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Morphodynamics in sediment-starved inner-shelf submarine canyons (Lower St. Lawrence Estuary, Eastern Canada)

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ABSTRACT

The contemporaneous activity and sedimentary processes in a series of inner-shelf submarine canyons located in the Lower St. Lawrence Estuary were examined using high-resolution multibeam bathymetry and backscatter data. The presence of crescent-shaped bedforms (CSBs) displaced upslope at the bottom of the canyons between 2007 and 2012 indicates that they are currently active through the remobilization of sediment by gravity flows. However, the shelf and shores of the region are characterized by the absence of sediment. Our results indicate that gravity flows currently eroding the canyon floors do not transport new material downslope coming from the shelf but rather remobilize in-situ deglacial sediments within the canyon thalweg. We suggest that slope failures and internal tides/waves are responsible for sediment remobilization in these canyons, although their role in the upslope migrating CSBs is unclear. This paper provides evidence that sediment supply is not a prerequisite for the modern activity of inner-shelf submarine canyons when processes such as slope failures and internal tides/waves are frequent enough to remobilize in-situ sediments.

1. Introduction

Submarine canyons are the main conduits for the transport of coarse continental and shelf sediments to deeper marine basins where fine-grained hemipelagic or pelagic sediments are usually deposited. Sediments flowing through submarine canyons mainly originate from rivers (Migeon et al., 2006; Chiang and Yu, 2008; Babonneau et al., 2013), ice-sheets (Jenner et al., 2007; Roger et al., 2013), longshore drift (Lewis and Barnes, 1999; Smith et al., 2005; Yoshikawa and Nemoto, 2010; Normandeau et al., 2013) or the remobilization of shelf sediment (Mountjoy et al., 2013). Recent studies demonstrate that some submarine canyons are active despite the present day sea-level highstand that is believed to diminish or stop their activity (Paull et al., 2003; Boyd et al., 2008; Babonneau et al., 2013). However, their modern activity is not controlled by sea-level change but rather by their proximity to a sediment source, as canyon activity depends largely on sediment supply rate at their head and on the prevailing oceanographic and climatic conditions (Puig et al., 2014). Therefore, canyons are generally considered inactive when no sediment is available on their neighboring shelf.

Sedimentary processes and their resulting morphological expression on the seafloor are still highly addressed in marine geological studies (Talling et al., 2013). In recent years, the advances in high-resolution multibeam bathymetric surveys have allowed to increase the detail of studies on sedimentary processes along submarine canyons (Lastras et al., 2009, 2011; Babonneau et al., 2013; Biscara et al., 2013). In these systems, triggers of submarine gravity flows were identified based on morphological features observed and described at canyon heads (García-García et al., 2012; Hill, 2012; Hughes Clarke et al., 2014), while bedforms were imaged and associated with certain types of sediment gravity flows (Puig et al., 2008; Paull et al., 2010). However, the link between bedforms and gravity flows is still subject to debate (Talling, 2014).

Here we report on a series of small-scale, inner-shelf submarine canyons located off Pointe-des-Monts, in the Lower St. Lawrence Estuary (Eastern Canada; Fig. 1) from high-resolution bathymetric data. Processes involved in their recent morphological change are discussed

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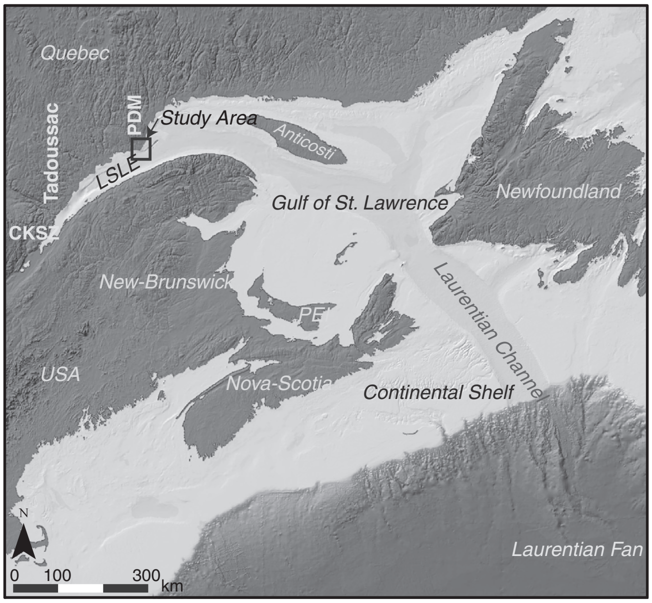

Fig. 1. Location of the Pointe-des-Monts (PDM) canyons, east of the Lower St. Lawrence Estuary (LSLE). The DEM comes from the Geological Survey of Canada (GSC).

based on the morphological features observed at the head and along the canyons. These observations indicate that the canyons are active today despite the absence of a sediment source at their head and their disconnection to a terrestrial drainage system.

2. Regional settings

Pointe-des-Monts is located in the Lower St. Lawrence Estuary (LSLE), at the western edge of the Gulf of St. Lawrence (Fig. 1). The north shore of the LSLE is underlain by Grenvillian metamorphic rocks of the Canadian Shield (Franconi et al., 1975). The submarine geomorphology of the LSLE is mainly characterized by the Laurentian Channel: a deep (365 m) and large-scale trough that extends from Tadoussac to the edge of the continental shelf (Piper et al., 2007). Within the inner-shelf of the Estuary and Gulf of St. Lawrence, the deepest depths are observed along the Laurentian Channel (~350 m in the LSLE). The margins of the Laurentian Channel are generally steep, reaching a mean of 7–9° in some areas, which allowed inner-shelf submarine canyons and channels to form (Duchesne et al., 2003; Gagné et al., 2009; Pinet et al., 2011). The origin of these canyons is still undocumented, although Pinet et al. (2011) indicated that they are Holocene in age. The steep slopes also favored the generation of mass movements in the LSLE (Duchesne et al., 2003; Cauchon-Voyer et al., 2008). These mass movements, with the Colombier landslide being the largest (Cauchon-Voyer et al., 2008, 2011), are mostly related to earthquakes from the Charlevoix–Kamouraska Seismic Zone (CKSZ). The largest event probably occurred in 1663, when a M ≈ 7 earthquake produced numerous mass movements in the province of Quebec, notably in the St. Lawrence Estuary and Saguenay Fjord (e.g., Locat, 2011; St-Onge et al., 2012). More recent events (1860, 1870—M ~ 6–6.5) were also hypothesized to have produced local slumping (Gagné et al., 2009), near the CKSZ (Fig. 1). During deglaciation, sedimentation rates were very high in the LSLE, which led to the deposition of >200 m of ice-proximal, ice-distal, paraglacial and postglacial sediments along the margins of the Laurentian Channel (Syvitski and Praeg, 1989; St-Onge et al., 2008; Duchesne et al., 2010).

The LSLE is a hydrodynamic environment driven principally by the semi-diurnal tides (~3 m tidal range), river runoff and wind (Koutitonsky and Bugden, 1991). The summer water column is continuously stratified but for the sake of simplicity it can be conveniently subdivided into four major layers: 1) an upper warm stratified layer (8–18 °C; 0–30 m); 2) a cold intermediate layer (−0.5–2 °C; 30–100 m); 3) a permanent thermocline (1.5–4 °C; 100–200 m) and; 4) a lower relatively warm layer (3–7 °C; 200–400 m) (Loring and Nota, 1973; Drinkwater and Gilbert, 2004). The combined effect of stratification, hydrodynamic and complex bathymetry leads to the presence of internal tides and higher frequency internal waves in the region (Forrester, 1974; Saucier and Chassé, 2000). These internal waves are thought to be predominantly generated at the shallow sill (20 m) found near the head of the Laurentian Channel where they have been mostly studied. Such internal waves are likely generated at various other places along the estuary, not yet documented.

3. Methods

The activity of the Pointe-des-Monts submarine canyons was assessed by using two sets of high-resolution multibeam bathymetric data. The first dataset was acquired in 2007 by the Canadian Hydrographic Service (CHS) with a Kongsberg EM-1002 multibeam echosounder (95 kHz) between 20 and 350 m water depth (3 m-grid) on board the F.G. Creed. The second dataset was acquired in 2012 with 1) a Kongsberg EM-2040 at a frequency of 300 kHz on board the R/V Coriolis II (1 m-grid) at depths of 20–350 m and 2) a Reson Seabat 8101 (245 kHz) at depths of 5–20 m (3 m-grid) on board the R/V Louis-Edmond-Hamelin (Fig. 2). A DGPS was used in each case, so the horizontal uncertainty does not exceed 2 m. The vertical uncertainty of the two echosounders is typically less than 0.1 m. However, the vertical uncertainty between the two datasets is greater for different reasons: 1) Tidal variations were not collected during the surveys and are based on corrected tidal variations recorded

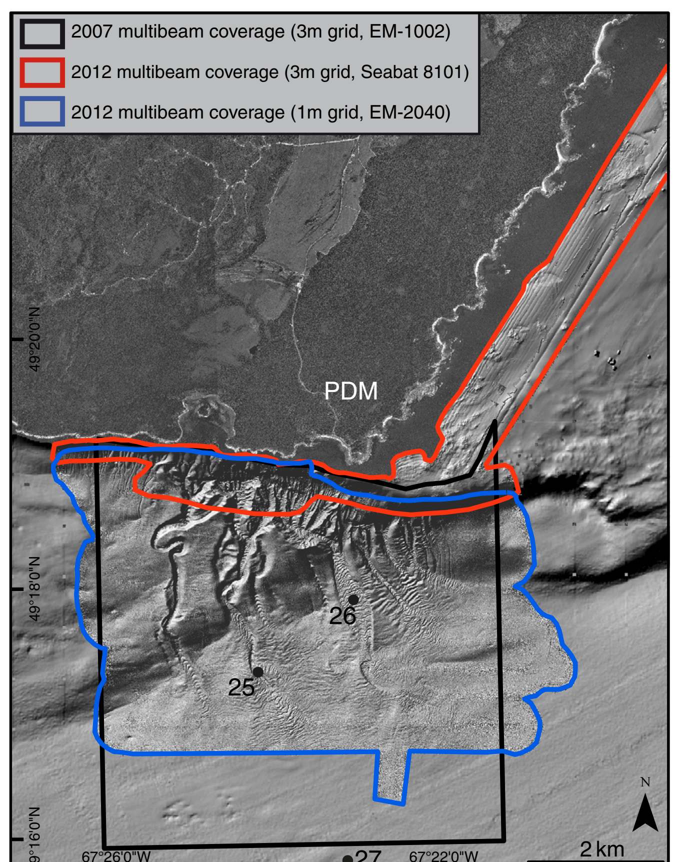

Fig. 2. Outline of multibeam surveys used in this study and conducted in 2007 and 2012. Location of surface sediment samples (25, 26, 27) are also shown.