Integrated seabed mapping of Frobisher Bay, southern Baffin Island, Nunavut to support infrastructure development, exploration and natural-hazard assessment

D.J. Mate1, D.C. Campbell2, J.V. Barrie3, J.E. Hughes Clarke4, J. Muggah4, T. Bell5 and D.L. Forbes2, 5

1Canadian Northern Economic Development Agency, Iqaluit, Nunavut (formerly Canada-Nunavut Geoscience Office, Iqaluit, Nunavut)
2Natural Resources Canada, Geological Survey of Canada–Atlantic, Dartmouth, Nova Scotia, Calvin.Campbell@NRCan-RNCan.gc.ca
3Natural Resources Canada, Geological Survey of Canada–Pacific, Sidney, British Columbia
4Department of Geodesy and Geomatics Engineering, University of New Brunswick, Fredericton, New Brunswick
5Department of Geography, Memorial University, St. John’s, Newfoundland and Labrador


Abstract

Integrated seabed mapping is an important prerequisite for effective management of offshore areas. With the rapidly expanding City of Iqaluit on its shores and mineral resources on nearby Hall Peninsula, Frobisher Bay will undoubtedly see new infrastructure development over the next several years. The 2014 field season marked the first of a two-year, collaborative, seabed-mapping project in the region. The purpose of the project is to improve understanding of the geology of Frobisher Bay and, ultimately, to support decision-making with respect to its seabed use. Using both legacy and newly acquired high-resolution seabed-morphology and geology data, the project will generate a suite of bathymetric and geological maps for the floor of Frobisher Bay. Initial results reveal three zones (outer, middle and inner) with distinctive seabed morphology and surficial geology, and extensive evidence of seabed-slope instability in the inner zone.

Résumé

La cartographie intégrée des fonds océaniques s’avère une étape préliminaire essentielle à la gestion efficace des zones extracôtières. En raison de l’expansion rapide le long de ses berges de la ville d’Iqaluit et de la présence de ressources minérales dans la péninsule de Hall avoisinante, la baie Frobisher peut s’attendre à voir la mise en place de nouvelles infrastructures au cours des prochaines années. La saison de terrain de 2014 a marqué la première année d’un projet collaboratif de cartographie de deux ans du fond marin de la région. Le but du projet est d’améliorer le niveau de connaissance au sujet de la géologie de la baie Frobisher et, en dernier ressort, d’appuyer la prise de décisions en matière d’utilisation des fonds marins de la baie. À l’aide aussi bien de données historiques que de données à haute résolution nouvellement acquises de la morphologie et de la géologie du fond marin, il sera possible de dresser une série de cartes bathymétriques et géologiques du fond de la baie Frobisher dans le cadre de ce projet. Les résultats préliminaires mettent en évidence trois zones (extérieure, centrale et intérieure) présentant une morphologie du fond marin et une géologie de surface à caractère distinctif, ainsi que de nombreuses indices attestant de l’instabilité des pentes sous-marines dans la zone intérieure.

Introduction

It is widely recognized that effective management of offshore regions requires the integration of multiple spatial datasets from the marine environment (e.g., Pickrill and Todd, 2003; Todd and Shaw, 2009; Brown et al., 2012).

Probably the most fundamental of these datasets is high-resolution bathymetric information, which is analogous to high-resolution topographic information on land. Collection of high-resolution bathymetry using multibeam echosounder systems (MBES), with coincident acquisition of acoustic-backscatter intensity data, provides detailed infor-
mation on the morphology and texture of the seabed. Combining these datasets with other coregistered data, such as sub-bottom profiles, potential fields (gravimeter/magnetometer), water-column imagery and ground-truth information from seabed samples and photography, provides fundamental marine-geoscience information for answering a wide range of management questions related to infrastructure development, navigation, fisheries, and mineral and energy resources (Pickrill and Todd, 2003).

Frobisher Bay is a large inlet with Nunavut’s capital city, Iqaluit, located near its innermost end (Figure 1). This makes the bay an important seaway for the transportation of commodities to and from the area. Frobisher Bay is a focus area for a number of infrastructure developments to support the growing population of Iqaluit, along with natural-resource development in the region. These initiatives include a possible new mine at the Chidliak diamond property, potential hydroelectric development at Jaynes Inlet and Armshow South, the proposed installation of a fibre-optic cable on the seabed and the construction of a new deep-water port. New marine-geoscience information is required to assess the feasibility of these projects and to determine potential constraints, such as nearshore ice, tidal currents, iceberg scour, submarine landslides, active faults, natural petroleum seeps, wave exposure, coastal instability and related hazards. The purpose of this paper is to provide details about a new seabed-mapping project in Frobisher Bay, planned for 2014 and 2015.

Project description and objectives

The Canada-Nunavut Geoscience Office, Natural Resources Canada, the Nunavut Department of Environment and partners from Canadian universities are collaborating to map the seabed of Frobisher Bay. The project will use previously collected bathymetric and geological data, supplemented by newly acquired multibeam, sub-bottom and core data, to characterize the seabed in the bay. The main objective of this work is to provide stakeholders and decision-makers with the critical marine-geoscience knowledge needed to manage development in the area. Specifically, the project will result in

- seabed mapping of potential approaches and areas suitable for port and submarine cable (fibre-optic and hydroelectric) development within Frobisher Bay;
- evaluation of potential marine geological hazards, including seabed sediment dynamics and slope stability, which may impact Arctic port development;
- assessment of the distribution of submarine landslides in Frobisher Bay and the regional risk of such natural hazards as earthquakes and tsunamis;
- confirmation and/or identification of natural petroleum seeps at the mouth of Frobisher Bay; and
- correlation of bedrock exposures at the seabed to the terrestrial bedrock geology between Hall Peninsula (Macchado et al., 2013b; Steenkamp and St-Onge, 2014) and Meta Incognita Peninsula (St-Onge et al., 2015), in order to further define the tectonic assemblage of southern Baffin Island and models for its metallogenic potential.

Methods

This study relies mainly on multibeam bathymetry, sub-bottom profiler and sample data collected by CCGS Amundsen and RV Nuliajuk. The Amundsen is equipped with a Kongsberg Simrad EM302 multibeam system consisting of 400 beams with a nominal frequency of 30 kHz. The sub-bottom profiler system on the Amundsen is a Knudsen 320BR 16-element echo sounder with a nominal frequency of 3.5 kHz. On the Nuliajuk, the multibeam system is a Kongsberg Simrad EM2040C consisting of 400 beams with a nominal frequency of 200 kHz. The sub-bottom profiler on the Nuliajuk is a Knudsen 3200 two-element echo sounder operating at 3.5 kHz.

Some multibeam and coincident sub-bottom profiler data already exist for Frobisher Bay. These were collected with the support of ArcticNet (http://www.arctinet.uqal.ca/) as part of the underway acquisition program on the Amundsen (Bartlett et al., 2006) and in the course of reconnaissance and opportunity-based data acquisition on the Nuliajuk (Hughes Clarke et al., 2015; Figure 1). In addition, the Geological Survey of Canada collected high- and ultra high resolution seismic-reflection profiles and seafloor samples in outer Frobisher Bay during six marine geological-survey expeditions to the area between 1968 and 1990 (Figure 1b). The seismic-reflection systems were typically a single small-volume air gun (0.16 L) and the Huntec Deep-Towed Seismic System (DTS) using a boomer plate source. The samples consist of piston cores and grabs. The geophysical and geological data collected during these early campaigns are valuable for understanding the subsurface stratigraphy in Frobisher Bay, despite the relatively sparse coverage.

Several map products will be produced as part of this project. The maps will be developed using methods applied to numerous other marine-mapping projects on Canada’s east and west coasts (e.g., Shaw and Todd, 2006; Pinet et al., 2011). The first map product generally consists of sun-illuminated seafloor topography accompanied by a description of the main geomorphological features of the seabed. The second map product is the geology sheet and is analogous to a surficial-geology map on land. This second sheet is a synthesis of all available geomorphological and geological data. In general, a genetic approach is used in mapping the sedimentary units, rather than the formational approach traditionally used in bedrock mapping (Shaw and Todd, 2006). Beyond these two sheets, additional geospatial in-
Figure 1: a) Frobisher Bay and vicinity, showing the coverage of multibeam bathymetry data prior to the start of the 2014 project; labelled squares indicate the locations of Figures 2a–c. b) Survey lines of high- and ultra high resolution seismic-reflection profiles collected by the Geological Survey of Canada between 1968 and 1990. Figure base map is from Google Earth™ (Google, 2014).
formation to be generated includes the seafloor-sediment texture (inferred from backscatter and sediment grain-size data), the distribution of such geological hazards as submarine landslides, locations of sediment transport and structural elements revealed in bedrock outcrops.

**Preliminary observations**

The existing multibeam data from Frobisher Bay reveal a range of geomorphologies preserved on the seabed that represents evidence of the region’s underlying bedrock, glacial and postglacial history and seabed processes.

The seabed of Frobisher Bay can be broadly divided into three morphological zones. Zone 1 is relatively smooth and extends from outer Frobisher Bay north of Edgell Island to off York Sound on Meta Incognita Peninsula (Figures 1, 2a). High-resolution seismic-reflection data collected in 1990 show that the seabed is underlain by an interval of well-stratified glaciomarine and postglacial sediments of varying thickness, overlying stacked till deposits that are typically in erosional contact with underlying bedrock (Figure 3). The transition between zones 1 and 2 is marked by a series of smooth bathymetric steps. Based on high-resolution seismic-reflection data (Figure 4), these steps may be the expression of underlying eroded bedrock draped by approximately 10 m of glaciomarine and postglacial sediment.

Zone 2 extends from York Sound to the mid-bay islands; here the seabed is characterized by an extensive zone of exposed bedrock with sediment infilling small basins and troughs (Figures 2b, 4). The bedrock shows similar lineaments to the bedrock on western Hall Peninsula and is possibly the submerged continuation of the granitic and meta-sedimentary rocks of the Western Lithological Domain of Machado et al. (2013a).

Zone 3 extends from the mid-bay islands to the head of Frobisher Bay (Figure 2). In this zone, the seabed consists of a mix of small areas of exposed bedrock, glacial moraines and drumlinoid features. Most of the seabed in zone 3 appears to be draped by several metres of glaciomarine and postglacial sediments that, in some locations, show evidence of mass wasting (Figure 5). The draped sediments give the seabed morphology in zone 3 a somewhat subdued appearance.

*Figure 2: Multibeam bathymetry data from Frobisher Bay showing the three broad morphological zones: a) the seabed of the outer part of the bay is smooth with some seafloor expression of underlying buried bedrock (zone 1); b) the middle part of the bay, seaward of the mid-bay islands, shows the seabed expression of bedrock and glacial erosion and deposition (zone 2); c) inside the mid-bay islands, there is evidence of glacial and postglacial processes (zone 3). Figure location is shown on Figure 1. Figure base map is from Google Earth™ (Google, 2014).*
Discussion

Early work on the marine geology of Frobisher Bay focused on the glacial and deglacial history of the region, based largely on sediment cores (e.g., Osterman and Andrews, 1983). Since these early research activities, there has been relatively little published on the marine geology of the area. The new mapping project will provide important insights into the seabed and sub-seabed geology of the region. This project is one of the first seabed-mapping projects for the Baffin region that is undertaking systematic and continuous data collection over a large area, rather than opportunity-based or targeted surveying of specific features. As a result, the ‘whole picture’ of the seabed geology of Frobisher Bay will be revealed.

It is apparent from the existing data in Frobisher Bay that the seabed geology is highly variable, ranging from fine-grained, unconsolidated marine sediments to intrusive and metamorphosed bedrock. The genetic mapping approach that will be applied in this project will provide information on the lithology of the mapped units. The glacial landforms preserved on the floor of Frobisher Bay, especially in the inner part of the bay, will help provide new information about the glacial history of this part of Baffin Island and can be compared to terrestrial and earlier marine-based published studies. Imaging of sedimentary bedforms will provide important insights into the circulation and tidal patterns. Interpretation of the existing data suggests evidence for seabed instability and geological hazards in the bay as well. This project will address these issues, first by mapping the distribution of the features and then by attempting to determine the cause and recurrence of hazard events, thus improving knowledge of tsunami risk and threats to coastal and seabed infrastructure.

Economic considerations

Besides helping to augment understanding of the geology of Frobisher Bay, the mapping results from this project will be a useful tool for a number of end-users. Similar studies from other Canadian marine areas have demonstrated the high utility of integrated seabed mapping (Todd and Shaw, 2009). This approach has been effectively used to plan in-stream tidal-power projects, manage offshore fisheries, reduce the impact of offshore development, establish marine protected areas and resolve seabed-use conflicts. This project will ensure that future management and potential infrastructure planning for Frobisher Bay are guided by the best available scientific information.

Conclusions

Frobisher Bay is an important waterway that will likely see infrastructure development in the near future to support...
rapid population growth in Iqaluit and natural-resource developments in the region. An integrated seabed-mapping project is underway in the bay that will provide key geoscience knowledge needed to manage this large offshore area. The regionally continuous mapping of the bay will provide valuable insights into the seabed geology, processes and hazards that would not be revealed in site-specific surveys.

Acknowledgments

The authors thank the captains, crews and scientific staff on board the RV *Nuliajuk*, CCGS *Amundsen*, and CCGS *Hudson* during surveys of the region. J. Kennedy is thanked for co-ordinating data collection on the *Nuliajuk*. ArcticNet, the University of New Brunswick and the Geological Survey of Canada provided data collected prior to the start of this project. Financial support for this study was provided by the Canadian Northern Economic Development Agency’s (CanNor) Strategic Investments in Northern Economic Development (SINED) program and the Program of Energy Research and Development (PERD).

Natural Resources Canada, Earth Sciences Sector contribution 20140337

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