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Geologic insights from multibeam bathymetry and seascape maps of the Bay of Fundy, Canada

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ABSTRACT

The macrotidal Bay of Fundy, Canada, was systematically mapped in the early 2000s using multibeam sonar technology, partly to support efforts to develop hydropower. The primary product was a suite of 1:50,000-scale maps of shaded seafloor relief and backscatter. In addition, a 'seascape' map was produced in an attempt to classify the entire bay in terms of morphology, texture, and biota. The eight seascape groups that are delineated reflect the strong signature of glaciation in much of the bay, the effects of Holocene tidal range expansion, and the results of modern processes under a dynamic current regime. As a result of the recent mapping we are able to argue that the muddy depocentre in the southwest of the bay was primarily active before the well-documented expansion of tidal range that occurred in the Bay of Fundy in the Holocene epoch. We further demonstrate the complexity of the seafloor in one of the glacial seascapes, and discuss the morphology and stability of a major tidal scour. The evidence obtained from multibeam sonar mapping reveals the complexity of the sea floor in the Bay of Fundy not necessarily apparent on the 1977 surficial geology map based on sparse lines of single-beam echo sounder data.

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1. Introduction

1.1. Background to the study

The macrotidal Bay of Fundy (Fig. 1) has experienced several major cycles of interest with respect to extracting tidal energy, and each cycle has been a trigger for scientific research and geological mapping. Minas Passage, a narrow channel connecting Minas Basin with the Bay of Fundy (Fig. 1), was initially surveyed in the 1960s as part of a proposal to build a tidal barrage. Subsequently, Fader et al. (1977) published a surficial geology map of the Gulf of Maine and Bay of Fundy. This was based on acoustic data from single-beam echo sounders, limited data from a high-resolution sub-bottom profiler system, and information from grab samples. The surficial geology formations identified included: (1) the Scotian Shelf Drift Formation (glacial diamict deposited under glacial ice or at an ice margin); (2) the Emerald Silt Formation (deposited by meltwater plumes); the LaHave Clay Formation (postglacial mud); and (4) the Sable Island Sand and Gravel Formation (mobile postglacial clastic sediments). Eventually interest in tidal power waned, particularly since modeling suggested that construction of the barrage could alter tidal regimes as far away as the northeastern U. S. (Greenberg, 1975).

There was a renewal in interest in tidal energy in the early 2000s, with Minas Passage the focus of plans to evaluate the potential of in-stream turbines placed on the seafloor. About this time the Geological Survey of Canada (GSC) partnered with the Canadian Hydrographic Service (CHS) to systematically map the Bay of Fundy using multibeam sonar systems, and was in a position to provide high-resolution bathymetric data to tidal energy proponents attempting to pinpoint sites for deployment of experimental tidal devices. A government-university-industry consortium established the first test site for in-stream tidal energy technology in 2009.

The completion of multibeam sonar surveys and ground-truthing expeditions saw the publication of several scientific papers (Shaw et al., 2010, 2012a; Todd and Shaw, 2012), and several types of map product, specifically: (1) 17 1:50,000 scale maps of shaded seafloor relief (e.g., Todd et al., 2011a); (2) 17 maps of backscatter strength (e.g., Todd et al., 2012a), and a 'seascape' map of the entire bay (Shaw et al., 2012b). All these maps are available for download from the Geological Survey of Canada. The information from the recent surveys provides fresh insights into the glacial and postglacial evolution of the bay and the morphology, texture, and relative mobility of the seafloor. Li et al. (in this issue) use the data to examine bedform dynamics near Cape Split

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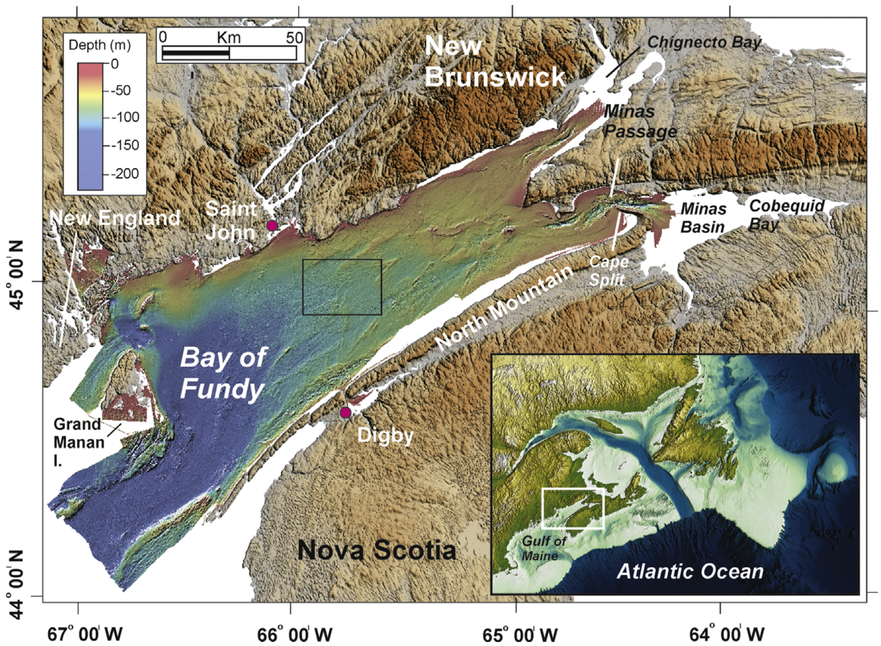

Fig. 1. Location of the Bay of Fundy, and extent of multibeam sonar mapping. The black rectangle shows the location of Fig. 9.

(Fig. 1) and Todd et al. (in this issue) use it to provide an overview of sandy bedforms. In that light, the goals of this paper are to describe the map products derived from recent multibeam sonar mapping, and examine some of the ways in which they further our understanding of the seafloor in this macrotidal environment.

1.2. *The study area*

The Bay of Fundy (Fig. 1) is a shallow, funnel-shaped body of water between New Brunswick and Nova Scotia. It is underlain by Triassic sandstones and a sequence of basaltic intrusions (Fader et al., 1977). In the northeast it divides into two arms: Chignecto Bay and Minas Basin. Chignecto Bay (Fig. 1) shallows and narrows to the northeast, and terminates in a series of estuaries that have been infilled by salt marshes fronted by mud flats. At Minas Passage (Fig. 1), a trough extending to 170 m below mean sea level is notable for tidal currents that reach 6 ms^{-1} at the surface and 2–3 ms^{-1} near the seafloor (Wu, 2013, pers. comm.).

As with other parts of the continental shelves of Atlantic Canada, the Bay of Fundy bears a strong imprint of glaciation. Using data from the multibeam surveys noted in this paper, Todd and Shaw (2012) described the retreat of late Wisconsinan glacial ice northeastwards up the bay in terms of glacial land systems – assemblages of landforms and sediments that reflect glacial processes. The basin to the east of Grand Manan Island (Fig. 1) hosts thick deposits of glaciomarine mud containing marine pelycypods with radiocarbon dates ranging up to 14,210 ^{14}C years BP (conventional). The basin flanks have streamlined landforms created by fast-flowing glacier ice. To the west of Grand Manan Island, fields of De Geer moraines – ridges of sediment that accumulated at a former ice margin – were created by northward – retreating grounded ice in shallow water. Drumlins with superimposed eskers on the south side of the bay, offshore from Digby (Fig. 1), were created by ice emanating from the interior of Nova Scotia that was confluent with ice flowing down the bay. The most extensive land system was in the mid- to upper-bay and comprised numerous arcuate moraines that record the final retreat of glaciers to the northeast. Large areas of sea floor in the southwest are imprinted by relict iceberg furrows and pits.

The Bay of Fundy has the World's largest recorded tides (16.3 m) (O'Reilly et al., 2005). Tidal range decreases towards the mouth of the bay, and is only one metre in the Gulf of Maine. The high tides are caused by near resonance of the Bay of Fundy–Gulf of Maine system. Tidal modeling shows how tidal range expanded during the Holocene in both the Bay of Fundy and the adjacent Gulf of Maine (Scott and Greenberg, 1983; Gehrels et al., 1995; Shaw et al., 2010). The range had been relatively small in the early Holocene, when relative sea level, having fallen from a high of +48 m ca. 13,500 BP, reached a lowstand depth of −25 m ca. 7000 BP (Amos and Zaitlin, 1984–1985; Shaw et al., 2002). With rising sea levels, tidal range had increased to near modern levels by the late Holocene (Shaw and Ceman, 1999).

2. 50,000 Scale maps based on multibeam sonar data

2.1. *Mapping surveys and data processing*

Hydrographic surveys were carried out between 1996 and 2009, mostly by vessels deploying various Kongsberg multibeam sonar systems. Launches deployed systems designed for shallow water while a larger vessel surveyed deeper water areas. In addition, some hydrographic surveys were conducted by the Ocean Mapping Group, University of New Brunswick (OMGUNB). The extent of multibeam coverage is indicated in Fig. 1.

Bathymetric data were processed in the Caris HIPS (Hydrographic Information Processing System) to remove outliers, and reduced to a common datum (Mean Sea Level) by OMGUNB. Data were imported to the GRASS GIS system and gridded, shaded, colour coded, and given artificial illumination. The raster images were then exported to an ARC GIS platform for map creation. Backscatter strength values were extracted using an empirical approach (Hughes Clarke et al., 2008). Although backscatter strength extraction was particularly challenging given the large number of differing multibeam sonar systems used over the years, the data for the entire bay were nevertheless integrated into a single regional coverage. Shifts in backscatter strength observed at the boundaries of the various survey areas are artifacts of data processing due to variable seafloor response to differing source

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