Preliminary interpretation of the marine geology of Frobisher Bay, Baffin Island, Nunavut

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Abstract

The seabed of Frobisher Bay exhibits a complex topography reflecting the predominance of exposed bedrock. Superimposed on the bedrock are landforms created by the flow of grounded ice during the last glacial period. As this ice retreated, glaciomarine sediment was deposited in bedrock troughs and was subsequently overlain by postglacial mud. Areas of the seafloor were impacted by icebergs at the retreating ice margin and by the modern iceberg flux. Slope failures in the seabed sediments are numerous.

Résumé

La topographie complexe du plancher océanique de la baie Frobisher est caractérisée par la présence prépondérante de substratum rocheux exposé. Des formes de terrain superposées au substratum ont été créées par l'écoulement de la glace échouée au cours de la plus récente époque glaciaire. À mesure que la glace reculait, des sédiments glaciomarins ont été mis en place dans des auges creusées dans le substratum, puis recouverts par des boues postglaciaires. Certaines étendues de plancher océanique portent la trace d'icebergs qui se trouvaient à proximité de la marge glaciaire en recul ainsi que du passage de nombreux icebergs contemporains. De nombreuses ruptures de pente ont eu lieu dans les sédiments sur le plancher océanique.

Introduction

Frobisher Bay, Nunavut, a macrotidal inlet of the Labrador Sea in southeastern Baffin Island, is 230 km long and varies in width from 40 km at its southeastern extremity to 20 km at its northwest end (Figure 1a). Potential competing industrial uses of ocean space in Frobisher Bay, coupled with concern for habitat protection, has led to the Canada-Nunavut Geoscience Office and the Geological Survey of Canada, in partnership with Memorial University's Marine Habitat Mapping Group, ArcticNet, and the Government of Nunavut, to undertake a regional seafloor geoscience mapping program. The aim of this work is to provide new knowledge of the seabed geology, geohazards and geological processes to underpin and manage future development in the region (Mate et al., 2015).

Multibeam sonar

As part of the ArcticNet program, the CCGS *Amundsen* surveyed several adjoining swathes along transit lines within Frobisher Bay in 2006, 2007 and 2008 (Bartlett et al., 2006; Hughes Clarke et al., 2015). The vessel was equipped with a Kongsberg Maritime (formerly Simrad, Inc.) EM 302 multibeam sonar system operating at a frequency of 30 kHz. Annually from 2012 to 2015, the RV *Nuliajuk*, operated by the Nunavut Department of Environment, conducted a series of surveys to complement the CCGS *Amundsen* survey coverage (Brucker et al., 2013; Muggah et al., 2013; Hughes Clarke and Renoud, 2014; Hughes Clarke et al., 2015). The RV *Nuliajuk* was equipped with a Kongsberg Maritime EM 2040C system operating at a frequency of 200 kHz with a depth range of up to 300 m.

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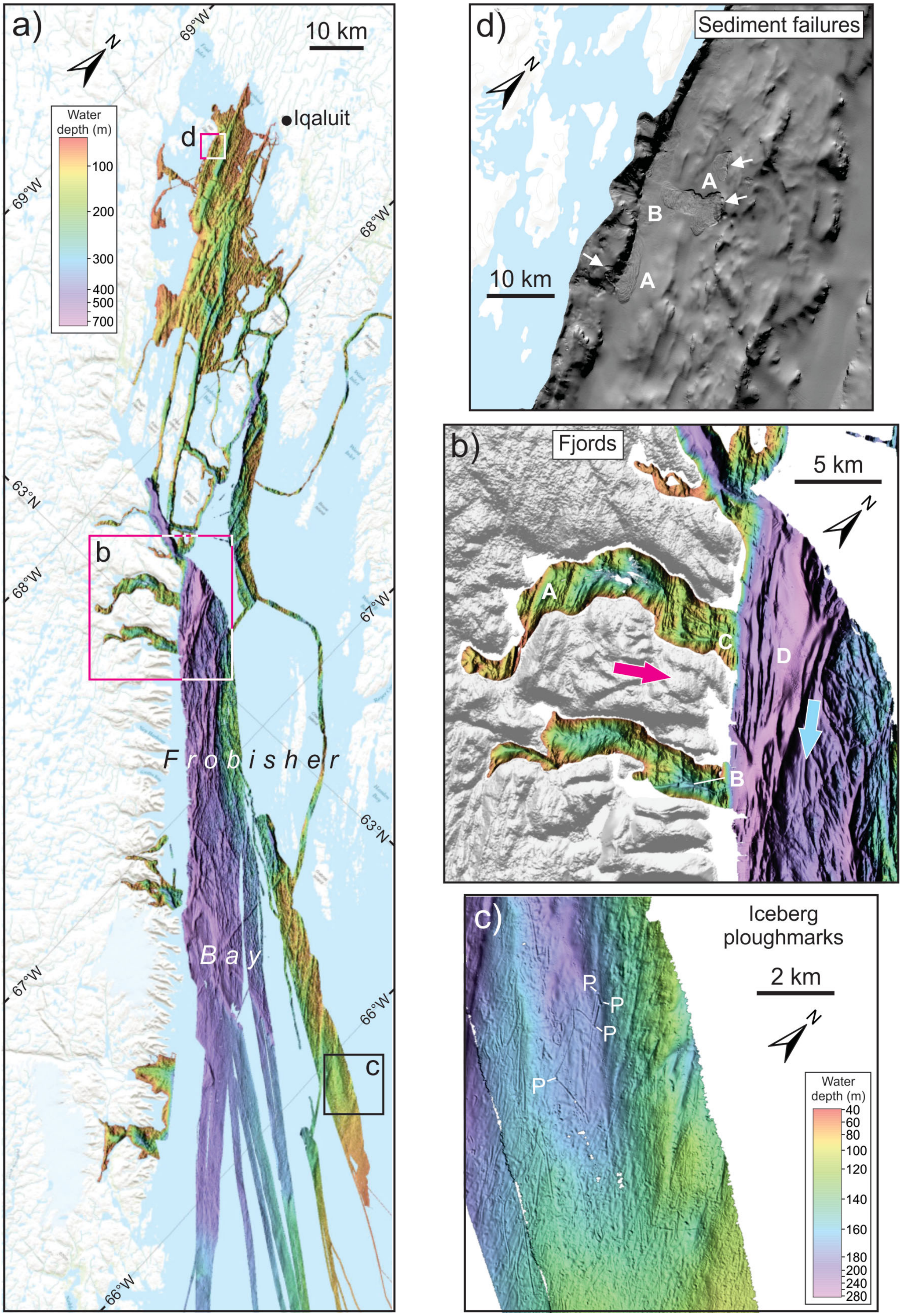
a)
10 km
N
Water depth (m)
100
200
300
400
500
700
Iqaluit
d
b
c
69°W
68°W
67°W
66°W
63°N
Frobisher
Bay
d)
Sediment failures
N
10 km
A
B
A
b)
Fjords
5 km
N
A
B
C
D
c)
Iceberg ploughmarks
2 km
N
P
P
P
P
Water depth (m)
40
60
80
100
120
140
160
180
200
240
280

Seabed morphology

This region is topographically complex, as a result of

- the strong southeast-trending bedrock structural grain;
- superimposed landforms created by fast-flowing grounded ice, trending at a slight angle to the structural grain;
- glacial landforms transverse to the structural grain, created at former ice margins;
- a drape of glaciomarine sediments deposited by meltwater plumes following ice retreat;
- areas of seafloor impacted by intensive iceberg flux soon after deglaciation;
- areas of seafloor impacted by modern icebergs;
- deposits of postglacial mud and
- submarine slope failures.

Three of these features are highlighted in Figure 1b, c and d.

Bedrock

The strong structural grain is likely imparted by rocks of the Cumberland Batholith (Steenkamp and St-Onge, 2014; St-Onge et al., 2015) that trend south-southeast (Figure 1a, b). Near the head of the bay, the bedrock ridges are shallow to <30 m in places, whereas the troughs attain maximum depths of approximately 260 m. Islands in the map area are separated by narrow troughs. At the southern end of the map area, bedrock topography demonstrates less of the south-southeast structural grain, perhaps indicative of the Lake Harbour Group (Machado et al., 2013). The channels in the south deepen to more than 600 m. Bedrock outcrops are rare on the ridged terrain because a veneer of glaciomarine mud is present.

Streamlined glacial landforms

Flow-parallel glacial landforms are created by moulding of deformable material underneath fast-flowing grounded ice. The glacial landforms occur primarily in the north of the bay, where they are commonly <1 km long and 5 m high, with a streamlined appearance, and are oriented toward the northwest, that is, they cut across the structural grain. Farther south they are longer (commonly 1.5 km), and follow the structural grain. They tend to have bedrock outcrops at the upstream end and taper to the southeast, in the form of crag and tail features. The pattern of the streamlined landforms in the north suggests that there was convergence of grounded ice into a fast flow directed down the bay to the southeast. Where ice flowed northeast from fjords to join the regional southeast flow, medial moraines and eskers are evident (Figure 1b).

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Figure 1: a) Seabed topographic image of Frobisher Bay based on multibeam sonar mapping. Grid cell size is 10 m. The water depth colour bar is hypsometrically optimized for the water depth range in the image. Locations of parts b, c and d are shown by labelled boxes; **b)** the south coast of Frobisher Bay is characterized by fjords carved by glacial ice flowing through restricted valleys to the northeast (pink arrow), normal to the southeast-trending bedrock structural grain that is clearly defined in the bathymetric data (A); evidence of the direction of ice movement includes medial moraines (B) and eskers (C); the floor of these fjords is at approximately 200 m water depth, perched 500 m above the seafloor of Frobisher Bay (D); ice flowing out of the fjords fed the dominant southeastern ice flow within the bay (blue arrow); **c)** seafloor sediments in outer Frobisher Bay exhibit linear to curvilinear depressions tens of metres in width and kilometres in length; wallow pits are indicated by (P); **d)** this image shows that the uppermost (postglacial) unit has failed in places, creating mass transport landforms (A); the headwall escarpments (white arrows) are several metres high; some slides appear fresh whereas others exhibit subdued relief and their depositional lobes are buried (B; image courtesy of the Ocean Mapping Group, University of New Brunswick).

Submarine moraines

Submarine moraines are deposits of ice-contact sediment, likely glacial diamicton, formed at ice margins. Two types are present: relatively long and wide moraines, and De Geer moraines. The first type extends transverse to the structural grain and ice-flow direction. They do not extend across the entire width of the bay, however, and exist as series of segments that are 1.5–6 km long and 30–50 m high, characterized by high backscatter strength. They occur either as simple ridges or as ridges with transverse streamlined ridges extending upstream from the former ice margin, along the former ice-flow direction. These transverse moraines formed when grounded ice retreating up the bay halted. The De Geer moraines consist of groups of short ridges of glacial diamicton <1 km in length, with heights of 2–10 m. De Geer moraines may indicate an incremental, perhaps annual, retreat of grounded ice in a north-northwesterly direction.

Glaciomarine sediment

Unconsolidated sediment overlies bedrock and glacial landforms in Frobisher Bay. Stratigraphically lowest is a draped veneer of glaciomarine sediment (likely gravelly sandy mud) derived from meltwater plumes during ice retreat. In troughs, the glaciomarine unit is overlain by postglacial mud.

Postglacial mud and pockmarks

Postglacial mud overlies the glaciomarine sediment and is mainly confined to the south-southeast–trending troughs. It is characterized by a smooth seafloor with little or no relief and high backscatter strength. This unit is derived from the reworking of glacial sediments and, to a lesser degree, from fluvial input. Large numbers of pockmarks are found in several concentrations in the northwestern part of Frobisher Bay. Pockmarks average 150 m in diameter and 2 m in depth. They result from the release of fluids—possibly methane—generated in the postglacial sediments.

Iceberg-impacted terrain

Iceberg-impacted terrain occurs as two classes. In the first class, intensive iceberg pitting is present in the northwest portion of Frobisher Bay down to depths of approximately 80 m. The pits have a degraded appearance and relief of several metres. This population of iceberg pits likely formed by icebergs originating at the grounded ice margin as it retreated northward. The second class of iceberg impacts occur in the southeastern part of the bay, are fewer in number, fresh-looking, and occur down to 200 m depth. They are mostly pits, although several long iceberg ploughmarks are present (Figure 1c). These ploughmarks were formed by the action of the keels of icebergs dragging through the seabed. Their crosscutting relationships indicate the relative ages of the ploughmarks. One iceberg left a record of abrupt changes in drift direction, associated in places with wallow pits (indicated by P in Figure 1c). This pattern is evidence of repeated groundings of the keel and subsequent drift of the iceberg in response to the driving forces of currents and wind; this process forms an ice-keel turbate (usually reworked glaciomarine sediment that is reworked by the ploughing action of ice keels, and in which the original stratigraphy is disrupted), which is colonized by benthic species after disruption. It is likely that this class of feature is a result of the modern iceberg flux.

Submarine landslides

An unusual feature of the seafloor in inner Frobisher Bay is the large number of submarine landslides (Deering et al., 2015). The slides have emanated from the western margin of the bay and from a ridge to the east, and have flowed in different directions into the intervening basin. They are commonly present on the slopes of the north-northwest–oriented ridges, and are distributed throughout the inner bay, although they are more prevalent on the west side (Figure 1d). A typical slide comprises a steep failure headwall and a low-relief, fan-shaped depositional lobe, commonly with compression ridges normal to the former flow directions. The failure surfaces may be the top of the glaciomarine sediments, and the failed material is the postglacial unit. Although many slides have a fresh appearance, others are subdued, with depositional lobes mantled by postglacial mud. In places, only the erosional chutes are found and depositional zones are completely buried. These observations suggest that failure has been occurring throughout the postglacial period, i.e., since ca. 7 ka BP.

Economic considerations

Seabed mapping is a globally recognized scientific best practice for providing information on which to base decisions about the multiple, potentially competing, uses of ocean space (Todd and Shaw, 2009; Heap and Harris, 2011; Baker and Harris, 2012, Barrie et al., 2014). Prudent management of Frobisher Bay ocean space would consider seabed geology and geohazards in the formulation of development plans that affect its ecosystem and exploitation of its resources. Developments in Frobisher Bay may include new port facilities, fibre-optic cable routes and local fisheries.

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