Government Gouvernement of Canada du Canada COMMISSION GÉOLOGIQUE DU CANADA Figure 3. Sediment bedform field and bedrock adjacent to Isle Haute, Nova Scotia. BAY OF FUNDY GEOMORPHOLOGY Geological history deposition began as early as 18 ka. Grounded ice was absent from the Gulf of Maine and Bay of Fundy I approximately 14 ka (King and Fader, 1986; Schnitker et al., 2001; Shaw et al., 2006). The Bay of Fundy exhibits geomorphological features formed during the Quaternary glaciation and deglaciation of the area. Figure 2. Sediment bedform field with bifurcating crestlines northwest of Isle Haute, Figure 4. A banner bank east of Cape Chignecto, Nova Scotia. height and hundreds of metres in length (Greenberg et al., 1997). B A Ydeposited as banner banks (Dyer and Huntley, 1999), flanking prominent headlands in the Bay of Fundy, 65°16′ 15′ 65°00′ This publication is available from the Geological Survey of Canada Bookstore (http://gsc.nrcan.gc.ca/bookstore\_e.php It can also be downloaded free of charge from GeoPub (http://geopub.nrcan.gc.ca/). doi:10.4095/288692 MAP 2188A SHADED SEAFLOOR RELIEF **BAY OF FUNDY, SHEET 15** Any revisions or additional geographic information known to the user Authors: B.J. Todd, J. Shaw, and D.R. Parrott would be welcomed by the Geological Survey of Canada OFFSHORE NOVA SCOTIA-NEW BRUNSWICK This map was produced by Natural Resources Canada in co-operation Digital base map (land area) from data compiled by Geomatics Canada, with Fisheries and Oceans Canada modified by GSC (Atlantic) Scale 1:50 000/Échelle 1/50 000 Multibeam bathymetric data collected by Canadian Hydrographic Service, Digital bathymetric contours in metres supplied by Canadian Hydrographic Service 1993, 2006–2009; Geological Survey of Canada 1999–2003, 2006–2009; and University of New Brunswick 1993, 1994, 2002–2008 and GSC (Atlantic) Universal Transverse Mercator Projection North American Datum 1983 Système de référence géodésique nord-américain, 1983 Multibeam bathymetric data compiled by Canadian Hydrographic Service, Magnetic declination 2011, 18°12'W, decreasing 7.9' annually © Sa Majesté la Reine du chef du Canada 2011 © Her Majesty the Queen in Right of Canada 2011 Geological Survey of Canada, and University of New Brunswick 1993–2010 This map is not to be used for navigational purposes Cette carte ne doit pas être utilisée aux fins de navigation Elevations in metres above mean sea level Digital cartography by P.A. Melbourne, Data Dissemination Division (DDD); and G. Grant, S.E. Hayward, and E. Patton, GSC (Atlantic) Depth in metres below mean sea level

## 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 recorded tides in the world of 17 m (O'Reilly et al., 2005; Bishop, 2008). This map is one of a series of maps that show seafloor relief of the Bay of Fundy and topography of the surrounding areas in shaded-relief view (coded by colour) at a scale of 1:50 000. The maps are based on multibeam-sonar surveys completed between 1993 and 2009 to map 13 010 km<sup>2</sup> of the seafloor. Water-depth contours generated from the multibeam-sonar data are shown (in white) on the colour-coded water-depth image at a depth interval of 20 m. Bathymetric contours (in blue) outside the multibeam survey area, presented at a depth interval of 50 m, are from the Natural Resource Map series (Canadian Hydrographic Service, 1967, 1974a, b, c). The broad intertidal zone in the Bay of Fundy presented a particular surveying challenge to the collection of water-depth 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. The complete Bay of Fundy seafloor relief map coverage is composed of seventeen adjacent map

areas at a scale of 1:50 000 (Fig. 1). In total, fifty-one maps constitute the Bay of Fundy map suite (three maps per map area: seafloor relief, backscatter strength, and surficial geology).

# MULTIBEAM BATHYMETRY DATA COLLECTION

Multibeam-sonar water-depth data were collected by the Canadian Hydrographic Service, the Geological Survey of Canada, and the University of New Brunswick. 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 survey employed a variety of survey vessels including: 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 • 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 Differential Global Positioning System was used for navigation and provided a positional accuracy of ±3 m. Survey speeds averaged 12 knots (22.2 km/h) on the CCGS Creed (and slower on the other survey vessels), resulting in an average data collection rate of about 2.5 km²/h in water depths of 35–70 m. The sound velocity in the ocean was measured during multibeam-sonar data collection and used to correct the effect of sonar-beam refraction. The 1992–2006 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). BATHYMETRIC DATA DISPLAY

The multibeam-sonar bathymetric data are presented at 5 m per pixel horizontal resolution. The shadedrelief image is presented with a vertical exaggeration of the bathymetry of 10 times and an artificial illumination of the relief by a virtual light source positioned 45° above the horizon at an azimuth of 315°. In the resulting image, bathymetric features are enhanced by strong illumination on the northwest-facing slopes and by shadows cast on the southeast-facing slopes. Superimposed on the shaded-relief image are colours assigned to water depth, ranging from red (shallow) to violet (deep). In order to apply the widest colour range to the most frequently occurring water depths, hypsometric analysis was used to calculate the cumulative frequency of water depth. The resulting colour ramp highlights subtle variations in water depth that would otherwise be obscured. Some features in the multibeam data are artifacts of data collection and environmental conditions

during the survey periods. The orientation of the survey track lines can, in some instances, be identified by faint parallel stripes in the image. Because these artifacts are usually regular and geometric in appearance on the map, the human eye can disregard them and distinguish real topographic features.

The Bay of Fundy is a southwest-trending funnel-shaped bay 155 km long that is 70 km at its entrance and tapers to 48 km wide at its northeastern end where it bifurcates into Chignetco Bay and Minas Channel (Fig. 1). The floor of the bay, although hummocky in detail, presents a gently dipping profile along its axis from northeast to southwest. Grand Manan Island and its adjacent southeastern shoals occupy nearly half the entrance to the bay, and divide it into two channels. Between Brier Island and Grand

Manan Island lie several isolated depressions that together form Grand Manan Basin. The maximum water depth within these depressions is 233 m and the depth to the sill between Grand Manan Basin and the adjoining deeper parts of the Gulf of Maine is 160 m. The large tidal oscillations within this geomorphic setting are due to the near resonance between the principal lunar semidiurnal (M<sub>2</sub>) component of the tide (representing 90% of the tidal energy) and the natural period (about 13 hours) of the Bay of Fundy-Gulf of Maine system. Tidal current speeds are about 0.75–1 m/s over much of the outer and central portions of the bay, but are considerably higher within constricted channels and passages to the northeast (Greenberg, 1990).

Geomorphological features revealed through mapping of the Bay of Fundy seafloor reflect the geological history of the region. The Bay of Fundy is situated within the Carboniferous-Triassic lowland Goldthwaite, 1924; Crosby, 1962; Williams et al., 1972) and is underlain by Triassic and Early Jurassic sandstone, shale, and basalt (Wade et al., 1996). Exposed bedrock has been modified by glacial erosion and exhibits a rugged surface. During the late Wisconsinan glacial maximum, culminating in the Gulf of Maine region at approximately 20 ka (20 000 BP), the Bay of Fundy was covered by a regional ice sheet that terminated to the south on the Scotian Slope (Schnitker et al., 2001; Hundert, 2003). The glacial maximum was followed by a multiphased retreat of the ice front. In the Gulf of Maine, ice-front retreat and glaciomarine

Moraines, drumlins, and megaflutes are topographically prominent. After grounded ice retreated from the area, icebergs scoured the seafloor in the waters east and south of Grand Manan Island. After deglaciation, relative sea level fell rapidly to a lowstand of about -30 m at ca. 7 ka (Amos and Zaitlin, 1985; Shaw et al., 2002) and then rose (Grant, 1970). From about 6.3 ka, tidal amplitude started to increase. This effect is continuing today (Godin, 1992). These high tides have resulted in large zones of erosion in areas with high current velocities such as Cape Split, Cape D'Or, and Cape Enrage (Fig. 1) Fidal eddies produced by headlands have created banner banks (Dyer and Huntley, 1999) on both side of coastal promontories. Coastal erosion is up to 6 m/a in some areas (Amos et al., 1991). Sediment derived from this coastal erosion, coupled with sediment from seafloor erosion and sediment delivered by rivers, has contributed to the development of broad intertidal mud flats in the inner Bay of Fundy. The coastlines of the bay also host salt marshes and dykelands (Ganong, 1903; Gordon et al., 1985). Seaward of the mud flats in the subtidal zone, the seafloor is variable in character, consisting of exposed bedrock, gravel, sand, and mud. In places, strong tidal currents create sand waves several metres in

Geomorphology of this map A series of detailed maps at a scale of 1:25 000 (Fig. 2–8) highlights geomorphological features in northeastern Bay of Fundy. For each of these detailed maps, the colour-range values are hypsometrically optimized and differ from the 1:50 000 map sheet colour-range values. This map shows the bathymetry of northeastern Bay of Fundy off Cape Chignecto and Cape D'Or, Nova Scotia and extending west to Martin Head, New Brunswick (Fig. 1). Water depths over most of the map area are less than 50 m, but reach over 120 m off Cape D'Or. Modern sediment deposits blanket much of the seafloor in this part of the bay (Fader et al., 1977). In places, the sediment is organized into bedforms under the influence of the current regime in the bay. Bedform morphology is a result of the interplay between substrate type, sediment characteristics and supply, and local current speed and direction. Within a sediment bedform field northwest of Isle Haute (Fig. 2), flow-transverse bedforms have pronounced, bifurcating crests up to 7 m high, with a general northern trend, normal to the prevailing southwest-northeast-orientated tidal-flow direction in the Bay of Fundy (Canadian Hydrographic Service, 1981; Greenberg, 1990). Adjacent to Isle Haute, a sediment bedform field has an associated depression, or moat, in the seabed (Fig. 3). Sediment is often found

such as Cape Chignecto (Fig. 4) and Cape D'Or (Fig. 5). Sediment erosion has occurred south of Cape D'Or in Minas Channel (Fig. 6), likely as the result of high current velocities. Glaciomarine and postglacial sediment up to 60 m thick has been eroded leaving a pattern of parallel ridges striking normal to the current direction. Although sediment mantles much of the seafloor in this part of the Bay of Fundy, evidence for the presence of glacial ice exists in places. In the northern portion of the map where the underlying till is thinly covered by sediment, a series of roughly parallel, sinuous moraine crests can be traced across the bay with an overall orientation of northwest-southeast (Fig. 7). Farther to the northeast in Chignecto Bay is another sinuous moraine (Fig. 8), marking the progressive retreat to the northeast of the ice sheet that occupied the Bay of Fundy.

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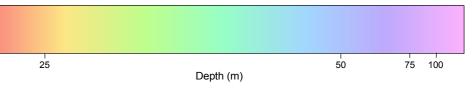
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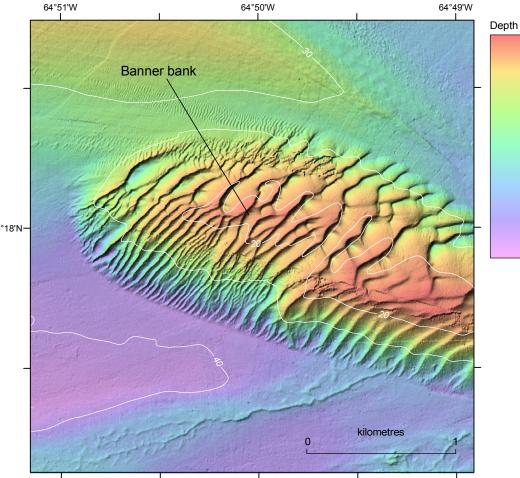


Figure 5. A banner bank west of Cape D'Or.

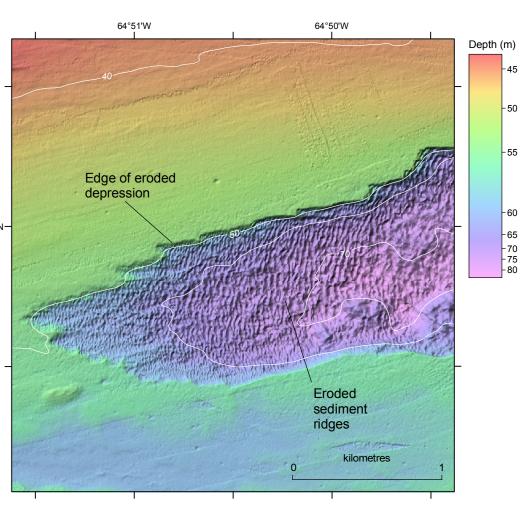
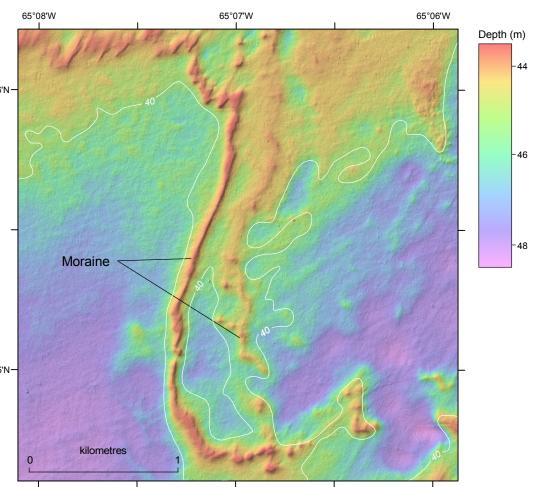
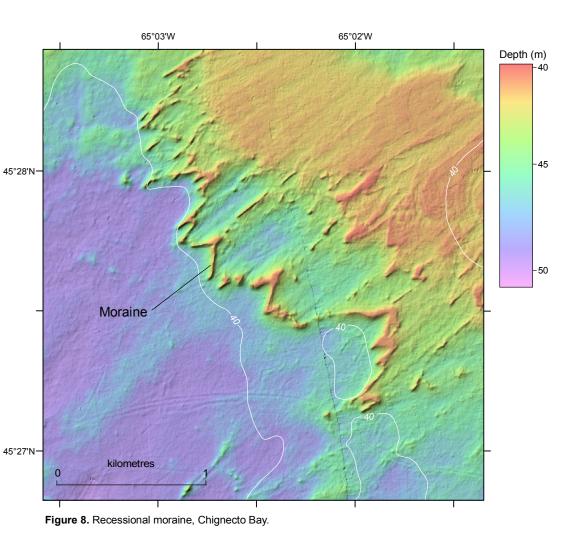
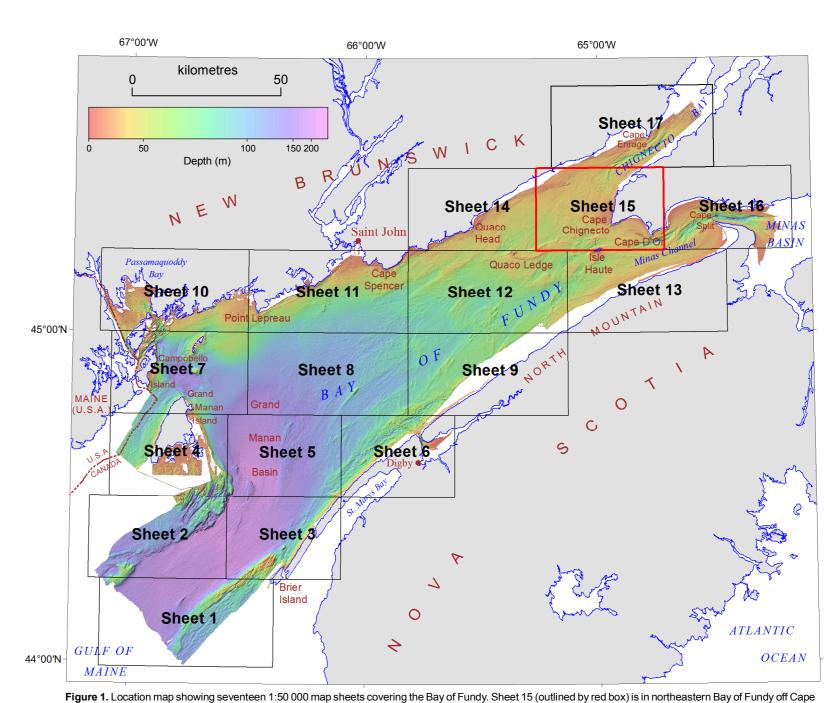


Figure 6. Eroded depression covered in sediment bedforms southwest of Cape D'Or.



**Figure 7.** Recessional moraine, Bay of Fundy.





Chignecto and Cape D'Or, Nova Scotia.

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