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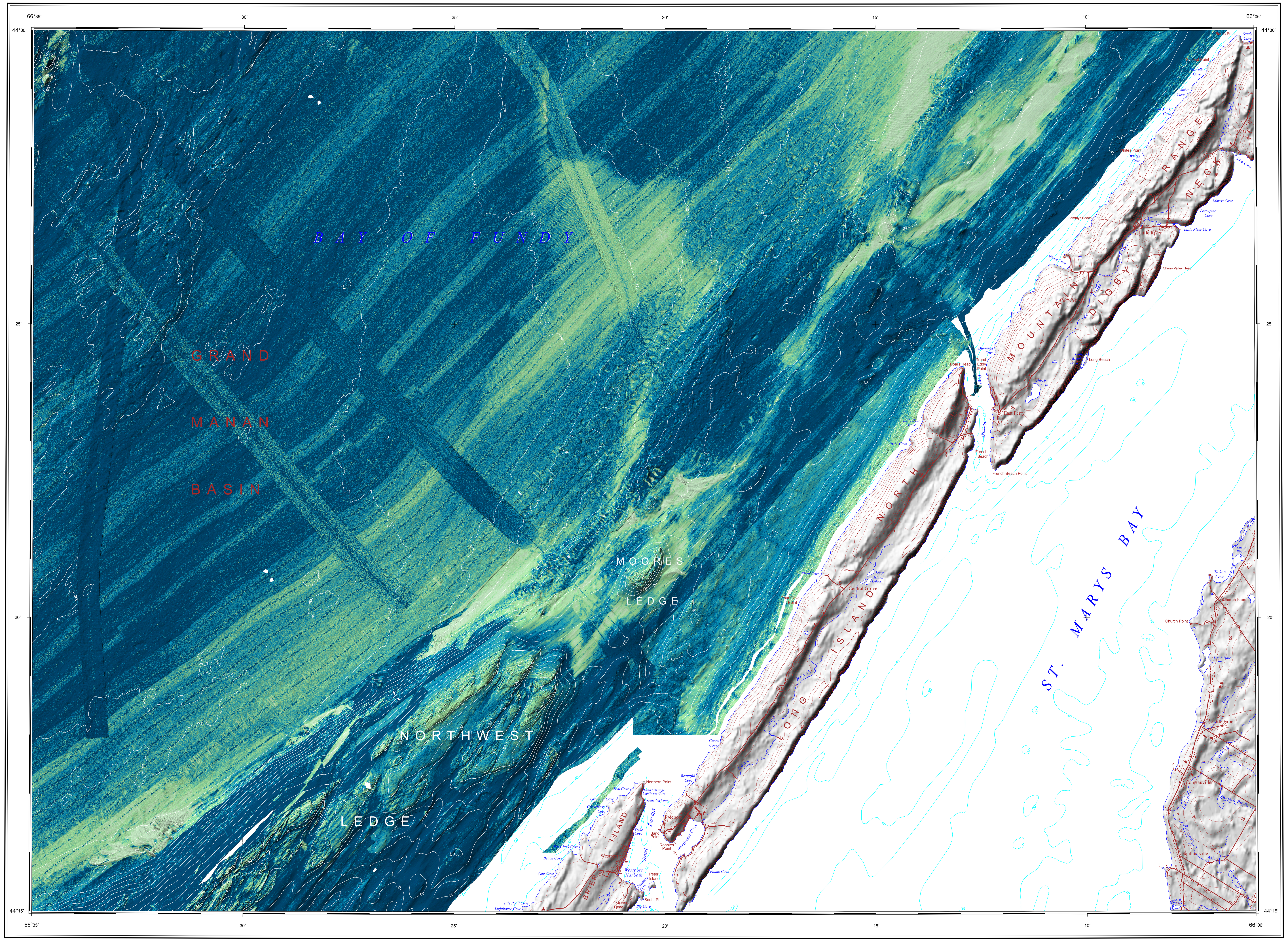

DESCRIPTIVE NOTES

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 (Amos et al., 1980) with the highest tides in the world (17 m according to O'Reilly et al. (2005) and Bishop (2008)). This map is one of a series of seventeen 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 geological nature of the substrate (Mitchell and Hughes Clarke, 1994). The backscatter strength maps are based on multibeam-sonar surveys covering 13,010 km^2 of the seafloor. Water-depth contours generated from the multibeam-sonar data are shown (in white) on the colour-coded backscatter strength image at a depth interval of 10 m. Bathymetric contours (in blue) outside the multibeam survey area, presented at a depth interval of 10 m, are from the Natural Resource Map series (Canadian Hydrographic Service, 1967, 1974a, b, c).

The complete 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, nineteen surveys were undertaken using five different vessels equipped 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 Canadian Coast Guard Ship (CCGS) *Frederick G. Creed*, a SWATH (Small Waterplane Area 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 200 or 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 2005) and Kongsberg EM3002 (post-2005) 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 by ensonifying a narrow strip of seafloor along track and detecting the seafloor by resolving the returned 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 provide ensonification overlap between adjacent lines.

The Differential Global Positioning System was used for navigation, providing positional accuracy of ±3 m. Survey speeds averaged 12 knots (22.2 km hr^{-1}) on the CCGS *Creed* (and slower on the other survey vessels), resulting in an average data collection rate of about 2.5 km^2 hr^{-1} in water depths of 35–70 m. The sound velocity in the ocean was measured during multibeam-sonar data collection and was used to correct the effect of sonar beam refraction. The data were adjusted for tidal variation using tidal 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., 2008) and hydrodynamic tidal models developed by the Canadian Hydrographic Service and Fisheries 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 collection of backscatter strength data. Historically, the intertidal zone was not surveyed due to the danger 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 dimensionless coefficient S_b is defined as the ratio of power backscattered from the sediment surface P_b per unit solid angle (W $steradian^{-1}$), divided by the product of the acoustic intensity I_i incident on the surface (W m^{-2}) and the effective insonified acoustic area A (m^2) (Mitchell and Somers, 1989):

$S_b = P_b / I_i A.$

Backscatter strength is the logarithmic form of this expression, i.e., $10\log_{10}S_b$, 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) measure the peak or average backscatter intensity as a voltage on the sonar receiver array. The value is a function of the sonar system and its geometric parameters. To reduce the backscatter intensity to backscatter strength, the following factors must be accounted for:

1. Sonar source levels, pulse lengths, 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 time-varying gains,
5. Local seabed slopes.

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 environmental assumptions (3, 5) may not be realistic (Hughes Clarke , 1993). Given the suite of 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 sonars could not be calibrated, an empirical approach through inter-sonar comparisons was undertaken (Hughes Clarke et al., 2008), including coping with:

- uncertainty in the absolute level of backscatter strength for 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,
- imperfect path length 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-source, acoustic backscatter data using a range of theoretical and empirical corrections (Hughes Clarke 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 do not necessarily reflect differences in seabed physical properties. Keeping these limitations 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., 1969, 1973; Pelletier and McMullen, 1972; Fader et al., 1977; Todd et al., 2010).

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 companion seafloor relief map (Todd et al., 2011). Ocean circulation in the Bay of Fundy is subject to strong tides (Garrett, 1972; Greenberg, 1983). The general current direction is northeast along the Nova Scotia coast and southwest 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, 5, 6, 8; *see* Fig. 1) is dominated by till deposited directly onto bedrock beneath the Laurentide 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 blue on this map series.

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 depocentre is likely the result of regional current circulation. Backscatter strength of the mud is low and appears light green on this map series.

Sand occurs in broad sheets and as individual bedforms (metres to kilometers in size) throughout much of northeastern Bay of Fundy (Sheets 9, 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 series.

Bedrock is exposed at the seabed 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. J.E. Hughes Clarke of the Ocean Mapping Group (OMG), Department of Geodesy 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. Multibeam-sonar data in Saint John Harbour, New Brunswick, were collected by D. Beaver (GSC), the University of New Brunswick and the Saint John Port Authority. D. Cartwright (OMG, UNB) processed the backscatter strength data under contract to the GSC. The authors thank the masters and crew of the survey vessels for their efforts at sea. Geographical Information Systems and cartographic support was provided by S.E. Hayward, E. Patton, P. O'Regan, G. Grant, and P. Melbourne. The authors thank M.Z. Li for scientific review of the maps.

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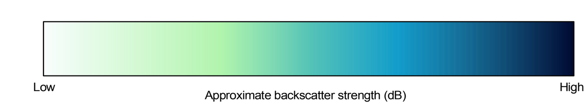
Table 1. Bay of Fundy survey by year, vessel, multibeam sonar instrument, and frequency of operation (adapted from D. Cartwright (unpublished report) and Hughes Clarke et al. (2008)). Note that all multibeam sonars are manufactured by Kongsberg. Colour-coded sonar types correspond with colour codes on 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	93/98
	CSL Heron	EM3002	300
2007	*CCGS Frederick G. Creed*	EM1002	93/98
	CCGS Matthew	EM710	71–97
	CSL Heron	EM3002	300
	CSL Pipit		
	CSL Plover		
2008	*CCGS Frederick G. Creed*	EM1002	93/98
	CCGS Matthew	EM710	71–97
	CSL Heron	EM3002	300
	CSL Pipit		
	CSL Plover		
2009	*CCGS Matthew*	EM710	71–97
	CSL Plover	EM3002	300



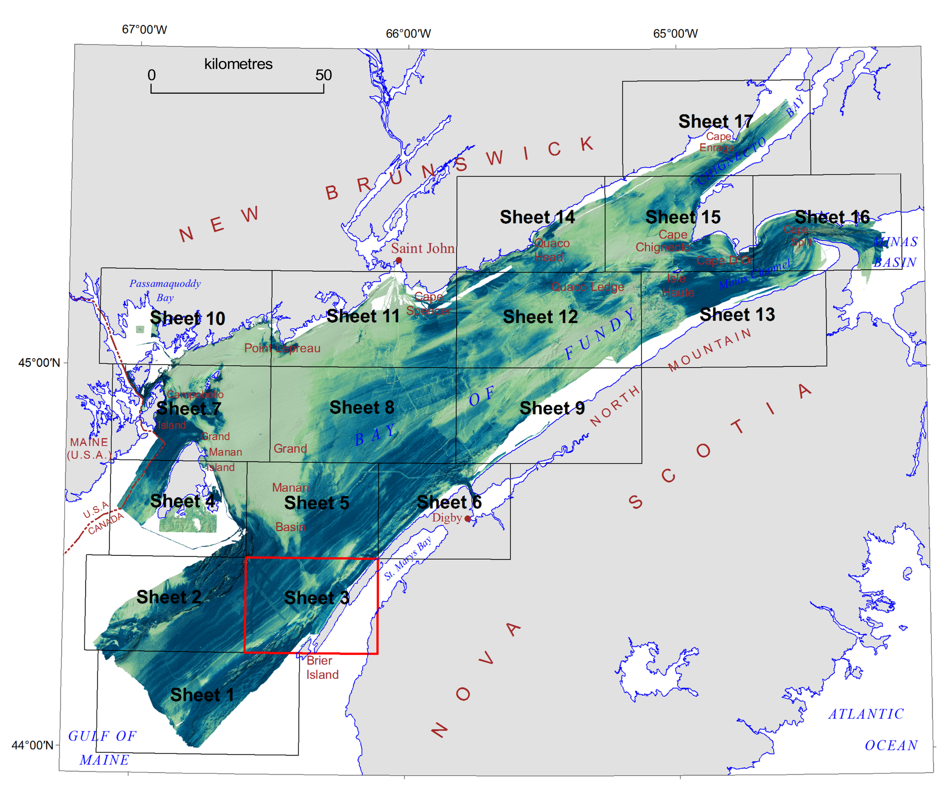


Figure 1. Location map showing seventeen 1:50 000 map sheets covering the Bay of Fundy. Sheet 3 (outlined by red box) is in southwestern Bay of Fundy north of Brier Island, Nova Scotia.

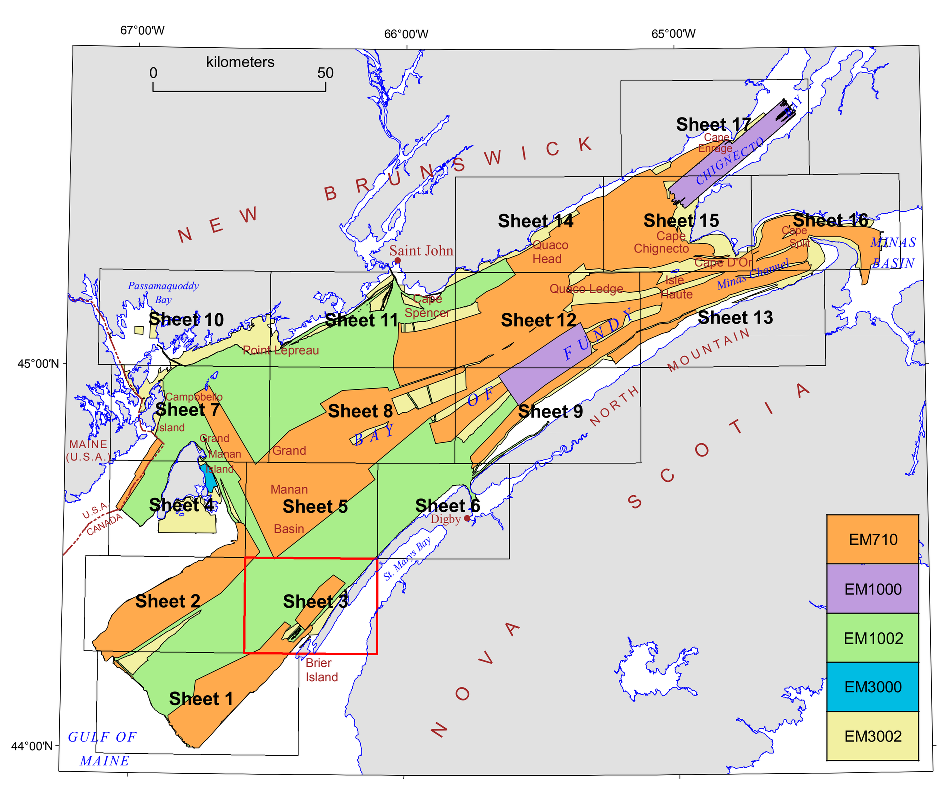


Figure 2. Location map showing the survey extents of multibeam sonar vessels and the year of survey in the Bay of Fundy. Colours refer to five multibeam sounder types (and frequencies) listed in Table 1.

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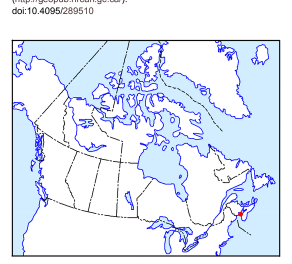


LOCATION MAP

Authors: B.J. Todd, J. Shaw, D.R. Parrott, J.E. **Hughes Clarke,** D. Cartwright, and S.E. Hayward

This map was produced by Natural Resources Canada in co-operation with Fisheries and Oceans Canada

Multibeam backscatter data collected by Canadian Hydrographic Service, 1993, 2006–2009; Geological Survey of Canada, 1999–2003, 2006–2009; and University of New Brunswick, 1993, 1994, 2002–2008

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 7022

BACKSCATTER STRENGTH AND SHADED SEAFLOOR RELIEF

BAY OF FUNDY, SHEET 3

OFFSHORE NOVA SCOTIA–NEW BRUNSWICK

Scale 1:50 000/Échelle 1/50 000

kilometres 1 0 1 2 3 4 kilometrès

Universal Transverse Mercator Projection | Projection transverse universelle de Mercator
North American Datum 1983 | Système de référence géodésique nord-américain, 1983

This map is not to be used for navigational purposes | 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

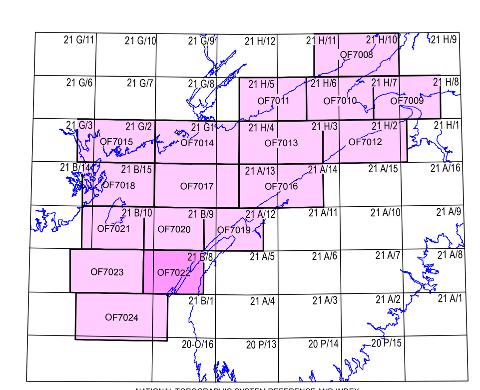
Digital base map (land area) from data compiled by Geomatics Canada, modified by GSC (Atlantic)

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

Magnetic declination 2011, 17°30'W, decreasing 6.9' annually

Elevation in metres above mean sea level

Depth in metres below mean sea level



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