U. Boyer-Villemaire, G. Labbé, G. Cauchon-Voyer, H. Gagné, P. Lajeunesse, J. Locat, and G. St-Onge, internal report, Université de Rimouski, 2006), and 6400 km^2 of multibeam bathymetry providing detailed seafloor morphology information (Campbell et al., 2006)

Syvitski and Praeg (1989) and Massé (2001) identified several seismic units of variable thickness and lateral extent within the lower St. Lawrence River estuary Quaternary succession. In the absence of deep wells, the interpretations of these units were mainly drawn from their reflection character. With such a perspective, the transparent character of a seismic unit may be interpreted as indicative of homogeneous rock type, of weak impedance contrast rock types, or of postsedimentation processes resulting in the mixing of several rock types. Similarly, the stratified aspect of a seismic unit is classically interpreted as resulting from sediment layers with contrasting physical properties.

Syvitski and Praeg (1989) described five seismic units which, from the base to the top, are interpreted as: ice-contact deposits including ice-loaded and ice-deposited sediments; ice proximal, coarser grained sediments deposited either during the rapid retreat of an ice terminus or in an ice-front stillstand setting; ice-distal sediments, probably marine clay, correlated with the Goldthwait Sea Clays (Dredge, 1983) mapped onshore; paraglacial coarse-grained deltaic sediments; and postglacial sediments deposited under modern sea-level and oceanographic condition. All these seismic units are interpreted as related to the advance and retreat of the Wisconsinian ice sheet.

Alternatively, Massé (2001) proposed that the Quaternary succession includes pre-Wisconsinian sediments. Among the seven stratigraphic units recognized by Massé (2001), the three lowermost units are interpreted as deltaic sediments formed during interglacial episodes predating the Wisconsinian, then the four uppermost units are related to postglacial late Wisconsinian and Holocene deltaic sediments.

METHODS

This study is based on 3300 km of high-resolution, single-channel, seismic-reflection data collected by the Geological Survey of Canada during cruises QSL0309 and QSL0408 (M.J. Duchesne, internal report, 2003; M.J. Duchesne and B.F. Long, unpub. report, 2004). During the surveys 55 seismic sections were gathered, most oriented perpendicular (northwest-southeast) to the estuary. The spacing between adjacent northwest-southeast lines is 2.5 km, 5 km, or 10 km (Fig. 1).

The seismic-reflection acquisition system consisted of a sparker source, one single-channel streamer, and one multichannel streamer (not discussed in the present paper; *see* Bellefleur et al. (2006)). Sources used for these surveys were two EG&G 3 and 9 electrodes sparker arrays of 2 kJ to 8 kJ with a frequency centred on about 200 Hz. The source was fired as a function of time, i.e. every 4 s, which means that traces are about 10 m apart. The source was towed 25 m behind the ship's stern at a depth of 1.5 m, whereas the streamer was surface-towed, 25 m in the rear of the source. Reflections were recorded with a 12 m long streamer containing 23 elements. Traces were recorded on time window of 1.25 s and sampled at 20 µs providing a vertical resolution of about 0.6 m based on the Rayleigh resolution limit (Sheriff, 2005). All traces were positioned by DGPS (Digital Global Positioning System).

Seismic traces were recorded in a SEGY format and positioning was merged to each trace header during postprocessing. Main processing steps included spectrum balancing, source deconvolution, band-pass filtering, and automatic gain control (Duchesne and Bellefleur, 2007; Duchesne et al., in press). Interpretation and horizon picking was done with the Kingdom Suite Seismic Software Package.

All time depths were converted to depth by using a constant velocity of 1520 m/s that corresponds to the average velocity of the sediments calculated from multichannel seismic data collected in the study area (Bellefleur et al., 2006). Depth-to-bedrock and total-sediment-thickness maps were generated by using triangulation and discrete smooth interpolation algorithms (Mallet, 1989). Depth and thickness categories were created by using the natural breaks method to enhance major features imaged by both the bedrock topography and the Quaternary sediment thickness distribution. This method determines categories statistically by finding adjacent feature pairs in the data set between which there is a relatively large difference in data value (Martin and Church, 2004). Final contouring of the maps was done by using a natural neighbour interpolator (Sibson, 1981).

RESULTS

Analysis of high-resolution seismic-reflection data shows that both the depth-to-bedrock and the total Quaternary sediment thickness decreases downstream and that bedrock reflection possesses variable seismic signatures. Eight seismic units have been distinguished in the Quaternary succession, five of them being of regional extent. Seismic units were identified and delimited as consecutive time intervals based on the amplitude, the morphology of the reflections, and the geometry of the seismic body.

Bedrock reflection

On seismic sections, bedrock reflections possess three distinct signatures. The first bedrock seismic signature (B1) consists of a relatively flat, high-amplitude reflection underlined in some locations by high-amplitude, slightly dipping reflectors (Fig. 2a). Upstream, this signature is mostly observed in the central portion of the basin (Laurentian Channel), whereas it characterizes the major part of the lower St. Lawrence River estuary downstream. The second bedrock seismic signature (B2) is represented by hummocky reflectors often associated with a series of aligned diffraction hyperbolas (Fig. 2b). On certain sections, other hyperbolas are imaged below the B2 seismic reflector. This reflection style is present upstream in the southern part of the Laurentian Channel and on the southern shoulder in the entire surveyed area. The third seismic signature (B3) is essentially imaged on the northern shoulder of the lower St. Lawrence River estuary and consists of sharp, high-amplitude, flat to undulated reflection (Fig. 2c). Sudden changes in depth reaching 61 m over 250 m of distance are also linked to this reflection style and resulted in a stair-like geometry.

Quaternary seismic stratigraphy

Seismic unit 1 (S1)

Within the Laurentian Channel, seismic unit 1 (S1) is stratigraphically the lowermost unit and unconformably overlies the bedrock (Fig. 3, 4a, b, 5). It is seismically transparent (although few discontinuous, low-amplitude reflectors are imaged locally) and has a high-amplitude reflector as upper boundary. The unit has a maximum thickness of 198 m in two troughs located in the upstream portion of the lower St.

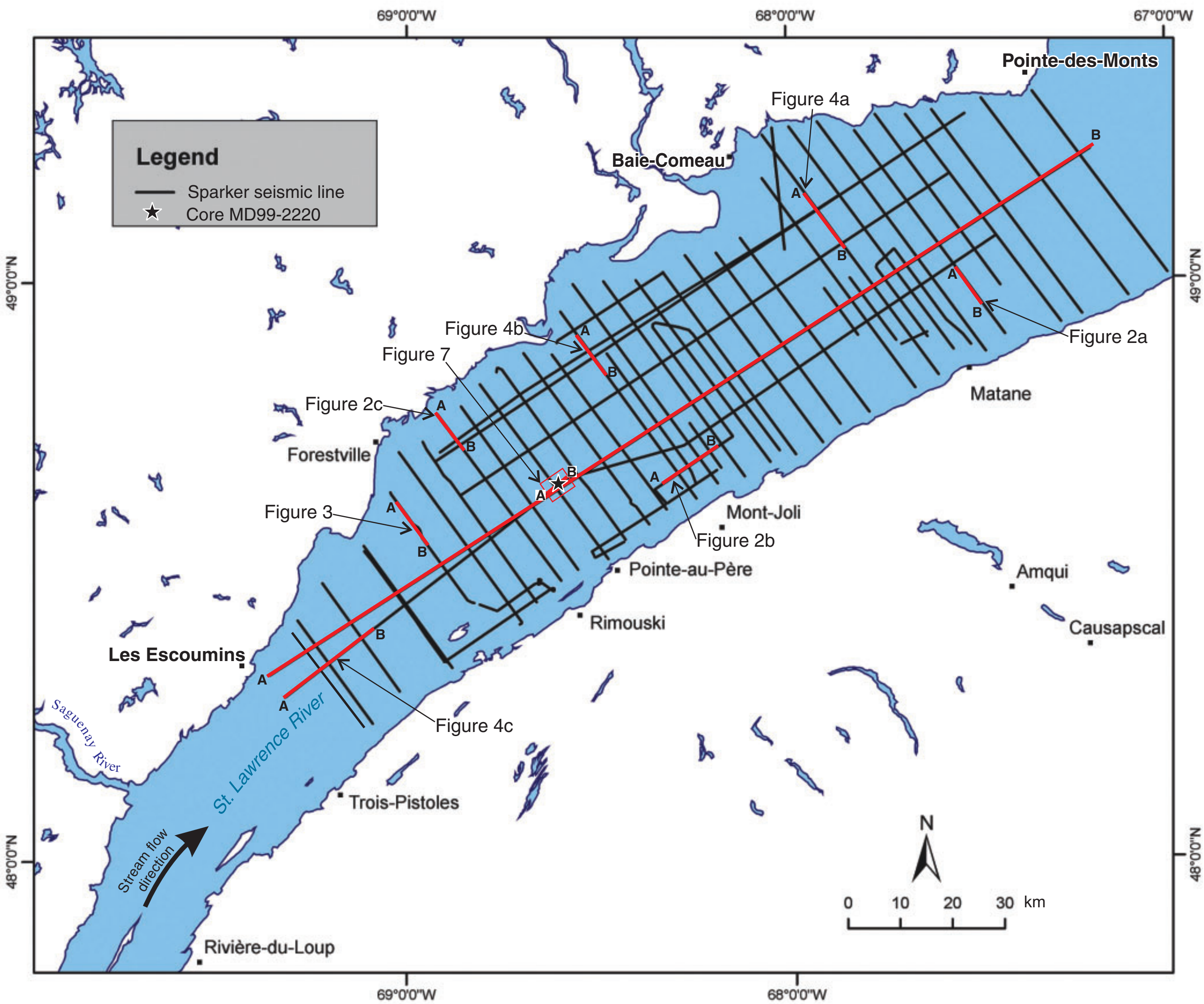

Figure 1. Location of the seismic sections collected during cruises QSL0309 and QSL0408.

Lawrence River estuary, and thins considerably downstream to less than 4 m in the easternmost part of the study area. Thin patches of S1 are discontinuously preserved on both shoulders of the Laurentian Channel.

Seismic unit 2 (S2)

Seismic unit 2 (S2) is defined by a series of parallel, high-amplitude reflections. The seismic character of the reflectors changes along the strike of the lower St. Lawrence River estuary, from flat in the upstream part to wavy, and even discontinuous in the downstream part (Fig. 3, 4a, b, 5). The S2 has a wedge shape with a maximum thickness of 68 m in the upstream region of the lower St. Lawrence River estuary, before diminishing to less than 8 m close to Pointe-des-Monts. In general, S2 totally drapes S1, including major topographic scarps; however, in the southwestmost portion of the study area where the steepest scarps and the thickest Quaternary succession are observed, reflectors of S2 abut against the upper part of S1, defining a convex geometry.

Seismic unit 3 (S3)

Seismic unit 3 (S3) is predominantly transparent with some low-amplitude, parallel reflections and few onlaps (Fig. 3, 4, 5). It covers the entire Laurentian Channel and corresponds to the main unit which fills small ponded basins located on both shoulders of the estuary. Similar to S1 and S2, its maximum thickness (190 m) is observed in the upstream sector of the Laurentian Channel and decreases gradually downstream to a few metres.

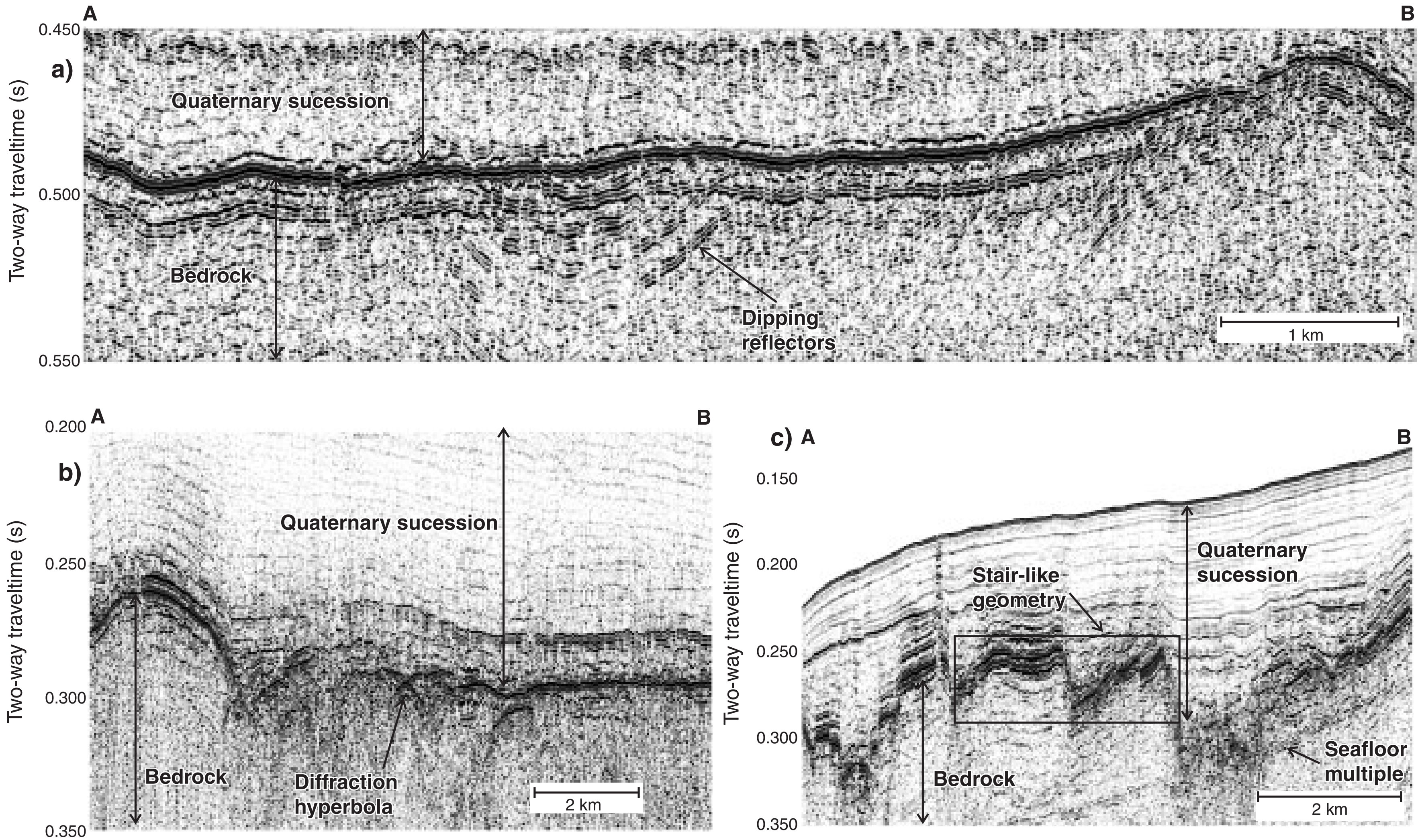

Figure 2. a) Bedrock seismic signature B1, **b)** bedrock seismic signature B2, and **c)** bedrock seismic signature B3. *See* text for details.

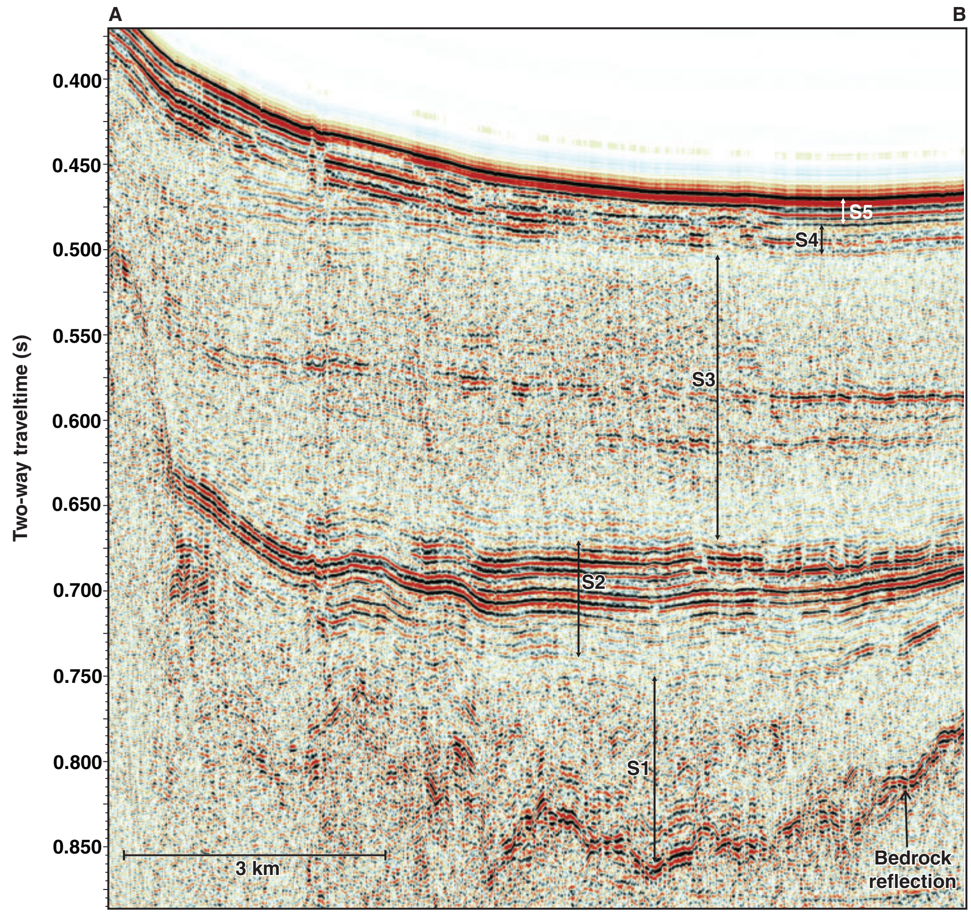

Figure 3. Seismic units of regional extent observed in the lower St. Lawrence River estuary. *See* text for details.

Seismic unit 4 (S4)

Seismic unit 4 (S4) consists of parallel to subparallel reflections of low amplitude. In the Laurentian Channel, it has a relatively constant thickness of 27 m before diminishing to less than 4 m in the eastern part of the lower St. Lawrence River estuary (Fig. 3, 4, 5). At some locations, its lateral extent is abruptly interrupted by seismic units of local occurrence. This unit is also present on both shoulders of the estuary.

Seismic unit 5 (S5)

Seismic unit 5 (S5) is generally transparent and includes some low-amplitude reflections parallel to the seafloor (Fig. 3, 4, 5). In the Laurentian Channel, it has a relatively constant thickness of 30 m to 38 m over the whole surveyed area.

Seismic unit 6 (S6)

Seismic unit 6 (S6) is a wedge-shaped unit of local lateral extent that shows a downlap geometry (Fig. 4a). Internally S6 consists of high- to medium-amplitude, flat, parallel reflectors that are sometimes interrupted by U-shaped features that include contorted reflections. The thickness of this unit ranges from 0 to 70 m. In map view, S6, which is located 15 km off the mouth of the Manicouagan River near Baie-Comeau, forms a conical body with a 42 km long axis striking northwest.

Seismic unit 7 (S7)

Seismic unit 7 (S7) includes contorted to chaotic low-amplitude reflections bounded by high-amplitude irregularly shaped reflectors (Fig. 4b). This seismic unit includes several disconnected wedge-shaped bodies along the northern flank of the Laurentian Channel. The thickness of the S7 ranges from 0 to 29 m.

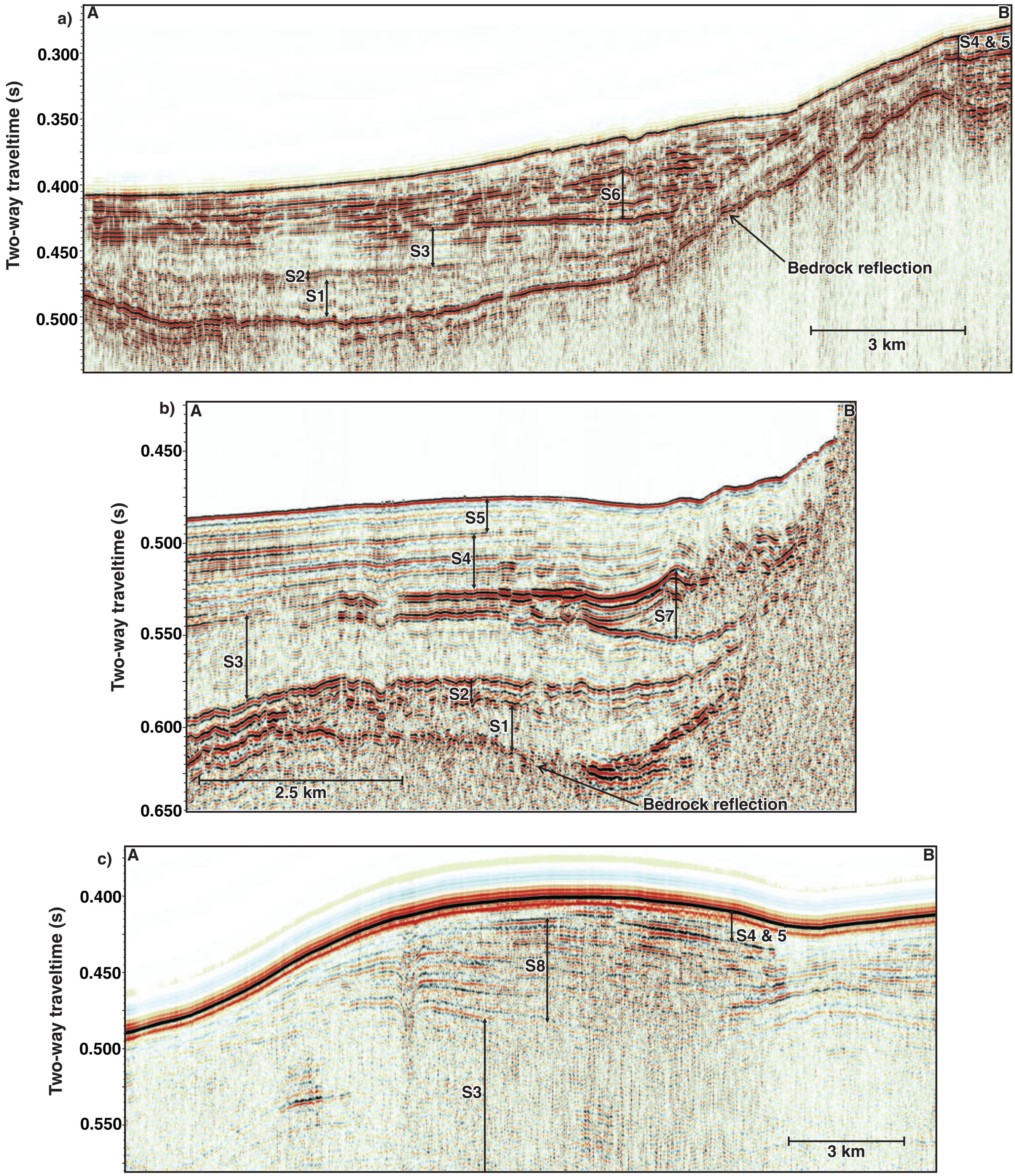

Figure 4. a) Seismic unit 6, **b)** seismic unit 7, and **c)** seismic unit 8. *See* text for details.

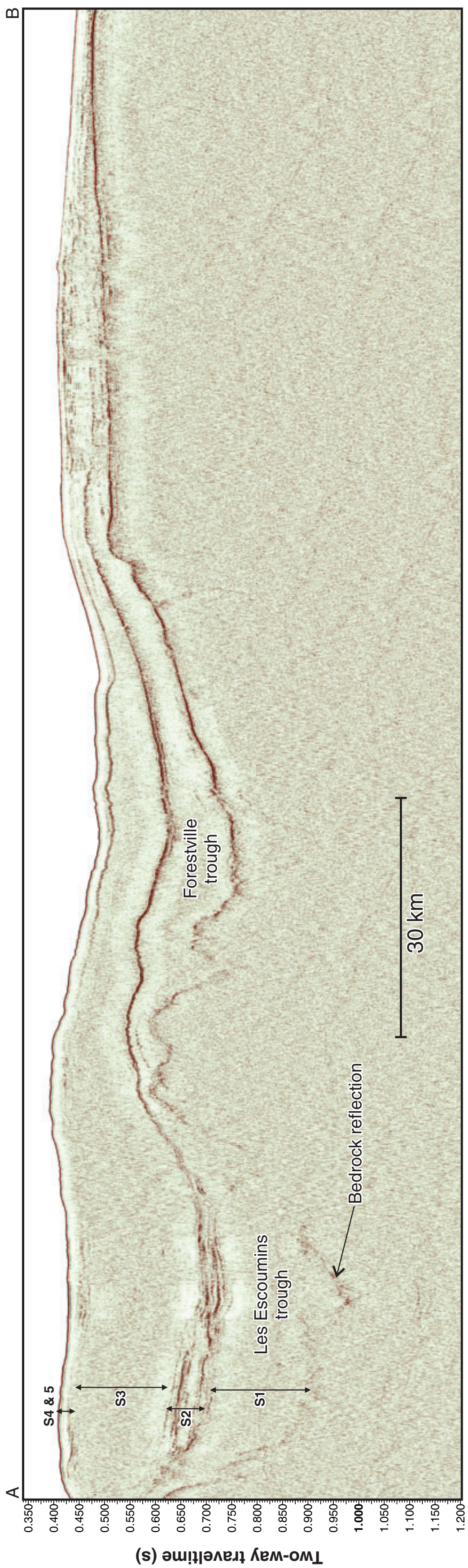

Figure 5. Seismic section AB crossing the entire surveyed area. *See* Figure 1 for location of the section.

Seismic unit 8 (S8)

Seismic unit 8 (S8) is a wedge-shaped unit of local lateral extent, only observed about 15 km east off Les Escoumins. This sedimentary body is 24 km long and 7 km wide (Fig. 4c). It is internally formed by medium-amplitude, sigmoidal reflectors. The thickness of this unit ranges from 0 to 55 m.

Correlations with core MD99-2220

In 1999, a 51.6 m piston core (MD99-2220) was collected from the middle of the Laurentian Channel, 23 km north of Rimouski (L. Labeyrie and E. Cortijo, IMAGES V internal report, 1999). This core was tied to seismic profile 04C-22. Figure 6 shows that the core penetrated S3 to 30 m and the totality of units 4 and 5. The upper 30 m of S3 corresponds to grey to dark grey laminated clay interpreted as glaciomarine sediments deposited from glaciofluvial plumes discharged from the retreating Laurentide Ice Sheet (unit 1 of St-Onge et al. (2003)). In this seismic unit, two ^{14}C dates of 8330 ± 70 BP and 7500 ± 70 BP, respectively, were obtained at a depth of 45 m and at the upper boundary of S3 (14.4 m). Based on the stratigraphy established by St-Onge et al. (2003), S4 and S5 correspond to a single rock unit (their unit 2) formed by dark grey, bioturbated silty clay. In the rock unit 2 of St-Onge et al. (2003) the grain-size curve presents a clear break at 11.8 m where grain size passes from very fine silt to fine silt, dated by ^{14}C at 6740 ± 70 BP. This grain-size variation is positively correlated to the reflector delineating S4 and S5.

Depth-to-bedrock and total sediment thickness maps

The depth-to-bedrock map of the lower St. Lawrence River estuary is showed on Figure 7. The depth to bedrock regionally decreases downstream as the dip of the Laurentian Channel wall becomes gentler and as the northern shelf and the St. Lawrence River get wider.

The bedrock topography is complex. In the downstream part of the study area, the map shows two neighbouring troughs within the Laurentian Channel, namely the Les Escoumins and Forestville troughs (*see* LET and FT on Fig. 7). The Les Escoumins trough is 47 km long, 8.5 km wide, and has a maximum depth of about 300 m relative to the local bedrock. The Les Escoumins trough is bordered by steep slopes on its northwestern and southeastern flanks, with maxima of 22º and 10º, respectively. The Forestville trough is 54 km long, 10.5 km wide, and has a maximum depth of about 190 m. The Forestville trough is delimited by more gentle slopes that do not exceed 10º. In the central and northern parts of the Laurentian Channel, the topography of the bedrock is smoother. A noteworthy feature is a northeast-trending topographic high that is up to 15 m high located offshore Matane and continuous for more than 40 km (*see* MH on Fig. 7).

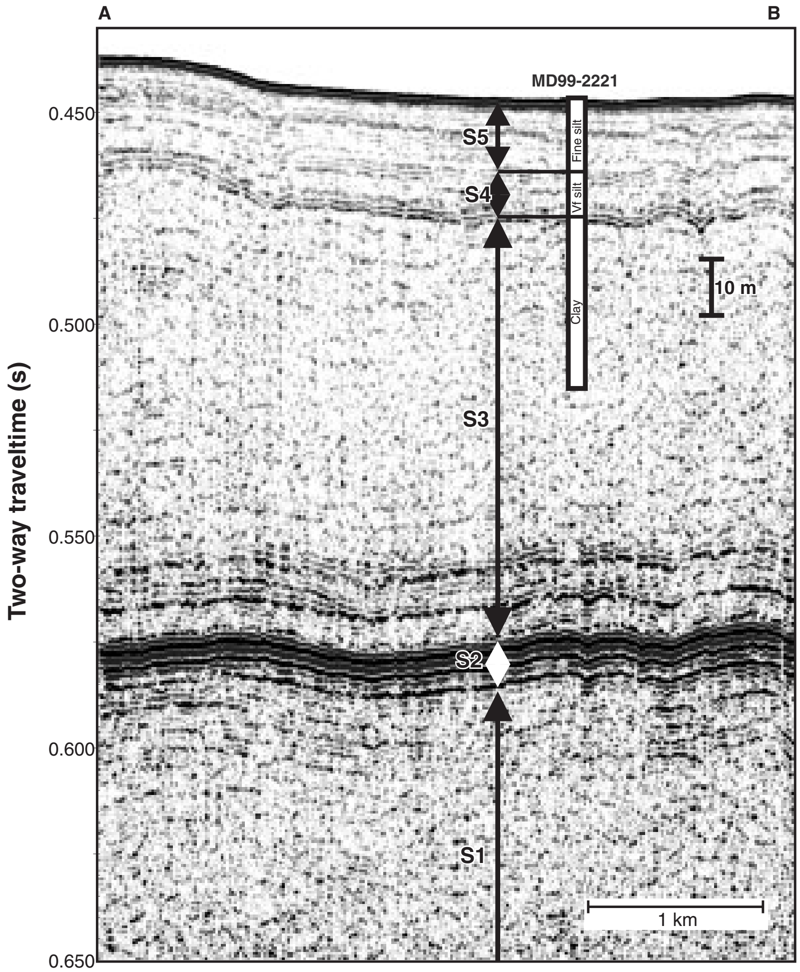

Figure 6. Correlation between core MD99-2221 and seismic section 04C-22. *See* Figure 1 for core and section location. Vf = very fine

Several local bedrock highs and lows are also present on both shelves of the lower St. Lawrence River estuary. Among the first-order features, the Bic Islands high is located on the southern shelf in the upstream portion of the study area and the Baie-Comeau high is located on the northern shelf around the Manicouagan Peninsula (Fig. 7).

Figure 8 shows the thickness map of the whole Quaternary succession. In the Laurentian Channel, the total sediment thickness decreases downstream, with a succession of steep highs and lows that corresponds to the Les Escoumins and Forestville troughs. The thinning of the sedimentary column affects all seismic units of regional extent (Fig. 5).

In the downstream part of the study area, steep escarpments that define the northwestern boundary of the Laurentian Channel are draped by a thin veneer of sediments. Quaternary deposits are thicker on the Laurentian Channel southeastern boundary that is characterized by gentler slope, except between Rimouski and Mont-Joli, where bedrock highs outcrop.

On the shoulders of the lower St. Lawrence River estuary, the general decrease in thickness of the Quaternary succession is locally interrupted by the presence of depocentres associated with modern tributaries of the St. Lawrence River. Sediment thicknesses between 30 m and 90 m are encountered in small bedrock depressions corresponding to local ponded basins, mostly located along the north shore of the surveyed area. The maximum thickness of the Quaternary succession was observed in the Les Escoumins trough and reaches about 420 m.

DISCUSSION

Geological significance of the bedrock reflections and bedrock topography

The distribution and boundaries of the seismic signature of the bedrock were discussed in detail by Pinet et al. (in press). Therefore this topic is only briefly presented in this paper. Below the bedrock seismic signature B1, slightly

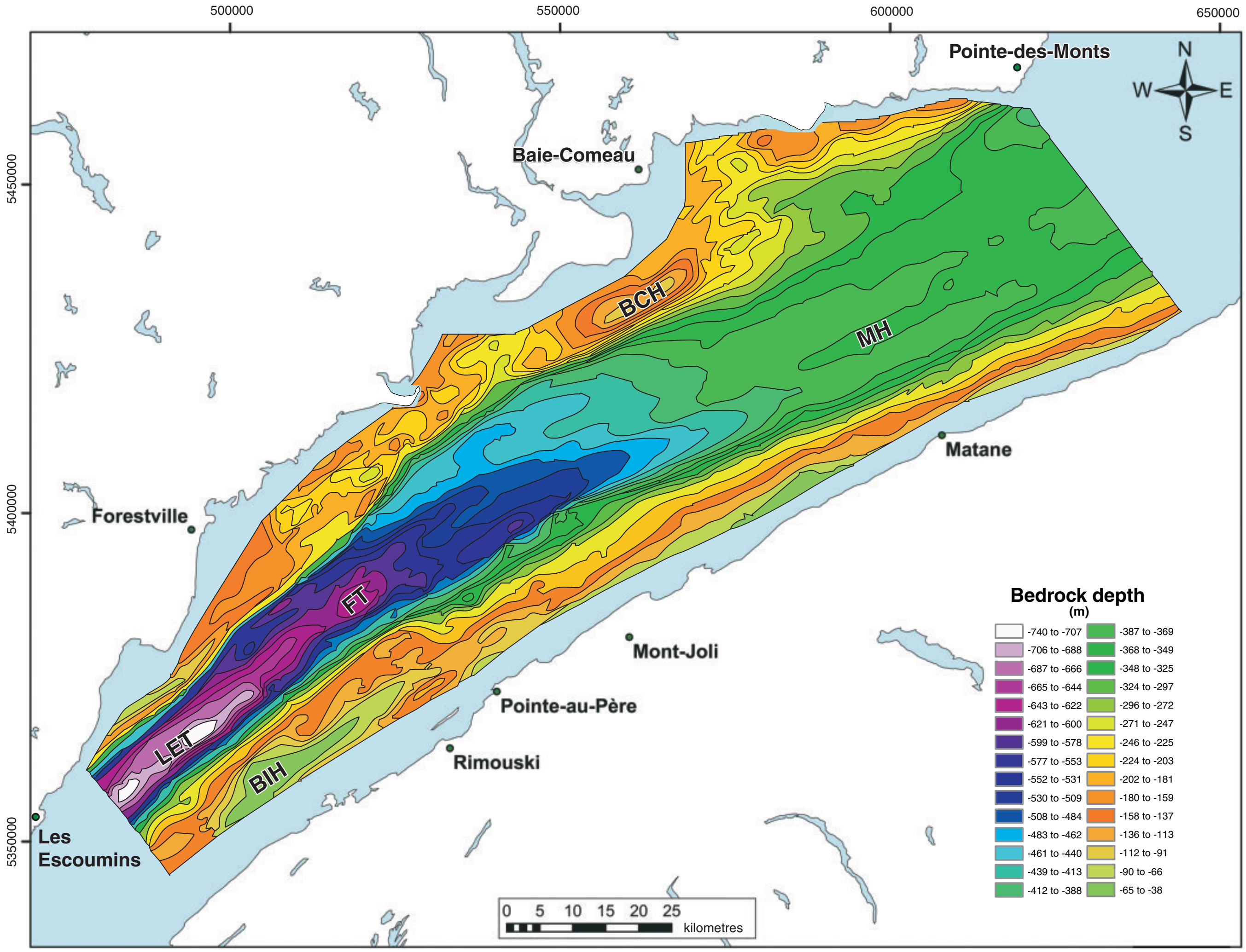

Figure 7. Depth-to-bedrock map of the lower St. Lawrence River estuary. Depths are relative to the sea level. BCH: Baie-Comeau high, BIH: Bic Islands high, FT: Forestville trough, LET: Les Escoumins trough, MH: Matane High.

dipping reflectors define broad synforms and antiforms associated to the St. Lawrence Platform (Paleozoic). This reflection pattern is incompatible with patterns observed in the Appalachian domain that are much more complex (D. Saucier, work in progress, 2007). The St. Lawrence Platform domain covers most of the Laurentian Channel and approximately 60% of the whole lower St. Lawrence River estuary. The limit between the Appalachian and the platform domains is clearly imaged on the seismic sections since the bedrock reflection of both domains are contrasting. Aligned diffraction hyperbolas located on the southern side of the surveyed area (bedrock seismic signature B2) are believed to be the seismic signature of the Appalachian domain. Diffraction hyperbolas are often caused by geometrically complex geological features, such as the highly deformed units of the Appalachian domain that are hardly resolved by single-channel, seismic-reflection systems because of their relatively short offset (Claerbout, 1985). The limit between the St. Lawrence Platform and the Grenville Province is not well defined and may correspond approximately to the northern flank of the Laurentian Channel (Pinet et al., in press). The high amplitude of the bedrock seismic event (bedrock seismic signature B3) on the northern shoulder of the estuary suggests a very strong acoustic impedance contrast induced by high-density rocks of the Grenville Province.

The bedrock morphology has been classically attributed to glacial overdeepening. This interpretation is substantiated by the fact that the Les Escoumins and Forestville troughs are located in the St. Lawrence Platform domain which is composed of softer rocks compared with surrounding domains (Grenville Province and Appalachian domain). Difference in the erosional strength may have favoured differential erosion, local overdeepenings, and therefore the creation of Les Escoumins and Forestville troughs in the narrowest part of the platform domain; however, in absence of additional arguments, the potential influence of a differential subsidence, a differential uplift, or a tectonic reactivation of the paleo-rift faults system cannot be ruled out.

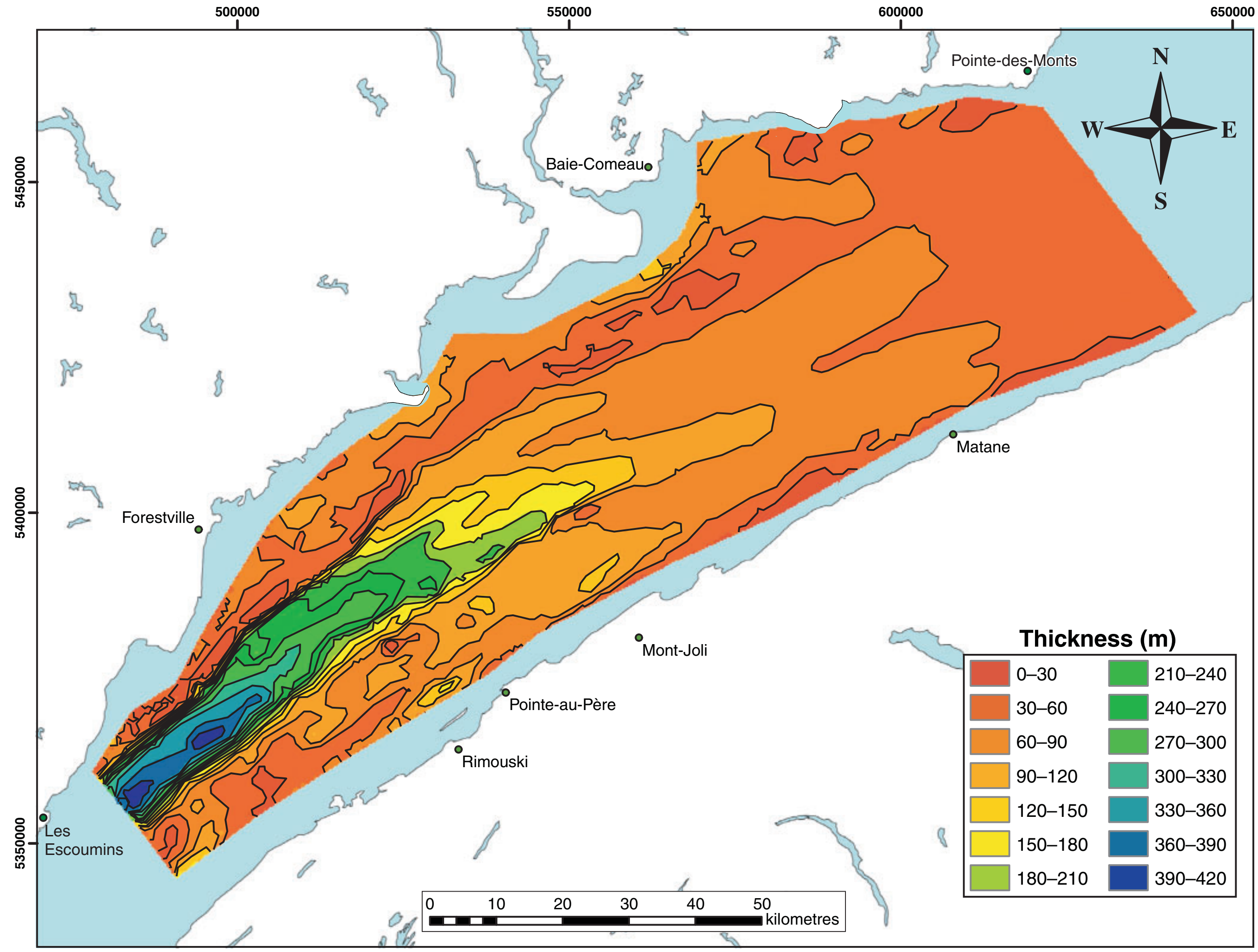

Figure 8. Total-thickness map of the Quaternary sediments in the lower St. Lawrence River estuary.

Geometrical relationships within the Quaternary lower St. Lawrence River estuary basin

Because of the lack of a complete geochronological framework that includes all units of regional extent (i.e. units 1 to 5), the following discussions are based on the superposition and geometry of the seismic units as well as on the geometrical relationships existing between these units.

In the downstream part of the study area, the lower St. Lawrence River estuary corresponds to a typical U-shaped sedimentary basin. Due to its transparent character, the relationship of S1 to the bedrock escarpment is not imaged. The S2 to S5 onlap fault-bounded bedrock escarpments and no clear tectonic reactivation of the faults have been imaged on the seismic sections.

The S1 is the unit that fills most of Les Escoumins and Forestville troughs. This unit is also the one that presents the most significant thickness variations throughout the study area. In most of the Laurentian Channel, S2 drapes S1; however, in the downstream sector where there is a strong inherited topography (Les Escoumins trough), unit 2 abuts against the top of S1. This indicates that: units 1 and 2 belong to different sedimentary sequences; and sedimentation rates and/or the sedimentation period was (were) insufficient to fill the accommodation space during the sedimentation period corresponding to unit 1. The geometrical characteristics of these seismic units thus suggest that the transition from unit 1 to unit 2 correspond either to a period of nondeposition or erosion, that the age of unit 1 will remain undetermined until the acquisition of geochronological data, and that the bedrock topography of the Les Escoumins and Forestville troughs predates S2.

On the shoulders of the Laurentian Channel, S1 and S2 are either nonexistent, thin, or trapped in small bedrock depressions. This characteristic raises the following questions; did both of these units or one of these two units drape the entire lower St. Lawrence River estuary basin before being eroded? Did a lowstand prevent S1 and S2 from being deposited on the shoulders of the basin? Was the deposition of these units limited to the centre of the Laurentian Channel and linked to proximal sedimentation? At the present time without lithological and geochronological evidence these questions are hard to answer; however, the fact that S1 and S2 seem to have been preserved locally away from the channel itself, suggests that subsequent erosion after deposition is the most likely hypothesis.

The seafloor of the Laurentian Channel is flat and does not present any typical glacial features. This characteristic is already largely observed at the top of S3. Unit 3 gradually thins downstream whereas units 4 and 5 possess a relatively constant thickness over the entire basin. This suggests that the deposition of S4 and S5 is linked to postglacial geological processes that are of regional extent. Comparison between the work of St-Onge et al. (2003) and this seismic stratigraphic study agree that at least the upper 30 m of seismic unit 3 are of Holocene age and that seismic units 4 and 5 represent Holocene to modern sedimentation. The clear shift between seismic units 3 and 4 was attributed by St-Onge et al. (2003) to a major reorganization of the Laurentide Ice Sheet meltwater routes. Concerning the grain-size variation positively correlated to the reflector bounding seismic units 4 and 5, the geological process or processes responsible for the change in grain size cannot be formally identified, but it is likely related to climatic changes and/or sea-level variations (G. St-Onge, pers. comm., 2006).

On the flanks of the basin, especially on the north, units 3, 4, and 5 are filling small ponded basins. The sedimentary thickness of these ponded basins is comparable to what is observed in some parts of the Laurentian Channel. This indicates that at the time of deposition the sedimentary influx was predominantly from the north shore as it is at present (Duchesne, 2005).

The effect of the inherited topography of the bedrock decreases from unit 1 to 5 as the units are draped on top of the bedrock, smoothing its relief and filling the accommodation space of the basin; however, even today the bedrock topography affects, in a more subtle manner, the morphology of the seafloor.

The S6, S7, and S8 are all of local extent. Unit 6 is associated with submarine fan deposits because of its localization and association to nearby rivers situated mostly on the north shore, its wedge-shaped geometry, and its downlapping internal configuration. Moreover, U-shaped, contorted and stratified high-amplitude, internal reflection patterns are reflections styles diagnostic of submarine fans attributed to channels, slumps and slides, and the alternation of fine- and coarse-grained layers (Berryhill et al., 1986; Fulthorpe et al., 2000; Gee et al., 2001; Hjelstuen et al., 2004). Both the internal configuration and the geometry of unit 7 suggest that it corresponds to the seismic expression of mass-wasting deposits. The close proximity of these seismic bodies from the steep northern flank of the Laurentian Channel is also indicative of their association with submarine slope failures. Seismic unit 8 is believed to be a contourite deposit. It has diagnostic reflection features of such deposits, i.e. it is characteristically mounded and elongated, parallel to the channel flank with internal reflections pinching toward the seafloor on each side (Faugères et al., 1999). The strong modern currents documented in the study area are also supportive for the occurrence of contourite drift deposits (Mertz and Gratton, 1995).

CONCLUSION

A detailed interpretation of the Quaternary succession is beyond the scope of this paper. Such an interpretation should be based on a detailed volume estimation of time-constrained seismic units and take into account the feedback effects between the inherited geometry of the lower St. Lawrence River estuary, glacial erosion processes, topography, sedimentation, isostatic rebound, sea-level change, and possibly neotectonics.

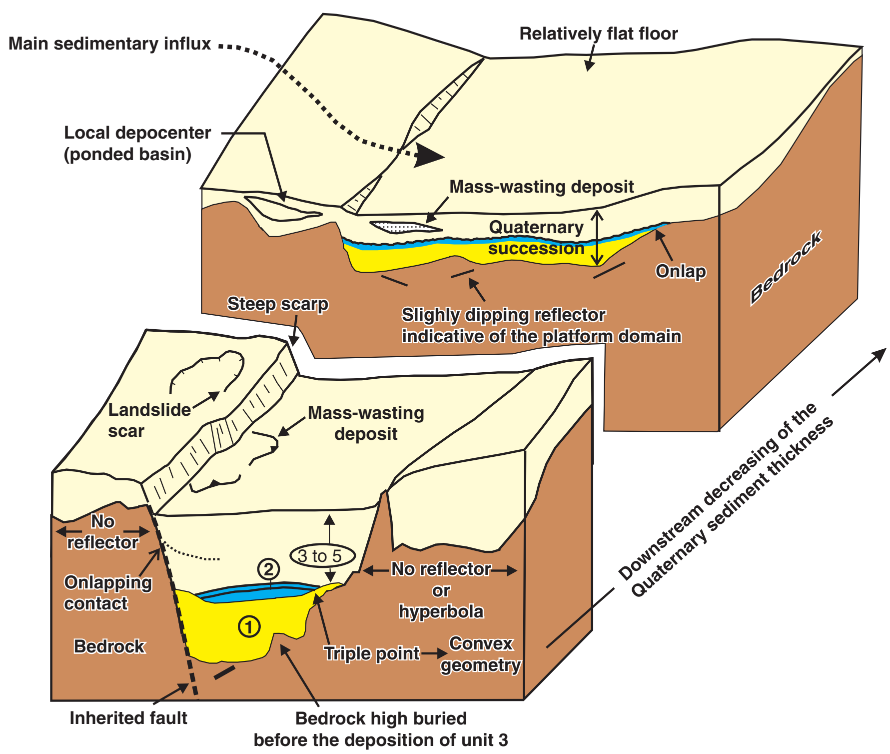

Figure 9. Schematic sketch illustrating the key parameters discussed in the text.

Figure 9 summarizes the observations made in the present study. Data presented in this paper show that the geometry and distribution of the Quaternary seismic units are closely linked to the topography of the underlying geological domains. Within the Quaternary succession, two main packages may be distinguished. The lower package (S1) has a highly variable thickness and fills up most of the Les Escoumins and Forestville bedrock troughs. The upper package (S2 to S5) may be further subdivided in two subpackages: the S2, which is mostly confined to the Laurentian Channel and contribute to the filling of the Les Escoumins and Forestville troughs; and S3 to S5, which covers the entire lower St. Lawrence River estuary, including the Laurentian Channel shoulders, suggesting that it was deposited in a physiographic setting close to the one that prevails today. The S6, S7, and S8 are the result of local geological processes such as the sedimentation of submarine fan, mass-wasting deposition, and contourite drifts mostly occurring along the flanks of the Laurentian Channel; however, without available lithological and geochronological information to tie with the seismic units, the geological signification of these units remains uncertain.

The high-resolution, seismic-reflection data presented in this paper offer the opportunity to describe the seismic unit geometrically and to consider a mass balance at the scale of the basin. Future work will focus on this issue in applying geomodelling approaches to refine existing isopach maps and to generate new ones for all seismic units to eventually obtain a 3-D view of the Quaternary succession and the underlying bedrock topography. Ultimately, land geology bordering the lower St. Lawrence River estuary will be tied to the marine domain to provide a better understanding about the Quaternary evolution of the basin.

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