

# Seafloor and Shallow Subsurface of the St. Lawrence River Estuary

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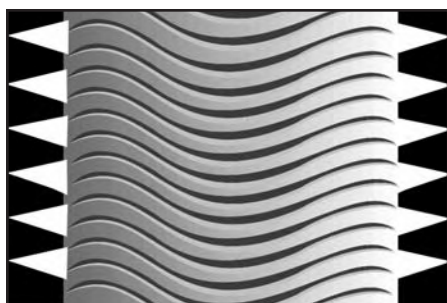
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Article abstract

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# ARTICLE



## Seafloor and Shallow Subsurface of the St. Lawrence River Estuary

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### SUMMARY

A new surficial geology map of the St. Lawrence River Estuary illustrates sediment distribution and variability in a relatively confined environment. This map is based on recently collected geophysical and geological data that provide a link between submarine landforms and sedimentary units. The strong dichotomy between the areas to the northeast and to the southwest of the Saguenay River is the main characteristic of the St. Lawrence River Estuary. To the northeast, the Lower St. Lawrence Estuary is mainly floored by fine silts within the Laurentian Channel and sediments varying from sands to fine silts on its margins. To the southwest, the Middle Estuary corresponds

to a high-energy sedimentary environment that precludes the deposition of fine-grained sediments. In the latter area, Holocene sediments are either absent or correspond to a sand unit shaped by currents.

### SOMMAIRE

Une nouvelle carte de la géologie des sédiments superficiels du fond marin de l'estuaire du Saint-Laurent présente un cas de la distribution et de la variabilité des sédiments dans un environnement relativement confiné. Cette carte est basée sur des données géophysiques et géologiques récentes qui assurent un lien entre le relief sous-marin et les unités sédimentaires. La forte dichotomie entre les zones situées au nord-est et au sud-ouest de la rivière Saguenay est la caractéristique principale de l'estuaire du Saint-Laurent. Au nord-est, le fond de l'estuaire maritime du Saint-Laurent est recouvert de silts fins au sein du chenal Laurentien et par des sédiments variant de sables à silts fins sur ses marges. Au sud-ouest, l'estuaire moyen correspond à un environnement sédimentaire de forte énergie qui empêche le dépôt de sédiments fins. Dans cette dernière zone, les sédiments holocènes sont absents ou correspondent à une unité sableuse façonnée par les courants.

### INTRODUCTION

Estuaries are semi-enclosed coastal bodies of water that have a free connection with the open sea and, within which, seawater is diluted with fresh water derived from land drainage. The location of estuaries at the transition zone between the fluvial and continental shelf environments implies an inherent geological complexity because of the interaction of terrestrial and marine sedimentary processes (Dal-

rymple and Choi 2007). Several parameters exhibit major changes both along and across the strike of estuaries, including depth, slope, intensity of tidal waves, salinity, and amount of suspended solid, among others. The variability of these parameters and their interaction may lead to a complex sedimentary architecture and influence sediment characteristics such as grain size, sedimentation rate, type of sedimentary structures and geomorphological signature of sedimentary accumulations.

The St. Lawrence River system is a major hydrographic feature of North America and is characterized by a large drainage area including and originating at the Great Lakes. In the St. Lawrence River Estuary, Quaternary sediments vary from less than 30 m to over 400 m in thickness (Duchesne et al. 2010). Previous studies of these sediments mainly investigated their overall architecture and the impact of the last glacial episode on the development of the Quaternary succession (e.g. D'Anglejan and Brisebois 1978; Syvitsky et al. 1983; Syvitski and Praeg 1989; Massé 2001; St-Onge et al. 2003, 2008; Duchesne et al. 2010). In this contribution, we focus on the geology of the seafloor and shallow subsurface. This approach became conceivable through the analysis of recently acquired geophysical (multibeam bathymetry and very high-resolution seismic reflection data; Pinet et al. 2011a) and geological (samples and photographs; Campbell 2007; Bolduc 2008) datasets for the St. Lawrence River Estuary. Through a basin-scale approach, the current study attempts to provide a snapshot of present-day sedimentation patterns and accumulations in this large estuarine sedimentary system. Such a snapshot may serve

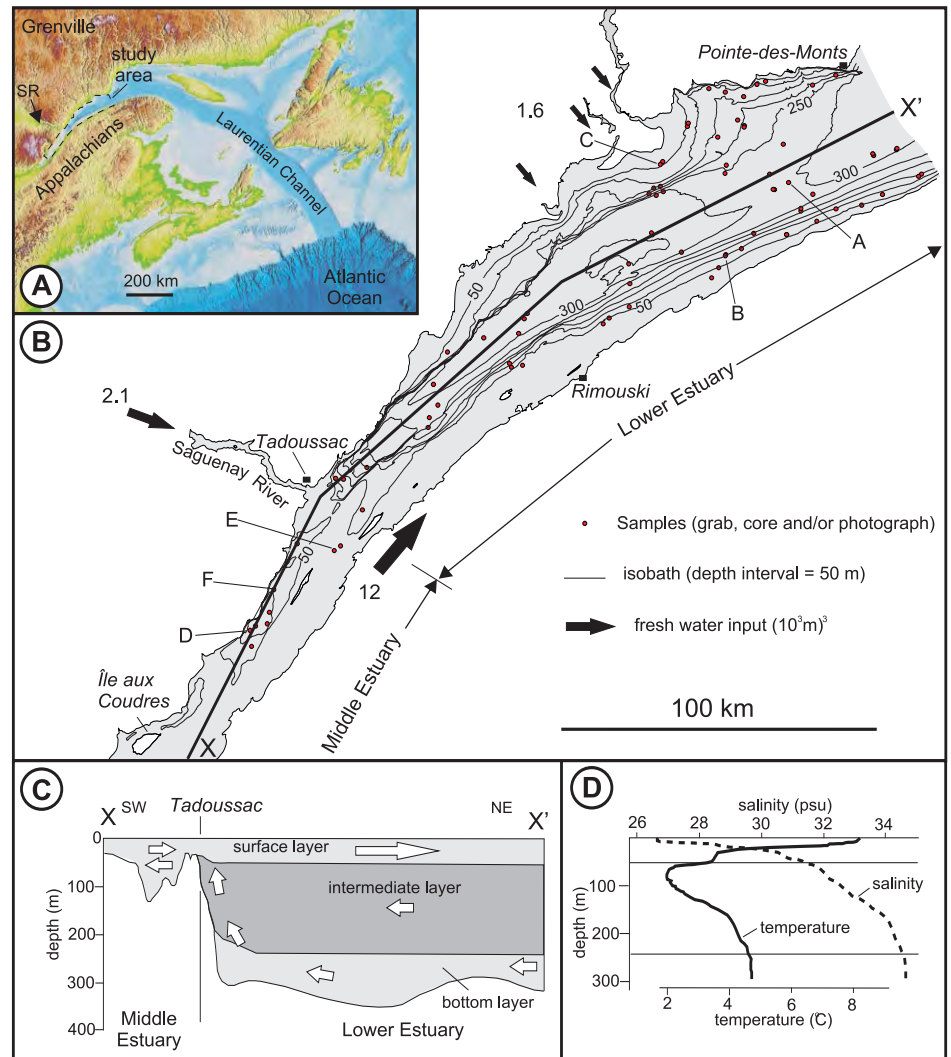
as an analogue for other sedimentary successions for which the physiographic, hydrographic and geologic conditions are uncertain.

## HYDROGRAPHIC AND PHYSIOGRAPHIC SETTINGS

The St. Lawrence River Estuary is among the largest in the world, extending for a distance of over 400 km, a width up to 50 km, and a depth of up to 350 m (Fig. 1). On the south shore, the Appalachian Mountains (Fig. 1A) exhibit relatively smooth relief, and elevation is generally less than a few hundred metres. The north shore, underlain by Grenvillian metamorphic rocks of the Canadian Shield (Fig. 1A), rises steeply and reaches elevations of more than 1000 m south of the Saguenay River.

The St. Lawrence River Estuary is traditionally divided into two segments on the basis of bathymetric signature (Fig. 1B); the Lower Estuary, which extends from the mouth of the Saguenay River northeast to Pointe-des-Monts, and the Middle Estuary, which encompasses salt water southwest of the Saguenay River. A distinctive feature of the Lower Estuary is the Laurentian Channel, which extends more than 900 km from the confluence with Saguenay River to the edge of the Scotian Shelf in the Atlantic Ocean (Fig. 1A). In the southwest part of the Lower Estuary, the Laurentian Channel exhibits the morphological signature of an incised-valley bounded by steep escarpments, whereas to the north, it is characterized by more shallowly dipping margins. Differential erosion has traditionally been considered as the main geological process responsible for the parallelism of the Laurentian Channel with bedrock boundaries, as it is hosted by softer rocks of the St. Lawrence Platform that are less resistant to erosion than the adjacent Grenvillian and Appalachian rocks (Pinet et al. 2008). The Middle Estuary is shallower and characterized by a 'rougher' bathymetry, including a network of interconnecting channels and basins between northeast-striking, kilometre-wide banks and islands.

The mean tidal range of the study area increases toward the southwest, from 3.0 m near Pointe-des-Monts to 4.4 m at Tadoussac (extreme



**Figure 1.** A. Hydrographic and physiographic setting of the St. Lawrence River Estuary. SR: Saguenay River. B. Simplified bathymetric map of the study area (see (A) for location). Bathymetric contours are 50 m apart. Locations indicated by dots typically represent more than one sample type (grab, core and photograph); see Campbell (2007) and Bolduc (2008) for details. The Lower and Middle estuaries are, respectively, upstream and downstream from Saguenay River. Letters A to F indicate the location of seafloor photographs in Figure 4. C. Longitudinal section of the St. Lawrence Estuary (see (A) for location) showing water-mass stratification and estuarine circulation (adapted from Syvitsky et al. 1983). The transition zone between the Lower and Middle Estuaries is characterized by an abrupt rise of the seafloor that strongly influences water circulation. D. Typical salinity and temperature profiles in the Laurentian Channel (redrawn from Syvitsky et al. 1983).

high water of 4.9 and 6.4 m respectively; Fisheries and Oceans Canada 2010). The estuary is characterized by a salinity-induced density stratification leading to the development of an estuarine circulation in which the denser, more saline bottom water flows slowly ( $\sim 0.5$  km/day) landward at the bottom of the estuary, whereas fresher water moves rapidly ( $\sim 10$ – $20$  km/day) seaward at the surface (Fig. 1C; Syvitski et al. 1983). Intensive mixing between

water layers occurs at the head of the Laurentian Channel, which is characterized by a sudden rise of the seabed near Tadoussac (Fig. 1C).

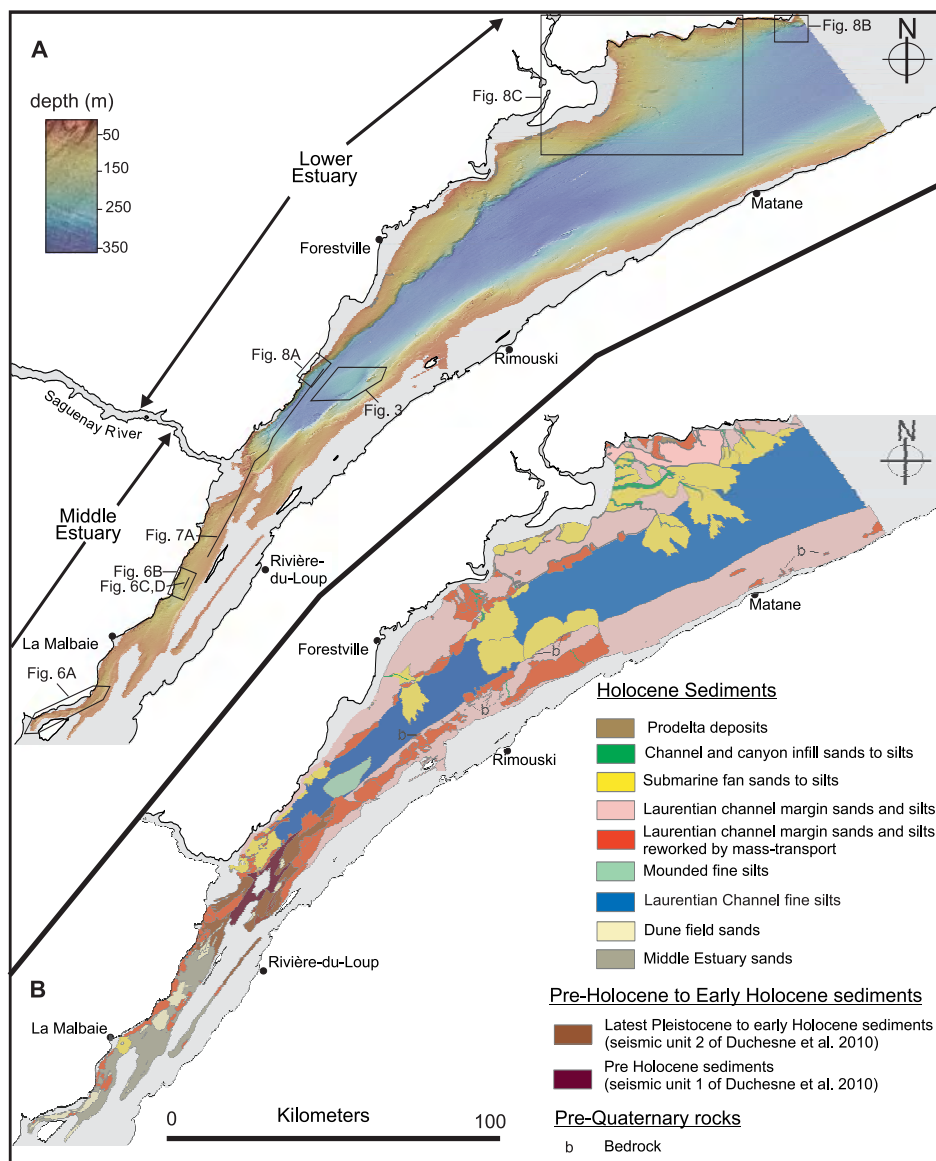
During the spring and summer, the water masses have a well-developed thermocline characterized by three layers (Syvitski et al. 1983; Fig. 1D). The minimum temperature ( $2^{\circ}\text{C}$ ) is found in the intermediate water layer (50–250 m). Salinity of the surface layer (0–50 m) ranges from 26–31 psu

(practical salinity unit) and steadily increases to 34.5 psu on the river bottom (Syvitski et al. 1983; Fig. 1D). Since the 1930s, a steady decrease of oxygen concentration in bottom waters has been documented (Gilbert et al. 2005).

The main sources of fresh water are the St. Lawrence River (12 000 m<sup>3</sup>/s near Tadoussac), the Saguenay River (2100 m<sup>3</sup>/s) and three large rivers on the north shore — the Betsiamites, Aux Outardes and Manicouagan rivers, which have a combined discharge of 1600 m<sup>3</sup>/s (Fisheries and Oceans Canada 2010). The St. Lawrence River alone transports more than 6.5 million tonnes of suspended solid into the Lower Estuary annually (Fisheries and Oceans Canada 2010). North of Saguenay River, most of these sediments are deposited on the floor of the Laurentian Channel, which previous studies have indicated to consist mainly of dark grey, bioturbated, fine silts (Nota and Loring 1964; St-Onge et al. 2003). Estimates of recent sedimentation rates range from 0.70 cm/yr off Rimouski to 0.22 cm/yr in the northern part of the study area (Smith and Schafer 1999).

**DATASETS AND METHODOLOGY**

Complete multibeam bathymetry coverage for water depths greater than 30 m is available between Îles aux Coudres to the southwest and Pointes-Monts to the northeast (Figs. 1B, 2A). The bathymetric coverage includes several surveys conducted between 1997 and 2007 by the Canadian Hydrographic Service using the Canadian Coast Guard Ship *Frederick G. Creed* and the bathymetric launch *Guillemot*. Multibeam systems onboard the *F.G. Creed* consisted of a Kongsberg EM-1000 (before 2005) and a Kongsberg EM-1002 (since 2005). On the *Guillemot*, multibeam systems consisted of a Kongsberg EM-3000 (before 2005) and a Kongsberg EM-3002 (since 2005). In addition to multibeam bathymetry, very high-resolution seismic reflection data (not shown) have been employed to image the shallow subsurface of the St. Lawrence River Estuary. These seismic data, which were collected in 2007 using a Hunttec DTS source with a peak frequency of ~900 Hz, have a vertical



**Figure 2.** A. Multibeam bathymetry of the study area. The multibeam data are artificially shaded to accentuate geomorphologic features; the artificial illumination source lies at an azimuth of 45° and at an angle of 35° above the horizontal. B. Geological map of surficial sediments of the St. Lawrence River Estuary (modified from Pinet et al. 2011a).

resolution of ~0.8 m (Campbell 2007; Bolduc 2008).

One hundred and forty-five seafloor sediment samples (86 grab samples and 59 short gravity cores less than 2 m long) and 79 seafloor photographic transects (consisting of 8 to 21 images) were collected at strategic sites to characterize surficial units (Campbell 2007; Bolduc 2008; Fig. 1A). Seafloor samples and photographs provide the critical link between the geomorphological units identified on multibeam bathymetry and the lithological characteristics of sediments.

During this study, surficial geology units (Fig. 2B) were primarily defined on the basis of their geomorphological signature (Pinet et al. 2011a). Surficial units consist either of homogeneous and well-sorted sediments (such as the Holocene Laurentian Channel fine silt unit; see below) or sediments with variable grain-size characteristics (such as the Holocene Laurentian Channel-margin sand to silt unit; see below). In most cases, surficial geology units have relatively sharp boundaries on the multibeam bathymetry map. Where not obvious on bathy-



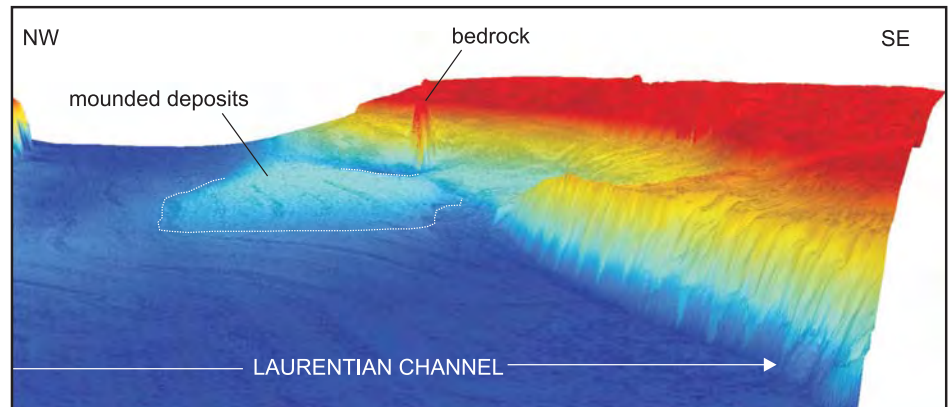
metric images, unit boundaries were defined on very high-resolution seismic lines and extrapolated from one line to the other. This was the case for the lower and upper boundaries of the latest Pleistocene to early Holocene sediment unit; these boundaries are easily identifiable on several seismic lines yet exhibit no clear geomorphological signature. Very high-resolution seismic lines were also critical for the interpretation of linear features associated with buried structures such as bedrock ridges (Pinet et al. 2011a).

## RESULTS

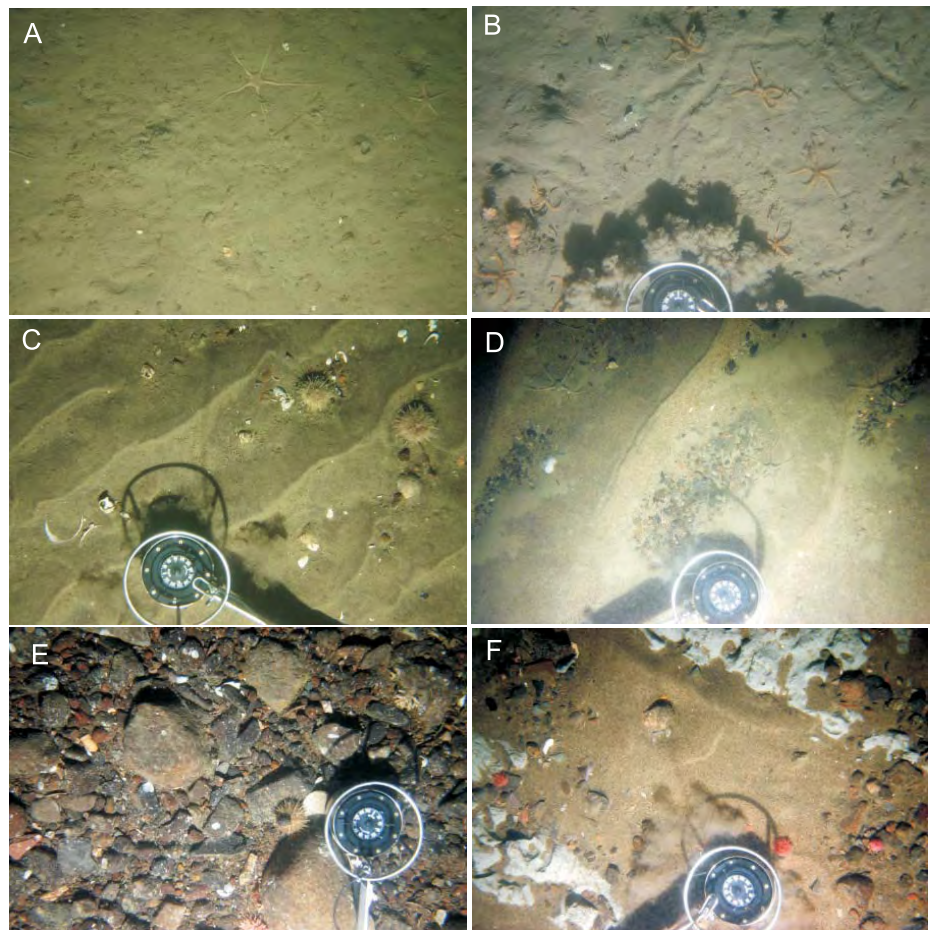
### Background Sediments in the Laurentian Channel

Northeast of the Saguenay River, the Laurentian Channel lies at depths averaging ~300 m and is characterized by a smooth geomorphologic signature lacking landforms associated with the glacial history. A ~17-km-long and ~6-km-wide mounded sedimentary body observed ~50 km southwest of Rimouski constitutes the main large-scale geomorphologic feature on the Laurentian Channel seafloor (Fig. 3). On seismic profiles, this feature is characterized by medium-amplitude sigmoidal reflections that led Duchesne et al. (2010) to propose that strong bottom currents in this area are responsible for shaping it. At a smaller scale, the Laurentian Channel seafloor is characterized by close to 2000 pockmarks ranging in diameter from <50 to ~700 m. These crater-like depressions have been studied in detail by Pinet et al. (2008, 2010) and Lavoie et al. (2010), and are interpreted to have formed through the release of gas from the subsurface.

Present-day sedimentation in the Laurentian Channel, including the mounded unit, consists of fine silt. Photographic analysis indicates no major variations in the grain size of surficial sediments. The majority of photographs exhibit evidence of bioturbation, with micro-relief, including burrow openings, up to a few centimetres in length (Fig. 4A). The most common macrofauna consists of sea pens, anemones and brittle stars. Grain size analysis of the sediments indicate a homogeneous lithology, having a gravel content consistently less than 1%, a

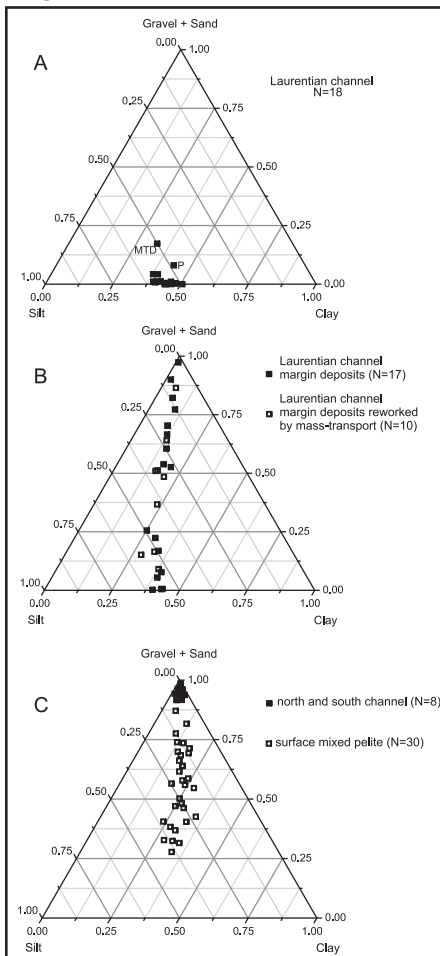


**Figure 3.** Perspective view toward the north showing mounded deposits in the Laurentian Channel, southwest of Rimouski. See Figure 2A for location. This large-scale geomorphological feature is interpreted as being shaped by strong bottom currents. The width of the near view is about 9 km.



**Figure 4.** St. Lawrence seafloor photographs (see Figure 1B for locations). The width of all photographs is approximately 80 cm. A. Typical Laurentian Channel seafloor, characterized by bioturbated fine silts. B. Seafloor of the southern margin of the Laurentian Channel, characterized by highly bioturbated, relatively fine-grained sediments (silt). C. Seafloor of the southern margin of the Laurentian Channel, characterized by relatively coarse-grained sediments shaped by current features (sand waves). D. Decimetre-scale sand waves and ponded zones of small pebbles and gravel. Brittle stars are visible. E. Pebble- and cobble-dominated seafloor. Visible marine organisms are sea urchins and anemones. F. Blue clay overlain by a thin veneer of sand, gravel and pebbles. Small anemones are visible.

cumulative sand+gravel content usually less than 3%, and a silt content varying between 49 and 60% (Fig. 5A). One sample of coarser grained sediment is located close to a mass-transport deposit, and another within a pockmark (Fig. 5A). These results compare well with previous studies reporting grain size analysis in the Laurentian Channel (Loring and Nota 1973; St-Onge et al. 2003).



**Figure 5.** Gravel+sand–silt–clay ternary diagram for samples collected on the Laurentian Channel seafloor (A), on its margins (B) and in the Middle Estuary (C). Data for the Middle Estuary are from D’Anglejan and Brisebois (1978). MTD: sample located close to a mass-transport deposit; P: sample located within a pockmark.

**Background Sediments on the Laurentian Channel Margins**

The geomorphological signature of both the northwest and southeast margins of the Laurentian Channel is more diversified than within the channel

itself. Both margins of the Laurentian Channel are characterized by an average down-dip slope of generally less than 2°. Along a significant portion of the estuary (Fig. 1), the boundary with the Laurentian Channel is marked by a bathymetric break expressed by escarpments (up to 180 m in height) or bedrock ridges (up to 90 m in height) that are the morphological expression of bedrock faults and erosion-resistant Paleozoic bedrock (Pinet et al. 2008). On the north shore, the margin locally displays linear features interpreted as paleo-iceberg scours (Pinet et al. 2011a).

Grain sizes of present-day sediments on the Laurentian Channel margins show a transition from sand to fine silt (Fig. 5B). However, the character of surface sediments changes rapidly over short distances in some areas, especially in the shallowest parts of the study area, and the gravel content of studied samples is locally over 10%. Photographs indicate that margin sediments are generally highly bioturbated (Fig. 4B). Current-shaped sedimentary structures such as sand waves up to a few decimetres in wavelength are locally observed at relatively shallow (< 100 m) water depth (Fig. 4C).

**Background Sediments in the Middle Estuary**

South of Saguenay River, Holocene sediments are mainly sand, which is commonly shaped into large current features such as dune fields up to 10 km in length and 2 km in width (Figs. 2 and 6). These features are characterized by linear or curvilinear crests up to 4 m high and 100 m in wavelength, having an average strike perpendicular to the estuary (Fig. 6; D’Anglejan 1971). Isolated barchans located close to dune fields are locally imaged on the multibeam bathymetry map (Pinet et al. 2011a). Dune fields attest to a well-established, tidally driven bottom current system upstream of the Saguenay River (D’Anglejan 1971) where the estuary drastically narrows and shallows. Grain size analysis indicates that dune field sediments consist of well-sorted sands and minor gravel (Figs. 4D and 5C; D’Anglejan and Brisebois 1978); finer grained sediments are also present, yet fine silts such as those observed in the Lower Estuary are

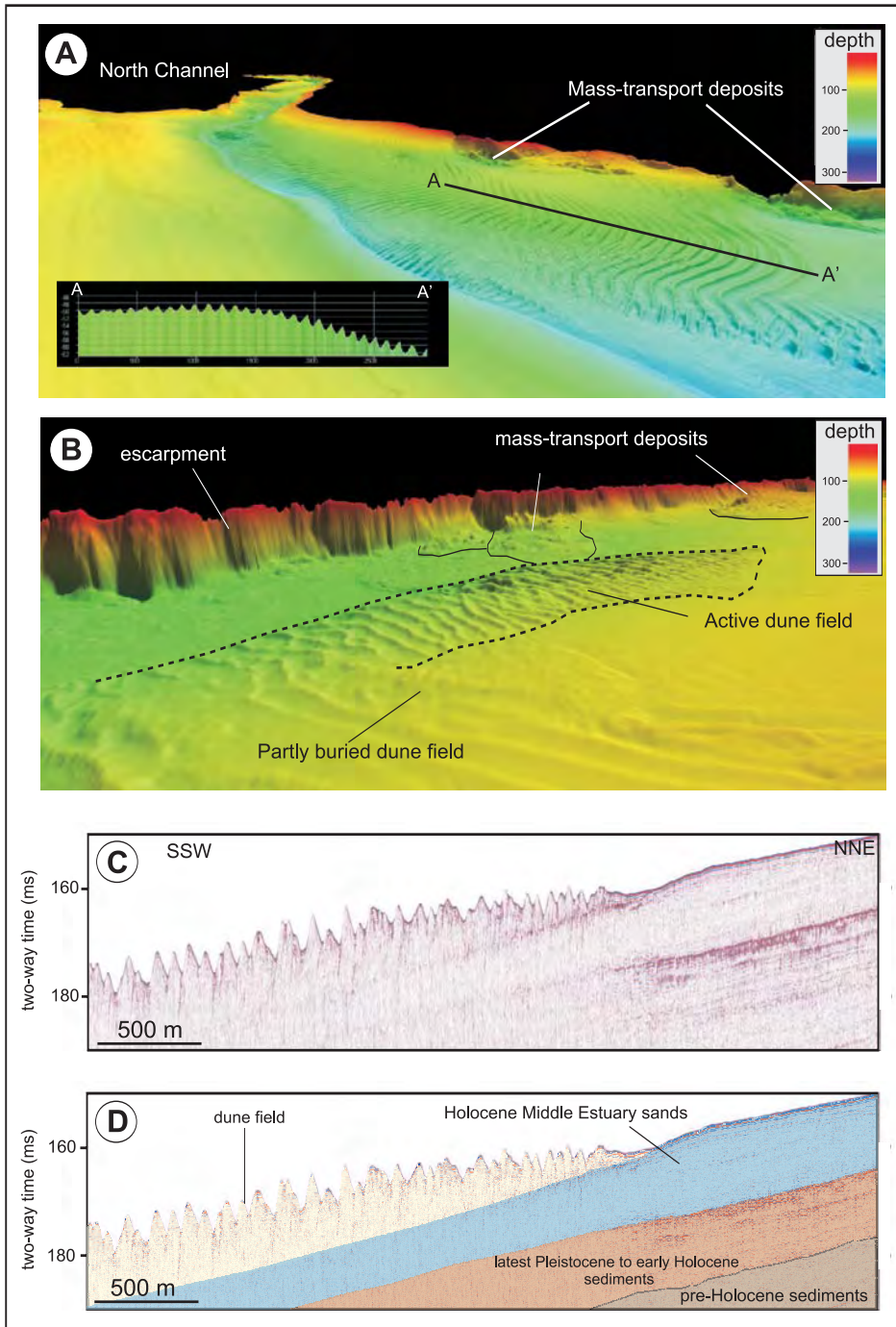
notably absent (Fig. 5C).

Northeast-striking high-resolution seismic lines (Fig. 7; see also Figure 7 of Duchesne et al. 2010) indicate that a latest Pleistocene to early Holocene regional-scale seismic marker (seismic unit 2 of Duchesne et al. 2010) dips away from a bathymetric high located near the mouth of Saguenay River. The upper and lower contacts of the seismic marker unit have no clear geomorphological signature. In the shallow parts of the bathymetric high, the oldest (pre-Holocene, but still undated) seismic unit (seismic unit 1 of Duchesne et al. 2010) crops out, indicating that erosion processes predominate over sedimentation in this area (Fig. 7A). On multibeam bathymetry images (Fig. 2), pre-Holocene sediments form a hummocky seafloor with short, elongated morphologic lows that strike in various directions and most likely result from iceberg scouring (Pinet et al. 2011b). Submarine photographs in this area indicate that the seafloor is either dominated by pebbles and cobbles (Fig. 4E) or made up of a light grey to bluish clay (Fig. 4F) that is locally overlain by a cm-thick discontinuous veneer of sand. The bluish clay corresponds to the type 2 (relict) pelites of Loring and Nota (1973) and to the blue-grey (layer 3) pelites of D’Anglejan and Brisebois (1978). Regionally, this clay unit is dated at around 12 000 years BP (calibrated) (St-Onge et al. 2008), confirming the seismic interpretation that Holocene sediments are absent in this area.

**Fan Deposits**

In both the Lower and Middle estuaries, gently sloping, subtle geomorphological features define cone-shaped units up to 15 km in width that are interpreted as submarine fans (Figs. 2B and 8). In several cases, fan sediments were diverted from the northwest and southeast margins of the estuary and delivered to fans located on the Laurentian Channel seafloor through submarine valleys and canyons (Fig. 8A, B). Fan sediments show significant grain size variability from sand to silt. Some segments of the submarine valleys and canyons have steep flanks, suggesting that at least some sediment was transported by turbidity flows that eroded the valley and canyons at the





**Figure 6.** A. Perspective view toward the south showing an 8.5-km-long dune field characterized by curvilinear crests. B. Perspective view toward the north showing a 7-km-long dune field. C and D. Very high-resolution seismic profile and interpretation illustrating a dune field within the St. Lawrence Middle Estuary. See Figure 2A for locations.

same time (Gagné et al. 2009). This transfer of coastal sediments to deeper environments contributes to the negative sediment budget along the coast. Locally, fans and channels show multiple crosscutting relationships that indicate a polyphase sedimentary history, such as at the mouth of Manicouagan

River, where four generations of fans and channels can be distinguished (Fig. 8C).

#### Mass-Transport Deposits

Seafloor instability features have been previously described for some parts of the St. Lawrence River Estuary (Cau-

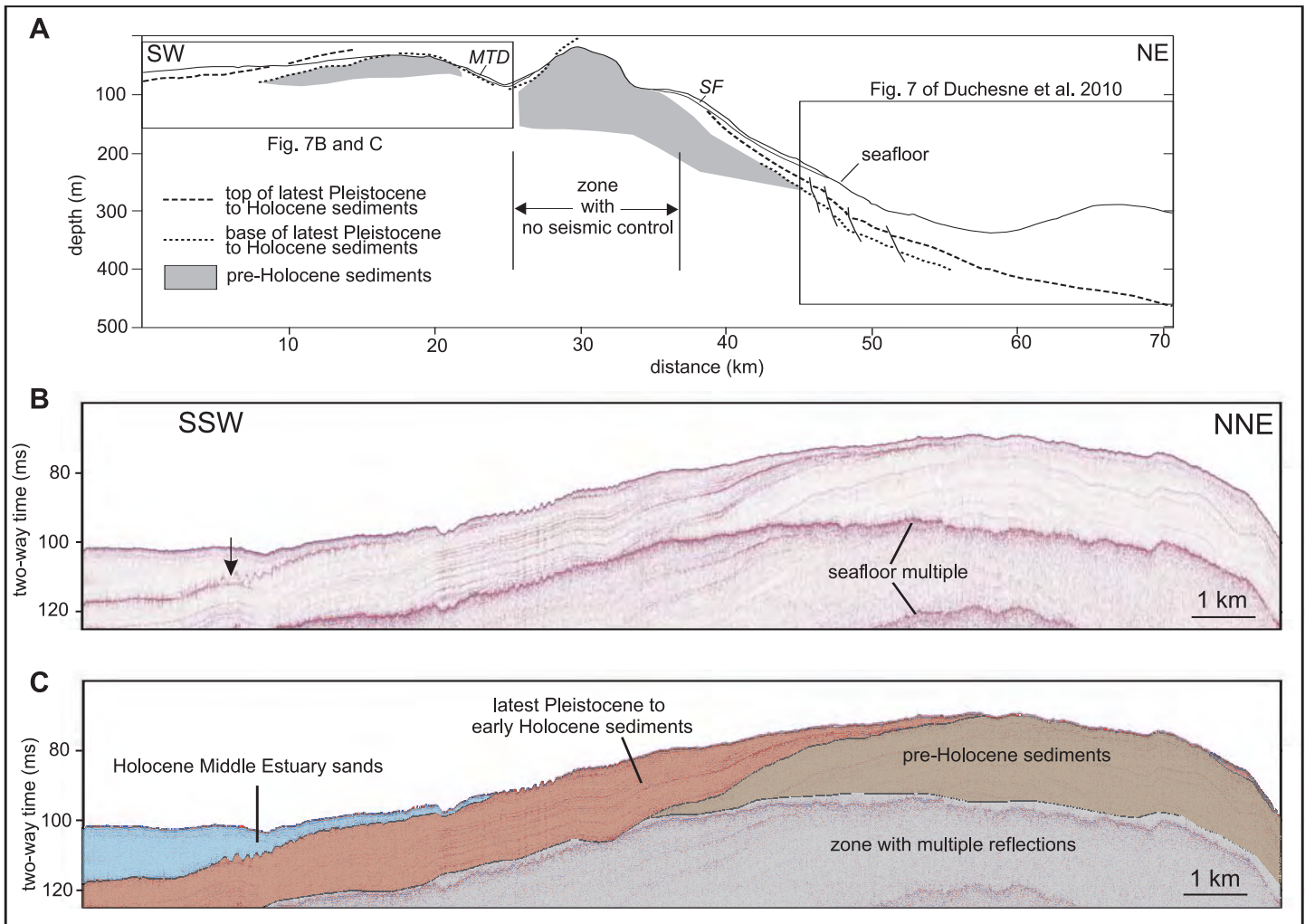
chon-Voyer et al. 2008; Campbell et al. 2008). However, analysis of the multi-beam bathymetry dataset indicates that submarine slides occur on a much larger scale than previously recognized and that sediments are reworked by mass-transport along significant segments of the Lower and Middle estuary margins. In the study area, 111 mass-transport deposits have been identified, representing 13% of the map area. Detailed study of mass-transport deposits is the objective of a companion paper.

Steep bedrock walls located along some segments of the St. Lawrence River Estuary, as well as earthquakes occurring in this seismically active area (Mazotti et al. 2005; Lamontagne 2009), act as a major predisposing factor for mass-transport (e.g. Syvitski and Praeg 1989; Duchesne et al. 2003; Campbell et al. 2008; Cauchon-Voyer et al. 2008). In the Betsiamites area, Cauchon-Voyer et al. (2008) recognized four phases of submarine landsliding since 9 ka BP. No additional constraints on the timing of mass-transport deposit emplacement have been collected during this study. However, the transition from submarine slides with a fresh geomorphological signature to partly buried slides with a subdued signature, as well as the large volume of sediments reworked by mass-transport processes on both flanks of the St. Lawrence River Estuary, suggest that the deposits result from several catastrophic events, at least some of which were likely triggered by earthquakes (Cauchon-Voyer et al. 2008; Campbell et al. 2008).

#### DISCUSSION

Short-term marine hydrodynamics is an important factor controlling sedimentation in estuaries (Dalrymple and Choi 2007). Because of the narrowing of the St. Lawrence River upstream of Saguenay River and the shallowing of the river floor – two characteristics largely inherited from bedrock geology (Pinet et al. 2008) – tidal height is amplified in the Middle Estuary compared to the Lower Estuary. In the Middle Estuary high-energy environment, which is characterized by a complex interplay of waves and tides, the Holocene sediment fill is reduced or absent (Fig. 7A).

Upstream of Saguenay River,



**Figure 7.** A. Interpretative cross-section based on very high-resolution seismic lines; note the high vertical exaggeration. MTD: Mass-transport deposit; SF: Saguenay fan. See Fig. 2A for location. B and C (see A for location). Very high-resolution seismic profile and interpretation illustrating the relationship between the main sedimentary assemblages of the St. Lawrence Middle Estuary. Note the presence of buried dunes in the southern part of the profile (arrow in B). Pre-Holocene sediments correspond to seismic unit 1 of Duchesne et al. (2010), whereas latest Pleistocene to early Holocene sediment corresponds to their seismic unit 2.

bottom currents are strong enough (generally 50–100 cm/sec, locally up to 150 cm/sec; D’Anglejan and Brisebois 1978) to locally generate large-scale migrating submarine bedforms in sandy material (Syvitski et al. 1983; Bolduc and Duchesne 2009; Fig. 6). The sand may have been remobilized either from the bathymetric high close to the Saguenay River mouth, which is more exposed to currents, or from Quaternary deposits on the shore that have been reworked by tides, fluvial erosion and ice rafting. However, these bottom currents are unlikely to have mobilized larger cobbles, which are major constituents of the seafloor in some areas (Fig. 4E). Alternative hypotheses for the formation of

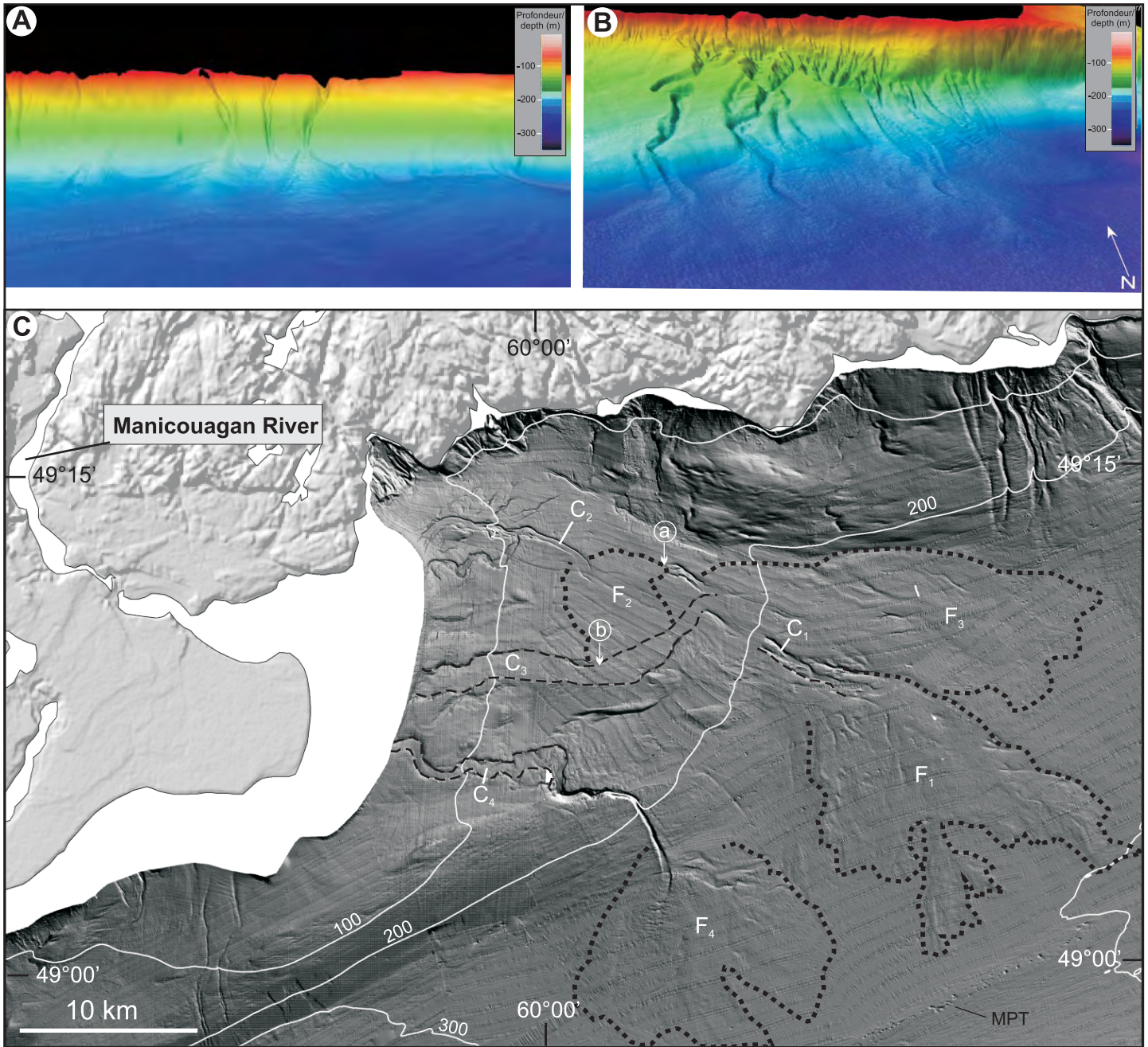
coarse-grained deposits include: 1) erosion of the fine-grained fraction by tidal re-suspension and formation of a residual seafloor comprising only the coarse fraction; 2) remobilization of coarse-grained sediments from the shore, followed by relatively short transport and sedimentation during the yearly ice break-out period, as documented by Dionne (1993); and 3) remobilization by storm waves of coarse-grained pre-Holocene sediments forming the shallow (10–100 m) part of the St. Lawrence seafloor close to the mouth of Saguenay River.

North of Saguenay River, in the Laurentian Channel, sediments are interpreted to have been deposited from the suspended load present in the

Lower Estuary. At the depths of the Laurentian Channel seafloor (>250 m), turbulence from tides and storm surges is not intense enough to cause re-suspension of fine silts, and erosion by post-sedimentation processes is minor.

In contrast, and as proposed by Loring and Nota (1973), the grain-size distribution of sediments deposited on some relatively shallow parts of the Laurentian Channel margins can be explained by turbulence from tides and storm surges, causing re-suspension of fine silts. The grain-size distribution of sediments on the margins is also a function of local sedimentary sources (i.e. St. Lawrence River tributaries) that may carry significant amounts of sediment. Fluvial input generally supplies





**Figure 8.** A and B. Perspective views of submarine fans formed when sediment pass through submarine valleys and canyons and settle on the Laurentian Channel seafloor. Near views are about 7 and 8 km wide for A and B, respectively. C. Submarine fans associated with the Manicouagan River. Based on crosscutting relationships, four generations of fans,  $F_1$  to  $F_4$  (oldest to youngest) and four generations of channels,  $C_1$  to  $C_4$  (oldest to youngest) may be distinguished. Fan  $F_2$  partly fills channel  $C_1$  at location a, whereas it is incised by channel  $C_3$  at location b. MPT: Matane pockmark train as defined by Pinet et al. (2010). See Figure 2A for all locations.

fine-grained sands and muds whereas the coarser sands are supplied by bed and shore erosion.

### CONCLUSION

Compared with other estuaries, in which facies characteristics and distribution record a complex but often progressive transition of physical

processes from river-dominated (river current) to marine-dominated (waves and tides), the St. Lawrence River Estuary is characterized by a sharp variation in sedimentary processes in the Middle versus the Lower Estuary. This variation is a consequence of contrasting hydrodynamic conditions related to major changes in the shape

of the St. Lawrence River Estuary. In the relatively shallow (generally less than 100 m) Middle Estuary, bedload reworking by bottom currents is the main process and precludes the deposition of Holocene fine-grained sediments. In some areas, erosional processes predominate over sedimentation and pre-Holocene sediments form



the seafloor. In the Lower Estuary (northeast of Saguenay River), sedimentation from suspended load is the predominant mechanism. Surficial sediments are Holocene in age and correspond to fine silt except close to local sedimentary inputs and in shallow areas where turbulence from tides and storm surges may cause re-suspension of fine-grained sediments.

#### ADDITIONAL MATERIAL

A 1:250 000 surficial geology map as well as twelve 1:50 000 shaded seafloor relief maps are available for free download at:

[http://geoscan.ess.nrcan.gc.ca/starweb/geoscan/servlet.starweb?path=geoscan/geoscan\\_f.web](http://geoscan.ess.nrcan.gc.ca/starweb/geoscan/servlet.starweb?path=geoscan/geoscan_f.web)

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#### REFERENCES

- Bolduc, A., 2008, Expédition 2007-048 du NGCC Matthew: levé géologique régional, estuaire du Saint-Laurent, 23 octobre au 4 novembre 2007: Geological Survey of Canada, Open File 5806, 91 p., 1 CD-ROM.
- Bolduc, A., and Duchesne, M. J., 2009, Découverte de mégadunes dans l'estuaire moyen du fleuve Saint-Laurent, Québec, Canada: *La revue des Sciences de l'eau*, v. 22, p. 125-134.
- Campbell, C., 2007, CCGS Matthew Expedition 2006-054: Regional groundtruth survey of the St. Lawrence Estuary, October 15–November 7, 2006: Geological Survey of Canada, Open File 5530, 65 p.
- Campbell, C., Duchesne, M., and Bolduc, A., 2008, Geomorphological and geophysical evidence of Holocene seafloor instability on the southern slope of the Lower St. Lawrence Estuary, Québec: 4<sup>th</sup> Canadian Conference on Geohazards, Université Laval, Québec, QC.
- Cauchon-Voyer, G., Locat, J., and St-Onge, G., 2008, Late-Quaternary morpho-sedimentology and submarine mass movements of the Betsiamites area, Lower St. Lawrence Estuary, Québec, Canada: *Marine Geology*, v. 251, p. 233-252.
- Dalrymple, R.W., and Choi, K., 2007, Morphologic and facies trends through the fluvial-marine transition in tide-dominated depositional systems: A schematic framework for environmental and sequence-stratigraphic interpretation: *Earth Science Reviews*, v. 81, p. 135-174.
- D'Anglejan, B.F., 1971, Submarine sand dunes in the St. Lawrence Estuary: *Canadian Journal of Earth Sciences*, v. 8, p. 1480-1486.
- D'Anglejan, B.F., and Brisebois, M., 1978, Recent sediments of the St. Lawrence Middle Estuary: *Journal of Sedimentary Petrology*, v. 48, p. 951-964.
- Dionne, J.-C., 1993, Sediment load of shore ice and ice rafting potential, Upper St. Lawrence Estuary, Québec, Canada: *Journal of Coastal Research*, v. 9, p. 628-646.
- Duchesne, M.J., Long, B.F., Urgeles, R., and Locat, J., 2003, New evidence of slope instability in the Outardes Bay delta area, Québec, Canada: *Geo-Marine Letters*, v. 22, p. 233-242.
- Duchesne, M.J., Pinet, N., Bédard, K., St-Onge, G., Lajeunesse, P., Campbell, D.C., and Bolduc, A., 2010, Role of the bedrock topography in the Quaternary filling of a giant semi-enclosed basin: The Lower St. Lawrence Estuary, Eastern Canada: *Basin Research*, v. 22, p. 933-951.
- Fisheries and Oceans Canada, 2010, <http://www.glf.dfo-mpo.gc.ca/os/goslim-gigsl/s-2-e.php>, last accessed May 2010.
- Gagné, H., Lajeunesse, P., St-Onge G., and Bolduc A., 2009, Recent transfer of coastal sediments to the Laurentian Channel, Lower St. Lawrence Estuary (Eastern Canada), through submarine canyon and fan systems: *Geo-Marine Letters*, v. 29, p. 191-200.
- Gilbert, D., Sundby, B., Gobeil, C., Mucci, A., and Tremblay, G.-H., 2005, A seventy-two-year record of diminishing deep-water oxygen in the St. Lawrence Estuary: The northwest Atlantic connection: *Limnology and Oceanography*, v. 50, p. 1654-1666.
- Lamontagne, M., 2009, Possible earthquake triggers of submarine landslides in the Estuary of the St. Lawrence River: Insights from the earthquake catalogue: Geological Survey of Canada, Open File 6007, 61 p.
- Lavoie, D., Pinet, N., Duchesne, M., Bolduc, A., and Larocque, R., 2010, Methane-derived authigenic carbonates from active hydrocarbon seeps of the St. Lawrence Estuary, Canada: *Marine and Petroleum Geology*, v. 27, p. 1262-1272.
- Loring, D.H., and Nota, D.J.G., 1973, Morphology and sediments of the Gulf of St. Lawrence: Bulletin of the Fisheries Research Board of Canada, Ottawa, v. 182, 147 p.
- Massé, M., 2001, L'évolution des dépôts quaternaire de l'estuaire du Saint-Laurent: Unpublished M.Sc. thesis, Université du Québec à Rimouski, 128 p.
- Mazotti, S., James, T.S., Henton, J., and Adams, J., 2005, GPS crustal strain, postglacial rebound, and seismic hazard in eastern North America: The St. Lawrence valley example: *Journal of Geophysical Research*, v. 110, no. B11301, 16 p.
- Nota, D.J.C., and Loring, D.H., 1964, Recent depositional conditions in the St. Lawrence river: A reconnaissance survey: *Marine Geology*, v. 2, p. 198-235.
- Pinet, N., Duchesne, M., Lavoie, D., Bolduc, A., and Long, B., 2008, Surface and subsurface signatures of gas seepage in the St. Lawrence Estuary (Canada): Significance to hydrocarbon exploration: *Marine and Petroleum Geology*, v. 25, p. 271-288.
- Pinet, N., Duchesne, M., and Lavoie, D., 2010, Linking a linear pockmark train with a buried Paleozoic structure: A case study from the St. Lawrence River: *Geo-Marine Letters*, v. 30, p. 517-522.
- Pinet, N., Brake, V., Campbell, C., Duchesne, M., Gagné, H., and Bolduc, A., 2011a, Surficial geology and shaded seafloor relief, St. Lawrence Estuary, Québec/Géologie de surface et relief ombré du fond marin, estuaire du Saint-Laurent, Québec: Geological Survey of Canada, Map 2161A, scale: 1:250 000.
- Pinet, N., Campbell, C., Brake, V., Duchesne, M., Côté, R., and Paquet, S., 2011b, Shaded seafloor relief, Baie-Sainte-Catherine, Québec/Relief ombré du fond marin, Baie-Sainte-Catherine, Québec: Geological Survey of Canada, Map 2171A, scale: 1:50 000.
- Smith, J.N., and Schafer, C.T., 1999, Sedimentation, bioturbation, and Hg uptake in the sediments of the estuary and Gulf of St. Lawrence: *Limnology and Oceanography*, v. 44, p. 207-219.
- St-Onge, G., Stoner, J.S., and Hillaire-Marcel, C., 2003, Holocene paleomagnetic records from the St. Lawrence Estu-

ary, eastern Canada: Centennial- to millennial-scale geomagnetic modulation of cosmogenic isotopes: *Earth and Planetary Science Letters*, v. 209, p. 113-130.

St-Onge, G., Lajeunesse, P., Duchesne, M.J., and Gagné, H., 2008, Identification and dating of a key Late Wisconsinan stratigraphic unit in the St. Lawrence Estuary and Gulf (Eastern Canada): *Quaternary Science Reviews*, v. 27, p. 2390-2400.

Syvitski, J.P.M., and Praeg, D., 1989, Quaternary successions in the St. Lawrence Estuary and adjoining areas, eastern Canada: An overview based on high-resolution seismo-stratigraphy: *Géographie Physique et Quaternaire*, v. 43, p. 291-310.

Syvitski, J.P.M., Silverberg, N., Ouellet, G., and Asprey, K.W., 1983, First observations of benthos and seston from a submersible in the lower St. Lawrence Estuary: *Géographie physique et Quaternaire*, v. 37, p. 227-240.

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The following was inadvertently omitted from the article "Great Mining Camps of Canada 3. The History and Geology of the Buchans Mine, Newfoundland and Labrador" (*Geoscience Canada* Volume 37, Number 4, December 2010):

#### Short Bio for Author

Geoff Thurlow first went to Buchans in 1971 and completed M.Sc. and Ph.D. theses at Memorial University on aspects of Buchans geology and lithogeochemistry. He worked at the mine initially for ASARCO and subsequently for Abitibi-Price until 1985, ultimately directing the exploration programs at the mine and its environs.