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Sediment transport processes at the head of Halibut Canyon, eastern Canada margin: An interplay between internal tides and dense shelf-water cascading

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A B S T R A C T

To investigate the processes by which sediment is transported through a submarine canyon incised in a glaciated margin, the bottom boundary layer quadrapod RALPH was deployed at 276-m depth in the West Halibut Canyon (off Newfoundland) during winter 2008–2009. Two main sediment transport processes were identified throughout the deployment. Firstly, periodic increases of near-bottom suspended-sediment concentrations (SSC) were recorded associated with the up-canyon propagation of the semidiurnal internal tidal bore along the canyon axis, carrying fine sediment particles resuspended from deeper canyon regions. The recorded SSC peaks, lasting less than 1 h, were observed sporadically and were linked to bottom intensified up-canyon flows (~40 cm s^{-1}) concomitant with sharp drops in temperature. Secondly, sediment transport was also observed during events of intensified down-canyon current velocities that occurred during periods of sustained heat loss from surface waters, but were not associated with large storm waves. High-resolution velocity profiles throughout the water column during these events revealed that the highest current speeds (~1 m s^{-1}) were centered several meters above the sea floor and corresponded to the region of maximum velocities of a gravity flow. Such flows had associated low SSC and cold water temperatures and are interpreted as dense shelf water cascading events channelized along the canyon axis. Sediment transport during these events was largely restricted to bedload and saltation, producing winnowing of sands and fine sediments around larger gravel particles. Analysis of historical hydrographic data suggests that such gravity flows are not related to the formation of coastal dense waters advected towards the outer shelf that reached the canyon head. Rather, the dense shelf waters appear to be generated around the outer shelf, where convection during winter is able to reach the sea floor and generate a pool of near-bottom dense water that cascades into the canyon during one or two tidal cycles. A similar transport mechanism is likely to occur in other submarine canyons along the eastern Canadian margin, as well in other canyoned margins where winter convection can reach the shelf-edge.

1. Introduction

Submarine canyons are morphological features that are found on many continental margins, acting as preferential conduits for transport of sediment from continental shelves towards deep-sea environments. During Plio-Pleistocene lowstands of sea level, sediment–gravity mechanisms (i.e. turbidity currents, debris flows) dominated transport through submarine canyons, funneling large volumes of terrigenous sediment to deeper parts of the continental margins (Shanmugam et al., 1985; Piper and Normark, 2009). Although Holocene sea-level rise has reduced drastically the supply of sediments to submarine canyons, it is widely recognized that canyons at present continue to be preferential conduits for the transfer of sediments from the shelf to the deep ocean.

During the last decades, several studies have provided information about contemporary sediment-transport processes acting within submarine canyons by means of analysis of combined currents and suspended-sediment concentration data. Most of them have been conducted using moored instruments placed at several heights above the sea floor, although few studies also have involved bottom-boundary-layer measurements. Storm-induced sediment gravity flows (Xu et al., 2002; Puig et al., 2003, 2004a; Xu et al., 2010; Martín et al., 2011; Masson et al., 2011; Mulder et al., 2012), enhanced off-shelf advection during storms (Carson et al., 1986; Martín et al., 2006), hyperpycnal flows and failures from recently deposited fluvial sediments (Khripounoff et al., 2012), dense shelf water cascading (Canals et al.,

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2006; Ogston et al., 2008; Puig et al., 2008), and trawling-induced resuspension (Palanques et al., 2006; Martín et al., 2007; Puig et al., 2012) largely dominate the present-day transfer of sediment through canyons. Additionally, internal waves periodically resuspend ephemeral deposits within canyons and contribute to disperse particles or retain and accumulate them in specific regions (e.g., Gardner, 1989a, b; Puig et al., 2004b; de Stigter et al., 2007).

The eastern Canadian continental slope is in places deeply dissected by a dendritic network of submarine canyons, which are separated by steep intercanyon ridges (e.g. Hesse et al., 1999; Mosher et al., 2004; Fig. 1). A late Pliocene lowstand of sea-level resulted in increased glacio-fluvial sediment transport to the slope and the initiation of widespread canyon cutting (Piper et al., 1987). Canyon incision increased during Early Pleistocene, resulting from either longer episodes of sea-level lowstand or an increase in sandy sediment delivered to the shelf break, although the overall style of sedimentation continued to be prodeltaic (Piper and Normark, 1989). The present day submarine canyons are a product of Quaternary ice-related processes that operated along the margin as icesheets crossed the shelf during major glaciations since 0.5 Ma. The general style of Quaternary deposition on the slope is principally from proglacial plume fallout deposits (mud with dispersed ice-rafted debris) with occasional thin turbiditic sand beds (Piper et al., 2005). Canyon floors locally record rare Holocene turbidity current deposits (Savoye et al., 1990; Jenner et al., 2007). The most remarkable sediment transport event in this margin occurred during the 1929 Grand Banks earthquake, which triggered a slump that evolved into a large turbidity current and broke a series of submarine cables and created a >150 km^3 sandy turbiditic deposit (~1 m thick) in the Sohm abyssal plain (Heezen and Ewing, 1952; Piper et al., 1988; Mosher et al., 2010).

Armitage et al. (2010) conducted a detailed analysis of 3D seismic reflection data with 2D high-resolution seismic-reflection profiles and shallow sediment cores in Halibut Canyon, off southwest Newfoundland (Fig. 2). The contemporary sediment transport processes operating on this canyon, however, could not be properly discerned, and the shelf-to-canyon sediment transport was attributed

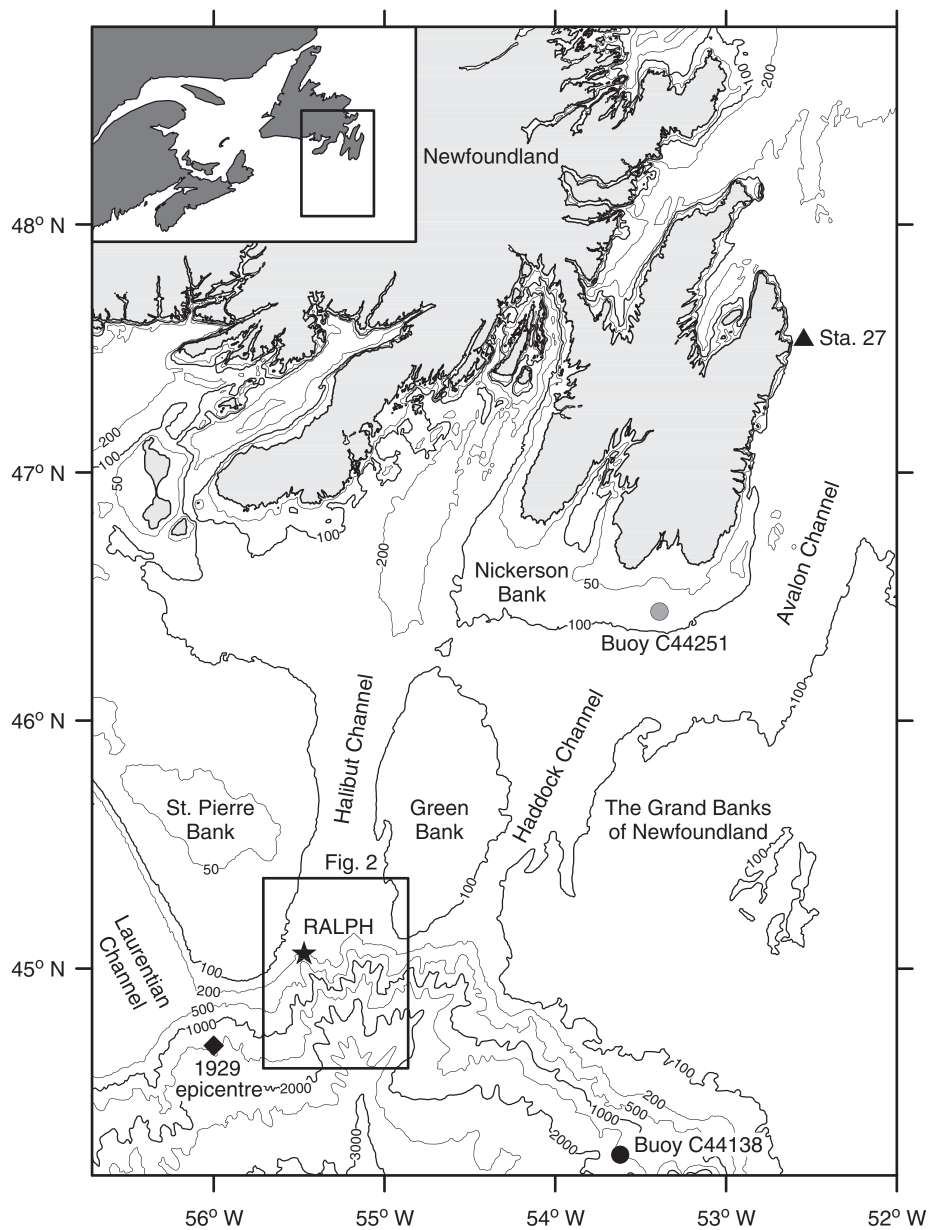

Fig. 1. Bathymetric map of the eastern Canada continental margin south of Newfoundland showing the position of RALPH deployment (star), the two meteorological buoys used in this paper (circles), the epicenter of the 1929 earthquake (diamond) and the long-term monitoring station 27 (triangle). Rectangle shows the canyon head area, enlarged in Fig. 2.