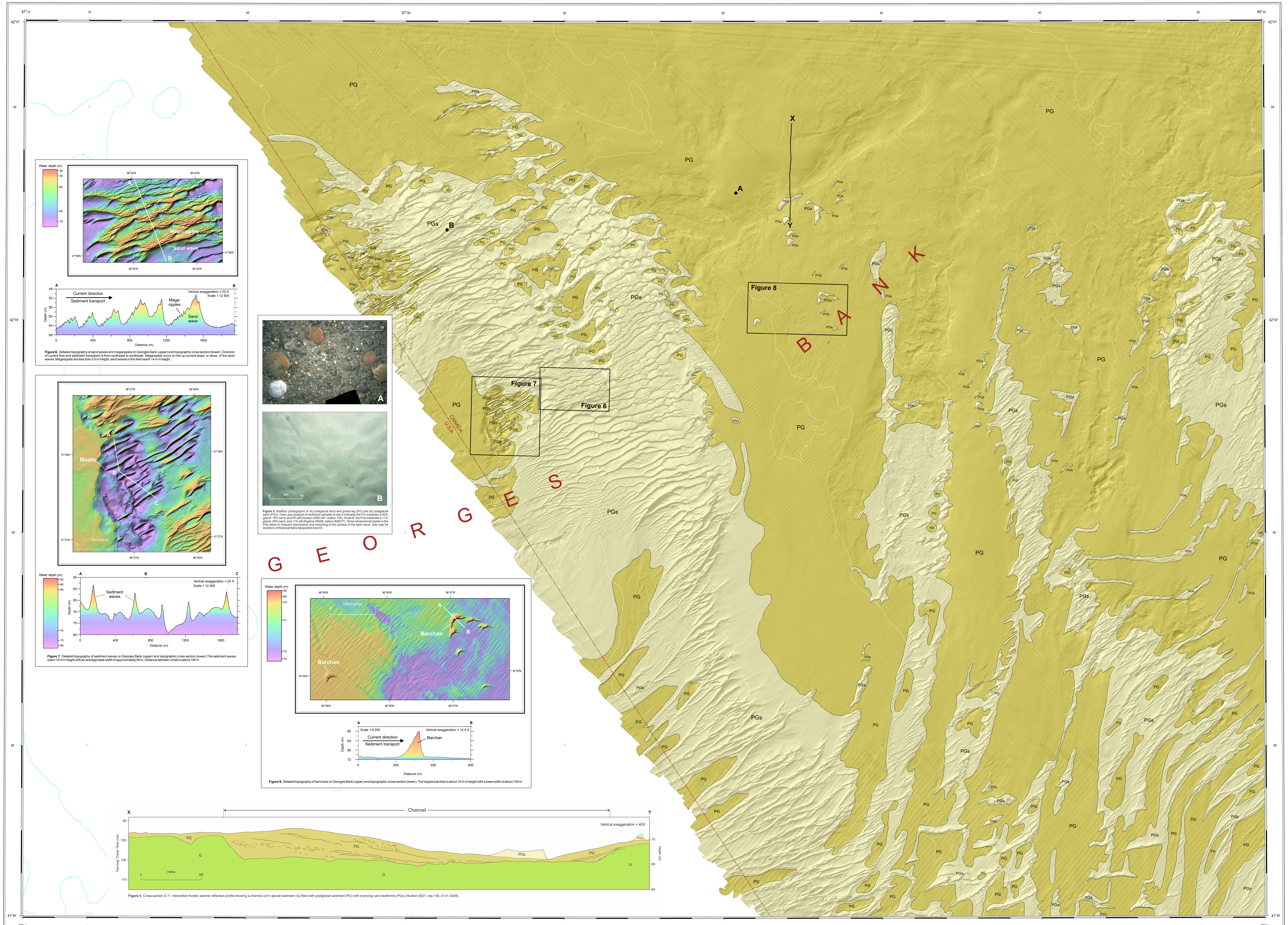


DESCRIPTIVE NOTES

INTRODUCTION

Georges Bank is a shallow submarine bank that lies south of Nova Scotia and east of Cape Cod, Massachusetts (Fig. 1). It bounds the seaward side of the Gulf of Maine and rises more than 300 metres (m) above the Gulf of Maine seafloor. The bank is approximately 280 kilometres (km) long and 150 km wide and has an area of 42,000 square kilometres (km^2) in water depths less than 200 m (Canadian Hydrographic Service, 1990, 1997; Valentine et al., 1992). 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 km^2) lies in Canadian territory. Most of the Canadian portion of Georges Bank has water depths between 60 and 90 m.

The bank waters are characterized by energetic tidal currents associated with the near resonance that exists between the principal lunar semidiurnal tidal component (M2) 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 centimetres per second (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 shows the surficial geology of a portion of the Canadian segment of Georges Bank at a scale of 1:50 000. Surficial sediment type is coded by colour on the map. This surficial geology map has a companion map of shaded-relief seafloor topography (Todd et al., 2013) and backscatter strength imagery that shows the relative reflectivity of the seafloor substrates in response to sound waves (Todd and Courtney, 2014). The maps are based on multibeam-echosounder surveys conducted in 1999 and 2000 to map 11,965 km^2 of the seafloor (Fig. 3). Details of the multibeam-echosounder data collection and processing are provided by Todd et al. (2013) and Todd and Courtney (2014). The shaded-relief seafloor topography and backscatter strength data, supplemented by sediment grain-size analyses and seabed photographs, provide a basis for interpreting the origin of seafloor features and the nature of materials that form the seafloor. On this map of surficial geology, water-depth contours generated from the multibeam- echosounder data are shown (in white) on the colour-coded surficial geology image at a depth interval of 10 m. Bathymetric contours (in blue) outside the multibeam survey area, presented at a depth interval of 25 metres, are from the Natural Resource Map series (Canadian Hydrographic Service, 1966, 1967, 1971, 1972).

The complete series of Georges Bank, Fundian Channel and Northeast Channel seafloor topographic map coverage comprises nine adjacent map areas at a scale of 1:50 000 (index map). 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). Only Sheet 4 has an associated surficial geology map.

GEOLOGICAL HISTORY

The morphology of the Gulf of Maine and Georges Bank is the result of marine sediment deposition during the Mesozoic (65–251 million years ago) and Cenozoic (present–65 million years ago) eras, erosion during the Tertiary period (1.8–65 million years ago), and glacial erosion and deposition during the Pleistocene epoch (11,430 years to 1.8 million years ago) of the Quaternary period (Uchupi and Bolmer, 2008). 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 forms a veneer of 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 post-glacial 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 ~6000 BP (radiocarbon years) (Shaw et al., 2002). Georges Bank surficial sediments were reworked and redistributed by marine processes during sea-level transgression and continue to be reworked under the modern oceanic regime (Butman, 1987; Twichell et al., 1987; Uchupi and Austin, 1987; Valentine et al., 1993).

The present morphology of the Gulf of Maine, Georges Bank, and the Fundian and Northeast channels displays the imprint of multiple glaciations during the Pleistocene epoch. 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. The Fundian and Northeast channels were a major outlet for glacial ice to the Atlantic Ocean (Dyke et al., 2002; Schnitker et al., 2001; Hundert, 2003; Stea, 2004; Shaw et al., 2006). Based on the mapping of glacial gravel collected from the seabed in the Gulf of Maine region, Pratt and Schlee (1969) and Schlee and Pratt (1970) reported that glacial ice lapped onto the northern margin of Georges Bank. Moraines were emplaced on the northern part of the bank and sand and silt outwash spread southward. The glacial maximum was followed by a multi-phased retreat of the ice front and the incursion of marine oceanic waters into the Gulf of Maine through the Northeast Channel. Within the gulf, ice front retreat and glaciomarine deposition began as early as 18 ka with grounded ice absent from the Gulf of Maine by approximately 14 ka (King and Fader, 1986; Schnitker et al., 2001).

GEOSCIENTIFIC DATA

High-resolution seismic-reflection data were collected over Georges Bank, Fundian Channel and Northeast Channel in 1999, 2000 and 2002 (Fig. 3; Todd et al., 2000, 2001, 2003) in order to complement the historical geoscientific information in the area and to assist the interpretation of the multibeam-echosounder data. The systems deployed included a Huntec Deep Tow Seismic (DTS) boomer, a single-channel sleeve-gun seismic reflection system, and a Simrad MS992 sidescan sonar (120 and 330 kHz). The geophysical surveys investigated different seafloor types and features identified using the multibeam bathymetric and backscatter data (Todd et al., 2013; Todd and Courtney, 2014).

Using a 0.75 m^3 Institutt for Kontinentalsokkel-undersøkelser (IKU) grab sampler, seafloor sediment samples were collected at sites best suited for groundtruthing multibeam imagery and geophysical profiles (Fig. 3). The sites were chosen to collect seafloor sediment samples representative of broad areas sharing similar geomorphology (Todd et al., 2013) and acoustic backscatter response (Todd and Courtney, 2014). Grain size analysis provided the percentage of gravel, sand and mud (silt+clay) in each sediment sample. These data were augmented by sediment samples and grain size analyses from the US Geological Survey (Poppe et al., 2005). Grain size descriptions based on the samples adhere to the Wentworth size class scheme for clastic sediments (Wentworth, 1922).

The multibeam bathymetric and backscatter data and the seismic-reflection profile data were used to identify locations where seafloor photographs were collected using Campod, an instrumented tripod equipped with oblique-and downward-oriented video and still cameras (Gordon et al., 2007). Campod was deployed while the ship slowly drifted across sites of geological or biological interest and was repeatedly landed on the seabed to obtain still photographs, thereby collecting high-resolution imagery along transects of 30 minutes duration that traversed up to 1000 m, depending on the current speed. About 10 still images, each showing an area of 0.96 m^2, were acquired per transect. In 2008, 401 seafloor photographs were acquired at 25 stations in the map area by the US Geological Survey using SEABOSS, a multi-instrumented platform equipped with a still camera (Blackwood et al., 2000).

SURFICIAL GEOLOGY

Syvitski (1991) showed that a complete deglacial sequence consists of some or all of the following features: ice-contact sediments, ice-proximal sediments, ice-distal sediments, paraglacial coastal sediments, and post-glacial sediments. The Quaternary stratigraphy of Georges Bank described here follows this deglacial sequence scheme. Earlier interpretations of surficial geological formations on Georges Bank were based on a regional understanding of the Gulf of Maine and Scotian Shelf (Fader et al., 1988; Fader et al., 2004). The formation names corresponding to the deglacial sequence names described here are noted in the legend and are shown in Figure 2. The veneer of Late Wisconsinan glacial sediment emplaced on Georges Bank likely consisted of, from north to south, ice-contact sediments, ice-proximal sediments, and ice-distal sediments. This veneer is 20 to 50 m thick, is generally devoid of internal seismic reflectors, and is incised in places by channels (Fig. 4) (Lewis et al., 1980). The bank is now isolated from other sediment sources by deep basins, and the postglacial sediments that now cover the map area were derived from the reworking by currents and waves of glaciogenic deposits. The present-day sediments are equivalent to the Sable Island Sand and Gravel Formation (Fig. 2, Drapeau and King, 1972; Fader, 1984). In some areas, winnowing of finer-grained sediment (silt and sand) from postglacial sediments resulted in gravel lag deposits that effectively armour the underlying sand and gravel against erosion. The morphology and extent of postglacial sediments are interpreted from the shaded relief map (Todd et al., 2013), the backscatter strength map (Todd and Courtney, 2014), seafloor sediment samples, photographs, video transects, and geophysical data (Todd et al., 2000, 2001, 2003).

Based on geophysical, geological, and photographic evidence, two Quaternary sediment units are mapped on Georges Bank. The area designated as postglacial sand and gravel (PG) is a well-sorted, generally coarse-grained sand, grading to rounded and subrounded pebble and cobble gravel (Fig. 5A), which forms a widespread surficial lag. The lag is overlain in places by well-sorted postglacial sand (PGs) occurring mainly as bedforms (Fig. 5B). The bedforms are the most prominent geomorphological features on the bank, are formed through sediment transport by strong tidal currents. Multibeam-echosounder sonar mapping of the Canadian portion of Georges Bank has provided unprecedented views of the morphology and distribution of these bedforms. In areas where ground-truth data were sparse, identification of sediment units was based on nearby backscatter and topographic imagery that had been ground-truthed using sediment samples, photographs, and video images.

Bedforms

At water depths of approximately 60 m or less, sediment on Georges Bank is continually reworked by tidal currents and episodically by storm-generated currents, resulting in a hierarchy of current-generated bedforms in sand-rich areas. Three types of bedforms are present in this map area. The first type occurs in sand-rich areas where mobile sand waves composed of medium to coarse sand are wave-like geometric configurations of the water–sediment interface that are formed by fluid flow over an erodable granular bed. The crests of the sand waves trend is approximately southwest–northeast, normal to the major axis of the semidiurnal tidal current (Butman and Beardsley, 1987). Sand wave crests display a complex anastomosing pattern in plan view (Fig. 6, upper panel). Superimposed on the sand waves and sharing the same general crest orientation are megaripples and ripples; these features have smaller wavelengths and heights and exhibit a complex three-dimensional pattern in plan view. The sand waves have wavelengths of 50–300 m and reach heights of 19 m. In cross section they are asymmetric with gently-sloping upcurrent (or stoss) faces, and steeply-dipping downcurrent (or lee) faces (Fig. 6, lower panel). This cross-sectional attribute of the sand waves, together with their crest orientation and overall distribution on the bank, indicates that the regional direction of sediment transport is from northwest to southeast. The presence of sand waves indicates that fluid velocities on Georges Bank are sufficient to erode and transport surficial sediment. Sand waves are migratory features and their height, wavelength, and speed and direction of migration are a function of sediment grain size in the eroding bed, water depth, and current velocity (see summary of references in Whitmeyer and FitzGerald, 2008).

The second style sand wave occurs within relatively small areas on Georges Bank. These bedforms have comparatively straight crests trending southwest–northeast, similar in orientation to crests within the sand wave fields (Fig. 7). although we lack direct sedimentological evidence for the composition of these features, their backscatter strength is similar to that of the sand wave fields and suggests that they are composed of well-sorted sand. These sand waves differ from those in the sand wave fields described above in that their simple, relatively straight crests show no bifurcation pattern. Also, in contrast to the asymmetrical profiles of the mobile bedforms within the sand wave fields, these features are symmetrical in profile (Fig. 7). We hypothesize that they are relatively immobile. Another difference between the [illegible]

LEGEND

QUATERNARY

POSTGLACIAL SEDIMENTS

Postglacial sediments result from reworking by ocean processes of earlier glacial sediments and from modern sediment transport and deposition. Postglacial sediments are commonly denoted as Sable Island Sand and Gravel Formation. Where filling channels in the underlying glacial sediment, postglacial sediment exhibits a reflection configuration of parallel to subparallel and oblique progradational seismic reflections.

PGs — ***Postglacial sand:*** *well-sorted sand, with characteristic parallel to subparallel, low amplitude reflections. Occurs in widespread bed forms.*

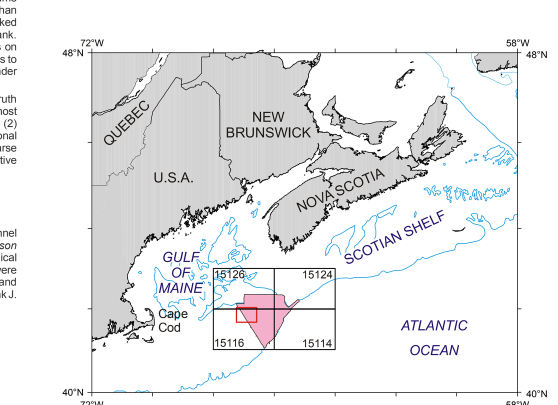
PG — ***Postglacial sand and gravel:*** *well-sorted sand, grading to rounded and subrounded gravels forming a widespread surficial gravel lag. Where filling channels in the underlying glacial sediment, postglacial sediment exhibits a reflection configuration of parallel to subparallel and oblique progradational seismic reflections.*

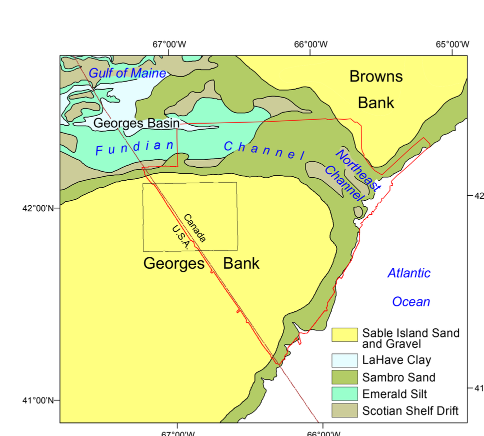
GLACIAL SEDIMENTS

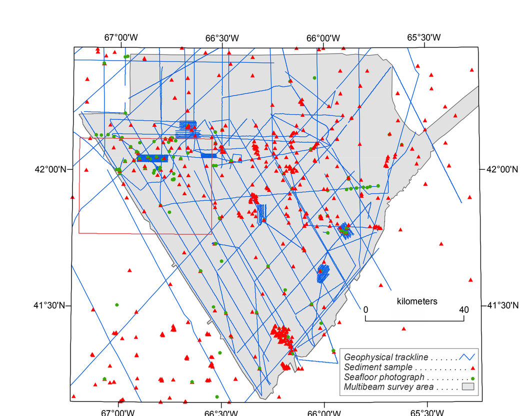
The extent of Pleistocene Epoch glacial ice on Georges Bank has not been clearly established. When deposited, glacial sediments likely consisted, from north to south, of ice-contact sediments, ice-proximal sediments, and ice-distal sediments. Glacial sediments are commonly denoted as the Scotian Shelf Drift Formation.

G — ***Glacial sediment:*** *unconsolidated sediment with incoherent seismic reflection configuration, probably consisting of a heterogeneous mixture of clay, sand, gravel and boulders varying in size and shape. Incised by channels in places.*

Geological contact (map unit boundaries are interpreted from multibeam sonar bathymetry and geophysical seismic profile data and are inferred contacts that may be gradational or conceptual in nature) . . . .







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SURFICIAL GEOLOGY AND SHADED SEAFLOOR RELIEF

GEORGES BANK, FUNDIAN CHANNEL, AND NORTHEAST CHANNEL

GULF OF MAINE

Scale 1:50 000/Échelle 1/50 000

kilometres 1 0 1 2 3 4 kilomètres

Universal Transverse Mercator Projection
North American Datum 1983

Projection transverse universelle de Mercator
Système de référence géodésique nord-américain, 1983