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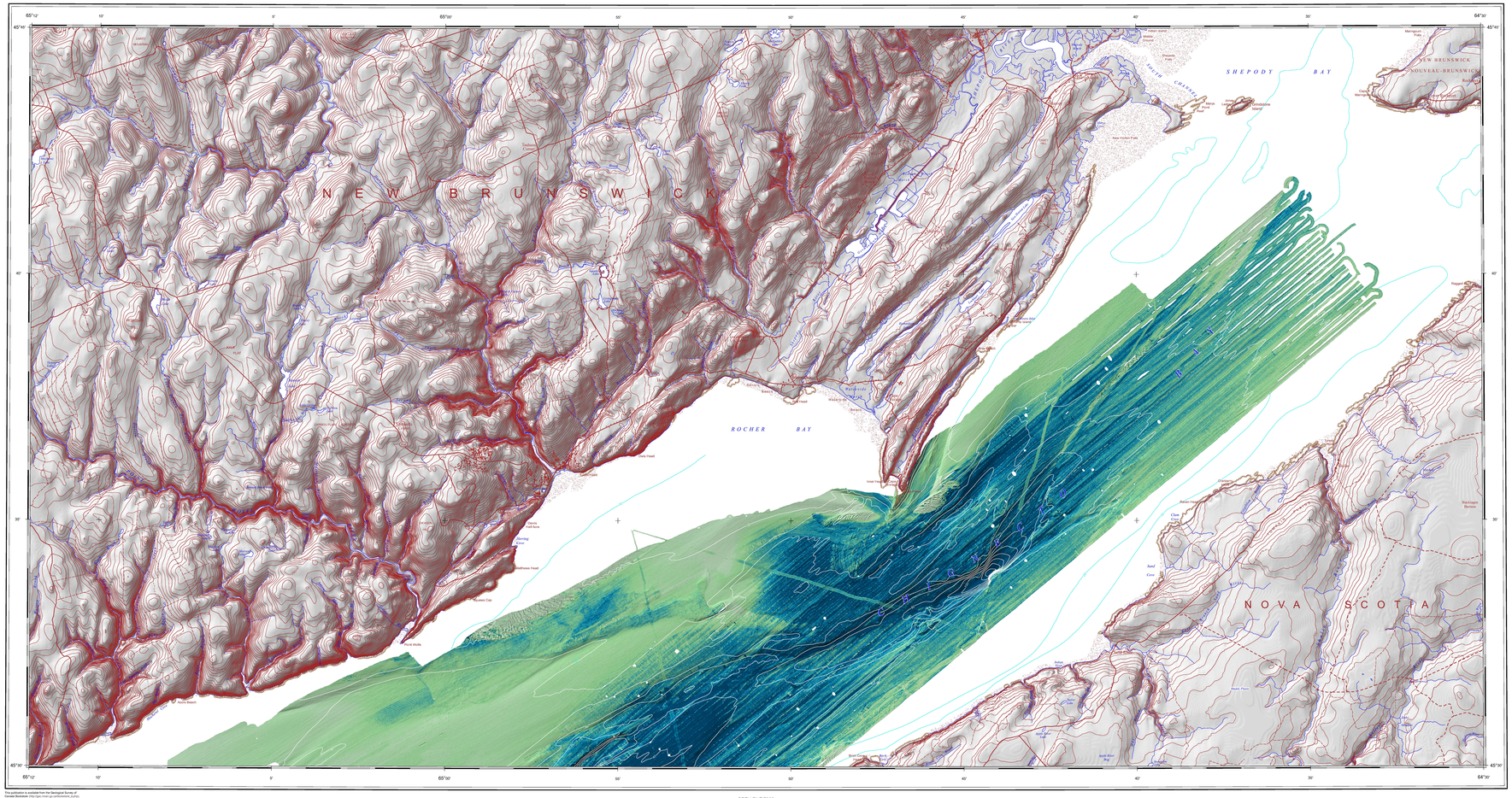

DESCRIPTIVE NOTES

INTRODUCTION

The Bay of Fundy, located on the east coast of Canada between the provinces of Nova Scotia and New Brunswick (Fig. 1) is a macrotidal estuarine embayment (Knox et al., 1980) with the highest tides in the world (Desplanque and Mossman, 2004). This map is one of a series of 17 maps that show the seven seamless contiguous maps that show seafloor relief of the Bay of Fundy in shaded-relief view and backscatter strength (coded by colour) at a scale of 1:50 000. Backscatter strength is used to remotely-sense the character of the seafloor sediments (Fonseca and Mayer, 2007; Fonseca et al., 2009). Backscatter strength maps are based on multibeam-sonar surveys covering 12 010 km² of the seafloor. Water-depth contours generated from the multibeam-sonar datasets are shown (in white) on the colour-coded backscatter strength maps. Depths range from 0 m, along the coastline and on the tops of the highest bedrock outcrops in the area, presented at a depth interval of 10 m, are from the Natural Resource Map series (Canadian Hydrographic Service, 1967, 1974a, b, c).

Each map sheet in the Bay of Fundy backscatter strength map coverage is composed of seventeen adjacent map areas at a scale of 1:50 000 (Fig. 1). This backscatter strength map has a companion seafloor relief map (Todd et al., 2011).

MULTIBEAM-SONAR SURVEYS

The University of New Brunswick, the Canadian Hydrographic Service and the Geological Survey of Canada conducted Bay of Fundy multibeam-sonar surveys from 1992 to 2009. During these eighteen years, seven different vessels were employed (Fig. 2) and they were outfitted with five different multibeam-sonar systems operating across a range of frequencies (Fig. 2, Table 1):

The work employed the following survey vessels (also see year-by-year version in Table 1):

- the CCGS Frederick G. Creed (previously named the Navicula and the Canadian Hydrographic Service Twin Hull) vessel equipped with a Kongsberg EM1000 (prior to 2003) and a Kongsberg EM1002 (post-2003) multibeam-sonar bathymetric survey system with 111 beams operating at 95 kHz with the transducer mounted in the starboard pontoon,
- the CCGS Matthew equipped with a Kongsberg EM710 multibeam-sonar bathymetric survey system with 400 beams operating at 70–90 kHz with the transducer mounted near the centre of the vessel, and
- hydrographic survey launches *Plover, Pipit*, and *Heron* equipped with Kongsberg EM3000 (prior to 2006) and Kongsberg EM3002 (post-2006) multibeam-sonar bathymetric survey systems with 160 to 254 beams operating at 300 kHz.

The survey systems use a sonar beam over an arc of about 130° across the ship's track and operate in shallow water (Courtney and Shaw, 2000) to produce a swath of soundings that are 3.5 times the water depth (echo into multiple beams (Courtney and Shaw, 2000). The width of seafloor imaged on each survey line was generally four times the water depth. Line spacing was about two to three times water depth to ensure adequate coverage between adjacent survey lines.

The Differential Global Positioning System was used for navigation, providing positional accuracy of ±1 m (Hughes Clarke et al., 2008; Shaw et al., 2008). The Bay of Fundy is a very energetic tidal system (as the survey vessels), resulting in an average data collection rate of about 2.5 km² hr⁻¹ in water depths of 35–70 m. The sound velocity in the ocean was measured during multibeam-sonar data collection and processing to correct for refraction of the sonar beam (Hughes Clarke et al., 2008) using sound velocity profile measurements and predictions from the Canadian Hydrographic Service. During the 2008 surveys, vessel elevations were also acquired using a combination of real-time kinematic GPS systems (Church et al., 2009). Tidal data were provided by the Canadian Hydrographic Service and the Bedford Institute of Fishers and Oceans Canada Coastal Oceanography Group (Dupont et al., 2005).

The broad intertidal zone in the Bay of Fundy presented a particular surveying challenge to the hydrographic survey vessels. Because of the large tidal range, there was a relatively short period of time (longer-term) involved in operating vessels in coastal areas that dry between tides. As part of the multibeam-sonar mapping, the intertidal zone was surveyed at high tide using shallow-draft survey vessels, thus overcoming operational challenges associated with deeper-draft survey vessels.

BACKSCATTER DEFINITION

The backscattering coefficient of a given sediment type (mud, sand, or gravel as defined by Wentworth (1922) and modified by Folk (1954)) at a given frequency is an inherent property of that geological material and varies with angle of incidence of the sonar beam to the seabed (the grazing angle). This backscattering coefficient (BS) is defined as the ratio of backscattered intensity (reflected energy per unit per unit solid angle (W steradian⁻¹), divided by the product of the acoustic intensity (incident on the surface (W m⁻²) and the effective insonified acoustic area *A* (m²) (Mitchell and Somers, 1989):

$$BS = \frac{I}{I_i A}$$

Backscatter strength is the logarithmic form of this expression, i.e., $10\log_{10}\beta$, with the unit of decibel (dB).

DATA PROCESSING

Backscatter data processing is treated thoroughly by Hughes Clarke et al. (2008) and is summarized here. Kongsberg EM multibeam-sonar systems used throughout the Bay of Fundy survey(s) measure the backscatter strength of the seafloor, however, the data are affected by a number of factors, both of the sonar system and its (geometric parameters. To reduce the backscatter intensity to backscatter strength, the following factors must be accounted for:

1. Transmitted source level and receiver sensitivity.
2. Three-dimensional beam patterns of the transmit and receive arrays.
3. Spherical spreading and ocean attenuation coefficients of the frequency in question.
4. Application of real-time ramp gains.
5. Local seabed slope.

The Kongsberg EM multibeam-sonar systems use a data reduction scheme that includes corrections for the five factors listed above (Hammerstad, 2000). However, this scheme is limited because there are discrepancies between the design of the sonar hardware and its performance (1, 2, 4), and because compensation algorithms (3, 5) are not implemented (Hughes Clarke et al., 2008). Because of the survey vessels, multibeam-sonar systems, and computer software and system hardware upgrades spanning the eighteen years of the Bay of Fundy survey, computation of seabed backscatter strength is challenging.

Because the scheme could not be calibrated, an empirical approach through inter-sonar comparisons was undertaken (Hughes Clarke et al., 2008), including coping with:

- sonar pulse length changes associated with water-depth and sediment types,
- sonar pulse length changes associated with water-depth and other factors,
- empirical sonar beam pattern corrections that do not account for different sediment types,
- variations in angular response for different sediment types,
- steep-seabed slopes,
- sonar frequency-dependent attenuation due to estimates of water column properties, and
- sonar frequency-dependant backscatter strength from a given sediment type.

BACKSCATTER DISTRIBUTION

The backscatter strength data shown on this map, and on the other maps of the Bay of Fundy map series (Fig. 1), have been integrated into a single regional coverage from multi-year, multi-sonar, acoustic backscatter surveys of the seafloor in the Bay of Fundy (Hughes Clarke et al., 2008; Shaw et al., 2008). The confidence in the mean backscatter strength is ±2 dB. Therefore, subtle shifts in backscatter strength observed at the boundaries of the component survey areas (Fig. 2) are artifacts of the data processing and should not be interpreted as geologically significant changes in seafloor sediment character. In mind, subjective interpretation of the backscatter strength data can be undertaken guided by the existing knowledge of the sedimentary facies in the Bay of Fundy (e.g., Swift et al., 1968, 1973; Pelletier and Swift, 1969; Swift et al., 1969; Pelletier et al., 1971).

The distribution of backscatter strength in the Bay of Fundy provides insight into ocean circulation and related modern-sea-floor sediment transport processes not apparent in the comparison seafloor relief map (Todd et al., 2011). Backscatter strength of the mud is low and appears light green on this map (e.g., Greenberg, 1983). The general current direction is northward along the Nova Scotia coast and southward along the New Brunswick coast with a counterclockwise gyre in the lower bay (Greenberg, 1984). The winnowing and transport of fine-grained sediment under the influence of currents results in remnant coarse-grained deposits. The seabed of central and outer Bay of Fundy and Grand Manan Channel (Sheets 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17; see Fig. 1) is characterized by Lacustrine Ice Sheet. The till is a poorly sorted sediment containing angular fragments of pebble to boulder sized material, and sand-, silt-, and clay-sized sediments in varying proportions. Backscatter strength of the till is high and appears dark green on this map.

Mud (silt and clay) has accumulated in northwestern Bay of Fundy between Grand Manan Island and the coast of New Brunswick (Sheets 5, 7, 8, 10, 11; see Fig. 1). This deposonite is likely the result of the counter-current circulation. Backscatter strength of the mud is low and appears light green on this map (see below).

Sand occurs in broad sheets and as individual bedforms (metres to kilometers in size) throughout the central and outer Bay of Fundy (Sheets 3, 12-16; see Fig. 1). This well-sorted sediment is mobilized through the action of strong tidal currents. Backscatter strength of the sand is low and appears light green on this map (see below).

Bedrock is exposed at the seafloor only rarely in the Bay of Fundy (Todd and Shaw, 2009). Where bedrock outcrops in Minas Passage (Sheet 16; see Fig. 1), its backscatter strength is high.

ACKNOWLEDGMENTS

B. MacGowan, M. Lamplugh and J. Griffin of the Canadian Hydrographic Service (CHS) organized the multibeam-sonar surveys of the Bay of Fundy and oversaw data processing. The Canadian Hydrographic Service provided the data to the Geological Survey of Canada (GSC) for further processing and interpretation. The GSC, the Canadian Hydrographic Service, the Department of Fisheries and Oceans and Geomatics Engineering, University of New Brunswick (UNB), supervised the earliest collection of multibeam-sonar data in the 1990s, followed by systematic mapping of the coastal areas of New Brunswick and Nova Scotia in the early 2000s. Scientists at the Bedford Institute of Oceanography (GSC), the University of New Brunswick and the Saint John Port Authority, D. Cartwright (ONC), UNB) processed the backscatter strength data under contract to the GSC. The authors thank the masters and crews of the survey vessels. Funding for the Geological Survey of Canada's Marine Geoscience Program and support was provided by S.E. Hayward, E. Patton, P. O'Regan, L. Grant, and P. Melbourne. The authors thank M.Z. Li for scientific review of the maps.

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Table 1. Bay of Fundy survey by year, vessel, multibeam-sonar instrument, and frequency of operation (adapted from D. Brown, Canadian Hydrographic Service, Dartmouth, Nova Scotia). Vessels and multibeam-sonar systems are manufactured by Kongsberg. Colour-coded sonar types correspond with colours coded on Figure 2.

Year	Vessel	Multibeam sonar	Frequency (kHz)
1992	CCGS *Frederick G. Creed*	EM1000	95
1993			
1994			
1996			
1999			
2002	*CSL Heron*	EM3000	300
2006	CCGS *Frederick G. Creed*	EM1002	95/98
	CSL Heron	EM3002	300
	CCGS *Frederick G. Creed*	EM1002	95/98
2007	CCGS *Matthew*	EM710	71–97
	CSL Pipit	EM3002	300
	CSL Plover		
2008	CCGS *Frederick G. Creed*	EM1002	95/98
	CCGS *Matthew*	EM710	71–97
	CSL Heron	EM3002	300
	CSL Pipit		
	CSL Plover		
2009	CCGS *Matthew*	EM710	71–97
	CSL Plover	EM3002	300

Low — Approximate backscatter strength (dB) — High

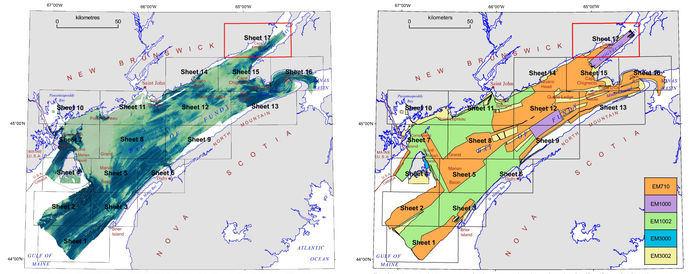

Figure 1. Location map showing seventeen 1:50 000 map sheets covering the Bay of Fundy. Sheet 17 (outlined by red box) is in Chignecto Bay which is the northeastern extension of the Bay of Fundy.

Figure 2. Location map showing the survey extents of multibeam-sonar vessels and the year of survey in the Bay of Fundy. Colours refer to the multibeam-sounder types (and frequencies) listed in Table 1.

The publication is available from the Geological Survey of Canada Bookstore (http://gsc.nrcan.gc.ca/intrepid_e.php) and from the Natural Resources Canada Publications Centre (http://geoscan.nrcan.gc.ca/).

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Multibeam backscatter data collected by Canadian Hydrographic Service, 1993, 2006–2009; Geological Survey of Canada, 2006 and 2008; and University of New Brunswick, 1993, 1994, 2002–2009.

Multibeam backscatter data compiled by Canadian Hydrographic Service, Geological Survey of Canada, and University of New Brunswick, 1993–2010

Digital cartography by P.A. Melbourne and P. O'Regan, Data Dissemination Division (DDD), and G. Grant, S.E. Hayward and E. Patton, GSC (Atlantic)

OPEN FILE 7008

BACKSCATTER STRENGTH AND SHADED SEAFLOOR RELIEF

BAY OF FUNDY, SHEET 17

OFFSHORE NOVA SCOTIA–NEW BRUNSWICK

Scale 1:50 000/Échelle 1/50 000

kilometres 0 1 2 kilometers

Universal Transverse Mercator Projection
North American Datum 1983
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Projection transverse universelle de Mercator
Système de référence géodésique nord-américain, 1983
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Cette carte ne doit pas être utilisée aux fins de navigation

Any revisions or additional geographic information known to the user would be welcomed by the Geological Survey of Canada

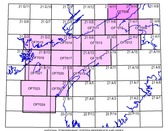
Digital base map (land area) from data compiled by Geomatics Canada, modified by GSC (Atlantic)

Digital bathymetric contours in metres supplied by Canadian Hydrographic Service and GSC (Atlantic)

Magnetic declination 2011, 18°18'W, decreasing 7.3' annually

Elevations in metres above mean sea level

Depth in metres below mean sea level



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