This map is not to be used for navigational purposes Cette carte ne doit pas être utilisée aux fins de navigation

DESCRIPTIVE NOTES

Georges Bank is a shallow submarine bank that lies south of Nova Scotia and east of Cape Cod, Massachusetts and bounds the seaward side of the Gulf of Maine (Fig. 1). Water depths on the bank range from less than 5 m to 200 m. The bank is approximately 280 km long and 150 km wide, and has an area of 42 000 km² in water depths less than 200 m. The Fundian Channel and Georges Basin bound Georges Bank to the north; Northeast Channel bounds the bank to the northeast and separates it from Browns Bank on the Scotian Shelf (Fig. 2). The international boundary between Canada and the United States transects Georges Bank, and the eastern part of the bank (~7500 km²) lies in Canadian territory and is the subject of this map series (Fig. 3).

The bank waters are characterized by energetic tidal currents associated with the near resonance that exists between the principal lunar semidiurnal tidal component (M_2) of the tide that represents 90% of the bank's tidal energy and the natural oscillation period of approximately 13 hours of the Bay of Fundy-Gulf of Maine system (Brown and Moody, 1987; Greenberg, 1990). The major axis of the semidiurnal tidal current ellipse is oriented northwest-southeast across the bank, and the amplitude of this current near the seabed increases from less than 10 cm/s along the deeper southern flank to greater than 100 cm/s on the relatively shallow northern edge of the bank (Butman and Beardsley, 1987). On the shallowest portions of Georges Bank (<50 m), tidal currents are so strong that complete vertical mixing of the water column occurs throughout the year (Butman and Beardsley, 1987). These strong currents also form large sand bedforms (Jordan, 1962; Stewart and Jordan, 1964; Todd and Valentine, 2012) and continuously rework the surficial sediments, thereby removing most of the clay, silt, and fine-grained sand and leaving coarse-grained sand and gravel (Twichell et al., 1987; Butman, 1987).

This map is one of a series that show seafloor topography of the Canadian segment of Georges Bank Fundian Channel and Northeast Channel in shaded-relief view (depth coded by colour) at a scale of 1:50 000. This topographic map has a companion map of backscatter strength that shows the relative reflectivity of the seafloor substrates in response to sound waves (backscatter strength) that will be published separately (B.J. Todd, P.C. Valentine, and J. Shaw, work in progress, 2012). Together, the shaded seafloor topography and backscatter strength maps provide a basis for interpreting the origin of seafloor features and the nature of materials that form the seafloor. The maps are based on multibeamsonar surveys conducted in 1999 and 2000 to map 11 965 km2 of the seafloor (Fig. 3). On this map, waterdepth contours were computer-generated from the multibeam-sonar data and are shown (in white) on the colour-coded water-depth image at a depth interval of 10 m for water depths less than 200 m and at an interval of 100 m for water depths greater than 200 m. Bathymetric contours (in blue) outside the multibeam survey area on this sheet, presented at a depth interval of 25 m, are from the Natural Resource Map series (Canadian Hydrographic Service, 1966, 1967, 1971, 1972); and bathymetric contours in Figures 1–3 are from the same sources. The complete series of Georges Bank, Fundian Channel, and Northeast Channel seafloor topographic maps comprises nine adjacent map areas at a scale of 1:50 000 (Fig. 3). In total, eighteen maps constitute the Georges Bank, Fundian Channel, and Northeast Channel map suite (two maps

showing seafloor topography and backscatter strength per map area).

Multibeam-sonar water-depth data are the basis for the seafloor shaded topographic map. The data were collected as a collaborative effort between the Canadian Hydrographic Service (CHS), the Geological Survey of Canada (GSC), the Canadian Offshore Scallop Industry Mapping Group, and the Ocean Mapping Group of the University of New Brunswick. The survey systems use multiple sonar beams angled downward and outward (from a location on the ship's hull) to ensonify a narrow strip of seafloor across the ship's track. The travel times of the outgoing sound waves and returning echoes from the seafloor are used to calculate the water depths of the ensonified area (Courtney and Shaw, 2000). On Georges Bank, the width of the seafloor swath imaged along each survey line was two to five times the water depth; in the deeper water of Fundian Channel, the ensonification width increased to five to six times the water depth. Line spacing was approximately three to four times water depth to provide up to 100% ensonification overlap between adjacent lines. Areas shown in white within the surveyed areas are places where no multibeam data were collected. Surveys were conducted as follows: by the CHS in Northeast Channel in 1999 (area A, Fig. 2), using the Canadian Coast Guard Ship (CCGS) Frederick G. Creed, a SWATH (Small Waterplane Area Twin Hull) vessel equipped with a

Kongsberg EM1000 multibeam-sonar bathymetric survey system with 60 beams operating at 95 kHz arrayed over an arc of 150° with the transducer mounted in the starboard pontoon • by the CHS and the Canadian Offshore Scallop Industry Mapping Group on Georges Bank in 1999 and 2000 (area B, Fig. 2), using the MV Anne S. Pierce equipped with a Kongsberg EM1002 multibeam-sonar bathymetric survey system with 111 beams operating at 95 kHz configurable over an arc of up to 150° with the transducer mounted on a ram extended beneath the hull, and by Clearwater Fine Foods, Inc. in Fundian Channel in 2000 (area C, Fig. 2), using the MV Anne S. Pierce equipped as described above. The Global Positioning System (with differential corrections) was used for navigation and provided a

positional accuracy of ±3 m. Survey speeds averaged 14 knots (26 km/h) on the CCGS Creed resulting in an average data collection rate of about 48 km²/h in water depths of 250 m. Survey speeds averaged 6 knots (11 km/h) on the MV Anne S. Pierce resulting in an average data collection rate of about 6.6 km²/h in water depths of 80 m. Sound velocity profiles were collected at regular intervals during multibeamsonar bathymetric data collection and were used to correct the data for refraction of the sonar beams due to density stratification in the water column. The bathymetric data were adjusted for tidal variation using an innovative tidal model that was developed for the seafloor mapping project by the Ocean Sciences Division of Fisheries and Oceans Canada at the Bedford Institute of Oceanography. The bathymetric data were processed using software developed by the Ocean Mapping Group at the University of New

BATHYMETRIC DATA DISPLAY

The multibeam-sonar bathymetric data are presented at 5 m per pixel horizontal resolution on Georges Bank and 10 m per pixel horizontal resolution in Fundian Channel and Northeast Channel. The shadedartificial illumination of the relief by a virtual light source positioned 45° above the horizon at an azimuth of 315°. In the resulting image, topographic features are enhanced by strong illumination on the northwestfacing slopes and by shadows cast on the southeast-facing slopes. Superimposed on the topographic 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. Each figure has a unique colour ramp, and the colour ramp for an inset map showing topographic detail may differ from the colour ramp used for the main map. 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.

GEOMORPHOLOGY OF GEORGES BANK, FUNDIAN CHANNEL, AND NORTHEAST CHANNEL

Georges Bank flanks the seaward side of the Gulf of Maine and rises more than 300 m above the Gulf of Maine seafloor (Fig. 1, 2). Most of the Canadian portion of Georges Bank has water depths between 60 m and 90 m (Canadian Hydrographic Service, 1990, 1997; Valentine et al., 1992), but depths shallow to 42 m near 42°N, 67°W. The bank surface gradually deepens seaward and has an average slope of less than 0.05° (0.9 m/km). The 200 m isobath along the southeastern margin of Georges Bank approximates the continental shelf break (Fig. 1). Seaward, water depths increase down the continental slope, which has an average slope of 7° (123 m/km). The seaward margin of the bank in Canada is incised by a number of submarine canyons, the largest of which are Corsair and Georges canyons (Fig. 2). Georges Bank is bounded to the north by the Fundian Channel which comprises Northeast Channel to the east and Georges Basin to the west (Fig. 2). Georges Basin is the deepest portion of the Gulf of Maine with a maximum depth of 377 m. The Fundian Channel north of Georges Bank is approximately 45 km wide and is bounded to the north by Browns Bank on the Scotian Shelf. The Fundian Channel narrows southeastward into Northeast Channel, which is approximately 28 km wide. The seaward sill depth in Northeast Channel is 232 m, and the channel mouth is incised by submarine canyons (Fig. 2).

Seismic-reflection profiles show that beneath the surface of Georges Bank there is a prominent unconformity formed on late Cretaceous and Tertiary sedimentary rocks (King and MacLean, 1976; Lewis et al., 1980). The surficial sediment overlying the unconformity is glacial debris transported to Georges Bank and other Gulf of Maine banks during the late Pleistocene epoch from continental areas to the north (Shepard et al., 1934, Knott and Hoskins, 1968; Oldale and Uchupi, 1970; Schlee, 1973; Schlee and Pratt, 1970; Fader, 1984; Fader et al., 1988; Todd et al., 2007). During the postglacial Holocene epoch (~12 000 years before present), sea level rose from a low stand 120 m below the present sea level (Emery and Garrison, 1967; King and Fader, 1986), and the bank was submerged about 6000 BP (radiocarbon years) (Shaw et al., 2002). Georges Bank surficial sediments were reworked by marine processes during sea-level transgression and continue to be reworked under the modern oceanic regime (Twichell et al., 1987; Valentine et al., 1993). The present morphology of the Gulf of Maine, Georges Bank, and the Fundian and Northeast channels mapped here displays the imprint of multiple glaciations during the Pleistocene epoch (~12 000 years ago to 2.5 million years ago). During the last glaciation of the Pleistocene, the Wisconsinan, the Laurentide Ice Sheet extended southeastward from central Canada across Maritime Canada and New England to the present northern margin of Georges Bank and the continental shelf edge off Nova Scotia and the Fundian and Northeast channels were a major outlet for glacial ice to the Atlantic Ocean (Shaw et al., 2006). Based on the mapping of glacial gravel collected from the seabed in the Gulf of Maine region, Schlee and Pratt (1970) reported that glacial ice lapped onto the northern

Geomorphology of Sheet 3 The northern portion of Northeast Channel and the southwestern edge of Browns Bank are shown on this map at a scale of 1:50 000. Inset maps at a scale of 1:25 000 (Fig. 4-7) highlight geomorphological features typical of the area. For each of these detailed maps, the colour-range values are hypsometrically optimized and differ from the colour-range values of the 1:50 000 scale map sheet. On the southwestern margin of Browns Bank, bounding the Northeast Channel, the shelf break is at On the southwestern margin of Browns Bank, bounding the Northeast Channel, the shelf break is at approximately 120 m water depth. At shallower depths, the seabed is relatively smooth except for a series of segmented ridges, each approximately 3.5 m in height and are oriented approximately east-west (Fig. 4). The ridges are subparallel, and the longest segment is 1.5 km in length. These features are interpreted to be De Geer moraines, which are small, transverse moraines formed at or close to the grounding line of a water-terminating glacier (Todd et al., 2007). The east-west orientation of De Geer moraine crests on Browns Bank suggests that the ice front retreated northward during the last deglaciation. In the northernmost portion of the map area, the shelf break occurs at the 130 m isobath where it is a linear escarpment aligned northwest-southeast. It is 10 m to 20 m high and 6 km long, with a southwest-facing slope of 46° (Fig. 5). On the southeastern margin of Browns Bank, in the eastern portion of the map area, the shelf break at

the transition to the continental slope occurs at 150 m water depth. On the upper continental slope, the relatively smooth seafloor rapidly steepens and becomes gullied at 400 m depth. Pits caused by iceberg keels are present below 300 m. A low ridge aligned northeast-southwest, possibly a terminal or recessional moraine, is present between 290 m in the east and 220 m in the west (65°25.5'W to The central portion of the map area is dominated by Northeast Channel where water depths in the channel axis reach 250 m and increase southeastward to more than 300 m in the head of a submarine canyon which opens to the Atlantic Ocean (Fig. 2). The seafloor in Northeast Channel displays a pattern of intersecting linear to curvilinear depressions, some over 5 km in length, and numerous, subcircular pits (Fig. 6). The linear depressions, or scour marks, and pits are interpreted as evidence of the ploughing

240 260 300 600 1000

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REFERENCES

Bigg, G.R., Wadley, M.R., Stevens, D.P., and Johnson, J.A., 1996. Prediction of iceberg trajectories for the North Atlantic and Arctic Oceans; Geophysical Research Letters, v. 23, p. 3587–3590. Brown, W.S. and Moody, J.A., 1987. Chapter 9: Tides; in Georges Bank, (ed.) R.H. Backus; Massachusetts Institute of Technology Press, Cambridge, Massachusetts, p. 100-107. Butman, B., 1987. Chapter 13: Physical processes causing surficial sediment movement; in Georges Bank, (ed.) R.H. Backus; Massachusetts Institute of Technology Press, Cambridge, Massachusetts, p. 147–162. Butman, B. and Beardsley, R.C., 1987. Physical oceanography; in Georges Bank, (ed.) R.H. Backus; Massachusetts Institute of Technology Press, Cambridge, Massachusetts, p. 88–98. Canadian Hydrographic Service, 1966. Natural Resource Chart 15116-A, bathymetry; Department of the Environment, Canadian Hydrographic Service, 1967. Natural Resource Chart 15114-A, bathymetry; Department of the Environment,

Ottawa, Ontario, scale 1:250 000. Ottawa, Ontario, scale 1:250 000. $Can adian\, Hydrographic\, Service,\, 1971.\, Natural\, Resource\, Chart\, 15124-A,\, bathymetry;\, Department\, of\, the\, Environment,\, And the Control of the Contr$ Ottawa, Ontario, scale 1:250 000. Canadian Hydrographic Service, 1972. Natural Resource Chart 15126-A, bathymetry; Department of the Environment, Ottawa, Ontario, scale 1:250 000. Canadian Hydrographic Service, 1990. Georges Bank eastern portion, chart L/C 4255; Fisheries and Oceans Canada, Ottawa, Ontario, scale 1:175 000. Canadian Hydrographic Service, 1997. Georges Bank, chart LC 8005; Fisheries and Oceans Canada, Ottawa, Ontario, Courtney, R.C. and Shaw, J., 2000. Multibeam bathymetry and backscatter imaging on the Canadian continental shelf; Geoscience Canada, v. 27, p. 31-42. Emery, K.O. and Garrison, L.E., 1967. Sea levels 7,000 to 20,000 years ago; Science, v. 157, p. 684–687.

Fader, G.B.J., 1984. Geological and geophysical study of Georges Basin, Georges Bank, and the Northeast Channel area of the Gulf of Maine; Geological Survey of Canada, Open File 978, 531 p. Fader, G.B.J., King, E., Gillespie, R., and King, L.H., 1988. Surficial geology of Georges Bank, Browns Bank, and the southeastern Gulf of Maine; Geological Survey of Canada, Open File 1692, 3 sheets, scale 1:300 000. Greenberg, D.A., 1990; Chapter 5: The contribution of modeling to understanding the dynamics of the Bay of Fundy and Gulf of Maine; in Modeling marine systems, (ed.) A.M. Davies; CRC Press, Boca Raton, Florida, p. 107–140. Jordan, G.F., 1962. Large submarine sand waves; Science, v. 136, p. 839-848. King, L.H. and Fader, G.B.J., 1986. Wisconsinan glaciation of the Atlantic continental shelf of southeast Canada; Geological Survey of Canada, Bulletin 363, 72 p.

King, L.H. and MacLean, B., 1976. Geology of the Scotian Shelf; Canadian Hydrographic Service, Marine Sciences Paper 7, Geological Survey of Canada, Paper 74-31, 31 p. Knott, S.T. and Hoskins, H., 1968. Evidence of Pleistocene events in the structure of the continental shelf off the northeastern United States; Marine Geology, v. 6, p. 543. Lewis, R.S., Sylvester, R.E., Aaron, J.M., Twichell, D.C., and Scanlon, K.M., 1980. Shallow sedimentary framework and related potential geologic hazards of the Georges Bank area; in Environmental geologic studies in the Georges Bank area, United States northeastern Atlantic outer Continental Shelf, 1975-1977, (ed.) J.M. Aaron; U.S. Geological Survey, Open-File Report 80-240-A, p. 5-1-5-25. Oldale, R.N. and Uchupi, E., 1970. The glaciated shelf off northeastern United States; U.S. Geological Survey, Professional Paper 700B, p. B167-B173. Schlee, J., 1973. Atlantic continental shelf and slope of the United States-sediment texture of the northeastern part; U.S. Geological Survey, Professional Paper 529-L, 64 p. Schlee, J. and Pratt, R.M., 1970. Atlantic continental shelf and slope of the United States-gravels of the northeastern part; U.S. Geological Survey, Professional Paper 529-H, 39 p. Shaw, J., Gareau, P., and Courtney, R.C., 2002. Palaeogeography of Atlantic Canada 13-0 kyr; Quaternary Science Reviews, v. 21, p. 1861–1878.

conceptual model of the deglaciation of Atlantic Canada; Quaternary Science Reviews, v. 25, p. 2059–2081. Shepard, F.P., Trefethen, J.M., and Cohee, G.V., 1934. Origin of Georges Bank; Geological Society of America, Bulletin v. 45, p. 281–302. Stewart, H.B., Jr. and Jordan, G.F., 1964. Underwater sand ridges on Georges Shoal; *in* Papers in marine geology, (ed.) R.L. Miller; Macmillan, New York, New York, p. 102–114. Todd, B.J., Lewis, C.F.M., and Ryall, P.J.C., 1988. Comparison of trends of iceberg scour marks with iceberg trajectories and evidence of paleocurrent trends on Saglek Bank, northern Labrador Shelf; Canadian Journal of Earth Sciences, Todd, B.J. and Valentine, P.C., 2012. Large submarine sand waves and gravel lag substrates on Georges Bank off Atlantic Canada.; *in* Seafloor geomorphology as benthic habitat: GeoHab atlas of seafloor geomorphic features and benthic habitats, (ed.) P.T. Harris and E.K. Baker; Elsevier, London, United Kingdom, p. 261–275. Todd, B.J., Valentine, P.C., Longva, O., and Shaw, J., 2007. Glacial landforms on German Bank, Scotian Shelf: evidence for Late Wisconsinan ice-sheet dynamics and implications for the formation of De Geer moraines; Boreas, v. 36, Twichell, D.C., Butman, B., and Lewis, R.S., 1987. Shallow structure, surficial geology, and the processes currently shaping the bank; *in* Georges Bank, (ed.) R.H. Backus; Massachusetts Institute of Technology Press, Cambridge, Valentine, P.C., Strom, E.W., and Brown, C.L., 1992. Maps showing the sea-floor topography of eastern Georges Bank; U. S. Geological Survey, Miscellaneous Investigations Series Map I-2279-A, scale 1:250 000. Valentine, P.C., Strom, E.W., Lough, R.G., and Brown, C.L., 1993. Maps showing the sedimentary environment of eastern Georges Bank; U.S. Geological Survey, Miscellaneous Investigations Series Map I-2279-B,

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