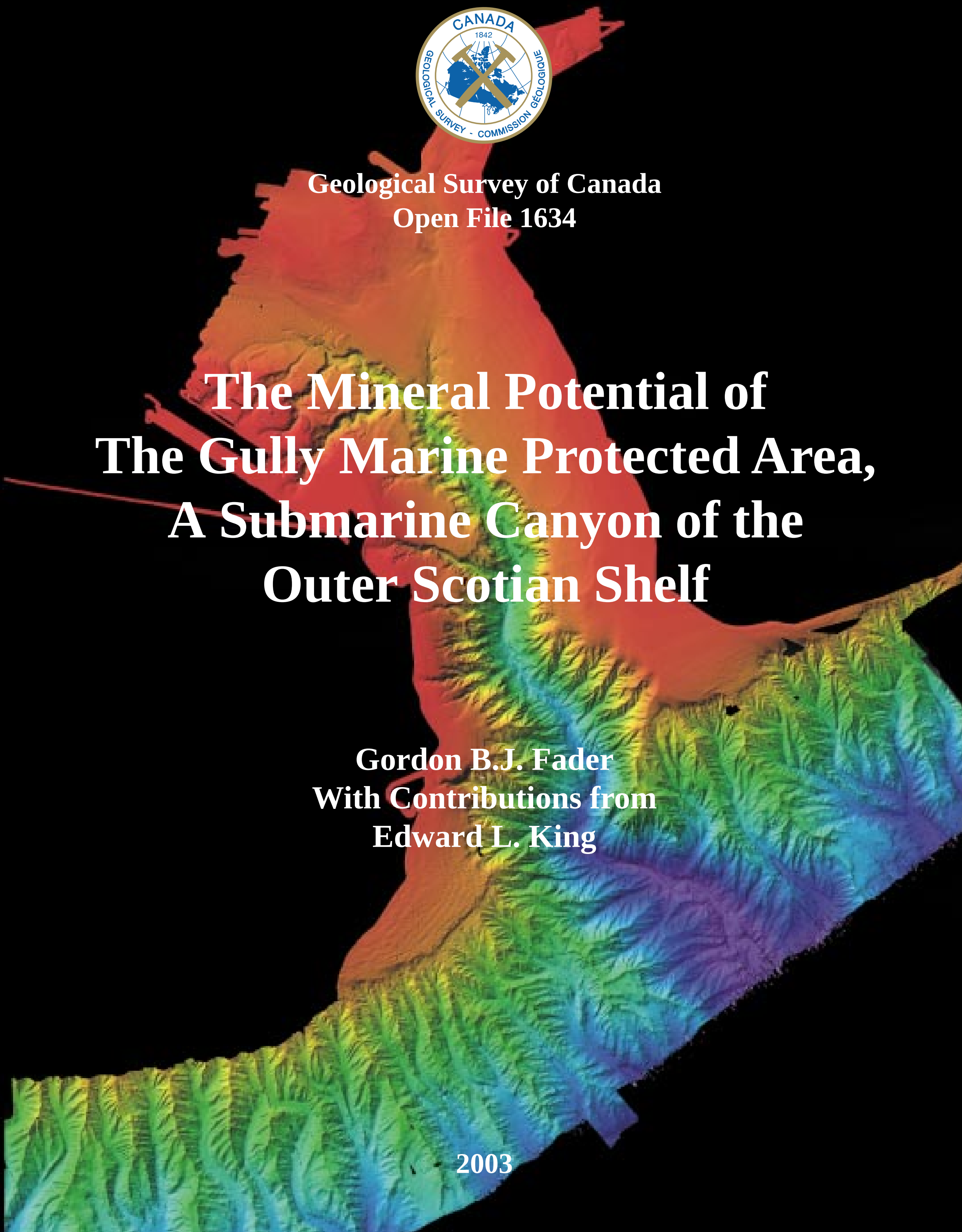

Geological Survey of Canada
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The Mineral Potential of The Gully Marine Protected Area, A Submarine Canyon of the Outer Scotian Shelf

Gordon B.J. Fader
With Contributions from
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2003

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The Mineral Potential of The Gully Marine Protected Area, A Submarine Canyon of the Outer Scotian Shelf

by

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Table of Contents

Executive Summary

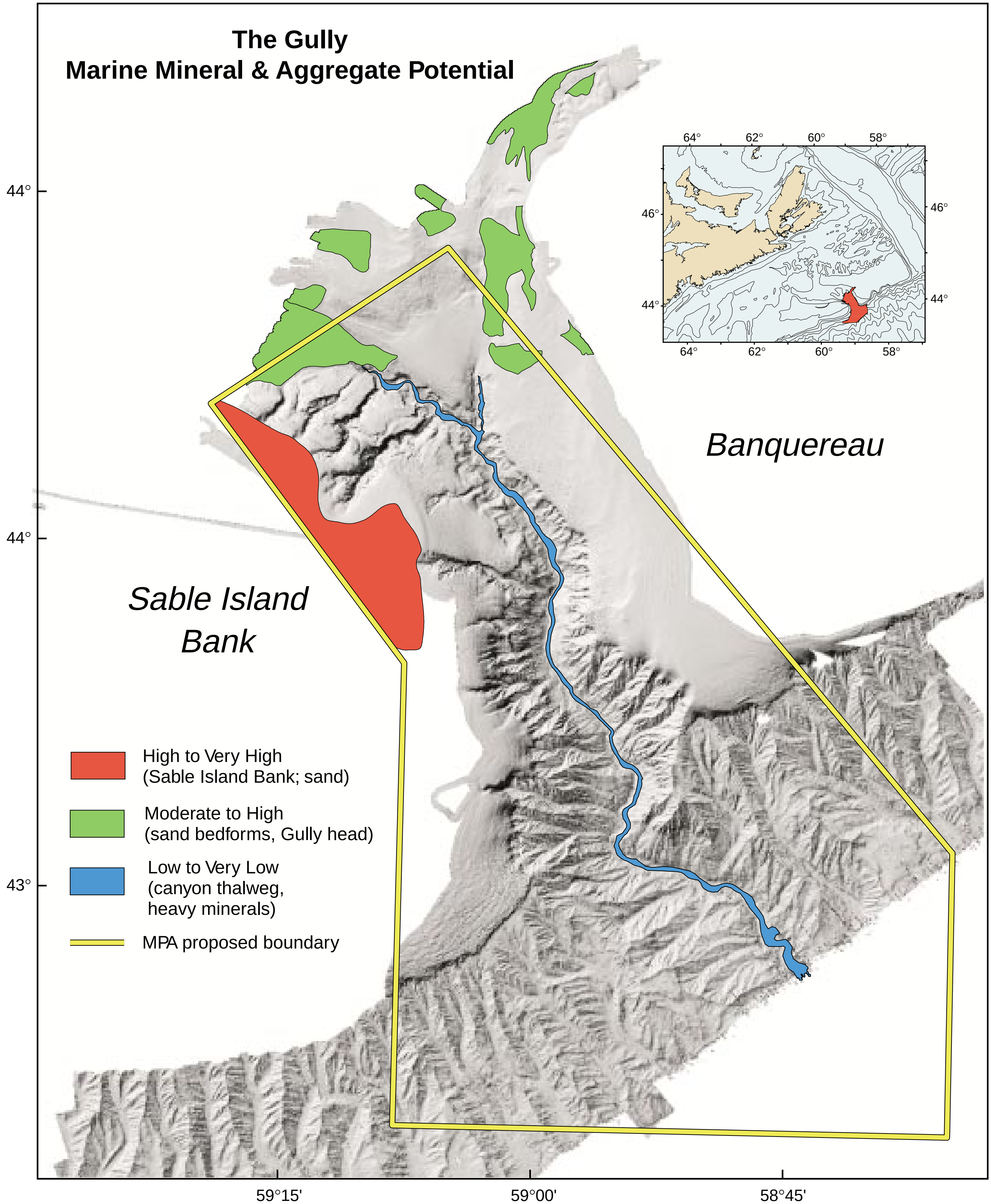
The Gully, the largest submarine canyon of the southeastern Canadian continental margin, is evaluated for its non-fuel mineral potential as part of an essential step in a formal declaration as a marine protected area (MPA) under Canada's Oceans Act. This mineral evaluation is largely based on an assessment of existing geoscience information and a geological understanding of materials and processes that occur and have occurred within The Gully region as a proxy for mineral occurrences. A geological interpretation of multibeam bathymetric data has given an in-depth understanding of The Gully.

Proposed boundaries for The Gully MPA, including an internal 3-area zonation, cut across geological boundaries and have not been based on geological criteria or a process understanding for selection. The proposed Gully MPA boundary is offset bathymetrically toward the southwest on Sable Island Bank, with a large bank area included in depths shallower than 100 m. Similar shallow areas on Banquereau, the western boundary of The Gully, are not included, resulting in a morphologically asymmetric MPA.

The greatest mineral potential within The Gully region is for sand and gravel deposits (aggregates). Some are very thick reaching over 30 m, with volumes of over 4 cubic km occurring on eastern Sable Island Bank within the proposed MPA area. These sands are well sorted and of suitable quality for a multitude of industrial uses. Other deposits of sand occur in deeper water in The Gully Trough area and at the head of The Gully in large sand wave fields. Sand is thin on Banquereau in the proposed MPA but thickens to the east outside the proposed boundary. Regionally available similar deposits of sand are widespread across the Scotian Shelf thus rendering The Gully materials as common and not unique.

The possibility of future erosion of Sable Island in a general environment of continued sea level rise enhances the value of the deposits of sand in the proposed MPA area as a readily available local source of material for island reclamation. The sands appear to be in transport to the east, to be eventually transported down The Gully, and if required, these materials could provide a viable cost effective candidate from within the bounds of the proposed Gully Marine Protected Area.

There is a moderate potential for phosphorite to be extensive within The Gully and crop out on steep exposed bedrock surfaces; however, its extraction would be technologically difficult. Carbonate resources within The Gully are considered to be low and calcium carbonate in the form of shells is widespread on adjacent Sable Island Bank. The potential for silica sand in The Gully is moderate in the inner areas adjacent to Banquereau. An understanding of the fluvial and glacial history of The Gully suggests that high-energy bottom water conditions have occurred periodically. These environments would have had the potential to concentrate heavy minerals such as glauconite, zircon, and garnet in the deep Gully thalweg and in many of the tributary and feeder canyons. Despite a moderate potential for existence, there are, however, no known occurrences. The heavy minerals are considered unlikely to be exploitable using known technology and in the present economic context.



Distribution of the mineral and aggregate potential of The Gully.

Introduction

This paper presents a preliminary assessment of the marine mineral potential of The Gully, a large submarine canyon on the outer part of the Scotian Shelf connecting the middle shelf to the continental slope between Sable Island Bank and Banquereau (Figure 1). Fisheries and Oceans Canada (DFO) is engaged in an assessment of The Gully as a Marine Protected Area (MPA) as a result of the Oceans Act. The Gully is sometimes referred to as The Sable Gully in an attempt to assist in an understanding of its location adjacent to Sable Island Bank and well-known Sable Island. It has been the focus of national and regional conservation efforts since the early 1990s. The Gully is perceived as a significant geomorphic shelf-edge submarine canyon along the eastern seaboard of Canada that contains special and unique biological communities. In 1997, a Gully Conservation Strategy was initiated by DFO as a result of growing concerns regarding its future conservation. In 1998, following a comprehensive science review, The Gully was designated an Area of Interest (AOI) within the MPA process. Following from this legal designation, the Government of Canada is obligated to review the non-living resource potential. This mineral assessment report is part of such a process. A parallel report on the hydrocarbon potential of The Gully will also be produced.

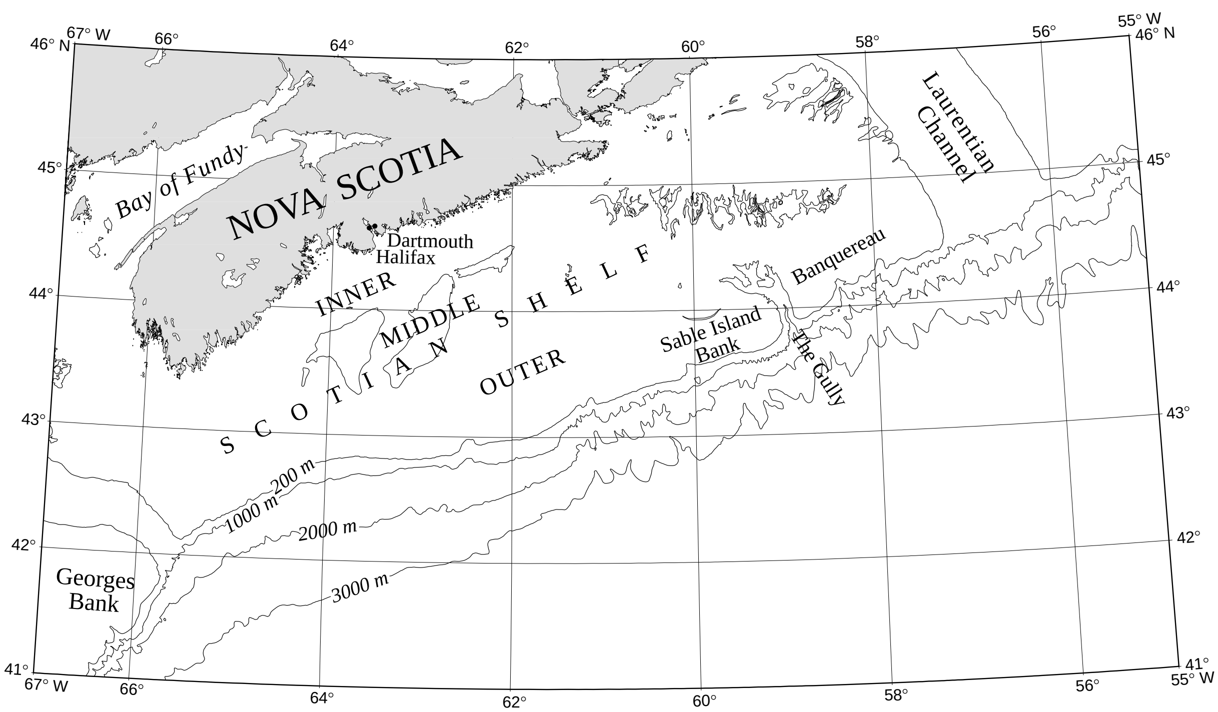


Figure 1: *Index for the Scotian Shelf showing the location of The Gully submarine canyon between Sable Island Bank and Banquereau on the outer Scotian Shelf. The Scotian Shelf geomorphic divisions of inner, middle and outer are indicated.*

Terms of Reference

The terms of reference for this report were prepared in a draft report in July of 2002 and include:

- an inventory of existing public and private data
- a compilation analysis and interpretation of the available data
- a description of geological conditions
- a description of known and predicted accumulations of commercial resources
- a rating of the mineral potential
- assessment of the economic and operational feasibility of economic development
- comparison of the mineral potential of The Gully to other areas of the Scotian Shelf.

The role of the Geological Survey of Canada with regard to a mineral assessment is to provide geoscience framework data to be used by NRCan policy staff and / or other agencies to: 1) assist in the design of the MPA including elements such as zoning schemes, boundaries and conflict resolution; 2) determine the economic and strategic value of the mineral accumulations; and 3) support the preparation of a regulatory cost and benefit analysis. For economic and operational comparisons regarding minerals and aggregates, the experience of other jurisdictions, particularly Europe is assessed given that Canada does not have a marine mineral mining policy or an active industry. However, dredging for maintenance of navigational channels and marine construction is a common activity and shares similar technology and methodology.

Scope of Present Study

The present study will consider the marine mineral potential of an area defined in a draft discussion document of Fisheries and Oceans Canada (DFO) dated Sept. 27, 2002 that has proposed preliminary boundaries for the Gully MPA and divided the area into management regions. Three management regions have been proposed and are termed Zones 1 – 3 (Figure 2). The overall shape of this Gully Management Area is only slightly different from earlier proposed areas but squares off the corners for simplicity in plotting and general user ease. Zone 1 is a deep-water core canyon area in depths greater than 600 m. Zone 2 is an area between 600 and 300 m in the canyon proper and includes all areas at the head and in deeper water on the continental slope. Zone 3 is the area above 300 m on Sable Island Bank and Banquereau.

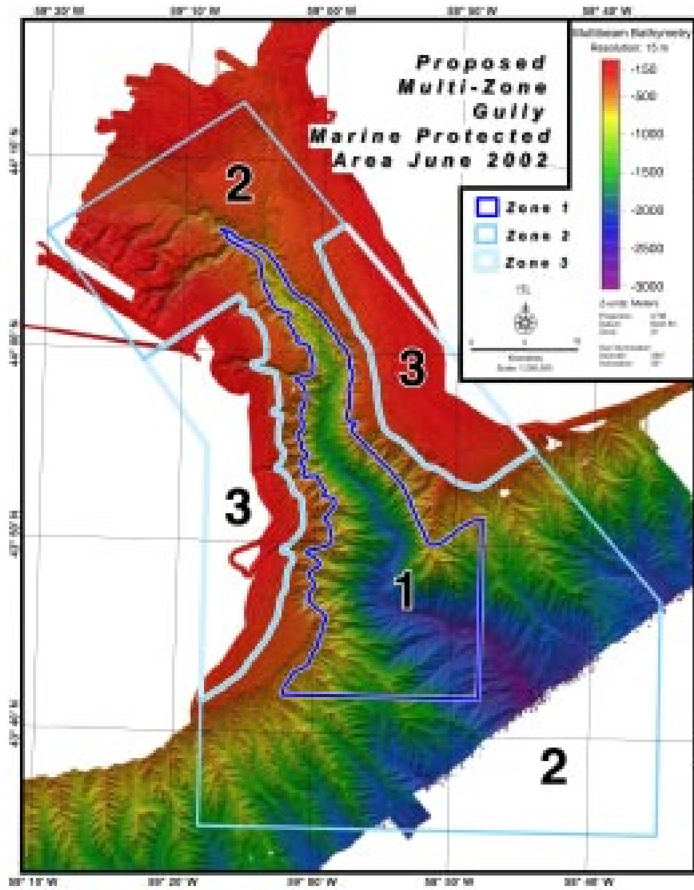


Figure 2: *Location of the proposed Gully Marine Protected Area boundary by Fisheries and Oceans Canada and internal zones superimposed on coloured-coded multibeam bathymetry. See text for discussion.*

The division of The Gully region into these zones has implications for a mineral assessment that need to be discussed. Zone 1, the deep-water area of The Gully, consists of ridge and valley morphology with steep slopes, rugged topography, and conduits of sediment transport toward the central deep-water thalweg of The Gully. Few samples have been collected in this area during surveys by Fisheries and Oceans Canada and observations are limited to video and photography. Additionally, bedrock outcrop, muddy sediments, downslope movements of material, slumps and other canyon hazards would make extraction of minerals a difficult and costly operation. The multibeam bathymetry from this deep region has less resolution than the shallow areas. This is a characteristic of hull-mounted multibeam bathymetric systems and not always understood when evaluating multibeam imagery across highly varied water depths. As a result, details of deep-water Gully processes are not as clearly portrayed and understood as those in shallower water.

From a geological perspective, Zone 2 contains three geomorphic zones: a 300 – 600 m upper Gully valley and ridge area; a relatively shallow Gully head region and a deep-water broad Gully mouth area that includes the adjacent continental slope of the Scotian Shelf to the northeast and southwest - areas outside the actual area of drainage for The Gully (Fader and Strang, 2002). The third zone is simply the 300 m and shallower areas on Sable Island Bank and Banquereau. Such a divisional system for The Gully cuts across geological boundaries and is not based on geological criteria or a process understanding of The Gully.

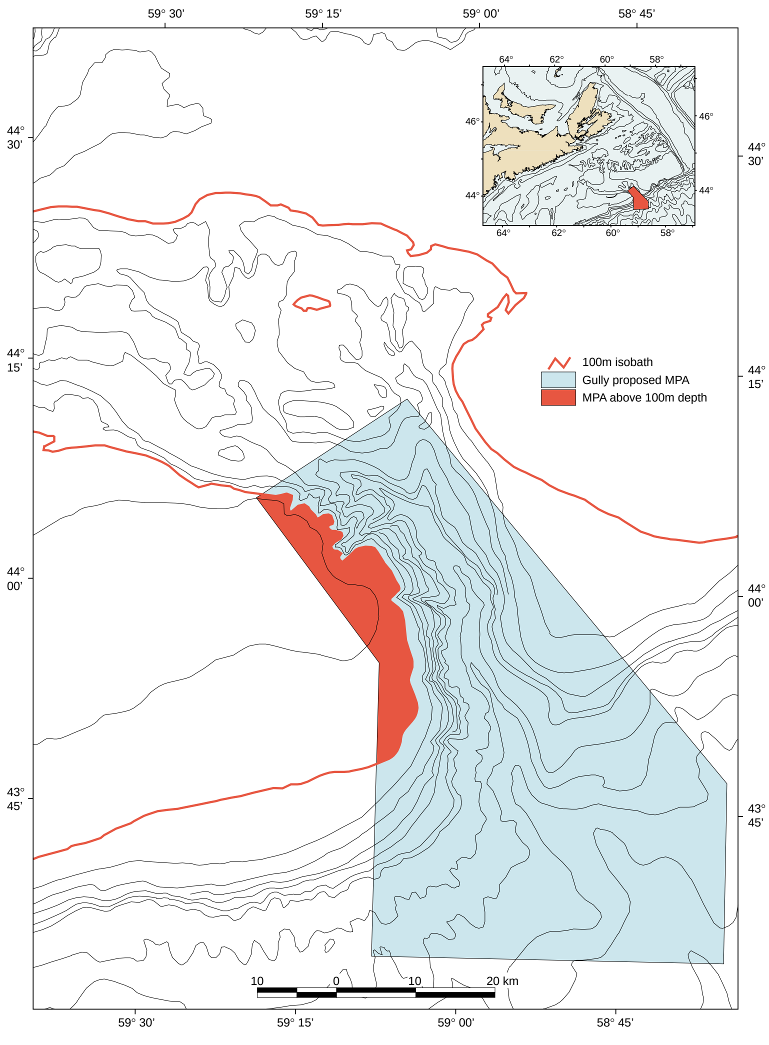


Figure 3: *A contoured bathymetric map of The Gully region (Canadian Hydrographic Service Chart) showing the 100 m depth contour highlighted, the proposed MPA boundary and the area of Sable Island Bank above 100 m water depth. This image shows that The Gully MPA boundary is offset bathymetrically toward the southwest on Sable Island Bank. For a better geological/morphological balance, the northeastern boundary could be moved to the northeast or the entire MPA area shifted to the northeast to include similar shallow areas on Banquereau.*

The proposed Gully MPA management area is asymmetrical in shape relative to the geographic position of The Gully and the adjacent banks (Figure 3). From a geological perspective, this is an imbalance in that a large area of Sable Island Bank above 100 m water depth is included, whereas similar depth areas of Banquereau are excluded. A better balance would be a positional shift to the northeast of the entire MPA region or a shift of the northeastern boundary alone.

The mineral assessment will compare and contrast minerals from the adjacent areas of the Scotian Shelf in particular with Sable Island Bank, Banquereau and The Gully extension to the north, (termed the Gully Trough) but will also include assessment of the mineral potential of the entire Scotian Shelf.

It should be noted that it appears from the published literature that no mineral assessment of a submarine canyon has ever been undertaken. This arises from: technological difficulties in assessing the mineral potential of deep and rugged terrain; a lack of understanding of the mineral potential of such areas; a perception that mineral extraction is a difficult and expensive undertaking in canyons and would likely never be attempted; and some of the technology to both assess mineral potential and to extract minerals in canyon environments has only recently been developed.

This is a preliminary report based only on rapid analysis of existing data without reprocessing or reinterpretation, and no new field data were acquired for this assessment. It is therefore equivalent to Phase I of the MERA process for terrestrial national parks (see MERA Terms of Reference @ http://www.nrcan.gc.ca/mms/poli/mera_e.htm).

Regional Physiography

The Scotian Shelf can be divided into three geomorphic zones (Figure 1): an inner shelf of seaward dipping hard bedrock outcrop bordering the mainland of Nova Scotia; a middle shelf of broad, deep large and small linear basins with intervening isolated small banks; and an outer shelf archipelago of broad shallow banks with few deeper saddles and large outer shelf crossing deep channels (King and Fader, 1986). The middle and outer shelf is a fluvially and glacially modified coastal plain. The Gully occurs mostly in the outer shelf geomorphic zone and is a true submarine canyon. It connects to the middle shelf and the continental slope of the Scotian Shelf as it separates the outer shelf banks of Sable Island Bank and Banquereau. The northernmost major inner area of The Gully swings to the west as The Gully Trough.

The middle and outer areas of the Scotian Shelf are part of the Submerged Atlantic Coastal Plain Physiographic Province (Figure 4). The inner shelf is a continuation of the Atlantic Uplands physiographic province of the maritime region, which includes a large part of the mainland of Nova Scotia and is a gently seaward dipping peneplain.

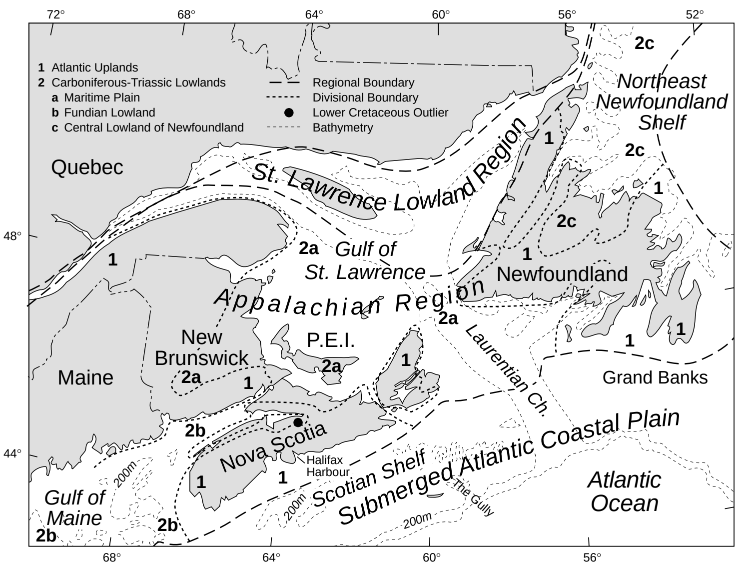


Figure 4: *Major physiographic provinces of Atlantic Canada. The Gully occurs in the Submerged Atlantic Coastal Plain province, from Fader and Miller, in prep.*

Study Area

Data Base

The Gully has been known for some time beginning with the first explorers and fishers who visited the new world from Europe and who were familiar with the outer shelf banks and adjacent areas. The first serious geological work began in The Gully in the 1960s (Marlowe, 1965) when echosounder profiles, cores and samples were collected. At that time, the shape of The Gully was only known from interpolation of sparse echosounder data, which only crudely portrayed the morphology. Poor navigation of both vessels and bottom sampling equipment renders observations from those data sets of limited present value. We are largely unable to correlate these observations with details in the multibeam bathymetry.

Fisheries and Oceans Canada conducted the first comprehensive scientific review of The Gully in 1998. In the 1998 review, Fader et al., (1998) summarized the existing knowledge on the surficial, bedrock geology and morphology of The Gully canyon region. They concluded that existing geoscience information was limited and patchy and that the collection of multibeam bathymetry would provide a significant advance in morphological characterization leading to a better understanding of seabed processes. Only limited multibeam data existed at this time confined to an area of the inner western part of The Gully extending to Sable Island Bank. In 2000, multibeam bathymetry was collected in a cooperative project of the Canadian Government and industry in deep and additional shallow water areas to provide a comprehensive assessment of Gully attributes (Figure 5, Fader and Strang, 2002).

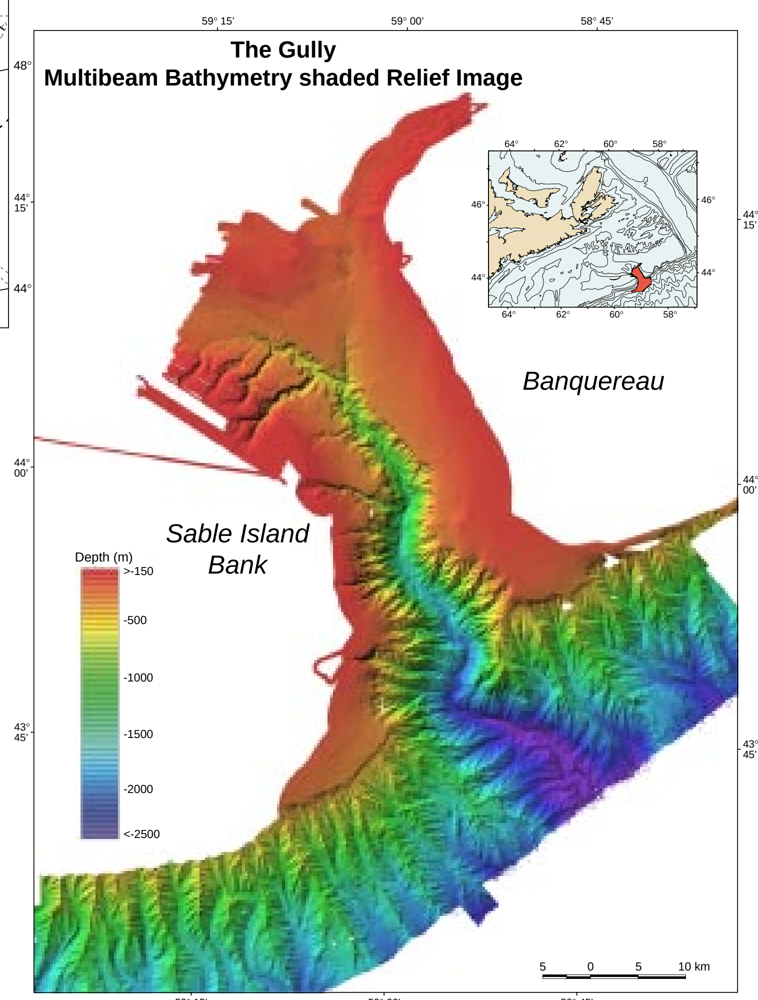


Figure 5: *Colour-coded shaded-relief multibeam bathymetric image of The Gully, outer Scotian Shelf from Fader and Strang, 2002.*

Multibeam bathymetry is an equivalent to detailed topographic maps of the land and covers 100% of the seabed. The images produced resemble aerial photographs of the land surface whereby the depth data is present in a colour-coded format and artificial shading is added for topographic enhancement. The resolution of these systems is in the order of metres to tens of metres. Multibeam bathymetric data is sparse across the Scotian Shelf with the densest area of coverage in the west and in site-specific areas of Sable Island Bank and the nearshore. Therefore, there is little contextual data of similar quality with which The Gully can be compared.

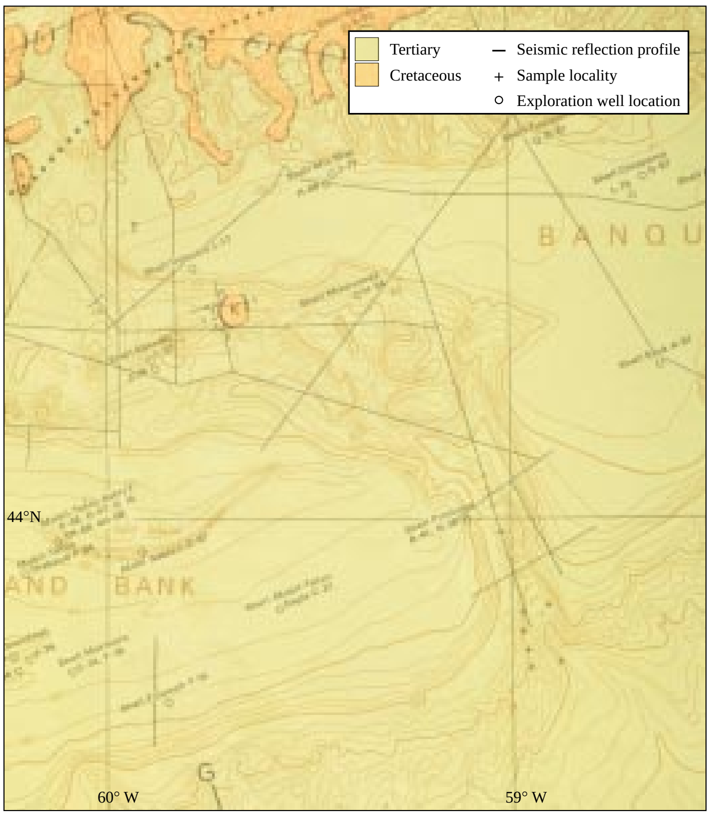


Figure 6: *Section of a bedrock map of the outer Scotian Shelf in the vicinity of The Gully from King and MacLean, 1976. Note the location of sparse seismic reflection data coverage in The Gully and bedrock sample locations from dredge hauls.*

Bedrock Geology

The regional bedrock geology of the area was first assessed and mapped by King and MacLean (1976) (Figure 6). Tertiary mudstones and sandstones underlie the Gully and the outer edge of the continental shelf. Within the inner part of The Gully, local salt domes rise through the sedimentary column, perhaps bringing Cretaceous sediments to the seabed in association with the diapirism. Regional airgun seismic reflection profiles were collected in The Gully and depict a steep walled canyon cut into bedrock in the deeper sections and thick surficial materials over several hundred metres in thickness in the shallower parts. Other V-shaped channels occur buried near The Gully and may be part of an earlier development, suggesting that its position has shifted with time. At various places near the edge of the Scotian shelf, including The Gully region, buried channels cut into older Tertiary bedrock are filled with younger Tertiary sediments. A major unconformity of Late Eocene age is interpreted for the Scotian Shelf (King et al., 1974). This unconformity indicates the presence of former fluvial channels with relief of at least 300 m and probably represents the beginning of the development of the present Gully. Ancestral shelf edge canyons may thus be of considerable antiquity, but The Gully remains unique as the only canyon along the Canadian seaboard that is so deeply incised today. The

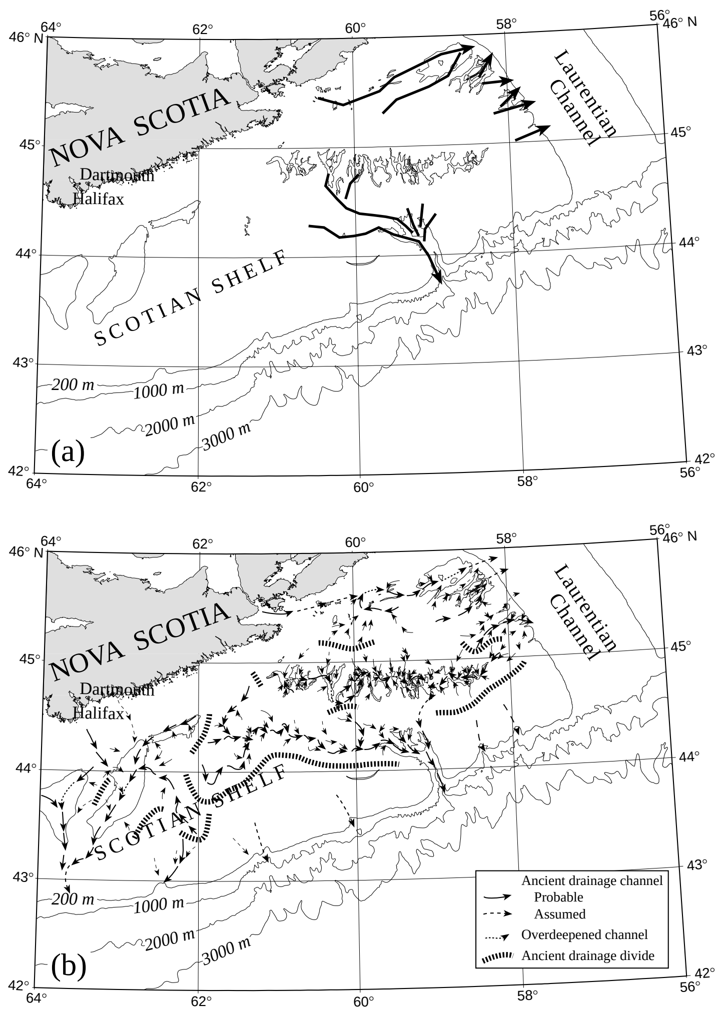


Figure 7: *Interpretations of glacial and fluvial drainage patterns on the eastern Scotian Shelf, a) from Stanley and Cok, 1968, and b) from King et al., 1974. Both interpretations were done independently and show similar patterns. The Gully is a conduit for both ice and water from the central Scotian Shelf to the edge of the continental shelf.*

seismic reflection profiles used in the study by King and Maclean, 1976, (Figure 6) were of intermediate resolution and did not provide detailed characterization of the bedrock surface and overlying sediments.

King at al 1974 mapped the distribution of a former drainage pattern developed at the Late Tertiary – Pleistocene unconformity (Figure 7b). This drainage pattern in The Gully region is very similar to one interpreted by Stanley et al., 1972 (Figure 7a). Together these assessments provide an understanding of the pre-glacial and glacial pathways for transport of sediments to The Gully. They clearly show that materials were sourced from the eastern part of mainland Nova Scotia and the inner Scotian Shelf, as well as the dissected area of the Scotian Shelf to the north of Banquereau. Knowledge of these pathways is very important for a mineral provenance understanding.

A recent overview of The Gully region is provided in the Scotian Shelf volume of the East Coast Basin Atlas Series of the Geological Survey of Canada, which contains a series of maps on the bedrock, surficial sediments, seabed and subsurface features, geotechnical sediment properties and continental slope sediments (Ross and Lewis, 1991). The thickness of the Banquereau Formation (Tertiary) in The Gully approaches 2500 m. This indicates that most of the Gully is cut into Tertiary sandstones, siltstones and mudstones. However, the deeper parts of The Gully may expose the Wyandot Formation and older Cretaceous age rocks. The Wyandot is a marine chalk and a prominent seismic reflection horizon across the Scotian Shelf. Salt diapirs may also crop out in the deeper water areas of The Gully.

During recent surveys by DFO and NRCan, seismic reflection profiles and sidescan sonograms were collected in the inner head of The Gully (Figure 8). These data are of high-resolution and clearly show relict and modern processes of slumping, iceberg furrowing and downslope movement of material. The seismic reflection profiles and sample and video stations were chosen on the basis of interpretation of the multibeam bathymetry.

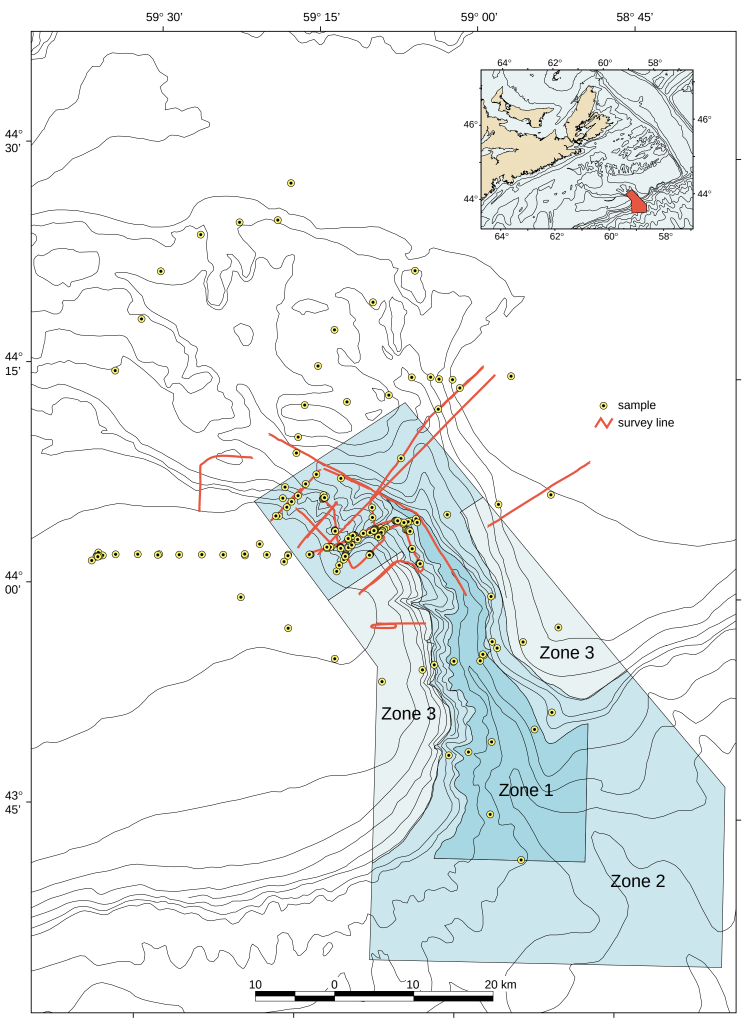


Figure 8: *The location of data collected in The Gully from 1998 to 2000. Circles represent video and photographic stations and ship's tracks are lines of high-resolution sidescan sonar coverage. Most were chosen to assist in interpretation of the multibeam bathymetry. Some samples were collected at the photographic stations. The proposed MPA zonation is also shown.*

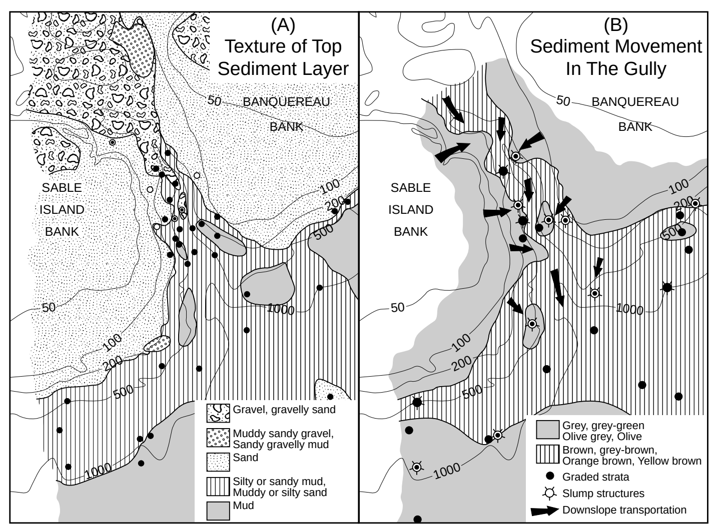


Figure 9: *Maps of the texture and colour of sediments in The Gully region and an interpretation of sand spill over pathways to The Gully from the adjacent banks. Locations of slump structures are also shown. After Stanley and Silverberg, 1969.*

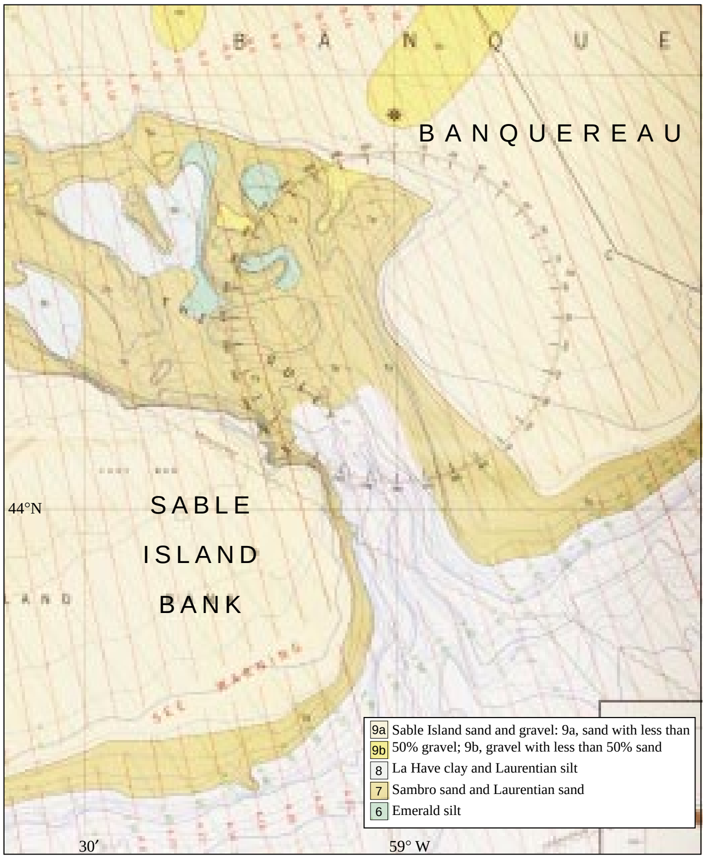


Figure 10: *Surficial geology map of the Gully region from MacLean and King, 1971. The deep-water areas were not mapped in this study and the sediments are presented in a formational framework, developed for the entire Scotian Shelf (King and Fader, 1986). Note the windows of Emerald Silt through Sambro Sand in the Gully Trough and Recent deposits of LaHave Clay to the northwest.*

Surficial Geology

The distribution of sediments at the seabed of The Gully region was first assessed by Cok (1970, and Stanley and Silverberg, 1969, Figure 9). This showed The Gully sediments to range from gravels in the shallow north to muddy sand in deep water. An assessment of the sediment mobility was also attempted in that study which interpreted sediment transport to The Gully from surrounding banks and the north. Sediment colour differentiated the shallow regions from the deeper areas of The Gully with a transition from grey green to brownish sediments. Slump structures were also noted. The surficial Quaternary geology of the inner portion of The Gully, the Gully Trough, the shallow areas of The Gully, and the surrounding banks was first mapped by Maclean and King in 1971, (Figure 10) from a study of echograms, airgun seismic reflection data, bottom photographs and seabed samples in a systematic shelf sediment mapping program. Glacial till (Scotian Shelf Drift) and glaciomarine sediments (Emerald Silt) occur in the subsurface overlying Tertiary bedrock. The thin Sambro Sand formation, a silty sand, and several patches of LaHave Clay, a Holocene mud deposit, in turn overlie these sediments. The glaciomarine Emerald Silt outcrops in several areas of the western extension of The Gully indicating that it is widespread in the subsurface beneath the thin Sambro Sand. Several terrace-like features on both Sable Island Bank and Banquereau adjacent to The Gully may relate to features formed at the position of former sea levels, glacial erosional platforms, the position of shelf edge spillover deltas, or may be features eroded at resistant geological horizons. There appears to have been little Holocene sedimentation and the present seabed distribution of sediments largely relates to a low sea level stand that occurred at the end of the last ice age approximately 18,000 years ago at a depth of 110 m. Controversy exists on the depth of the Wisconsinan low sea level position in the Sable Island region of the outer shelf. Scott, 1977, for example, estimated a depth of approximately 70 metres while Fader, 1991b, and King and Fader, 1986, proposed a deeper depth of 110 m. Samples used in the mapping of the surficial geology are sparse and were not collected in the deeper areas of The Gully, deeper that 300 m.

Cok, 1970, and Stanley et al., 1972 conducted a comprehensive collection and assessment of the sediments on the eastern Scotian Shelf including the area of The Gully as part of a Dalhousie University PhD thesis. They also assessed the heavy mineral content of these samples. These studies represent the only assessment of minerals from The Gully and major surrounding banks and are summarised in this report.

Mineral Development Agreements (MDAs) between the provinces and the federal government resulted in assessments of the aggregate and the gold placer potential of the Scotian Shelf and adjacent areas during the early 1990s (Maritime Testing 1995 and 1996; Fader et al., 1993, Stea et al., 1993 and Fader and Miller, 1994). The Gold placer assessment was conducted mainly in the nearshore of the Scotian Shelf in a zone extending from Lunenberg to Country Harbour. The aggregate assessment was more widespread and was based on the previous surficial mapping program of the Scotian Shelf (Figure 11) and new multibeam mapping programs. Large banks, trangressed areas, the inner Bay of Fundy and areas off Cape Breton Island were focal points of the study. Banquereau was found to contain large deposits of silica sand as well as other deposits of

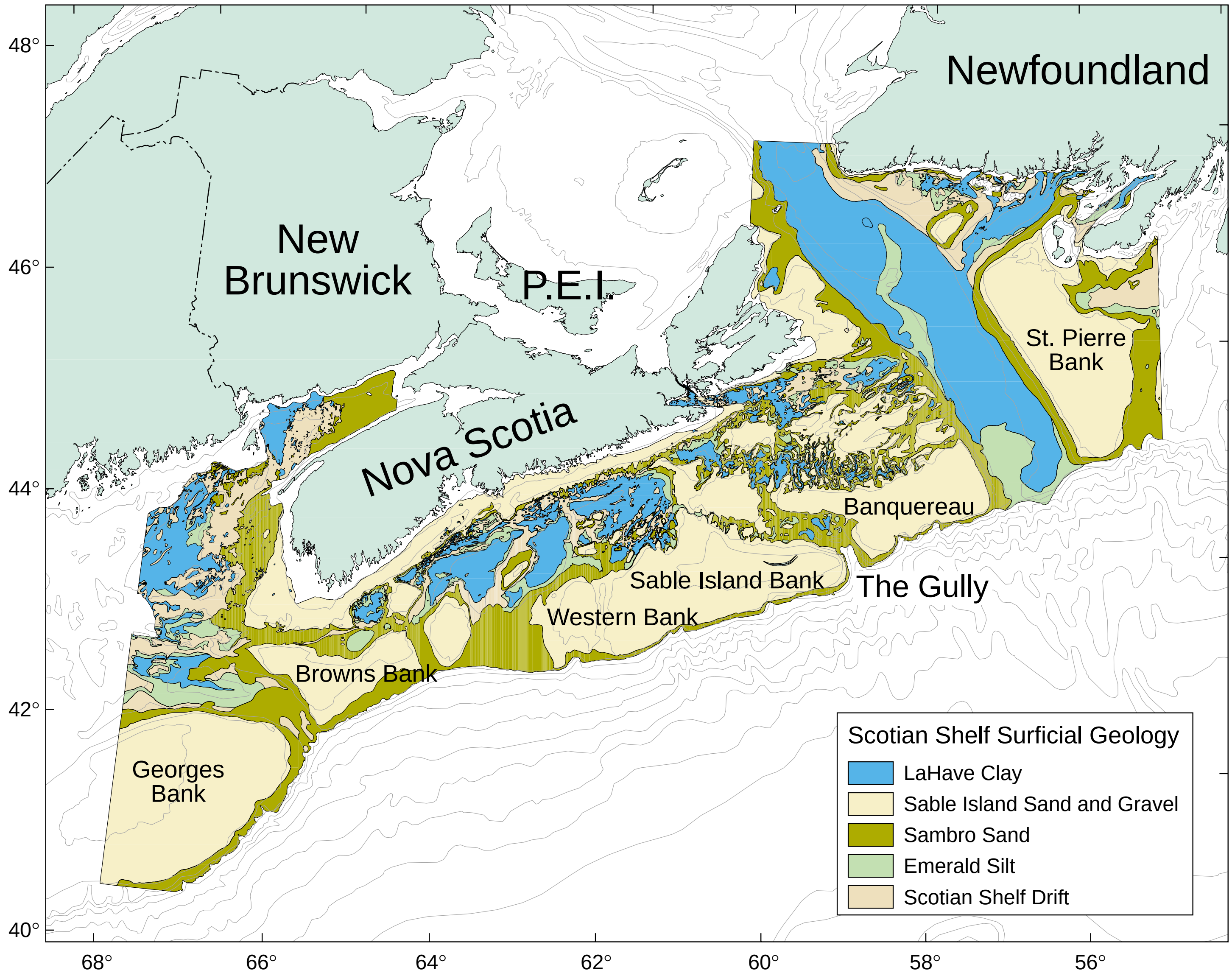


Figure 11: *A compilation of the surficial geology of the Scotian Shelf showing the location of The Gully (after Fader, 1991b). Note that The Gully cuts between Sable Island Bank and Banquereau on the outer shelf as the largest submarine canyon.*

potential aggregate. Sable Island Bank and Georges Bank were not included in those surveys because it was anticipated that both lucrative fisheries and a perceived fragility of Sable Island would not permit seabed mining operations to be conducted in those regions. Results from these MDA sponsored studies will be summarized in this paper.

As a result of the discovery and production of hydrocarbons from Sable Island Bank during the 1990s, a focused high-resolution study of sediment transport, sediment stability and Quaternary stratigraphy has been undertaken (King, 2001). A regional compilation of all seismic reflection data and seabed samples has produced an understanding of the geological history and processes active on Sable Island Bank. This information and its relationship to The Gully is incorporated in this report.

In 2000, new multibeam bathymetry was collected for the entire Gully by industry and government and when combined with earlier multibeam bathymetry from the inner Gully, produced a comprehensive bathymetric data set for Gully assessment and characterization (Figure 5). This multibeam bathymetric information was processed and interpreted by Fader and Strang, 2002. New seismic reflection, sidescan sonar data and sample and video information provided ground truth. This comprehensive data set allowed a better interpretation of the history of formation of The Gully, distribution of materials on the seabed, slopes, and an understanding of both relict and active processes. It is this modern data set that has provided considerable insight into processes active in The Gully and the framework for a mineral assessment.

Amos (1989) conducted submersible dives in parts of The Gully and observed and interpreted terraces on the seabed as forming during previous low sea level stands. Video and bottom photographs were collected in The Gully during joint surveys by DFO and NRCan conducted between 1997 and 2000 (Figure 8). Sites were chosen based on interpretation of the multibeam bathymetry to understand the various morphologies, sediment distributions, and seabed processes. Photographic and video systems termed Campod and Videograb were both used in deeper water and Towcam provided video transects in shallower water. In total 92 stations were occupied in The Gully and interpreted for sediment type, morphology and benthic habitat (Kostylev, 2002). Eight Benthos camera stations were undertaken in deeper water. This information is also used in this report to assess seabed materials and processes in The Gully.

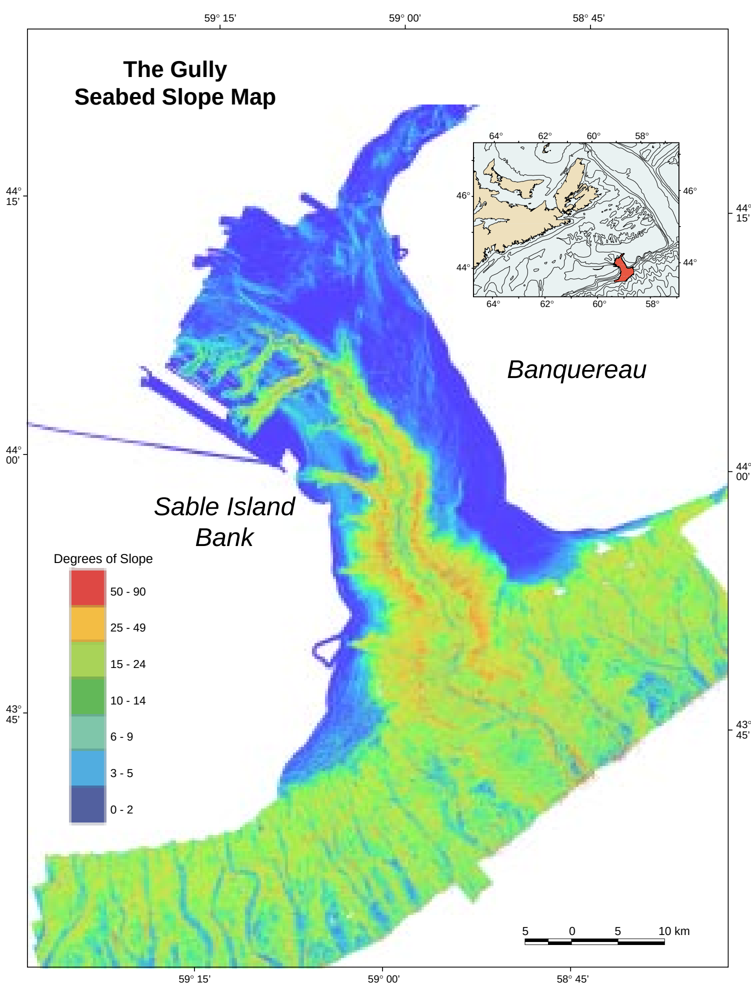


Figure 12: *A seabed slope map of The Gully. Note the steep slopes greater than 50 degrees within the Gully canyon and a lack of such steep slopes on the adjacent continental slope southeast of Sable Island Bank and Banquereau. This map was produced from multibeam bathymetry (from Fader and Strang, 2002).*

There are two major limitations to an assessment of the mineral potential of The Gully. Firstly, modern georeferenced samples are rare and those that exist were not chosen to assess the mineralogy. They were chosen to ground truth the multibeam imagery for a geological interpretation. Secondly, no samples from the modern suite have been processed from The Gully for their mineral content. We therefore must rely on information on the mineralogy from adjacent banks of the outer Scotian Shelf, older processed samples from The Gully and postulated models of sediment transport to and down The Gully as a conduit from the shelf to the continental slope and deep ocean. The major effort on recent study of The Gully was to understand benthic communities and seabed habitat that lead to the use of photographic systems and not seabed samples as the prime source of information. Additionally, there has never been a comprehensive geological assessment of The Gully to collect a data set of remote sensing sidescan sonar, high-resolution seismic reflection profiles and georeferenced bottom samples (Fader and Strang, 2000). In fact, most observations and samples of the seabed occur in water depths less than 500 m because of depth limitations of Bedford Institute of Oceanography (BIO) surveying and sampling equipment. This leaves the 500 to 3000 water depth areas of the central core of The Gully largely unsurveyed other than the multibeam bathymetry. In these deep areas we rely on a few camera stations for information. Despite the depiction of the deep water Gully as an area of rugged valley terrain on multibeam bathymetry, many photographs show that the seabed is covered with muddy sediments, with the exception of the deep-water thalweg of The Gully that is sand floored.

Geological Interpretation of Multibeam Bathymetry

The multibeam bathymetric database was processed to produce a colour shaded-relief image (Figure 5) and seabed slope image (Figure 12) (Fader and Strang, 2002). The multibeam was integrated with previously collected seismic reflection air gun profiles, sidescan sonograms, bottom sample information, video and photographic information, mostly collected in the under 400 m water depth zones of the inner Gully. An interpretation of Gully materials, seabed features, and processes was based on this assessment (Figure 13). The surficial sediments of The Gully region are classified in a formational framework consistent with published maps on the surficial geology of the Scotian Shelf by the Geological

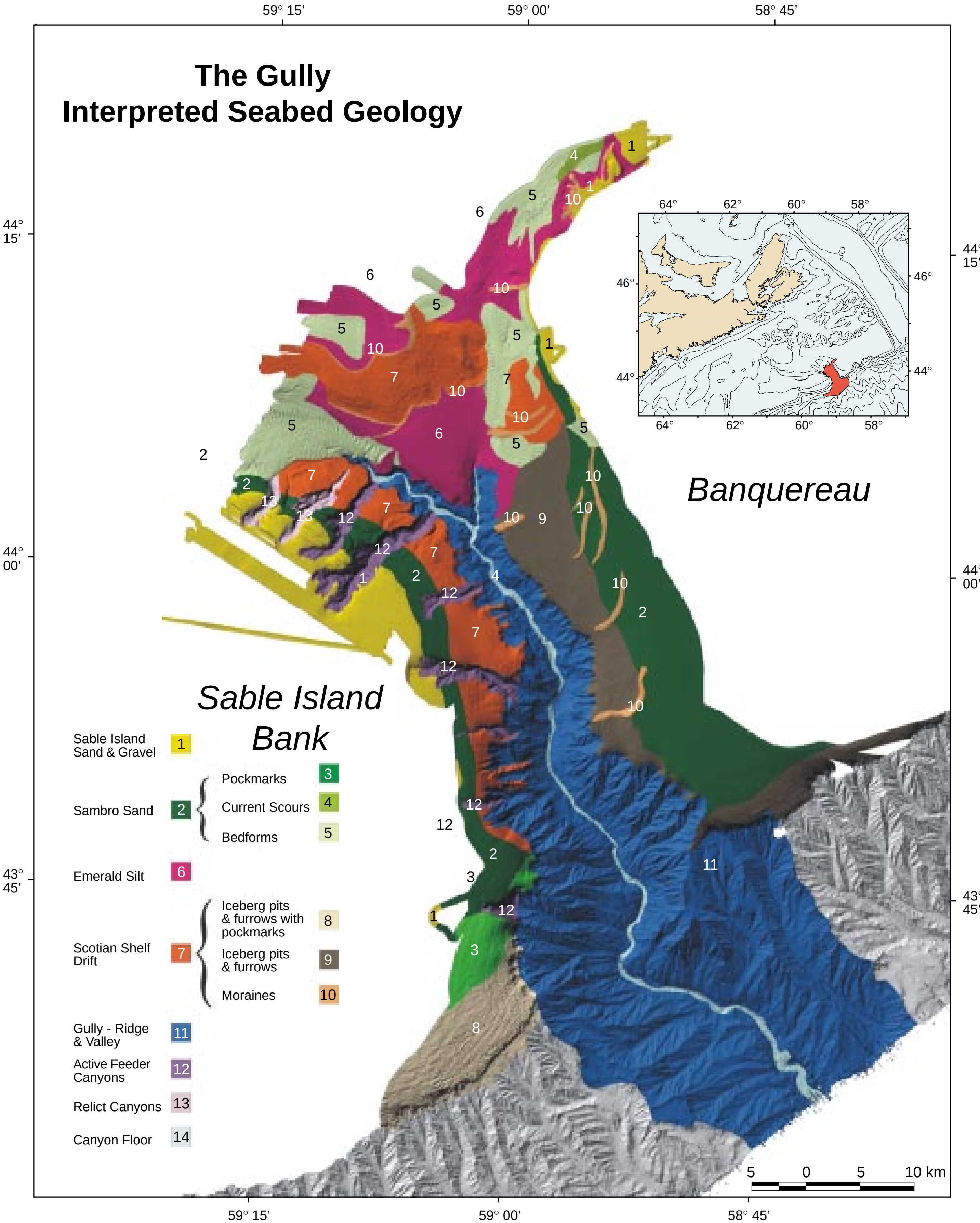


Figure 13: *An interpretation of the seabed geology of The Gully from Fader and Strang, 2002, superimposed on a grey scale shaded-relief multibeam bathymetric image. Both seabed features, processes and sediment formations are interpreted and classified. Note the sand deposits of the inner Gully, unit 5; the narrowing of the deep water Gully ridge and valley province beyond the shelf edge, unit 11; and the retreat moraines on the Banquereau flank, unit 10.*

Survey of Canada (King and Fader, 1986). Figure 14 is a map of The Gully showing selected contours derived from the multibeam bathymetry. The shape of The Gully from these contours differs considerably from previously published hydrographic charts, particularly in deep water. The following is a brief discussion of the major findings from the report of relevance to an assessment of the mineral potential.

Buried Channels

Seismic reflection profiles show the presence of generations of buried and infilled channels in the subsurface throughout The Gully area. Some of these buried channels are deeper than the present thalweg of The Gully and indicate it has likely shifted its location many times in the past. The thalweg (deepest channel floor profile) of The Gully presents a remarkably uniform, sand-covered surface, sloping at approximately 2 degrees seaward from its head, (profiles 13 and 18, Figure 15 and Figure 16). Only at 2700 m water depth does the slope of the thalweg begin to decrease slightly. No overdeepening of the present channel floor occurs along the thalweg, suggesting either minimal glacial erosional effects in the deep channel or that sediment deposition in the Recent time period has flattened the channel floor. The latter interpretation is considered more accurate.

Where the contours first begin to close at the head of The Gully, the seabed is sand-floored and occurs within a large area of bedforms. A large megaflute (triangular–shaped current-scoured depression) occurs on the seabed to the northwest of The Gully head, suggesting formation by periodic, high velocity, southeastward flowing bottom water in recent time. The sediment at the head is similar in texture and lithology to fine- medium-grained sand found on Sable Island Bank. The head of The Gully is bifurcated into two channels, a minor one that extends to the north and the major channel that extends to the northwest, profile 14 (Figure 15). This suggests that the dominant processes of erosion have come from the west. Based on photographic observations, the deep-water channel floor of The Gully to 600 m water depth consists of rippled sand with accumulated organic floc in the troughs of the bedforms. This indicates that sand is in transport down The Gully from shallower regions in the northwest.

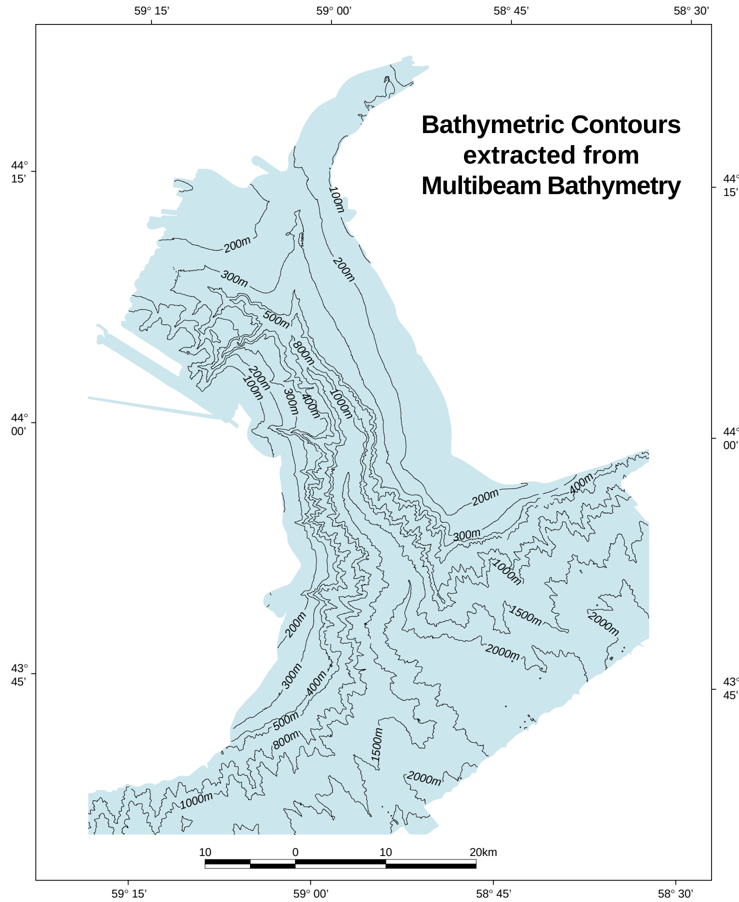


Figure 14: *A contoured bathymetric map of The Gully with selected contours extracted from the multibeam bathymetry. This bathymetric presentation differs from older published hydrographic charts (Figure 3).*

Feeder Canyons

Nine major canyons or channels (termed feeder channels or canyons) and many other smaller associated channels are located on the west flank of The Gully incised into Sable Island Bank (Figure 13). This is in contrast to the east (Banquereau) flank of The Gully where no present day feeder canyons extend on Banquereau. Buried feeder canyons could extend under Banquereau, but high-resolution seismic reflection data have not been collected on western Banquereau for such an evaluation.

In general, the slopes in the feeder canyons are less than those encountered in The Gully where some are over 50 degrees (Figure 12). The feeder canyons on the Sable Island side are asymmetric with gentler and longer slopes on their south side and steeper and rougher slopes on the north side. This suggests that sand on Sable Island Bank may be in active transport moving from south to northeast along the southwest flank of Sable Island Bank and entering the feeder canyons from the south. The two most northerly of the nine feeder canyons are relict and

The Gully Bathymetric Profiles

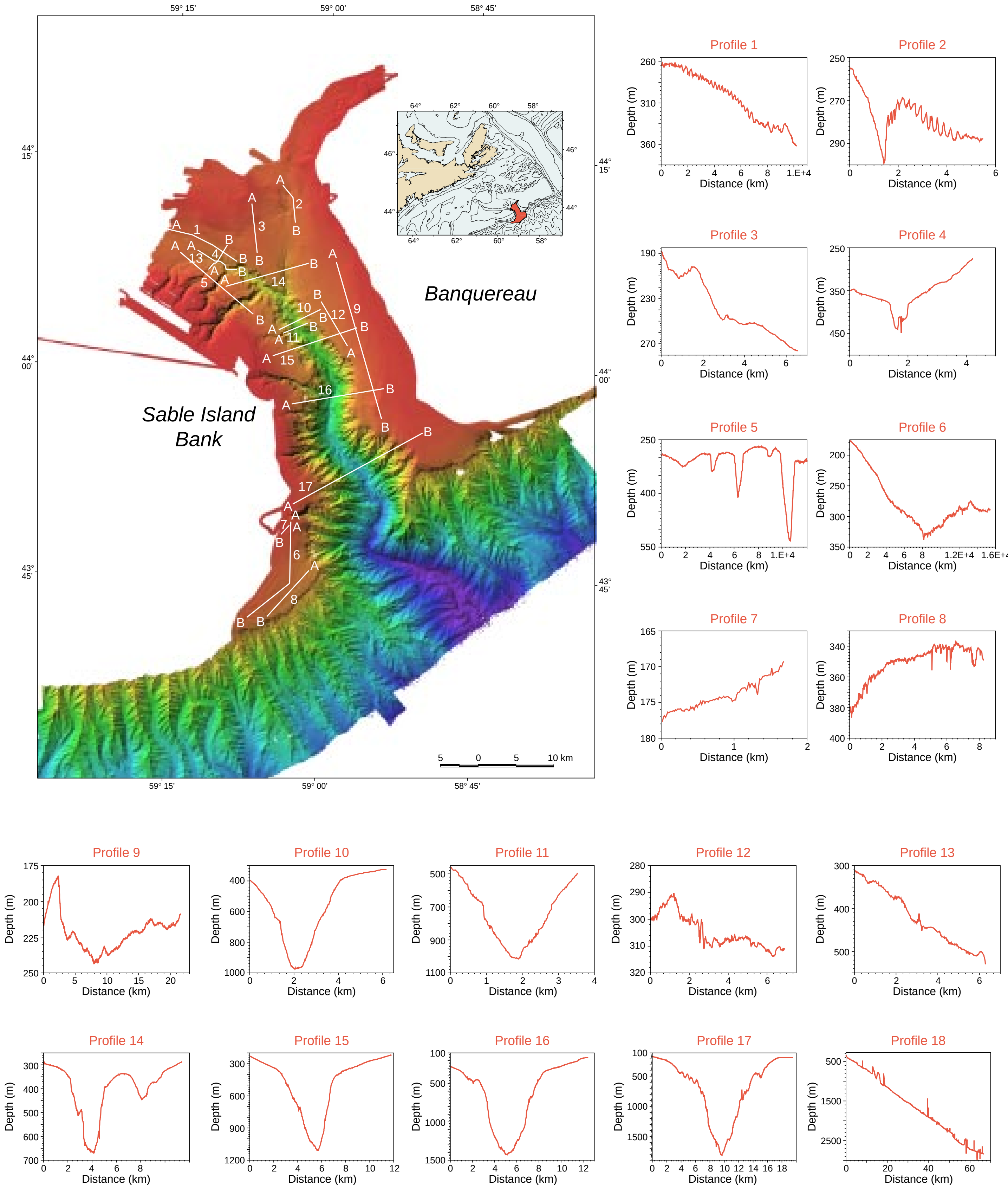


Figure 15: *A multibeam bathymetric map of The Gully from Fader and Strang, 2002, showing the location and profile of selected bathymetric profiles throughout The Gully to illustrate characteristics. Note the variation of vertical scale on each of the profiles selected to maximize the portrayal of Gully morphological attributes. The profiles have vertical exaggerations of approximately 10X. Profiles 1 and 2 are over sand wave fields; 3 and 9 are over moraines; 5 is across feeder canyons 1 to 4; 7 is across gas-escape pockmarks; 8 is across iceberg furrows; 10, 11, 14, 15, 16, and 17 are across the main canyon, and profile 18 is along the thalweg of The Gully.*

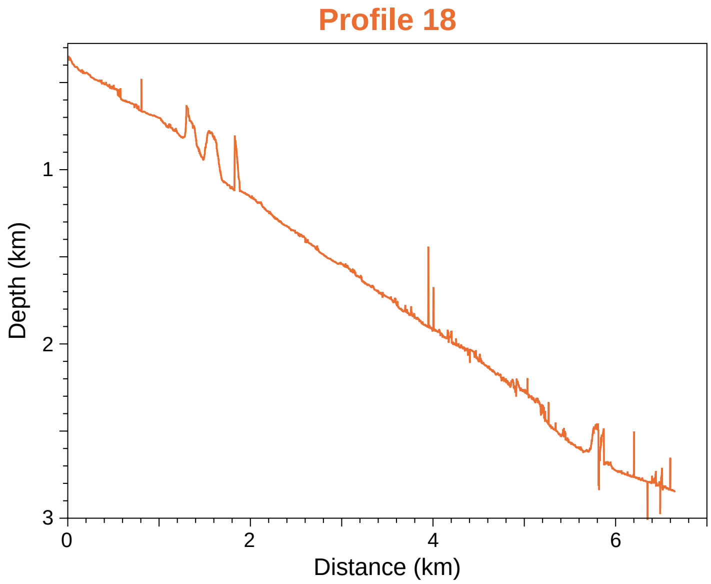


Figure 16: *A profile (profile 18, Figure 15) along the thalweg of The Gully from multibeam bathymetry. The excursions from the straight line are small ridges to the side of the thalweg that were crossed during profile selection. The profile presents a remarkably uniform seaward sloping surface uninterrupted by depressions and ridges. This indicates that The Gully is an active canyon with sand moving to deeper water. Previously formed glacial overdeepened depressions have been infilled.*

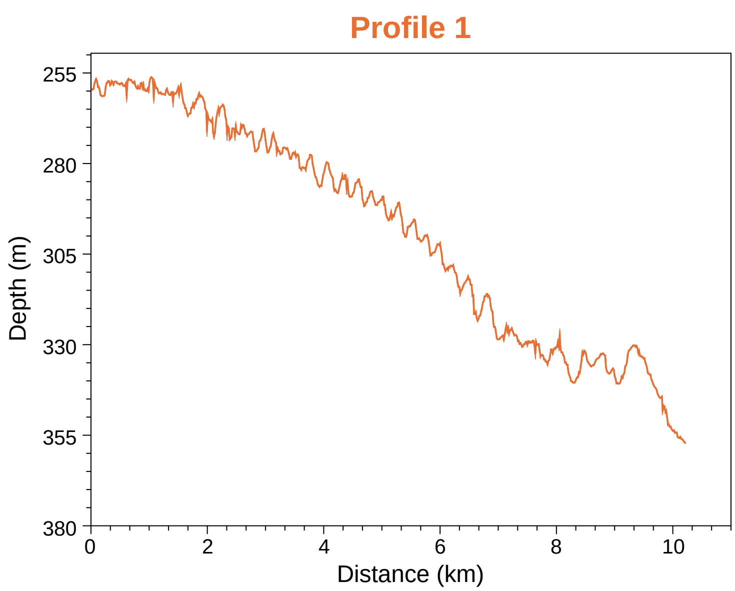


Figure 17: *A profile (profile 1, Figure 15) across a sand wave field in the inner Gully extracted from multibeam bathymetry. The sand waves are up to 11 m in height and are active.*

do not have a continuous path to the main Gully channel. The most northerly channel appears blocked by glacial material that is in turn overlain with sand waves. The second channel to the south has a shallow sill near the connection with the main channel of The Gully. The northernmost 6 feeder canyon heads extend on Sable Island Bank to present water depths of 100 m or less. Such a shallow depth suggests that they were connected to the subaerially exposed part of Sable Island Bank during the post-glacial low sea level stand. All of the feeder canyons have sand filled catchment basins at their heads that vary in size and give way to bedrock-controlled walls in deeper water toward The Gully. Ledges, terraces, near vertical local slopes of exposed sandstone and mudstone, and down slope minor gullies are characteristics of the feeder canyons. The minor gullies trend normal to the feeder canyons and are narrow linear depressions clearly seen on sidescan sonar imagery. Apart from the area of their catchment heads, the feeder canyon edges are generally represented by abrupt terminations of flat seafloor.

Glacial History

At 800 m water depth there is a major change in morphology within The Gully. In shallower depths to the northwest there are many linear scarps oriented parallel to the long axis of The Gully (Figure 5). They cut and block some of the feeder channels to the north and south of feeder canyon 5 with sill-like ridges. Broad terraces are common in depths shallower than 800 m. This morphology is interpreted to have formed directly as a result of erosion and deposition by grounded glaciers during the maximum extent of the last glaciation (Wisconsinan), approximately 20 000 ybp, and perhaps during earlier glaciations. The linear features are interpreted as subglacial moraines.

In areas deeper than 800 m, The Gully does not show any of these linear ridges and consists of a very uniform ridge and valley morphology suggesting that ice was not grounded in depths deeper than 800 m. The deeper areas of The Gully must have formed in response to submarine erosional processes that included sub-glacial meltwater erosion, currents, slumping, grainflows and iceberg furrowing. Supporting this interpretation is the slope map of the seabed (Figure 12, from Fader and Strang, 2002) which shows a series of greater than 50 degree, linear Gully-parallel scarps in depths shallower than 800 m. The slopes are calculated from the varing depth data of the multibeam bathymetry and represent local slopes only. The slope map also shows that many slopes of 50 degrees and greater occur within The Gully in contrast to the adjacent areas of continental slope off Sable Island Bank and Banquereau where few areas have slopes greater than 50 degrees. This suggests that erosional processes have been different and perhaps more intense within The Gully than on the adjacent continental slope. Such steep slopes are also likely developed on lithified materials rather than unconsolidated sediments.

Moraines

There are several types of moraines both buried and exposed within The Gully (Figure 13). A series of curvilinear ridges up to 10 m in height, profile 9, occurs on western Banquereau. These features are interpreted as recessional glacial moraines, demarcating a northwesterly sequential retreat of grounded ice in The Gully region. Their presence on the southwest corner of Banquereau suggests that the last ice (Wisconsinan) advanced to the edge of the continental shelf. These moraines likely consist of till and are gravel covered at the seabed. They only occur on Banquereau, as the ice was likely floating over The Gully in depths greater than 800 m. A similar set of recessional moraines would be expected to occur on the Sable Island side of The Gully, but none are evident at the seabed. Moraines likely occur on Sable Island Bank but are buried in the subsurface and covered by more recent sediment. The location and orientation of the moraines on the Banquereau side of The Gully suggests that a tongue of glacial ice may have occupied The Gully while ice was generally absent on Banquereau. Floating ice shelves fed from ice streams and grounded in places may have occupied The Gully later than the general retreat of ice from the adjacent bank areas.

In the shallower northern part of The Gully are several subparallel ridges of lobate-shaped moraines, profile 3, similar to retreat moraines of the inner basins of the Scotian Shelf. They are up to 8 m in height and are 300 m in width. Seaward of the moraines the seabed is flat and featureless consisting of glaciomarine sediment while proximal to the moraines the seabed is hummocky and rough, and likely formed at the sole of the glaciers. This seabed is gravel covered till which is evidence for grounded glaciers in the inner Gully.

Bedforms

Large areas of bedforms (sandwaves, megaripples) occur in the inner Gully mostly in water depths between 200 and 400 m (Figure 13). These bedforms occur in the northwest and northeast area of the inner Gully. The largest of the sandwaves is over 11 m in height (Figure 17). Most of the bedforms are asymmetric with the steepest flanks downslope to the east, indicating net transport directions down The Gully. The bedform areas continue down the actual geomorphic head of The Gully supporting an interpretation of active and continuous sand transport from shallower areas. The bedforms in the northeast area of The Gully indicate sand transport down the north arm of The Gully. They occur in water depths too deep to be influenced by waves and are therefore interpreted to be current generated.

Iceberg Furrows and Pits

On the southeast flank of Sable Island Bank near the mouth of The Gully and the west flank of Banquereau adjacent to The Gully are large areas of iceberg furrows and iceberg pits. They result from grounding by icebergs and reach depths of 10 m. Iceberg pits form as a result of bearing capacity failure of the seabed as grounded and more or less stationary icebergs change draft and roll over or terminate upslope in response to currents and winds. Iceberg pits are isolated semicircular, amphitheater-shaped, boulder rimmed depressions. Iceberg furrows in contrast, are linear bermed trenches that can extend for tens of kilometres in length. The area of The Gully has a preponderance of iceberg pits versus furrows. Other areas where such preponderance occurs are interpreted to arise from very hard seabeds or a lack of propelling currents and winds that prevent the icebergs from moving laterally while grounded. The pits and furrows in The Gully are interpreted as mostly forming in late glacial time, during the late Wisconsinan ice recession with preservation to the present. The material in which they formed is largely coarse-grained glacial material (till). None occur on the east flank of Sable Island Bank opposite the dense distribution on Banquereau supporting an interpretation of Holocene and recent sand transport to the east on Sable Island Bank to bury such features. Sidescan sonar data from the inner Gully deep-water area shows iceberg furrows parallel to the axis of the main Gully channel. These do not show on multibeam bathymetry because they occur on steep slopes and are likely very shallow in depth.

Pockmarks

North of the southwest Gully area of iceberg furrows and pits, (Figure 13) is a large zone of circular non-rimed depressions interpreted as pockmarks, (gas-escape vents). Several hundred of these features occur and extend to over 2 m in depth and several hundred m in diameter. Pockmarks do not form in homogeneous sand-sized material and require a mud component (cohesive character) to develop and preserve the passage of gas. The gas is likely hydrocarbon gas and not biogenic because of the close proximity of discovered gas fields (Primrose wellsite) up dip to the north. Upon closer examination, some of the pockmarks appear to continue to the south in the adjacent area of iceberg pits and furrows but are hard to differentiate in this terrain. It is not known if the pockmarks are actively venting gas. If actively venting, they could contain enhanced biological communities at their base resulting from chemosynthetic processes. It is interpreted that gas is actively venting from the pockmarks due to their fresh appearance and the presence of similar fields of active pockmarks in the large basins of the central Scotian Shelf.

Main Gully Shape

The steep-walled “ridge and valley” deep water core area of The Gully, most of which occurs in Zone 1, widens seaward as it approaches the outer shelf between Banquereau and Sable Island Bank (Figure 13) until the shelf break, where it narrows farther seaward. This narrowing suggests that the processes that have eroded The Gully originated on the shelf and not on the adjacent slope of the Scotian Shelf. It also supports the concept of major erosion during glaciation. This central ridge and valley core of The Gully is the least studied and understood area.

Slumps

In the inner part of The Gully near the head, and in the northern most feeder channels are areas of interpreted slides and slumps. These are associated with large isolated slump blocks, debris fields in deeper water, circular headwall scarps and sharp well-defined canyon edges. The slumping history is not understood, including the mechanisms for initiation. Slumped features are not evident in the deep-water multibeam bathymetric database but Stanley and Silverberg 1969 interpreted slump structures in deep water (Figure 9). They are expected to occur but the lower resolution of the multibeam mapping systems in deeper water may not have provided sufficient resolution for characterization.

Marine Minerals

Marine minerals on the continental shelf are classified into two general types: industrial minerals and metallic minerals. Industrial minerals include sand and gravel (aggregates), silica sand, calcium carbonate and phosphorite. Shelf metallic minerals, often referred to as placer minerals, are usually concentrations of heavy minerals with a specific gravity greater than quartz. Placer deposits can be divided into allochthonous and autochthonous types. Autochthonous placers are residual deposits formed close to their source and include gold and platinum. Allochthonous minerals form through processes of selective grain sorting and can occur at great distances from source. Examples include zircon, rutile, ilmenite, garnet and diamonds.

Metallic minerals can be sourced from terrigenous and in some cases marine rock types. Those considered to be of economic value are gold, platinum group metals, rutile, zircon, monazite, garnet, ilmenite and magnetite. Industrial minerals tend to occur in large deposits and have a low unit volume whereas metallic minerals command higher unit values and generally occur in localized deposits of low volume. Emory-Moore (1993) evaluated geological controls on the formation of placer deposits in a former glaciated environment for the Newfoundland region. In order to determine potential mineral areas, characteristics such as sediment cover, mineral occurrences, bedrock lithologies, ice flow directions, transport distances and drainage basin locations were evaluated. This approach identifies and ranks areas based on their suitability to contain placers.

Mineral Assessment Procedures

Scoates et al. (1986) documented a qualitative procedure for assessments of mineral potential that has been in use by the Geological Survey of Canada for terrestrial national park proposals since 1980. This was applied to assessing marine mineral potential of the South Moresby Island region of western British Columbia by Jefferson and Schmidt (1992, Open File 2480) and of Bona Vista - Funk offshore area of Newfoundland by Emory-Moore, (1997, Open File 3435). The marine areas of Torngat Park study area of northern Labrador has also been assessed but so little data were available that no procedure was required (Emory-Moore, 1997, Open File 3435).

The criteria established to rate the mineral potential of a region include geological environment, knowledge of mineral occurrences, likelihood of accumulations and uncertainty. The mineral potential ranges from not assessed, through low, moderate and high ranges and is given numeric ratings ranging from 1 to 7 where 1 represents very high potential and 7 very low (Table 1). Areas to be assessed are divided into regions called domains and are delineated on the basis of bedrock geology and coastal geomorphology (physiography). A modified approach will be used in the assessment of the mineral potential of The Gully which divides the Gully region into the inner Gully Trough, the deeper water canyoned terrain of The Gully, the adjacent surrounding banks, and areas of intermediate depth in the inner Gully region. It does not conform to the proposed zonation system for Gully management (Figure 2) that crosses geomorphic regions.

It is also important to clarify definitions regarding potential mineral resources as a framework for mineral assessment. A resource is a mineral concentration of which we are confident of its existence and forms the source from which mineral commodities may be derived. If economically mineable, it is considered a reserve. It is common to find that many so-called resource inventories are only geological assessments that determine only the likelihood of existence.

Numeric Rating	Potential	Criteria
1	Very High	- Geological environment is favourable. - Significant deposits/accumulations are known. - Presence of undiscovered deposits/accumulations is very likely.
2	High	- Geological environment is very favourable. - Occurences are present but significant deposits/accumulations may not be known. - Presence of undiscovered deposits/accumulations is likely.
3	Moderate to High	- Intermediate between moderate and high potential. - Reflects greater uncertainty.
4	Moderate	- Geological environment is favourable, occurences may or may not be known. - Presence of undiscovered deposits/accumulations is possible.
5	Low to Moderate	- Intermediate between low and moderate potential. - Reflects greater uncertainty.
6	Low	- Some aspects of the geological environment may be favourable but are limited in extent. - Few, if any occurences are known. - Low probability that undiscovered deposits/accumulations are present.
7	Very Low	- Geological environment is unfavourable. - No occurences are known. - Very low probability that undiscovered deposits/accumulations are present.
n	Not Assessed	- Deposit type unknown, overlooked, beyond the scope of the assessment, or not worth mentioning at the time the assessment was done (could be a high rating in the future).

Table 1: *Rating categories for mineral potential after Scoates et al., 1986.*

The Shelf Working Group of the NRCan Departmental Coordinating Committee on Ocean Mining, which functioned in the 1980s, prepared a framework for assessing the mineral potential of an area that incorporates the likelihood of existence and exploitability, Internal Report 1980-9, (Figure 18). This system uses 5 subdivisions of likelihood of existence that are:

1) Quantified deposit: direct evidence demonstrates the quality and quantity of a mineral concentration.
2) Known Occurrence: mineral concentrations are known by direct evidence, but quality and quantity are uncertain.
3) Speculative occurrence: only indirect indications of minerals, such as geological setting, suggest a concentration.
4) Unknown: direct or indirect evidence in not sufficient to indicate a mineral concentration.
5) Absent: direct evidence is sufficient to indicate it is unlikely a mineral concentration exists.

This classification is also useful for this study particularly applied to the zonal classification of The Gully as proposed by DFO. The likelihood of existence system has flexibility in that it can accommodate situations where sample data are lacking and other indirect evidence such as the presence of suitable source rock, appropriate depositional environments and known geological history is applied. It can also accommodate negative factors such as dilution by glacial depositional processes or burial by recent sedimentation.

Based on knowledge of the bedrock geology, the Quaternary geology, sediment distributions, an interpretation of the recently collected multibeam

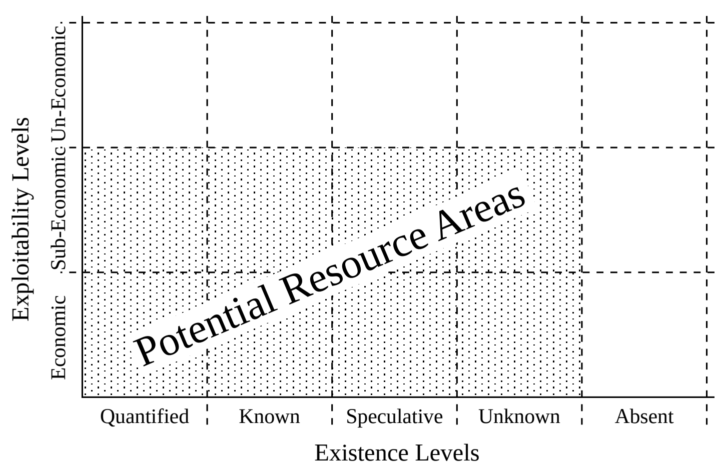


Figure 18: *A basic resource area assessment scheme developed by an NRCan shelf minerals working group.*

bathymetry, sea level history and geological history of the Scotian Shelf, and including previous research on sediment mineralogy, there are both industrial and placer minerals known and expected to occur within The Gully and surrounding study area. These include sand and gravel (aggregates), silica sand, carbonate, phosphorite, rutile, zircon, and garnet. These will be discussed in more detail in the following sections. An emphasis has been placed on the aggregate potential of the region because more is known about their charateristics and they represent the greatest potential for extraction.

Sand and Gravel (Aggregates)

Globally, sand and gravel are the least valuable marine commodities by volume, but are required in enormous tonnages to supplement onshore resources in many parts of the world. Sand and gravel are used in either the construction industry or in beach replenishment programs. Canada's main experience in offshore aggregate extraction has been dredging in the Beaufort Sea to produce artificial islands for placement of oil wells. Volumes in excess of 20 million cubic metres have been extracted for this purpose. Other dredging programs have been undertaken in Prince Rupert, B. C. (about 175,000 cubic metres were dredged annually in the 1980s for local consumption) and Vancouver Harbour.

The Scotian Shelf contains vast reserves of sand and gravel contained within the Sable Island Sand and Gravel Formation (Fader and Miller, 1990). The outer banks of the Scotian Shelf, such as Brown's Bank, Middle Bank, Misaine Bank and Banquereau (Fig.11), are known to have thick sand and gravel deposits. Many of these have been tested for aggregate properties (Maritime Testing, 1992 and 1996). Georges Bank and Sable Island Bank have environmental restrictions related to existing and important fisheries and a perceived fragility of Sable Island so were not included in this assessment.

The inner shelf areas of the Maritime Provinces are closer to potential local markets and can also provide sources of aggregate. On the inner continental shelf above the depth of the post-glacial lowstand of sea level, sand and gravel deposits occur and extraction is possible. Beyond that, in deeper water of the middle shelf, muddy sand and till deposits predominate. The quality of sand and gravel depends in large measure on the hardness and durability of the minerals contained in the source rocks. Testing has shown that Scotian Shelf and Bay of Fundy aggregates could be utilized for road sub-base, railway ballast, abrasives, and filter sands. Testing for concrete and asphalt use has shown that the Nova Scotian offshore source areas comply with national standard (CSA) for concrete aggregates (Maritime Testing, 1992), but the deleterious effects of grain rounding and salt-coating on concrete durability have yet to be fully evaluated. Such characteristics are not a problem in the use of marine aggregate in the United Kingdom where washing of marine aggregate is often undertaken to reduce chlorides.

Most of the sand and gravel deposits on the Scotian Shelf formed by and during the marine transgression at the end of the last glaciation. These areas occur in depths above 100 m in the offshore and 70 m in the nearshore. They were formed through erosion of preexisting glacial materials subjected to passing beach fronts. Well-rounded pebbles, cobbles and boulders and well-sorted sands were developed. Modern sediment transport also occurs in shallower depths from storm driven currents and waves. The gravel seabeds tend to be relict with little modern movement with the exception of areas of "ripples in gravel" which are occasionally redistributed during major storm events.

Within The Gully study area, there are two zones of potential sand and gravel that could be used for industrial applications. These are the sands and gravels of the Sable Island Bank area above 100 m water depth, to a lesser extend the sands of the Banquereau portion of the study area (Zone 3), and deeper water areas in the inner part of The Gully adjacent to Sable Island Bank and Banquereau (Zone 2) (Figure 2). Although Sable Island Bank and western Banquereau were not studied during regional aggregate assessment programs during the early 1990s, extensive mapping and sediment assessment programs have been conducted on Sable Island Bank in relation to hydrocarbon exploration and development. These have concentrated on understanding foundation stability issues and sediment transport. Some of this information can, however, satisfy the requirements for an aggregate assessment. Fine-grained sand is not normally sought after in the construction industry as coarse and angular and variable-sized sand grains and granules are preferred. The sand on the eastern edge of Sable Island Bank and the western area of Banquereau is medium-grained and more desirable for use as aggregate (Figure 19). There are deposits of sand on Sable Island Bank that range over 30 m in thickness (Figure 20) indicating a considerable volume of material and those on Banquereau in the MPA area are slightly thinner. Localized deposits up to 25 m in thickness occur to the east of the MPA area on Banquereau (Figure 20). These aggregate deposits in Zone 3 areas on Sable Island Bank rate as having a high to very high potential.

Recent Research on Sable Island Bank Sands

Evidence from recent study of Sable Island Bank indicates that the most recent glacial margin on Sable Island Bank was a re-advance to the present Sable Island postion following retreat from a glacial maximum shelf-edge position (King 2001). This was a meltwater-dominated regime whereby sub-glacial streams fed a morainal bank and associated distal sandy apron deposit comprising over 320 km^3 (McLaren, 1988). This sand body was partially emergent and formed the large proto-Sable Island (King 2001), which, with subsequent sea-level rise, has progressively been submerged. The

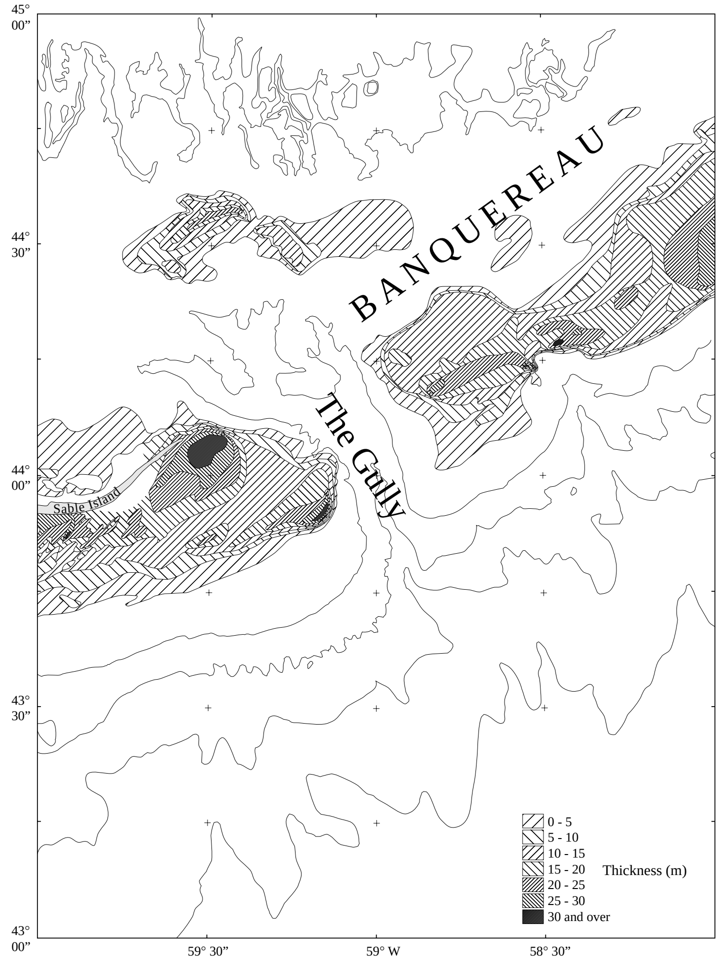


Figure 20: *Isopach of sand thickness compiled from Amos and Fader, 1985 for the Gully region. Note the two deposits on eastern Sable Island Bank that attain thicknesses of 30 m. A large deposit near feeder canyon 4 is missing from this compilation, as data did not exist during this compilation. The thick deposits of Banquereau lie to the east of the proposed Gully MPA. Thicknesses were not calculated for the deeper regions of the Gully canyon.*

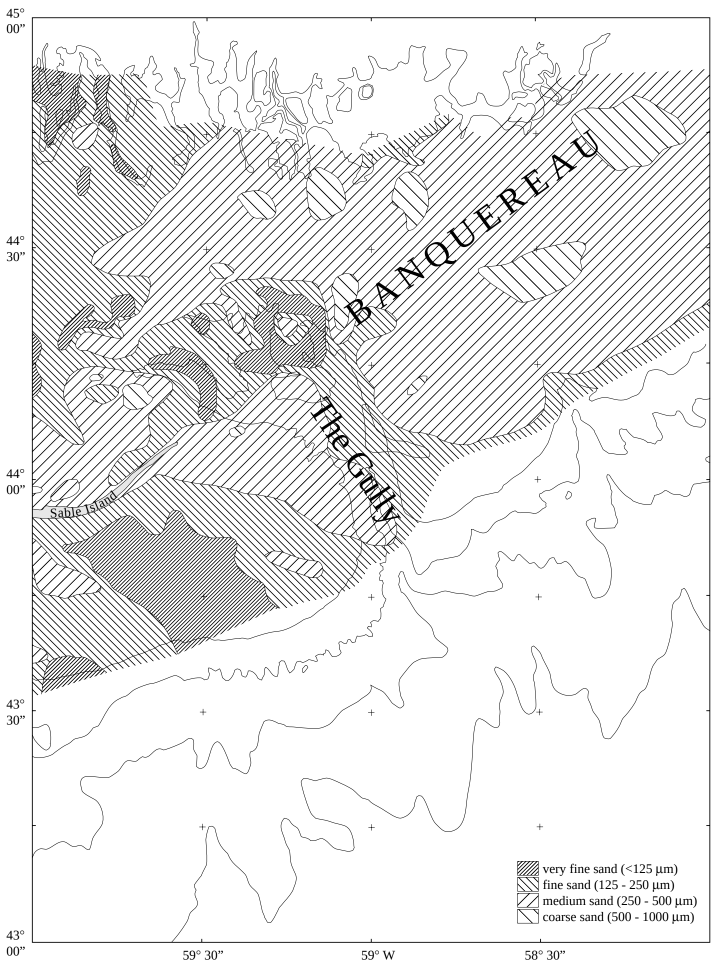


Figure 19: *A compilation of sand grain sizes from the Gully region, after Amos and Fader, 1985. Note that the western Gully region is dominated by medium sand and the eastern area by fine sand. Coarse sand is rare in the region.*

meltwater domination and a largely Mesozoic and Cenozoic source rock resulted in a sandy deposit, locally over 30 m thick. As sea-level rose, these sands were further reworked in coastal and shallow marine environments which locally eroded, transported and sorted and then re-deposited the sands, largely in the form of large bedforms and thick prograding sand sheets. These deposits reshaped the bank morphology through creation of the Northern Spur, DeBarres Spur, and East Bar.

At this time the feeder canyons on the western flank of The Gully (features 12 and 13 on Figure 13) would have further developed and acted as conduits for significant removal of sand from the bank. The nature of the prograding sand sheets within the proposed MPA and their association with the canyons is discussed below. With continued sea-level rise, the present oceanographic regime evolved and most bank transport became eastward, associated with a series of large sand ridges on the southern flank of Sable Island.

Prograding Sand Sheets

Thick sand sheets with a prograding internal stratigraphy dominate the northeasternmost area of Sable Island Bank. They consist of two main stratigraphic units, a lower and an upper, separated by an unconformity. The upper unit also contains sub-units of individual but smaller prograding sheets. Figure 21 shows the general 3 dimensional structure of these sand bodies. Two isopach maps of these sand units have been produced to illustrate their distribution, thickness and volumes; Figure 22 depicts a map of both the upper and lower sand units (total sand volume) while Figure 23 shows only the uppermost unit. The development of two or more units reflects as many phases of sand transport and deposition interrupted by a major hiatus. These likely reflect a step-wise history of relative sea-level change following glacial retreat; a major phase of transport occurred with re-advance of the glacier and massive sand input. This deposited the lower prograding sand unit, mainly in a northward (also NW and NE) direction though, in the present vicinity of DeBarres Spur, some additional southward transport. However, with retreat of this ice and associated crustal rebound, relative sea-level lowered again, causing some truncation and removal of the first (lower) sand sheet and remobilization of the sands all across the bank with the subsequent transgression. This transgression and the shallow open water conditions following it produced an unconformity (U-1 in King, 2001) marking the boundary between the upper and lower prograding sand units. Eastward-dominated transport, combined with the massive volumes of sand supplied/reworked by this transgression, led to build-up of the upper prograding sand unit, presumably nearly to a level near the sea-surface of that time.

Gully Trough Sands

The deposits in the deeper water areas of the inner Gully and the Gully Trough differ from those on the adjacent banks. They were not formed by the marine transgression of the seabed as these areas have always remained below water. They occur in depths greater than 100 m ranging up to 300 m, and the western zone is quite large. This deposit consists of medium-sized sand that is formed into a variety of bedforms. The sand waves of this deposit range up to 11 m in height (Figure 13 and 17) and are asymmetrical in shape with their steep sides toward the east indicating transport toward the head of The Gully. This body of sand likely formed from spillover off the adjacent banks and from winnowing of glacial materials

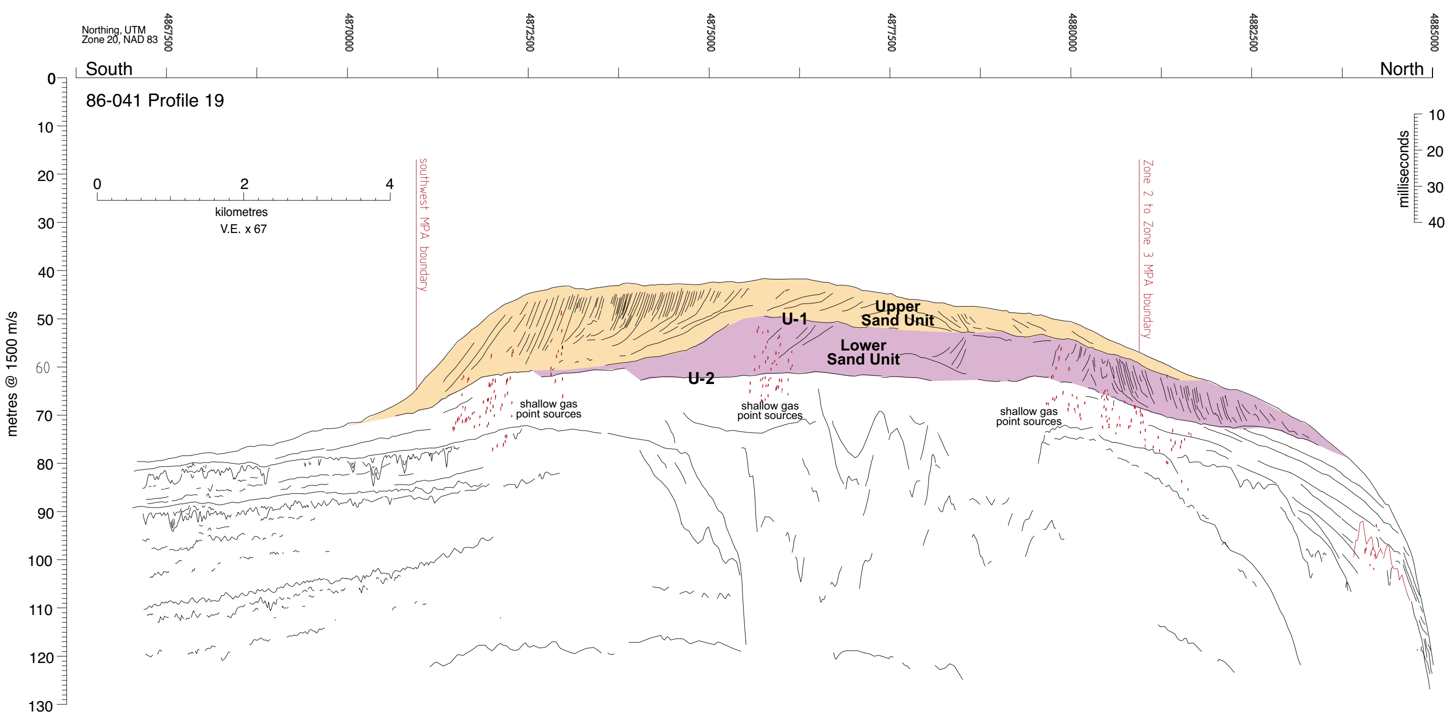


Figure 21: *An interpretation of a seismic reflection profile from eastern Sable Island Bank over DeBarres Spur near feeder canyon 5 (E on Figure 22) on the western edge of The Gully. Note the two large sand bodies each prograding in different directions and a thin layer of recent mobile sand at the seabed.*

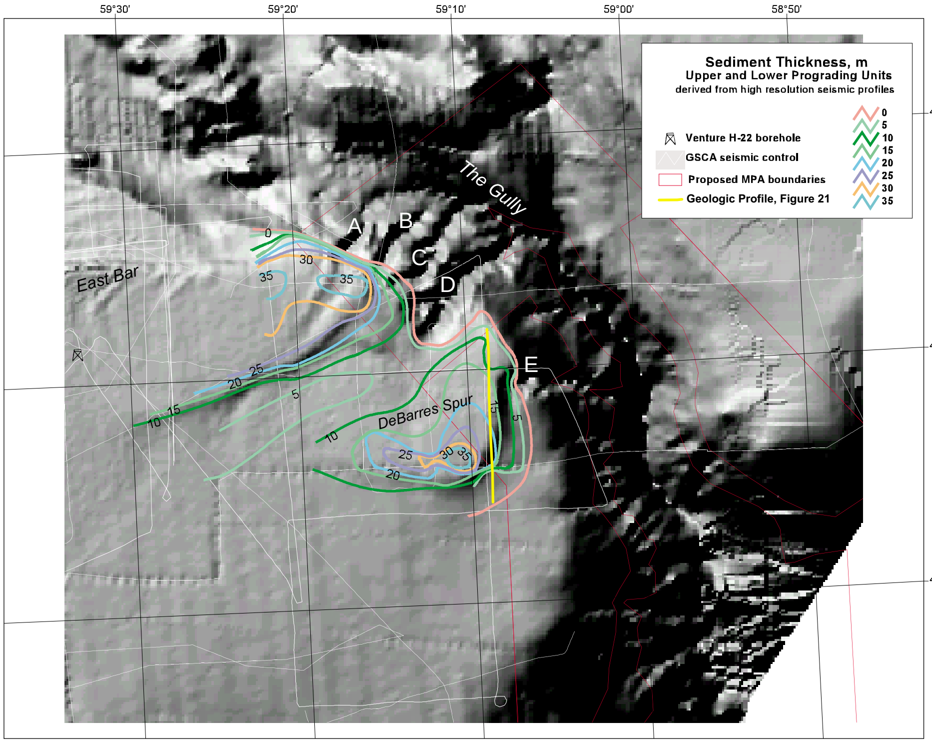


Figure 22: *An isopach map of upper and lower sand units overlain over a regional DTM (digital terrain model) with shaded-relief (not multibeam bathymetry). Feeder canyons 1-5 are referred to on this diagram as A-E. Two sand bodies are contoured, East Bar extension and DeBarres Spur. The geological crossection* in Figure 21 is shown.

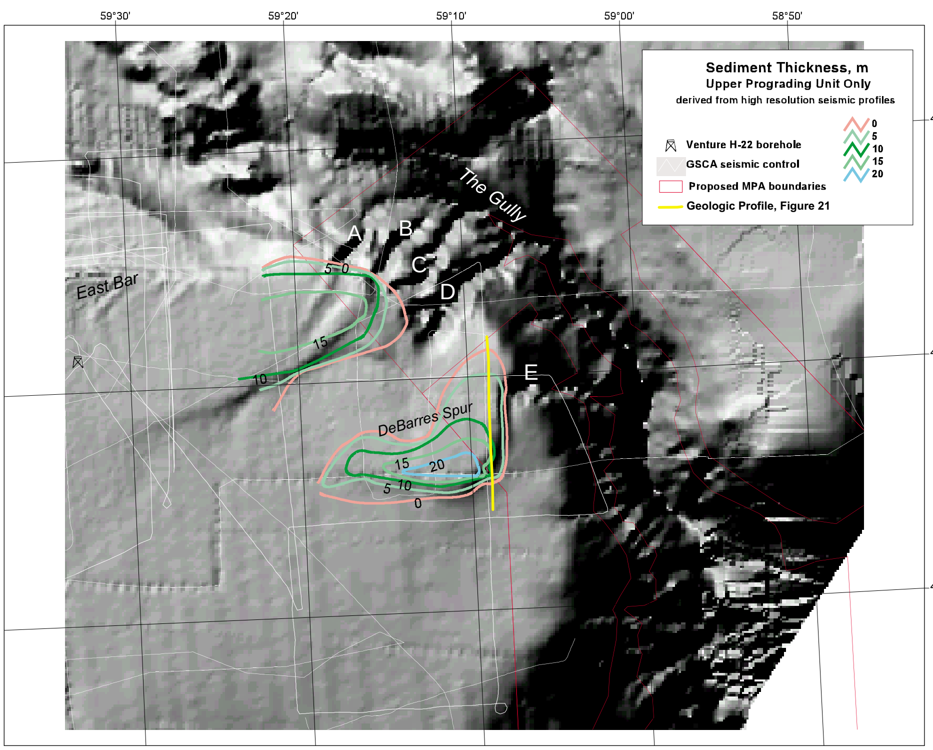


Figure 23: *An isopach map of sediment thickness of the upper prograding unit only, overlain over a regional DTM.*

on the seabed by strong currents in postglacial time. It continues into the head of The Gully indicating active sand transport. Samples and video of the bedforms in this deposit show sharp crests indicating recent mobilization. The sand deposits on the eastern side of the inner Gully near Banquereau are not as extensive or thick and occur in several isolated patches. Assuming an average thickness of 2 m, the volume of sand in the inner Gully, Map Unit 5 on Figure 13 is 227.5 million cubic metres.

All of these deep-water deposits of sand at the head of The Gully are classified as occurring within the Sambro Sand Formation. They are interpreted to overlie subsurface glacial till and glaciomarine sediment. These aggregate deposits in the deeper water areas of the inner Gully are therefore rated as having a moderate to high potential. Although of wide extend and appropriate properties for aggregate use, their deep water occurrence, in contrast to the widespread availability of similar materials in much shallower water across the banks of the Scotian Shelf, make the deposits in The Gully head a less likely target for extraction and sub-economic.

Sand Transport off Sable Island Bank

A controversy exists as to the contribution of sand-sized material from Sable Island Bank to The Gully through sediment transport processes. Amos and Nadeau (1988) interpreted that a condition termed a "hydraulic fence" skirted the eastern flank of Sable Island Bank that prevented the large-scale transfer of material off the bank. They postulated that such a condition traps sand on the bank especially where sediment transport is limited to the near bed region. Amos and Nadeau (1988) presented a transport model (Figure 24) based on a study of sand bedform geometries which showed a dominant transport direction of north to south along the eastern flank of Sable Island Bank with limited transfer to The Gully down one of the northwestern feeder canyons. This interpretation is in contrast to a model of Stanley et al., 1972, (Figure 24) who envision a greater transfer of sediments to The Gully. They indicate two major transport directions off eastern Sable Island Bank, one to the north toward the Gully trough and the other to the east toward The Gully. Fader and Strang (2002) postulated erosion of sand from Sable Island Bank to The Gully but in the opposite direction, south to north, along the southeastern Sable Island Bank flank in the central and southern area of the western part of The Gully. This issue remains unresolved especially regarding the quantities and triggers for sand transport to The Gully. Evidence from recent video and photographic observations along with sidescan sonar transects and multibeam interpretation indicates that most of the feeder canyons on the western flank of The Gully have catchment basins at their heads with active sand in transport toward The Gully.

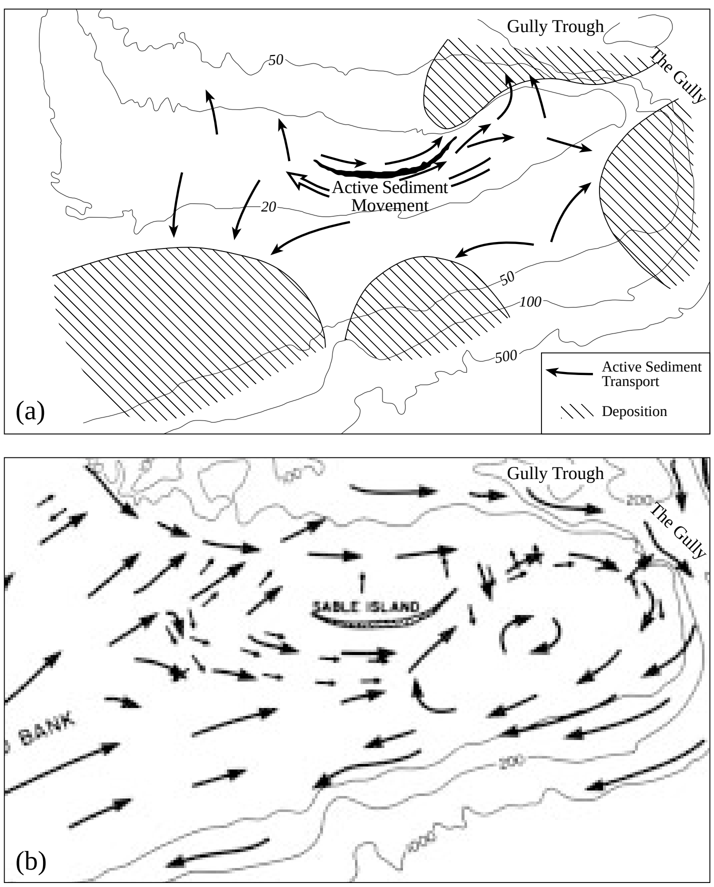


Figure 24: *Interpretations of sediment transport off Sable Island Bank, a) from Stanley et al., 1972, and b) from Amos and Nadeau, 1988. Although of regional extent they show some similarity as well as differences. A depicts more transport to the Gully Trough and b shows limited transport to The Gully down canyon 4, (D) on Figure 22.*

Sand Transport and Relationship to Canyon Evolution

The shelf-edge canyons on the west flank of The Gully (Figure 5), and labeled A through E on the low resolution shaded relief image in Figures 22 and 23) show different degrees of present activity, as interpreted from the multibeam images and noted in previous sections. The northernmost Canyon A has sediment draping and a sill, suggesting relative inactivity. A similar draping characterizes the canyon south of this (B). In contrast, the canyons south of this again (C, D and E) show a well-developed dendritic drainage channel system at the heads and a continuous thalweg linking with the main thalweg of The Gully, suggesting more recent activity. This difference in morphology can be explained in terms of the evolution of the sand sheets discussed in the preceding section.

The initial (lower sand unit) sand sheet development, which transported sand to the east and north, would have actively fed the northernmost canyons while furthering their development. However, by the time of the upper sand sheet development (with subsequent transgression), erosion of the lower sand unit along its southern flank resulted in development of an E-W oriented, south-facing flank with topographic relief of between 8 m in the west to over 15 m in the east. This erosional edge is continuous over more than 25 km, extending from south of East Bar to the vicinity of the "active" canyons C and D heads. It presents a topographic feature which, since formation, would have acted to steer sediment transported from the west to canyons C and D while "starving" the northern ones, A and B. Thus, eastward-transported sand on the bank would have followed this flank and preceded down the canyons C and D into The Gully. However some portion of this sand was swept to the south to remain on the bank and deposit DeBarres Spur (Upper Sand Unit). The toe (southern limit) of the DeBarres Spur deposit also falls at the head of a Canyon (E) suggesting some degree of bypass across the spur, during its development and into The Gully via a path down Canyon E. Perhaps the position of Canyon E thus prevented further southward extension of DeBarres Spur. Deeper water, eastward sediment transport along the basal flank of the NE portion of the bank (still a site of active bedforms) has partially buried the largely inactive canyons (A and B).

Bank Area (MPA Zones 2 and 3) Aggregates

The shallow areas of the proposed MPA (Zone 3 and the shallow northern part of Zone 2) have been dominated by low sea-level stand processes in the past (as discussed earlier) with the result that these former coastal and shallow water environments have given rise to moderate to well-sorted sands and gravel deposits.

The Banquereau flank of The Gully has a thin sand blanket, generally less than 5 m thick, that thins to nearly zero in about 110 metres of water on the eastern flank of The Gully. Well-sorted sands in bedform (megaripple) fields on the southwestermost corner (Amos et al. 1988), mapped from sidescan sonograms, cover about 85 km^2 and are limited to a relatively small volume of less than 0.1 km^3 assuming a 1 to 1.5 m average sand thickness. No samples are available.

In contrast, the Sable Island Bank side of The Gully has the thick sand deposits of East Bar and DeBarres Spur. The new sediment thickness maps were prepared from all relevant seismic coverage on the eastern Sable Island Bank in the vicinity of The Gully (Figs. 22 and 23). Figure 22 depicts both the upper and lower sand units (total sand volume) and Figure 23 shows only the uppermost unit.

Sediment volumes in these deposits have been estimated where they fall within the boundaries of the proposed MPA. The upper sand unit contains about 0.8 km^3 of sand (see following section for sediment description) while the lower and upper sand units combined contain about 4.2 km^3. These are significant sediment volumes yet represent only between one third and one half of the total sand volumes. Below the progradational sand units are sands from a more direct glacial depositional event. If conditions can be correlated from other parts of the bank, these are likely very dense fine sands with occasional silty or clay rich layers up to several metres thick. Their density or more variable grainsize may render these deposits less suitable for aggregate.

Aggregate Characteristics: Correlation with Borehole Data

Only limited sampling of the sand units has occurred within the proposed boundaries of the MPA. However, the sand units are continuous over a large area, including the Venture hydrocarbon production site where Borehole H-22 penetrates to 19.5 m below sea floor, (Jacques/ McClelland 1983) intersecting the more distal equivalents of the lower sand sheet (ie. the sand sheet prograded in a NW direction here). The position of this borehole and seismic control linking it to the MPA area are shown in Figure 22. No cone penetrometer data were collected at this site and the sandy nature of the material precludes laboratory shear strength measurements. The log indicates very uniform well-sorted fine to medium sand with silt percentages generally under 5 % and rare traces of gravel or shells. It is undetermined if the dominance of fine sand is a function of the distal position of this borehole with respect to the sand sheet as a whole, such that coarser sands predominate nearer The Gully, or if fine sand dominates the entire sand body. Local thin beds of siltier or gravelly material commonly at one to two meter intervals may reflect grainsize differences along the clinoforms (e.g. top and base of the paleo slip faces of the sand sheet).

The lower sand sheet, intersected by the borehole, is more closely associated with the latest glacier readvance. Its time equivalents on the flank of The Gully become more seismically laminated, resembling the pro-glacial Emerald Silt of the basin areas. In contrast, the upper sand sheet (isopach, Figure 23) is the product of further reworking of these earlier sands and by geological inference may be better sorted. This, together with its near ouctropping nature likely renders this upper sand unit as opposed to the lower, the most suitable aggregate source.

Erosion of Sable Island and a Beach Replenishment Scheme

A long-standing question regarding Sable Island has been its long-term stability in a very dynamic environment of disappearing ponds, evolving sand dunes and shifting spits (Cameron, 1965, Medioli et al. 1967). The question involves aspects such as sediment transport rates and directions and relative sea-level change. On a geologic time scale (several millennia) the island has clearly been progressively drowned (e.g. Scott et al. 1989; King, 2001; Amos et al. in prep). However the factors causing this relate to sea level changes induced by global glaciation of 15 to 25 thousand years before present and their effect has been exponentially diminished with time. It must be emphasized that no clear evidence exists for an historic trend toward the disappearance of Sable Island. Indeed, even the historic trends of eastward migration may be largely apparent (Medioli et al. 1967). However, the potential for change, especially in light of modern climate change and sea-level rise, brings to question the potential mitigation measures for hypothetical erosion and drowning of the Island.

The most recent long-term sediment transport direction, as noted above, is in an easterly sense, ultimately from the shallow bank, toward and into The Gully via the west-flank canyons. Though this has clearly prevailed in the past, present fluxes and pathways are unknown. Sable Island is considered a strategic feature of the outer continental shelf and is valued for aspects such as its unique habitat, safety potential for offshore hydrocarbon development, and potential ecotourism. If, in the future, mitigation measures are required to maintain the stability of Sable Island, one such measure is beach sand replenishment. The argument can be made that artificial replenishment on the western end of the island sourced with aggregate from the eastern regions results in a recycling and thus minimized environmental impact beyond the bank (ie. The Gully). The proposed MPA in The Gully may have some impact in this hypothetical consideration because the aggregate resources on the bank edge represent the nearest volumetrically significant aggregate source and part of this falls within the proposed MPA boundaries. The replenishment/recycling hypothesis is immature in that fluxes and details of sediment transport pathways are unknown such that the magnitude of artificial sediment removal volume from the east, and thus its feasibility, remain speculative. Nevertheless, given the potential longevity of an MPA and the ambiguity about the long-term fate of Sable Island, the possibility is raised here.

As stated earlier, the volume of bank contained aggregate within the proposed MPA boundaries is about 4 km^3 (4 x 10^9 m^3). This represents only about one half to one third of the aggregate volume in this depocenter, most of which lays outside (west of) the proposed MPA boundaries (Figs. 22 and 23). As inferred earlier, these deposits may represent several millennia of deposition. As such, this volume is considered significant in relation to present sediment flux across Sable Island Bank. However, lacking any quantification of this flux, this conclusion is tentative.

Despite these limitations, the amount of aggregate outside the proposed MPA boundaries is also considerable and would exceed, in terms of beach replenishment, the capabilities/feasibility of a mining operation, should such a scheme be considered. The deeper water depocenter comprising De Barres Spur is likely the more benign in terms of present sediment transport, compared to the East Bar deposit, simply due to the deeper water depth. Thus, should mining take place, impacts to the present regional sediment transport system would likely be minimal. Both deposits are relict, lying below a thin, more recent sand cover of up to two metres in thickness. Other considerations regarding such a mining operation such as water depth, technology, and proximity to the MPA are not considered here. Other potential shallow water aggregate sources are present farther afield, such as in sand ridges on Middle Bank or thick sand sheets on Banquereau but would involve greater transport distances.

Phosphorite

Nodules of Phosphorite are known from the outer area of the continental shelf off the United States extending from Florida to the north. They tend to occur in deep water greater than 300 m depth but because of limited sampling have been regarded only as potential resources. They occur within Oligocene to middle Miocene sediments along the entire North American margin (Manheim, 1972). Reprecipitated and remobilized phosphorite grains often form slabs, cobbles and crusts within the Tertiary section. These middle Tertiary sediments contain more than 1% P202 and extend northward to the Grand Banks of Newfoundland (Figure 25). Tertiary rocks are normally buried on the continental shelf beneath sands and off Canada have an additional burial history associated with multiple shelf-crossing glaciations and deposition of till and glaciomarine sediment. Known outcrops of Tertiary sediments occur on Georges Bank and in shelf edge canyons (Stanley et al., 1967). Submarine canyons like The Gully are areas where Tertiary bedrock is expected to crop out and indeed the multibeam bathymetry, sidescan sonar data and bottom photographs clearly shows that this is the case. Manheim, 1972, (Figure 25) shows a probable occurrence of continuous phosphatic sediments along the outer Scotian Shelf as well as a document occurrence in The Gully. Although this documented occurrence is not referenced, it likely results from early sampling in The Gully using dredge hauls.

None of the recently collected samples were analysed for phosphorite within The Gully. Even if it was widespread, removal would constitute seabed mining of layers within exposed Tertiary sedimentary bedrock. This would be a difficult proposition given the deep water, steep slopes of The Gully, near vertical cliffs, overhangs, and constant downward sediment movement. Where buried beneath glacial materials, excavation of the overburden would be required. Even though phosphorite may be extensive within The Gully and crop out on exposed bedrock surfaces, its extraction would be technologically difficult using known technology and in the present economic context. Other areas of the shelf such as Georges Bank also have phosphatic nodules exposed at the seabed in shallow water and on relatively flat surfaces that would be much easier to extract. It is considered that the potential for phosphorite in The Gully is moderate but for the above reasons is considered to be uneconomic.

Calcium Carbonate

Calcium carbonate exists in the form of shells (broken and whole), coral, coraline algae, concretions and sand. It has a multitude of industrial uses including cements, paints, soil conditioning and recently has been used to deacidify lakes and streams. Presently only local extraction of marine shell occurs in Canada but the practice is widespread globally. In Ireland, concretionary marine algae growths called maerl are presently being considered for extraction.

Shells scattered and concentrated across the seabed are common on the Scotian Shelf particularly on the offshore banks and in some areas are found in circular-shaped dense patches termed "shell beds" (Fader, 1991). Eastern Sable Island Bank has vast areas of the seabed covered with shell beds. These shells are disarticulated and concentrated in patches with a diameter up to 10 m. The shells appear to be in transit from west to east across the banks and their distribution is attributed to energy conditions associated with the formation of sand bedforms at the seabed. They tend to locate in the lowest hydrodynamically stable locations in the troughs of bedforms or slight depressions on otherwise flat sand surfaces. Shell beds on Banquereau are also widespread and there they appear to be accumulating in linear clam dredge scars on the seabed as well as in circular patches. The harvest of clams on Banquereau is an active and lucrative industry. Presently the shells are returned to the seabed in the dredging area after meat extraction.

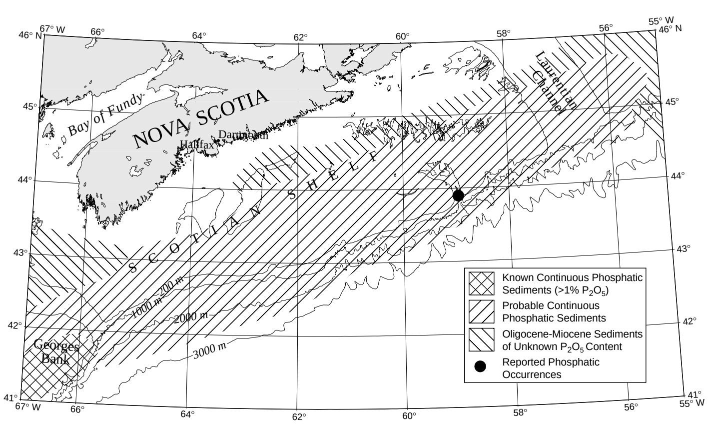


Figure 25: *A map of the distribution of known and probable phosphatic sediments for the Scotian Shelf modified after Manheim, 1972. Note the location of a dredge haul sample taken from The Gully.*

In The Gully area shells were observed between sandwaves in their troughs and in a few other scattered regions. Shell beds similar to those on the adjacent banks were not observed. Stanley et al., 1972 measured and plotted the occurrence of shell fragments in bottom samples from The Gully (Figure 26). These values indicate that the greatest density occurs on the Sable Island Bank area that is to be expected given the dense distributions of shell beds on eastern Sable Island Bank. The high values continue to the south downslope into 500 m water depth west of The Gully. Lower concentrations occur down to 200 m water depth in the northern Gully increasing to 500 m water depth toward the south. In the deep-water areas below 500 m shell fragments were low. These results for The Gully should be considered as inconclusive as too small a number of samples were collected and processed.

Carbonate from shells is considered to be a low value/ high volume commodity. Given a wide distribution of shells on the adjacent banks and the fact that they are presently a byproduct of the clam fishery and discarded to the seabed indicates that there is no present demand. Should such a demand develop it is unlikely that The Gully would be a source area given its deep depths, rugged terrain, downslope movement of sediment, and no, as yet, clearly defined localized deposits. It is therefore considered that carbonate resources in The Gully are both low and unlikely to be exploitable using known technology in the present economic context.

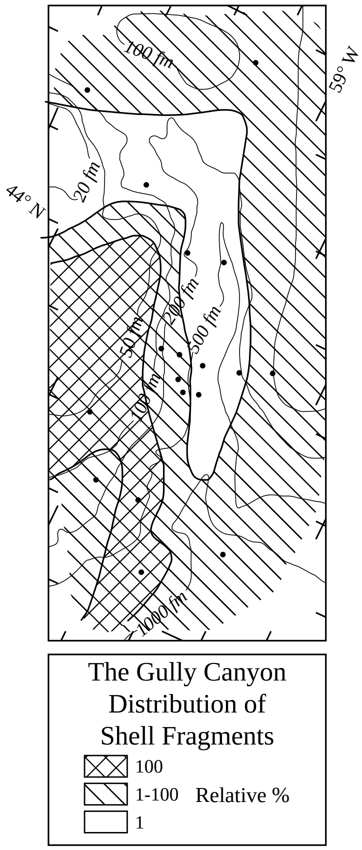


Figure 26: *The Gully percentage of shell fragments (carbonate) from Stanley et al., 1972, in the 500-1000 micron size fraction. Black dots represent sample locations.*

Silica Sand

Silica sand occurs on the continental shelf off eastern Canada in several localities. These are near the Magdalen Islands in the Gulf of St. Lawrence, at the Hibernia region of Grand Bank, Grand Banks of Newfoundland, and on Eastern Shoal, Banquereau. It has a wide variety of uses in glass and specialty glass, solar cells, fibre optic cables, insulation and a variety of other mineral processing and industrial uses. A deposit of silica sand on Eastern Shoal, Banquereau, discovered during MDA sponsored geological surveys is a very large deposit and occurs in shallow water so that extraction could be both technically possible and economic. Samples of the deposit were processed to determine purity. Six sand samples were tested from Eastern Shoal of Banquereau and were found to contain high percentages of quartz with few impurities (Maritime Testing, 1995). Chemical analyses of the samples showed the material was of suitable quality for the glass container industry and coarser fractions could be used for blasting sand. The deposit encompasses most of Eastern Shoal that is approximately 30 km long and 10 km wide. Vibrocores were collected to determine volumes and indicate suitable material at least 3 m in thickness but the seismic reflection profiles (Amos and Knoll, 1987) show that thicknesses could reach 30 m.

A geological interpretation for the origin of the silica indicates that this material is likely derived from subsurface Tertiary and perhaps Cretaceous sandstone outcropping to the north. Eroded by subglacial processes during the Quaternary from shelf crossing glaciers, the material has passed through the transgressing beach zone during the Wisconsinan postglacial period. Questions remain on whether the ice repetitively advanced across Banquereau during the Pleistocene and whether the sands have been reworked many times.

The Gully, situated to the west and south of Banquereau has a potential for occurrences of silica sand deposits. Areas of sand bedforms that occur on the northeastern area (Zone 2) of the inner Gully are interpreted to have been sourced from sand spillover off Banquereau. These sand areas are interpreted from multibeam bathymetry and sidescan sonar data and have not been sampled. The Gully boundary area also covers the southwestern corner of Banquereau which is an area dominated by sand. This zone could also contain deposits of silica sand. It is however, deeper than its counterpart on the opposite side of The Gully, Sable Island Bank, and has not been transgressed during the Holocene.

The Eastern Shoal deposit of silica sand contains very large volumes of material available in shallow water. Such a widespread availability suggests that potential silica sand deposits in The Gully and surrounding area of Banquereau are of less importance given their greater depth of occurrence, patchiness, and present unknown status. The silica sand potential of the area is therefore considered to be low.

Mineralogy of Sable Island Bank Sand

Recent samples collected by the Geological Survey of Canada and Fisheries and Oceans Canada during joint surveys in The Gully region (Figure 8) have not been processed for their mineralogy, as the objectives of the surveys were a geological and benthic habitat characterization. Therefore, in order to assess the mineral potential of The Gully we must rely on an older study conducted by Stanley et al., 1972. They discuss The

Gully region in terms of the adjacent banks of Sable Island and Banquereau, the Gully Trough to the northwest, and the central deep incised area of The Gully described as the Gully canyon. Some of that report will be summarized here. Based on an assessment of sediment transport on the Scotian Shelf and particularly the outer banks (Figure 24) most researchers agree that sand from Sable Island Bank is transported down the feeder canyons and smaller valleys of The Gully. It is therefore important to assess the mineralogical content of the sands on Sable Island Bank as a potential source for placers in The Gully.

Iron-stained quartz is the most abundant component of the sand on Sable Island Bank (Stanley et al., 1972). Feldspar is less than 15 % of the content and both quartz and feldspar are sometimes coated with ocherous hematite. Shell fragments are highly abraded and range to 10 % of the total sample volume. Mica ranges to 5 %. Garnet dominates the transparent heavy mineral suite ranging to greater than 50 %. In the 1960s there were proposals to extract garnet from the sands of Sable Island beaches but beach mining was never permitted. Hornblend, kyanite and tourmaline range between 16 and 32 % of the suite. Magnetite and ilmenite account for over 50 % of the heavy mineral assemblage. Iron nodules and dark green glauconite range to 4% of the light mineral fraction and are more prevalent on the southern part of Sable Island Bank. Pebbles consisting of a variety of mainland Nova Scotian lithologies, as well as subsurface Tertiary and Cretaceous bedrock of local origin occur on Sable Island Bank as well.

Gully Trough Mineralogy

James (1966), Cok (1970) and Stanley et al., (1972) assessed the mineralogical composition of the Gully Trough region that occurs to the north and west of The Gully. It is important to summarize that information here as the Gully Trough served as a conduit to The Gully for both pre-glacial rivers, glacial ice streams from the northwest, sub and proglacial meltwater and is a likely source for some of the sediments. Within the Gully Trough, quartz is a major component of the sand-sized fraction. Three types are recognized consisting of iron-stained quartz, clear quartz and green-stained quartz. These variations are interpreted to indicate subaerial exposure and high-energy abrasion. Glauconite is common, grains are corroded and it is interpreted to have originated from erosion of older Tertiary and Cretaceous bedrock.

Heavy minerals are most abundant in the Gully Trough on the banks and topographic highs of that region. Most of these areas were subaerially exposed or covered by very shallow water during the postglacial period and many were transgressed during the Holocene. The heavy mineral content drops off below 200 m. Stanley et al., 1972 indicate that the heavy mineral content in the Gully canyon is high in relative contrast to the Gully Trough area and they attribute this to shorter distances of sediment transport from the adjacent bank tops.

Mineralogy of The Gully (Gully Canyon) Carbonate

Lower amounts of shell and shell fragments occur in the deep water Gully canyon axis than on the canyon walls and mouth (Stanley et al., 1972) (Figure 26). The areas with the highest shell content extend from the eastern and southeastern margins of Sable Island Bank and continue downslope into the canyon. This is in agreement with the large number of shell beds found on the eastern area of Sable Island Bank (Fader, 1991).

Glauconite

Glauconite is rare on the eastern margin of Sable Island Bank and the upper areas of the Gully canyon (Figure 27). Areas with greater than 8% Glauconite occur at intermediate depths of between 100-800 m on the west wall of the canyon and on parts of the Banquereau margin. This suggests that the glauconite is of local origin from the canyon margins likely sourced from Tertiary bedrock.

Heavy Minerals

The heavy mineral content of The Gully was assessed from a study of the fine-grained sand component (Stanley et al., 1972). The distribution of zircon (Figure 28) is irregular. In the coarse 125 to 250 micron size fraction, zircon is relatively abundant in the upper Gully and at its mouth, while sparse in the central portion. The proportion of opaque minerals in the coarser fraction increases to the south and does not appear to be related to the morphology of The Gully (Figure 29). The relative percentage of fine fraction opaques does display such a relationship with samples from the canyon axis being of low value.

Within the coarse fraction of garnet (Figure 30), values are low in a region extending from Banquereau down the canyon east wall and across the mouth. High garnet values occur along the axis of the canyon. It is postulated that some of the linear trends along the margins of the canyon may be related to local sources cropping out along the canyon walls, Stanley et al., 1972. This outcrop is verified by recent photographic and video observations collected along the canyon walls in depths down to 500 m.

The assemblage of both opaque and heavy minerals is similar to that found in Oligocene and Miocene rocks on the walls of the canyon (Marlowe, 1969). Erosion of exposed bedrock in The Gully has contributed some of these minerals. However, Stanley et al., 1972 conclude that the mineral suite of The Gully is largely sourced from plutonic, metamorphic and sedimentary rock terrains 200 kilometers to the northwest from the mainland of Nova Scotia and the adjacent inner Scotian Shelf and as such are classified as allochthonous minerals.

Heavy Mineral Placers In the Deep Water Gully

The downslope movement of material in The Gully has been clearly observed form video observations during the most recent surveys. In places, this erosion of the walls of The Gully is exacerbated by bottom living demersal fish that remobilize sediments resting on bedrock-controlled ledges. Sidescan sonar clearly shows patterns of downslope movement of fine-grained material across bedrock ledges. The deep-water thalweg floor of The Gully consists of with fine-grained sand and organic flock with active ripples on the sand surface. Slumps are clearly seen with headwall scarps in the shallower areas of The Gully near the head. The multibeam bathymetry suggests that ice was grounded in at least 800 m of water depth during the Wisconsinan maximum advance depositing bouldery tills and producing linear side canyon sills and channel blocking moraines. Below this depth, there is a major change in materials and morphological character suggesting that the deeper areas have never been subjected to direct ice erosion. All of these observations and characteristics

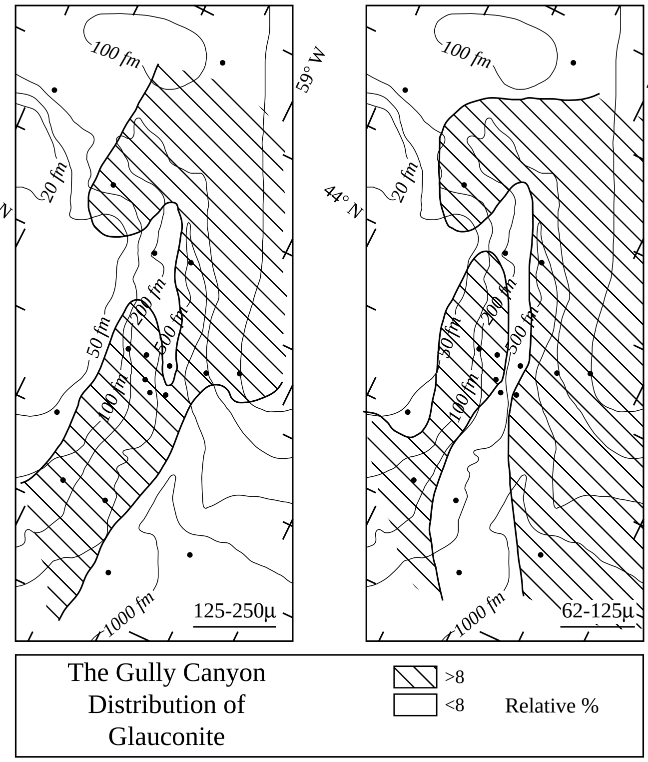


Figure27: *The Gully percentage of glauconite in the a) 125 – 250 micron and b) 62 – 125 micron size fraction from Stanley et al., 1972. Black dots represent sample locations.*

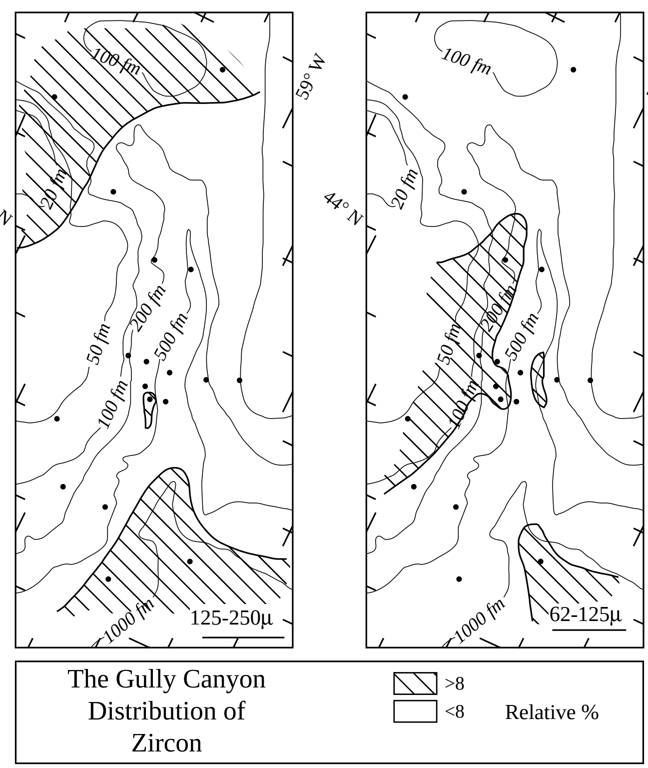


Figure 28: *The Gully relative percentage of zircon in the a) 125 – 250 micron and b) 62 – 125 micron size fraction from Stanley et al., 1972.*

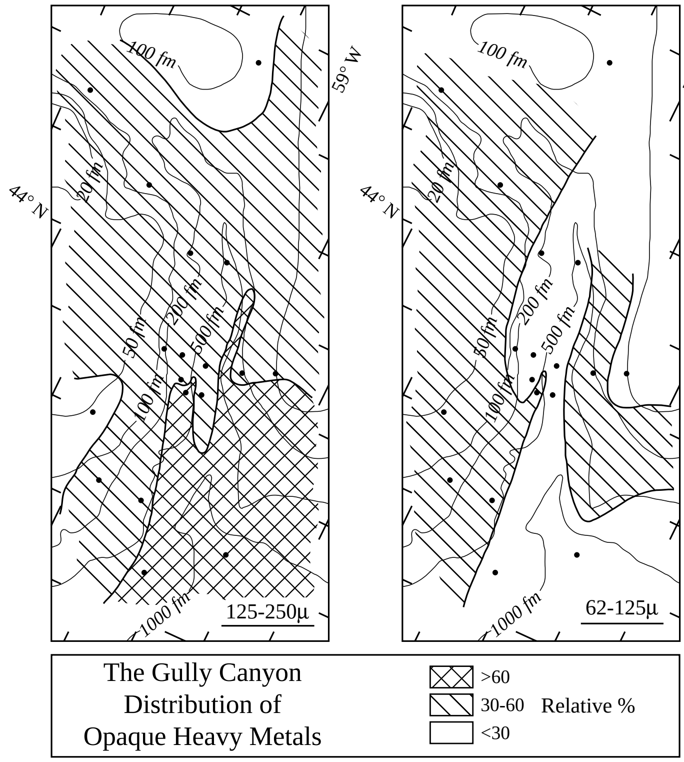


Figure 29: *The Gully relative percentage of opaque heavy minerals of the a) 125 – 250 and b) 62-125 micron size fraction from Stanley et al., 1972.*

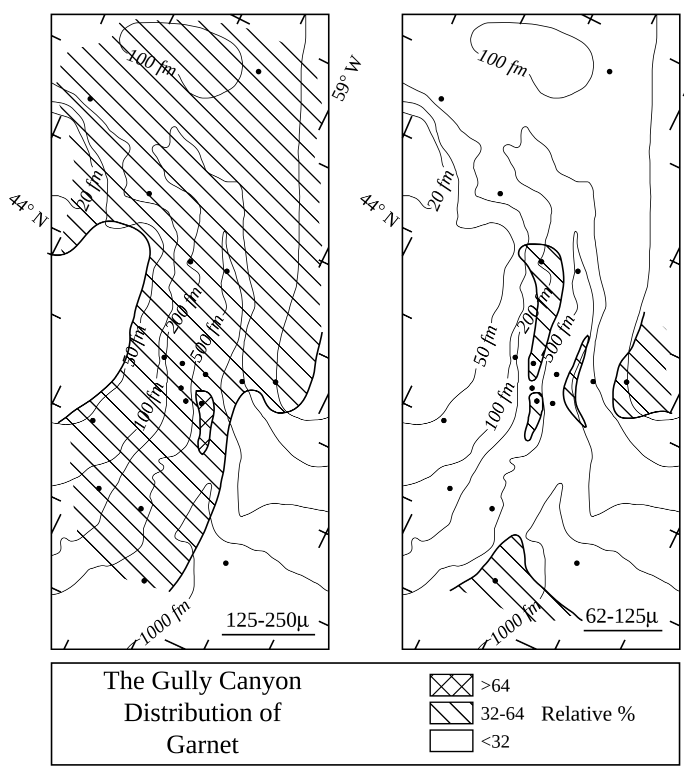


Figure 30: *The Gully relative percentage of garnet in a) 125 – 250 and b) the 62 – 125 micron sized fractions from Stanley et al., 1972.*

indicate that indeed The Gully is, and has been, a conduit for movement of glacial and post-glacial material from the shelf and adjacent banks as well as subjected to internal erosion.

The presence of glacial ice in the inner Gully suggests that sub glacial meltwater periodically flowed down The Gully deep thalweg and subjected previously deposited sediments and bedrock to variable high-energy environments. These water movements would have provided enough high energy to concentrate minerals in local areas. A bathymetric profile along the thalweg of The Gully (Figure 16) shows a uniform non-overdeepened profile along its length. This indicates that recent sediment transport and deposition has infilled overdeepened depressions that would be expected to occur along the channel given a history of multiple glaciation and varying energy conditions. No samples of concentrated heavy mineral deposits have been collected in the deep-water areas of The Gully. Such deposits may be buried beneath muddy sediments that occur in the deeper areas of The Gully. So despite having reoccurring potential environments for the concentration of minerals, none to date have been sampled. This would require a deep-water sampling capability to core granular materials and a better understanding of where they might occur based on the collection of high-resolution seismic reflection profiles. The potential for heavy mineral occurrences in The Gully is therefore considered to be low to very low.

Summary and Discussion

An understanding of the geological history of The Gully including the most recent glacial history has been greatly advanced by the collection, processing and interpretation of multibeam bathymetry. Evidence from this information suggests that ice was grounded in depths as deep as 800 m during the late Wisconsinan last ice advance, and this information provides an environmental control on the potential for mineral development in those depth ranges. Marine deposited tills generally lack an economic concentration of minerals so most of the inner Gully (Gully Trough) is considered to have a low to very low potential. The exception occurs with regard to aggregates. Postglacial transgression of areas shallow than 100 m (Sable Island Bank east) has resulted in the development of lag gravels and transgressive well-sorted sands of potential economic value. Additionally, modern sediment transport processes and spillover form adjacent

Sable Island Bank and Banquereau has deposited sand and gravel in some areas of the inner Gully. The shallow areas above 100 m water depth of eastern Sable Island Bank and western Banquereau have been transgressed and these areas are also a potential source of extractable aggregates. The deposits on the bank areas are more likely a potential target for extraction because of their shallow depths of occurrence in contrast to those found in deeper water in the inner Gully. Thus the potential for aggregates in The Gully study area is considered to be high.

During retreat of glacial ice from the Gully region, as indicated by a series of retreat moraines on the Banquereau flank of The Gully, it is interpreted that significant subglacial meltwater events provided high energy conditions within The Gully. These could have sorted, transported and deposited concentrations of minerals from both the Gully Trough and the adjacent banks. Such concentrations would be buried beneath Holocene fine-grained muds and sand later transported from the adjacent banks. Cok, (1970) in an assessment of the heavy mineral assemblages of the eastern Scotian Shelf suggested that The Gully province was mineralogically very simple. Garnet was considered to be the only significant heavy mineral. The source for this material was considered to be the mainland of Nova Scotia, therefore, the Tertiary and nearby Cretaceous bedrock was considered to have contributed few heavy minerals to The Gully, mostly glauconite. Some of the sands on the adjacent banks and in the inner Gully could represent silica sand deposits but have not been evaluated for this potential. Significant deposits of silica sand on eastern Banquereau occur in much shallower water depths and offer alternate sources.

The greatest potential for mineral extraction within The Gully region lies with sand and gravel deposits. Some deposits are very thick (Figure 20) and occur in enormous quantities. The sands are well sorted and of suitable quality for a multitude of industrial uses. However, regionally available similar deposits across the Scotian Shelf render The Gully materials as common and not unique. The exception may lie with future needs for a local source of aggregate (sand) for beach/island reclamation in a general environment of sea level rise and island erosion associated with preservation of Sable Island as a strategic feature of the outer Scotian Shelf. A readily available source of material from eastern Sable Island Bank, already in transport to be eventually lost down The Gully, could provide a viable and cost effective candidate from within the bounds of The Gully proposed Marine Protected Area.

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References

Amos, C. L., 1989. Quaternary sediments and bedforms of the Scotian Shelf observed from the submersible Pisces IV; in Submersible Observations off the East Coast of Canada, D. J. W. Piper (ed.); Geological Survey of Canada, paper 88-20, p. 9-26.

Amos, C. L. and Fader, G. B. 1988. Natural Resource map Series of Sable Island Bank, the Gully, Middle Bank, and Banquereau; Geological Survey of Canada, Open File 2244.

Amos, C. L., and Knoll, R. 1987. The Quaternary sediments of Banquereau, Scotian Shelf, Geological Society of America Bulletin 99: p. 244-260.

Amos, C. L. and Nadeau, O., C. 1988. Surficial sediments of the outer banks, Scotian Shelf, Canada. Canadian Journal of Earth Sciences. Volume 25. Number 12. p. 1923-1944.

Amos, C.L, Chiocci, F.L., La Monica, G.B., Cappucci, S., King, E.L., Li, M.Z. and Corbani, F. (in prep.) The origin and character of modern shore-normal channels from the shoreface of Sable Island, Canada.

Cameron, H.L., 1965. The shifting sands of Sable Island. Geographical Review, v. 55, p. 463-476.

Cok, A. E. 1970. Morphology and Surficial Sediments of the Eastern half of the Nova Scotian Shelf. Unpublished Ph.D. dissertation, Dalhousie University, Halifax, 261 pages.

Emory-Moore, M. 1993. Marine Placer formation on glaciated coastlines: deposit types, assessment criteria and site investigations in Newfoundland and Labrador; Ph. D. dissertation, University of Mississippi, 169 p.

Fader, G. B. J., 1991a. Gas-related sedimentary features from the eastern Canadian continental shelf. Continental Shelf Research, Vol. 11, Nos. 8 - 10, pp. 1123 - 1153.

Fader, G.B.J., 1991b, in: Ross, D. I.; Lewis, C. F. M.; Howie, R. D.; Cant, D.; Bates, J. L. 1991. Surficial geology and physical properties 5: surficial geology / Géologie des formations en surface et propriétés physiques 5: géologie des formations en surface; Scotian Shelf / Plate-forme Néo-Écossaise Geological Survey of Canada, East Coast Basin Atlas Series, page 119.

1990, Fader, G.B.J. and Miller, R.O., Nearshore Nova Scotia Studies for Marine Placers and Aggregates. Nova Scotia Department of Mines and Energy Open House, Nov. 1990.

Fader, G.B.J. and Miller R.O., 1994. The aggregate potential of the Scotian Shelf and adjacent areas, Proceedings Coastal Zone Conference, Halifax, September, pp. 230-262.

Fader, G.B.J. and Miller, R.O. (in prep.) The surficial geology of Halifax Harbour, Nova Scotia. Geological Survey of Canada Bulletin.

Fader, G. B. J.; Miller, R. O.; Stea, R. R.; Pecore, S. S. 1993. Cruise report, C.S.S. Dawson 91-018, inner Scotian Shelf, June 4-21, 1991; Geological Survey of Canada, Open File Report No. 2633, 30 pages.

Fader, G. B. J., Piper, D. J. W. and Amos, C. L. 1998. Surficial, bedrock geology and morphology of The Gully, In: Harrison, W. G. and D. G. Fenton (eds.) The Gully: A Scientific Review of its Environment and Ecosystem. DFO Can. Stock Assessment Sec. Res. Doc. 98/83. pp. 7-12.

Fader, G. B. J., and Strang, J. 2002. An interpretation of multibeam bathymetry from The Gully, outer Scotian Shelf: materials, habitats, slopes, features and processes. In: Advances in Understanding The Gully Ecosystem: A Summary of Research Projects Conducted at the Bedford Institute of Oceanography (1999-2001), Edited by D. C. Gordon Jr. and D .G. Fenton. Canadian Technical Report of Fisheries and Aquatic Sciences No. 2377. pp. 5-16.

James, N. P., 1966. Sediment Distribution and Dispersal patterns on Sable Island and Sable Island Bank. M. Sc. Thesis, Dalhousie University, Halifax, Nova Scotia, Canada. 254 pages.

King, E.L., 2001. A glacial origin for Sable Island: ice and sea level fluctuations from seismic stratigraphy on Sable Island Bank, Scotian Shelf, offshore Nova Scotia. Geological Survey of Canada, Current Research 2001-D19, 11 p.

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.

King, L. H., and MacLean, B. 1976. Geology of the Scotian Shelf. Geological Survey of Canada, Paper 74-31.

King, L. H., MacLean, Brian and Fader, Gordon B. 1974. Unconformities on the Scotian Shelf. Canadian Journal of Earth Sciences, Volume 11, Number 1. pp 89-100.

Kostylev, V., 2002. Benthic assemblages and habitats of the Sable island Gully. In: D.C. Gordon and D.G. Fenton, eds. Advances in understanding the Gully Ecosystem. A Summary of Research Projects Conducted at the Bedford Institute of Oceanography (1999-2001), Edited by D. C. Gordon Jr. and D .G. Fenton. Canadian Technical Report of Fisheries and Aquatic Sciences No. 2377, pp17-30.

MacLean, B. and King, L. H. 1971. The surficial geology of Banquereau and Misaine Bank. Geological Survey of Canada, Paper 71-52.

Manheim, Frank T., 1972. Mineral Resources off the Northeastern Coast of the United States. United States Geological Survey, Geological Survey Circular 669. 28 pages.

Maritime Testing (1985) Limited. 1995. Aggregate testing of marine sand and gravel samples from offshore Cape Breton Island; Geological Survey of Canada, Open File Report No. 3087, 107 pages.

Maritime Testing (1985) Limited. 1995. Testing of marine seabed samples from the eastern Scotian Shelf for aggregate characteristics; Geological Survey of Canada, Open File Report No. 3177, 250 pages.

Maritime Testing (1985) Limited. 1996. Testing of marine seabed samples from the Scotian Shelf, Bay of Fundy and adjacent areas for aggregate characteristics, CSS Hudson mission 95-030; Geological Survey of Canada Open File Report No. 3370, 303 pages.

Marlowe, J. I,. 1965. Probable Tertiary Sediments from a Submarine Canyon off Nova Scotia. Marine Geology, V 3, pp. 263-269.

Marlowe, J. I,. 1969. A Succession of Tertiary Strata off Nova Scotia, as determined by dredging. Canadian Journal of Earth Sciences, V 6, pp. 1077-1094.

McLaren, S.A,. 1988. Quaternary seismic stratigraphy and sedimentation of the Sable Island sand body, Sable Island Bank, outer Scotian Shelf; Unpublished MSc Thesis, Centre for Marine Geology, Dalhousie University, Technical Report 11, 95 p.

Medioli, F,. Stanley, D.J. and James, N., 1967. The physical influence of a paleosol on the morphology and preservation of Sable Island, of the coast of Nova Scotia. *In* Quaternary Soils (R.B. Morrison and H.E. Wright editors). Proceedings of the International association for Quaternary Research, v. 9, VII Congress. pp. 246 –259.

Jacques/McClelland Geosciences Inc., 1983. Venture H-22 Wellsite Jack-up rig foundation analysis Zapata “Scotian” Geotechnical report, Project No. GO14, June 1983.

Scoates, R. F. J., Jefferson, C. W. and Findlay, D. C. 1986. Northern Canada mineral assessment: in Prospects for mineral resource assessments on public lands; Proceedings of the Leesburg Workshop, M. Cargill and S. B. Green (eds.), United States Geological Survey, Circular 980, p.111-139.

Scott, D. B., 1977. Distribution and population dynamics of marsh-estuarine foraminifera with applications to relocating Holocene sea level. Ph. D. Dissertation, Dalhousie University, Halifax, 207 p.

Scott, D.B; Boyd, R.; Douma, M.; Medioli, R.S.; Yuill, S.; Leavitt, E.; and Lewis, C.F.M,. 1989. Sable Island Bank: Holocene relative sea-level changes and Quaternary glacial events on a continental shelf edge; In: (D.B. Scott, P.A. Pirazzoli and C.A. Honig, editors) Late Quaternary sea-level correlation and applications: NATO ASI Series C, Mathematical and Physical Sciences, v. 256, p.150-120.

Stanley, D. J. and Silverberg, N., 1969. Recent Slumping on the Continental Slope off Sable Island Bank, Southeast Canada. Earth and Planetary Science Letters, v 6, pp.123-133.

Stanley, D. J.; Swift, D. J. P.; Silverberg, N.; James, N. P. and Sutton, Robert G., 1972. Late Quaternary Progradation and Sand Spillover on the Outer Continental Margin off Nova Scotia, Southeast Canada. Smithsonian Contributions to the Earth Sciences. Number 8. 88p.

Stea, R. R.; Pecore, S. S. and Fader, G. B. J., 1993. Quaternary stratigraphy and placer gold potential of the inner Scotian Shelf. Nova Scotia Department of Natural Resources, Mines and Energy Branches Paper 93-2, 62p.