Marine Geology 400 (2018) 76–93

Contents lists available at ScienceDirect

Marine Geology

journal homepage: www.elsevier.com/locate/margo

Impact of relative sea-level changes since the last deglaciation on the formation of a composite paraglacial barrier

Julie Billy[a,*], Nicolas Robin[a,*], Christopher J. Hein[b], Duncan M. FitzGerald[c], Raphaël Certain[a]

[a] Université de Perpignan Via Domitia, CEFREM UMR-CNRS 5110, 52 Avenue Paul Alduy, 66860 Perpignan Cedex, France
[b] Department of Physical Sciences, Virginia Institute of Marine Science, College of William & Mary, Gloucester Point, VA 23062, USA
[c] Department of Earth and Environment, Boston University, 675 Commonwealth Avenue, Boston, MA 02215, USA

ARTICLE INFO

Editor: E. Anthony

Keywords:
Seismic profiling
Ground-penetrating radar data
Paraglacial barrier
Gulf of Saint Lawrence
Stratigraphic framework
Regressive-transgressive sequences

ABSTRACT

Comprehensive onshore-offshore surficial and sub-surface mapping of a composite barrier (combination of prograded, aggraded, and/or transgressive segments) have provided a better understanding of the (i) mechanisms responsible for the formation and development of coastal barrier systems, (ii) relationships and interactions among individual parts of those systems, and (ii) the overall stratigraphic framework of subaerial and subaqueous segments of the barriers. Here, we investigate these facets of barrier evolution through integration of stratigraphic data from subaqueous high-resolution seismic and subaerial ground-penetrating radar, sedimentology (terrestrial cores and seafloor surface samples), and merged topographic and bathymetric mapping of the Miquelon-Langlade Barrier (northwest Atlantic Ocean, south of Newfoundland). This barrier system has two open coasts and evolved in a paraglacial setting, influenced by the reworking of glaciogenic sediment (glacial moraines) in a regime of complex sea-level changes. The barrier stratigraphic sequence is placed within the context of a shifting period from shoreline transgression to one of regression; the resulting sedimentary units reflect the isolated position of the Saint-Pierre-and-Miquelon Archipelago distal from continental influence. Seismic profiles reveal the position of the lowstand shoreline, located 20–25 m below modern sea level, further refining the existing lowstand model of southern Newfoundland. Continuous onshore-offshore subsurface geophysical mapping of the barrier allows for the identification of the relative positioning of distinct sedimentary units interpreted as subaerial barrier (beaches, dunes, spit), shoals, and shoreface deposits, and allows for estimation of the total barrier sediment volume (235×10^6 m^3) and its relative subaqueous (90%) and subaerial (10%) components. Moreover, it reveals the three distinct morphological units comprising the Holocene barrier: (i) central, regressive, swash-aligned beach-ridge plains developed atop both thin (westward-prograding) and thick (eastward-prograding) shoreface deposits, (ii) drift-aligned, elongating spits located in the northwest and northeast of the island, and (iii) a transgressive barrier located adjacent to the northwest spit, pinned on its landward side to parabolic sand dunes, and currently experiencing erosion and limited overwash. Finally, this study places evolution of this system in the framework of paraglacial barrier evolutionary typology.

1. Introduction

Coastal systems—consisting of emerged landforms such as barriers, spits, beach ridges, beaches, dunes etc., in addition to their seaward terminations (shoreface deposits)—evolved in response to changes in the ratio between the rate of sediment accumulation and the rate of accommodation creation (space available for sediments to fill, a function of relative sea-level (RSL) variations and shoreface morphology) (e.g. Carter, 1988; Roy et al., 1994; Short, 1999; Timmons et al., 2010). Three main morpho-sequences are identified when the rate of sediment accumulation exceeds, is less than, and equals than rate of accommodation creation, respectively (e.g. Galloway and Hobday, 1983; Davis and FitzGerald, 2004; Costas and FitzGerald, 2011; Otvos and Carter, 2013): (i) regressive (prograded) barriers defined by a seaward extension of the barrier either under normal (sediment supply dominated; (e.g. Rodriguez and Meyer, 2006; Barusseau et al., 2010)) or forced (RSL fall dominated; e.g. Tamura et al. (2008); Sanjaume and Tolgensbakk (2009)) regression as beach-ridge foredune-ridge, strandplain, chenier, or prograded barrier systems; (ii) transgressive (retrograded) barriers defined by landward shoreline translation in response to either erosion or overwash-induced rollover (e.g. Mellett et al., 2012; Lima et al., 2013; Otvos and Carter, 2013); and (iii) stationary

* Corresponding authors.
E-mail addresses: juliebilly@gmail.com (J. Billy), nicolas.robin@univ-perp.fr (N. Robin).

https://doi.org/10.1016/j.margeo.2018.03.009
Received 29 November 2017; Received in revised form 30 March 2018; Accepted 31 March 2018
Available online 03 April 2018
0025-3227/

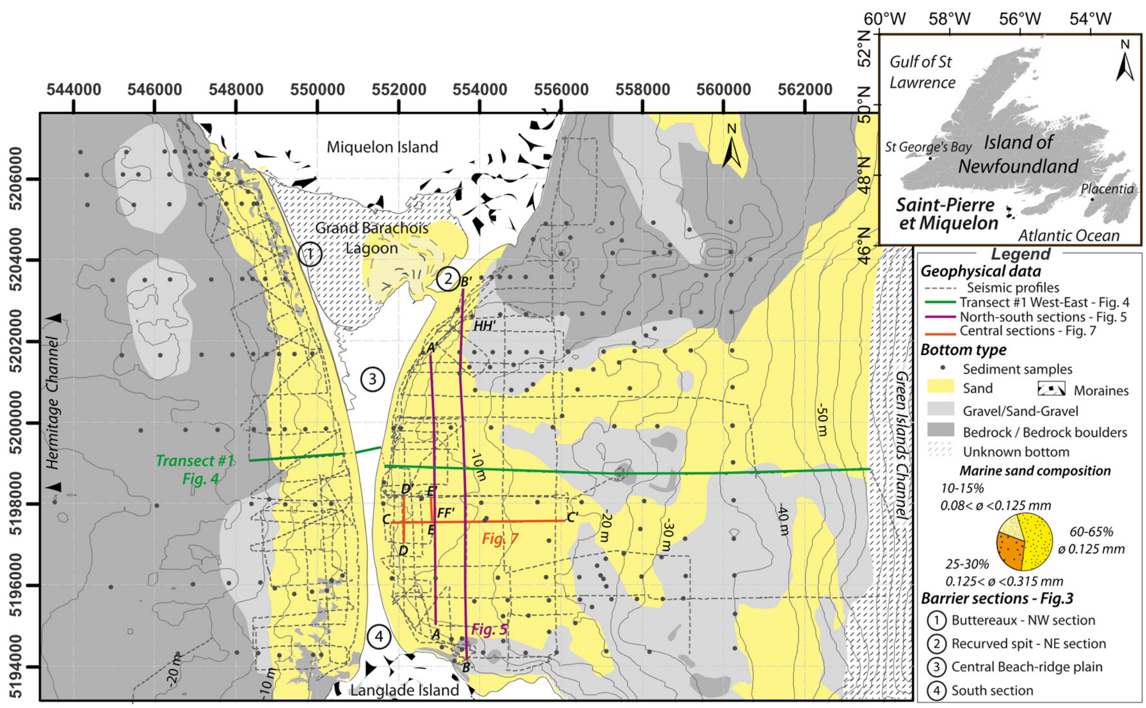

Fig. 1. Location map of the study area (the Miquelon-Langlade barrier) and data collected as part of this study. All data are projected in WGS 84 Zone 21 N. The Saint-Pierre-et-Miquelon Archipelago is located south of Newfoundland (inset), in the Gulf of Saint Lawrence. The barrier is composed in 4 sections (see Fig. 3): 1) at the north-west: les Buttereaux; 2) at the North-east: a mainland-attached recurved spit; 3) central northern beach-ridges plains; and 4) southern, small beach-ridge plains. The map locates marine sediment samples (black points) and seismic profiles along the west and east sides of the Miquelon-Langlade Barrier (gray dotted lines). Colour lines correspond to profiles shown in Figs. 4, 5, and 7. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

(aggraded) barriers characterized by vertical growth through the stacking of sand layers (e.g. Simms et al., 2006). However, single coastal systems are commonly much more complex than these end members and often defined by a combination of prograded, aggraded, transgressive segments; these are termed composite or hybrid barriers (Otvos, 1982, 2012). Investigations of such systems contribute to improved knowledge of the factors influencing coastal-system development, variations through time, and interactions or connections with pre-existing coastal features (underlying geology and antecedent topography).

Stratigraphy holds the potential to record the history of coastal system formation and evolution, as well as the sedimentation processes, time-varying sediment delivery rates (Vespremeanu-Stroe et al., 2016), role of inherited topography (FitzGerald and Heteren, 1999), and changes in RSL (Costas and FitzGerald, 2011; Billy et al., 2015; Costas et al., 2016), wave energy (Allard et al., 2008; Hein et al., 2013), tidal regimes (Hayes, 1979; Chaumillon et al., 2013), and climate (Billeaud et al., 2009; Costas and FitzGerald, 2011). Only few studies (Timmons et al., 2010; Oliver et al., 2017) utilize both onshore and offshore datasets to explore the stratigraphic record as preserved on both sides of the modern shoreline. However, the combination of both shallow seismic (offshore; e.g. Certain et al. (2005); Mellett et al. (2012); Billy et al. (2013); Aleman et al. (2014)) and ground-penetrating radar (onshore; Rodriguez and Meyer (2006); Hede et al. (2013); Lima et al. (2013)) technologies presents a powerful tool with which to investigate the evolutionary history of, in particular, composite barrier systems.

Paraglacial coastal systems are those whose characteristics reflect: (i) glacio-isostatic and eustatic sea-level changes, (ii) reworking of generally glacigenic sediment representing a range of grain sizes, and (iii) a clear influence of bedrock or inherited geomorphology (Church and Ryder, 1972; Forbes and Syvitski, 1994; Ballantyne, 2002; Hein, Fitzgerald, Buynevich, et al., 2014). Given their commonly complex histories of post-glacial sea-level change, paraglacial coastal systems may record in their subaerial and subaqueous sedimentary archives evidence of transitions between shoreline transgression and regression. Examples of such paraglacial sedimentary archives include the Gulf of Saint Lawrence (Boyd et al., 1987; Orford et al., 1991a; Forbes and Syvitski, 1994), the Gulf of Maine (van Heteren et al., 1998; Hein, Fitzgerald, Buynevich, et al., 2014), the Baltic coast (Hoffmann et al., 2005; Harff and Meyer, 2011), and the coast of Alaska (Hayes and Ruby, 1994).

Here, we present the results of continuous onshore-offshore geophysical mapping of a paraglacial, composite barrier located south of Newfoundland and develop an evolutionary model of its formation following the last deglaciation. The morphology and internal architecture of the subaerial segments of the barrier are derived from published data (Billy et al., 2014, 2015) and are supplemented with new seafloor sediment samples and seismic surveys collected along the barrier's two open coasts. The proposed stages of barrier formation correlate with the overall stratigraphic framework available from this combined onshore-offshore mapping and are placed in the context of the paraglacial environment in which the system developed. Finally, the importance of this kind of comprehensive study is discussed and results are compared to existing stratigraphic models and paraglacial barrier evolutionary models. Moreover, this study provides an example of the utility of developing onshore-offshore geophysical datasets to: (i) investigate barrier stratigraphic complexity, (ii) highlight correlations between sedimentary units and contacts to better establish the developmental framework of the barrier, and (iii) to estimate barrier sediment volumes and quantity of sediment deposits needed to form this coastal feature.