Continental Shelf Research 83 (2014) 64–85

Contents lists available at ScienceDirect

Continental Shelf Research

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

Research papers

# Distribution of subtidal sedimentary bedforms in a macrotidal setting: The Bay of Fundy, Atlantic Canada

Brian J. Todd [a,*], John Shaw [a], Michael Z. Li [a], Vladimir E. Kostylev [a], Yongsheng Wu [b]

[a] Geological Survey of Canada (Atlantic), Natural Resources Canada, Bedford Institute of Oceanography, Box 1006, Dartmouth, NS, Canada, B2Y 4A2
[b] Coastal Ocean Science Section, Ocean Science Division, Fisheries and Oceans Canada, Bedford Institute of Oceanography, Dartmouth, NS, Canada B2Y 4A2

ARTICLE INFO

*Article history:*
Received 4 April 2013
Received in revised form
6 November 2013
Accepted 18 November 2013
Available online 26 November 2013

*Keywords:*
Bedforms
Morphology
Sediment
Multibeam sonar
Macrotidal
Bay of Fundy

ABSTRACT

The Bay of Fundy, Canada, a large macrotidal embayment with the World's highest recorded tides, was mapped using multibeam sonar systems. High-resolution imagery of seafloor terrain and backscatter strength, combined with geophysical and sampling data, reveal for the first time the morphology, architecture, and spatial relationships of a spectrum of bedforms: (1) flow-transverse bedforms occur as both discrete large two-dimensional dunes and as three-dimensional dunes in sand sheets; (2) flow-parallel bedforms are numerous straight ridges described by others as horse mussel bioherms; (3) sets of banner banks that flank prominent headlands and major shoals. The suite of bedforms developed during the Holocene, as tidal energy increased due to the bay approaching resonance. We consider the evolution of these bedforms, their migration potential and how they may place limitations on future in-stream tidal power development in the Bay of Fundy.



## 1. Introduction

The Bay of Fundy, located on the Atlantic coast of Canada between the provinces of Nova Scotia and New Brunswick (Fig. 1), is a macrotidal estuarine embayment (Amos et al., 1980) with the highest recorded tides in the world of 17 m (Dawson, 1899; Archer and Hubbard, 2003; O'Reilly et al., 2003, 2005; Bishop, 2008). These large tides generate strong currents. Harnessing these currents to generate power has been the focus of engineering schemes dating back to 1910 and has periodically garnered attention throughout the past century (Baker, 1982). A tidal power station was completed at Annapolis Royal, Nova Scotia in 1984 and a tidal barrage up to 8 km in length was proposed thirty years ago for the Minas Basin (Daborn and Dadswell, 1988; Desplanque and Mossman, 2004). Studies predicted widespread environmental effects from such a structure, including alteration of the tidal range throughout the Bay of Fundy and Gulf of Maine (Greenberg, 1975, 1979). With recent revived interest in marine renewable energy, coupled with advances in the engineering design of underwater structures and the success of 'in-stream' power extraction installations elsewhere (e.g. United Kingdom, France), Minas Passage at the head of the Bay of Fundy (Fig. 1) is now the subject of an engineering study as a site for future electricity generation (Electric Power Research Institute, 2005; Karsten et al., 2008). In the future, tidal power installations may be emplaced at other, more widespread, locations in the bay and could take the form of arrays of devices linked by submarine cables. Any infrastructure associated with power generation devices emplaced on the seabed must take into account potential geohazards.

The objective of this paper is to describe the morphology, architecture, and spatial relationships of a spectrum of subtidal sedimentary bedforms on the floor of the Bay of Fundy. As sand banks and large bedforms in the upper Bay of Fundy have been well described in other recent studies (e.g. Shaw et al., 2012b; Li et al., 2013), the focus of this paper is on the central Bay of Fundy (Fig. 2). Sedimentary bedforms are widely recognized as a geohazard for cables and pipelines (Whitehouse et al., 2000; Barrie et al., 2005). For example, if bedforms migrate across emplaced infrastructure, loads can be exerted by the weight of the sediment that exceeds the infrastructure design strength and failure results (Németh et al., 2003).

For this study, the seafloor relief of the Bay of Fundy was mapped using a suite of multibeam sonar systems between 1993 and 2009 (Todd et al., 2011a, 2011b). The resulting imagery shows, in unprecedented detail, the geomorphology within the bay (Figs. 1 and 2). This imagery, interpreted in conjunction with sediment sample analyses, high-resolution seismic reflection profiles, and numerical models of the current regime, provides new insight into the characteristics, genesis and behaviour of subtidal sedimentary bedforms in this unique environment. Sediment is organized into bedforms under

* Corresponding author. Tel.: +1 902 426 3407; fax: +1 902 426 6186.
*E-mail addresses:* Brian.Todd@NRCan.gc.ca (B.J. Todd), John.Shaw@NRCan.gc.ca (J. Shaw), Michael.Li@NRCan.gc.ca (M.Z. Li), Vladimir.Kostylev@NRCan.gc.ca (V.E. Kostylev), Yongsheng.Wu@dfo-mpo.gc.ca (Yongsheng).

0278-4343/$ - see front matter 
http://dx.doi.org/10.1016/j.csr.2013.11.017

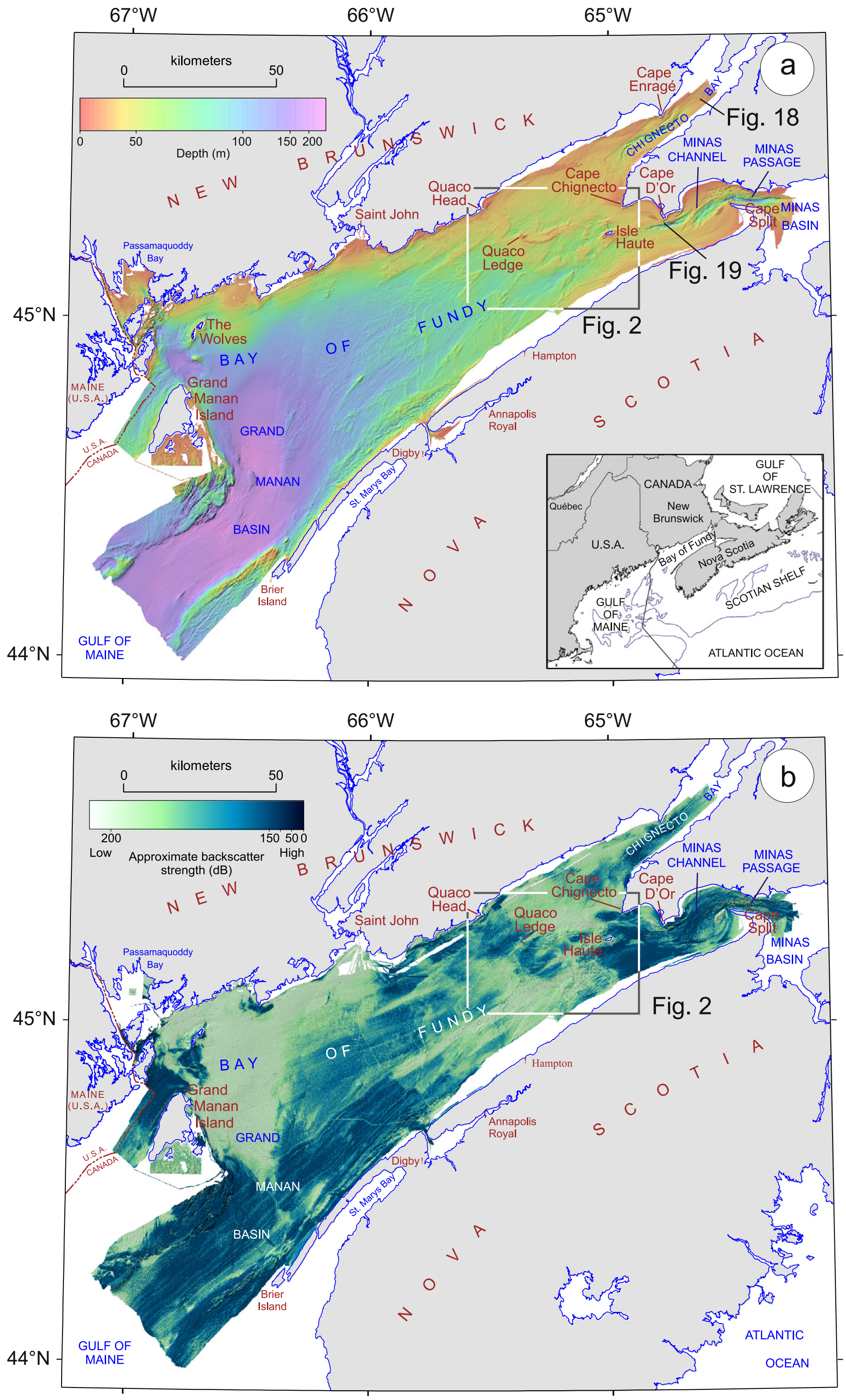


**Fig. 1.** Small scale map of the Bay of Fundy on the Atlantic coast of Canada showing (a) the regional bathymetry of the bay and (b) the backscatter strength of geological materials on the seabed. Outline box delineates the extent of the bathymetric image shown in Fig. 2. Inset map of offshore Atlantic Canada and northeastern USA in (a) shows the Gulf of Maine and Scotian Shelf; the 200 m isobath is shown in blue. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

the influence of the current regime in the bay and bedform morphology is the result of the interplay between substrate type, sediment characteristics and supply, and current speed and direction. The descriptive classification used in this paper for sediment bedforms (i.e., dunes) follows that of Ashley (1990) as modified by Dalrymple and Rhodes (1995) and outlined in Table 1.

Sea floor sediments in the Bay of Fundy have been studied both geologically and geophysically for the last fifty years. Investigations based on sediment sampling attempted to map textural provinces in the bay (Forgeron, 1962; Swift et al., 1969; Pelletier and McMullen, 1972; Pelletier, 1974). Gravel was found to be predominant at depths greater than 40 m, sand occurred in the eastern and western parts of the bay, and mud was concentrated to the northeast in Chignecto Bay and in the Grand Manan Basin east of Grand Manan Island (Fig. 1). Sub-bottom seismic reflection profiles first revealed sediment bedforms ranging from discrete, individual dunes to fields of bedforms