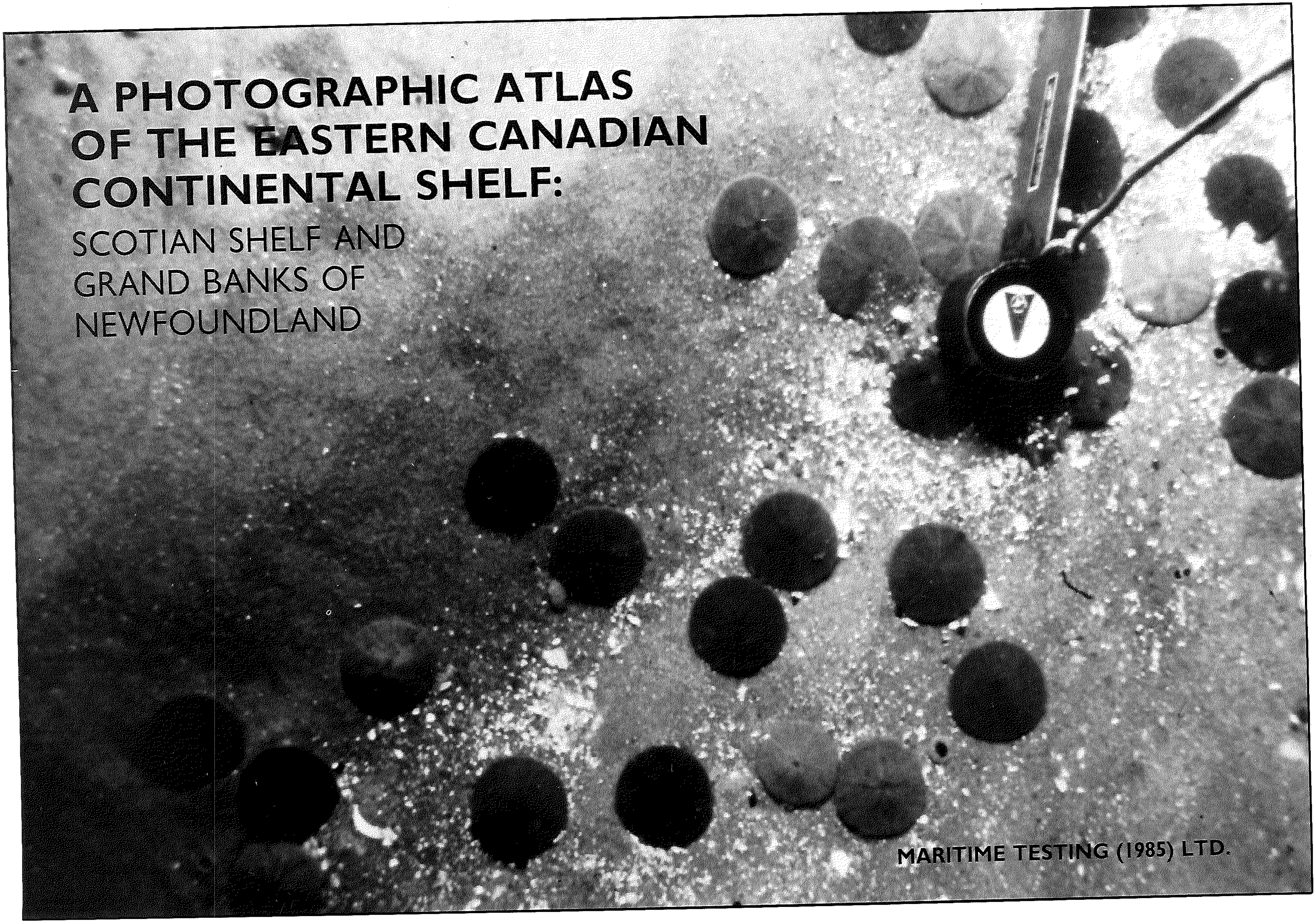
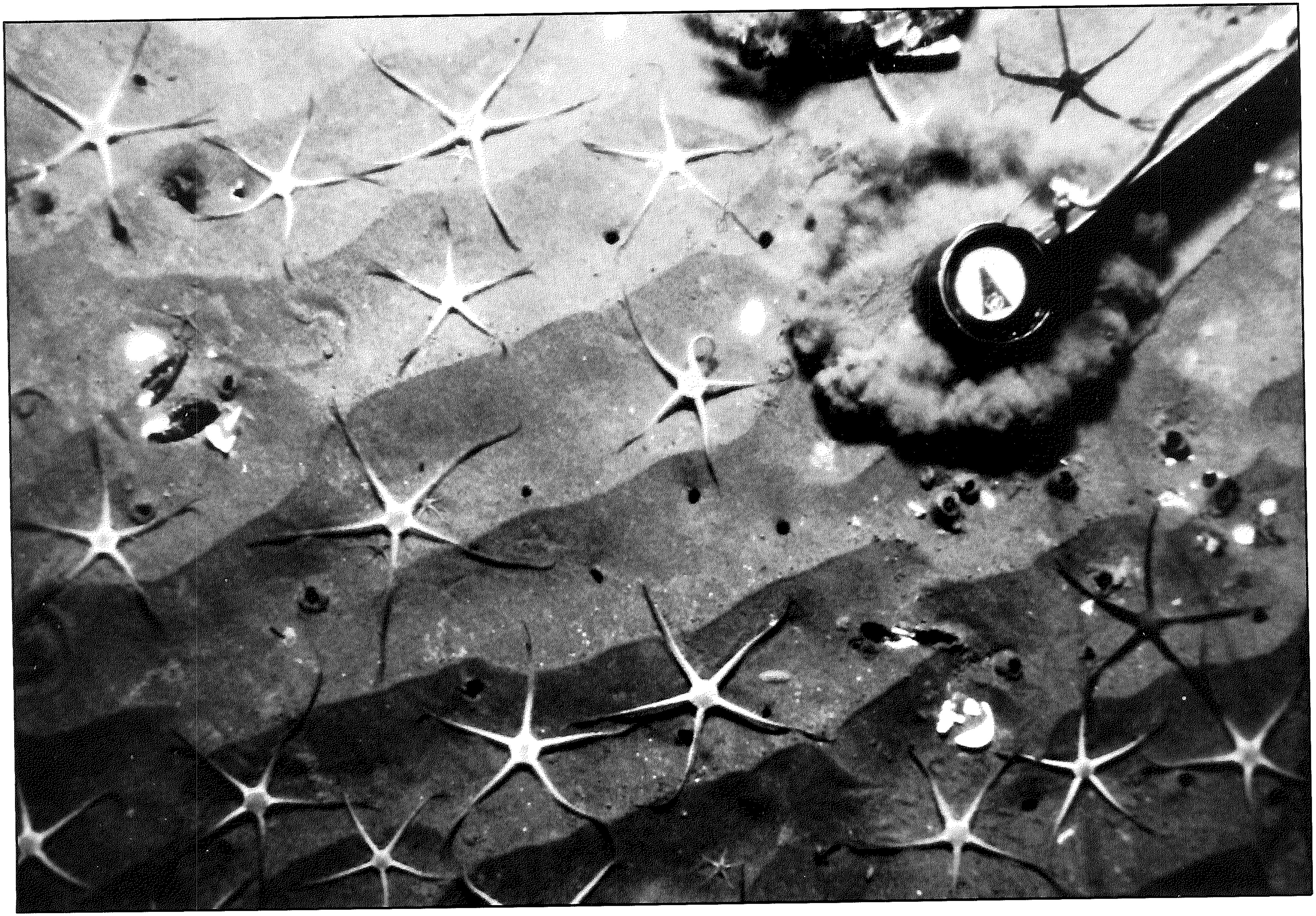


A PHOTOGRAPHIC ATLAS OF THE EASTERN CANADIAN CONTINENTAL SHELF:

SCOTIAN SHELF AND GRAND BANKS OF NEWFOUNDLAND

MARITIME TESTING (1985) LTD.



A PHOTOGRAPHIC ATLAS OF THE EASTERN CANADIAN CONTINENTAL SHELF

Scotian Shelf

Grand Banks of Newfoundland

Maritime Testing (1985) Limited

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ABSTRACT

This photographic atlas of the Scotian Shelf and Grand Banks of Newfoundland utilises a large collection of seabed photographs held mainly by the Atlantic Geoscience Centre, Geological Survey of Canada, at the Bedford Institute of Oceanography. The photographs were collected over many years in support of geological surveys of the eastern Canadian continental shelf, and have been largely inaccessible to the scientific, academic and industrial community. The atlas presents information on surficial sediments and benthic organisms identified from the photographs.

Photographs are presented to illustrate all of the surficial geological formations which occur on the contentintal shelf off southeastern Canada. Some geographical regions have better representation than others. Major benthic community types are well represented in the photographs. Where photographs were available, emphasis was placed on areas of special interest such as potential hydrocarbon reserves - the Venture area of Sable Island Bank, the Hibernia area of Grand Bank, and Georges Bank.

A series of indices permit the atlas to be used on a physiographic, geological, biological or geographical basis, and data tables enable cruise reports and other data collections that accompanied individual photographs to be accessed.

Résumé

Cet atlas photographique de la plateforme Scotian et des Grands Bancs de Terre-Neuve utilise une grande collection de photographies du fond marin détenues en grande partie par le Centre Géoscientifique de l'Atlantique, Commission Géologique du Canada, Centre Océanographique de Bedford. Les photographies ont été recueillies sur plusieurs années dans le cadre d'études géologiques de la plateforme continentale de l'est du Canada. Jusqu'à présent, la plupart de ces photographies n'étaient pas accessibles à la communauté scientifique, académique et industrielle. L'atlas présente des informations sur les sédiments de surface et les organismes benthiques identifiés à partir des photographies.

Les photographies sont présentées pour illustrer toutes les formations géologiques superficielles que l'on trouve sur le plateau continental au large du sud-est du Canada. Quelques régions géographiques sont mieux représentées que d'autres. Les principaux types de communautés benthiques sont bien représentés par les photographies. Lorsque les photographies étaient disponibles, l'emphase a été mise sur des secteurs d'intérêt spécifique comme les réserves potentielles en hydrocarbures: la zone Venture du banc de l'Ile de Sable, la zone Hibernia des Grands Bancs et le Banc George.

Une série d'indexes permet d'utiliser cet atlas sur une base physiographique, géologique, biologique ou géographique. Des tables de données rendent accessibles les rapprts des missions océanographiques ainsi que les autres séries de données qui accompagnent chaque photographie.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

Many people have contributed, either directly or indirectly, to the evolution and production of this atlas. We wish to thank L.H. King, B. MacLean, and H. Josenhans who collected many of the early photographs of the Scotian Shelf during the development of the surficial mapping programme. R.O. Miller provided valuable information on much of the station data and provided easy access to the large collection of photographs. G. Collins, M. Keen, D. Ross and R. Taylor provided management advice and support of the project. N. Fenerty, former head of the BIO photo laboratory, together with R. Belanger, H. Weile and K. Bentham provided support to the camera frame design, maintenance, and took many of the photographs while at sea. I. Hardy reviewed an earlier draft of the atlas and made available many of the photographs and charts that were used.

We also thank the manager of the Unsolicited Proposals fund for support of the project. B. Hargrave and P. Schwinghamer provided funding, moral support and helped formulate many of the original ideas during design of the atlas. The original idea for this atlas, together with a first draft of the proposal, was provided by S. Conover.

Photographs and interpretation were provided by the following: C. Amos provided BRUTIV material taken from Banquereau and Sable Island Bank and reviewed sections on bedforms; M.-I. Buzeta of Fundy Bear Enterprises provided photographs of Passamaquoddy Bay; D. Davis discussed the content of photographs; E. Dawe provided photographs of Conception Bay; M. Douma permitted us to peruse the Microfiche Well Site Reports which is progress; D. Forbes provided photographs taken by hand from Pisces IV off the eastern shore of Nova Scotia; D. Frobel made photographic viewing room available for viewing tapes; B. Frost provided information on the photographs from the southwest Scotian Shelf; J. Grant provided slides of Emerald Bank and Emerald Basin; M. Hutcheson provided photographs from the Hibernia area of the Grand Banks; D. Lawrence found several charts for the project; D. Lefevre had prints made of photographs from off Cape Sable south shore Nova Scotia; U. Lobsiger provided technical information on photographs from the southwest Scotian Shelf; C. Majka provided station data on the Emerald Bank and Emerald Basin photographs; K. Muschenheim contributed valuable discussion on the impact of some species on sediments; R. Parrot provided material from the Grand Banks; D. Peer contributed to the general biological discussion of some photographs; C. Ross allowed viewing of well site surveys; T. Rowell printed photographs; A. Ruffman provided access to his files and suggestions on photographs sources; P. Smith reviewed the Physical Oceanography; P. Stall supplied photographs from the Scotian Shelf, Emerald Bank and mid shelf area; M. Strong provided photographs of Passamaquoddy Bay; G. Tidmarsh permitted use of Texaco well site survey material from northern George's Bank; L. Watling helped with some invertebrate identification; and D. Wildish provided photographs of the southwest Scotian Shelf. To each of you, together with anyone whose name has been left out, we offer our thanks.

CHAPTER 1

INTRODUCTION

The idea for this atlas of underwater photographs grew and developed as a result of interest from both government and industry over many years. Most of the photographs were initially collected as an essential groundtruth component of surficial geological mapping programs of the continental shelf by the Atlantic Geoscience Centre, Geological Survey of Canada, at the Bedford Institute of Oceanography. Few of the many hundreds of photographs collected were actually published, but their interpretations were incorporated into geological maps of sediment type and distribution. As the southeastern Canadian offshore was explored for hydrocarbons and later evaluated for the development of these resources, the photographic data base was consulted on a regular basis. For the atlas the information taken from the photographs concerned environmental issues such as the distribution and diversity of the benthic communities, evidence of sediment transport, foundation stability and the effects of exploratory drilling for hydrocarbons. As the systematic mapping progressed across the Scotian Shelf to the Grand Banks of Newfoundland, the application of new geophysical equipment such as high resolution seismic reflection and sidescan sonar systems required additional detailed groundtruthing of small seabed features. This resulted in the development and application of new systems for the collection of photographic data such as the "BRUTIV" towed camera sled and the use of submersibles, such as Alvin and the Pisces IV, and remotely operated vehicles, ROV's. When taken in its entirety, the photographic resource was considered as a regional data base with locations well-representative of the varying environments of the continental shelf such as water depth, physiographic setting and sediment type.

During the collection and interpretation of the bottom photographs, geologists realised not only the immense quantity of available information concerning the biology of the seabed, but also the potential for correlation between sediment type and benthic communities. The biological scientific community became interested in the data base for these reasons and consulted it regularly. This use expanded to the industrial community from both a fisheries and petroleum perspective and the photographs were used more and more for a wide variety of reasons. These ranged from the assessment of the potential for a new Icelandic scallop fishery on the Grand Banks to the documentation of seabed geological conditions along the proposed pipeline corridor from the Venture gas field on Sable Island Bank to Nova Scotia.

For these reasons we realised that the resource was important to a wide variety of users and that it was essential to raise the awareness of the collection, to summarise the large number of photographs, and to demonstrate the correlation between the benthic communities and the seabed geology. After several failed earlier attempts to undertake such a project, its value became more obvious to a wider community and funding was secured. The compilation and interpretation of the data during the atlas preparation also increased the awareness of the potential for such a data base. Trends in sediment transport and their effects on the geology and benthic communities became clearer and similarities among broad areas of the shelf could be observed that in the absence of such a regional comparision would normally be missed. The regionality of the data base provides baseline information on the health and diversity of the benthic community which can serve as background information for environmental assessment and global change studies.

The atlas is designed to meet the needs of a wide variety of users. This includes specialists in the fields of engineering, sedimentology, biology, ecology and those with a more general interest in the seafloor such as the fishing community and oceanographic students. It is not a comprehensive compilation of all environments of the shelf as existing photo stations were used in the text and funding was not sufficient to fill some of the gaps. As well as the photographs from the Atlantic Geoscience Centre, additional photographs have been used that were collected by other agencies and by private individuals as indicated in the Acknowledgements.

Bottom photography was first used as a scientific tool by scientists at the Bedford Institute of Oceanography in 1964. The first pictures were collected with bottom-triggered camera systems using black and white film. The use of colour film was introduced in 1968-69, although black and white pictures continued to be taken after this date, mainly for reasons of picture quality in scientific publications. The earliest photographs on the Scotian Shelf that were accessed in this atlas are from 1969, and pictures from the Grand Banks of Newfoundland date from 1973. Video, submersible and ROV photography has been introduced in recent years, and some examples of photographs using these techniques are included in the atlas.

The original basis for the collection of the photographs was geological, and was often designed as a groundtruthing method for results from remotely sensing seismic reflection and sidescan sonar data. Because of this relationship and the correlation often seen between sediment type and benthic distributions, the atlas is constructed using geology as the framework for presentation of the data. In addition, the distribution of sediments on the continental shelf is directly related to water depth (geomorphology).

Areas of greater geological complexity and/or interest have a more complete coverage. As might be expected, areas of greater economic interest, such as the Venture and Hibernia areas of the shelf have a greater intensity of coverage.

Within the atlas it is possible to access the pictures from a geographical standpoint by consulting the index for location names. The photographs have been divided into two main groupings, the Scotian Shelf and the Grand Banks of Newfoundland.

Chapters describing the methodology, geology, physical oceanography and benthic biology of the Scotian Shelf and Grand Banks of Newfoundland have also been included. These are intended as summary chapters and the reader is referred to scientific reports where details are presented.

CHAPTER 2

METHODOLOGY

Methods in Underwater Photography

Most of the photographs used in this atlas were collected using a standard 35 mm camera with a wide angle lens enclosed in a water-tight case with a port. This set-up is equipped with a light source synchronised with the shutter.

A simple arrangement of this equipment can be hand-held and used by divers; however, the divers are limited by depth, and photographs from this source are rarely from depths exceeding 50 m.

A more robust arrangement of the equipment is deployed directly on a cable from a ship, and is used for continental shelf photography. The camera, mounted in a frame with the light source, may be triggered by a weight (a compass with a vane seen in many of the photographs). The weight hangs below the camera, and when it touches the bottom it triggers a switch which allows the camera to fire. The camera is raised and lowered many times at a single station. This method achieves a series of photographs at a fixed distance from the bottom. The main disadvantages of this method is that a plume of fine-grained sediment may be thrown up by the weight as it lands on certain sediments, and the weight often appears on the photographs. Alternatively, the camera may be triggered by a system where the distance from the sea floor is regulated by a series of reed-switches and magnets suspended below the camera. This method results in less disturbance of the sediment. Similarly, a pinger attached to the camera frame can determine distance from the sea floor, and the camera is fired at a prescribed distance from the bottom. New electronic and sonar equipment is now available which gives a read-out of the distance from the seabed and other important information on each frame. However, in all the systems other than the weight triggered setup, the added complexity sometimes results in problems and increased time on station. Like all marine equipment, the philosophy of "keep it simple" often works best.

Some studies use time lapse photography, deploying the camera on a sturdy frame or tripod on the seabed. The camera takes photographs at regular intervals over a prescribed time period, or can be controlled to turn on in response to an event such as a storm. Other methods use a frame of precise size equipped with two cameras at a fixed distance from the seabed. These cameras are set to fire simultaneously, producing stereo pairs of photographs, which, when viewed in a stereo viewer, appear three dimensional.

Cameras may be attached to towed vehicles such as BRUTIV, a bottom-referencing underwater towed instrument vehicle. These devices are towed by a ship over large distances, and the camera takes pictures of the seabed at regular intervals. Remotely operated vehicles (ROVs) can also be used for this purpose.

In addition to the above methods, pictures may be taken outside or within a submersible, using either still or video cameras. Several of the photographs used in this atlas were taken from the submersible Pisces IV.

Scale

Unfortunately, because of the varied sources, methods of photography and instability inherent in the camera frame system (ship drift or strong currents often turn the camera on its side), no scales are available with the photographs. For geological purposes the focal distance of the ship mounted camera frame is fixed, and standard at 1 m above the seabed. In some of the pictures, however, the compass/weight can be seen. It has an overall length of 320 mm; the compass is 75 mm in diameter and the vane is 245 mm long. In other pictures, scale may be deduced from familiar invertebrates such as sand dollars or brittle stars, whose size may be estimated.

Identification of Sources of Photographs

The first resource investigated was at the Atlantic Geoscience Centre, Geological Survey of Canada, at Bedford Institute of Oceanography. This collection was predominantly held by G.B. Fader, Environmental Marine Geology, who has been responsible for the acquisition and collation of many photographs of the seabed off eastern Canada in the course of regional surficial geological investigations. They were available in album or colour transparencies format. Most of the photographs in this atlas came from that source. Several other scientists from the Atlantic Geoscience Centre provided valuable additional material from particular sites or of particular features. In addition, scientists at the Department of Fisheries and Oceans (Dartmouth, Halifax, St. Andrews, St. Johns and Mont Joli), Defence Research Establishment Atlantic (Dartmouth), Dalhousie University, local consulting companies and other individuals were canvassed for photographs of the seabed. Enquiries were also directed to oil companies

(Texaco and Mobil) and Teleglobe Canada, a telecommunication company. The end result was a large collection of seabed photographs ranging from northern Grand Bank to northern Georges Bank. Included were photographs of coastal and mid-shelf areas, basins, channels, and inner and outer banks, as well as unique areas such as Flemish Cap.

Selection of Photographs

Selection of photographs was made by choosing the photograph with the clearest image from each series of a particular geological, biological or area feature. In several instances, compromises were reached where even the best photograph of a series was of poor quality but was included because of its content.

Analysis of Photographs

Photographs were initially examined to determine the sediment type and to select a representative set for each of the surficial formations from the Scotian Shelf and the Grand Banks of Newfoundland (Tables 1 and 2). In addition, they were also examined to ensure that the different biological communities described in classical ecological treatments of the area were also represented. The sediment type was then described based on a textural assessment of the sediment in the photograph, or from samples collected at the same location. Shape, sorting and size of the clasts, amount and nature of biogenic growth and presence or absence of bedforms (ripples, megaripples) were evaluated. The sediment size classification (Wentworth scale) was consulted where samples at that location had previously been analysed. The sample positions were plotted on published and compiled maps of sediment distribution and an overall

Table 1

Distribution of Photographs by Photo Number on Sediment Types of the Scotian Shelf

Sable Island Sand Facies	Sand and Gravel Gravel Facies	LaHave Clay	Sambro Sand	Emerald Silt	Scotian Shelf Drift
9	13	10	9	24	32
39	14	11	12	29	47
43	15	23	17	31	48
45	16	25	18	33	49
46	19	26	27	37	51
53	20	31	28		52
54	21	32	30		81
55	35	34	40		
56	36	38	50		
57	41				
58	42				
59	65				
60	66				
61	67				
62	68				
63	75				
64	76				
69					
70					
71					
72					
73					
74					
77					
78					
79					
80					

Table 2
Distribution of Photographs by Photo Number on Sediment Types of the Grand Banks of Newfoundland

Grand Banks Sand and Gravel: Sand Facies	Grand Banks Sand and Gravel: Gravel Facies	Placentia Clay	Adolphus Sand	Downing Silt	Grand Banks Drift	Bedrock
6	85	101	97	90	7	137
87	86	102	98	91	8	138
108	88	153	118	155	92	139
110	89	154	149	93	140	157
111	104	156	160		94	
112	106		161		95	
113	109		162		96	
114	123				99	
115	129				100	
116	130				103	
117	131				105	
119	132				107	
121	133				128	
122	134				155	
124	135					
127	136					
140	142					
141	143					
146	145					
148	147					
150	151					
152						

determination of the formation represented by the sample was made. In areas where samples were collected from transitional formation boundaries, further evaluation of the field data logs, and/or supporting sidescan sonar and seismic reflection data was undertaken.

The marine animals and plants in each photograph were identified to the lowest possible taxonomic level. Comments were then added on the observed biological features as well as on the biological community. Notes on the interactions of the fauna with the sediments and other environmental features were combined with the above comments to develop a balanced informative caption to accompany each photograph.

The geographic location (latitude and longitude) and the water depth (m) were included for the majority of the photographs. Locations of all photographs are indicated on Figure 1. The cruise and station numbers and the source of each photograph is included in Appendix Tables 1 and 2.

Sample Data Requests

Requests for Atlantic Geoscience Centre sample and record availability should be directed to Director, Atlantic Geoscience Centre, Bedford Institute of Oceanography, P.O. Box 1006, Dartmouth, Nova Scotia, Canada, B2Y 4A2. Plots of the samples and record locations within specified boundaries can also be directed to the Data Management Section (PSS), Atlantic Geoscience Centre, at the above address or phone (902) 426-3410.

CHAPTER 3

BEDROCK AND SURFICIAL GEOLOGY OF THE SCOTIAN SHELF AND GRAND BANKS

Scotian Shelf

Physiography

The Scotian Shelf has been divided into three distinct physiographic zones: an inner shelf bordering mainland Nova Scotia; a middle shelf area of isolated banks with intervening basins; and an outer shelf consisting of a series of wide, flat banks with little bottom relief (Figures 1 and 2).

Inner Shelf. The inner shelf represents a submarine extension of the Atlantic Uplands, a division of the Appalachian region (King et al., 1974). Its surface bears many similarities to the adjacent land mass of mainland Nova Scotian and generally reflects the morphology of the underlying bedrock. It extends seaward about 25 km to a water depth of 100-120 m. Bedrock often outcrops on the inner shelf as linear ridges. Since the coastline of southeastern Nova Scotia is a drowned river system, subaerial and subglacial drainage channels are numerous on the inner shelf. The surficial sediments are thin, often a veneer, and the only thick deposits occur in buried channels or depressions protected from erosion during the last marine transgression. The gravel clasts of the gravel facies of the Sable Island Sand and Gravel formation may be only a single layer in thickness. Reworking of the underlying fine-grained sediments by the infauna may result in gradual lowering of the sea floor as these sediments are suspended in the water column and consequently transported by water movements. Gravel is the dominant grain size of the seabed sediment.

Middle Shelf. The middle shelf consists of a series of broad open depressions to the east and many small isolated depressions in the west. It is 80 km wide off southwestern Nova Scotia and broadens to 140 km at the Laurentian Channel. A trough, varying from 40-50 km wide and 145-180 m deep, runs along the entire inner length of the middle shelf. Emerald Basin, with depths reaching 291 m, lies seaward of the trough. In the eastern zone, the middle shelf is dissected by an east-west trending series of partly disconnected valleys with intervening ridges and chains of partly isolated small banks. This complex morphology is considered to result from a mixture of preglacial Tertiary fluvial erosion followed by local overdeepening by glacial ice and subglacial meltwater streams. Both the middle and outer shelves belong to the submerged Atlantic Coastal Plain physiographic province.

Outer Shelf. The outer shelf zone is parallel to the shelf edge and is 50-75 km wide. It is composed mainly of large, flat topped banks with little bottom relief. The largest of these banks, Sable Island Bank, extends 26 m above sea level where it forms Sable Island. These outer shelf banks are breached by broad flat saddles as well as The Gully, a large submarine canyon running from west to east. The shelf edge is illustrated in Figure 3, a sidescan sonogram of an area south of LaHave Bank on the Sambro Sand formation.

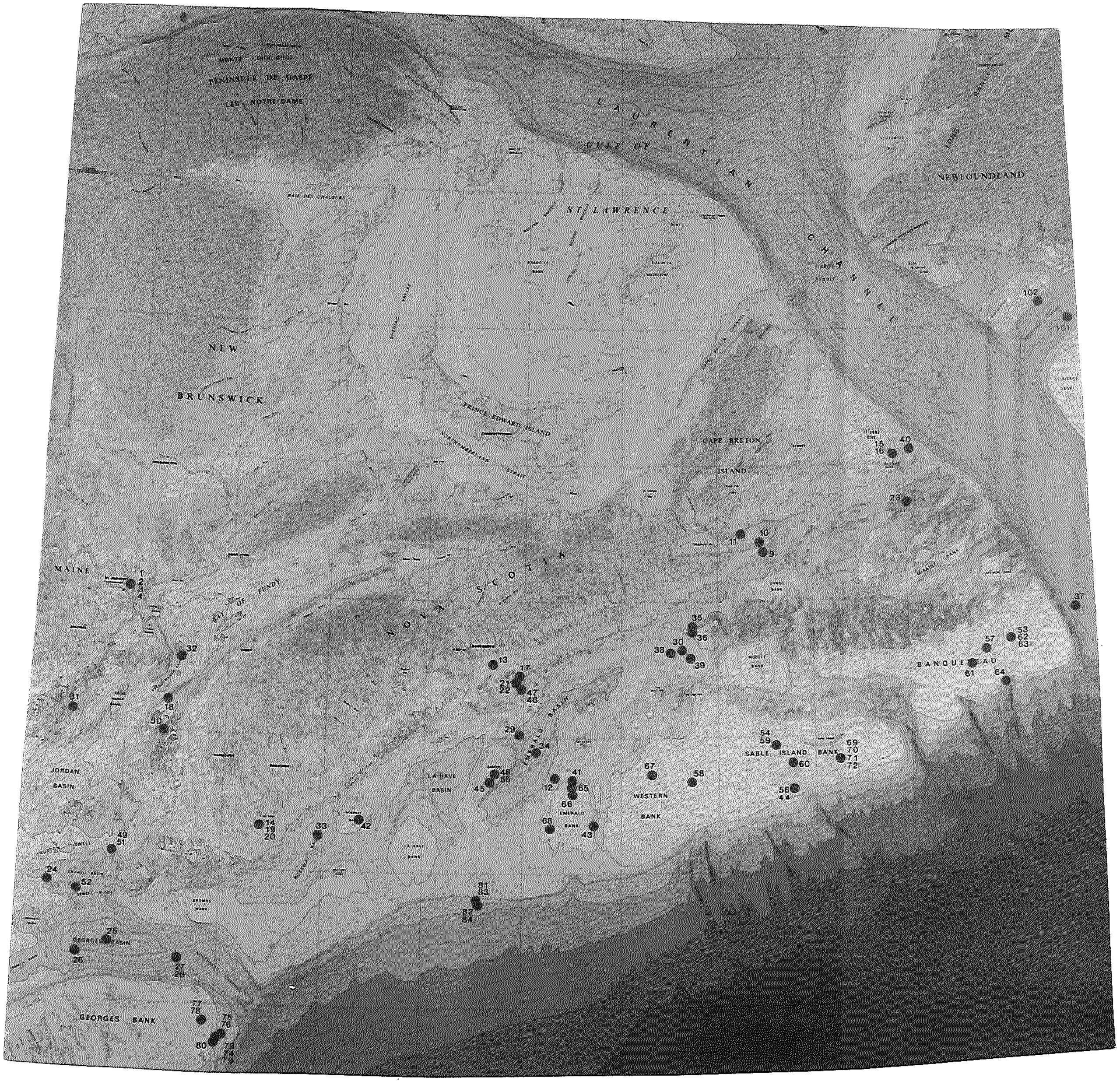

Figure 1. Bathymetry of the Scotian Shelf showing photograph locations.

ORPHAN KNOLL
LABRADOR BASIN
NOTRE DAME CHANNEL
NORTHEAST NEWFOUNDLAND SHELF
NEWFOUNDLAND
AVALON PENINSULA
AVALON CHANNEL
ST PIERRE CHANNEL
FLEMISH PASS
FLEMISH CAP
BEOTHUK KNOLL
THE GRAND BANKS OF NEWFOUNDLAND
ST PIERRE BANK
HALIBUT CHANNEL
GREEN BANK
WHALE BANK
GRAND BANK
LAURENTIAN CHANNEL
SOUTHEAST SHOAL
LAURENTIAN FAN
NEWFOUNDLAND SEAMOUNTS
NEWFOUNDLAND BASIN
TAIL OF THE BANK
NEWFOUNDLAND RIDGE
802
107
105
85
86
87
88
89
100
99
145
146
162
160
155
156
91
95
96
129
154
151
152
140
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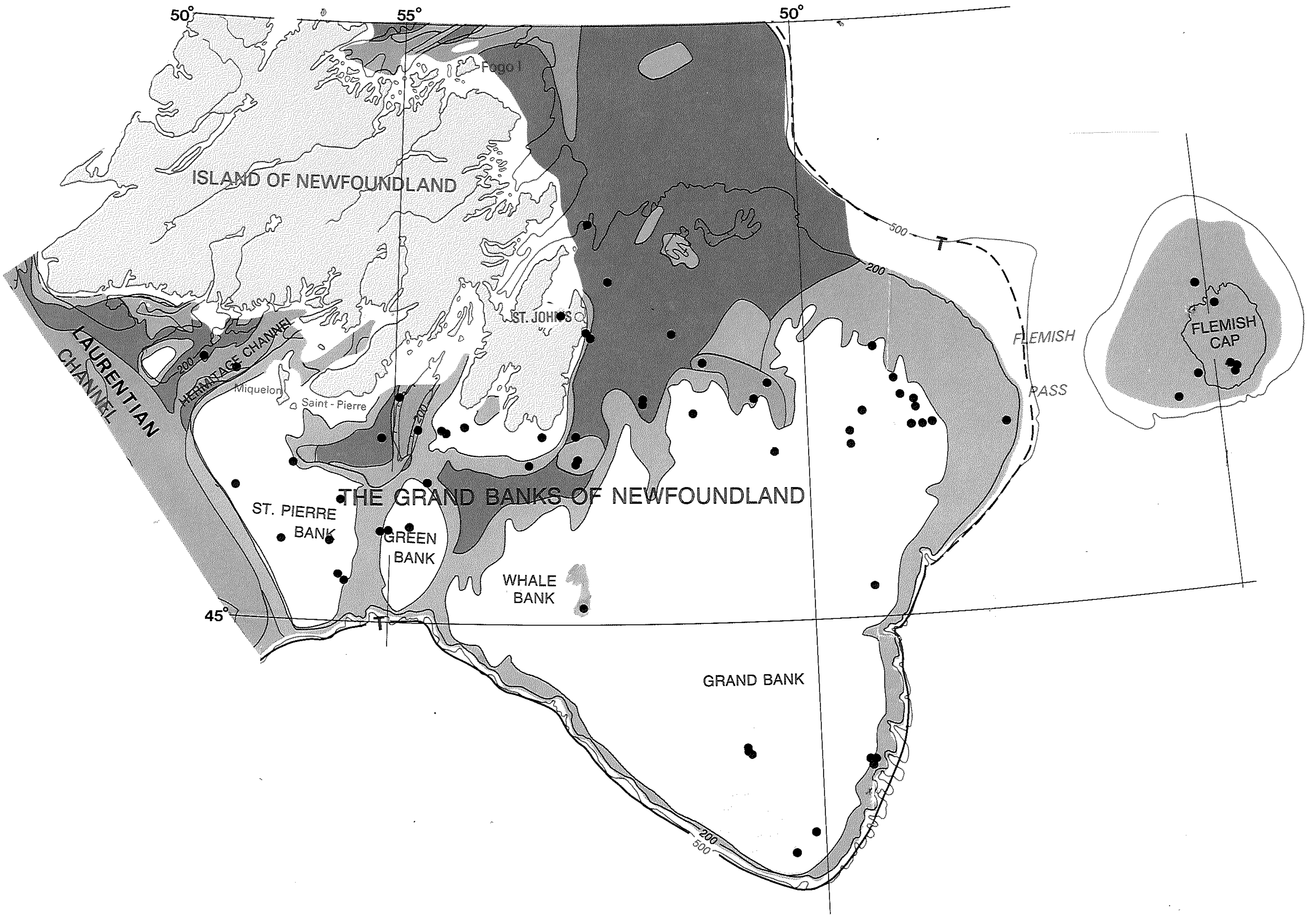
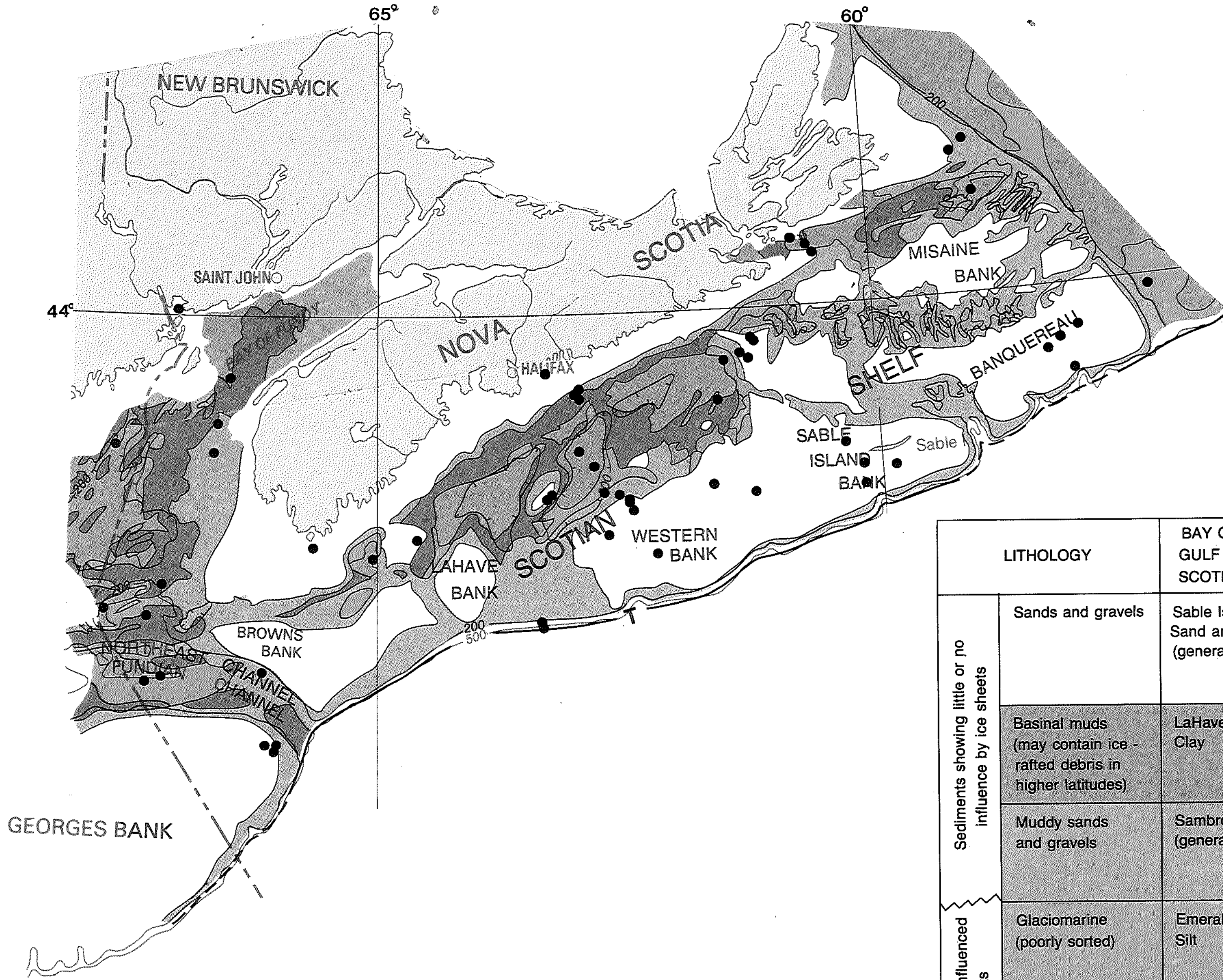


Figure 2. Quaternary Geology of the Scotian Shelf and Grand Banks of Newfoundland (Energy, Mines and Resources Canada, 1986)



Photographic Station ●

Geological boundary (defined, interpreted) ....

Seaward limit of till occurrences (known, uncertain) ..—T— –T–

	LITHOLOGY	BAY OF FUNDY GULF OF MAINE SCOTIAN SHELF	GRAND BANKS OF NEWFOUNDLAND
Sediments showing little or no influence by ice sheets	Sands and gravels	Sable Island Sand and Gravel (generally a veneer) 60m	Grand Banks Sand and Gravel (generally a veneer) 20m
	Basinal muds (may contain ice - rafted debris in higher latitudes)	LaHave Clay 70m	Placentia Clay 30m
	Muddy sands and gravels	Sambro Sand (generally a veneer) 20m	Adolphus Sand and Gravel (generally a veneer) 10m
Sediments strongly influenced by ice sheets	Glaciomarine (poorly sorted)	Emerald Silt 140m	Downing Silt 90m
	Glacial drift	Scotian Shelf Drift 100m	Grand Banks Drift 60m

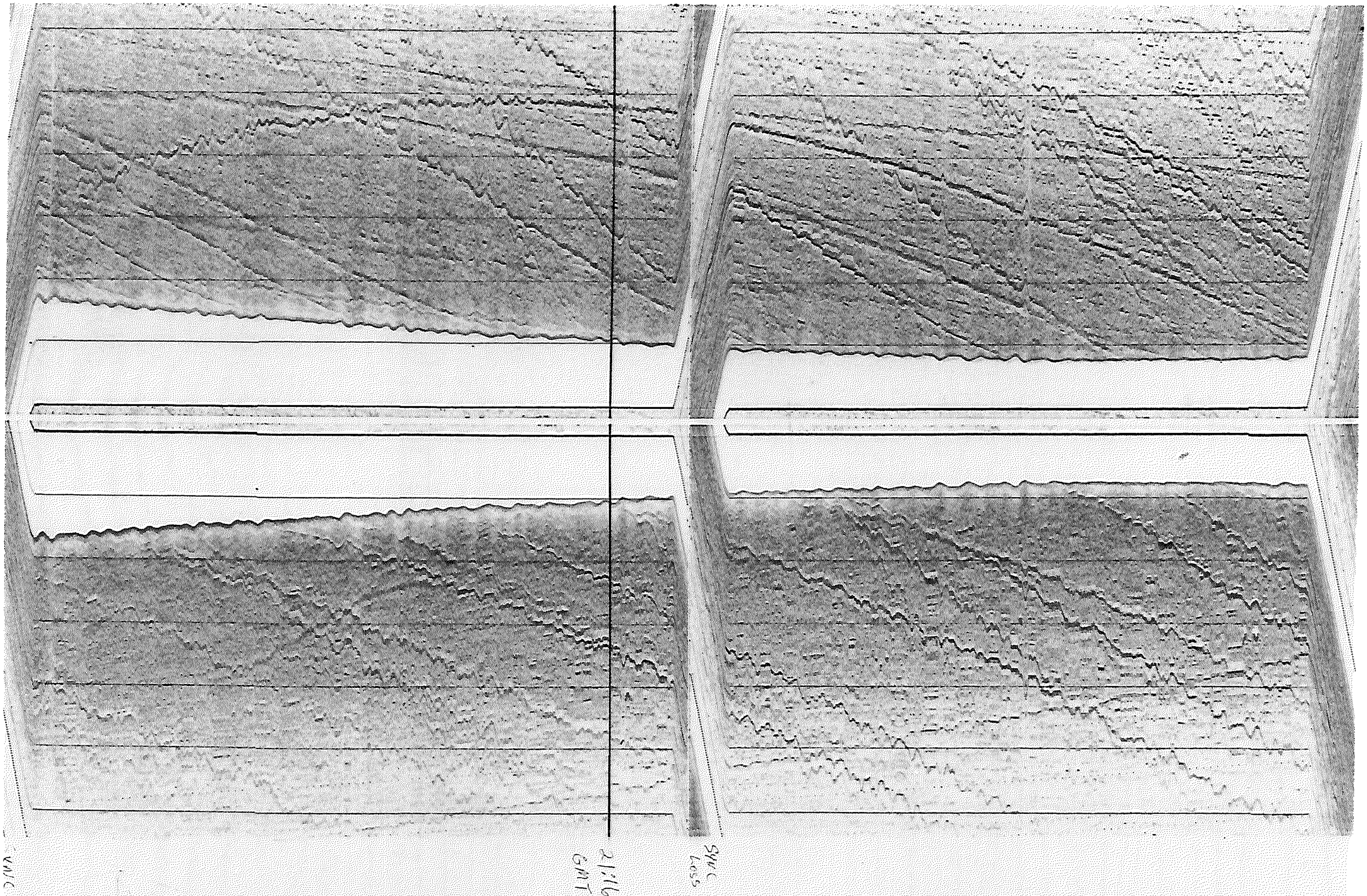


Figure 3. Sidescan sonogram from the shelf edge south of LaHave Bank showing trawl marks

Bedrock Geology

The bedrock geology of the Scotian Shelf is extracted from a map and report by King and MacLean (1976). It is composed of two distinct geological provinces. The first, forming mainland Nova Scotia and the inner shelf, is part of the Appalachian System, which stretches 300 km from eastern Canada southwest to the southern United States. This region, known offshore as acoustic basement because of the high reflectivity of the rock and lack of penetration of acoustic energy, formed in Precambrian to Triassic times. Rocks of acoustic basement consist of Cambro-Ordovician Meguma Group intruded by Devonian granites. The Meguma Group consists of thick deposits of slate, quartzite and greywacke deposited over 200 million years. Along the southeast coast of Cape Breton the lithology of the acoustic basement is not yet known, and it is referred to as a pre-Pennsylvanian unit.

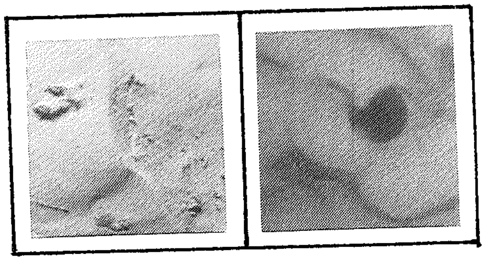
The second major province, comprising the middle and outer shelves, is known as the East Coast Geosyncline, and is formed of a thick wedge of Jurassic to Quaternary sediments overlying the acoustic basement beginning at about 45-50 km offshore. These sediments are thick deposits that accumulated along the western basin of the Atlantic Ocean as it was being formed during late Triassic to Quaternary (and Present). These sediments thicken seaward, forming a wedge over 12 km deep in some places. In the Venture gas field, for instance, the East Coast Geosyncline sediments are up to 8 km thick. Bedrock rarely outcrops at the seabed on the middle and outer shelf except in The Gully.

Surficial Geology

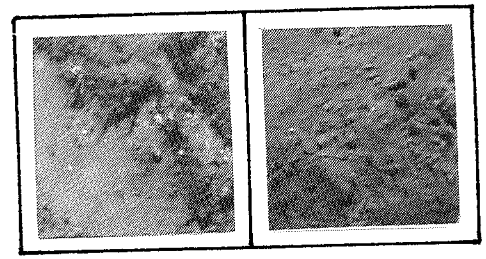
Of particular importance to this atlas are the surficial sediments overlying bedrock. Five Quaternary formations have been identified and described on the Scotian Shelf by King 1970,MacLean and King 1971, Drapeau and King 1972, MacLean, Fader and King 1977 and Fader, King and Josenhans 1982. These are Scotian Shelf Drift, Emerald Silt, Sambro Sand, LaHave Clay, and Sable Island Sand and Gravel (Figures 2 and 4).

Scotian Shelf Drift. The lowermost Quaternary unit is a glacial till called the Scotian Shelf Drift, which was deposited beneath glaciers that extended across the shelf. It is poorly sorted, dominantly sandy, but contains angular pebbles, cobbles, boulders, and abundant silt and clay (Figure 4). The colour is very dark greyish brown. Thickness ranges from 1-150 m, and the surface of the till, characteristically rough and undulating, generally parallels the underlying bedrock surface except in areas of thick morainic ridges. Almost all till surfaces on the Scotian Shelf are covered with iceberg furrows (King and Fader 1986). The iceberg furrows are interpreted as relict features formed during the final breakup of the glacial ice from the Scotian Shelf. The iceberg scouring produces ridges, pits and linear depressions ranging up to 7 m in depth, the average being 3-4 m. With time, the finer (silt and clay) sediment of the iceberg furrows is eroded, and the surface of the till appears to consist only of gravel (pebbles-boulders).

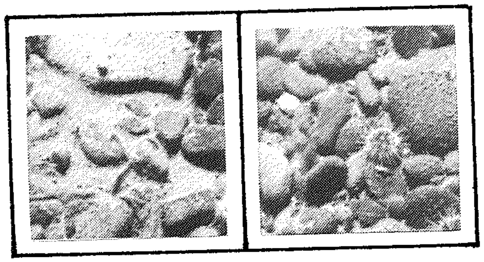
Emerald Silt. Scotian Shelf Drift is partly overlain and interbedded with Emerald Silt, a fine-grained, rhythmitically banded, glaciomarine silty sediment which, in places, is sandy and gravelly (Figure 4). Its colour is very dark greyish brown to green. Its surface is generally



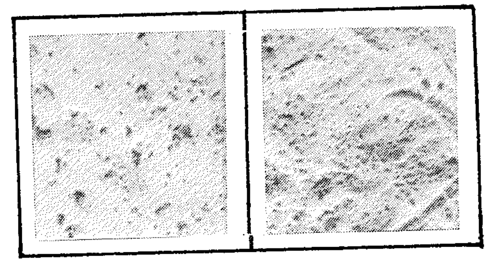
Sable Island Sand and Gravel,
Sand Facies



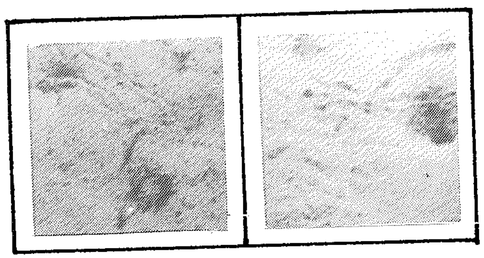
Sambro Sand



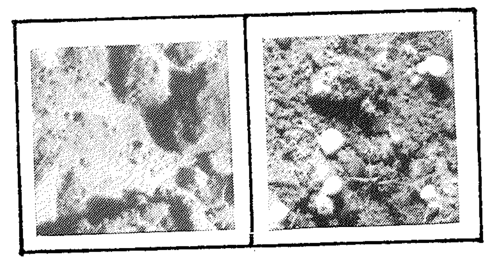
Sable Island Sand and Gravel,
Gravel Facies



Emerald Silt



LaHave Clay



Scotian Shelf Drift

Figure Sediment Types, Scotian Shelf

smooth and flat, contrasting with the rough relief of the till of the Scotian Shelf Drift. Thickness is from 1 m to >200 m thick in depressions like the Cow Pen. Emerald Silt is confined mainly to the basins and depressions of the middle shelf, but may occur on the inner and outer shelf as buried deposits beneath thick sand and gravel.

Sambro Sand. Sambro Sand is a muddy to gravelly sand and overlies the Emerald Silt and Scotian Shelf Drift. It is dark greyish brown, moderately to well sorted, fine- to medium-grained, and grades to a sandy gravel (Figure 4). It also contains small amounts of silt (10%) and clay (5%), which helps to separate this formation from Sable Island Sand and Gravel described below. Although pockets of Sambro Sand up to 20 m thick do occur, this formation generally exists as a thin veneer only a few metres thick overlying till and Emerald Silt. Its surface may be flat and smooth to undulating and hummocky. The Sambro Sand is a fringing deposit around the banks of the shelf and occurs in water depths greater than 110-120 m. It formed during a low stand of sea level at approximately 15 000 YBP in response to reworking by currents and wave action.

LaHave Clay. This formation overlies the Scotian Shelf Drift and Emerald Silt. It is very dark greyish brown, loosely compacted, and composed of silty clay and clayey silt (Figure 4). Deposits are less than 75 m thick, and surfaces are smooth and flat. Gas escape cone-shaped depressions up to 15 m deep and several hundred metres in diameter (pockmarks) occur in the deep basins of the shelf within the LaHave Clay.

Sable Island Sand and Gravel. This unit overlies the Scotian Shelf Drift and Emerald Silt, and is a lateral equivalent and coeval to LaHave Clay. It is buff to greyish brown in colour, consisting of fine to coarse grained, well-sorted sand, grading laterally to coarse gravel with rounded boulders (Figure 4). Two units are recognised: a sand unit with <50% gravel; and a gravel unit with <50% sand. Thickness of either unit does not generally exceed 15 m. The sand surface is smooth, hard and flat, and bedforms such as sand waves, ridges, ribbons and megaripples occur across the seabed. The gravel surface is rough and irregular on the inner shelf, and rough but flat elsewhere.

Grand Banks

Physiography

Three distinct physiographic regions are also recognised on the Grand Banks: a narrow coastal area bordering mainland Newfoundland, an inner trough and an offshore area of large flat banks (Figures 1 and 2).

Coastal Region. A narrow coastal region represents a submarine extension of the Atlantic Uplands and Carboniferous-Triassic Lowlands, both divisions of the Canadian Appalachian region. Areas of the Atlantic Uplands correspond to the acoustic basement. Its surface bears many similarities to the adjacent land mass of Newfoundland and reflects the high relief surface irregularities of the underlying bedrock. Several isolated banks occur on the Carboniferous-Triassic Lowlands.

Inner Trough. The inner trough is much narrower than on the Scotian Shelf, and is represented by the Avalon and St. Pierre Channels and an unnamed channel south of southwestern Newfoundland.

Many of the fiords along the coast of Newfoundland cut across the inner shelf and are connected to the outer shelf by large transverse troughs.

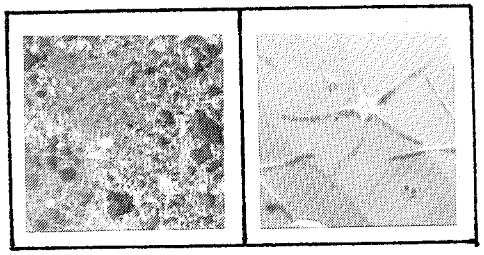
Offshore Region. The offshore region is composed mainly of large, flat topped banks with little relief separated by extensive channels and deeps. The largest of these banks, Grand Bank, extends to 36 m below the sea surface.

Bedrock Geology

The Grand Banks of Newfoundland are composed of three distinct geological provinces. The first, forming Newfoundland and the adjacent coastal region, is part of the Canadian Appalachian System. This region, known offshore as acoustical basement, formed in pre-Pennsylvanian times is assumed to be similar to the rocks forming the adjacent land mass. They consist of Precambrian volcanic, sedimentary and plutonic rocks and Cambrian-Devonian metamorphic and granitic rocks. The inner trough is underlain by well indurated Cambrian-Devonian (?) sediments overlain by a thin veneer of iceberg scoured till. The outer banks are underlain by Coastal Plain sediments, Cretaceous-Tertiary in age and consisting of softer sandstone and mudstone. The surficial sediments are thinner on the Grand Banks than on the banks of the Scotian Shelf. Bedrock is often close to the seabed, buried by lag gravels and sands.

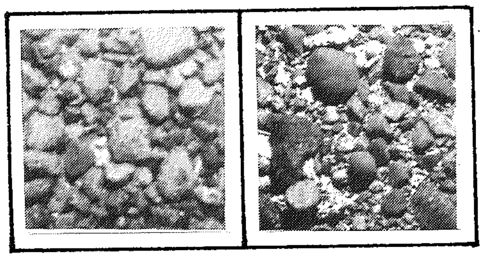
Surficial Geology

Five Quaternary formations have been described on the Grand Banks (Fader and Miller, 1986). These have been designated Grand Banks Drift, Downing Silt, Adolphus Sand, Placentia Clay, and

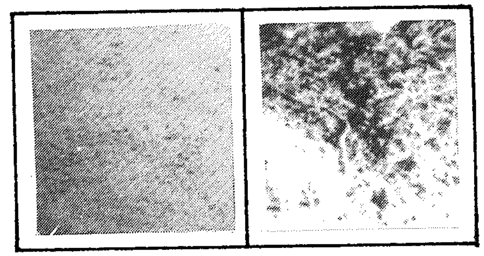


Grand Banks Sand and Gravel,
Sand Facies

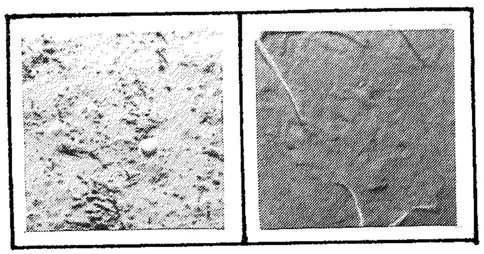
Adolphus Sand



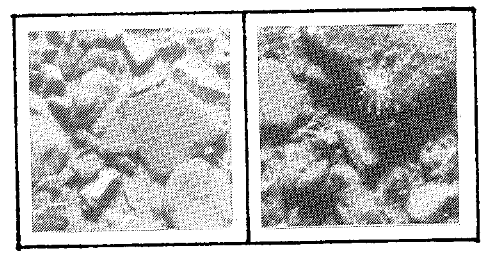
Grand Banks Sand and Gravel,
Gravel Facies



Downing Silt



Placentia Clay



Grand Banks Drift

Figure 5. Sediment Types, Grand Banks

Grand Banks Sand and Gravel (Figures 2 and 5).

Grand Banks Drift. The lowest Quaternary unit is a till called the Grand Banks Drift, equivalent to the Scotian Shelf Drift. It is poorly sorted and dominantly sandy, but contains angular pebbles, cobbles, boulders, and abundant silt and clay (Figure 5). Colour is very dark greyish brown. Thickness ranges from 1-150 m, and the surface of the till, characteristically rough and undulating from iceberg scouring, generally parallels the underlying bedrock surface except in areas of morainic ridges. Morainic ridges are fewer in number than on the Scotian Shelf.

Downing Silt. The Grand Banks Drift is partly overlain by and interbedded with Downing Silt, a fine-grained silty sediment which, in places, is sandy and gravelly (Figure 5). Colour is very dark greyish brown to greenish brown. Its surface is generally smooth and horizontal, contrasting with the till of the Grand Banks Drift. Thickness is from 1 m to >200 m thick in buried channels on the eastern edge of Grand Bank. Only a few areas of Downing Silt are encountered across the Grand Banks.

Adolphus Sand. Adolphus Sand overlies the Downing Silt and Grand Banks Drift and occurs in water depths greater than 100 m. It is dark greyish brown, moderately to well sorted, fine- to medium-grained, and grades to sandy gravel (Figure 5). It may contain small amounts of silt (10%) and clay (5%), which helps to separate this formation from Grand Banks Sand and Gravel described below. Although pockets of Adolphus Sand up to 10 m thick do occur, this formation generally exists as a thin veneer only a few metres thick. Its surface may be flat and smooth to undulating and hummocky. On the edge of the bank, areas of sandy bedforms occur within the

Adolphus Sand.

Placentia Clay. This formation overlies Grand Banks Drift and Downing Silt. It is very dark greyish brown, loosely compacted, and composed of silty clay and clayey silt (Figure 5). Deposits are less than 30 m thick, and surfaces are smooth and flat. The Placentia Clay often contains an ice rafted gravel component.

Grand Banks Sand and Gravel. This unit overlies the Grand Banks Drift and the Downing Silt, and is a lateral equivalent and of the same age as Placentia Clay. It is buff to greyish brown in colour, consisting of medium- to coarse-grained, well sorted sand, grading laterally to coarse gravel with rounded boulders (Figure 5). Two units are recognised: a sand unit with <50% gravel; and a gravel unit with <50% sand. Thickness of either unit does not exceed 20 m. The sand surface is smooth, hard and flat. The gravel surface is rough on the inner shelf, and rough but flat elsewhere. Boulders are common across the banks. The dominant bedforms across Grand Bank are sand ridges which range up to 12 m in height. They are large, undulating bedforms which overlie gravel lag surfaces.

Dynamic Processes

Two types of dynamic processes, water driven and gravity driven, affect sediment distributions in the marine environment. Gravity driven processes include creep, slumping, sliding, and the formation of turbidity currents, and require some event to set in motion unstable sediments resting on oversteep slopes.

Water driven processes include waves, tidal currents, and density-driven currents. For sediment to be transported by these processes a threshold of "boundary shear stress" must be exceeded. Flow velocity is the single most important factor, although particle size and shape, bedform roughness and water depth all play significant roles. Severe storms that produce high flow velocities have the greatest effect on sediment transport. Sediment can be supported as bed load (ie. in contact with the seabed) or suspended load (ie. in the water column).

Features readily apparent in the sandy areas of the banks are sand bedforms - ridges, waves, ribbons and megaripples (Amos and King 1984) with wavelengths varying to 30 m, and sand ripples, microscale versions of the same thing but with wavelengths of less than 1 m. These occur in trains with crests perpendicular to current flow.

CHAPTER 4

PHYSICAL OCEANOGRAPHIC OVERVIEW OF THE SCOTIAN SHELF AND GRAND BANKS

The physical marine environment, together with the distribution of surficial sediments, provides the habitat for the marine biological community. An appreciation of the basic oceanographic features of an area is therefore necessary in order to understand the factors that shaped and are presently shaping the seabed and biological communities which manifest themselves in the photographs.

The major surface currents off the Canadian east coast are illustrated in Figure 6. There is a general tendency for the water to flow in a southwesterly direction over the continental shelf. Both the Grand Banks of Newfoundland and the Scotian Shelf are influenced by essentially the same water masses, such as the Labrador Current and the Gulf Stream.

Grand Banks of Newfoundland

The eastern Canadian continental shelf off the south and southeast coasts of Newfoundland forms the Grand Banks of Newfoundland. Physical oceanographic conditions on the Grand Banks are profoundly influenced by the cold waters of the Labrador Current, which has a large freshwater input, and hence low salinity. The shape of the banks and intervening channels directs the southerly flow of the Labrador Current into two branches. The smaller inner branch flows south

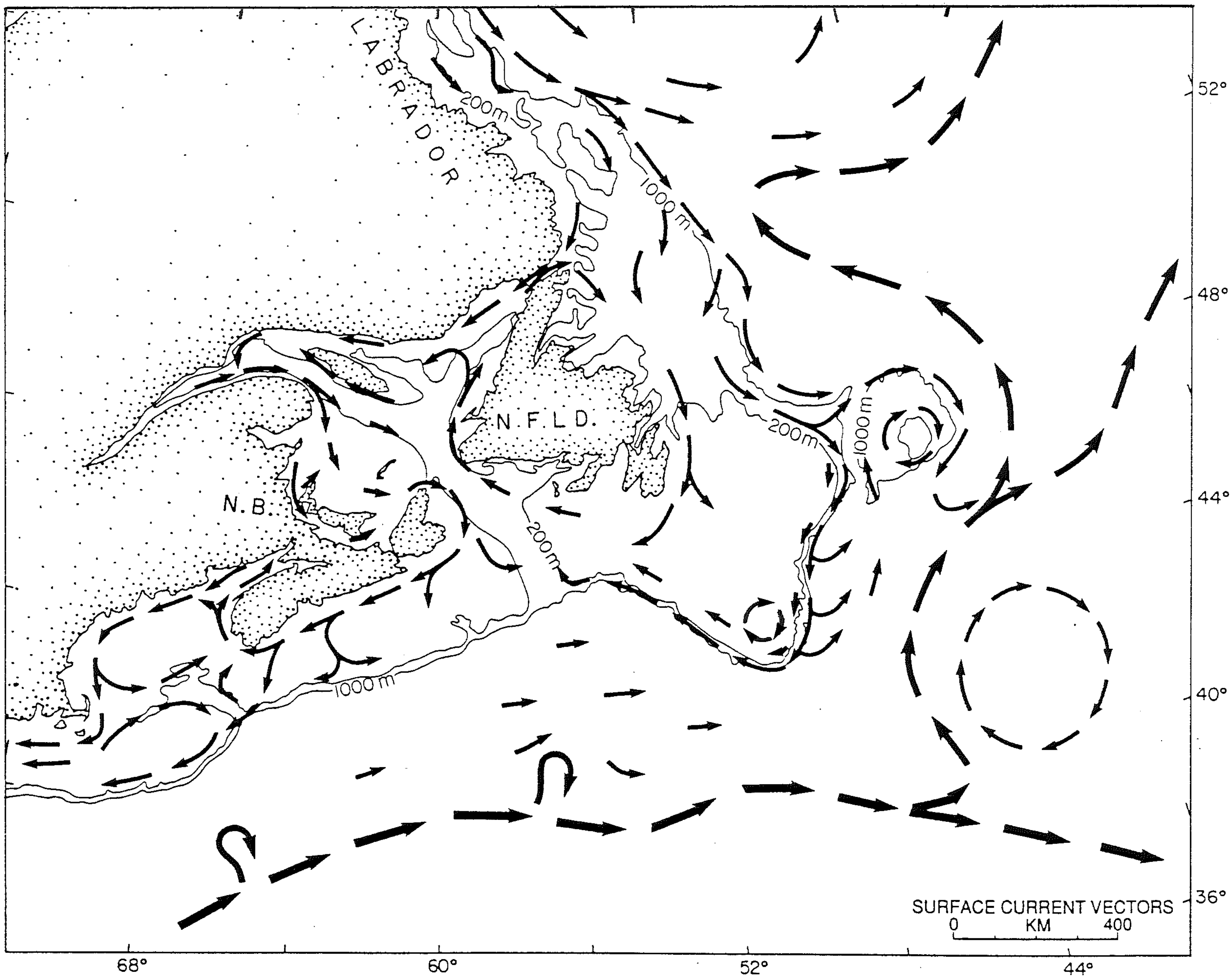


Figure 6. Surface currents off Canada's east coast

through Avalon and Haddock Channels, while the larger outer branch follows along the north-eastern edge of Grand Bank, through Flemish Pass, and continues south along Grand Bank, past the Tail of the Bank, finally turning west toward the Scotian Shelf (Figure 6).

On the Grand Banks, the fastest surface flow is in the Labrador Current east of Grand Bank along the continental slope, while currents on the banks are weak and variable in direction. Bottom currents (Figure 7) indicate that the flow of the Labrador Current at depth is continuous through Avalon and Halibut Channels and continues westward into the Laurentian Channel.

Three primary water masses influence the Grand Banks. In addition to the Labrador Current, Slope Water (water covering the continental slope between the banks and the deep ocean floor) extends from south of the Scotian Shelf to just south of the Grand Banks. Mixed water, a mixture of Slope Water and Labrador Current Water modified by seasonal heating and input of fresher water from the west, is found over the Grand Banks. A fourth water type, known as atypical water, is occasionally formed by local mixing of Slope Water and neighbouring water masses. The Gulf Stream brings warm, more saline water from the south into the region. South of the Grand Banks it splits, with a part turning north to mix in the Slope Water region with the Labrador Current. The Gulf Stream indirectly affects the Grand Banks through the cross-shelf mixing of coastal and offshore waters (of the Gulf Stream) that contain gyres which separate from northward meanders of the Gulf Stream, trapping warm, saline water and persisting for as long as a few months to a year.

Surface current circulation is influenced by a number of factors, including waves, tides and winds. Permanent weak gyres are present in the Tail of the Bank region and stronger ones are

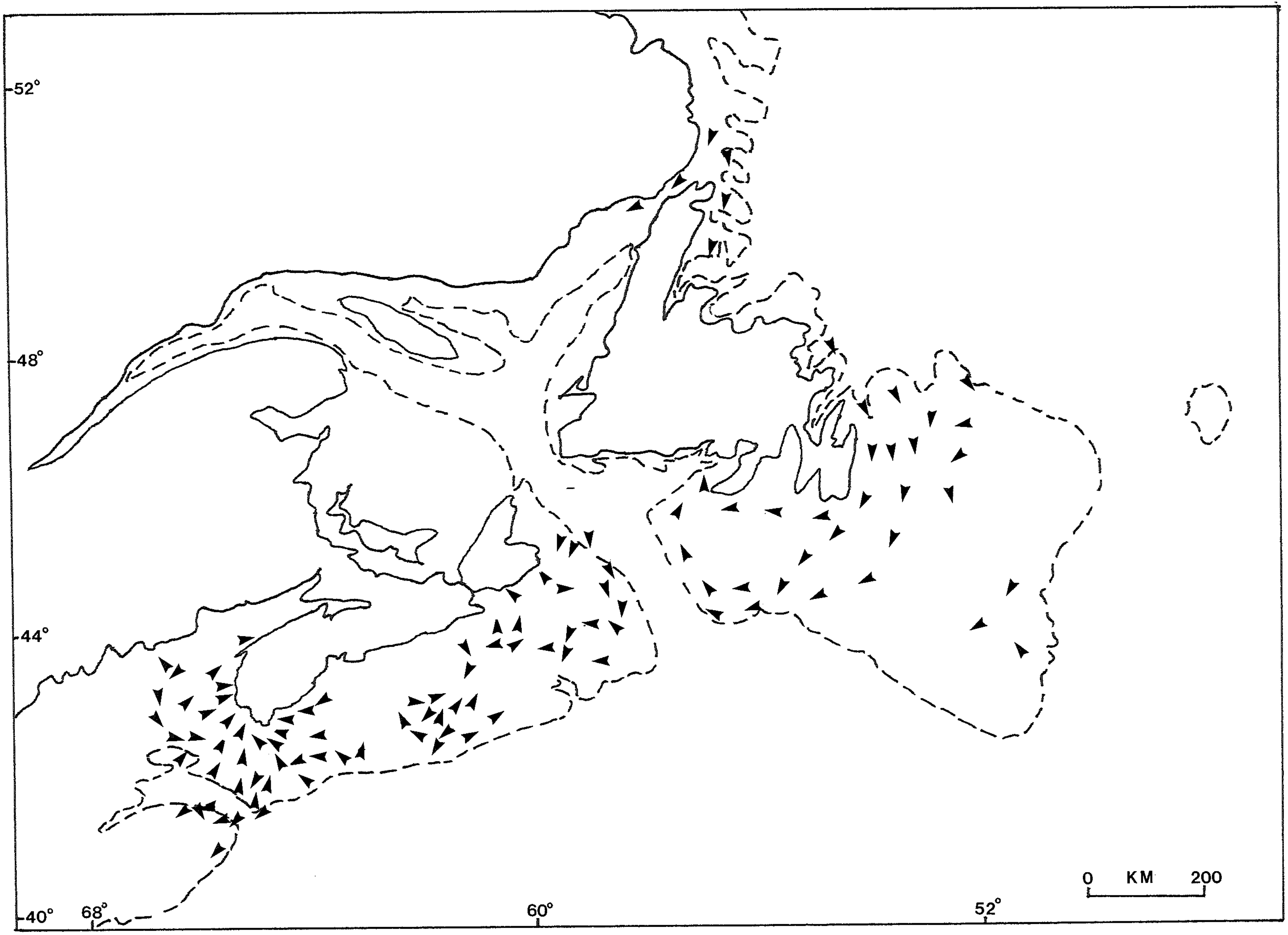


Figure 7. Bottom currents on the Scotian Shelf and Grand Banks of Newfoundland

present on Flemish Cap. Oceanic fronts, areas of active, turbulent mixing, occur at the boundaries of different water masses, and on the Grand Banks are found mainly to the south and east of Grand Bank, and over the Tail of the Bank. Upwelling occurs in the vicinity of the shelf break, and results in the transfer of nutrient rich water from deeper areas onto the banks. Upwelling is thought to be wind driven, and consequently occurs more frequently in the winter months when wind speed and duration are greater.

An additional phenomenon on the Grand Banks of Newfoundland is the occurrence of icebergs, which originate from glaciers off Greenland and Ellesmere Island to the north. The majority of icebergs in eastern Newfoundland follow the main streams of the Labrador Current. However, some icebergs drift onto the Grand Banks. When an iceberg moves into an area where the water depth is less than its draft it will impact and scour the seabed, typically forming iceberg furrows and pits. The width, depth and length of an iceberg scour depend on the iceberg itself, the surficial sediments and the driving forces - wind and current. These iceberg furrows and pits may persist for a long time, or may be quickly eroded, especially if formed in sandy sediments.

Scotian Shelf

The two main sources of water on the Scotian Shelf are Slope Water and the outflow from the Gulf of St. Lawrence, usually referred to as the Cape Breton Current. These waters join, becoming known as the Nova Scotian Current, and flow southwest, parallel to the coastline over the inner half of the shelf (Figure 6). The bulk of the transport of the Nova Scotian Current is confined to the inner 80-100 km of the Scotian Shelf. As the Nova Scotian Current moves down the coast, it is modified by exchanges with offshore waters which tend to flow in a northeast direction parallel to the coastline and inshore of the Gulf Stream, resulting in higher salinity, heat content and nutrient values.

Over the continental shelf three water layers can be distinguished. The surface layer has a low salinity as a result of runoff, with a temperature which varies seasonally. The intermediate layer is cold, with a higher salinity. The bottom layer, which is most important in terms of the benthos, is warm, with a temperature of > 5° C, and saline (> 33.5°/oo). During the winter months there may be increased vertical mixing, and on the shallowest banks the water column may be well mixed throughout the year. On the other banks the water is stratified, except in the Gulf of Maine where tidal mixing plays a role.

Two water masses can be distinguished within the slope water. On the surface is a layer of warm slope water, itself a mixture of Gulf Stream and coastal surface waters, which is more saline than surface coastal water. Below 200 m, Labrador Slope water, a mixture of Labrador Current water and North Atlantic water, occurs. A sharp frontal region characterises the boundary between these two layers. The warm slope water has an eastward component of flow, whereas the Labrador Slope water has a westward component of mean flow.

In spite of the above designations, the Slope Water is an area of considerable variability and heterogeneity. The Gulf Stream frequently sheds large scale volumes of water in the form of rings and meanders, which move off to the north into the Slope Water region. They carry subsurface oceanic water to the edge of the shelf, and these warm, saline features may have a profound impact on the biology and physical oceanography of the outer shelf region when they impact upon the shelf edge.

Surface current circulation on the Scotian Shelf is forced by a variety of oceanographic and meteorological factors operating over a range of time scales. These include tides, waves, winds, density gradients and water flow from adjacent areas. Oceanographic fronts occur where water properties vary dramatically over small distances. Fronts between coastal, slope and Gulf Stream waters exist along the Scotian Shelf, and are associated with regions of high productivity. Anticyclonic gyres occur over Georges Bank, Browns Bank and in the vicinity of Sable Island.

The circulation in the Bay of Fundy - Gulf of Maine area is dominated by tidal forces, and the turbulence created results in a well-mixed water column in shallow areas. This results in the formation of oceanic fronts between shallow and deeper stratified waters within the Gulf. In the area off southwest Nova Scotia upwelling occurs, produced by a combination effect of the bottom topography and changing density fields. This, together with the fronts, results in raised nutrient levels and hence high biological productivity in this area. Upwelling can also occur at the shelf break in response to strong, persistent easterly winds.

Circulation patterns deeper in the water column are not as well understood, but the general circulation pattern is a southwesterly flow along the coast except perhaps in deeper areas such as Emerald Basin (Figure 7). Bottom drifter experiments have shown current speeds of 0.5 to 1.5 $cm.s^{-1}$ in a southwesterly direction over Banquereau. Between Sable Island and the mainland the net bottom drift is variable and ill-defined. However, as some photographs show, the net bottom flow is considerable. Extensive seabed sediment reworking on large and small scales occurs as a result. An anticyclonic current pattern with some northward drift is discernible over Emerald Bank. On the northeast edge of the Scotian Shelf the drift is in a southerly direction. Around southwest Nova Scotia the currents generally move along the depth contours with an area of currents in varying directions on the outer portion of the shelf (Lauzier 1967).

CHAPTER 5

THE BENTHOS OF THE SCOTIAN SHELF AND GRAND BANKS OF NEWFOUNDLAND

Living on, in, or attached to the seabed is a diverse community of plants and animals known as the benthos. Among the animals are bottom-dwelling fish, including the important commercial groundfish species such as cod, as well as numerous other species. These, although not all fished for food, have an important place in the ecosystem. Overshadowing the fish in number and diversity, are representatives of all phyla of invertebrates, the animals without backbones, which in ancient times first inhabited the seas. Benthic invertebrates have an important place in the ecosystem, utilising food which reaches the seabed from the water above. Largely as a result of their activity, little food material reaching the bottom enters the sediments. Benthic invertebrates are the major food source for demersal (bottom-dwelling) fish.

The plant life of the seabed occurs mainly in shallow environments where sunlight can penetrate to the bottom. Included are the seaweeds, which live either attached to or encrusting hard surfaces, and microscopic single-celled algae which inhabit the surface layers of sediments. In some cases these small plants have adapted to shifting bottom substrate by forming sticky mats, which become important not only as food for benthic animals but for stabilising bottom sediments against the forces of waves and currents. The seaweeds or macroalgae are important primary producers in nearshore areas to a depth of about 30 metres, where they provide food and shelter for invertebrates and fish. The remains of seaweeds and the microorganisms that decompose them form detritus, the basic food material of a great variety of bottom invertebrates and fish.

In water deeper than about 50 metres, the amount of light reaching the bottom is small, and the benthos is composed almost entirely of fish and invertebrate animals. Here, most energy reaching the bottom comes from food produced by phytoplankton in the water column which settles to the seabed either as intact plant cells or in the remains and solid wastes of water column organisms. Bottom animals in many phyla have found niches filtering some of this suspended food material from the water (suspension feeders) (Photos 1 and 2), while many survive through feeding on the detritus and sediment and the associated microorganisms (deposit feeders). Many are predaceous, feeding on other organisms. Invertebrates in the phylum Cnidaria (containing the jellyfish, anemones, hydroids, and corals) use poisonous stinging cells to trap organisms from the plankton (Photos 3 and 4).

Recently, venting gases (methane and hydrocarbons) have been identified as a possible food source for the benthic community, (Levy and Lee 1988). Methane metabolising bacteria forming white slime mats have been found in many shelf areas, often associated with hydrocarbon seepages. Both the Scotian Shelf and the Grand Banks of Newfoundland have deep geological reservoirs that contain large amounts of hydrocarbons and large areas of pockmarks (gas venting craters) have been found, but the subject remains an area of active research.

The invertebrates of the benthos are a diverse group, and their activities and modes of life are complex. In size, the benthos can range from single-celled protozoans such as ciliates and amoebas (a group known collectively as the microfauna); to the minute multicellular organisms, such as nematodes and bottom-dwelling copepods, generally less than a millimetre in size which live in the spaces between sediment particles (the meiofauna); to the larger organisms of the sea bed, such as sea stars, worms, anemones (the macrofauna). Invertebrates which are larger still, and include the larger benthic invertebrates such as sea urchins and benthic fish, are often termed collectively the megafauna.

The life habits of benthic invertebrates are also diverse. Some animals (the infauna) live within the sediments, either feeding on it or using it as a refuge while remaining connected to the surface and feeding there. Many, such as the predaceous sea stars, snails, commercially important scallops and attached sea anemones, live at the interface between sediment and the water column and are known as epifauna. Some groups, including predaceous lysianassid amphipods, some shrimp and other crustaceans, and even some fish such as sand lance, inhabit the bottom for part of the time and feed in the water column for the rest of the time (hyperbenthos).

Benthic invertebrates are the main food source for demersal fish which are the basis for major commercial fisheries on the Grand Banks and Scotian Shelf (note the trawl marks in the Sambro Sand formation seen in the sidescan sonogram from the shelf edge south of LaHave Bank, Figure 3), as well as in many other areas of the world. In addition, they have been recognised as having importance in processes which release nutrients from the sediments, stimulating plant production in the water column. Demersal fish are illustrated in Photos 5, 6, 7 and 8. The combined activities of benthic invertebrates and fish have a major influence on both the structure and distribution of sediments. In a short time, fish and invertebrates can erase sand ripples on the seabed; the activity of invertebrates burrowing in soft sediments can make them more fluid, mix the sediments and reduce their stability, making them more susceptible to resuspension and/or slumping. The resuspension and subsequent transport of fine-grained

These photographs were taken in shallow water in Passamaquoddy Bay, New Brunswick.

Photo 1 (approx. 45°08'N, 67°08'W, 10 m)
Highly productive environments or those to which particulate food material is transported by currents have abundant and diverse life. This crowded scene includes a variety of suspension feeding organisms which rely on suspended living matter for nutrition. The extended fans of flesh-coloured phoronids, members of a small phylum of worm-like invertebrates, and a forest of finely branched pink hydrozoan colonies and white bryozoans filter particles from the water. Several closed anemones occur to the right of the photo, and sponge-encrusted brachiopods, probably Terebratulina sp. occur in the upper and lower centre. Finger like fans of colonial bryozoans, also suspension feeders, occur throughout. The large boulders or bedrock are encrusted by pink coralline algae.

Photo 2 (approx. 45°08'N, 67°08'W, 13 m)
The suspension feeding tunicate, the sea vase, Ciona intestinalis, rests near sponges and attached suspension feeding brachiopods, Terebratulina sp. A polychaete, probably Pomatostegus sp., appears, showing its tube lying on a rock at middle right. Fan shaped colonies of bryozoans occur throughout. The substrate of bedrock or large boulders is encrusted with coralline algae. A small orange tunicate is seen in the foreground.

Photo 3 (approx. 45°08'N, 67°08'W, 17 m)
The burrowing cerianthid sea anemone shown in this photo lives on stable sandy to muddy bottom in which it constructs a tube, an adaptation in this member of the phylum Cnidaria to a life on soft bottoms. The burrowing anemone preys on small animals which contact its tentacles, which can reach 30 cm in length. After they retract, the tentacles often leave a pattern of radiating streaks on the sediment surface. Also present in the photo is the green sea urchin, Strongylocentrotus droebachiensis, here feeding on detritus on the substrate surface. Sea urchins also scrape the pink stony encrustations of coralline algae, seen in the background. The substrate is a muddy, gravelly sand.

Photo 4 (approx. 45°08'N, 67°08'W, 13 m)
A stalked sea anemone, possibly the ghost anemone, Diadumene leucolena, and one of its offspring formed by budding, rest on a mixed substrate of sand and gravel. The tentacles are oriented perpendicular to the current direction to increase the chance of capturing passing prey organisms. Also present is a green sea urchin, Strongylocentrotus droebachiensis.

Photo 1

Photo 3

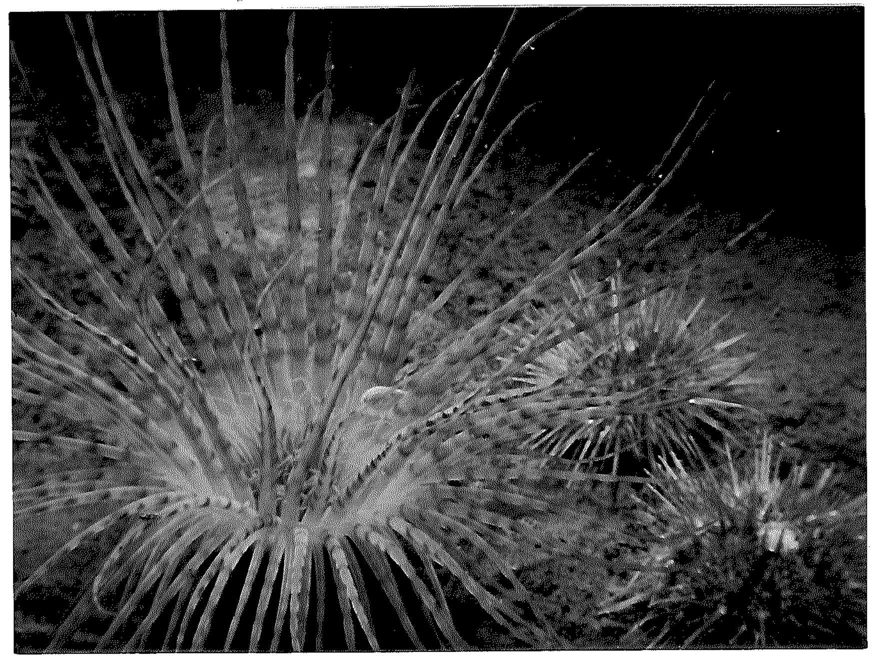


Photo 2

Photo 4

Of the many thousands of photographs taken of the seabed, few captured examples of one of the sea's more significant elements, the fish. In this series of photographs from the Grand Banks (Photos 6, 7 and 8) and Flemish Cap (Photo 5) four fish are shown.

Photo 5 (46°50.4'N, 44°49.4'W, 139 m)
Against a background of outcropping granodiorite (bedrock) on Flemish Cap, densely colonised by attached and encrusting invertebrates, a lone silver hake (Merluccius bilinearis) grazes. Bottom communities such as this are likely to provide an abundance of food for these highly motile predators. Orange encrusting sponges, brachiopods, bryozoans, anemones and sea stars are visible.

Photo 6 (46°49.09'N, 48°56.25'W, 70 m)
In this photograph from the Hibernia area of northeastern Grand Bank, a bottom-feeding flounder is observed on the Grand Banks Sand and Gravel. Some traces of its feeding activities can be seen to the right of its head. It appears to make a succession of marks on the rippled sand as it explores for food. Similar marks have been attributed to flatfish in the Bay of Fundy (Risk and Craig 1976).

Photo 7 (46°34'N, 52°49'W, 140 m)
An ocean pout (Macrozoarces americanus) is seen on a substrate of glacial till of the Grand Banks Drift formation from the Avalon Channel. Common on the Grand Banks, these fish scavenge along the seabed. A gravelly bottom is preferred, as they nudge the clasts aside in their search for animals such as molluscs and crustaceans.

Photo 8 (46°34'N, 52°49'W, 140 m)
This large skate of the family Rajidae, disturbed by the camera lights, flaps out of the way. Several species of skate have been reported for this area in the Avalon Channel. The substrate is Grand Banks Drift, an iceberg furrowed glacial till seabed.

Photo 5

Photo 6

Photo 7

Photo 8

sediments may result in a gradual lowering of the sea floor. Often, soft seabed sediments are extensively marked with tracks and traces, burrows, tubes and mounds, resulting from the activities of bottom organisms (Photos 9, 10, 11 and 12), increasing the roughness of the seabed and making it more susceptible to erosion. Mollusc shells accumulate in interesting and significantly dense zones termed "shell beds" on the continental shelf, and shell and other skeletal material from a variety of invertebrates can form an important component of many sediment types.

Benthic organisms have evolved in shape, form, and habit to fill most available seabed niches. Among polychaete worms, for example, there are species which lay a delicate net of tentacles on the substrate to channel fine detritus particles to the mouth; others, flattened in body form, build portable tubes of sand grains, and drag them across the bottom in the search for prey; some threadlike species navigate the interstitial spaces between sand grains and consume microscopic benthic algae; some build tubes leading deep into the seabed where they feed on sediment particles and channel the waste material to the sediment-water interface; some live in tubes attached to rocks; and some have fans to catch suspended particles.

The occurrence of particular species in an area also results from the interplay of several key environmental factors. Oceanography plays a major role. Most benthic invertebrates have planktonic eggs and larval stages which float in the water for a time before they settle to the bottom, and movements of water masses are essential in dispersal. Further, conditions of temperature and salinity, as well as adequate production of food in the water column, influence the survival of these early stages. As the development period of the larvae is relatively fixed, there is a further critical time window during which a suitable bottom site must be found. Most species tend to have a fixed geographic distribution, which may range from a few degrees of latitude to tens of degrees, corresponding closely to water mass distributions and existence of conditions which are optimal for their survival.

Bottom substrate type is one of the most important factors in settlement and survival of benthic invertebrates. Initially, even the larvae of some species make a choice the instant they touch bottom, settling only on substrate which meets certain criteria. Naturally, organisms developing on substrates to which they are adapted do best. Organisms finding adequate substrate but at depths at which there is insufficient food available do not survive. Further, success of benthic invertebrates depends on more immediate physical factors, such as temperature, level of biological production in the overlying water column, current, wave energy, and seabed stability. High energy environments, typified by the exposed rocky shoreline, are areas of high food availability and are colonized by organisms capable of firm attachment to the substrate. Current in these areas, as in others, is important in bringing food to many organisms. For example, suspension feeders such as mussels filter phytoplankton from the water, and cnidarians such as anemones need a constantly renewing supply of planktonic prey organisms at any depth at which they are found. Organisms living on the shallow offshore sandy banks have to deal with maintaining position in the shifting sand and have adapted to these environments by developing heavy shells (molluscs) and skeletons (sand dollars) to resist transport and breakage. Powerful foot muscles in molluscs permit burrowing and movement. Attached organisms tend not to occur on suitable substrate in areas of shifting sand and high currents because newly settled stages are abraded off the rocks or frequently buried. Throughout there are coloniser species which invade and are highly successful on newly disturbed areas of the bottom.

Photo 9 (45°22.5'N, 60°31.8'W, 116 m)
This photograph was taken east of Canso, Nova Scotia, north of Canso Bank on the Inner Shelf and near a transition between Sable Island Sand and Gravel and the finer Sambro Sand formation. The sediment, a muddy sand, bears many imprints of brittle star arms. These predatory and scavenging Ophiura-type brittle stars frequently occur in "muddy" substrate communities, where they forage for infauna. A crab track leads diagonally to the upper left of the picture. Numerous burrow openings, mounds, tubes and trails of other invertebrates are also to be seen, indicating the presence of a rich infaunal community including burrowing deposit feeders, responsible for considerable bioturbation of the sediments. Also present are burrowing anemones and hydroids attached to scattered hard substrate.

Photo 10 (45°25'N, 60°39'W, 159 m)
The clayey and sandy silt of the LaHave Clay seen in this photograph from an area off the mouth of Chedabucto Bay, south of Cape Breton Island, is also marked by the activities of the benthic fauna. Numerous fine tracks, some presumably made by the shrimp visible in the picture, cover the sediment surface. A hydroid colony is also present in the upper right. Many shrimp occur in the photographs from the Chedabucto Bay area.

Photo 11 (45°29.1'N, 60°44.4'W, 139 m)
A burrowing anemone (Cerianthus sp.) can be seen in this photograph of LaHave Clay at the mouth of Chedabucto Bay, south of Cape Breton Island. Several burrows, possibly made by anemones, are visible. Bivalve and gastropod trails can be discerned in the clayey silt sediment. Many star-shaped markings, apparently caused by the feeding activity of the brittle stars, occur. The invertebrate community consists of these predatory brittle stars plus numerous infaunal and epifaunal species, which disturb the sediments as they carry out their normal activities.

Photo 12 (43°42'N, 62°39'W, 146 m)
The fine grained sediments of the silty and clayey sand of Sambro Sand on the northwest flank of Emerald Bank serve as a template for the trails of a heart urchin, Brisaster sp. The surface is criss-crossed with tracks of invertebrates, such as gastropods, annelids and nemerteans, and bears the star-shaped impression of a brittle star (upper left). The surface is also perforated and pelletised by a rich infauna usually found associated with, and responsible for, considerable bioturbation of these sediments.

Photo 9

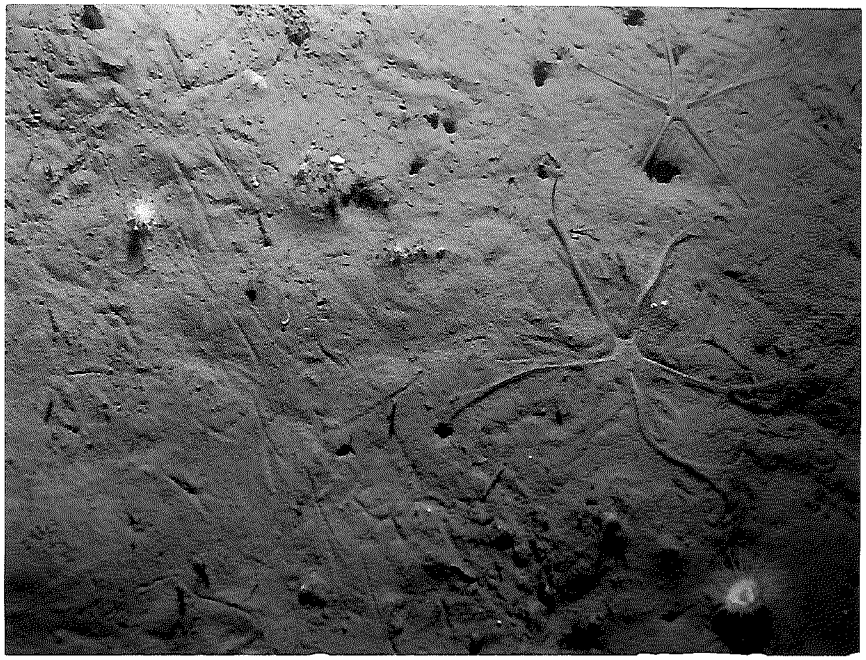


Photo 11

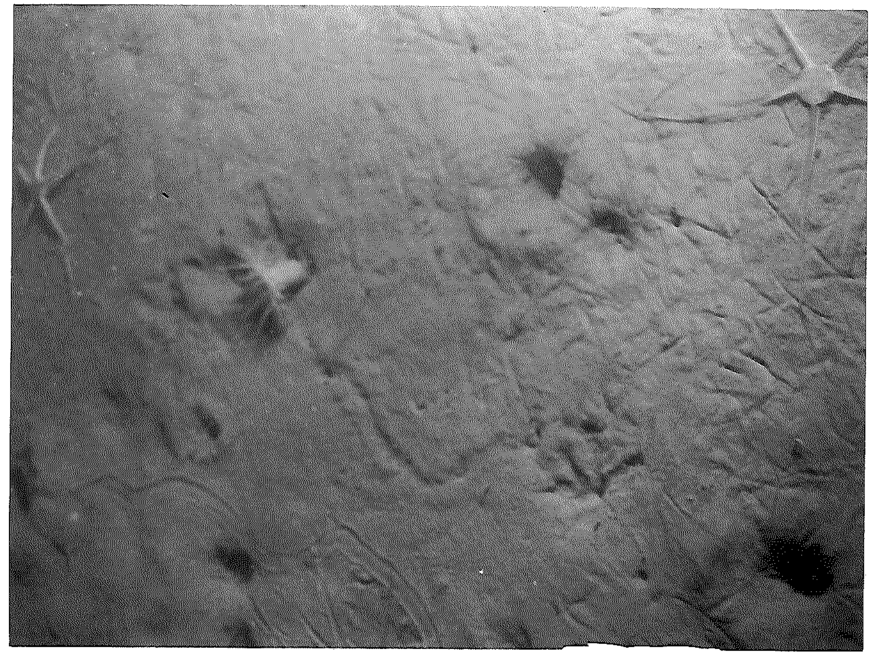


Photo 10

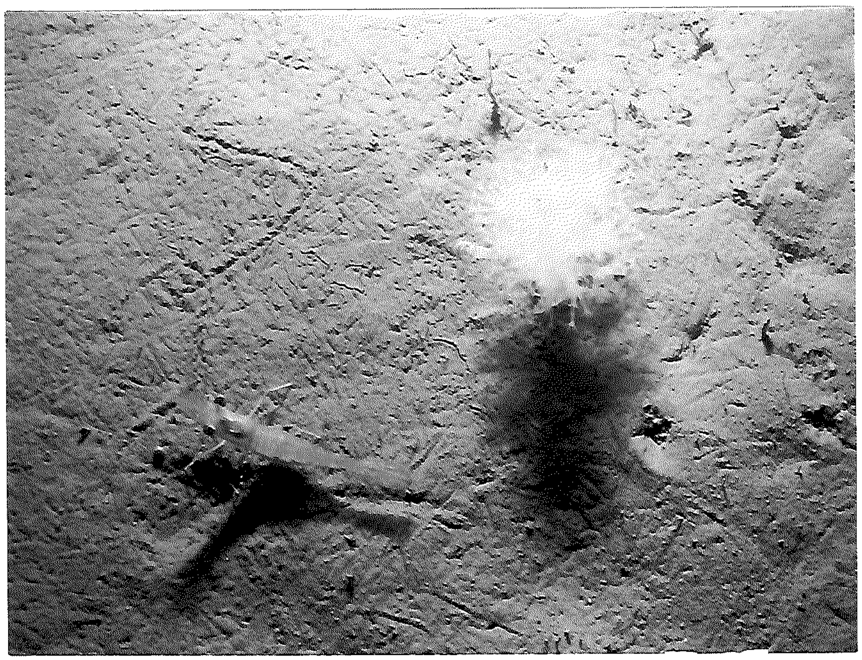


Photo 12

The high variability of ocean processes can result in considerable fluctuation in the abundance of invertebrates settling and developing in an area. The combination of countless benthic invertebrates and fish establishing in suitable areas form a variety of communities. The balance of dominance and important species results not only from the physical factors associated with the location but also from biological interactions, such as predation, reworking of the sediments, symbiotic relationships, and so on. The more conspicuous macrofauna, and incidentally also those which are most visible on bottom photographs, are usually used to characterise communities, and serve as a convenient starting place in analysis and comparison.

The benthos of the Grand Banks and Scotian Shelf are among the most interesting faunas of the world, although as yet still little studied. The former is one of the richest fishing grounds in the world, with a large part of production attributable to fish feeding on the benthos. The Scotian Shelf supports significant demersal fish and invertebrate fisheries. High production of benthos, which occurs mostly near the edges of the Banks, is linked to elevated water column productivity arising from water mass movements in both areas (see Chapter 4), and possibly in part, as noted earlier, from hydrocarbon seepages.

The Grand Banks of Newfoundland has many benthic species in common with areas to the north through the influence of cold water masses originating there, chiefly the Labrador Current. Species living at depths less than about 100 metres are mainly those which can survive on bed-rock or gravel bottom or resist abrasion by the shifting veneer of sandy substrate. Motile organisms such as the sand dollar, Echinarachnius parma, and sand dwelling molluscs, crustaceans and polychaetes are characteristic of these areas. The most numerous organism on the sandier parts of the Grand Banks is a tiny interstitial polychaete worm, Exogone hebes, only several millimetres long. The Grand Banks are unusual in having such a great expanse of bottom at such a shallow depth. Parts of the central part of the banks with shallow bedrock outcrops (Virgin Rocks and Eastern Shoals) have communities typical of the exposed rocky environments of coastal Newfoundland. Elsewhere on the banks, where bedrock is only a few metres below the surface layer of gravel and shifting sand, organisms must adapt to a less stable bottom.

Towards the southern Grand Banks the shallower topography and extensive stretches of fine-grained sand have distinctive, though not-well-known faunas. Patches of suspension-feeding holothurians (sea cucumbers) and dense concentrations of suspension-feeding molluscs (*Mesodesma deauratum*) have been observed in places, attesting to the high water column productivity there. The bottom of the key Southeast Shoal area is important in the biology of bottom-associated fish species, including the capelin, *Mallotus villosus*, for which it is the only known offshore spawning area, and is a feeding area for humpback whale. Sand dollars are widespread and the bottom fauna is probably typical of the organisms found in sandier substrates over the rest of the Grand Banks.

Below about 100 metres the substrate is more stable, influenced less by storm-induced movement of substrate. Brittle stars, *Ophiura* sp., form a characteristic community ringing the banks in this zone, which coincides with bottom substrate containing silt-sized sediment which marks the low stand of the Holocene sea level. With increasing depth off the banks, the substrate becomes muddier in general, though deep ocean currents in lower slope regions, for instance off the Northeast Newfoundland shelf, winnow the bottom material, leaving coarser substrate. Areas of current movement in deep water can support epifauna such as sponges and anemones, which feed on the suspended particulate matter and small planktonic organisms and larval stages, brought by the current. The areas of finer substrate at greater depth foster increasing numbers and diversity of deposit-feeding organisms.

The Scotian Shelf is influenced by the colder water masses from the north and thus shares many species with the Grand Banks of Newfoundland. Nevertheless, the influence of warmer water masses to the south and generally warmer water in the area, coupled with the low salinity water originating in the Gulf of St. Lawrence, allow species to live here which are not abundant or are non-existent on the Grand Banks. The factors which govern the distribution of organisms on the Scotian Shelf and the Grand Banks are, however, quite similar, and many of the communities are also similar.

The offshore banks of the Scotian Shelf have substrate varying from boulder strewn coarse gravel to fine sand characteristic of the shallow areas of Sable Island Bank. The rising sea level at the end of the last glacial episode caused the coastal zone to creep across what is now the Scotian Shelf, winnowing out much of the silt and clay sized sediment on the banks and leaving only the sand and gravel (See Chapter 3). The sand has been, and still is, transported at shallow depths on the Shelf by wave and current activity, creating a mobile benthic environment in which specially adapted organisms survive. Areas of coarse substrate on the banks are inhabited by interstitial organisms and motile species with limited attached fauna. Sands on the banks are typified by sand dollars, *Echinarachnius parma*, whose shape assists in burrowing and stabilises them against currents and waves, and several large mollusc species, *Arctica islandica* and *Spisula polynyma*, which are capable of rapid burrowing. Numerous other sand dwelling invertebrates are also present.

Off the banks at depths greater than about 100 metres the substrate begins to increase in silt and clay (mud) content, and brittle stars, chiefly Ophiura sp., become common. Water masses on the continental slope are under the influence of similar water masses as slope regions of the Grand Banks, and similar animals can be found.

Subtidal communities consist of a diversity of marine algae and their associated faunas. Sea urchins, mussels and a variety of other invertebrates are common. Nearshore on coarse substrate in subtidal high energy environments, the attached horse mussel, Modiolus modiolus, occurs with coralline algae encrusting on rocks.

Unlike the Grand Banks, the Scotian Shelf has a number of large basins, with soft muddy bottoms and a characteristic fauna. With increasing depth in the basins, the fauna changes from one dominated by more motile forms to deposit feeders. The transition is similar to that found moving off the continental shelf toward deep water, though mud is found at much shallower depths in the basins of the shelf. The muds are also found in protected coastal inlets in Nova Scotia and Newfoundland where similar animal groups occur.

The benthos is the object of important commercial fisheries in both Newfoundland and Nova Scotia. Sea scallop (Placopecten magellanicus) is an important species on Georges and St. Pierre Banks. Lobster fished both nearshore and offshore in Nova Scotia are staple fisheries. Stimpson's surf clam, Spisula polynyma, is the object of a major commercial fishery on Banquereau and Arctica islandica and the surf clam Spisula solidissima have been fished in nearshore areas for a number of years. The deeper mud bottoms in many areas support a snow crab fishery. The benthos is important in a wide range of man's activities, from serving as food and being a source of chemicals and new pharmaceuticals, to being the source of carbonate for various industries. Its importance is likely to increase with increased awareness of the resource.

CHAPTER 6

THE SCOTIAN SHELF

Introduction

The portion of the Continental Shelf off eastern Nova Scotia is known as the Scotian Shelf (Figure 1). It extends from Georges Basin in the southwest to the Laurentian Channel in the northeast, and covers an area of approximately 120 000 km^2. From an economic standpoint, the Scotian Shelf supports important commercial fisheries (shellfish, groundfish and finfish) and also contains proven reserves of natural gas near the Venture area of Sable Island Bank. The area to the west of the Scotian Shelf, including Georges Basin and Georges Bank (eastern Gulf of Maine), has been included in this atlas, although it is not formally part of the Scotian Shelf.

The distribution of the photographic stations used in this document is shown on the bathymetry map, Figure 1. It is clear that the stations are not evenly distributed along the shelf as they were collected for a variety of scientific programs. Some regions, such as the west/east line extending from Halifax to Emerald Bank, have been extensively studied by the Department of Fisheries and Oceans and the Atlantic Geoscience Centre and, as such, the photographic resource was large. Other areas, such as around the Venture site, have also been well studied by industry and the scientific community. There are no available bottom photographs for some of the other regions.

The distribution of photographs also reflects the subdivision of the Shelf into three main physiographic zones for the purpose of presentation. We have chosen, based mainly upon geological considerations discussed in Chapter 3, to divide the Shelf into an Inner, Middle and Outer Shelf. In addition to meeting certain standards of quality and uniformity, photographs were then selected that provided representative samples of the surficial sediment formations in numbers that approximated their distribution across the seabed. The major physiographic divisions of the Shelf were then further subdivided into banks, channels, basins etc. as the photographic resources permitted. Photographs from these areas are presented below.

Inner Shelf

The Inner Shelf is a submarine extension of the Atlantic Uplands, and generally represents the maximum seaward extent of the coastline of Nova Scotia in late glacial and post-glacial times. This outer boundary is approximately defined by the 115-120 m isobath. We have chosen to truncate the area under consideration in the Bay of Fundy at approximately 66° W longitude as the quality of photographs taken further up the Bay suffers from the high suspended sediment loads characteristic of the area. The Inner Shelf fringes the coast of Nova Scotia to the edge of the Laurentian Channel.

The surface of the Inner Shelf is extremely rough and heterogeneous and was formed as a series of beaches as the post-glacial sea transgressed the area and eroded much of the pre-existing glacial material. The seabed is strewn with glacially derived boulders and large areas of outcropping bedrock are evident as ridges and in isolated large patches. The Inner Shelf is continually washed by the southwesterly flowing Nova Scotia Current, and the presence of the major sediment type, Sable Island Sand and Gravel, reflects wave and current activity in its general lack of fine-grained sediments (Photos 14, 15, 19, 20, 21 and 22). Gravel ripples are common and occur just off the coast (Photo 13). Rough and hard substrate and types lacking a fine component provide a habitat for a variety of animals and plants, both attached and those capable of movement (motile) over the bottom. Burrowing forms are present in some of the areas photographed but, in this area, bioturbation of the seafloor sediments is not a major factor in seabed dynamics. The fauna seen in these photographs includes attached forms, such as anemones (Photos 14, 19 and 21), bryozoans (Photos 15, 20 and 22), sponges (Photos 14, 15, 20, 21 and 22), soft corals (Photo 15), hydroids (Photos 15 and 20) and tunicates (Photo 14). Motile epifauna include brittle stars (Photo 15), sea urchins (Photo 15), sea stars (Photo 14) and molluscs (Photos 14, 15 and 22). There is not much evidence of infauna, as there is a general lack of sand and muddy sediments, although in Photos 20 and 22 tentacles of a burrowing holothurian can be seen. In Photo 16 there is a higher proportion of sand to gravel, and here there is more evidence of infauna, although the epifauna is similar to that in the other photographs. Photographs in this series are remarkably similar, whether taken from off Cape Sable or from Scatarie Bank. In Photo 13, of gravel ripples off Halifax, there is little evidence of animal life.

Toward the seaward edge of the Inner Shelf, the Scotian Shelf Sand and Gravel grades to Sambro Sand (Photos 17 and 18) which contains more silt and clay-sized fractions. In Photo 18 the gravel component predominates, and here again occurs a diverse attached epifauna. However, this sediment, which contains more fines, is a more suitable environment for infauna, here represented by polychaetes. In Photo 17 there is little or no gravel present, and there is evidence of a rich infauna.

Photo 13 (44°35'N, 63°23'W, 25-30 m)
Gravel ripples of the Sable Island Sand and Gravel formation, formed by longshore currents, occur along the coast of Nova Scotia's Eastern Shore. The ripples, which occur in ribbons illustrated in this photograph taken off Osborne Head at the mouth of Halifax Harbour, are 2 to 25 m wide and have a wavelength of 1.7 to 2.8 m. Sediment size grades from a fine gravel on the crests to much coarser pebbles and cobbles in the troughs. Crests are usually linear but can fork or flatten. This type of bottom lacks an extensive zoological community but marine algae grow on large cobbles and boulders. Shells of bivalve molluscs have been accumulated by water movements. Areas of gravel ripples are common on the inner shelf and may occupy large areas of seabed.

Photo 14 (43°20'N, 65°37.5'W, 32 m)
In this photograph from the inner shelf south of Cape Sable, the seabed is rough due to the densely packed cobbles and boulders of the Sable Island Sand and Gravel formation. These are colonised by encrusting organisms such as anemones, sponges, tunicates and coralline algae. Small sea stars can be seen and some seaweed debris is present, and filamentous algae occur on some of the boulders. The presence of anemones suggests an ample food supply carried by currents, and resuspension, which may in part be induced by the roughness of the seabed.

Photo 15 (46°04'N, 59°07'W, 128 m)
The sediment on the outer edge of the coastal zone off northern Nova Scotia on St. Anns Bank east of Scatarie Island is Sable Island Sand and Gravel. Here, large subangular to subrounded cobbles and pebbles occur mixed with sand, and support a rich fauna which includes suspension and deposit feeding brittle stars, sea urchins, soft corals and sponges. A snail (probably *Aporrhais* sp.) is visible and scattered patches of bryozoans and hydrozoans can be seen encrusting some of the clasts.

Photo 16 (46°04.02'N, 59°07.04'W, 128 m)
The gravel component of the Sable Island Sand and Gravel formation near Scatarie Bank, which is in the pebble-cobble size range, is seen here. The sand matrix beneath the gravel provides an ideal substrate for a surface deposit feeding terebellid polychaete, whose thread-like tentacles can be seen slightly to the left of centre. Suspension feeding brittle stars, soft corals and scallops (*Placopecten magellanicus*) and a suspension feeding bivalve (the two adjacent siphons to the left of centre) are visible. Surface detritivore/carnivores such as *Ophiura* - type brittle stars and the sea urchin, *Strongylocentrotus droebachiensis*, are visible. Hydroid polyps are also present. The fauna in this area represents a balanced community typical of gravelly-sand habitats. The seabed is covered with a thin layer of fine-grained sand which may have been brought to the surface by infauna.

Photo 13

Photo 15

Photo 14

Photo 16

Photo 17 (44°26'N, 63°03'W, 100 m)
A dense population of tube-building polychaetes occurs on the Sambro Sand formation (gravelly sand) on the outer part of the Inner Shelf south of Halifax. The polychaetes probably belong to the family Eunicidae, which live in horizontal tubes which they carry about. Large numbers of these tubes can alter the current flow over the sediment surface. These carnivores often compete with ophiuroid brittle stars. Also present are sea stars, possibly Henricia sp.

Photo 18 (44°13.5'N, 66°36'W, 104 m)
On the Inner Shelf of Nova Scotia, at the mouth of the Bay of Fundy, the seabed is predominantly gravel. The substrate in this picture is Sambro Sand, gravel facies. The gravel clasts are rounded to subrounded pebbles and cobbles. The benthic fauna consists of suspension feeding sessile animals, such as hydroids and bryozoans. Horizontal tubes of onuphid polychaetes are seen in the silty and clayey sand between the gravel clasts; these tubes are constructed from small particles of fine gravel and material supplied by the disarticulated broken shells of the dead bivalve molluscs present. Compare these tubes with those seen in Photo 17 built using finer-grained sediments. Bivalve shells, probably Modiolus sp., are present, although most appear to be dead.

Photo 19 (43°20.0'N, 65°37.5'W, 32 m)
The seabed off southern and southwestern Nova Scotia is often extremely rough due to the dominance of outcropping bedrock. In this area south of Cape Sable on the Inner Shelf, the sediment is Sable Island Sand and Gravel, with gravel in the pebble to boulder range predominating. The sand-sized material is thin. Boulders of over 2 metres in diameter have been reported, and in this photograph the boulders may be outcropping bedrock and occur across large areas of the seabed. The boulders may be heavily colonised (see Photo 20), or, as shown here, sparsely colonised by a single anemone and a few barnacles. This suggests that the sand and fine gravel is in regular transport. In the shelly sand-pebble hash accumulated between the gravel clasts there is little or no evidence of fauna, but this substrate can harbour a variety of small infaunal organisms.

Photo 20 (43°20.0'N, 65°37.5'W, 32 m)
In this area of Sable Island Sand and Gravel south of Cape Sable, and south of Photo 19 above, a dense, long established community exists on large boulders or bedrock. The degree of encrustation by anemones, finger-like sponges, bryozoans and hydroids suggests a highly developed community in equilibrium. Sandy substrate is not discernible. The branchial tentacles of sea cucumbers, probably Cucumaria sp., can be seen in the upper right of centre. Motile epifauna, such as crabs, echinoderms and gastropods are usually found in such communities, but none are visible here.

Photo 17

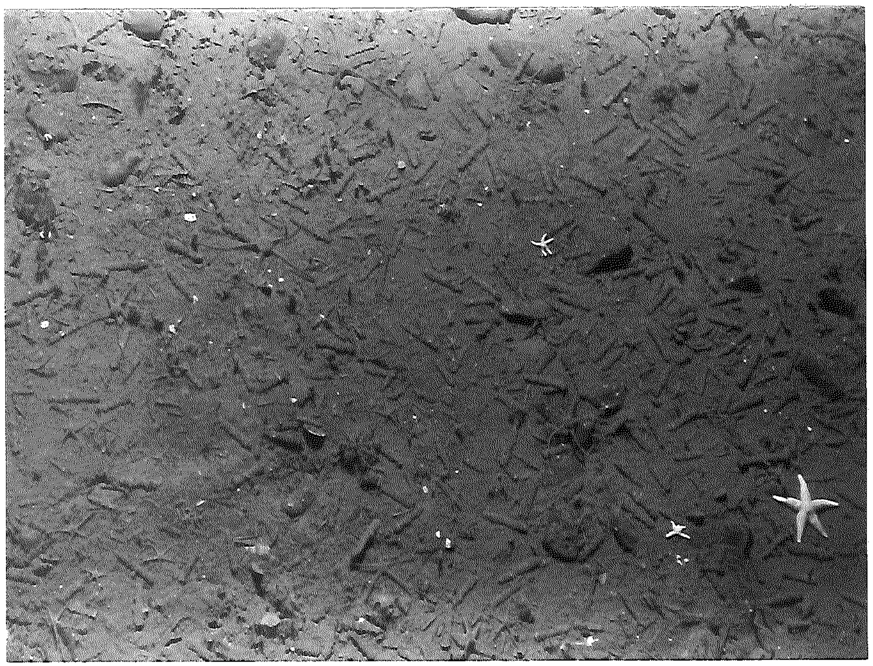


Photo 19

Photo 18

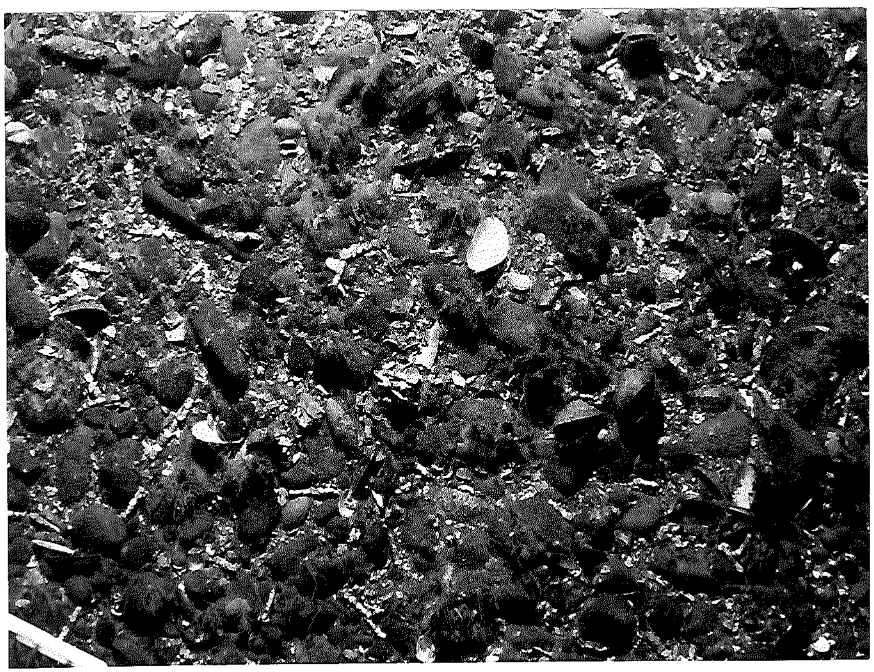


Photo 20

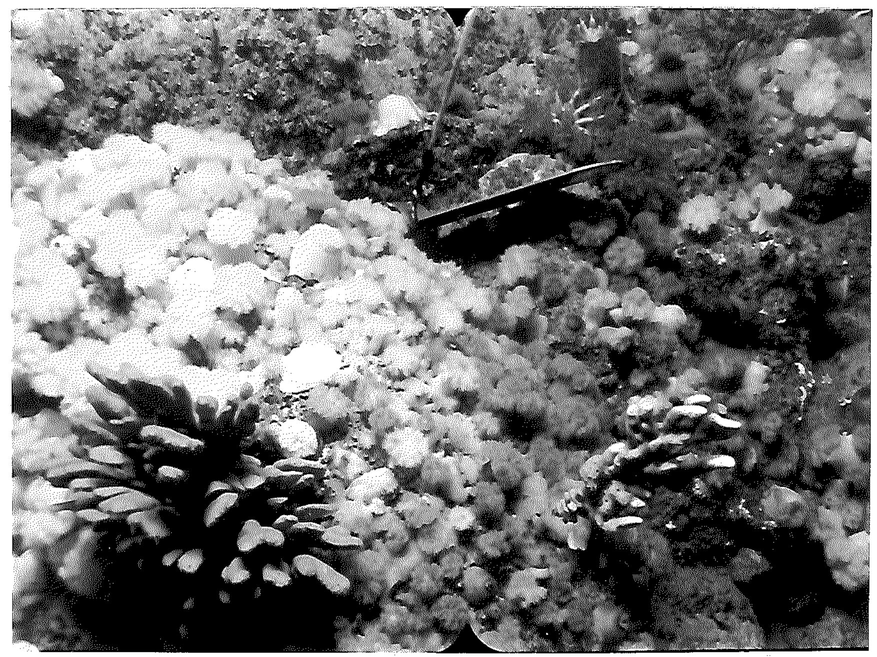


Photo 21 (44°25'N, 63°04'W, 68 m)
Southeast of Halifax on the Inner Shelf, Sable Island Sand and Gravel occurs. The cobbles and boulders are subangular to subrounded in shape and not well sorted. The most conspicuous features of the epifauna are the white calcareous tubes built by serpulid polychaetes, and numerous small anemones adhering to a boulder in the lower left-hand corner. The surfaces of the other boulders have patches of sponges and hydroids, and a thin coating, probably bacterial, to which detritus has become attached. The visible epifauna in this photograph are mainly suspension feeders.

Photo 22 (44°25'N, 63°04'W, 68 m)
The seabed at the outer edge of the Inner Shelf off Halifax is a lag gravel, probably developed on a till. The clasts range in size from pebbles to boulders and are subangular in shape. The small amount of mud matrix provides a suitable substrate for some burrowing holothurians, but epifauna in the form of hydroids, bryozoans and small molluscs are the most conspicuous. In the upper left of the picture, a tubicolous polychaete adhering to the larger rocks can be seen spreading its food capturing tentacles. Some mineral tubes of small, motile polychaetes can be seen. The cobbles have an encrustation of coralline algae.

Photo 23 (45°42.5'N, 58°57.8'W, 270 m)
The area between Scatarie and Misane Banks, called St. Anns Basin, is part of the Central Shelf trough and demonstrates the characteristics of a true shelf basin. It is deep with a clayey silt substrate of LaHave Clay. The tracks and traces of invertebrate activity are etched in this fine grained sediment, which appears to be heavily pelletized. An abundance of brittle star tracks appears in the lower foreground. The sediment surface is covered with tiny pits, each probably representing a burrow of a small polychaete or amphipod. A patch of reworked sediment is evident near a burrow to the right of centre. This environment provides no suitable substrate for an attached fauna. The very fine grained nature of the sediment suggests little current activity in this area.

Photo 24 (42°51.0'N, 67°39.3'W, 220 m)
This photograph from Crowell Basin, Gulf of Maine, shows a seabed environment of Emerald Silt, a sandy-clayey silt. The fine-grained muddy sediment is perforated by a variety of tubes and burrows. The tubes are probably made by polychaetes and amphipods. The more slender white tube in the lower foreground is probably that of a suspension feeding sabellid polychaete. On substrates of this type, the rich infauna may rework the sediments to depths of 12 cm or more (Wildish and Lobsiger 1987).

Photo 21

Photo 23

Photo 22

Photo 24

A few localised depressions, such as Chedabucto Bay, contain pockets of LaHave Clay (Photos 10 and 11) which, in contrast to areas of seabed covered in Sable Island Sand and Gravel, are relatively featureless. Here, bioturbation of the fine-grained sediment is observed. Brittle stars are the main epifaunal species seen, and traces are left on the sediment by a diverse infauna.

Middle Shelf

The Middle Shelf is an area of large depressions and isolated banks in the central Scotian Shelf, immediately offshore of the Inner Shelf. It is a geomorphically complex area, and extends along the entire length of the Scotian Shelf, forming a broad trough, approximately 40-50 km wide and 145-180 m deep. Two large transverse depressions, Emerald and LaHave Basins, which are separated by Sambro Bank, branch from this trough and reach depths of up to 291 m. To the east, the Middle Shelf is dissected by a system of partly disconnected valleys with intervening ridges and a chain of isolated banks, the main ones being Middle, Canso and Misaine. The Middle Shelf is characterised by the presence of a series of outcropping morainic ridges with relict iceberg furrows between Emerald Silt and LaHave Clay. The Middle and Outer Shelves are part of the submerged Atlantic Coastal Plain.

The flow of water across this area is primarily from northwest to southeast, and is part of the Nova Scotia Current, a cold water mass spilling out of the Gulf of St. Lawrence and combining with a portion of the inshore Labrador Current. Towards the outer portion of the Middle Shelf the current flow is less predictable as warmer slope water may become mixed with the main current.

Basins

Photographs from Grand Manan, Jordan, Crowell, and Georges Basins together with those from Northeast Channel have been included in this section although they are not all within the Middle Shelf division of the Scotian Shelf. However, they have features in common with LaHave, Roseway and Emerald Basins and the large unnamed basin to the south of Scatarie Bank (Photo 23), which is referred to as St. Anns Basin. The predominant sediment types in these deeper areas are LaHave Clay (Photos 23, 25, 26, 32 and 34) and Emerald Silt (Photos 24, 29 and 33). Photo 31, from Jordan Basin, shows a thin substrate of either Emerald Silt or LaHave Clay. Both LaHave Clay and Emerald Silt contain large proportions of silt and present smooth, flat surfaces, except in areas where pockmarks occur. Photo 30, from the flank of Middle Bank, shows a sediment of Sambro Sand. All the photos in this section are from muddy sediments with the exception of Photos 27 and 28 from Northeast Channel. This is an erosional area of high current flow, associated with the inflow and outflow of tidal currents to the Bay of Fundy. Here the sediment is Sambro Sand, which is rippled by the current and, in Photo 27, shows a gravel component.

Environments of fine-grained, silt and clay sediments usually provide no suitable substrate for macroscopic attached animals, and generally there is an absence of epifauna to be seen in these representative photographs with the exception of Photos 25 and 26, in which an anemone (Photo 25), hermit crabs (Photo 26) and tunicates (both photos) are observed. In contrast, there is ample evidence for the presence of an abundant diverse infauna. Burrowing deposit and

Photo 25 (42°25.2'N, 67°4.5'W, 354 m)
In Georges Basin, Gulf of Maine, the fine grained sediment of LaHave Clay hosts a large number of stalked tunicates and tube-building and burrowing taxa. Some small brittle stars are also present. The openings of two large tubes, possibly those of polychaetes, project from the sediment. The LaHave Clay contains a significant sand-sized component. The presence of the stalked tunicates indicates current activity which also suggests a small coarse component in the sediment to which they can attach. The seabed surface is not extensively pitted, perhaps indicating a low density of infaunal invertebrates.

Photo 26 (42°20.4'N, 67°21.6'W, 304 m)
In the southern part of Georges Basin there is considerable water movement. Water movement through the Northeast Channel sweeps the flanks of Georges Basin and develops sand waves on its flank at 160 m water depth. The sediment of LaHave Clay has a coarser sand component, providing a suitable substrate for a cerianthid anemone and stalked and non-stalked tunicates. Saucer shaped casts (lower centre), hermit crabs, numerous horizontal and vertical tubes, and star-shaped feeding traces of surface deposit feeding bivalves can also be seen on the seabed.

Photo 27 (42°20.1'N, 66°7.2'W, 240-260 m)
Northeast Channel is a deep glacial channel separating Browns and Georges Banks. A gravel lag beneath the thin, clean, coarse Sambro Sand is exposed by the high currents in this area, and the sand itself is rippled. Shell fragments can be seen in the troughs of the ripples and thus enhance the outline of the ripples. Little bioturbation of the surface sediments appears to occur. Sea stars and gastropods can be seen in this photograph, but fauna does not appear to be generally abundant.

Photo 28 (42°20.12'N, 66°7.2'W, 240-260 m)
This photograph shows a similar substrate to that in Photo 27, consisting of a rippled sediment of Sambro Sand. The sand ripples are accentuated by the colour difference between the sand and the shell debris in the troughs. The presence of what looks like fecal casts, seen in a trough (upper left) suggests the presence of infauna, but evidence of animal activity is erased by the currents. Much of the Northeast Channel is a glacial till sediment with a thin veneer of Sambro Sand formed by current erosion. Sand waves are present in adjacent areas.

Photo 25

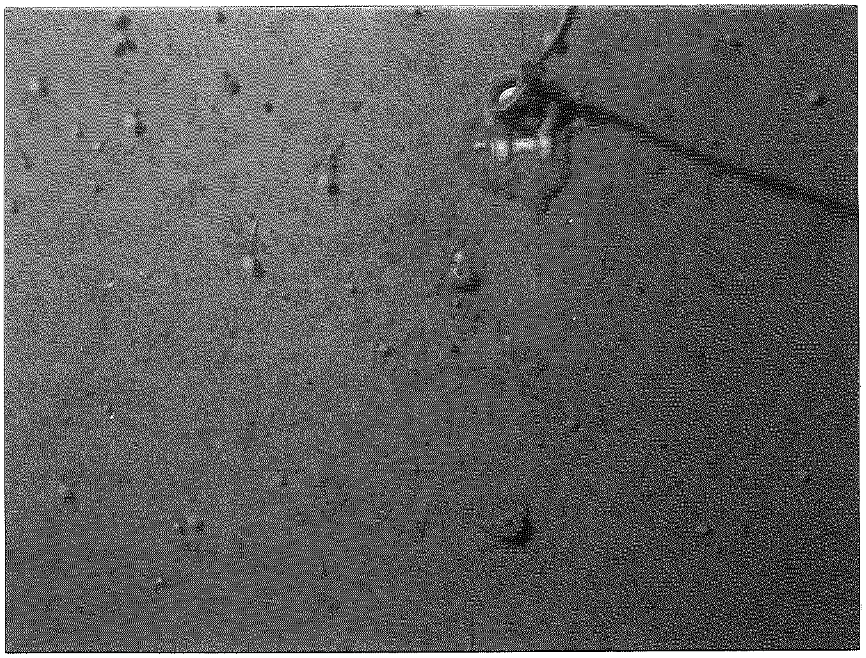


Photo 27

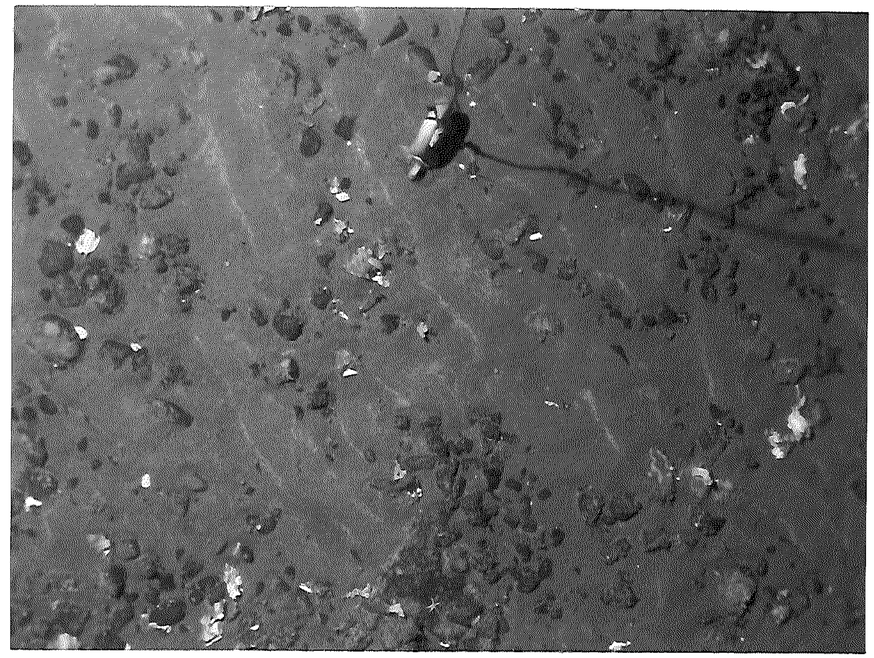


Photo 26

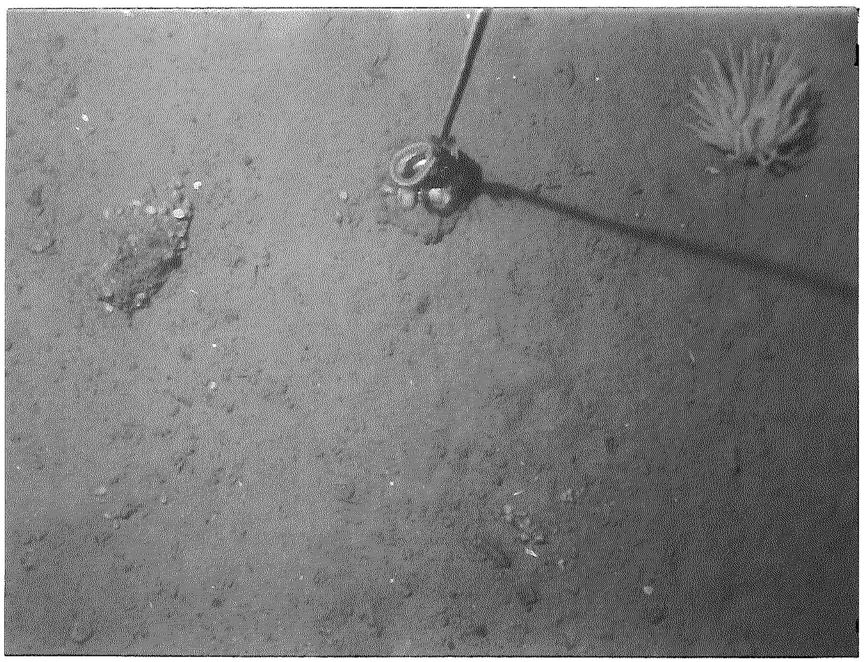


Photo 28

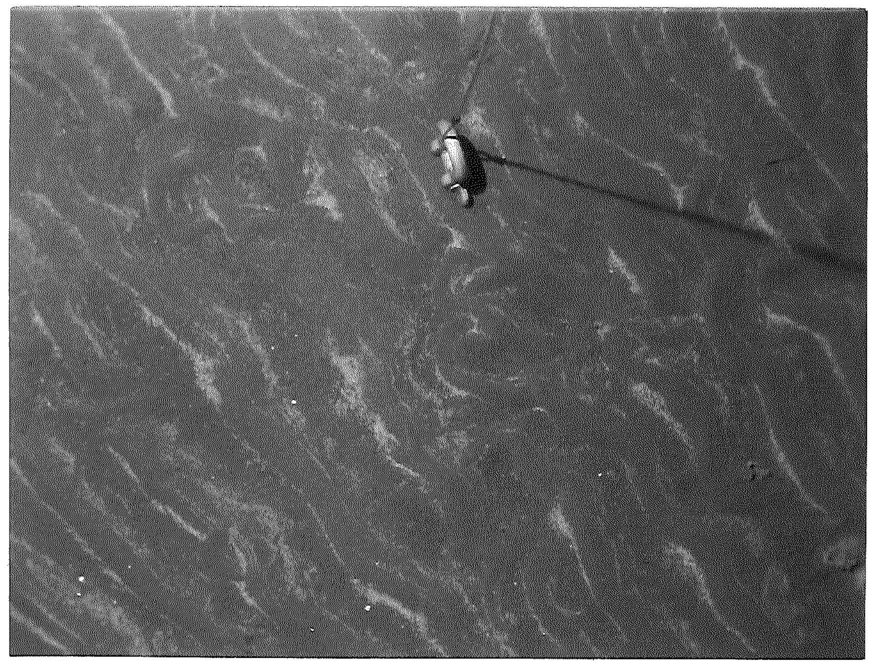


Photo 29 (44°03'N, 63°03'W, 215 m)
Deep in Emerald Basin, deposits of Emerald Silt show the entrances to many burrows, probably made by burrowing anemones and polychaetes. Two holes occurring close together perhaps represent the two openings to a U-shaped burrow. Emerald Basin contains large areas of pockmarks (gas venting craters) which range to 15 m in depth and several hundred metres in diameter.

Photo 30 (44°39.25'N, 61°21.6'W, 121 m)
On the flank of Middle Bank adjacent to Emerald Basin, a Sambro Sand (muddy sand) substrate prevails. It appears to support a rich infauna, a reflection of increased abundance frequently seen on silty substrates. Although few large tube builders are seen in this photograph, a great deal of bioturbation is evident in the heavily pelletised layer overlain with numerous mounds, tracks, traces, and burrows created by the infauna. The anemone, Tealia sp., and scavenging sea stars, brittle stars, tubicolous polychaetes and molluscs can be seen.

Photo 31 (44°08'N, 67°32'W, 180 m)
In Jordan Basin, Gulf of Maine, at the mouth of the Bay of Fundy, the substrate is either LaHave Clay or Emerald Silt. A large amount of reworking of the sediment is evident, mainly due to infaunal activity. Burrows and numerous fecal mounds produced by deposit feeding polychaetes can be seen. The thin tubes also seen over the surface may have been formed by the tube-building amphipod, Erichthonius sp.

Photo 32 (44°32'N, 66°27'W, 192 m)
In Grand Manan Basin, southeast of Grand Manan Island, Bay of Fundy, the sediment is interpreted as being a thin layer of LaHave Clay overlying glacial till (Scotian Shelf Drift)(Fader et al. 1977). This photograph is at the boundary between Scotian Shelf Drift and LaHave clay, and is unusual. The spiral structure was not seen in any other photographs, and the exact cause of the formation could not be determined. Several Ophiura-type brittle stars are also evident.

Photo 29

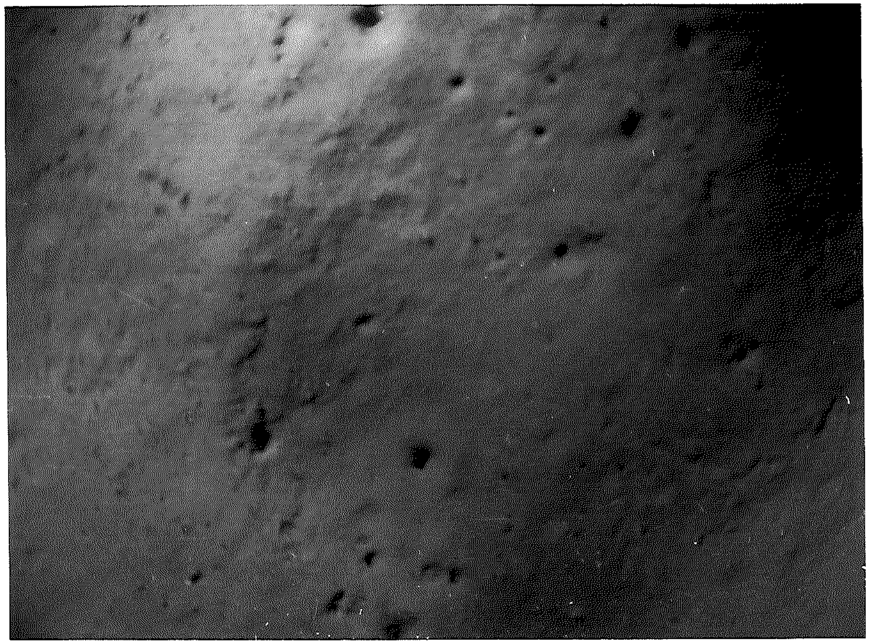


Photo 31

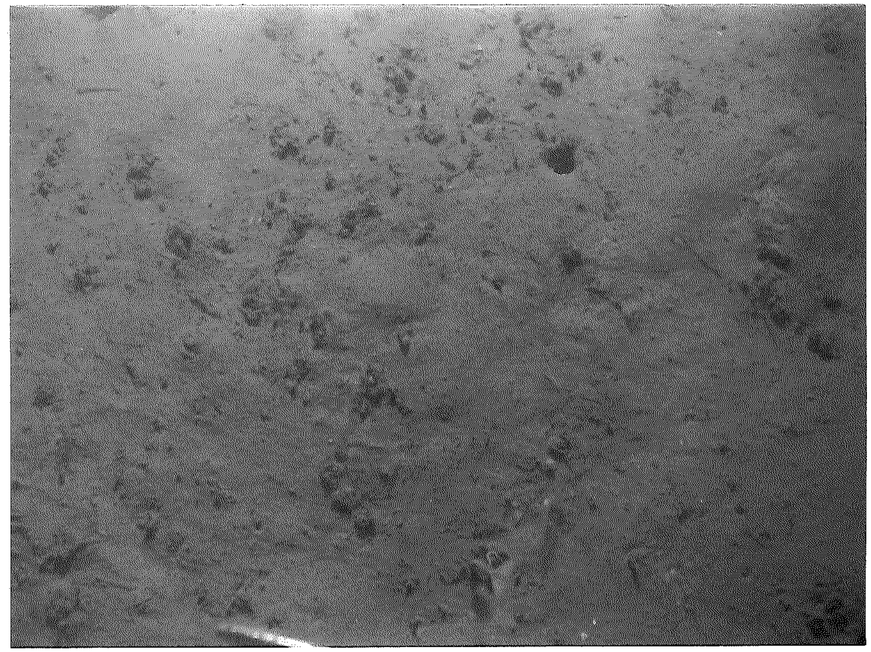


Photo 30

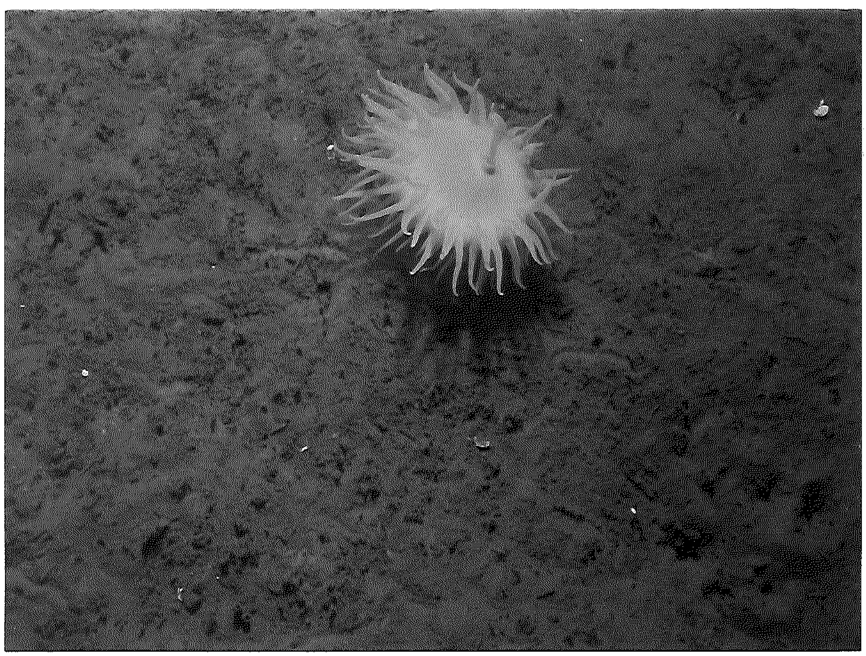


Photo 32

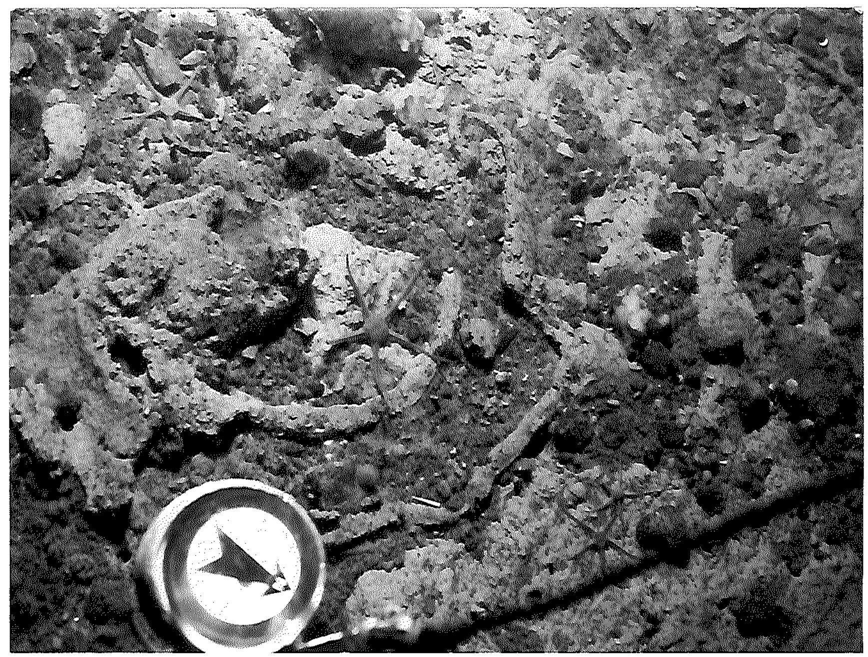


Photo 33 (43°13.5'N, 65°02.5'W, 160 m)
The surface sediments in Roseway Basin, as in other basins, are fine-grained and muddy. In the area from which this photograph was taken, the sediment is a poorly sorted clayey and sandy silt of the Emerald Silt formation. It is heavily pelletised and has numerous tubes and burrows, suggesting the presence of a rich infauna. Pockmarks also occur in Roseway Basin.

Photo 34 (43°53.5'N, 62°52.2'W, 264 m)
In this deepest part of Emerald Basin the sediment is LaHave Clay. This photograph shows the fine-grained surface texture of biologically created mounds, depressions, holes, burrows and deposits (compare with Photo 29, also from Emerald Basin). As in other areas of similar sediment, a rich infauna is probably present. Comparison with Photo 33 from Roseway Basin suggests that although both are inhabited by numerous organisms within the sediments, the communities are different.

Photo 35 (44°48'N, 61°16'W, 120-140 m)
In this photograph taken on northwest Middle Bank, the Sable Island Sand and Gravel occurs as the gravel facies with less than 50% sand. The clasts are a mixture of subrounded to rounded and subangular shapes. This poorly sorted sediment contains little infauna. Sand dollars (Echinarachnius parma) and a scavenging/carnivorous tube-building polychaete (possibly of the family Eunicidae or Onuphidae) are the only fauna evident. Attached epifauna are not observed.

Photo 36 (44°46'N,61°15'W, 120-140 m)
At this station in the central shelf area on northwestern Middle Bank, the Sable Island Sand and Gravel varies from sand to cobble patches with a sandy matrix. The latter is observed in this photograph. The gravel is well to moderately rounded and some of the clasts appear to have been recently moved, hence the absence of both fauna and fine sediment particles. Numerous tubes of motile surface feeding polychaetes occur over the sandy areas and among the clasts. The occurrence of these tubicolous polychaetes suggests the presence of a moderate current, as the use of portable tubes has been developed in some cases by animals that live in high current regimes. The sinuous tubes of other polychaetes and hydroid polyps are visible on some of the cobbles.

Photo 33

Photo 35

Photo 34

Photo 36

suspension feeders have left typical signs of their activities in the form of fecal pellets, mounds, burrows and tubes. The retention on the sediment surface of evidence of bioturbation suggests that the currents in these areas are less intense (Photos 23 and 24).

Photos 27 and 28, from Northeast Channel, demonstrate a different type of environment, where there is a strong current flow and evidence of bioturbation of the sediment is quickly erased.

Other disturbances of the sediments in these basins include pockmarks made by the escape of gas, and trawl marks (see Figure 3, a sidescan sonogram from the shelf edge). The circular disturbance of sediment seen in Photo 32 is of unknown origin.

Photo 38 is from the flank of northeastern Emerald Basin adjacent to Middle Bank, and shows a typical LaHave Clay sediment representative of the entire basin. As the depth decreases at the flanks of Emerald Basin towards Middle Bank and Emerald Bank, a transitional zone occurs, where the sediment becomes more coarse grained, changing from Sambro Sand (Photo 30, Middle Bank; Photo 12, Emerald Bank), to Sable Island Sand and Gravel (Photo 39, Middle Bank; Photo 65, Emerald Bank). In both Photos 30 and 38 the presence of numerous infauna is evidenced by a high amount of bioturbation visible. In Photo 30, a number of epifaunal species such as anemones, sea stars, brittle stars and polychaetes, which prey on the infauna are also seen. In Photo 38 molluscs are the main epifaunal animals present.

Banks and Other Features

From the deep basins to the shallow banks a change in sediment distribution from LaHave Clay to Sambro Sand and to the more coarse-grained and thoroughly sorted Sable Island Sand and Gravel occurs. This is well illustrated by the series with Photo 38 (LaHave Clay), Photo 30 (Sambro Sand) and Photo 39 (Sable Island Sand and Gravel), which demonstrates a transition from Emerald Basin to Middle Bank.

The banks included in the Middle Shelf zone are an unnamed bank to the northwest of Middle Bank (Photos 35 and 36), Roseway (Photo 42), Sambro (Photos 45, 46 and 55), Middle, Canso and Misaine Banks, and other small isolated banks in the area (Photo 40).

Roseway Bank is covered with Sable Island Sand and Gravel, grading to sediments with silt and clay with increasing depth below 110-120 m. In the vicinity of Photo 42 the substrate is greater than 50% gravel, and contains numerous rounded to subrounded pebble, cobble and boulder sized clasts. The geological maps presented in Figure 2 indicate that the substrate on Sambro Bank is similar to that found on Roseway Bank, i.e., gravelly. However, Photos 45, 46 and 55 from the shallowest area of this bank show a greater amount of sand.

Similarly, northwestern Middle Bank has the same sedimentary characteristics. It is located on a proposed pipeline route between the Venture gas field and the mainland of Nova Scotia. Both Photographs 35 and 36 are located close to a boundary between the two main divisions of Sable Island Sand and Gravel formation, greater than 50% sand and greater than 50% gravel. These photographs show rounded to subrounded cobbles lying on a matrix of coarse-grained, well sorted

Photo 37 (44°52'N, 57°13'W, 443 m)
The Laurentian Channel is a wide (90 km), deep (540 m) transverse channel separating the southwestern edge of the Grand Banks from the northeastern edge of the Scotian Shelf. This photograph from the Scotian Shelf side of the channel shows a seabed of Emerald Silt, a clayey sandy silt, which provides an excellent template for recording faunal tracks and traces. In this picture the presence of numerous infaunal animals is suggested by the holes, burrows, fecal casts and pellets, worm tubes and mounds. The marks around the burrow on the left could be a holothurian track. A sea pen, which has left marks in the sediment, is seen on the left-hand side of the photograph, and a tube, perhaps made by a sabellid polychaete, appears in the upper part of the photo.

Photo 38 (44°38'N, 61°30'W, 115 m)
This photograph of the seabed to the west of Middle Bank, on the flank of northeast Emerald Basin, shows an environment similar to that illustrated in Photo 30, although the substrate in this area is LaHave Clay, a clayey silt. Tracks and traces are visible, and a burrowing anemone and numerous molluscs are present immediately under the surface of the sediment. Animal tracks and looser reworked sediment occur in the surface layer.

Photo 39 (44°35'N, 61°16'W, 100 m)
In this area of Middle Bank, a gravelly sandy sediment of Sable Island Sand and Gravel is found. Ripple marks are not as evident here as on the eastern side of the banks, and the tracks seen suggest a small silt and clay component. Burrows, mounds and faecal pellets indicate the presence of many infaunal animals, and numerous worm tubes (Eunicidae or Onuphidae) are scattered over the surface. Sea stars (Henricia sp., centre, Asterias sp., upper right) and sand dollars are also visible.

Photo 40 (46°06'N, 58°56'W, 137 m)
The eastern flank of St. Anns Bank descends gradually into the Laurentian Channel. The substrate of Sambro Sand, a mixture of gravel, sand, silt and clay, is inhabited by numerous infaunal and epifaunal species. The most conspicuous of the epifaunal species are the tube-building polychaetes (both horizontal and vertical tubes are seen), occasional brittle stars, sea stars and gastropods. The large burrow openings may have been made by suspension feeding holothurians, as several of these are seen in other photographs from this station. Attached to the occasional pebbles projecting through the sediment are palm-shaped colonial bryozoans. Animal tracks and numerous mounds of unseen invertebrates also occur. In general, a balanced, undisturbed, relatively diverse fauna is observed.

Photo 37

Photo 38

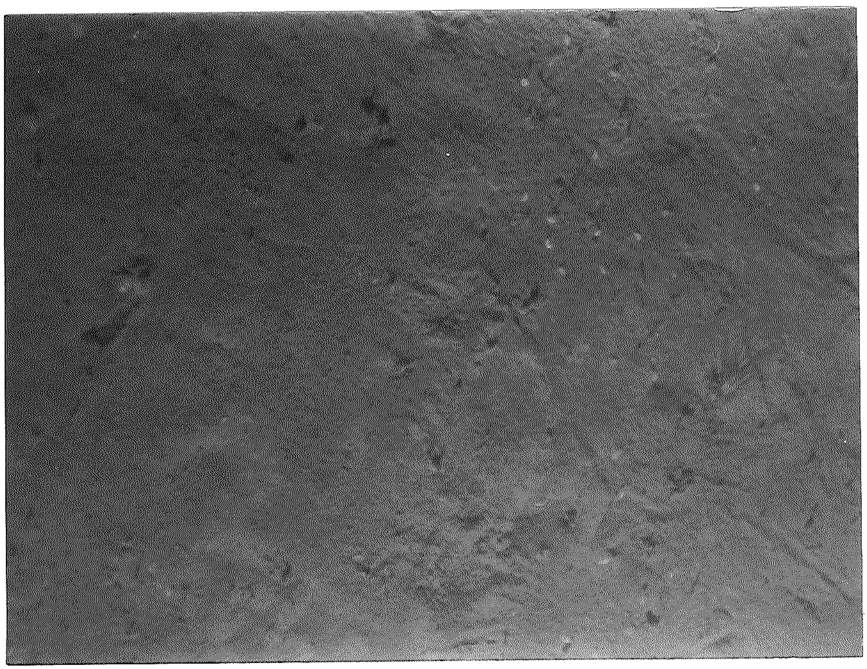


Photo 39

Photo 40

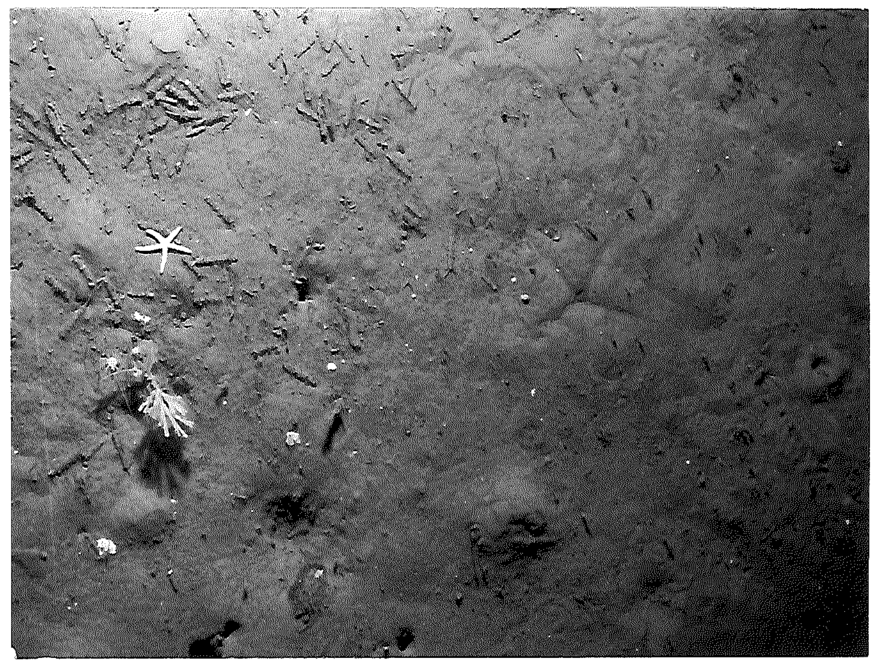


Photo 41 (approx. 43°40'N, 62°29'W, 80-90 m)
On the northwestern edge of Emerald Bank, epilithic growth can be seen on the well-rounded pebbles, cobbles and boulders of the Sable Island Sand and Gravel formation found in this region. The pinkish tinge is due to the presence of the coralline alga, *Lithothamnium* sp. A fuzzy organic/bacterial coating occurs on some of the cobbles. Numerous hydroid colonies and scattered barnacles, sponges and tunicates are present, but the community otherwise is not diverse. Large gravel patches like these cover more than 50% of the area of Emerald Bank and 25% of Western Bank.

Photo 42 (43°23.77'N, 64°38.07'W, 71 m)
In this area of Roseway Bank the substrate is composed of the rounded to subangular cobbles and boulders of the gravel facies of Sable Island Sand and Gravel. The boulder in the upper left hand corner bears a colourful display of various sponges, solitary examples of which occur elsewhere on the cobbles. Grazing epifauna such as sea stars and gastropods are feeding on these lightly colonized cobbles, and tunicates can be seen on the lower surfaces of some of the larger clasts. The encrusting alga, *Lithothamnium*, is common. This photograph is typical of the eastern 75% of Roseway Bank.

Photo 43 (43°21.2'N, 62°16.5'W, 110 m)
On eastern Emerald Bank in a saddle known as Western Gully, the Sable Island Sand and Gravel (sand facies) shows signs of considerable biological activity. The numerous faecal casts co-occur with tracks and trails made on the sediment surface. Several colonies of soft corals find suitable substrate on which to grow. Frequent tracks leave an indication that a considerable amount of epifaunal activity occurs here.

Photo 44 (43°35.4'N, 60°15.6'W, 82 m)
This photograph shows the fine-grained sand of the Sable Island Sand and Gravel formation from southwest Sable Island Bank. This photograph comes from an area of shell beds, as interpreted from sidescan sonar. Degraded ripples are shown along with broken and whole shells of *Arctica islandica* Some of the shells are embedded in the sediment, which suggests that the shell bed may be old and in the process of being exposed. A gastropod track winds through the photograph.

Photo 41

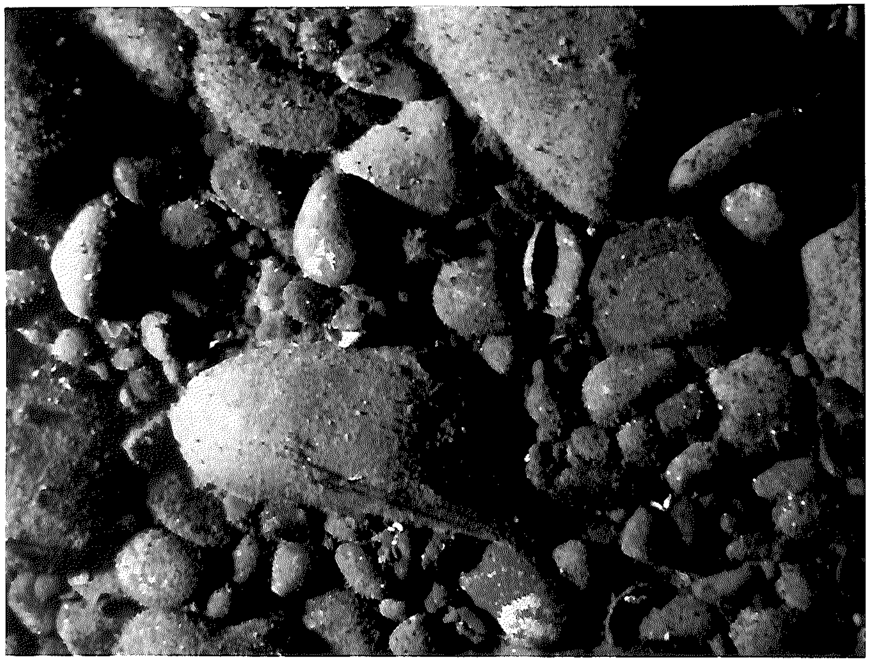
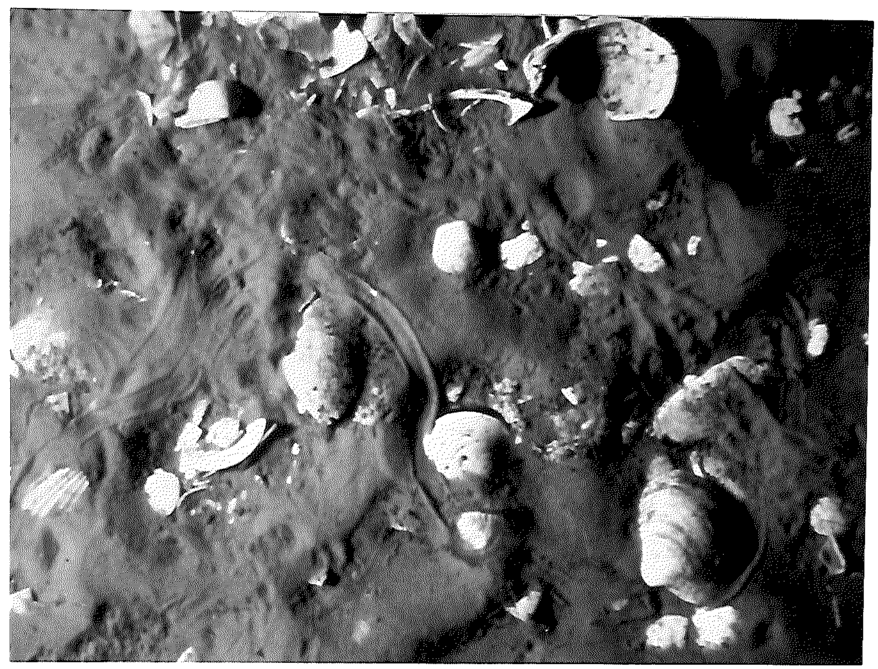


Photo 42

Photo 43

Photo 44



sand. Photo 39, located further to the south on the flank of Middle Bank, is located in an area of Sable Island Sand and Gravel consisting almost entirely of sand.

The benthos on the shallower areas of the Middle Shelf is, as elsewhere, dependent on the sediment type. In the area shown by Photos 35 and 36 on Middle Bank, the instability of the clasts precludes the development of an attached epifaunal community. Infaunal community development is also similarily limited, with sand dollars (Photo 35) and polychaete tubes (Photos 35 and 36) being the only evidence of its presence. In contrast, the sandy environment seen in Photo 39 supports both a rich epi- and infaunal community, with sea stars, sand dollars and numerous tubes visible. This sandy environment south of northwestern Middle Bank appears to represent the deepest transition between the silts and clays of Emerald Basin to the sandy/gravelly substrates found on the banks themselves (see Photos 30 and 38). The sediment in Photo 39 does not appear to be typical of Sable Island Sand and Gravel as seen in other photos such as 58 and 67 from Sable Island Bank, and it may contain some silt and clay.

On Sambro Bank there are numerous signs of infauna (note the bioturbation seen in Photo 55) and there is some attached epifauna on the gravel clasts (Photo 45, hydroids, and Photo 46, sponges). Mobile epifauna is represented by gastropods and sea stars. On northwestern Middle Bank, in a transitional area between sand and gravel, there is a mixed fauna. Polychaetes and sand dollars occur on the sandy sediment, but there is no attached epifauna, possibly as a result of the instability of the gravel in the currents. On Roseway Bank the gravel clasts are larger, and therefore rather more stable, and some biological growth is apparent. The red alga Lithothamnium grows on the cobbles and some sponges are attached to a large, more stable, boulder (Photo 42). Grazers such as sea stars and gastropods are associated with this encrusting growth.

Photos 47 and 48 were collected adjacent to the edge of the Inner Shelf near Halifax Harbour. Both are from an area of Scotian Shelf Drift, with small pockets of LaHave Clay. The sediment seen in these photographs is predominantly silt and clay, with a small amount of gravel dispersed throughout, and may be close to the contact between the Scotian Shelf Drift and the LaHave Clay. The benthos again reflects the sediment composition. As might be expected, the softer sediments are able to support a diverse infauna, and these have left traces in the silty clay. Infaunal polychaetes have also been able to incorporate the sediment particles in their tubes. This, together with other infaunal processes, results in sediment sorting. Attached epifauna in this area includes anemones and sponges, and sea cucumbers are seen in both pictures.

Photos 12, 40 and 50 from different areas of the Middle Shelf are all from similar depths and all illustrate Sambro Sand. Photo 50 shows large boulders and cobbles scattered on the surface whereas Photos 12 and 40 have a mixture of sand, silt and clay. The biological habitat provided in these areas is therefore significantly different. In Photo 50 there is a large amount of attached fauna, including barnacles, hydroids, anenomes, and tunicates. Visible organisms include scallops and many signs of infaunal activity are apparent. These include fecal mounds, burrows, tubes and trails. In Photos 12 and 40, the lack of a cobble/boulder substrate precludes the development of as extensive an attached epifaunal community as seen in Photo 50. Instead, a mobile epifaunal community is evident. Here, the epifauna consists of seastars, brittle stars, gastropods, heart urchins and tube building polychaetes. The occasional pebble protruding through the sediment in Photo 40 is colonised by bryozoans. As in Photo 50, the

Photo 45 (43°39.25'N, 63°20'W, 110 m)
On Sambro Bank the sediment is of the Sable Island Sand and Gravel formation, but near the Sambro Sand interface. Numerous horizontal polychaete tubes (family Eunicidae or Onuphidae) occur, pulled along by the organisms inside, and a sea star, probably Henricia sp., lies on the surface of the sediment. Mounds, burrows and fecal pellets and casts create a highly-textured, heavily-turbated substrate. Tracks of animals, including those of the sea star, show up on the soft upper layer of fines deposited over the surface of the sand and gravel substrate, and suggest that a silt and clay component is present. One rock in the foreground is covered with a thick hydroid growth on which a lone sea urchin is grazing.

Photo 46 (43°44.34'N, 63°16.38'W, 125 m)
This photograph is also from Sambro Bank. The substrate is coarse sand with some gravel of the Sable Island Sand and Gravel formation. The gravelly fraction provides a site of attachment for some sessile organisms such as a sponge (right). Several elongated organisms near the top are probably shrimp. A few biogenic features, such as mounds, fecal deposits and holes can be seen on the surface. The sediments probably support a fairly rich interstitial fauna of small macrofauna and meiofauna.

Photo 47 (44°21'N, 63°01'W, 135 m)
Sponges adhering to firm substrate of the muddy till of the Scotian Shelf Drift north of Emerald Basin indicate the presence of a slight current. Immediately below the large sponge (upper left) can be seen an intertwining mass of polychaete tubes (also seen in Photo 40). The disturbed appearance of the sediments surrounding these tubes suggests that they were made by deposit feeding terebellids. The tentacles of a buried sea cucumber are visible (upper left). Evidence for the presence of numerous other infaunal invertebrates is provided by mounds, holes and tracks over the pelletised surface. In some cases the mounds appear to be of sorted fine-grained sediment. This results from bioturbation by infauna (note the mound between the sponge and mass of tubes).

Photo 48 (44°21'N, 63°01'W, 135 m)
In the central shelf area, north of Emerald Basin, the sediment is Scotian Shelf Drift. The various sized particles of gravel in the mud matrix create a habitat suitable for a diverse fauna. The epifauna comprises anemones (lower left and upper right), sponges, probably Clathria sp. and Artemesina sp., and sea cucumbers, Cucumaria sp. (upper left). Several egg-shaped tunicates also occur. The presence of sponges in the benthos indicates the occurrence of slight current. The mounds and tubes scattered over the pelletised surface of the fine grained sediments suggest a dense infauna.

Photo 45

Photo 46

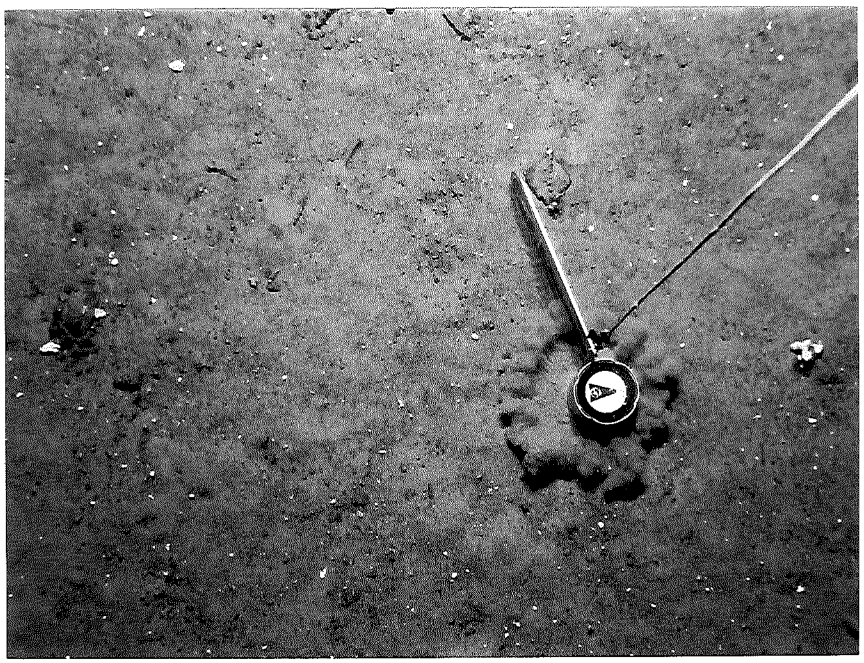


Photo 47

Photo 48

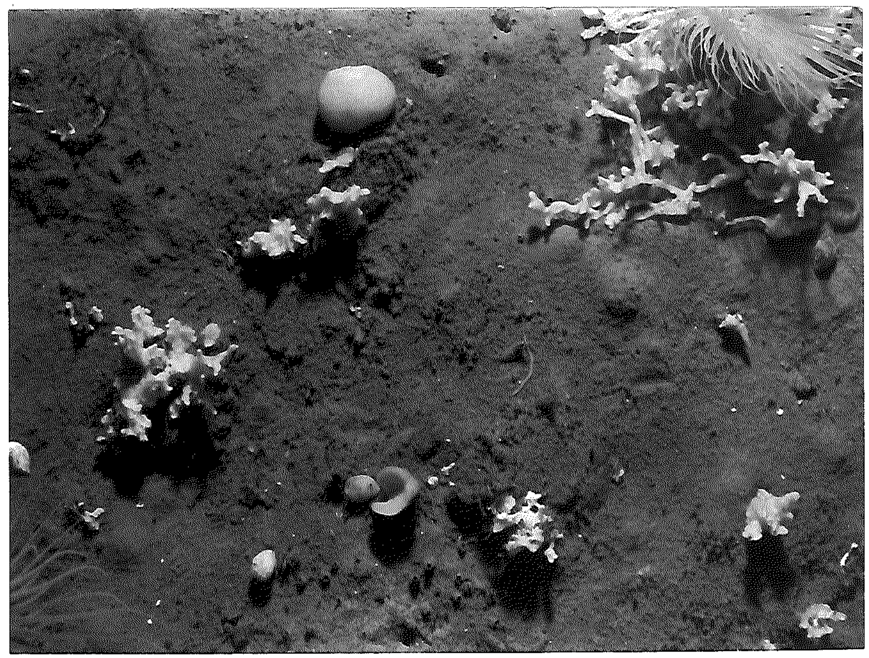


Photo 49 (43°06.4'N, 67°04.3'W, 175 m)
In this area of the eastern part of Truxton Swell, Gulf of Maine, the surficial sediment is Scotian Shelf Drift . The silty clayey sand is an ideal substrate for sabellid polychaete worms, whose tubes are seen projecting from the sediment. Fecal casts and a mound of sorted sediment, probably made by a deposit feeding polychaete, can be seen to the right of and above the buried deposit feeding mud star, *Ctenodiscus crispatus*. A lone mollusc and a stalked organism, possibly a tunicate, can be seen in the upper left corner. A current, going from upper left to lower right, bends the sabellid tubes until they are almost parallel to the sediment. Note the conspicuous gastropod trail. Most of the till surfaces of the Gulf of Maine are covered with relict iceberg furrows and this may represent the trough of one.

Photo 50 (44°00'N, 66°37'W, 135 m)
The seabed near the mouth of the Bay of Fundy, south of Brier Island, is of Sambro Sand. The clayey and silty sand has cobbles and boulders scattered on its surface. A boulder provides suitable substrate for the large (maximum 10 cm in diameter) anemone (*Tealia* sp.), barnacles (*Balanus* sp.), and, on the underside, tunicates. Feathery hydroids also occur. The sediments appear to be heavily turbated, showing fecal mounds, burrows, tubes and trails. Scallop (*Placopecten magellanicus*) lie just exposed in the sediment. The Sambro sand in this area is a modified till, the surface of which has been eroded and infilled.

Photo 51 (43°07.3'N, 67°04.3'W, 175 m)
This photograph, also from the seabed on the eastern area of Truxton Swell, illustrates the typical textured characteristics of Scotian Shelf Drift, and may represent the seabed near or on the berm of an iceberg furrow. The epifaunal community includes attached forms of anemones (a large example of these with retracted tentacles can be seen, upper right), sponges, bryozoans, hydroids and some brachiopods (probably *Terebratulina septentrionalis*), all suspension feeders, nourished by the constant supply of food carried by the currents in this area. A calcareous, branch-like bryozoan seen here is *Idmidronea* sp. The infaunal community in the sediment between the cobbles and boulders is very active, causing considerable bioturbation. The surface of these sediments is heavily pelletised and perforated with holes. Wandering gastropods graze on available material adhering to the rocks.

Photo 52 (42°48.4'N, 67°25.0'W, 180 m)
Seabed substrate on Sewell Ridge, Gulf of Maine, is Scotian Shelf Drift. Here pebbles and boulders are scattered across the seabed. The till of Sewell Ridge, like all the other deep water till outcrops in the Gulf of Maine, is covered with relict iceberg furrows. The brachiopod-bryozoan community is typical of this area, and extends northeastwards into the Bay of Fundy, where it is eventually replaced by a *Modiolus* community.

Photo 49

Photo 51

Photo 50

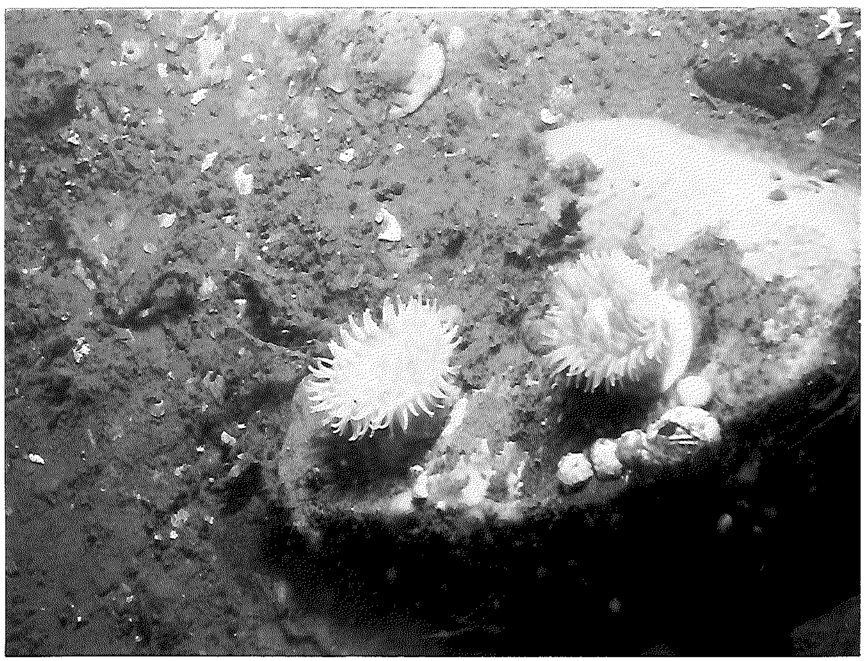
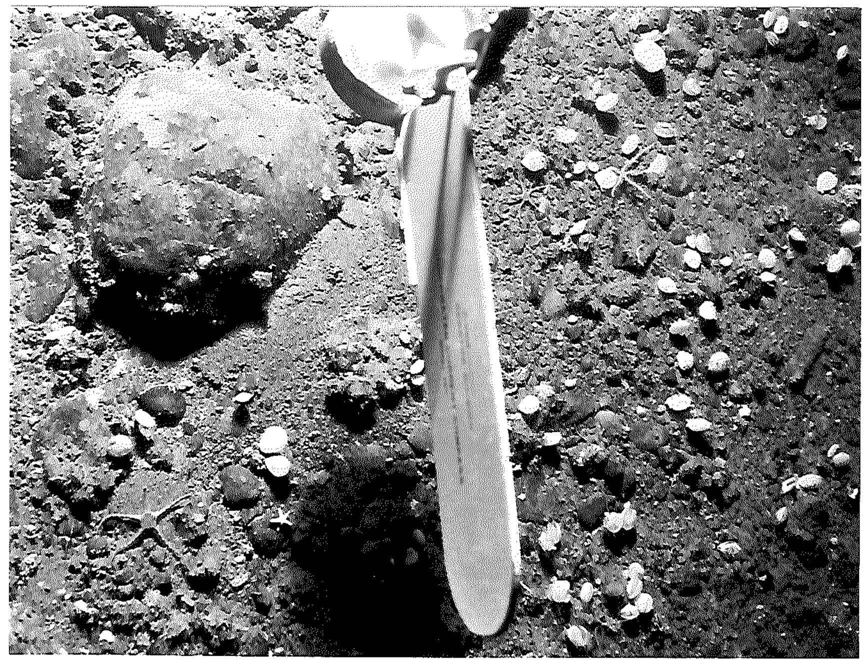


Photo 52



muddy sand of the Sambro Sand formation shows evidence of extensive bioturbation.

The area west of the Scotian Shelf in the eastern Gulf of Maine is an area of complex underwater topography of ridges, swells and basins sharing similar features with the middle Scotian Shelf. Photographs from the shallower areas (Photos 49, 51 and 52) are presented here for comparative purposes. (The basins are described above) On Truxton Swell on the northern edge of Crowell Basin (Photos 49 and 51) the sediment is Scotian Shelf Drift. Photo 49 shows fine-grained sediments comprising silty clayey sand. The silty clay is a suitable substrate for infaunal animals, including sabellid polychaetes. The outline of a mud star (Ctenodiscus Crispatus)can be seen just beneath the surface of the fine-grained sediments. A strong left to right current sufficient to align the sabellid tubes almost parallel to the sediment is evident. In Photo 51, from the same area, the sediment has a greater gravel component, and is therefore able to support a different fauna from that shown in Photo 49. Attached epifauna includes anenomes, sponges, bryozoans, hydroids and brachiopods (this area in general is an area of brachiopod occurrence). The fine-grained sediment between the larger gravel-sized clasts supports a fauna similar to that seen in Photo 49.

On the southern side of Crowell Basin, near Sewell Ridge, the sediment is also Scotian Shelf Drift, but here the gravel content is even greater than to the north. The dominant organisms comprise a brachiopod/bryozoan community with numerous suspension feeding brittle stars. In all of these photographs (49, 51 and 52) the presence of suspension feeding brachiopods and bryozoans, together with an alignment of sabellid tubes, indicates the presence of a strong current (the inflow and outflow of the Bay of Fundy) carrying sufficient suspended organic matter to support a benthic community. The presence of brachiopds, which are attached, indicates that although the currents in the area may be strong at times, they do not cause appreciable local sediment redistribution.

Outer Shelf

The outer shelf is defined as an archipelago of banks with intervening saddles parallel to the shelf edge. It is part of the Atlantic Coastal Plain, and varies in width from 50 to 75 km. It comprises a series of broad, flat-topped banks with little bottom relief, intervening saddles which are slightly deeper with gentle relief, and a few deep channels such as The Gully, a deep submarine canyon separating Banquereau and Sable Island Bank. Sable Island itself extends 26 m above the sea surface.

The predominant sediment type on the Outer Shelf is the Sable Island Sand and Gravel formation. By definition, it does not contain silt or clay. The outer shelf area is covered mainly in Slope Water, which is a mixture of the Nova Scotia Current and North Atlantic Drift. Current flows are variable both in direction and strength.

Two main subdivisions of the Outer Shelf zone are used here: Banks (which are further subdivided on the basis of sediment texture), and the Shelf Edge (which includes the Laurentian Channel). Georges Bank has also been included in the Banks section because it is similar to the other banks.

Banks

The banks of the Outer Shelf include Browns, Baccaro, LaHave, Emerald, Western, Sable Island and Banquereau Banks (see Figure 1, bathymetry). These are mainly flat and shallow, and, with the exception of Sable Island Bank and Banquereau, are not separated from each other by significant bottom relief.

The offshore commercial fishery for demersal species on the Scotian Shelf is centred on these banks, while oil and gas exploration has taken place on Sable Island (Venture), Banquereau, Browns and Georges Banks.

The first two subdivisions in this category are based upon the relative amounts of sand and gravel in the surficial sediments; Sable Island Sand and Gravel is divided into two categories, sand facies with less than 50% gravel, and gravel facies with less than 50% sand. In addition, further subdivisions were made possible as some banks had sufficient photographic resources to permit a more detailed breakdown.

Banks - Sand Facies

Photographs from Banquereau, Sable Island and Browns Banks are included in this section. The sediment is Sable Island Sand and Gravel, sand facies, which contains less than 50% gravel. The sediment particle sizes range from fine (Photo 59) to medium (Photo 61) sand. One photograph shows Sambro Sand (Photo 64 from the edge of Banquereau). Near the centre of Sable Island Bank, a considerable amount of shell debris is mixed with the sand (Photos 44 and 60); this debris includes valves of the ocean quahog *Arctica islandica*.

The environment of the outer shelf is dynamic because of the shallowness of the banks , their proximity to the shelf edge and variable current flows in this region. The strongest currents are usually found over the outer banks. Upwelling is also a factor, particularly near The Gully and to the south of Emerald Basin. As a result of these and other factors, including storms, waves and tides, the surface of the banks is frequently covered by sand ridges and rippled sand of various wavelengths (see Photos 44, 53, 54, 56, 59, 61, 63 and 64). In Photo 62, the wave-formed ripples have shell debris preferentially accumulated in the troughs of the ripples. Dense accumulations of sand dollars may occur on these banks (Photo 57), and these can alter the formation of sand ripples or even erode previously formed bedforms.

Animals found in this environment include those able to move across shifting sands, for example, sand dollars (see Photo 57), and those capable of burrowing into the sediment, such as sea cucumbers (Photo 61). Sand dollar densities can be high, as these animals aggregate in response to stimuli such as food availability. Photo 57 shows densities of >100 per m^2. Other photographs from Banquereau show lower densities (Photos 61, 63 and 64). Other epibenthic animals seen in these photographs from the banks of the outer shelf include sea stars (*Asterias* sp., Photo 58). Shell debris is seen in photos 61 and 64. Photographs of the Sable Island Sand and Gravel sand facies do not show many smaller epifaunal organisms, nor do they show extensive signs of infauna. An exception is Photo 61, which shows the tentacles of several burrowing sea cucumbers. Tubes and burrow openings can be seen in Photos 58 and 61. The lack of silt and clay sized material in these sediments precludes the excavation of extensive burrows, and the dynamic nature of the environments causes most traces of infaunal activity to be rapidly obliterated.

Photo 53 (approx. 44°40'N, 57°55'W, 50 m)
This BRUTIV photograph from eastern Banquereau is an example of the typical seabed of the bank, the Sable Island Sand and Gravel formation, sand facies, and shows a complex ripple field. Aggregations of sand dollars, Echinarachnius parma, sometimes occur as these organisms forage for food in the fine-grained sand. The substrate, although bare in appearance, nevertheless harbours numerous small forms of infaunal invertebrates, interstitial fauna and occasional large, deposit feeding molluscs such as Spisula polynyma and Arctica islandica.

Photo 54 (approx. 43°55.8'N, 60°25.6'W, 28 m)
On Sable Island Bank west of Sable Island the fine sand of the Sable Island Sand and Gravel formation shows linguoid current ripples. The current is moving towards the bottom of the picture. The sand across this part of Sable Island Bank is very thick (up to 60 m). In this dynamic area, frequent storms can obliterate biogenic traces. Infauna are probably present; but no signs are evident on what appears to be a freshly rippled surface.

Photo 55 (43°44.34'N, 63°16.38'W, 135 m)
At this site on Sambro Bank, central Scotian Shelf west of Emerald Basin, the seabed consists of a coarse gravelly-sandy substrate of Sable Island Sand and Gravel. Here, mounds of finer sand piled up by the infauna suggest considerable reworking and a rapid sediment turnover. This illustrates how effective the process can be, as the top several centimetres of the sediment undergo sorting and transportation to the substrate surface.

Photo 56 (43°38'N, 60°16'W, 65 m)
On outer Sable Island Bank southwest of Sable Island, the sediment type is Sable Island Sand and Gravel, sand facies. The hexagonal patterns seen in the sand were generated by two sets of waves approaching from different directions. The events causing this sculpturing are intermittent, and tracks and feeding trails of the inhabitants persist and accumulate in the interim.

Photo 53

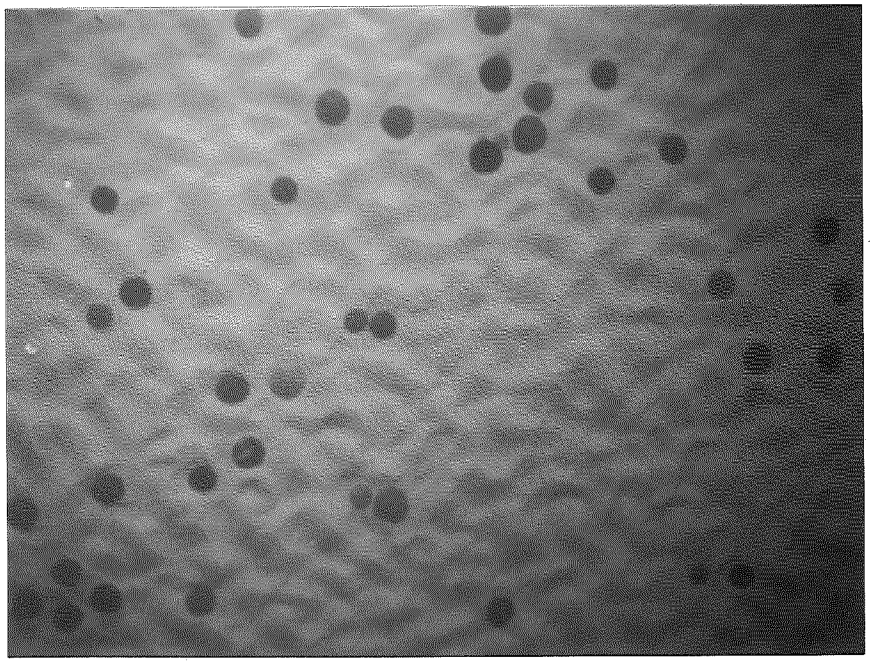


Photo 55

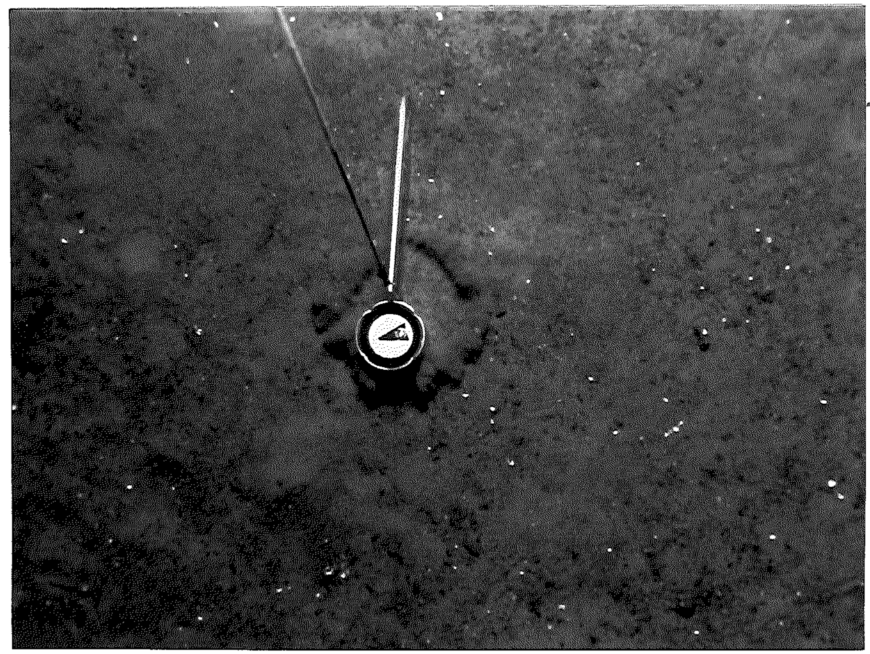


Photo 54

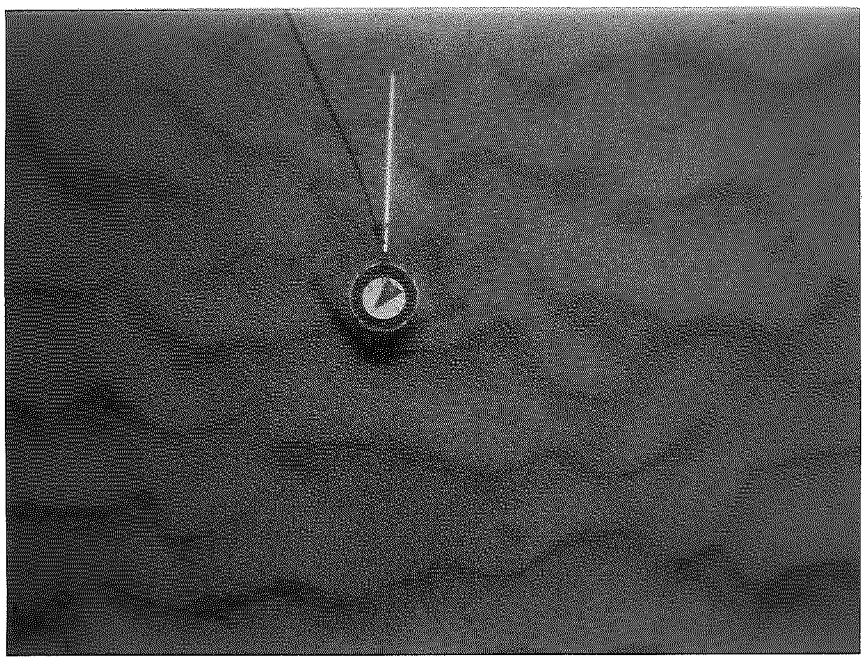


Photo 56

Photo 57 (44°35'N, 58°10'W, 65 m)
On central Banquereau a rippled sandy seabed prevails, and occurs generally above the 100 m isobath (Amos and Nadeau 1988). An aggregation of sand dollars (Echinarachnius parma) is shown in the medium-sized sand grains in the Sable Island Sand and Gravel formation, sand facies. Dense aggregations of sand dollars occur across Banquereau and may influence the formation, distribution or persistence of sand ripples (Amos, 1989). Sand dollars are highly motile and large aggregations probably assemble in response to chemical cues, indicating the presence of available food.

Photo 58 (43°40'N, 61°16'W, 40 m)
This oblique photograph of western Sable Island Bank shows sand dollars and sea stars, Asterias sp. To the left of the sea stars can be seen indications of burrowing activity by infauna within the sandy Sable Island Sand and Gravel substrate. The sediment shows a hexagonal pattern of ripple marks, formed by waves from two directions. Animal tracks and some small worm tubes are visible. Fewer epifaunal species are noted than in Photo 57.

Photo 59 (43°55.78'N, 60°25.56'W, 28 m)
West of Sable Island on Sable Island Bank, the seabed sediments are the Sable Island Sand and Gravel formation, sand facies. The sediments are extensively rippled by currents, and frequent storms obliterate biogenic traces. Little or no biogenic material can be seen in this photograph, although occasional patches of shell debris occur in this area.

Photo 60 (approx. 43°48'N, 60°15'W, 45 m)
Southwest of Sable Island on Sable Island Bank, patches of coarse, clean sand of the Sable Island Sand and Gravel formation alternate with patches containing considerable shell debris, including valves of Arctica islandica. Shell deposits are a common feature of continental shelves worldwide. The kinds of shell material making up the deposit varies between areas, reflecting the predominant organisms in an area. Shell hash and shell beds are also seen in Photo 71 (Sable Island area), Photo 143 (St Pierre Bank), and Photo 148 (Hibernia area). The dynamic nature of the seabed of Sable Island Bank sharply defines the boundaries of these shelly patches (Amos, 1989).

Photo 57

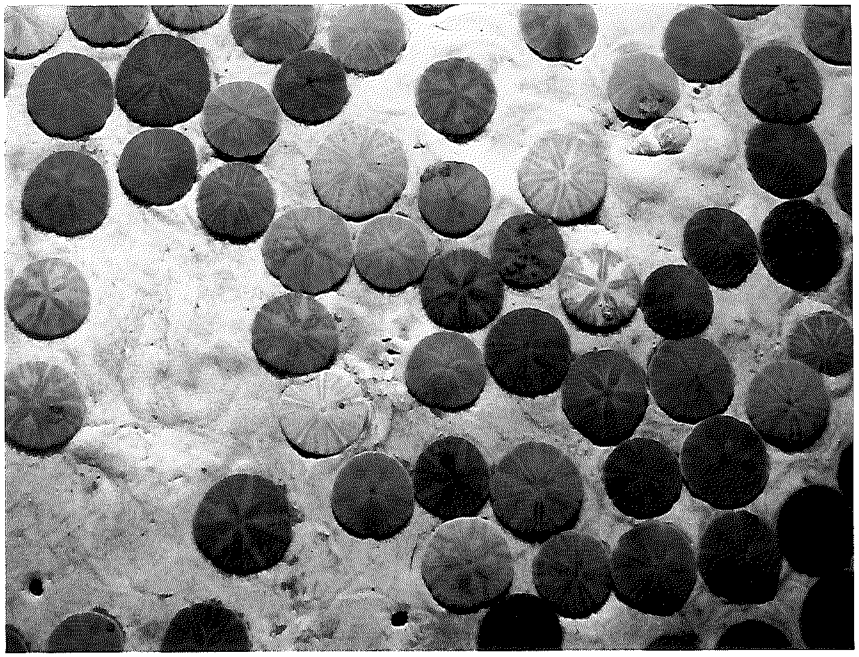


Photo 59

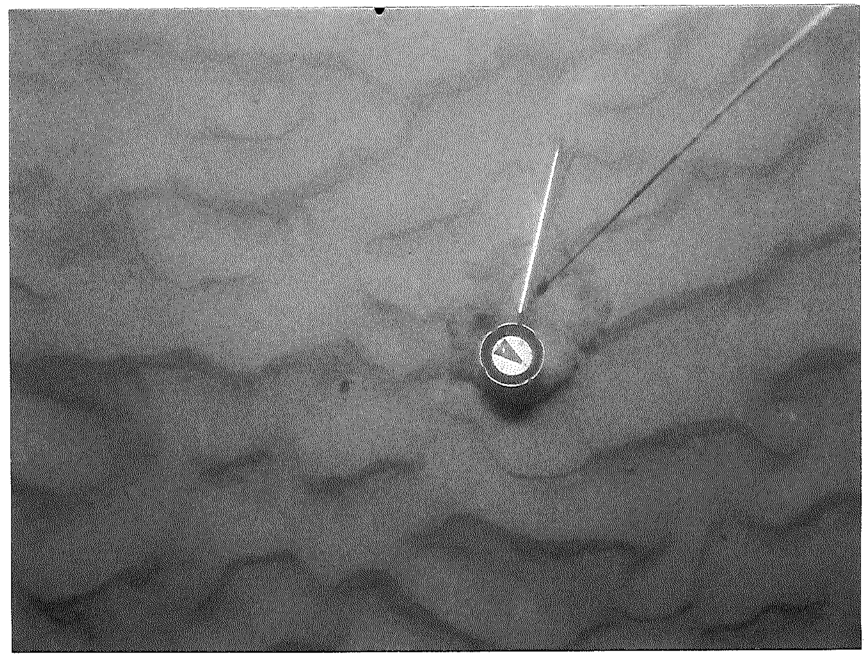


Photo 58

Photo 60

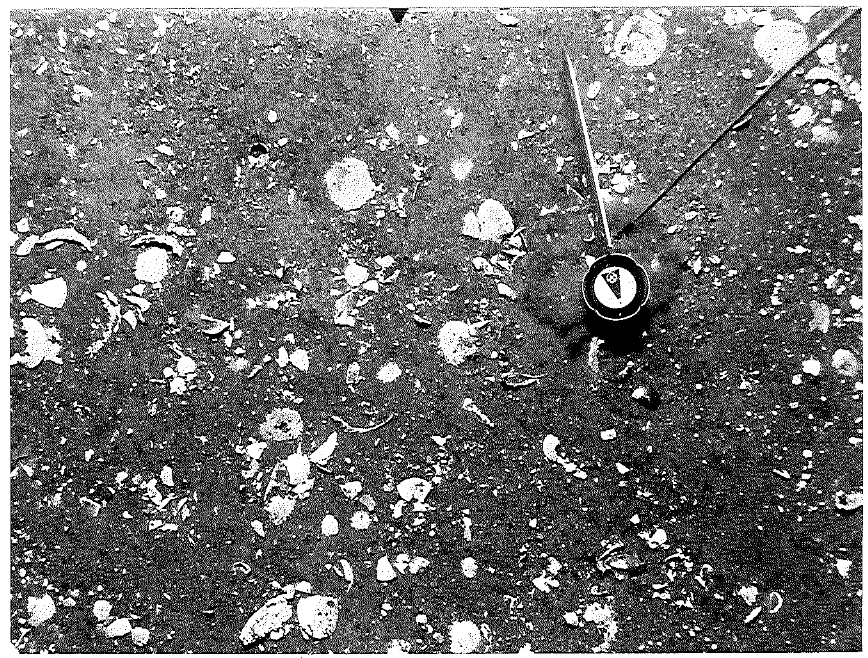


Photo 61 (approx. 44°30'N, 58°20'W, 50 m) The sediment shown here on Middle Banquereau is Sable Island Sand and Gravel, sand facies, of medium-grain size. The sediment surface shows asymmetric sinuous current-formed ripples. The distribution of biota on Banquereau is variable. In this photograph, together with the ubiquitous sand dollars, increasing numbers of holothurians occur. Disarticulated valves of surf clams (Spisula sp.) are randomly distributed over the surface, as are tubes of subsurface deposit feeders. The benthic community consists mainly of burrowing subsurface deposit feeding infauna and a highly motile surface deposit feeding epifauna. Both elements of this fauna are responsible for considerable bioturbation of this dynamic environment.

Photo 62 (approx. 44°40'N, 57°55'W, 48 m) In this photograph of Banquereau taken from BRUTIV Dive 3, the degraded wave-formed ripples in the substrate of Sable Island Sand and Gravel (sand facies) have an approximate wavelength of 0.5 m. They appear to be much larger than those at the other end of the bank (compare with Photo 63). Shell debris, including shells of Spisula sp. and possibly Arctica sp., is accumulated in the troughs and highlight the otherwise subdued bedforms. The crests of the sand ripples appear to be biogenically reworked by both infauna and motile epifauna.

Photo 63 (approx. 44°40'N, 57°55'W, 50 m) The seabed of eastern Banquereau consists of medium-fine sand of the Sable Island Sand and Gravel formation. The irregular ripple pattern is nearly erased by normal random water movements and animal activity. In this photograph, the epifauna are the deposit feeding sand dollars and a gastropod, apparently Aporrhais sp., which may be feeding on a sand dollar. A school of sand lance, probably the offshore species Ammodytes dubius, can be seen swimming close to the seabed. Sand lance burrow in the sand at night to avoid predation, and thus effect a considerable amount of bioturbation. During the day they emerge to feed on plankton.

Photo 64 (approx. 44°20'N, 58°00'W, 50 m) On the middle southern edge of Banquereau the sediment is Sable Island Sand and Gravel, consisting of fine-grained sand. The wave-formed ripple pattern is perforated by stout tubes with raised entrances, possibly of polychaetes or amphipods, and more slender tubes that could have been made by suspension feeding sabellid polychaetes. Subsurface deposit feeders, together with the surface deposit feeding sand dollars, cause considerable bioturbation of these fine grained sediments. Shell debris also occurs, and considerable marking and imprinting of the surface is evident.

Photo 61

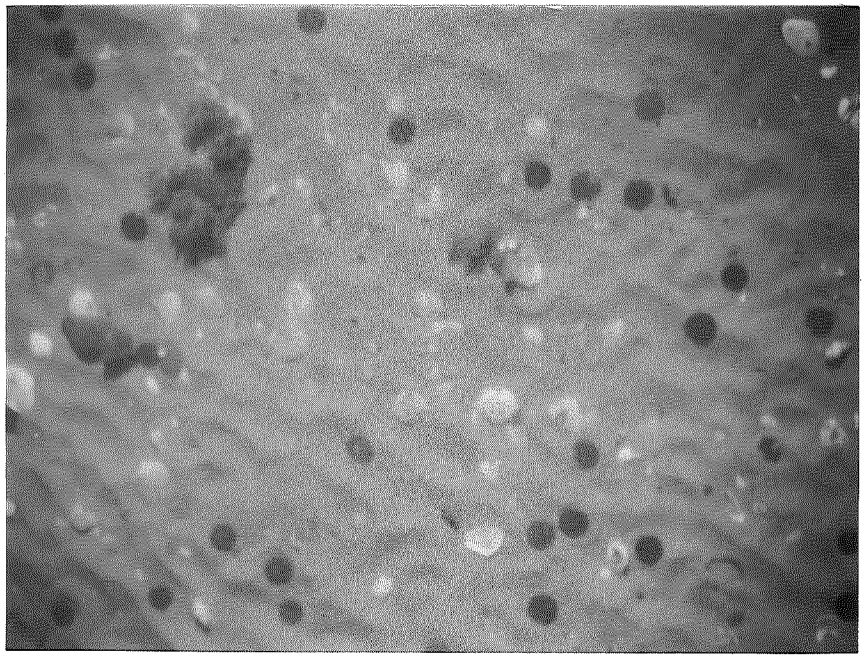


Photo 63

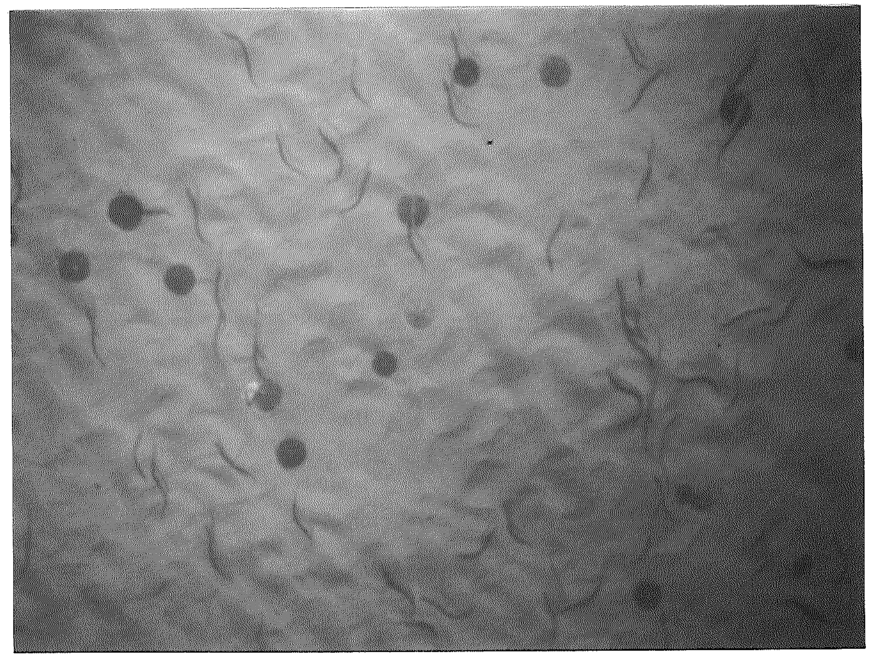


Photo 62

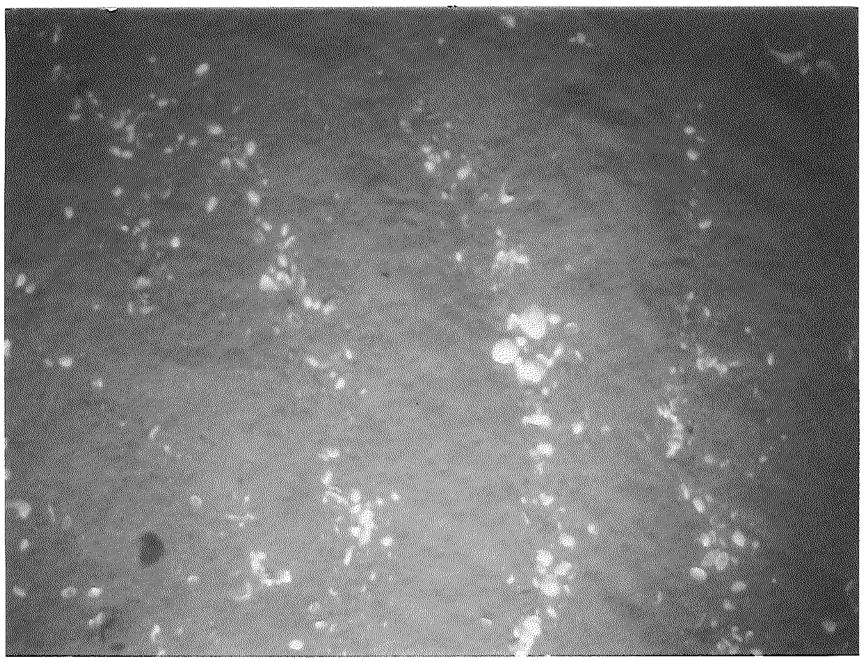


Photo 64

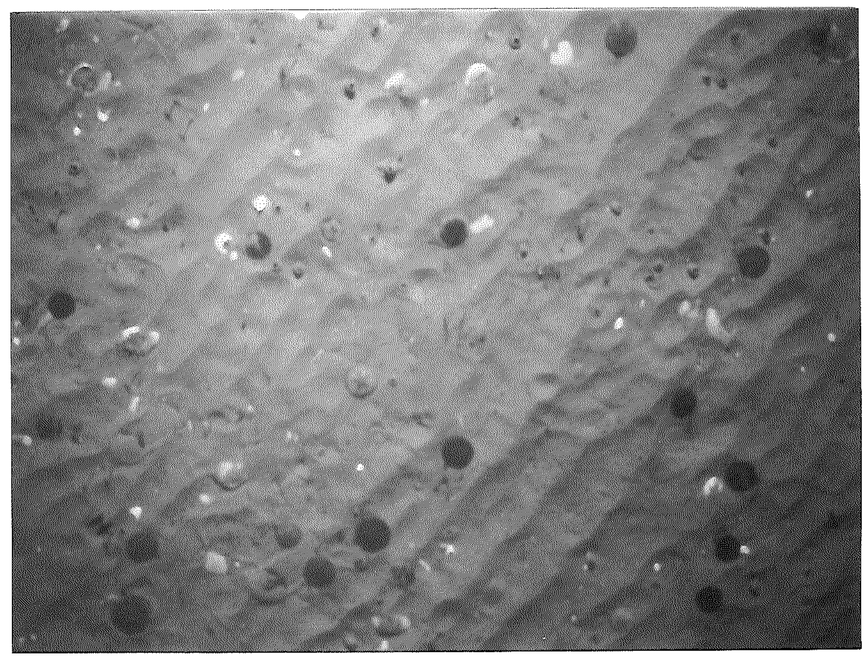


Photo 64 from Banquereau indicates the presence of numerous tubes and burrows on Sambro Sand. The stout tubes were probably made by polychaetes or amphipods, and the slender tubes by sabellid polychaetes. Both the worms and sand dollars are responsible for considerable bioturbation and reworking of the surficial sediments. The shell material in Photo 60 could provide a micohabitat for small epifaunal and infaunal organisms.

Fish aggregations are rarely seen in routine bottom photography but in Photo 63 a group of small fish, perhaps sand lance (Ammodytes sp.), are seen swimming near the sandy seabed.

Banks - Gravel Facies

Photographs from Western and Emerald Banks are included here to illustrate communities within coarse sand. Similar substrate also occurs on Browns Bank (see Figure 8) and LaHave Bank. The sediment is the Sable Island Sand and Gravel gravel facies with more than 50% gravel.

The larger sand-sized material in this sediment type affords more opportunity for the development of an attached fauna, but due to instability in areas of variable current velocity, the communities normally do not reach biological maturity, and remain in earlier successional stages, as in Photo 66. Here the fauna includes barnacles and foraminiferans. Where the current velocities are low, or where the clasts are larger and less likely to be rolled, the greatest amount of attached community development occurs, as in Photo 67 in which bryozoans and larger anemones are present. In contrast, in Photo 66 the clasts are small enough to be frequently rolled by the currents, effectively precluding the development of an extensive attached community.

The development of an attached benthic community leads to an associated grazing fauna which may include gastropods, sea urchins, and chitons (Photos 66, 67 and 68). However, the preponderance of gravel does not provide a suitable habitat for sand dollars, which are found in large numbers on sediments containing a higher proportion of sand-sized particles (compare with the previous section). There is not much evidence of an infaunal community to be seen in these photographs, although such a community can exist in all but the most dynamic of environments. Photo 66 shows several polychaete tubes among the cobbles. In Photo 68 from Emerald Bank a mud star is seen, suggesting the presence of more fine-grained substrates in the vicinity.

The Venture Area of Sable Island Bank

Four photographs from an area near the Venture gas field are presented here (Photos 69 - 72). The sediment of Sable Island Sand and Gravel, sand facies, is rippled by wave action, and shell debris is visible in all the photographs. The fauna seen in Photos 69, 70 and 72 is typical of sandy sediments in this region, with numerous sand dollars present. Photo 71 illustrates a shell bed, a number of which occur across southern Sable Island Bank.

Browns Bank

A selection of seven photographs is presented in this composite to illustrate the variation in surficial sediments on Browns Bank, a typical offshore bank on the Scotian Shelf. The sediments vary from sand to pebbles and boulders.

Photo 65 (43°37.06'N, 62°32.76'W, 80 m)
This photograph from near the northern edge of Emerald Bank shows Sable Island Sand and Gravel, sand facies. This example is near the transition between the sand and gravel facies. Some epifaunal species may grow attached to the pebbles, cobbles and boulders in this environment, but in this picture, the clasts are devoid of animals. This may be due to current scour by a bedload of abrasive sediment, which might discourage settlement, growth and development of these more fragile forms. A similar interpretation is proposed for a lack of fauna in Photo 19, southwestern Nova Scotia. Visible in the fines are scattered burrows and fecal mounds. The short, linear, unoriented bodies casting shadows may be planktonic chaetognaths.

Photo 66 (43°35.52'N, 62°28.43'W, 80 m)
On the northern part of Emerald Bank, the Sable Island Sand and Gravel seen here is the gravel facies. The gravel clasts are generally small, in the pebble to cobble range, and are well-rounded. Conditions do not appear to be suitable for the development of a sessile community, perhaps because of sand transport across the gravel surface. The substrate shows little or no encrustation, apart from very small barnacles or foraminiferans (probably Cibicides lobatulus) on the cobbles. Sea urchins and gastropods are the only epifauna seen. Occasional polychaete tubes can be seen on the surface among the cobbles.

Photo 67 (43°44'N, 61°41'W, 62 m)
Western Bank, the western part of Sable Island Bank, is part of the outer banks of the Scotian Shelf. This photograph is of the gravel facies of the Sable Island Sand and Gravel formation in the centre of a large patch of gravel over 20 km in width. Here, sand in active transport is not readily available. A dense population of animals is seen on the cobbles. The bottom current appears to be strong enough to maintain a constant flow of food to the sessile organisms. This community includes numerous colonies of hydroids and encrusting sponges and bryozoans. Some of the clasts have an encrustation of coralline algae, and barnacles are also present. A chiton, which feeds on such encrustations, can be seen in the lower-middle foreground of the photograph.

Photo 68 (43°20'N, 62°45'W, 95 m)
On the western side of Emerald Bank, the Scotian Shelf Sand and Gravel formation occurs as a mixture of sand with rounded to subrounded pebbles, cobbles and boulders. Tube-building serpulid polychaetes and small gastropods can be seen on the larger gravel clasts. Motile epifauna move in and out of this fairly uniform community. The white balls on the cobbles at centre may be brachiopods, and a mud star (Ctenodiscus crispatus) is seen in the upper left of the photo, suggesting the presence of fine-grained substrate nearby. The absence of soft-bodied encrusting organisms on the gravel suggests a high sediment bedload in the waters sweeping over this area.

Photo 65

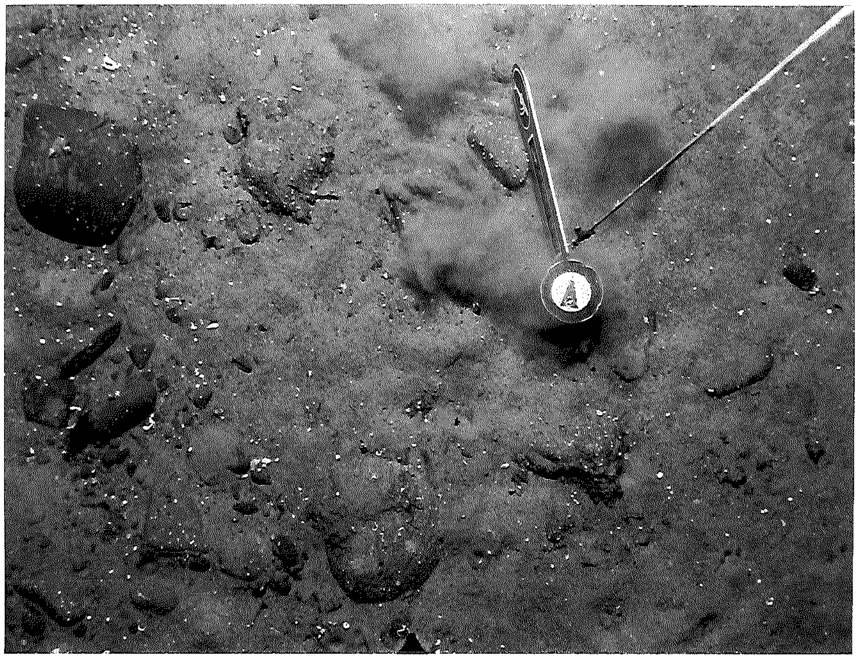


Photo 67

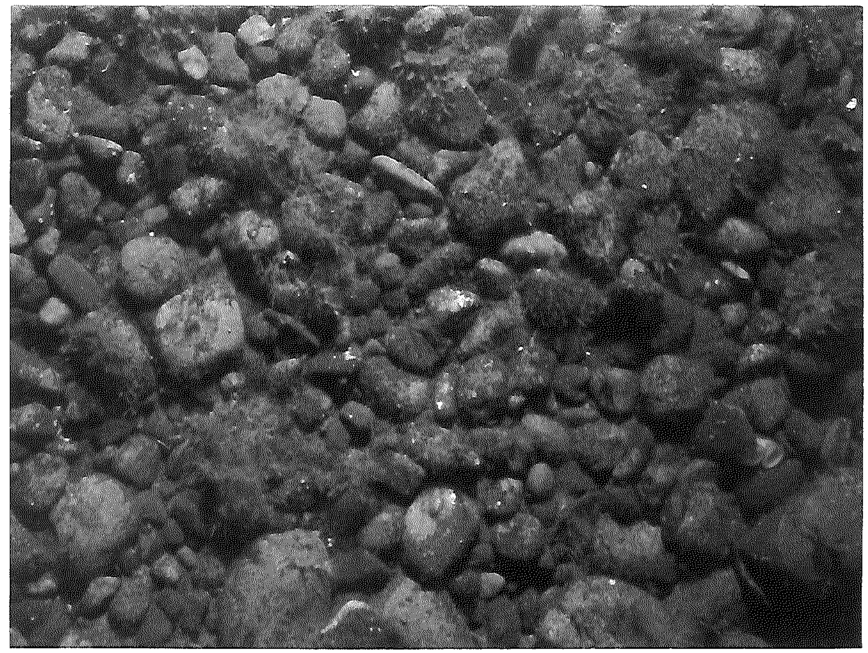


Photo 66

Photo 68

The following four photographs were taken during a BRUTIV transect south of Sable Island from 43°49.45'N, 59°46.07'W to 43°44.44'N, 59°44.40'W, near the Venture gas field.

Photo 69
A mixture of wave-formed, rippled, fine-grained sand of the Sable Island Sand and Gravel formation with shell debris is seen on Sable Island Bank, south of Sable Island near the Venture hydrocarbon discovery. Some of the shells are *Arctica islandica* and *Spisula* sp. (upper left). Several sea cucumbers lie on the seabed. Hydroids, and possibly colonial bryozoans, are attached to the cobbles. Scattered sand dollars (*Echinarachnius parma*) and brittle stars also occur.

Photo 70
Fine-grained sand with abundant shell fragments and whole shells of both large (*Arctica* sp. and *Spisula* sp.) and small species of bivalves occur on Sable Island Bank as part of the sand facies of the Sable Island Sand and Gravel formation. The sediment surface shows wave-formed ripples. Also visible are sand dollars (*Echinarachnius parma*) and gastropods (possibly *Buccinum* sp.), and occasional tubes with raised entrances (probably made by polychaetes or amphipods). A hydroid polyp is attached to a shell in the middle right of the photograph.

Photo 71
A dense distribution of shells termed a "shell bed" on Sable Island Bank, south of Sable Island, appears to consist entirely of empty shells of the surf clam, *Spisula* sp. The site occurs within the Sable Island Sand and Gravel formation. A sea cucumber is seen resting on the surface and hydroid polyps grow on several shells. Shells are transported by currents and wave activity and deposited in seabed lows such as troughs of shoreface connected sand ridges and other depressions (Amos and Nadeau, 1988). Shell beds such as these are numerous across the southern area of Sable Island Bank and show on sidescan sonograms as isolated, highly reflective dark patches.

Photo 72
Wave-rippled fine-grained sand of the Sable Island Sand and Gravel formation on Sable Island Bank bears numerous invertebrate tracks and shells. A gaping shell of the ocean quahog *Arctica islandica* appears in the lower right of the photograph. The other larger bivalve shells are *Spisula* sp. Many shells of smaller species are also abundant, as are sand dollars, *Echinarachnius parma*. As ripples are quickly degraded or eroded by the movement of sand dollars and other organisms, these ripples must be freshly formed and are constantly being regenerated.

Photo 69

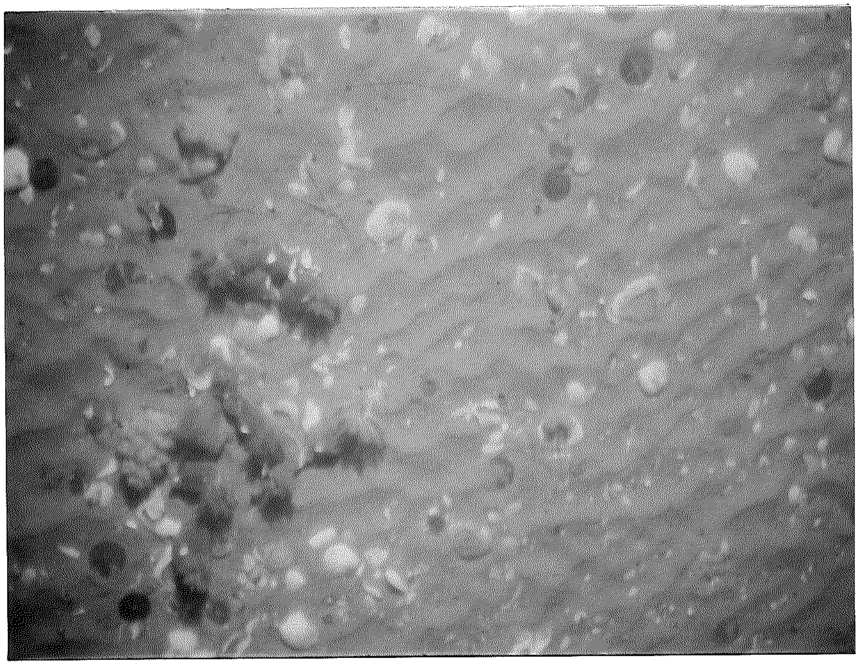


Photo 71

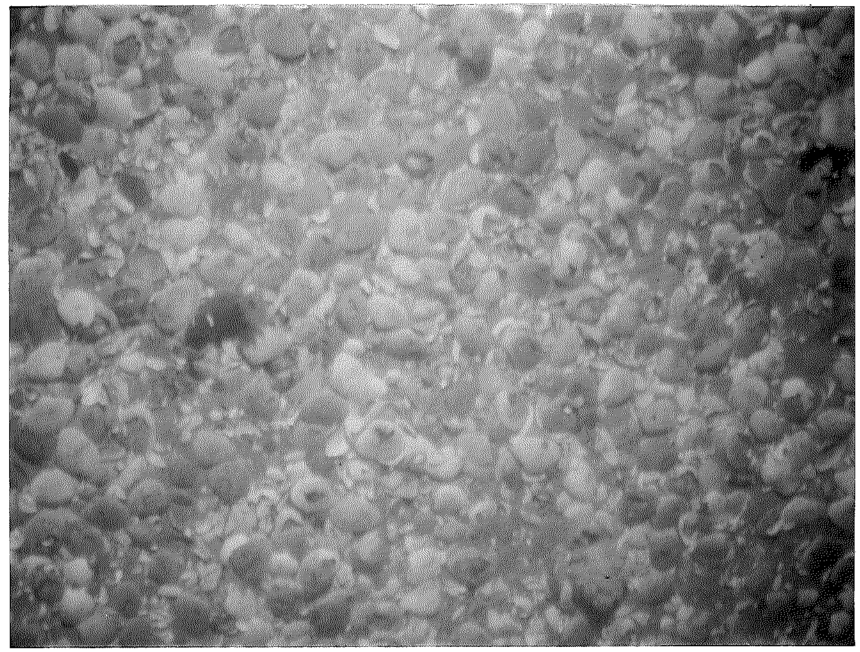


Photo 70

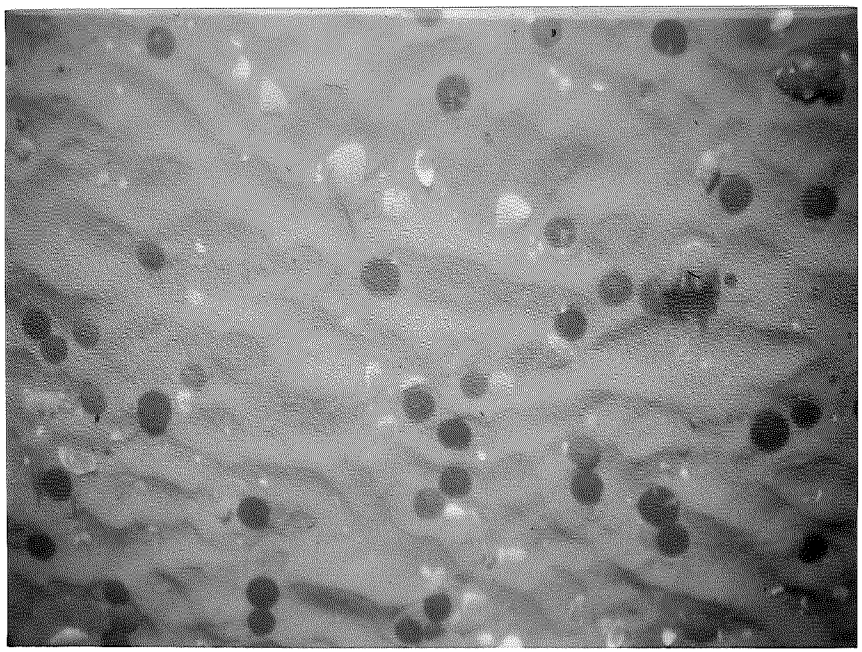
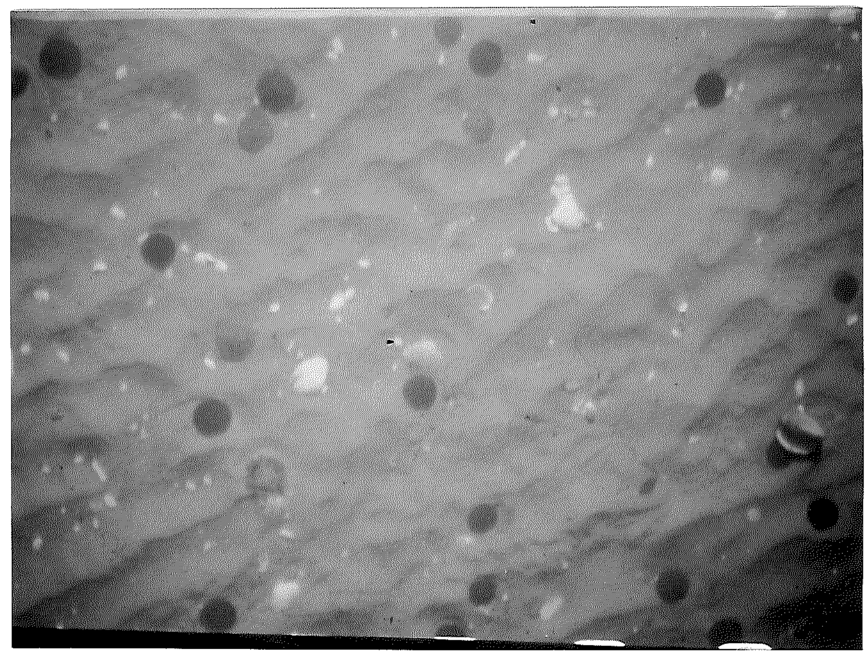


Photo 72



Georges Bank

These photographs were all taken on the northeast tip of Georges Bank in the vicinity of test drilling for oil and gas exploration on the Canadian portion of the bank.

The flat, relatively featureless surface of the bank is similar in aspect to that found on the outer banks on the Scotian Shelf. The sediment type identified here is Sable Island Sand and Gravel occurring in water depths above 110-120 m. Sand ripples also occur in this area and are apparent in photos 73 and 80. A boundary between a rippled area and a non-rippled area is seen in photo 74. Shell debris is evident in some areas, especially in the troughs of the ripples (see Photos 73, 74, 78 and 80). In photos 75 and 76 the sediment appears to have more than 50% gravel, and in the other area a sediment with more than 50% sand is apparent.

The waters over Georges Bank have relatively high primary productivity which, when combined with the shallow depths, results in high levels of organic matter being available to the benthos. The dominant, commercially important, species is the giant scallop, Placopecten magellanicus, a suspension ffeder which utilises organic matter from the water column and resuspended from near bottom.

Substrates which include larger sized gravel clasts such as cobbles and boulders can support an epilithic faunal community which, in this area, includes bryozoans, hydroids, tunicates and sponges (Photos 75 and 76). Mobile epifauna is represented by sea stars (Photo 75) and sea urchins, whose tracks are seen in Photo 73. The sandy areas between the gravel supports a sparse infauna. Polychaete tubes are apparent in Photo 80. Sediment instability makes the environment unsuitable for many infaunal animals.

The rippling of the substrate mentioned above indicates the considerable, though periodic, current flows in these areas. Depressions made by fish feeding and tracks left by sea urchins (Photo 73), and sitz marks left by scallops (Photos 77 and 79) persist between episodes of high current.

Shelf Edge

Seaward of the Outer Shelf, water depths increase sharply along the shelf edge to the continental slope and rise. Towards the east, the Scotian Shelf also descends into the more shallow Laurentian Channel (see Figure 1).

Photo 37, from the Scotian Shelf side of the Laurentian Channel, shows a substrate of Emerald Silt. It was taken from a deep location in one of the isolated depressions in the channel. This sample shares sediment characteristics with samples taken from Emerald and LaHave Basins. As in other silty depositional environments, the benthic community is dominated by infaunal organisms evidenced by the numerous tracks, burrows and mounds shown in the photograph. In addition, marks left by a a sea pen, Pennatula sp., are seen on the left of the picture.

Photographs 81, 82, 83 and 84 were taken from a submersible dive at depths of between 300 and 700 m directly seaward of the outer shelf south of LaHave Basin. They were taken in an area of relict iceberg furrows on the edge of the shelf. The dominant substrate is Sambro Sand and the photos show sand interspersed with cobbles and boulders. The cobbles and boulders create an

Figure 8
Sediment variability on Browns Bank
(Approximately 42°23'N to 42°52'N, 65°15'W to 66°30'W)

This collection of small photographs indicates the regional distribution and variability of seabed sediment on and around Browns Bank on the southwest Scotian Shelf. The sediments vary from well rounded cobbles and pebbles with boulders to fine, well-sorted sand. The banks are often very complex in their distribution of sand, gravel, shells and bedforms, and require sidescan sonograms and samples to properly map the relative distribution.

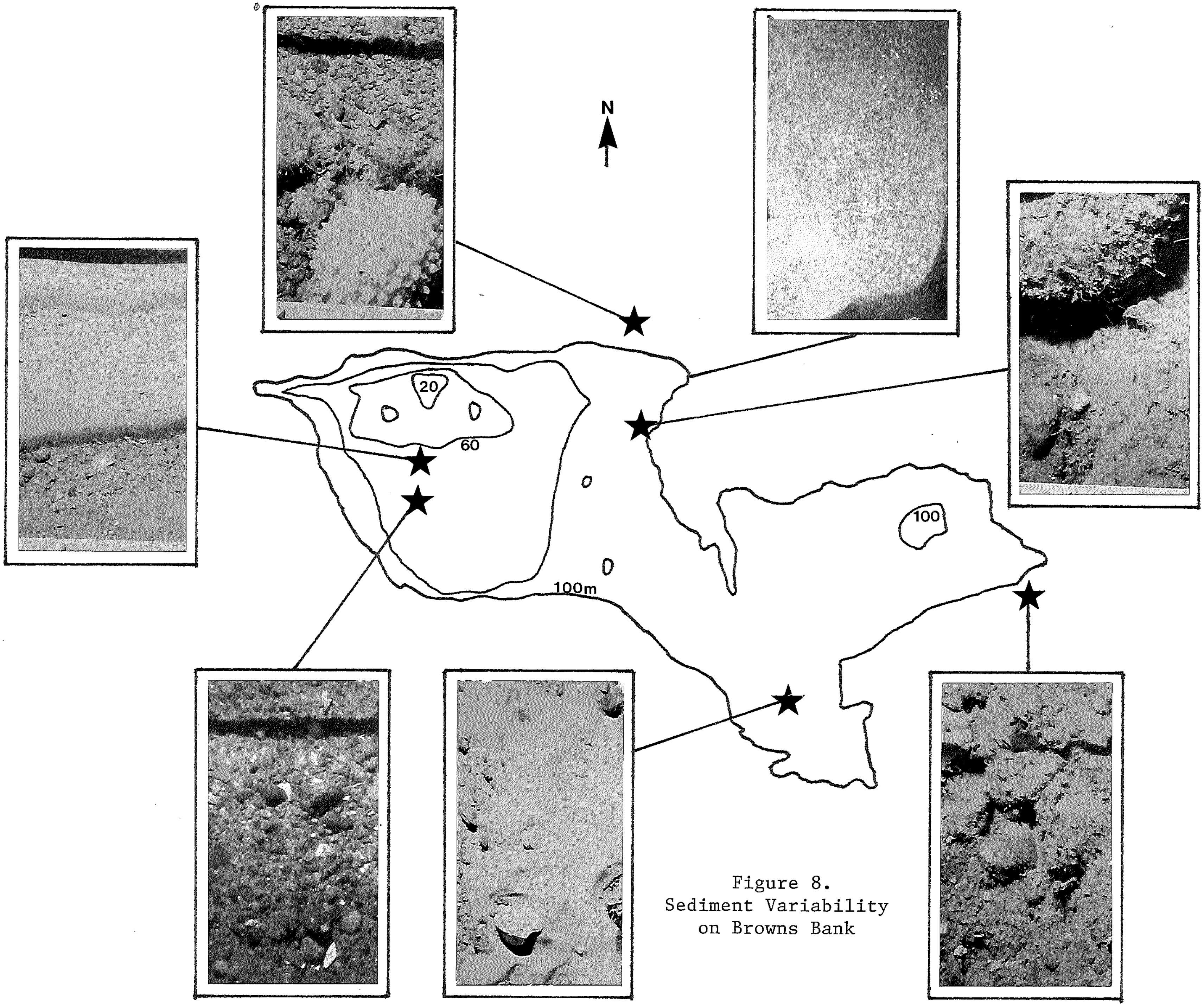


Figure 8.
Sediment Variability
on Browns Bank

Banks - Georges Bank

The series of photographs (73-80) was taken in and around the proposed Hunky Dory well site of Texaco Canada Resources Ltd.

Photo 73 (41°45.72'N, 65°57.48'W, 107 m)
The coarse to fine-grained sand of the Sable Island Sand and Gravel formation is mixed with shell debris and is heavily rippled by the current. Shells are visible at upper right. Traces of feeding activity by fish, lower left, and tracks left by a sea urchin, lower right, are visible. Depressions (lower left) appear to have been made by scallop (<u>Placopecten magellanicus</u>) movements.

Photo 74 (41°45.72'N, 65°57.48'W, 107 m)
In the same area (see Photo 73) on eastern Georges Bank, an edge of a rippled seabed can be seen. The coarser, poorly-sorted gravelly sediments of the Sable Island Sand and Gravel formation adjacent to the rippled sand seem to support a higher density of sea scallop (<u>Placopecten magellanicus</u>) but other fauna are not in evidence. The dynamic nature of this habitat prevents colonisation by attached forms and suggests that benthic fauna would be generally represented by deposit-feeding infauna.

Photo 75 (41°48.75'N, 65°55.80'W, 105 m)
The pebble-cobble gravel clasts of Sable Island Sand and Gravel formation, gravel facies, are dominant in this area, and the micro-roughness of the seabed is increased. The presence of motile epifauna such as sea stars, probably <u>Asterias</u> sp., as well as some attached forms, such as fleshy sponges, hydroids and bryozoans, indicates a slightly more stable environment than that seen in Photos 73 and 74. This habitat also supports sea scallop (<u>Placopecten magellanicus</u>). This variability within a small area indicates how habitat features (seabed sediments) control the patchy distribution observed for benthic fauna. The finer substrate supports a variety of infauna.

Photo 76 (41°48.75'N, 65°55.80'W, 105 m)
The poorly sorted gravelly sediment of the Sable Island Sand and Gravel formation at this site on the northern edge of Georges Bank hosts a variety of epibenthic organisms as well as infauna. The larger gravel clasts are sparsely colonised by bryozoans, hydroids and tunicates. Sea scallop are also present, and an unidentified fish skims over the surface. This pattern of faunal distribution contrasts sharply with Photo 79, where little colonisation is observed.

Photo 73

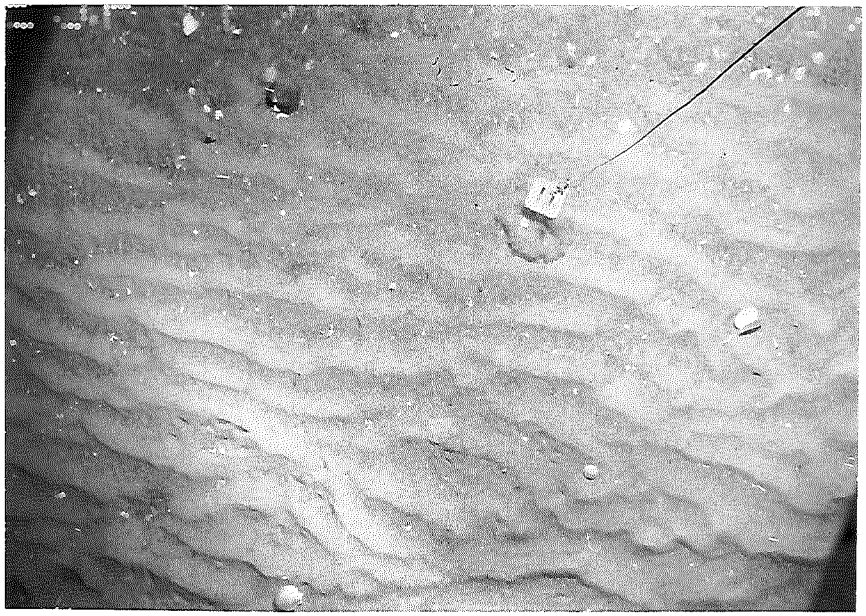


Photo 74

Photo 75

Photo 76

Banks - Georges Bank

The series of photographs (73-80) was taken in and around the Hunky Dory proposed well site of Texaco Canada Resources Ltd.

Photo 77 (41°51.88'N, 66°5.78'W, 93 m)
South of the area shown in Photo 78, the sand of the Sable Island Sand and Gravel formation is rippled by currents, resulting in sorting of the grain sizes. The coarser gravel and shell fragments are found in troughs of the ripples, whereas the finer grained material is found on the ripple crests. Biogenic material or traces are not evident in this photograph.

Photo 78 (41°51.88'N, 66°5.78'W, 94 m)
The Sable Island Sand and Gravel sediment in this area of northeastern Georges Bank consists mainly of poorly sorted coarse to fine sand, with small pebbles and some shell debris, including some small sea scallop shells. The pebbles and fine gravel are aligned parallel with the current direction. No epifauna is visible, and traces of invertebrate activity do not seem to have persisted on this substrate, probably because of the nature of the sediment and currents which sweep the bottom, from bottom left to top right of the picture (see also Photo 77).

Photo 79 (41°46.12'N, 65°57.07'W, 105 m)
In this photo from the eastern edge of Georges Bank, Gulf of Maine, a high density of scallops is evident on the sand and fine gravel sediments of the Sable Island Sand and Gravel formation. "Sitz" marks, which cover much of the surface of the seabed, indicate where the suspension feeding scallops have rested. The activities of various infaunal animals have resulted in a considerable bioturbation.

Photo 80 (41°46.12'N, 65°58.88'W, 104 m)
The relatively fine sediments in this area are Sable Island Sand and Gravel with a mixture of sand and fine gravel. The benthic community includes scallops and a rich, diverse infauna. A colonial hydroid or bryozoan grows on a shell at bottom left, and the scallop at bottom right also supports a hydroid growth. The tube building polychaete fauna is represented by at least two major families: the onuphids and the terebellids. The tubes of the former are heavily encrusted with small gravel clasts and shell debris. The terebellid tubes, on the other hand, are coated with fine sand particles. Feeding modes of these taxa include suspension feeders, subsurface and surface deposit feeders and carnivores.

Photo 77

Photo 79

Photo 78

Photo 80

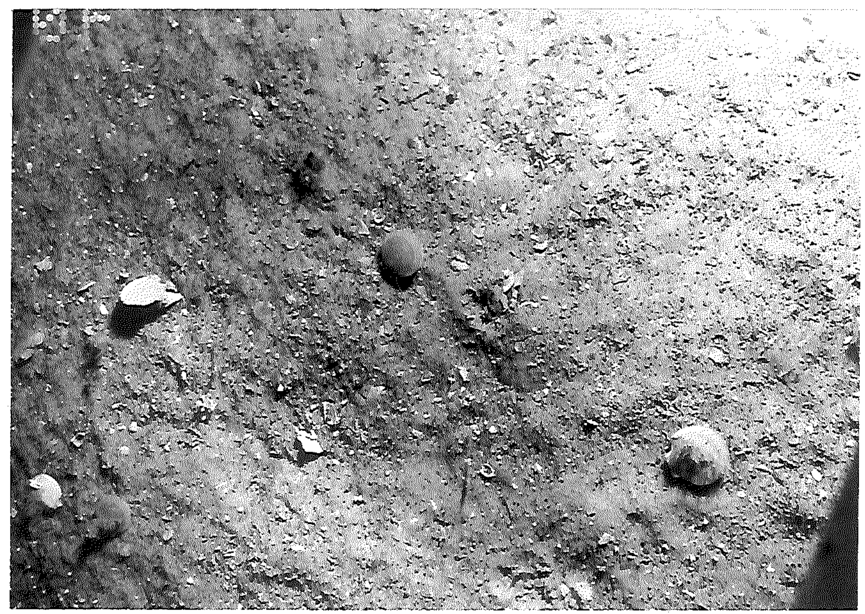


Photo 81 ($42^{o}47$'N, $63^{o}26$'W to $42^{o}48$'N, $63^{o}27$'W, 470-310 m)
This photograph shows a low ridge of boulders, cobbles and pebbles in a matrix of sand encountered on Pisces submersible Dive 1051. Sidescan sonar from the region shows the seabed to be an iceberg furrowed glacial till. The most obvious fauna observed are the redfish, Sebastes sp. These specimens are not as intensively coloured as their shallower water counterparts. This lighter phase is known to inhabit slope depths off the Scotian Shelf. During submersible dives in this area (Hill et al., 1983) redfish were seen nosing into the sediment, but it is not known whether this is a major cause of resuspension. Several small sponge formations, together with a thin hydrozoan film, can be seen on the various sized clasts. The greater sediment bedload in currents up to 25 cm/sec might account for the low encrustation of these boulders.

Photo 82 ($42^{o}47$'N, $63^{o}26$'W to $42^{o}48$'N, $63^{o}27$'W, 470-310 m)
Pisces submersible Dive 1051 traversed a valley on the Scotian Slope in an area of relict iceberg furrows. This photograph shows a large boulder partially buried in a sandy matrix, showing intense colonisation on one side. A scour pit on the opposite side of this boulder suggests that the side shown here is the leeward side. The anemone appears to be long established, as do the tunicate and encrusting sponges also seen on the boulder. Redfish, Sebastes sp., can be seen to the right of the boulder.

Photo 83 ($42^{o}44.98$'N, $63^{o}28.51$'W to $42^{o}46.92$'N, $63^{o}28.39$'W, 700-400 m)
Isolated boulders are observed on a sea floor of sand and fine gravel. The large boulder has several large encrusting sponge colonies, as well as numerous large anemones. The scour pit around the boulder suggests that there is a strong current resulting in sand transport in this area. The orange streaks in the water column above the boulder are euphausiids, Meganyctiphanes norvegica. The large boulder is likely to have been transported and deposited by an iceberg.

Photo 84 ($42^{o}44.98$'N, $63^{o}28.51$'W to $42^{o}46.92$'N, $63^{o}28.39$'W, 700-400 m)
This Pisces submersible dive (1053) was conducted on the muddy mid-slope area, where pits, mounds and other evidence of bioturbation were reported (Hill et al., 1983). Swarms of euphausiids, probably Meganyctiphanes norvegica, occur just above the seabed. A single suspension feeding anemone is attached to a partially buried angular boulder.

Photo 81

Photo 83

Photo 82

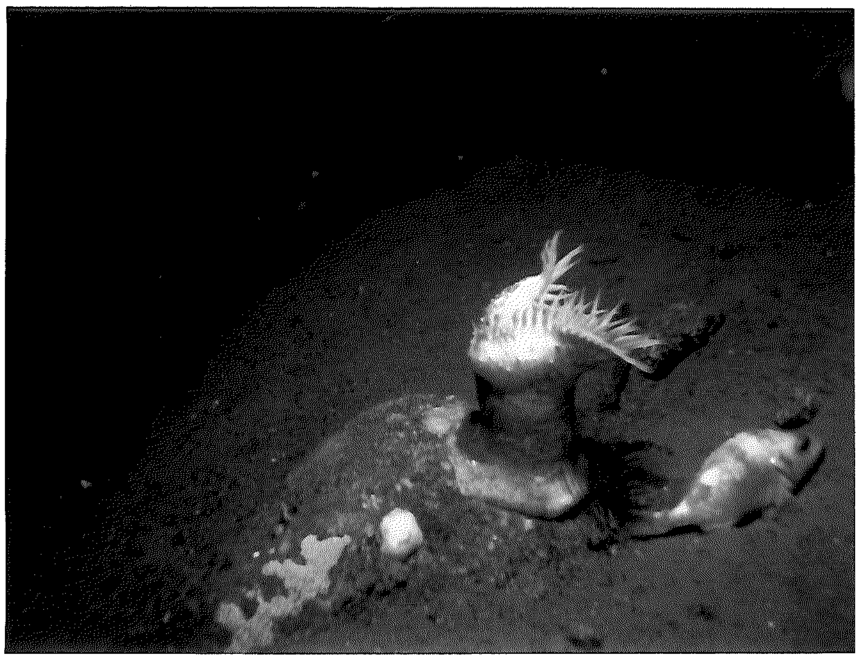


Photo 84

environment suitable for the growth of attached fauna, such as sponges (Photo 81) and anemones (Photo 82). Redfish, *Sebastes* sp., which do not occur in shallow waters, are seen in Photos 81 and 82. Crustaceans, probably the euphausiid, *Meganyctiphanes norvegica*, are seen swimming above the substrate in Photos 83 and 84. In Photo 84, considerable bioturbation of the soft sediment is apparent.

Scour pits visible around the base of the boulders in Photos 82 and 83 suggest the presence of currents in the area. The presence of suspension feeding animals, and the fact that biological encrustation is not evenly distributed over the surface of the boulders, supports this supposition.

CHAPTER 7

THE GRAND BANKS OF NEWFOUNDLAND

Introduction

The Grand Banks of Newfoundland occur to the northeast of the Scotian Shelf, separated from it by the Laurentian Channel. They extend from the Laurentian Channel in the west to Flemish Pass in the east, and are bordered on the northeast by the Northeast Newfoundland Shelf. They cover an area of approximately 270 000 km^2. Although separated from the Grand Banks, Flemish Cap has been included in the atlas.

The Grand Banks of Newfoundland is an area of great economic importance for its fisheries, which mainly utilise groundfish and are a resource used by many nations. Recently, large oil reserves have been located in an area known as Hibernia, named after the first well where large amounts of hydrocarbons were found (P15). It occurs in the northeast portion of Grand Bank.

The distribution of photos is shown in Figure 1, which includes a bathymetry map of the Grand Banks. The photographs are not uniformly distributed, as large areas of Grand Bank have not been photographed. Some local areas, however, such as Hibernia, have been extensively photographed.

In contrast to the Scotian Shelf, the photographs have been grouped into only two categories;

Bays, Channels and nearshore Coastal Areas; and Outer Shelf. This is because mapping of the surficial geology has not been completed on the Grand Banks, and, in addition, the area of the inner shelf and adjacent nearshore depressions is much smaller than the large area of the offshore banks. Also, the inner trough - Avalon Channel and St. Pierre Channel - connects with shelf transverse channels such as Halibut and Haddock Channels which occur between the large offshore banks.

Bays, Channels and Coastal Areas

This section includes all the major channels, coastal bays, and shallow coastal regions. Of these areas, Avalon Channel is by far the best represented in the photographs.

In contrast to the Scotian Shelf, where water depths are generally shallow (less than 50 m) in the areas immediately adjacent to the coast (less than 50 m) water depths off Newfoundland are often deeper immediately near the coast than they are at the furthest offshore limits of the shelf outer banks. The largest geomorphic feature in this category is the Avalon Channel, which extends around the Avalon Peninsula in the south and splits into Halibut, Haddock and St Pierre Channels which continue further to the south and west. These channels separate the rugged coastline, with its deep, incised fiords and deep-silled coastal bays, from the flat sandy expanses of the offshore fishing banks. The inner coastal zone ranges in width from the eastern side of Avalon Peninsula, near St. John's, where it is almost nonexistent, to its widest extent of greater than 20 km south of the Avalon Peninsula and east of Placentia Bay.

The water movements in the area are dominated by the southerly flow of the inshore branch of the cold Labrador Current, which flows through the Avalon Channel and Haddock Channel and, to a lesser extent, Halibut and St. Pierre Channels. Current flows within the Labrador Current are greatest in winter, and icebergs with their accompanying scouring of the seabed are an important factor in this region in the spring. Iceberg furrows occur throughout the Avalon Channel and iceberg pits (isolated circular depressions) are found in the vicinity of the southeast corner of the Avalon Peninsula.

Bays

Three of Newfoundland's numerous bays are illustrated in this section. Motion Bay is a small bay to the south of St. John's, and is typical of many of the bays in this area. Placentia Bay is a large, deep bay separating the Avalon and Burin Peninsulas, and is important in terms of offshore oil development, as fabrication plants for some of the facilities may be constructed there. A petroleum refinery is located at Come By Chance at the head of the bay. During the 1929 Grand Banks earthquake, a large tsunami was generated which propagated up Placentia Bay, flooding the coastal communities to a height of 11 m above high tide. Severe damage and loss of life resulted from the tidal wave. Photograph 89 is from Conception Bay, another large silled bay on the north of the Avalon Peninsula.

In Motion Bay the seabed consists of the Grand Banks Sand and Gravel formation. The four photographs (85, 86, 87 and 88) were all taken at the same station while the ship was anchored, demonstrating a high degree of variability of the substrate, ranging from fine sand (87), to pebbles (86), to cobbles (88), to bedrock with boulders (85). This variability is also reflected in the benthos. In Photos 85 and 88 there is a considerable amount of attached growth

Photo 85 (47°27.61'N, 52°40.85'W, 32 m)
The seabed of Motion Bay, a small open bay on the east coast of the Avalon Peninsula south of St. John's, is of the Grand Banks Sand and Gravel formation, gravel facies. This photograph shows a seabed of large boulders or bedrock to which the macrophyte Agarum and some fine, filamentous algae are attached. Encrusting coralline algae can be seen densely coating most of the hard substrate, and a grazing sea urchin is visible in the lower left of the picture. Numerous gastropods are also grazing over the substrate. Part of the view in this and the other photos on this page is obscured by a water droplet on the camera lens. Contrast this picture with 86, 87 and 88 from the same station.

Photo 86 (47°27.61'N, 52°40.85'W, 32.9 m)
A considerable amount of variability of sediment type at the seabed of Motion Bay, south of St. John's, is apparent. This sediment type is the gravel facies of the Grand Banks Sand and Gravel formation. Some sorting of the sediments is evident. The sediments shown here are coarse sand with pebbles and some shell hash. Epifauna are represented by an occasional sea star and branching bryozoans. Infauna are far more numerous, and the openings of many burrows perforate the sandy sediments.

Photo 87 (47°27.61'N, 52°40.85'W, 32.9 m)
This photograph collected at the same station as Photographs 85, 86 and 88 in Motion Bay on the Avalon Peninsula, shows a fine sand sediment of the sand facies of the Grand Banks Sand and Gravel formation. Occasional disarticulated shells of bivalves, one of which is Cyrtodaria sp., are visible. The paired holes in the seabed are probably siphon openings of a buried bivalve. Other burrow openings, which usually occur singly, are possibly made by unidentified invertebrates, possibly burrowing crustaceans. The bioturbation of the sediments produced by the infauna is augmented by the movements of sand dollars, sea urchins and molluscs. Note the two hermit crabs, right, and the numerous tracks and traces.

Photo 88 (47°27.61'N, 52°40.85'W, 32.9 m)
At the same station in Motion Bay, south of St. John's on the Avalon Peninsula, the sediment consists of a mixture of sand and gravel, and would probably be classified as the gravel facies of the Grand Banks Sand and Gravel formation if samples were analysed. Here, the fine sand is mixed with a significant proportion of pebbles and cobbles. These display a considerable amount of epilithic growth, including coralline algae, sponges, hydroids and bryozoans, suggesting that the substrate is fairly stable. The sandy interstices are perforated by the burrowing activities of crustaceans and bivalve molluscs.

Photo 85

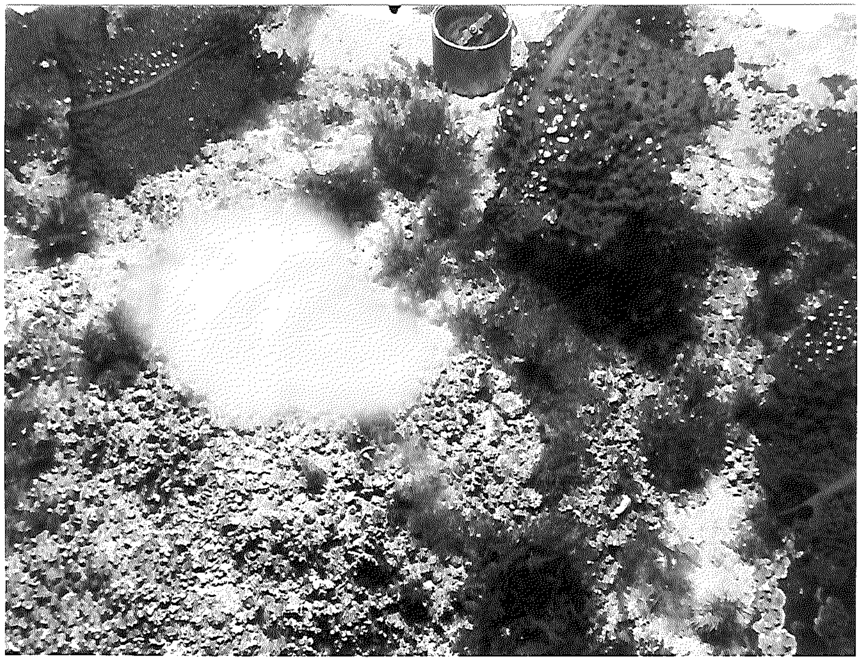


Photo 87

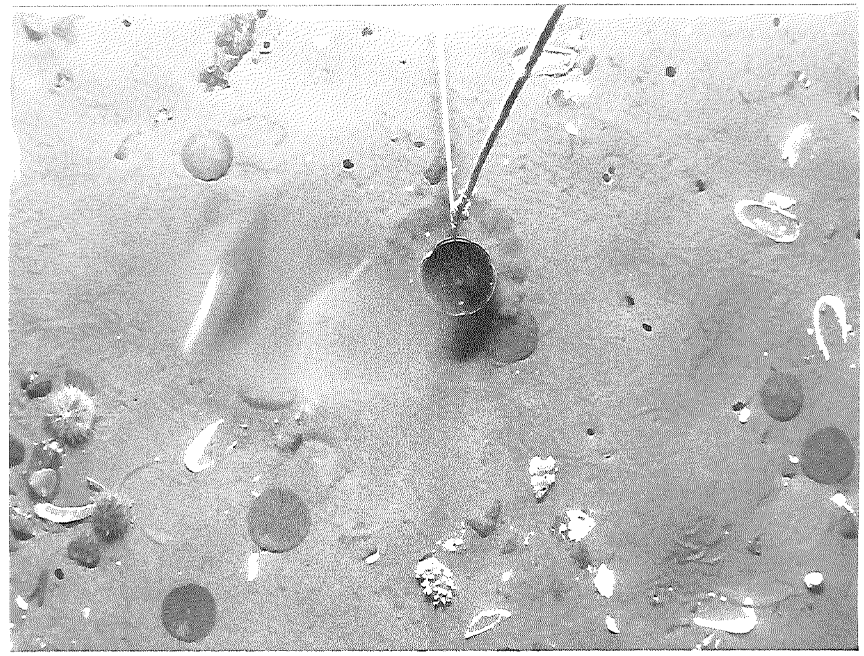


Photo 86

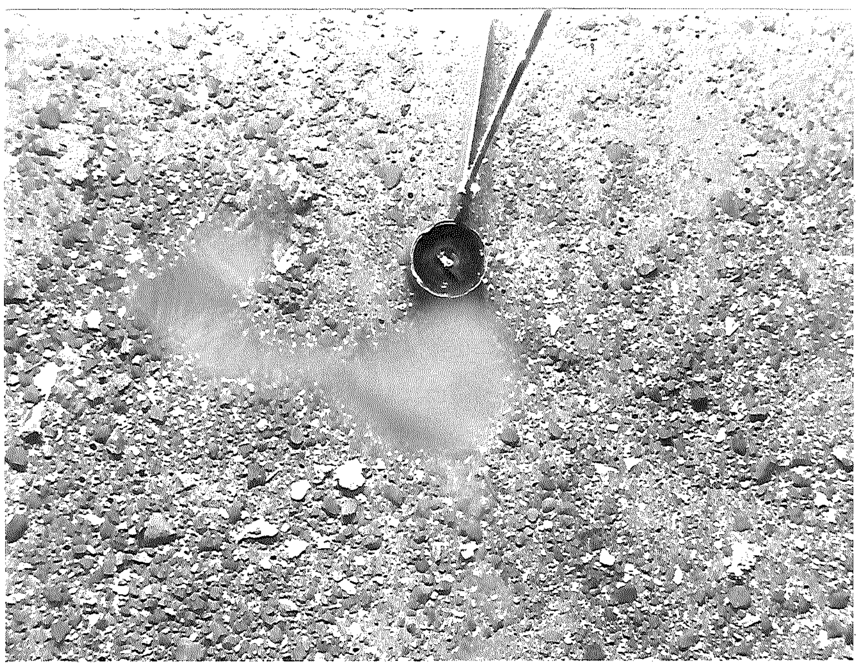


Photo 88

Photo 89 (47°33'N, 53°00'W, 46 m)
This photograph from Conception Bay, northern Avalon Peninsula, of Grand Banks Sand and Gravel formation, gravel facies, shows unusually angular boulders in a matrix of fine sand. They are encrusted with Lithothamnium sp., and provide a habitat for algae, the common sea star (Asterias vulgaris), anemones and sea urchins. The mottled arms of ophiuroids can be seen protruding from the substrate. This community, typical for this substrate, also includes the gastropod Aporrhais occidentalis. The sandy substrate between the boulders probably contains a significant invertebrate population. Some of the boulders may have been ice rafted.

Photo 90 (46°38.56'N, 54°39.5'W, 179 m)
This photograph is from the eastern side of Placentia Bay. Large erosional scours (megaflutes) cut into the sediments in this area and are thought to have resulted from the tsunami associated with the 1929 Grand Banks earthquake. Large aggregations of at least two species of brittle stars can be seen partially buried in the Downing Silt. Many of these have the tips of their arms raised in order to suspension feed, while others eat small invertebrates and sediment particles. The sediments are heavily bioturbated with some faecal mounds evident. A few gravel clasts are colonised by sponges and bryozoans. Sea urchins and large worm-like animals can be seen foraging for food. Venting gas may play a role in the rich benthic community, as pockmarks are prevalent in the area.

Photo 91 (46°51.4'N, 54°52.1'W, 238 m)
This is an oblique photograph of the seabed from the west side of Placentia Bay. The Downing Silt is inhabited by a diverse fauna, including a large number of subsurface deposit feeders. These, together with motile epifauna, are responsible for general bioturbation of the heavily pelletised sediment. Mounds and burrows are present. Animals visible in this picture include burrowing anemones, nemertean worms, deposit feeding sea stars and molluscs, and suspension feeding soft corals and sponges. A basket star (Gorgonocephalus arcticus) is barely visible in the background.

Photo 92 (46°30.8'N, 55°10.8'W, 152 m)
The Grand Banks Drift in the western part of Placentia Bay is typical of till seabeds on the Grand Banks. Here, large boulders and cobbles protrude from a matrix of silt, clay and sand. These surfaces are covered with iceberg furrows, mostly relict. They are inhabited mainly by highly motile brittle stars, snow crabs and occasional attached fauna, such as anemones and tunicates. Sea urchin tests are also visible. This is in contrast to the deeper areas of Placentia Bay, where the fine, silty sediments occur. This cobble substrate is coated with fine organic debris deposited from the water column.

Photo 89

Photo 91

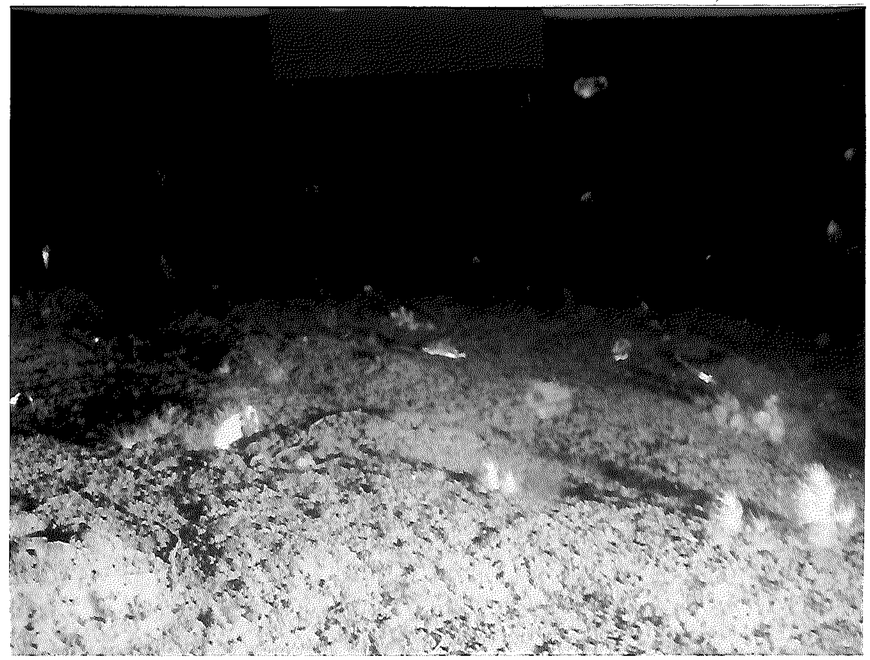


Photo 90

Photo 92

of both plants and animals. The occurrence of the macrophytes is made possible because the water depths are shallow at this station, allowing sufficient amounts of light to penetrate for photosynthesis. Attached animals include sponges, hydroids and bryozoans. In the areas without significant amounts of coarse gravel (see Photos 86 and 87) infauna is more prevalent than epifauna, and the epifauna that is present is generally motile rather than attached. Sand dollars, sea urchins and sea stars are the common organisms observed.

Photo 89 is from Conception Bay, a large deep bay similar to Placentia Bay. This photograph, however, comes from a shallow, coastal area, where the substrate is Grand Banks Sand and Gravel, gravel facies. The environment here is similar to that seen in the gravelly parts of Motion Bay (Photo 85) although the animals are somewhat different, in that brittle stars are present. The water here is shallow enough for the occurrence of algae, and both brown and red species are visible.

Placentia Bay is represented by Photos 90, 91 and 92. Of these, Photo 91 is further up the bay, while the others are on the outer part. Placentia Bay has relatively steeply sloping sides compared to other slopes on the Grand Banks, which are gentle, and reaches depths approaching 300 m. Grand Banks Drift (Photo 92), Adolphus Sand, Downing Silt (Photos 90 and 91), Placentia Clay and Grand Banks Sand and Gravel, all of the Grand Banks surficial formations, are present. The deep, cold, silty seabed of the bay is favoured habitat for snow crab, and these animals occur in sufficient numbers to support a crab fishing industry. Large male snow crabs are uniformly distributed throughout the deep water (R. Miller, pers. comm.). Female and juvenile crabs may be found in groups in the gravelly areas of the bay.

The Downing Silt supports a rich fauna, dominated by infauna, which produces a large amount of bioturbation. Brittle stars are seen in abundance in Photo 90, and other epifauna such as sea urchins and nemertean worms can also be seen in this picture and in Photo 91. Some attached animals, sponges, bryozoans and soft corals, are attached to the gravel clasts which protrude through the soft silt. An attached fauna in the form of anemones and tunicates is seen on the angular clasts of the Grand Banks Drift observed in Photo 92. Motile fauna, such as brittle stars, are also apparent.

Channels

Photographs were available from Avalon, Hermitage, and Halibut channels only. The surficial geology in Haddock Channel is similar to that of the Avalon Channel (see Figure 2), and the seabed consists of Adolphus Sand, a gravelly muddy sand.

One of the major influences on the benthos in this region is the Labrador Current, a deep, cold current that flows through the Avalon Channel and largely out through Haddock Channel. It has a profound influence on the sediment characteristics and distribution of benthic organisms in the area.

At the northern, wider section of the Avalon Channel, the sediment is mainly Grand Banks Drift, a poorly sorted sediment of glacial till (see Photos 93, 94, 95, 96, 99, 100, 105 and 107) corresponding to Scotian Shelf Drift on the Scotian Shelf. From submersible (Pisces) dives in the Avalon Channel (Fader, in press) the seabed was seen to consist of a winnowed lag gravel deposit over the till, only a few clasts thick. Iceberg furrows cover the entire seabed, some

Photo 93 (46°27.09'N, 52°46.98'W, 182.9 m) The substrate in this picture from the Avalon Channel southeast of the Avalon Peninsula is Grand Banks Drift with typical angular cobbles and pebbles. It is an area of relatively high current, and the silt and clay matrix of the till has been eroded, producing a lag gravel surface. The seabed here is probably the trough of a large iceberg furrow, and the sediment distribution is typical. The fauna is characteristic of a cobble bottom overlying a finer substrate. Sessile, suspension-feeding invertebrates such as the soft coral, probably *Duva* sp., and motile filter-feeding brittle stars of the *Ophiopholis*- type, are seen. Note that a group of brittle stars, possibly *Ophiura* sp., have a similar orientation and are possibly moving in the same direction. Sea urchins and shells of an unidentified mollusc are also observed. Vertical tubes, possibly of a polychaete worm, are seen on one of the cobbles.

Photo 94 (46°24'N, 52°48'W, 174 m) In this part of the Avalon Channel southeast of the Avalon Peninsula the substrate is Grand Banks Drift. There appears to be less erosion of silt and clay sized sediment here compared with Photo 93. Currents are evident from the presence of suspension feeders such as the branching bryozoans, hydroids and the *Ophiopholis* - type brittle star. A carnivorous gastropod, possibly *Colus* sp., is seen on the fine-grained sediment of the underlying matrix.

Photo 95 (approx.46°52'N, 51°58.5'W, 138 m) On the eastern flank of the Avalon Channel, east of the Avalon Peninsula, a gravel lag of angular pebbles and cobbles of Grand Banks Drift overlies finer grained sediment. Suspension-feeding epibenthic *Ophiura*-type brittle stars occur amongst the clasts. Sea urchins are also present. Infaunal animals lie buried in the sediment, and faecal mounds of sorted fines occur. A long food-collecting tentacle of a terebellid polychaete is visible on the sediment surface on the left side of the photograph.

Photo 96 (46°53.9'N, 51°58.6'W, 139 m) A large boulder of the Grand Banks Drift formation from the eastern flank of the Avalon Channel east of the Avalon Peninsula shows linear lamination fractures, indicating a sedimentary lithology. It is colonised by a large specimen of soft coral and several small colonies of sponges, tunicates and bryozoans. Surrounding the large boulder are pebbles and cobbles with a small amount of muddy sand matrix. The till is thin across much of the northern Avalon Channel area, often less than 2 m in thickness, overlying sedimentary bedrock of Cambrian-Devonian age.

Photo 93

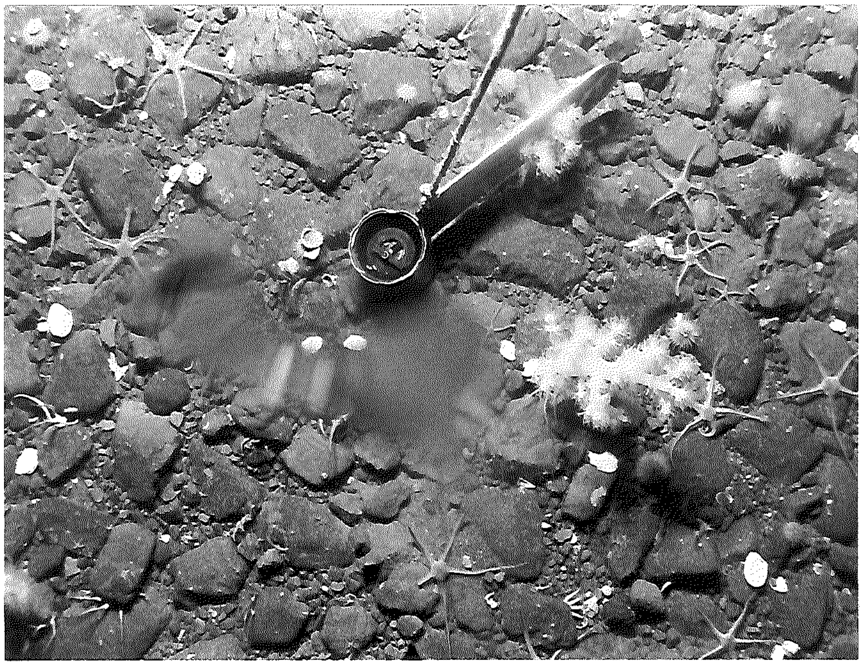


Photo 95

Photo 94

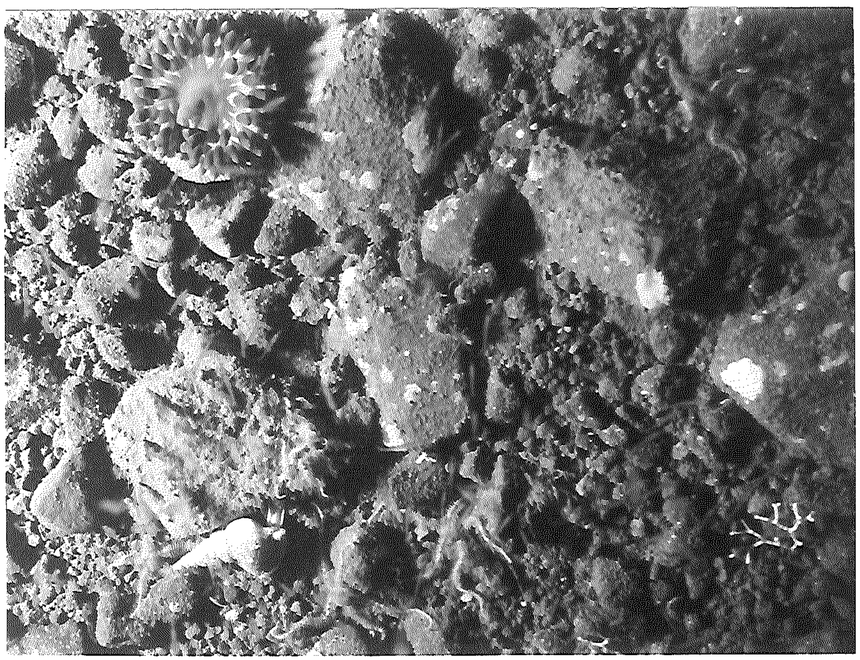


Photo 96

Photo 97 (45°48', 55°05', 146 m)
The seabed on the flank of Green Bank is Adolphus Sand. Tracks, burrows and tubes of the rich invertebrate infauna typical of such muddy sand substrates are easily seen in the photograph. The depression at lower left appears to contain a tunicate. Detritovore/carnivore Ophiura-type brittle stars are plentiful.

Photo 98 (46°20'N, 53°25'W, 110 m)
In this area off the mouth of Trepassey Bay south of the Avalon Peninsula, near the low stand of the late Pleistocene-Holocene sea level, the sediment is Adolphus Sand. The seabed is reworked by an epifauna of sand dollars and deposit feeding gastropods, Aporrhais occidentalis. Burrows of infauna are visible. Two-groove, three-ridge tracks of meandering Aporrhais sp. are scattered over the surface, as are sinusoidal sand dollar tracks. Densities, based on this picture, which shows an area of 0.5 m^2, are about 14 gastropods per m^2 and 25 sand dollars per m^2. The largest sand dollar in this photograph is approximately 5 cm in diameter. The sand in this area overlies iceberg furrowed Grand Banks Drift, in some areas completely burying the till, and in other places only infilling the furrow troughs.

Photo 99 (47°25.4'N, 51°44.1'W, 179 m)
This photo is from northeastern Avalon Channel, east of St. John's, and illustrates Grand Banks Drift, perhaps overlain by thin Downing Silt. The finer-grained silt and clay sediment is more characteristic of areas such as Hermitage and Halibut Channels. Burrowing anemones, probably Cerianthus sp., and sessile soft corals are also present. Holes, trails and tracks made in the soft sediment are evidence of a rich infauna. The Ophiura-type brittle star feeds on detritus and smaller infauna. Iceberg furrows are common across the seabed and greatly influence the distribution of seabed sediments.

Photo 100 (47°23.19'N, 52°33.27'W, 168 m)
This photograph is from the eastern Avalon Channel, southeast of St. John's, and is an example of Grand Banks Drift with a winnowed surface. The occurrence of the deposit feeding gastropod, Aporrhais sp., indicates the presence of infauna in the fine-grained sediments between the clasts. Empty mollusc shells are also present. Motile suspension feeders such as the Ophiopholis-type brittle stars and sessile suspension feeders, including the soft coral, egg-shaped colonial tunicates, sponges and bryozoans (both branching and encrusting forms) are able to locate here because of the cobbly and bouldery substrate. Sea urchins are also visible.

Photo 97

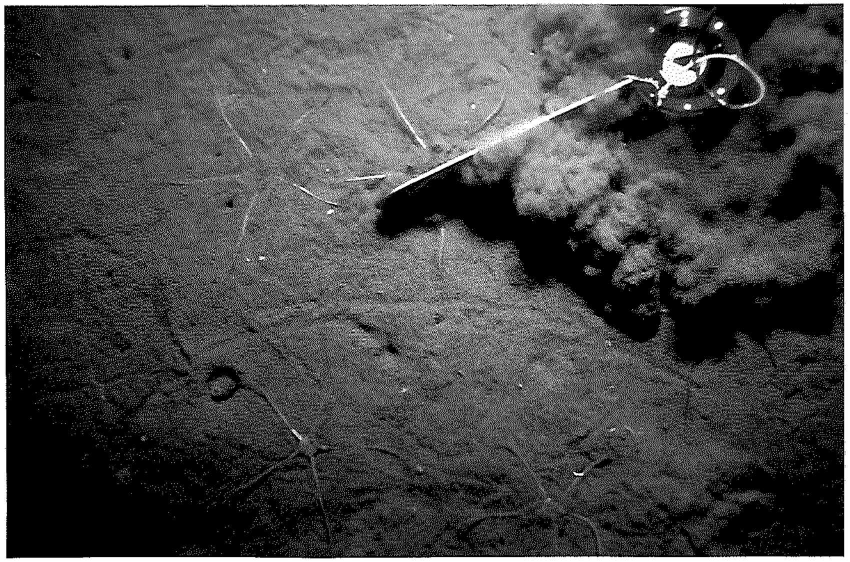


Photo 98

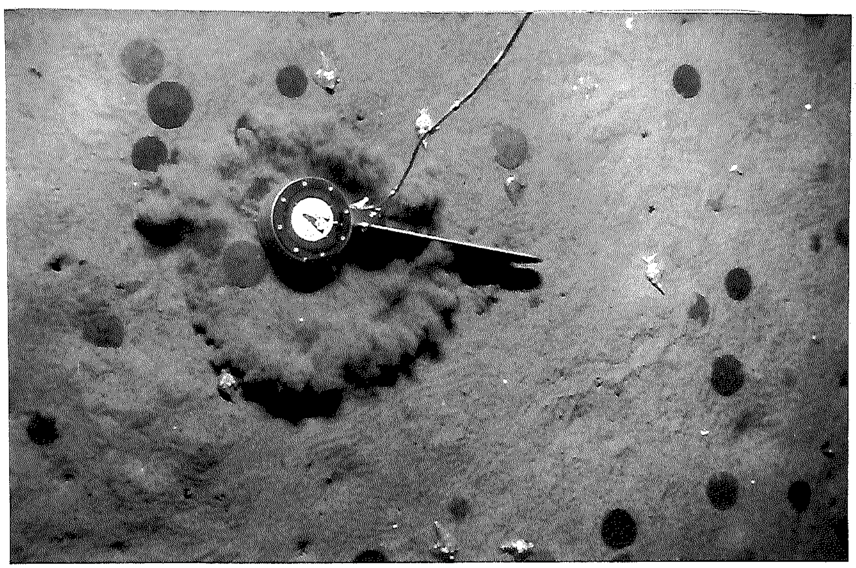


Photo 99

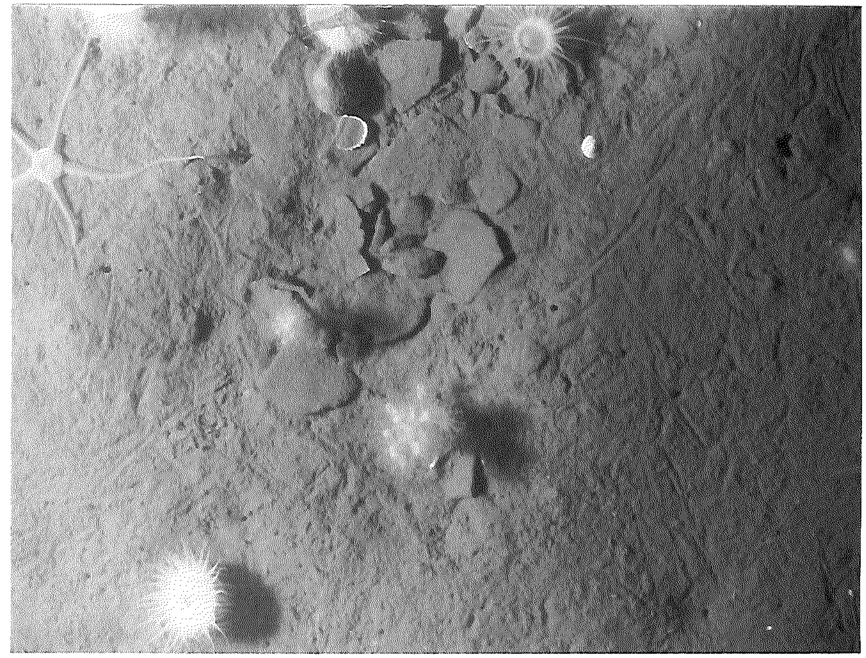


Photo 100

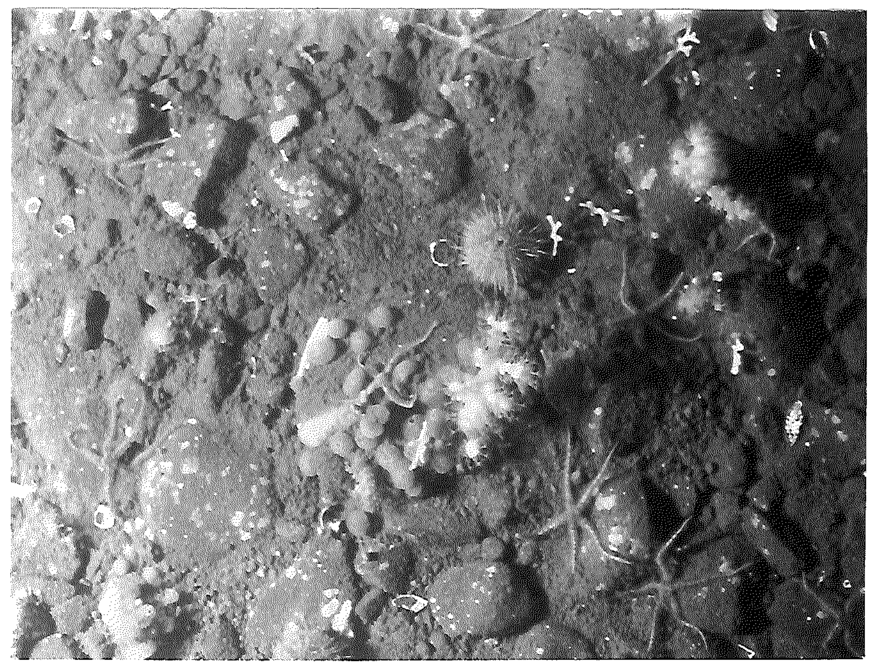


Photo 101 (47°01.2'N, 57°06.2'W, 301 m)
In Hermitage Channel off the south coast of Newfoundland, many interesting seabed features of biotic origin can be recognised in the fine silty clay of the Placentia Clay formation. Burrows, small mounds, faecal piles and granular pellets on the surface indicate the presence of an active infaunal community. Minute polychaetes have formed a band of fine pits in the left of the photo, and also form fine tubes. The hatch-mark patterns have been left by an Ophiopholis-type brittle star. The high density of tracks and impressions in the Placentia Clay of this area suggests a low energy environment.

Photo 102 (47°08.5'N, 57°26.4'W, 212 m)
The seabed northeast of Burgeo Bank, on the western flank of Hermitage Channel, is shown. Although occurring in an area of Grand Banks Drift, this bottom photograph suggests that the seabed may be covered by thin Placentia Clay, which borders Grand Banks Drift a few kilometres to the east. The bottom supports a rich infauna. The seabed near the mud star, Ctenodiscus crispatus, is pitted with holes that could possibly be the burrow openings of small amphipods. Slender tubes of sabellid polychaetes extend above the surface of the substrate, and tentacles of surface deposit feeding terebellid polychaetes are seen spreading over the sediment surface. Four stalked anemones, Boltenia sp., flank the sea star.

Photo 103 (46°34.51'N, 53°12.30'W, 78 m)
Taken southeast of Trepassey Bay, south of the Avalon Peninsula, this photograph shows subangular boulders and cobbles of the Grand Banks Sand and Gravel formation, gravel facies. They are encrusted with hydroids, bryozoans and tunicates. Both attached and burrowing sea anemones occur on a variable sediment of fine gravel and coarse sand in the interstices between the large gravel clasts.

Photo 104 (46°34.51'N, 53°12.30'W, 78 m)
This photograph from the nearshore area south of Trepassey Bay is from the same area as Photo 103, and shows a similar sediment. Subrounded cobbles and boulders of the Grand Banks Sand and Gravel formation, gravel facies, support a fauna which includes sessile, attached species such as anemones, hydroids and bryozoans, and motile forms, such as the grazing sea urchin, Strongylocentrotus droebachiensis. A variety of organisms live in the sediment between the cobbles. Many of these cobbles are encrusted with coralline algae. The environment shown here is similar to that seen in Photo 85, from Motion Bay, on the east coast of the Avalon Peninsula.

Photo 101

Photo 103

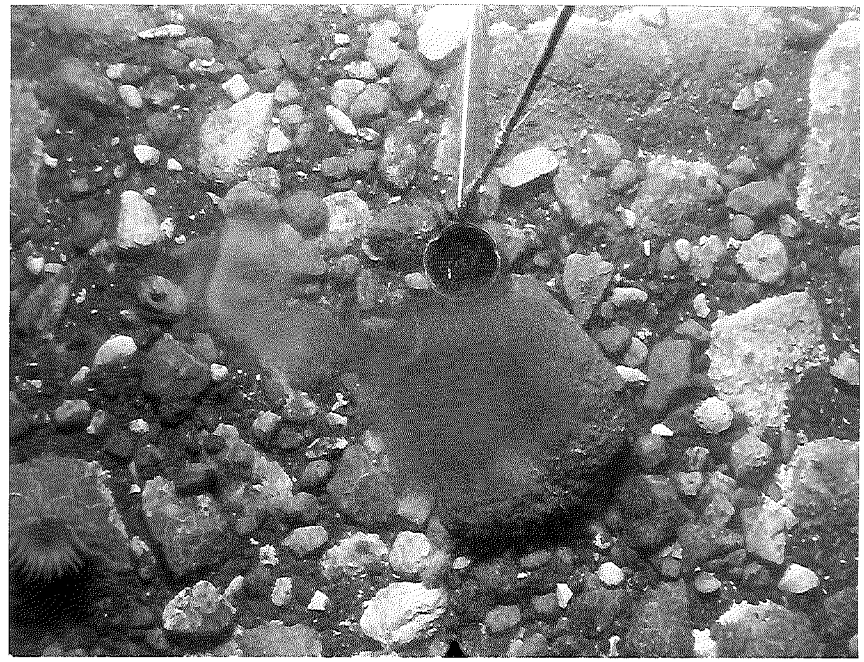


Photo 102

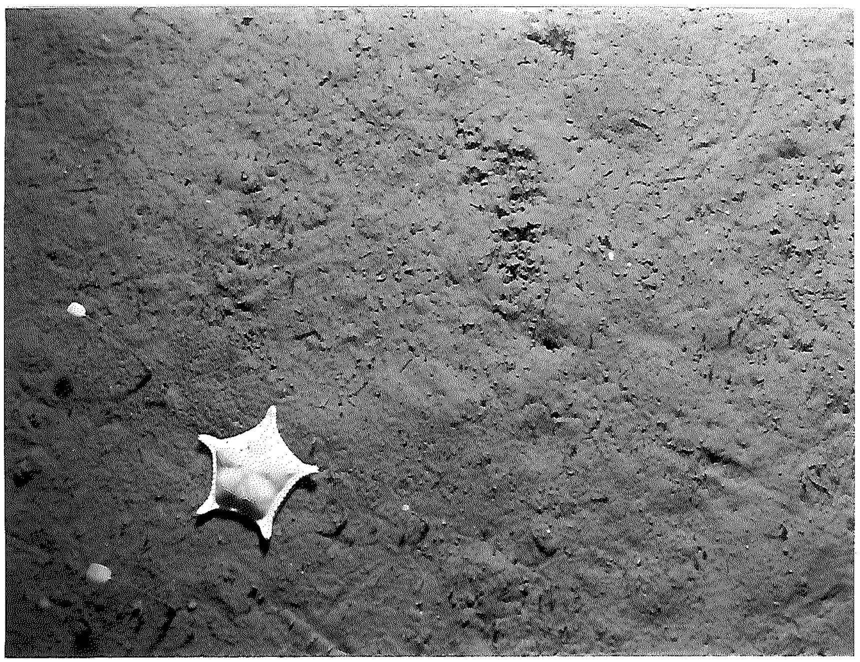
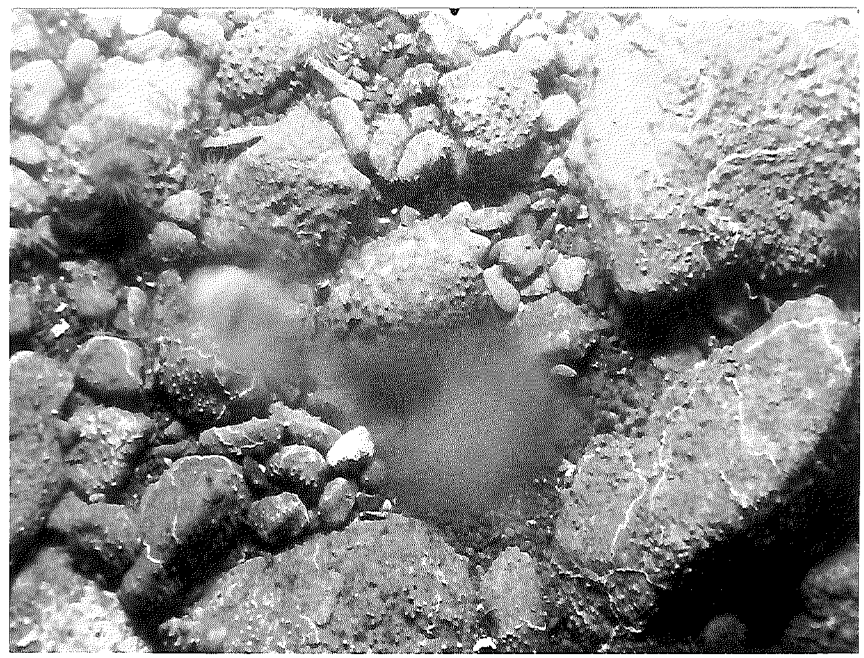


Photo 104



as deep as 12.5 m. The berms or ridges of the iceberg furrows are composed almost entirely of boulders. It is interpreted that the sand, silt and clay-sized sediment is eroded from the seabed by the Labrador Current. The iceberg furrows on the seabed are probably a mixture of old (relict) and modern iceberg scouring. To the south of Avalon Peninsula into Haddock Channel, the Grand Banks Drift is overlain by Adolphus Sand. Two facies of Adolphus Sand are recognised, one with less than 10% gravel (Photo 98), and one with less than 10% sand.

The deeper portion of the flow of the Labrador Current is partially obstructed from passing into St. Pierre and Halibut Channels by a sill extending between Green Bank and the coastal area south of Cape St Mary's. In Halibut Channel, sediments are largely Adolphus Sand (Photo 97) with some local deposits of Grand Banks Drift in the south and Downing Silt (extending from Placentia Bay) in the north. St. Pierre Channel, from which there no photographs were located, contains a mixture of Grand Banks Drift, Emerald Silt, Adolphus Sand and Grand Banks Sand and Gravel, grading from deep water in the east to shallow water in the west near the islands of St. Pierre and Miquelon.

Hermitage Channel, which is much deeper than the other channels, reaching a depth of 415 m, shows similarities in surficial sediment distributions and benthic environments to some of the larger bays such as Placentia Bay. Placentia Clay (Photos 101 and 102) occurs in the deeper parts, overlying Grand Banks Drift as the water shallows toward Burgeo Bank.

The Grand Banks Drift more commonly includes angular to subangular cobbles and boulders than the till on the Scotian Shelf which is not as winnowed. These clasts act as a suitable substrate for attached epifauna such as sponges (for example see Photos 100 and 128), anenomes (Photo

105), bryozoans (Photo 94), hydroids (Photo 105), tunicates (Photo 96) and soft corals (Photo 105). All of these organisms are suspension feeders depending on organic matter carried in the Labrador Current. Motile suspension feeders also occur, and include the brittle star, Ophiopholus sp. (Photo 93). Deposit feeding organisms include Ophiura sp. (Photo 95), gastropods (Photo 94), and sea urchins (Photo 95). In the softer silty and clayey sand between the cobbles and boulders, there is evidence of infaunal activity. For example, Photo 99 shows burrowing anenomes and evidence of disturbance of the surface sediments by infaunal organisms. Photo 99 also shows evidence of bioturbation and in Photo 95 a long food-collecting tentacle of a terebellid polychaete is evident.

The community found in the gravelly facies of the Adolphus Sand formation closely resembles that found on Grand Banks Drift (see Photo 94). However, in the sandy facies of Adolphus Sand, a different biological community exists (Photo 98) where the dominant organisms are the gastropod, Aporrhais occidentalis, and the sand dollar Echinarachnius parma, both of which are found in abundance on this sediment. Evidence of burrowing infaunal organisms is also common.

In Halibut Channel the sediment is mainly Adolphus Sand, which is equivalent to the Sambro Sand from the Scotian Shelf and supports a rich infaunal biological community as demonstrated by the amount of bioturbation visible in Photo 97.

The Placentia Clay of Hermitage Channel supports a rich infaunal community which includes polychaetes and nemerteans. Numerous marks in the sediment, including those made by feeding fish, are visible (Photo 101). Photo 102, with the same sediment type,from the western side of Hermitage Channel, supports a similar biological community.

Photo 105 (approx. 47°55'N, 52°29'W, 190 m) This photograph taken from the Pisces IV submersible (Dive 1071) off Conception Bay, north of the Avalon Peninsula, shows a seabed of Grand Banks Drift. The seabed is strewn with pebbles, cobbles and boulders covered with a thin layer of silty clay sediment. The seabed in this area is a large sill composed of till over 50 m thick which separates Conception Bay from the deeper Northeast Newfoundland Shelf. This area is covered with a mixture of relict and modern iceberg furrows and pits. Tunicates, soft corals, anemones, sponges, branching calcareous bryozoans and hydroids adhere to the boulders, suggesting that a moderate current is present, and that a supply of particulate material is available for food. Motile fauna such as gastropods, crabs and shrimp can be seen amongst the organisms on the cobbles and boulders.

Photo 106 (46°38.10'N, 54°05.78'W, 84 m) As the inner branch of the Labrador current sweeps through the Avalon Channel, one arm parallels the coast of the Avalon Peninsula towards Placentia Bay. This picture from south of St. Mary's Bay shows a current swept seabed of Grand Banks Sand and Gravel, gravel facies. The rounded cobbles are heavily encrusted with organisms. A crab can be seen in the centre of this picture. Other fauna include encrusting sponges, bryozoans, tunicates and barnacles, and low-growing soft corals and stalked tunicates. Several of the ubiquitous sea urchins are also present.

Photo 107 (approx. 48°17'N, 52°40'W, 190 m) In this area northeast of Trinity Bay, large angular boulders of the glacial till of Grand Banks Drift are seen at the seabed. This photograph of a junction between the flanking berm and the flat floor of an iceberg furrow was taken from the Pisces IV submersible (Dive 1073). The right-hand side of the photograph shows a silty sandy matrix of the till, perhaps brought to the surface by burrowing organisms. The boulders are encrusted with bryozoans, sponges and anemones. The deposit feeding gastropod Aporrhais sp., other molluscs, brittle stars of the Ophiura - type and sea urchins are also found. It can be inferred from the fauna that this is an area with some current.

Photo 108 (46°36.36'N, 54°21.9'W, 98.8 m) This photograph is located in an area of Grand Banks Sand and Gravel on the eastern flank of Placentia Bay, south of Newfoundland, and shows a sandy gravel with shell hash. Sea cucumbers, possibly Psolus sp., are embedded in the areas of finer sand, and scallops and sand dollars sit on the surface. Encrusting bryozoans, sponges and possibly barnacles cover some of the cobbles. The epifaunal community observed here is characteristic of a sand, gravel and shell hash substrate.

Photo 105

Photo 107

Photo 106

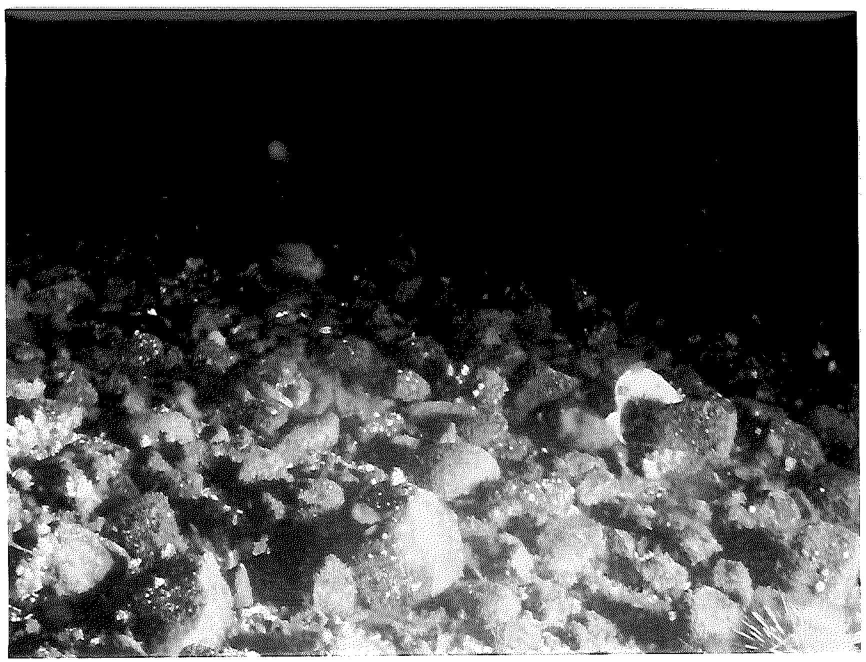
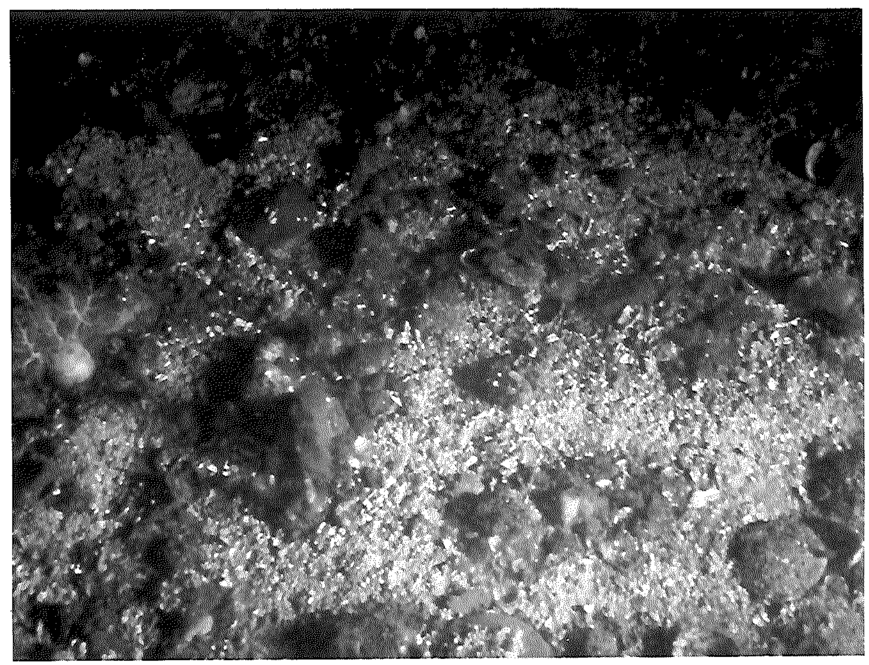


Photo 108



The series of photographs described above demonstrates that within the channels there appear to be only three different types of biological communities; one found on fine-grained silty clay deposits, one found on sandy deposits, and a third, which is variable, found on till (gravelly) deposits. The variablity appears to be controlled by the sediment particle size, i.e. the relative amounts of pebbles/cobbles/boulders, sand and silt/clay.

Coastal Areas

The coastal zone immediately offshore of southeastern Newfoundland is limited in width as the coastline is dominated by the presence of large deep bays and steep coastal fiords. The widest part of the inner shelf occurs south of the Avalon Peninsula where it is more than 20 km wide and is illustrated by Photographs 103, 104, 106, 108 and 109.

This entire area consists of Grand Banks Sand and Gravel formation, the same sediment found on the major offshore banks. However, in the coastal area, the sediment is generally more than 50% gravel, in comparison with the offshore banks which are predominantly sand. Shell hash is visible in photo 108.

The absence of silt and clay-sized material in this sediment results in a limited infaunal deposit feeding community, largely dominated by burrowing anenomes which occur in the interstices between the cobbles and boulders (see Photo 103) and sea cucumbers in areas of finer sand (Photo 108). The epilithic community is typical for the area and includes byrozoans (Photo 104), sponges (Photo 106), tunicates (Photo 103), hydroids (Photo 109), soft corals (Photo 105) and barnacles (Photo 106). Motile epifauna includes holothurians and brittle stars (Photo 109), gastropods (Photo 107), bivalves (Photo 109), scallops (Photo 108), sand dollars (also in Photo 108), and sea urchins and crab (Photo 106).

Outer Shelf

The Outer Shelf includes the large shallow banks, most in less than 100 m water depth, and the intervening isolated basins and deeps. The major channels between the banks have been included in the previous section. The banks in this grouping from west to east are Burgeo, St. Pierre, Green and Whale Banks and the largest, Grand Bank. These together represent in excess of 75% of the area referred to as the Grand Banks of Newfoundland.

Flemish Cap has also been included in this section. Although separated from the banks of the shelf by the deep water of Flemish Pass, it has a benthic environment similar to that on the outer banks.

Banks

The banks are shallow, less than 100 m water depth, and are generally covered with the Grand Banks Sand and Gravel formation. Localised distributions of other sediments such as Adolphus Sand may occur in some areas. Bedforms such as sand ridges, sand ribbons and megaripples are widespread. Sand ridges are common over the southern part of Grand Bank, but are not resolvable in bottom photographs because they have wavelengths of kilometres. Small scale bedforms such as megaripples and current ripples are visible on the photographs.

Photo 109 (46°37.7'N, 54°23.6'W, 101 m)
This photograph was taken on the east side of Placentia Bay southwest of the Avalon Peninsula. The seabed sediment is Grand Banks Sand and Gravel, gravel facies, with a large amount of organic growth. Animals seen here include sea cucumbers (Psolus sp.), brittle stars and burrowing anemones in the interstices between the pebbles and cobbles. Motile gastropods and bivalves are deposit feeding over the mixed substrate. A large gastropod, probably Buccinum sp., is seen in the centre left of the photo. Bryozoans, hydroids and soft corals are also visible.

Photo 110 (46°15.2'N, 56°12.6'W, 111 m)
In this slightly oblique photo of the seabed on the northeastern side of St. Pierre Bank, the sediment is coarse sand of the Grand Banks Sand and Gravel formation, sand facies. The photograph is taken on a sand megaripple with pebbles in the trough of the bedform. Sand dollars (Echinarachnius parma) make tracks along the side of a sand wave. Their three-lined trails are easily visible in the centre of the picture. The tubes with raised lips are a widespread feature of sandy substrates on the Grand Banks and Scotian Shelf.

Photo 111 (46°03.8'N, 55°44.5'W, 64 m)
This photograph from the northeast side of St. Pierre Bank shows a fine sand of the Grand Banks Sand and Gravel formation. This substrate is an excellent template for the tracks of the motile invertebrate fauna, sand dollars, gastropods and worms. Clear tracks of Buccinum sp. are shown. Tubes with raised lips made by an unidentified organism perforate the surface of the sand, which is etched with numerous tracks and traces. A moon snail (Polinices sp.) is seen at the left of the photo. The fine sand on St. Pierre Bank appears to be mainly confined to the north and eastern sides of the bank (see Figure 9).

Photo 112 (46°08'N, 54°33'W, 100 m)
On the edge of Green Bank, south of Placentia Bay, the sandy sediments of the Grand Banks Sand and Gravel formation include a few pebbles and cobbles, thus providing a mixed environment suitable for mixed populations. A crab, probably Hyas sp., sits under a cover of sand in the lower left. Motile species, such as sea urchins, gastropods, sand dollars and crabs; and sessile forms of soft corals and burrowing anemones (lower left); and the tracks and burrows of unknown species are present. Note a sinuous sand dollar track at upper right. The organism responsible for other sinuous tracks could not be identified. Shells of the bivalve Cyrtodaria siliqua and a gastropod are also visible.

Photo 109

Photo 111

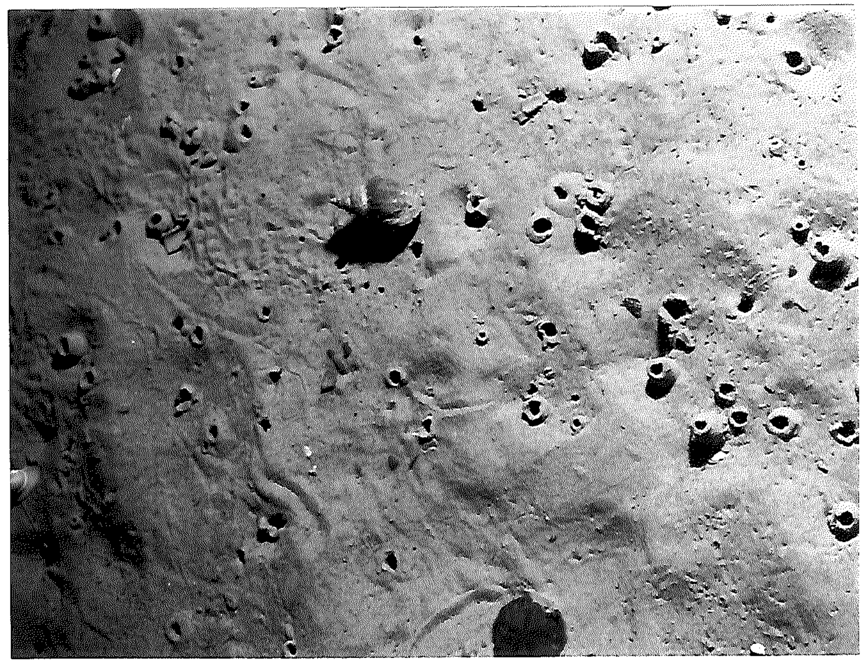


Photo 110

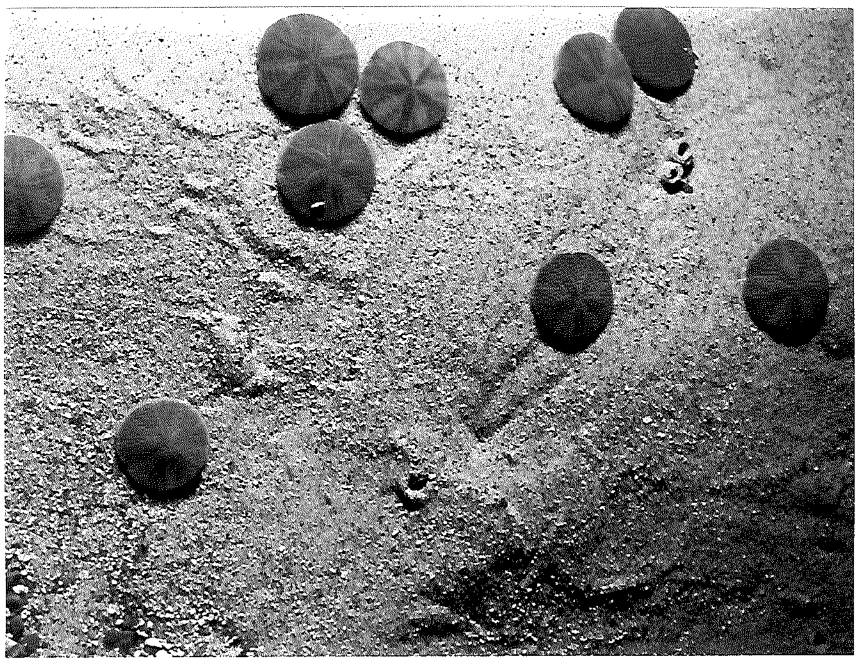
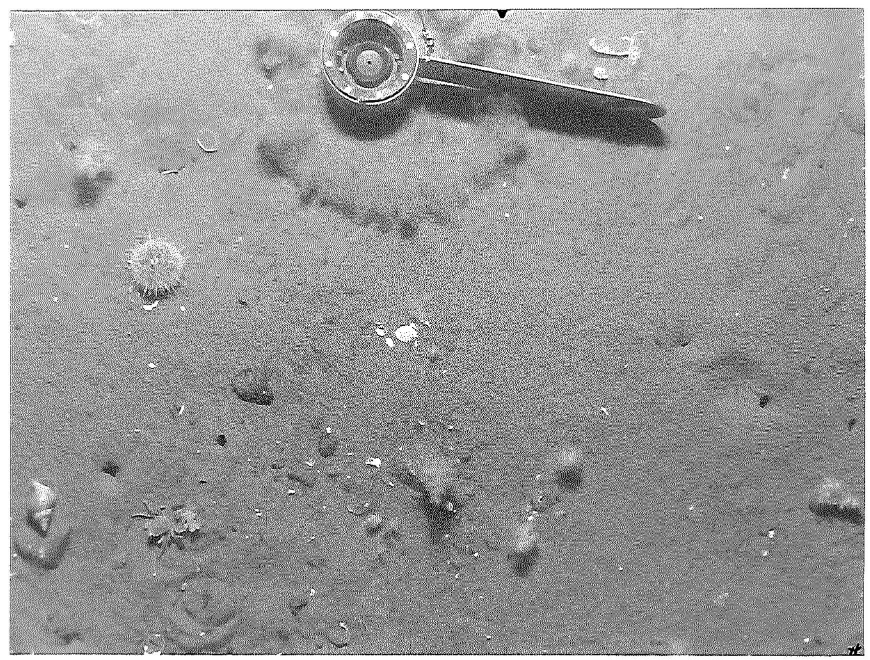


Photo 112



Water circulation over the offshore portion of the Grand Banks is variable as it is a product of several water masses, the Labrador Current, Slope Water and the Gulf Stream (see Chapter 4). Bottom currents in these areas are variable in direction and strength, and are generally less than 4 cm/s. Persistent gyres have been postulated to exist over Southeast Shoal. Extensive upwelling also occurs along the shelf break.

Banks - Sand Facies

Photographs of the sand facies of the Grand Banks Sand and Gravel are available from St. Pierre, Green and Grand Banks. The largest area of Grand Bank is covered in sand which is developed into large sand ridges overlying lag gravels (Fader and Miller 1986). The gravel sometimes outcrops in the troughs of the sand ridges. The photographic coverage of Grand Bank is limited.

A series of photographs of the sand facies of Grand Banks Sand and Gravel from different areas across the Grand Banks of Newfoundland has been selected to illustrate variation and similarities within this sediment type. The sediments range in size from very fine to coarse sand. Shell fragments occur mixed with the sand and bedforms are often present.

On St. Pierre Bank, Photographs 110 and 111 show two very different types of substrate (see St. Pierre Bank section). In Photograph 110, the sediment is a coarse well-sorted sand. A megaripple is evident. In Photograph 111, the sand is much finer and well-sorted. A megaripple is also apparent in this photo. On Green Bank, Photograph 112 shows a flat seabed of Grand Banks Sand and Gravel.

Photographs from northeastern Grand Bank also show other sediment variations. In Photo 114, the sediment is very fine sand with little bottom relief. Photograph 113, however, shows a wave formed rippled sandy surface with some shell debris similar, in fact, to the seafloor on Sable Island Bank (Photo 58) on the Scotian Shelf. In Photograph 121 the fine sand shows a complex ripple field, but no shell debris. Additional photographs of this general area are presented in elsewhere in the atlas.

West and south of Southeast Shoal on Grand Bank (Photos 115 and 116), the sediment is again sandy, with ripples and some shell debris. The surface of the sediment has a widespread distribution of complex bedforms, including wave-formed ripples (Photo 116), megaripples and sand ridges. The coarser sediment, including shell debris and pebbles, is often preferentially accumulated in the troughs of the wave formed ripples (Photos 124 and 127). The line of accumulated shell debris, shown in Photo 115, may also occur in the trough of a larger scale bedform. In Photo 127, a boulder from the trough of a sand ridge is shown. Photo 122, also from an area thought to be in the trough of a large sand ridge, contains a large boulder surrounded by a white filamentous mat of bacteria, interpreted to be feeding on hydrocarbon gas escaping from subsurface bedrock through the surficial sediments.

On the eastern area of Southeast Shoal, near the shelf break, dense aggregations of sea cucumbers, in sufficient quantities to show up on sidescan sonar as circular to linear patches of high acoustic backscatter, are evident in Photos 125 and 126. These organisms may be occurring in high densities in response to high availablitity of suspended food matter carried onto the banks by upwelling along the shelf break front, or supported by bacteria feeding on

Photo 113 (46°34.28'N, 49°30'W, 69.5 m)
On northern Grand Bank wave-formed sand ripples occur in the Grand Banks Sand and Gravel formation, sand facies. Most of the sand on Grand Bank is found in large sand ridges which overlie lag gravel surfaces. Sand dollars and the commonly occurring tubes of an unidentified organism occur in abundance. Sand dollar activity probably contributes to the eradication of wave and current generated ripples. A small thorny skate rests on the bottom in one of the ripple troughs.

Photo 114 (46°45'N, 48°44.9'W, 81 m)
This fine grained sand seabed of the Grand Banks Sand and Gravel formation, sand facies, found in the Hibernia area on northern Grand Bank is highly colonised. Fan worms (filter feeding, tubicolous polychaetes), sand dollars and various tubes and burrows can be seen, as well as the large, six-armed sea star Leptasterias sp. Some shell debris is visible, including the shell of Cyrtodaria siliqua, and is typical for the area. This picture shows the biota which develops after a period of low current and wave activity. Ripples are absent in this photograph, which was taken during May, 1987, and have been erased by animal activity. The seabed is usually rippled by wave action in the winter.

Photo 115 (43°50'N, 50°44'W, 69.5 m)
Southwest of Southeast Shoal, the sediments are coarse sand of the Grand Banks Sand and Gravel formation, with large amounts of shell debris intermixed and concentrated in the troughs of bedforms. A few tubes of the polychaete Onuphis sp. can be seen in this picture; in other photographs from this station large numbers of these tubes are visible. Compare this with Photo 144 from the Hibernia area of northern Grand Bank, which has a similar sediment distribution.

Photo 116 (43°51.42'N, 50°44.72'W, 62.5 m)
This photograph is also from southern Grand Bank west of Southeast Shoal, and shows a similar but coarser sediment to that seen in Photo 115. The wave-formed ripples of the Grand Banks Sand and Gravel formation are smaller and sharper than those in Photo 115, and consist of finer, sand-sized material overlying a pebbly-shelly sand. The distance between ripple crests is approximately 1 m. Epifauna are not evident in this photo, but are probably present in the area.

Photo 113

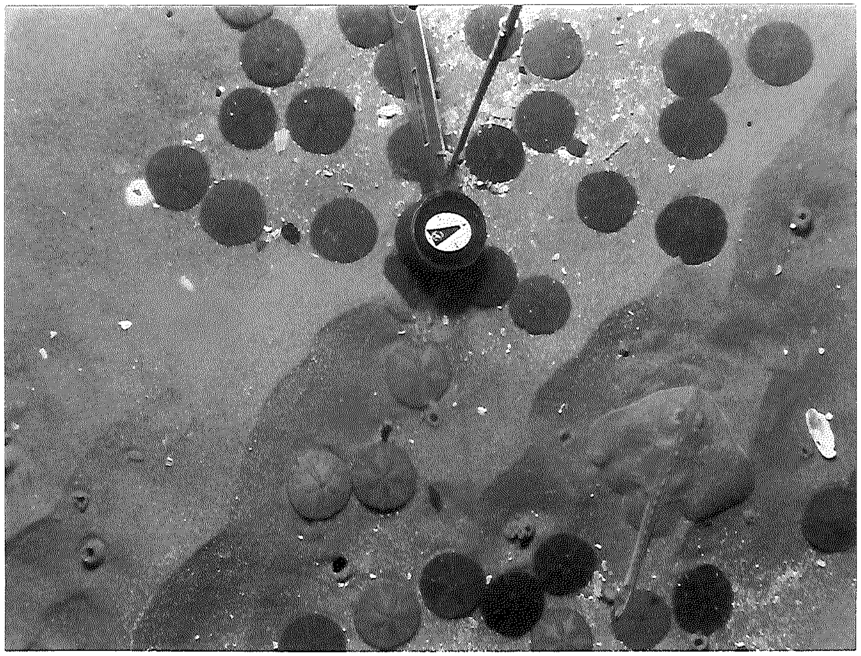


Photo 114

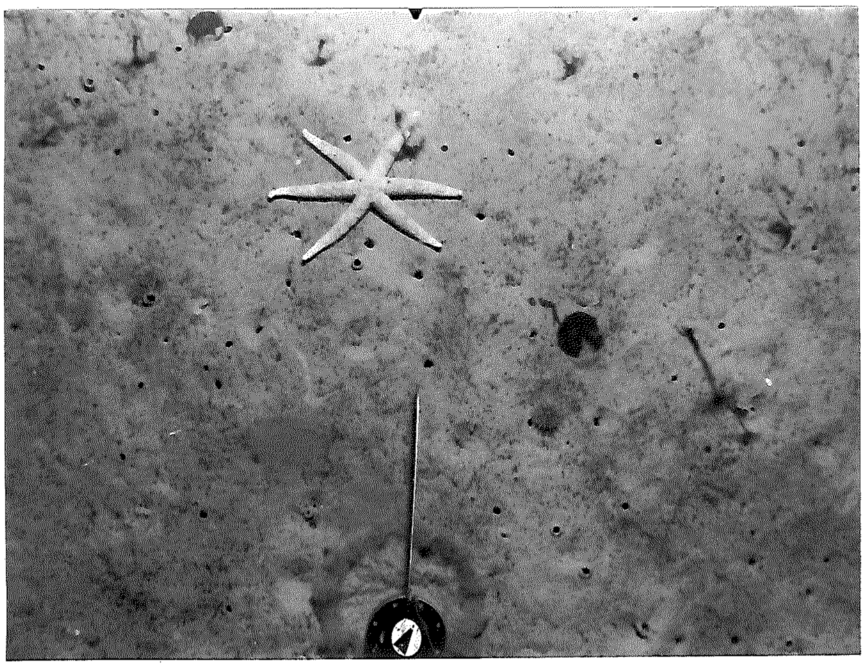
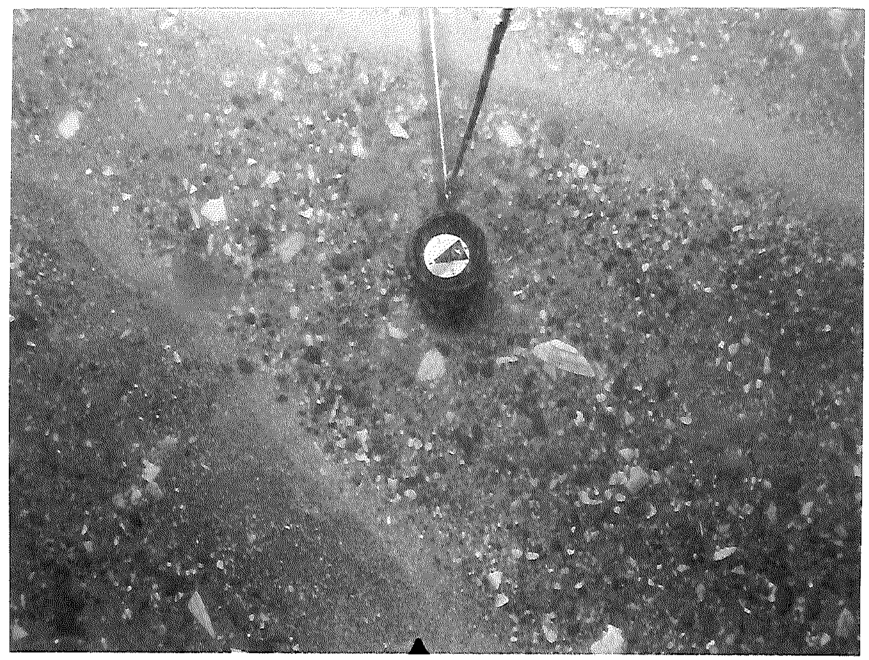


Photo 115

Photo 116



venting hydrocarbon gas. Another photograph from the same region (118) also shows the presence of sea cucumbers although in much lower density. This photograph taken at a depth of 149 m shows many features in common with Photo 149 (137 m) further north along the eastern edge of northeastern Grand Bank. Photograph 119, taken in shallower water to the west of Photo 118, shows a different community, dominated by sand dollars and tube building epifaunal species. In Photo 120, from the Tail of the Bank, the sediment is predominantly fine rippled sand.

In general, the sand substrate found over much of the area of the large offshore banks is unsuitable for the development of an attached community of organisms such as bryozoans, sponges, and associated epifauna seen in photographs from the Avalon Channel and the coastal zone.

On the coarser sand sediments (coarse sand with fine gravel/shells), for example see Photo 124, benthic organisms are in low abundance on the shell debris and coarse sand, and are generally limited to animals such as annelids and small crustaceans. Where the sediment contains larger clasts (cobbles and boulders) that are less often moved by the currents, a limited epilithic community develops (see Photo 122) that includes hydroids and bryozoans. The sand-sized sediment between the larger clasts is inhabited by smaller infaunal organisms. Attached epifauna is also observed on the large boulders in photographs 122 and 127, including anenomes and sponges. The mat of bacteria surrounding the boulder in Photo 122 is the only example of this feature shown in the atlas, but bacterial mats have been found on Green Bank as well as southern Grand Bank.

Sand dollars inhabit the sandy sediments in some areas, as illustrated in Photo 110 from St Pierre Bank, where the sediments appear to be coarse sand with no shell hash. Sand dollars are also widespread and occur in large numbers over much of the finer sand sediments of the northeastern Grand Bank including the Hibernia Area (Photos 113 and 121). They seem to be replaced as the dominant organism in other areas, such as the Tail of the Bank, by brittle stars (see Photo 120). Here, however, the sand is muddy, containing a substantial silt and clay component, unlike the other bank areas of the shelf. Burrowing organisms are evident in both of these environments. In yet other areas, see Photos 115 and 117, neither sand dollars nor brittle stars are particularly abundant. In Photo 117 the most frequently occurring animals are burrowing organisms such as an unidentified invertebrate, whose tubes are visible on the sediment surface. In the area shown in Photo 115, no animals occur with any great frequency. A partially buried flatfish is observed in Photo 113.

In areas where the fine-grained, sand sized sediments are found, as seen in Photos 111, 112 and 114, evidence of a more developed infaunal community is seen, including polychaetes and crustaceans. Some epifaunal organisms persist, and sea stars, sea urchins, crabs and sand dollars are apparent.

Banks - Gravel Facies

Photographs presented in this section are from St. Pierre, Green and Grand Banks. The gravel facies of Grand Banks Sand and Gravel is less common than the sand facies on the banks. Nine photographs have been selected to illustrate the gravel component of Grand Banks Sand and Gravel.

The individual clasts range in size from pebbles (Photo 130) to boulders (Photo 136), but are

Photo 117 (43°11'N, 50°09'W, 67 m)
Compare the amount of shell debris in the Grand Banks Sand and Gravel formation in this photograph from the Tail of the Bank with Photo 120 from the same area. This debris is intermittently exposed and buried by the migrating wave-formed ripples, and is normally concentrated in troughs. Large tubes of an unidentified invertebrate are abundant, as are tracks and faecal mounds. Also in this photograph are seen barnacles and colonial bryozoans attached to shells of the bivalve *Spisula* sp.

Photo 118 (43°47'N, 49°19'W, 149 m)
On the eastern edge of Southeast Shoal near Hoyles Canyon at the shelf edge, the sandy silty substrate of the Adolphus Sand shows none of the rippling observed to the south on the Tail of the Bank, probably a function of the greater depth. The seabed is strewn with shell debris and some of the densest patches of *Ophiura* - type brittle stars and holothurians (*Cucumaria frondosa*) seen in any of the photographs. Lipped tubes of an unidentified invertebrate occur throughout this photo. Terebellid tentacles can be seen as the animals deposit feed on the surface. Shells include Iceland scallop (*Chlamys islandica*), surf clam (*Spisula* sp.) and propeller clams (*Cyrtodaria siliqua*). A deposit feeding gastropod (*Aporrhais occidentalis*) and sand dollars are also present. In this unique area sidescan sonograms show dense benthic communities on a sandy seabed, perhaps concentrated by a combination of food from upwelling and subsurface gas venting.

Photo 119 (43°47'N, 49°23'W, 59 m)
At this location on the eastern edge of Southeast Shoal, the substrate is Grand Banks Sand and Gravel formation, sand facies. The rich infauna of this area is indicated by the holes, tubes and burrows, and by the numerous shells (mainly from the bivalve *Mesodesma* sp.) evident in the photograph. Epifauna consists mainly of deposit feeders such as sand dollars and gastropods (*Buccinum* sp.). A considerable amount of bioturbation caused by these surface deposit feeders and by burrowing infauna can be seen here as well. Sweeping traces of plant-like colonial bryozoans, attached to some of the mollusc shells are seen. Tracks of a small sand dollar appear on the upper left.

Photo 120 (43°01'N, 50°21'W, 72 m)
Note the rippled fine sand characteristic of the Tail of the Bank. The sediment here is interpreted to represent either Adolphus Sand or a sandy facies of Placentia Clay. Along the southwest edge of Grand Bank an unusual muddy sand continues for over 300 km. In places it overlies the Grand Banks Sand and Gravel formation. Further study of the unique setting of the sediments is underway. *Ophiura*-type brittle stars and unidentified tubes are distributed uniformly over the bottom. A shell of *Cyrtodaria siliqua* is visible resting on the sand. The tentacles of suspension feeding holothurians (sea cucumbers) are seen in this photo. Holothurians occur in very high numbers north of this area (Photos 118, 125 and 126).

Photo 117

Photo 118

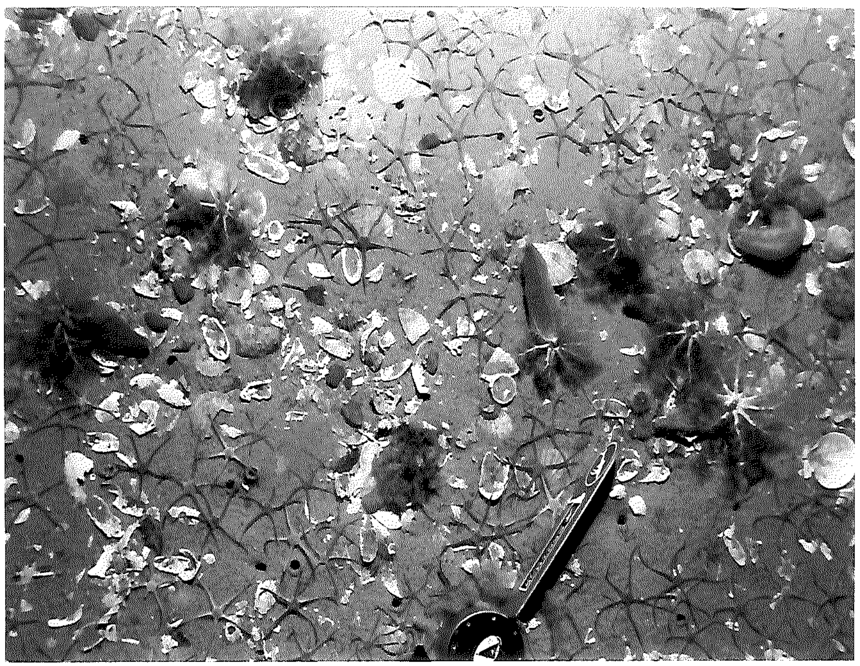


Photo 119

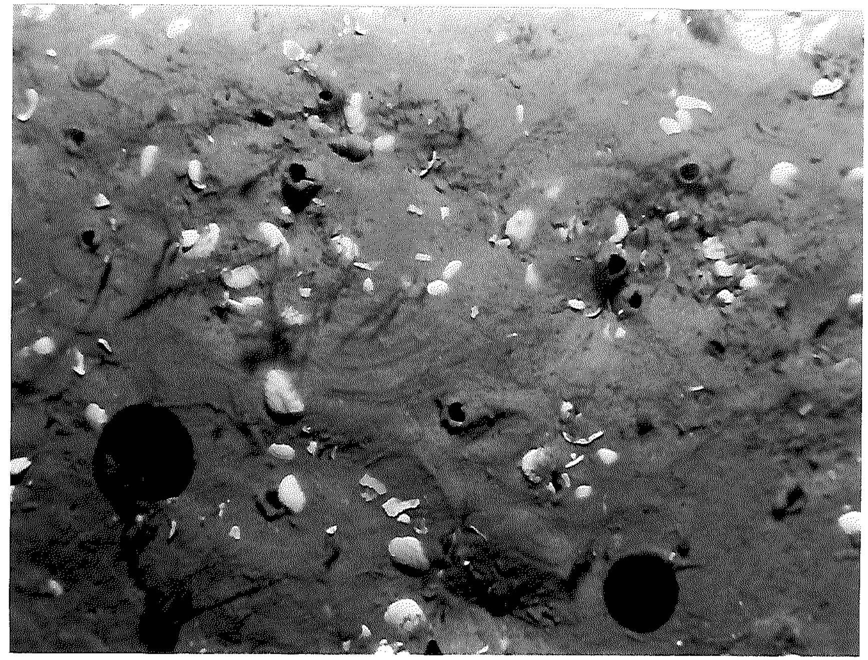


Photo 120

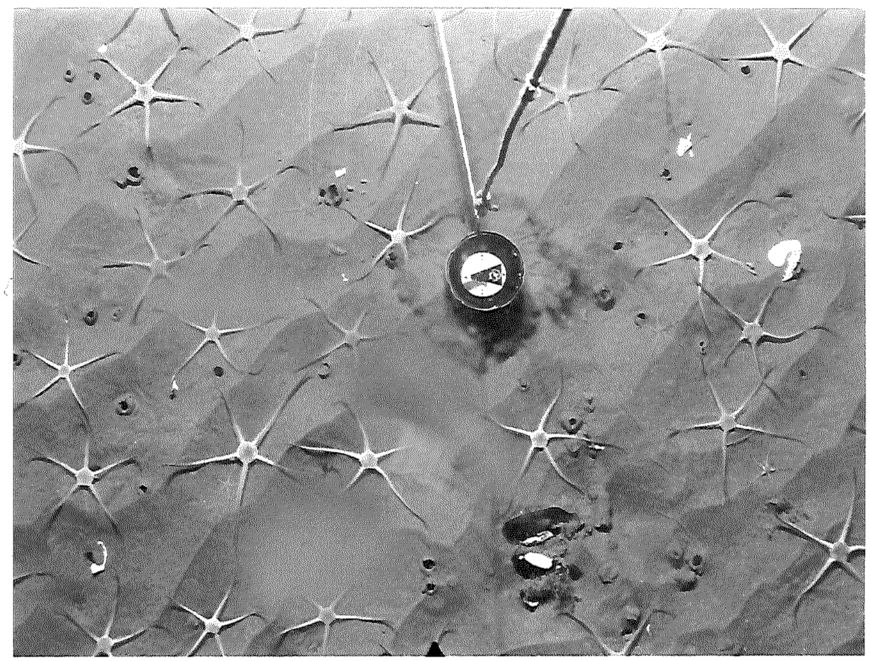


Photo 121 (approx. 46°35N, 48°41W, 80 m) Scattered sand dollars (Echinarachnius parma) inhabit a complex rippled seabed of Grand Banks Sand and Gravel, sand facies, near the Hibernia hydrocarbon discovery on northern Grand Bank. This photograph is from a large sand ridge.

Photo 122 (approx. 43°51'N, 50°45'W, 62 m) This picture was taken from a Pisces IV submersible dive (1) across the trough of a sand ridge in the Grand Banks Sand and Gravel formation west of Southeast Shoal. The boulder shown occurs in an area interpreted as the trough of the sand ridge consisting of thin, patchy sand overlying coarse gravel (Fader 1985). Large patches of white filamentous material, thought to be mats of bacteria which feed on hydrocarbons seeping from the subsurface bedrock, can be seen surrounding the boulder. The boulders support a fauna of sessile animals such as bryozoans, hydroids, anemones and sponges, indicating fairly clean water rich in food particles. A slight scour depression rings the boulder. Some of these scours can extend to 5 times the diameter of the boulder in areas where the sand is thick. Only the top of this boulder is protruding from the seabed which suggests that it is likely larger than 3 m in diameter.

Photo 123 (approx. 46°35.45'N, 48°49'W, 75 m) Sand, pebbles, cobbles and boulders of the gravel facies of the Grand Banks Sand and Gravel formation are seen in this photograph from the Hibernia area on northern Grand Bank. The boulders have a small amount of encrustation by a few hardy tunicates, some low-growing bryozoans and hydroids. Iceland scallops, (Chlamys islandica) are present and brachiopods are also seen. High currents in the area carry winnowed sand which may discourage the development of a rich epifauna on the boulders and cobbles.

Photo 124 (43°51.6'N, 50°45.8'W, <100 m) This photograph is from an area of megaripples developed on the Grand Banks Sand and Gravel, sand facies, in an area west of Southeast Shoal. Large shells and pebbles have accumulated in the troughs. These megarippled seabeds incise the large sand ridges of the Grand Banks, and cover large areas of the seabed. The sediment of the sand ridges is fine gravel and sand, while in the megarippled areas the sediment is coarser (Fader and Miller 1986). Elsewhere in this area heavily colonised boulders and a bouldery-cobbly bottom were encountered. Anemones and sea stars, possibly Asterias, can be seen on the boulders. Very little epifauna is observed on the shell hash, and infauna is probably mostly annelids and crustaceans with a low biomass (Emery et al., 1965).

Photo 121

Photo 123

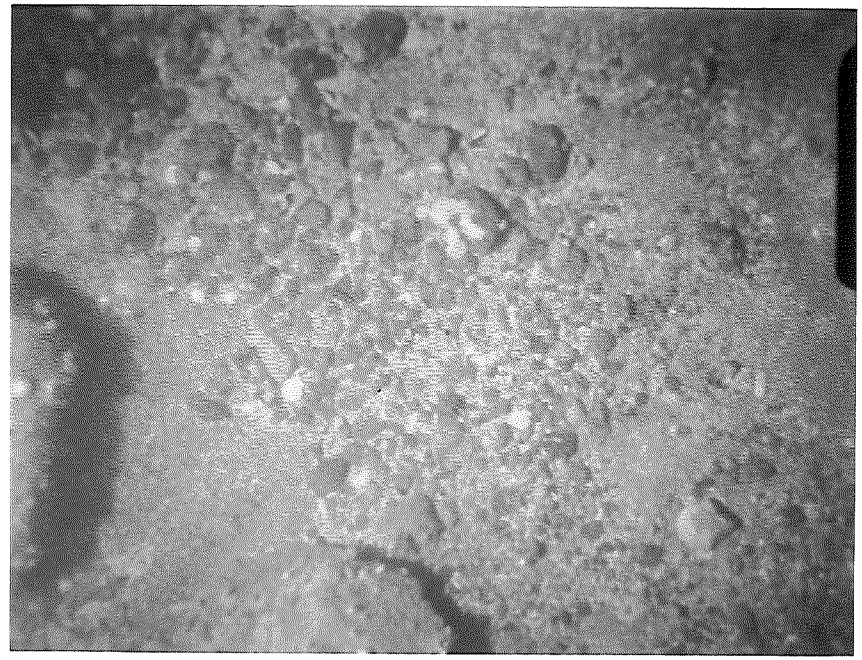


Photo 122

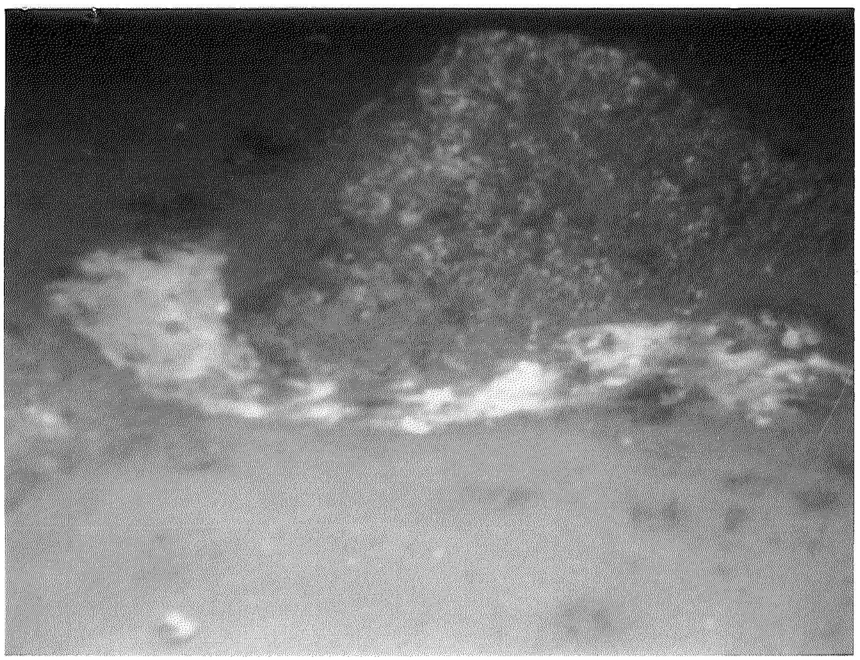
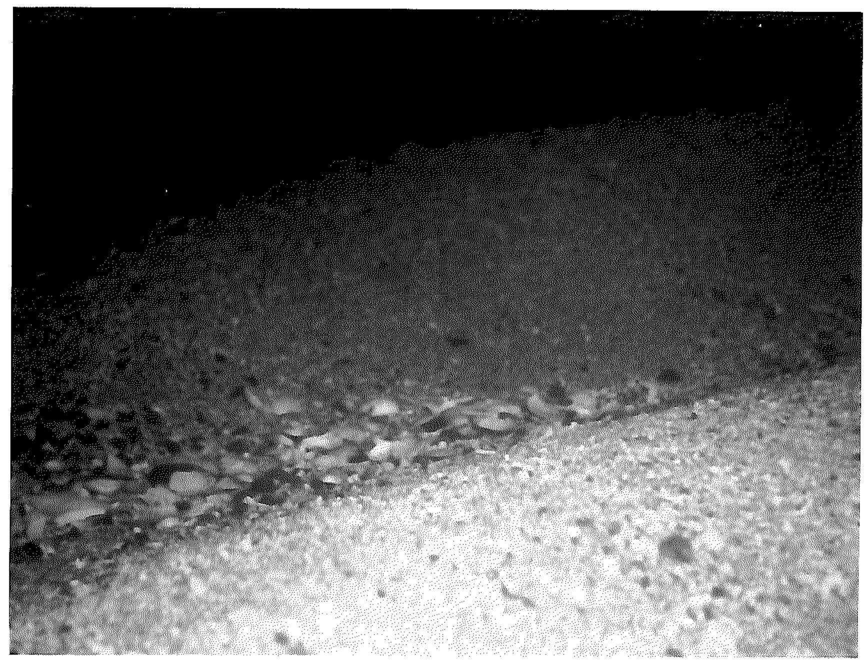


Photo 124



Photos 125 and 126 (approx. 43°42'N, 49°21'W, 120 m))
Large aggregations of holothurians (probably the sea cucumber, Cucumaria frondosa, see Photo 118 from Southeast Shoal) were encountered on Grand Bank near Hoyles Canyon in an area where sidescan sonar showed dense bioherms. The shapes of the patches of holothurians are varied and bizarre, ranging from 50 m circular-elliptical, beaded, to circular depressions with tails. Photo 125 shows the tail of a much larger circular patch. Little is known about the relationship between their occurrence, sediment transport, textural variation, etc. C. frondosa can reach lengths of approximately 15 cm. They are suspension feeders and have richly branched tentacles for capturing food particles. They occur where there is an adequate supply of water-borne food, and their presence here can perhaps be related to enhanced primary productivity occurring near the shelfbreak. The surrounding area of fine sand with some shell debris is also inhabited by another echinoderm, the Ophiura- type brittle star. Gas escape at the seabed may also play a role in their occurrence.

Photo 127 (43°51.2'N, 50°45.8'W, 70 m)
The mainly sandy seabed of southern Grand Bank features large sand ridges up to 12 m in height. The sediment is the Grand Bank Sand and Gravel formation, sand facies, overlying a gravel lag surface. During a survey using the Pisces IV submersible, numerous boulders were observed in the troughs of these ridges (Fader in press). This photo, (slightly out of focus) shows an example of such a boulder. The attached anemones, probably Tealia sp., have a maximum size of 12.5 cm, indicating that the boulder is approximately 1.5 m in height. Other organisms on the boulder include encrusting sponges and tunicates.

Photo 128 (46°34'N, 52°49'W, 140 m)
Shown here is the "Superfurrow area" of the Avalon Channel, named for the largest iceberg furrow found on the Grand Banks, 12.5 m deep and 500 m wide. The surrounding seabed is glacial till (Grand Banks Drift) and is heavily furrowed by icebergs (Fader 1985). The troughs of the furrows appear flat and the berms are made of piles of boulders, which are sometimes very large (>5m in diameter) and seem to have rolled down the rim to the outside area of the troughs. The boulder seen here appears to have been in its present position long enough for growth of a large sponge and numerous other encrusting organisms. A basket star (Gorgonocephalus arcticus) whose arms can reach a length of 36 cm, can be seen, bottom left.

Photo 125

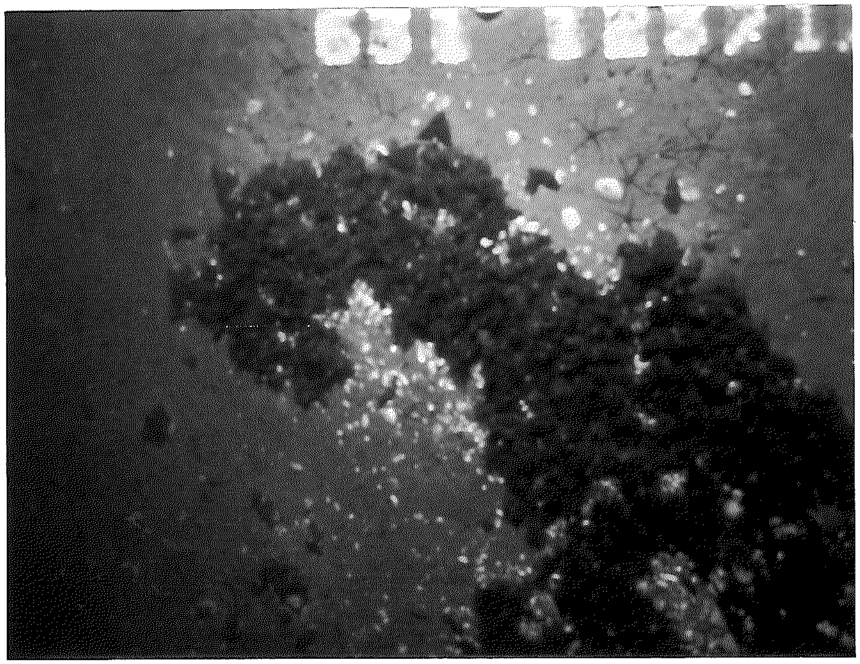


Photo 126

Photo 127

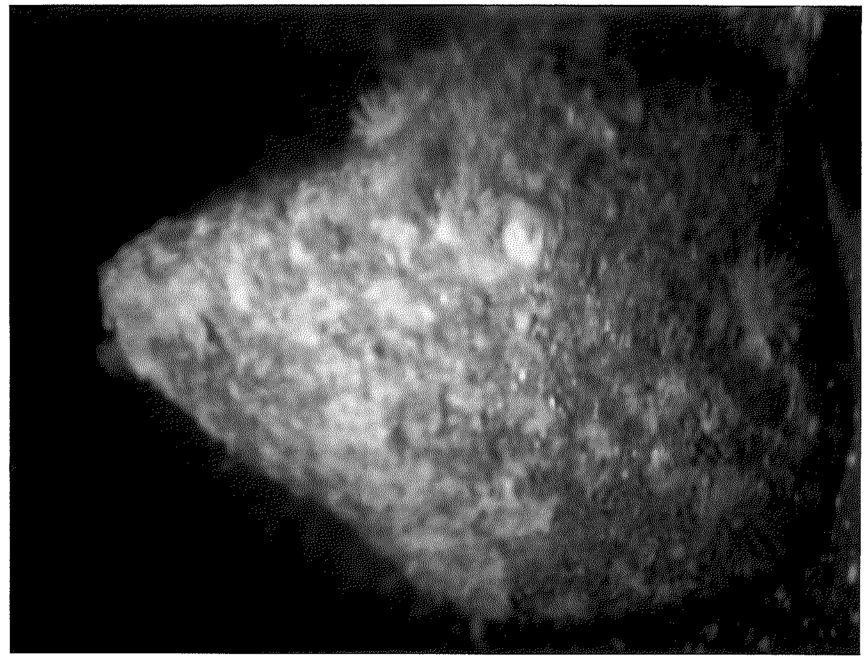


Photo 128

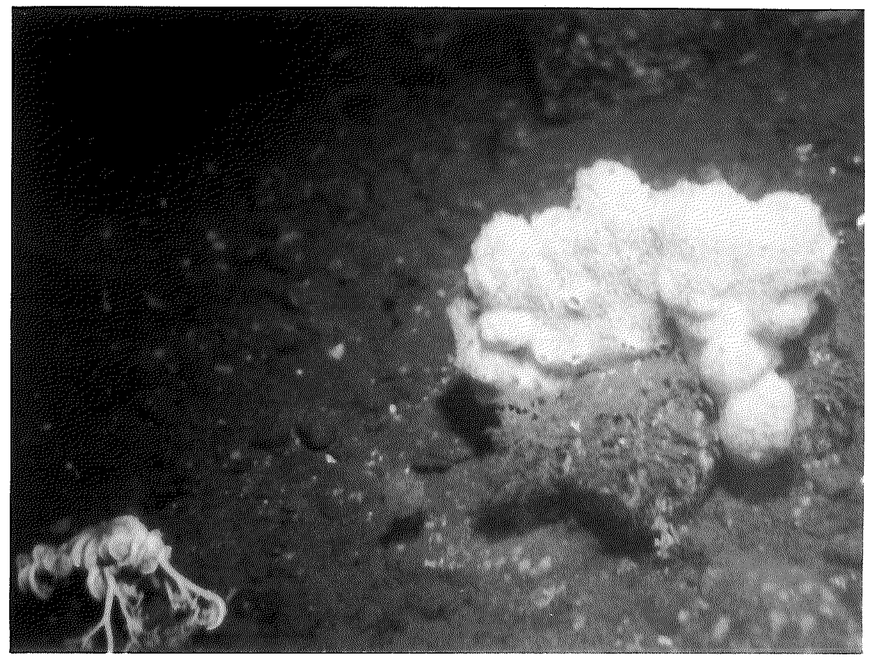


Photo 129 (46°46.6'N, 51°21.0'W, 86 m)
East of the Avalon Channel, northwest of Virgin Rocks, the sediment is Grand Banks Sand and Gravel, gravel facies. The fine sediments (silt and clay) have been winnowed out during the transgression, but the cobbles appear to be stable, as the presence of species such as soft corals, bryozoans and hydroids suggests. This type of bottom is called a lag gravel. Sea urchins and small gastropod molluscs feed over the surface of the cobbles, and barnacles are seen adhering to them. The former graze on epilithic films and the latter filter feed. The direction of the current can be inferred from the way the attached species of hydroids, bryozoans and soft corals lean (see top of photo). The scallop (probably Iceland scallop) feeds on suspended particulate material.

Photo 130 (45°48'N, 55°01'W, 88 m)
On the western flank of Green Bank (the eastern side of Halibut Channel south of the Avalon Peninsula) the subrounded pebbles and cobbles of the Grand Banks Sand and Gravel formation, gravel facies, look virtually abiotic. There is little, if any, encrustation or biogenic covering on the small pebbles and cobbles. This is possibly due to the high currents in the area which tend to dislodge and roll smaller pebbles across the seabed. However, the larger cobbles do have some tunicates and bryozoans attached to them. Some motile epifauna is present in the form of several small shrimp and gastropods, as well as several scallops.

Photo 131 (45°16'N, 49°16'W, 70 m)
The seabed substrate of eastern Grand Bank between Lilly and Carson Canyons is variable. In this area the Grand Banks Sand and Gravel, gravel facies, consists of a pebble-cobble layer. There is also a large shell component in the substrate. This area of Grand Bank is dominated by gravel seabeds with large boulders. A few isolated sand ridges overlie the gravel lag and it appears that the sand is in transport to the southeast. The sand has been winnowed from between the larger cobbles, but the current is probably not strong enough to overturn them, as demonstrated by the presence of attached and encrusting organisms. These include soft corals, anemones, bryozoans and sponges. Motile epifauna such as crabs, shrimps and gastropods are also present.

Photo 132 (45°48'N, 55°01'W, 86 m)
The substrate on this area of Green Bank, in slightly shallower water than that seen in Photo 130, is Grand Banks Sand and Gravel, gravel facies, with a minor sand component. It is inhabited by burrowing organisms such as holothurians and burrowing anemones, and by attached fauna such as encrusting, branching bryozoans, hydroids and barnacles. A sea star and a scallop lie on the sand, and motile epifauna working over the cobbles include numerous sea urchins, gastropods and an occasional crab.

Photo 129

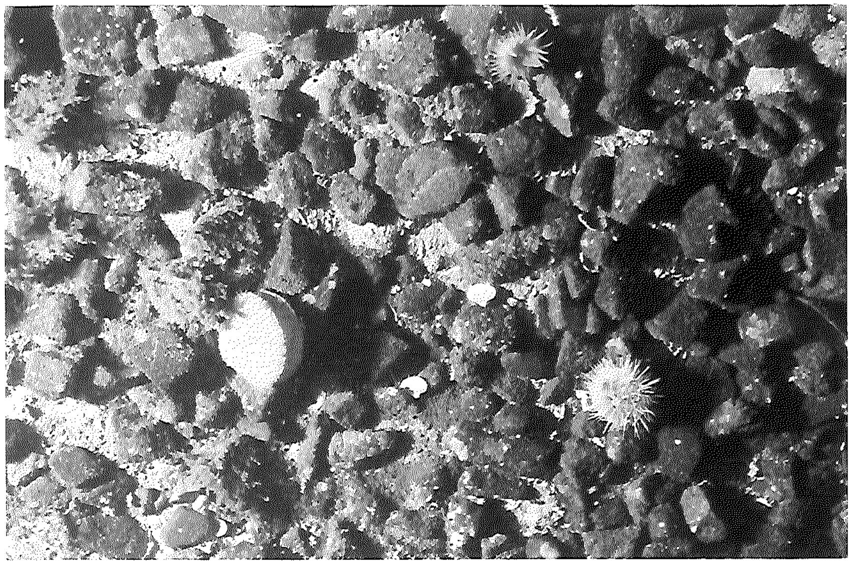


Photo 130

Photo 131

Photo 132

mainly of the cobble size. No significant accumulations of shell deposits are seen in these pictures, and bedform features are not visible in the photos selected. However, both are prevalent.

The benthic community that typically develops on this type of substrate is varied, ranging from extremely limited (see Photos 130 and 133) to well developed (Photo 135), where there is a dense population of brittle stars and the cobbles are heavily colonised by tunicates and sponges. Photographs of similar substrates from areas close to each other can show remarkable variations in the benthic communities present (compare Photos 134 and 135).

The biota on these substrates includes brittle stars (for an example see Photo 134), sea urchins (Photo 129), Iceland scallops (Photo 123), sponges (Photo 131), hydroids (Photo 132), soft corals (Photo 131), bryozoans (Photo 123), gastropods (Photo 134), shrimp (Photo 130), crabs (Photo 131), tunicates (Photo 130), barnacles (Photo 132), anenomes (Photo 131), and clams (Photo 134). The infauna, which inhabits the softer sediments between the cobbles, includes polychaetes (Photo 134), holothurians (Photo 132) and burrowing anenomes (Photo 132).

Photograph 136 from Green Bank shows a large boulder of the Grand Banks Sand and Gravel formation heavily encrusted with bryozoans, hydroids, sponges, soft corals and tunicates. This picture demonstrates that the development of the benthic community is often largely a function of sediment stability, as this large boulder is unlikely to be moved by the water movements, as compared with the smaller pebbles and cobbles seen in the other photographs.

Bedrock Outcroppings

Photographs 137, 138 and 139 were taken at one station on Eastern Shoals on Grand Bank, east of the Avalon Peninsula. This is an area of particular interest as it has similar geological and biological features to an adjacent shallow area, Virgin Rocks, which has been considered as a possible site for the construction of an offshore terminal associated with the development of hydrocarbons at the Hibernia area of northeast Grand Bank. This area also has significance in that it is one of the few places located so far offshore that has biological production from attached plants (seaweeds). These photographs show the acoustic basement (bedrock) with no overlying surficial sediments other than a few large boulders of local bedrock. The sediments have probably been eroded because of the rough and steep topography of the bedrock.

One of the most obvious biological features of this area is the abundance of the encrusting red coralline alga Lithothamnium sp. The photos show an established benthic community comprised almost entirely of attached and motile epifaunal organisms. Infaunal organisms are not common due to the lack of surficial sediments in which to burrow. The common organisms include anenomes, hydroids, bryozoans, sponges, urchins, crabs, sea cucumbers, scavenging gastropods and basket stars.

Banks with Shell Deposits

Photographs included in this section are from St Pierre, Green and northern Grand Banks. No photos are available from Southeast Shoal, where extensive shell deposits of both living and dead Mesodesma deauratum have previously been observed (Hutcheson et al., 1981).

Photo 133 (45°42.5'N, 55°40.0'W, 61 m)
On the eastern area of St. Pierre Bank a shelly, poorly sorted gravelly substrate of Grand Banks Sand and Gravel, gravel facies, contains pebbles which are small enough to be overturned by current and wave activity. This prevents the growth of encrusting or attached fauna on any but the largest cobbles. Note that many of the pebbles and cobbles are well rounded. Epifauna such as sea urchins, which graze on epilithic encrustations, are present. The portable tubes of an onuphid polychaete and bivalve mollusc shells are visible. Encrusting epifauna are small. Bryozoans and barnacles can be seen on some of the larger cobbles. Note the general paucity of macro-epifauna.

Photo 134 (46°06.21'N, 56°56.2'W, 51 m)
On northwestern St. Pierre Bank the sediment is Grand Banks Sand and Gravel, gravel facies, of pebble- to boulder-sized clasts. This stable substrate provides a good surface for encrusting and attached organisms such as coralline algae, bryozoans, hydroids, tunicates and barnacles. Bivalves (scallops and clams), tubicolous polychaetes (onuphids) and more motile grazing species such as brittle stars and small gastropods can be seen. A large cockle shell, probably Cardium sp., can be seen at the bottom of the photo. Compare with similar conditions from northern Grand Bank in the Hibernia region (Photo 151).

Photo 135 (45°50.16'N, 56°12.5'W, 54 m)
Towards the centre of St. Pierre Bank the fauna encountered is remarkably different from that in Photo 134, northeastern St. Pierre Bank. This possibly results from the coarse texture of the gravel-sized sediments. Here, the Grand Banks Sand and Gravel formation, gravel facies, consists of cobble to small boulder sized fragments. The dominant and most conspicuous component of the biota is an unusually dense concentration of Ophiopholis-type brittle stars, which lie between the clasts, waving their arms to capture current-borne particles. Tunicates and sponges also feed on water-borne particles, and motile species such as sea urchins and some gastropods feed on epilithic encrustations. Coralline algae encrustations give some of the cobbles a rough appearance. Similar dense populations of brittle stars occur across large areas of St. Pierre Bank. The current direction would appear to be from lower right to upper left.

Photo 136 (46°08.50'N, 54°33.50'W, 100 m)
Glacial or iceberg derived boulders on Green Bank provide a stable substrate for encrusting, attached forms and their associated fauna. The boulders of the Grand Banks Sand and Gravel formation, gravel facies, are so heavily encrusted by colonising organisms that it is impossible to determine the lithology. The boulder in this picture is approximately 60 cm across and supports a community of soft corals, branching and encrusting bryozoans, hydroids, tunicates, and sponges.

Photo 133

Photo 135

Photo 134

Photo 136

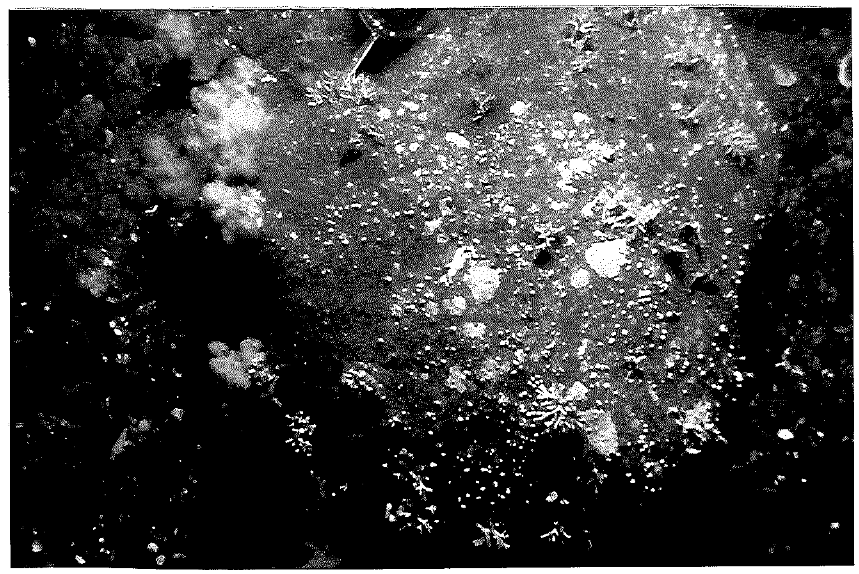


Photo 137 (46°25'N, 50°29'W, 44 m)
Eastern Shoal is an area of shallow bedrock outcropping on the northwestern portion of Grand Bank, east of the Avalon Peninsula. The rough topography and high current velocities in this area control the composition of the benthic community. The coralline encrusting alga, Lithothamnium sp., is visible on the boulders and bedrock, an indication of the shallow water depths encountered here. Encrusting invertebrates such as sponges (orange to yellowish-orange encrustations) and bryozoans grow over the rock faces. Attached epifauna, including soft coral, anemones and hydroids flourish here. Motile scavengers, although not seen in this picture, would be expected to occur in such environments.

Photo 138 (46°25'N, 50°29'W, 44 m)
The absence of fine-grained sediments in this area of bedrock outcropping in the Eastern Shoals area of Grand Bank results in an ideal habitat for both motile and attached forms of epifaunal animals. In this photograph the most conspicuous invertebrates are the suspension feeding basket star (Gorgonocephalus arcticus), and the sea cucumber (Cucumaria frondosa). Herbivorous sea urchins (Strongylocentrotus sp.) leave bare, scraped areas on the rock, creating suitable sites of attachment for such animals as anemones, bryozoans and hydroids. White, sinuous, calcareous tubes of serpulid polychaetes are visible against a background of coralline algae on the bedrock at lower left. A small gastropod is also seen in this area.

Photo 139 (46°25'N, 50°29'W, 44 m)
Bedrock outcropping with a small amount of sand in this area of Eastern Shoals, Grand Bank, is partially covered by the coralline encrusting alga, Lithothamnium sp. Hydroid colonies, sponges, tunicates and anemones grow in abundance. This attached community supports a variety of motile scavengers, including numerous small crustaceans, including a small crab, possibly Hyas sp. (to the left of centre) visible under magnification. These are probably feeding on organisms associated with the attached colonies. A camouflaged sea urchin in the upper right is grazing on the rock surface, as are several gastropods.

Photo 140 (46°48.6'N, 48°45.6'W, 82 m)
It is often said that "a picture is worth a thousand words",and this photograph taken from a submersible is an excellent example. It is of the side of an experimental excavation called a "Glory Hole" dug near the B-08 well site in the Hibernia area of Grand Bank. It is a large pit where well heads for petroleum production may be placed to be protected from icebergs. The photograph shows Tertiary bedrock, sandstone and siltstone, overlain by the Grand Banks Sand and Gravel formation, and illustrates how thin these sediments often are on the Grand Banks, sometimes less than 1 m thick. Shell debris is scattered across the seabed in the foreground, and several crabs can be seen.

Photo 137

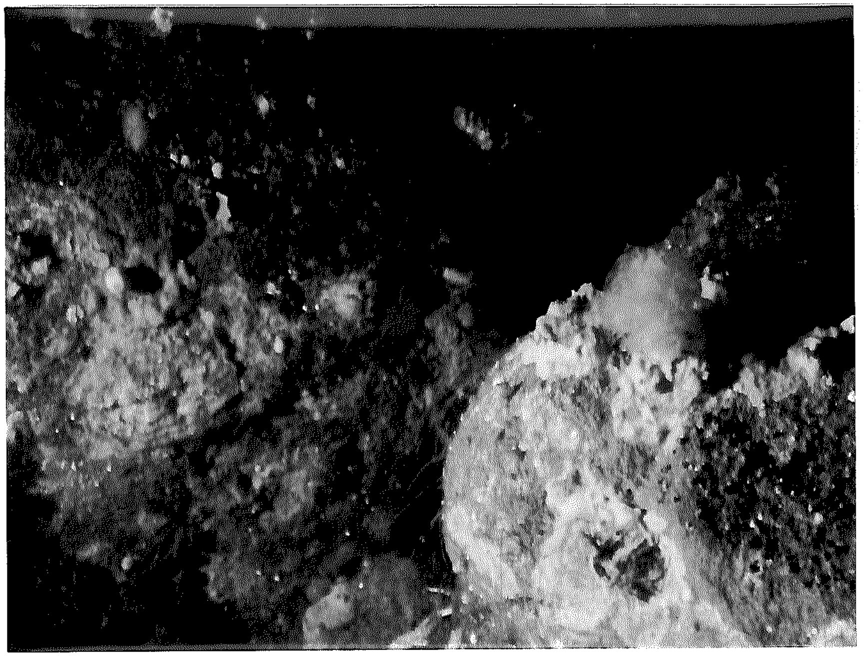


Photo 138

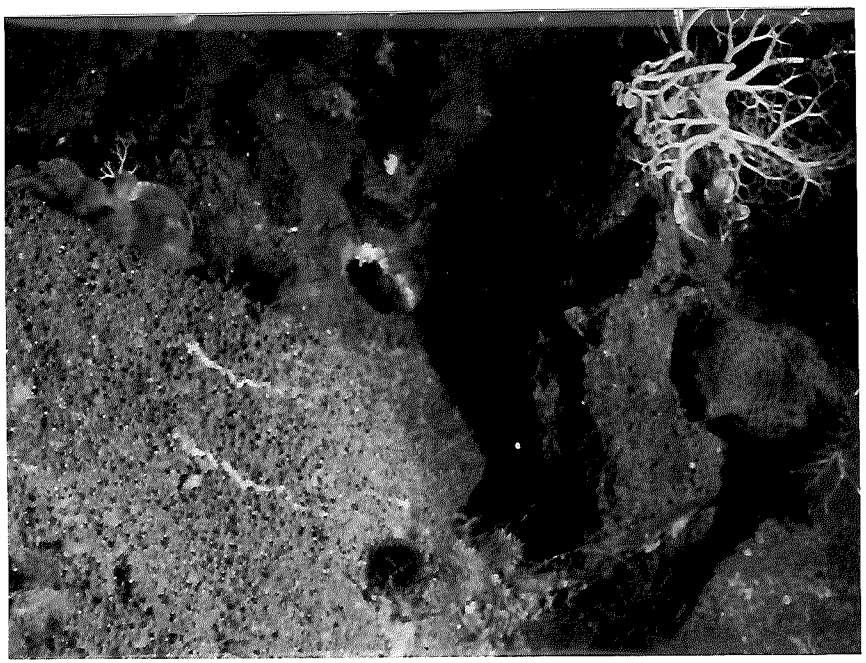


Photo 139

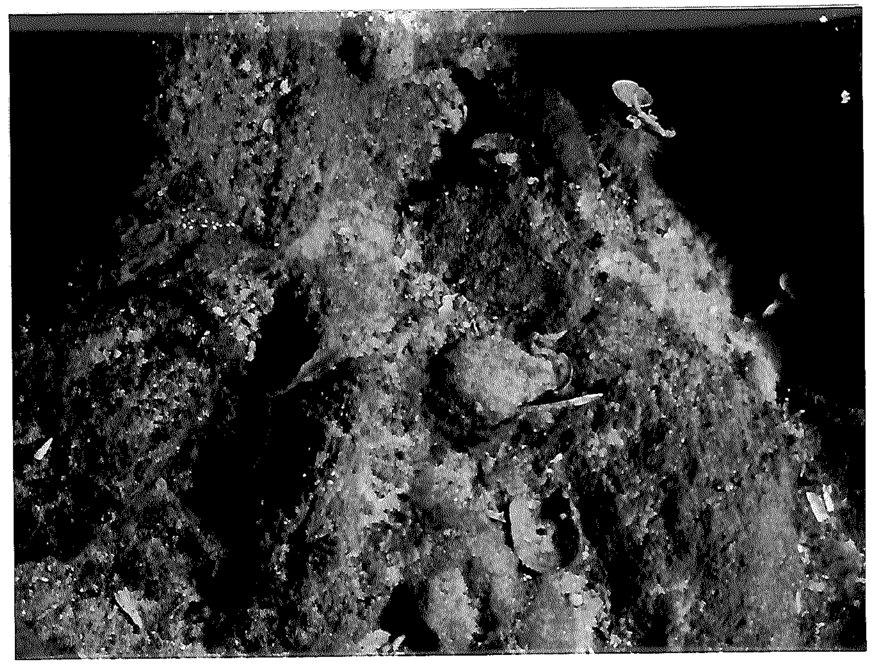
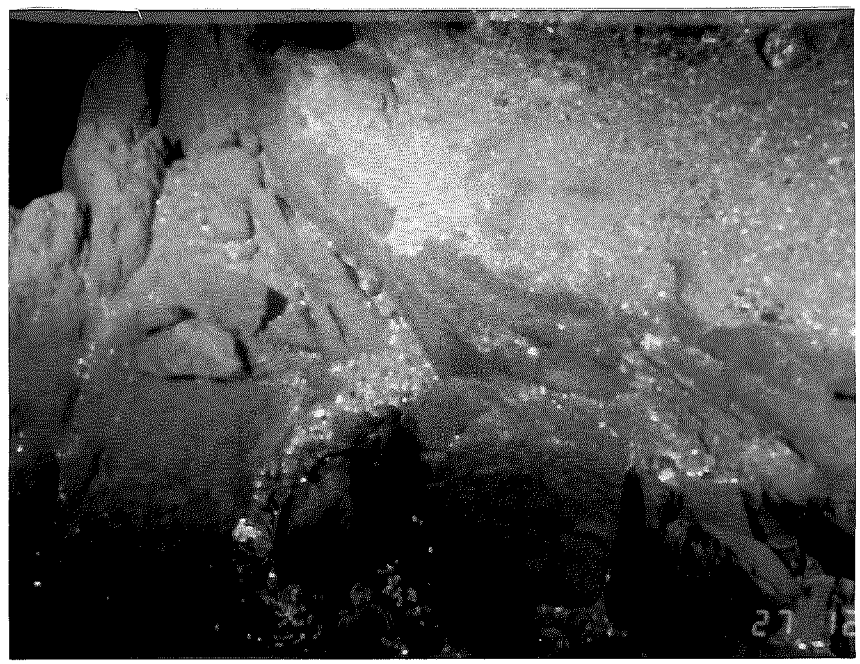


Photo 140



Shell deposits illustrated here range from shell debris accumulated in the troughs of ripples (Photos 143 and 144) to extensive deposits that obliterate any view of the underlying sediment (Photos 141 and 142). The origin of shell beds is not known with certainty; however, thick shell deposits can accumulate by catastrophic mortality in a community, followed by its subsequent exposure, as illustrated in Photo 141, showing a shell deposit of the burrowing bivalves Spisula sp. and Cyrtodaria siliqua. In such cases the shells remain reasonably intact, suggesting limited transport. In other cases, shells can be preferentially accumulated in the troughs of sand bedforms by water movements. In Photo 144, where this has occurred, the shells tend to be broken rather than intact. On Southeast Shoal, densities of living, surface dwelling bivalves (Mesodesma deauratum) have been measured that exceeded 3000 individuals and 22 kg/m^2.

Where the shell hash is in a thin layer (as in Photo 144) polychaete tubes demonstrate the presence of an infaunal community. In areas where the shell debris is thick, no such evidence can be seen, although field studies have suggested that infaunal communities may be extensive. (Hutcheson et al., 1981).

A small epifaunal community consisting of urchins and shrimp can be seen in Photograph 142. A large sea cucumber is visible on the surface of the shell hash in Photograph 143.

St. Pierre Bank

A series of nine photographs has been chosen to illustrate the varibility of surficial sediment distribution on St. Pierre Bank, a typical offshore bank and one of the major banks in the Grand Banks system (see Figure 9).

The dominant sediment type is Grand Banks Sand and Gravel, ranging from very fine sand on the northeastern corner to cobbles and boulders in the western part. Shell beds are located in the southern area of the bank. From a regional perspective, such as this photo mosaic, one can determine the general trends in sediment/biological distribution over a very broad area. Gravel dominates the seabed of the central and western areas of the bank, while sand occurs more predominantly along the northeastern edge.

The Hibernia Area of Northeast Grand Bank

These photographs were taken from the northeastern part of Grand Bank, in the area of the Hibernia hydrocarbon discovery. They serve to show the kind of variability in benthic community development and sediment texture that can occur over a relatively small area of a large offshore bank. One photograph (Photo 140) shows the nature of the underlying bedrock (sandstone, siltstone) and the very thin overlying Grand Banks Sand and Gravel formation from an experimental excavation at a well site.

Sediments range from fine sand to rounded cobbles with boulders, and are of the Grand Banks Sand and Gravel formation (Photos 147, 148, 150, 151 and 152) and adjacent Adolphus Sand (Photos 145, 146 and 149). The benthic communities observed are typical of these sediments.

Photo 140, which shows the bedrock overlain by the thin sand and gravel, illustrates that the sediment thickness in this area is less than 5 m, probably with an average of 1-2 m.

Photo 141 (45°19.7'N, 55°35.6'W, 37 m)
The shell beds on southeastern St. Pierre Bank are composed of broken and whole shells overlying fine gravel and sand of the Grand Banks Sand and Gravel formation. Larger shells appear to be the surf clam (Spisula sp.) and shells of Cyrtodaria siliqua, the propeller clam, are also present. The shells occur in the troughs of gravel and sand megaripples and are relatively intact. The origin of shell accumulations is not known, but intact shells could indicate that the environment is not dynamic; that a recent catastrophic event caused enormous mortality of the bivalve; or that fine gravel is less erosive than sand- sized material. Living clams are normally deeply buried. Only a lone anemone can be seen here. In other photographs from the same area, sea urchins, crabs and the tentacles of sea cucumbers are visible. A diverse infauna has been reported for some shell beds on Grand Bank (Hutcheson et al., 1981).

Photo 142 (45°48.73'N, 54°46.48'W, 69 m)
A shelly gravel facies of the Grand Bank Sand and Gravel formation from central Green Bank consists of bivalve shells over coarse sand and fine gravel with cobbles and pebbles. These communities did not necessarily live where they are presently found, but the intact nature of these shells suggests limited transport. Sea urchins and shrimp are visible. Hutcheson et al. (1981) suggest that shell hash communities are dominated largely by infauna, particularly polychaetes.

Photo 143 (45°19'N, 55°35'W, 48 m)
Taken on southeastern St. Pierre Bank in an area adjacent to Photo 141, this photograph shows a shell-filled trough of a gravel ripple in the gravel facies of the Grand Bank Sand and Gravel formation. The shells are mainly of Mesodesma sp., with some Spisula sp. and Cyrtodaria sp. Holes in some of the shells were drilled by predatory whelks. Epifauna consists of the suspension feeding sea cucumber (Cucumaria frondosa) and several anemones attached to shells. Shell hash has a diverse fauna of small organisms living in the particle interstices.

Photo 144 (46°34'N, 49°29'W, 69.5 m)
The seabed of northern Grand Bank, west of the Hibernia region, shows a mixture of sand and gravel with shells of the Grand Banks Sand and Gravel formation. Without samples from the area it would be difficult to estimate whether this is the gravel or sand facies of the formation. Tubes protrude through the sandy surface. The depressions around the tubes may have been created by the organism after sand crests built up around the tube tops.

Photo 141

Photo 143

Photo 142

Photo 144

Figure 9
Sediment Variability on St. Pierre Bank
(Approximately 44°58'N to 46°51'N, 55°20'W to 57°13'W

A collection of photographs from St. Pierre Bank, Grand Banks of Newfoundland, shows the relative distribution of sand, gravel and shells of the Grand Banks Sand and Gravel formation, and illustrates the regional distribution of sand along the eastern edge and gravel across the remainder of the bank. Details vary greatly, and local distributions are highly variable.

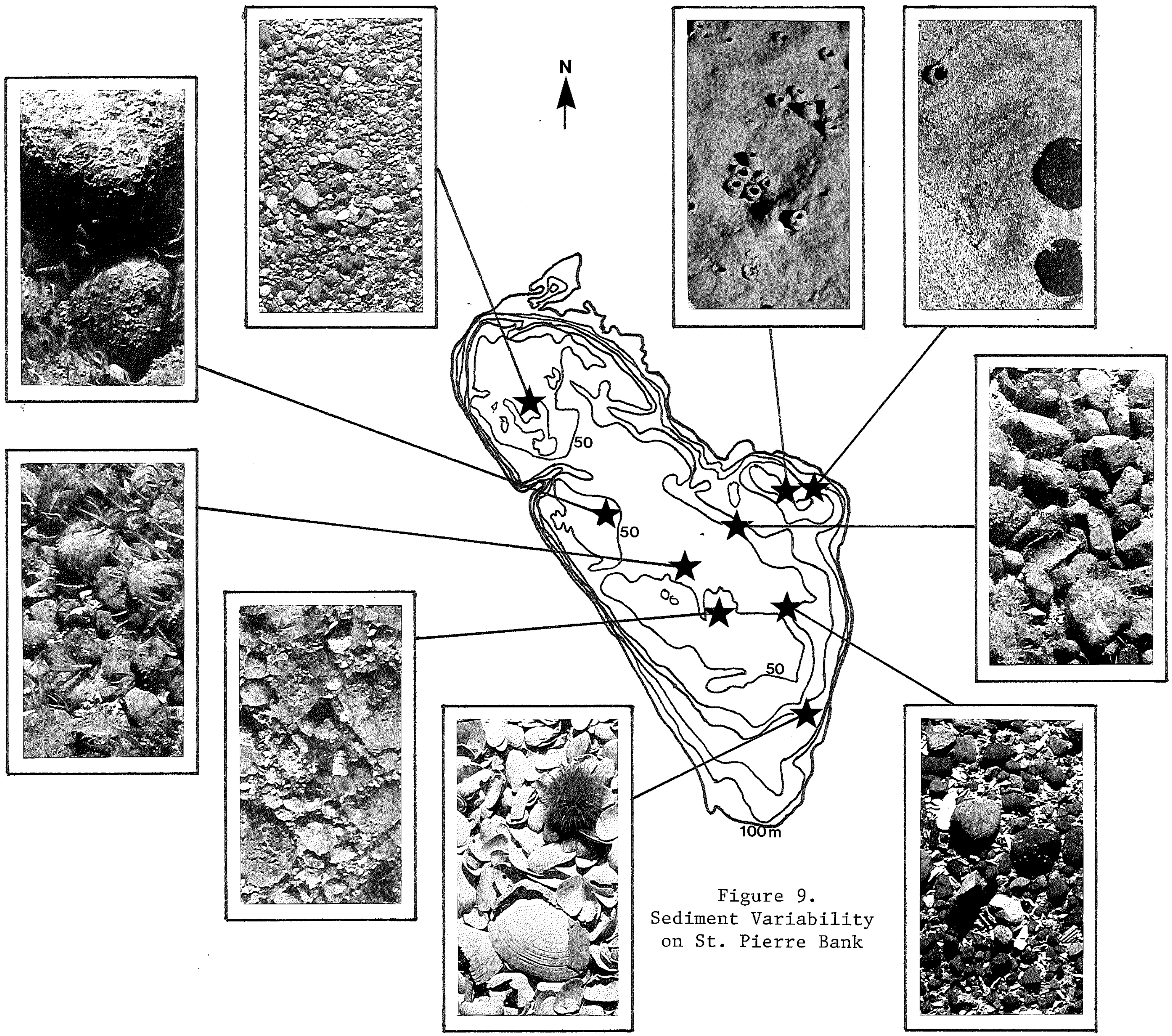


Figure 9.
Sediment Variability
on St. Pierre Bank

Photo 145 (approx. 47°16'N, 49°08'W, 95 m) This picture from north of the Hibernia area on Grand Bank shows a sediment of Grand Banks Sand and Gravel, gravel facies. The epilithic fauna attached to the rounded gravel appears to consist of tunicates, occasional soft corals and the coralline alga Lithothamnium sp., which successfully colonise the area. Species have to be resistant to abrasion by sand carried by currents. Gastropods are seen amongst the cobbles in this area.

Photo 146 (approx. 47°16'N, 49°08'W, 95 m) A skate lies on the fine-grained sand of the Grand Banks Sand and Gravel, sand facies, in this area of northern Grand Bank, north of the Hibernia area. The area is littered with bivalve shells, and Ophiura-type brittle stars are numerous. Little disturbance of the bottom, in the form of either ripples or animal tracks, is evident.

Photo 147 (approx. 46°35'N, 48°41'W, 80 m) In this gravelly sandy area of northern Grand Bank in the Hibernia region, the seabed is the gravel facies of the Grand Banks Sand and Gravel formation. Overlying the gravel lag are wave formed ripples with sharp crests, composed of medium to coarse sand. A large angular boulder, possibly ice rafted, occurs in the lower right of the photograph. Little or no growth can adhere to the rocky substrate, except in cases where the larger rocks are not likely to be moved by water movements, or are large enough to protrude above the seabed. Barnacles seem to be the only epifaunal coloniser. These areas, however, support a varied infauna.

Photo 148 (approx. 46°40'N, 49°25'W, 70 m) On northern Grand Bank, west of the Hibernia area, the seabed consists of the sand facies of the Grand Banks Sand and Gravel formation. Megaripples, with fresh, sharp crests occur. The troughs are of slightly coarser sediment with shell debris, and in them are found sand dollars (Echinarachnius parma). The burrows of unidentified invertebrates are more numerous in the troughs, although some tubes penetrate the sand ripples. A large gastropod, probably Colus sp., is also visible.

Photo 145

Photo 146

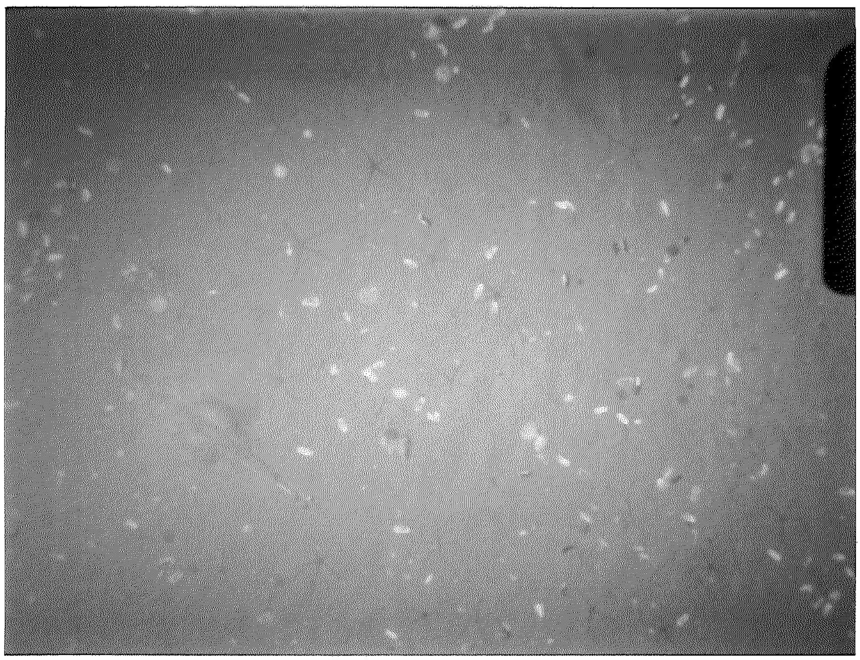


Photo 147

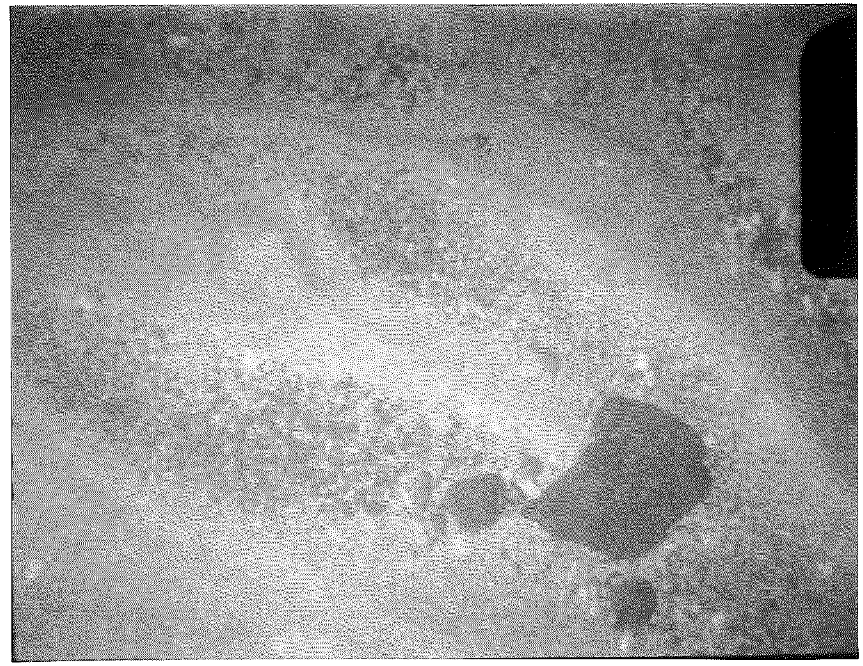


Photo 148

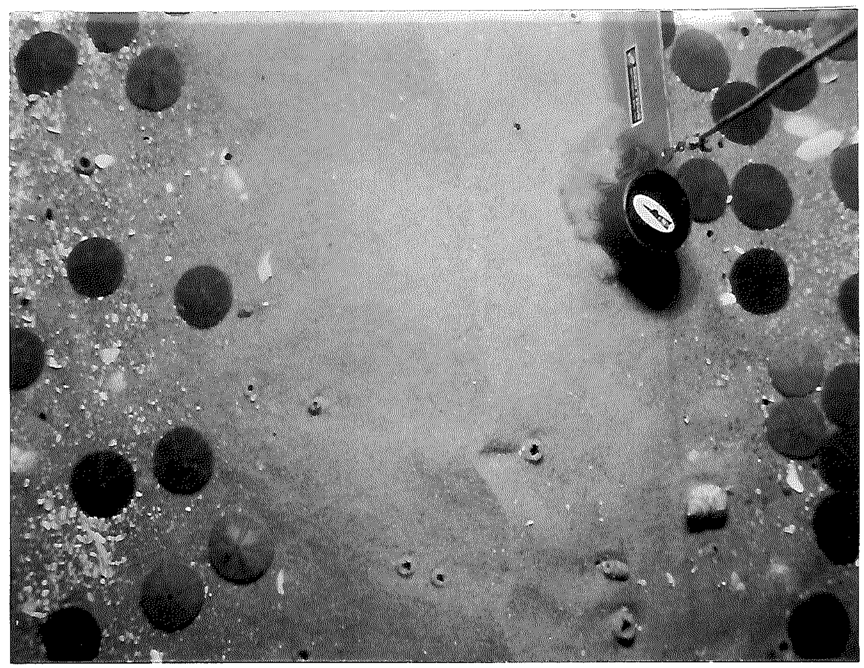


Photo 149 (46°34.04'N, 47°44.02'W, 137 m)
This photograph is from the northeastern part of Grand Bank, east of the Hibernia region, and shows sediment of the Adolphus Sand formation. A few scattered pebbles occur across the seabed, together with numerous shell fragments. The major feeding modes of the dominant benthic invertebrates collected in the Hibernia area are suspension and surface deposit feeding, and carnivorous (Hutcheson et al. 1981). The surface deposit feeding sand dollars and brittle stars are the main species seen in the picture. Tubes and tracks of the carnivorous polychaete Onuphis sp. can be seen over the surface, together with an occasional scavenging gastropod. Numerous holes made by burrowers suggest an abundant infauna. The observed community is highly characteristic of this environment.

Photo 150 (46°36.8'N, 48°31.5'W, 94 m)
In the Hibernia area of northern Grand Bank, the very fine sand of Grand Banks Sand and Gravel facies termed the boundary sand, has been shaped into ripples by waves. A considerable amount of bioturbation occurs, caused by subsurface burrowing, tube building and surface activity of the epifauna. The traces of these activities may remain in the sand for variable periods of time, but in general are obliterated by water movements and animal activity. Some of the sand deposits sampled appeared to contain a high percentage of silica, and when analysed were found to represent a possible deposit of material suitable for making glass.

Photo 151 (47°00'N, 48°59.9'W, 91 m)
Towards the northeast edge of Grand Bank, northwest of the Hibernia region, the seabed consists of Grand Banks Sand and Gravel, gravel facies. The gravel is a well-sorted mixture of subrounded to subangular clasts, some transported by glaciers and others by icebergs in postglacial times. The epibenthic community here is dominated by colonies of barnacles attached to the gravelly clasts and scattered scallop shells. Mobile epifauna in this area include sea urchins and gastropods, which feed primarily by rasping encrusting growth from the pebbles and cobbles, and sea stars and hermit crabs, which are scavengers and carnivores.

Photo 152 (47°00'N, 48°59.9'W, 91 m)
Northwest of the Hibernia region, northeastern Grand Bank, strong currents ripple the sand facies of the Grand Banks Sand and Gravel formation, creating bedforms with troughs of gravel and crests of sand. The gravel consists of pebbles and cobbles, and the sand is coarse. Some barnacles encrust a cobble in the central area of this photograph, but longer established colonies are not found in this frequently disturbed environment. Some sand grain tubes of carnivorous onuphid polychaetes are also visible. Although few animals are seen in this photograph, analysis of the benthos suggests a well developed infaunal community (Hutcheson et al., 1981).

Photo 149

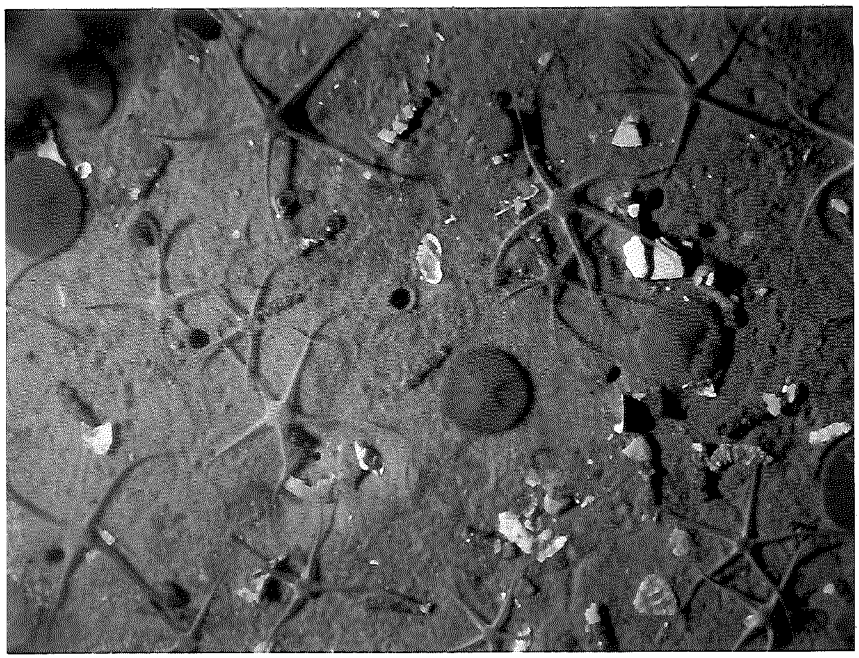


Photo 151

Photo 150

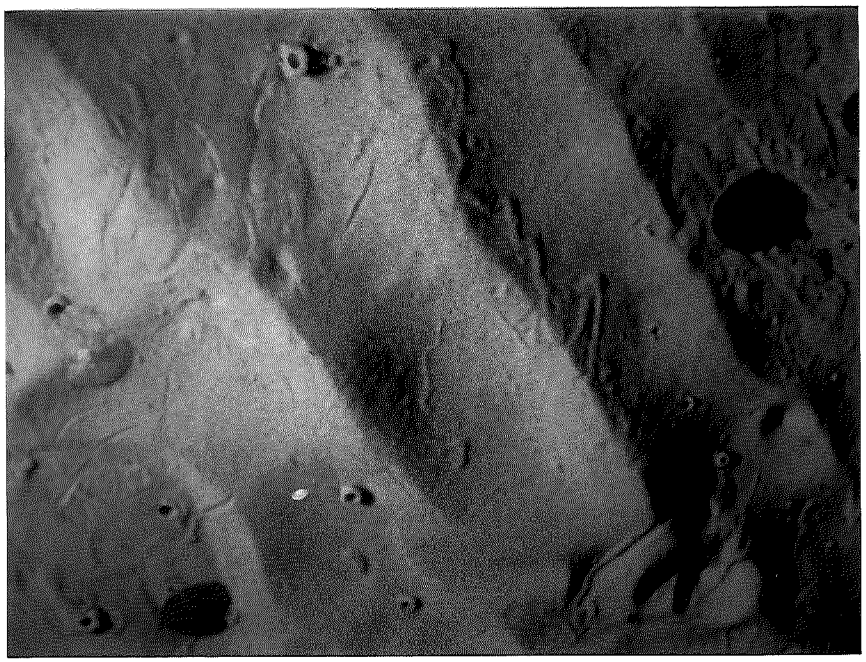


Photo 152

Deeps and Basins

Photographs have been selected to show the sediments found in the deeps and basins separating the offshore banks from the adjacent channels, and from small isolated depressions within the confines of large banks.

Three of the photos (Photo 154, Whale Deep, and Photos 153 and 156, Downing Basin) show a sediment of Placentia Clay. The sediment in Photo 155, from the edge of Downing Basin nearest the Avalon Channel, may represent either Grand Banks Drift or eroded Downing Silt. A community of attached filter feeders occurs on the larger pebbles seen in Photo 155.

The seabed of the basins appears to be generally flat and featureless when compared with the sand surface of the surrounding banks. Flatfish feeding tracks are evident in Photo 153, indicating that the infaunal community is probably well developed. This conclusion is supported by the abundance of scavenging and predaceous brittle stars in Photos 153, 154, 155 and 156. Other organisms observed on this sediment include hermit crabs and nemertean worms. The surface of the sediment retains numerous signs of bioturbation left by the activities of the infaunal community.

Flemish Cap

Photographs from both the top and flanks of Flemish Cap are shown. The distribution of sediments on Flemish Cap is less well understood than other areas of the Grand Banks. However, based on regional correlation, seismic reflection and sidescan sonar data and a few samples, which showed muddy sands with gravel, the sediment appears to be similar to that found in depths below 120 m on the Grand Banks, Adolphus Sand. Other features, termed "ring structures", which appear as large, 50-100 m in diameter, circular features across many areas of Flemish Cap, are interpreted as iceberg grounding features, perhaps similar to iceberg pits, widespread in the Hibernia area of Grand Bank. The icebergs would continually overturn, and sort as well as deposit coarse material of the pre-existing sediment.

In some locations the veneer of sediment is thin, and outcroppings of granodiorite (acoustic basement) are evident (Photo 5 in Chapter 5). In other instances, the sediment veneer appears to be thicker and contains a considerable amount of silt and clay sized particles (Photo 161). Elsewhere, sediments vary from Adolphus Sand (Photo 160), to coarse sand (Photo 159), to pebbles and cobbles (Photo 158) and finally to boulders and bedrock outcropping in Photo 157. In all these photographs there appears to be ample evidence for a significant silt/clay component. The glacial - postglacial history of Flemish Cap is not well understood at this time, but preliminary interpretation suggests that it may have supported its own ice cap but was not subaerially exposed during low sea level stands like the adjacent Grand Banks. The shallowest point on Flemish Cap is 126 m, and bedrock outcrops. This would result in the formation of seabed sediments similar to Adolphus Sand from the Grand Banks.

Numerous brittle stars inhabit the finer grained featureless sediments. Evidence of bioturbation of these soft sediments is present, and is especially noticeable in Photo 159, where large burrows and signs of sediment disturbance can be seen. Where the sediments include gravel and/or bedrock, brittle stars are replaced as the dominant organism by an attached community of brachiopods and other encrusting species, such as anenomes, and soft corals, which are

Photo 153 (45°11'N, 52°35'W, 113 m)
The substrate in Whale Deep is described as a dark brown to grey sandy-mud. It represents the Placentia Clay formation. The mud is thin in Whale Deep and sand sometimes occurs overlying the mud. Like other fine-grained substrates, it is occupied by an abundant infauna for which highly motile predators such as the brittle star <u>Ophiura</u> sp. constantly forage. Tracks and feeding pits in the upper right hand corner of the photograph were possibly made by flatfish (Risk and Craig 1976). The sediment surface has been disturbed as a result of animal activity.

Photo 154 (46°50.1'N, 50°44.8'W, 139 m)
This photograph shows Placentia Clay from the southern flank of Downing Basin, east of the Avalon Peninsula. Downing Basin has an unusually large amount of subsurface shallow gas. On several occasions, gas has been seen venting the seabed. Numerous brittle stars and one hermit crab in a heavily encrusted snail shell are visible, as is an elongate cone-shaped tube (lower left) of the deposit feeding polychaete <u>Pectinaria</u> sp. A small area of hard substrate provides a stable substrate for an erect bryozoan colony. Numerous tracks and pits made by both infauna and scavenging epifauna can be seen.

Photo 155 (47°09.5'N, 51°11.3'W, 106 m)
This photograph was taken at the western side of Downing Basin on Grand Bank. The sediment is either Grand Banks Drift or an eroded Downing Silt. Many clasts occur at the seabed. The mixed community includes motile surface feeders such as sea urchins and gastropods, attached suspension feeders such as <u>Ophiopholis</u> - type brittle stars, branching and encrusting bryozoans, anemones and hydroid polyps. A considerable amount of sediment reworking is apparent, and many holes, mounds and burrows are present. The deposit feeding gastropod <u>Aporrhais</u> sp. is visible in the lower right of the picture.

Photo 156 (47°00'N, 50°34'W, 234 m)
Amongst the numerous trails and tracks in the fine sediment of Placentia Clay from Downing Basin, east of the Avalon Peninsula, is a foraging hermit crab, which feeds on other invertebrates. A nemertean (a non-segmented, highly predaceous worm) can be seen making its way over the surface of the seabed. Two species of brittle stars, large and small members of the <u>Ophiura</u>-type, are abundant in this area, suggesting the presence of numerous infaunal animals on which they feed. There are relatively few areas of muddy seabed on the Grand Banks of Newfoundland as compared to the Scotian Shelf.

Photo 153

Photo 155

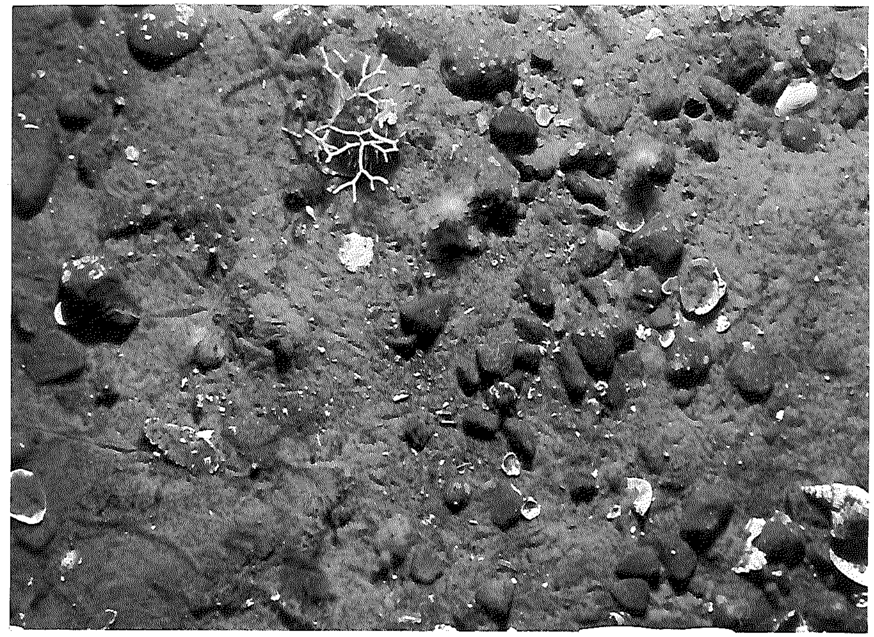


Photo 154

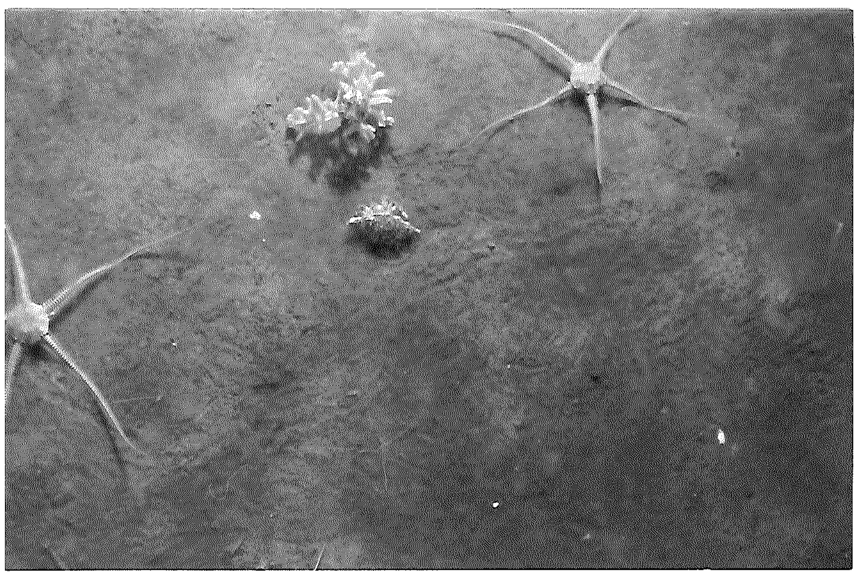


Photo 156

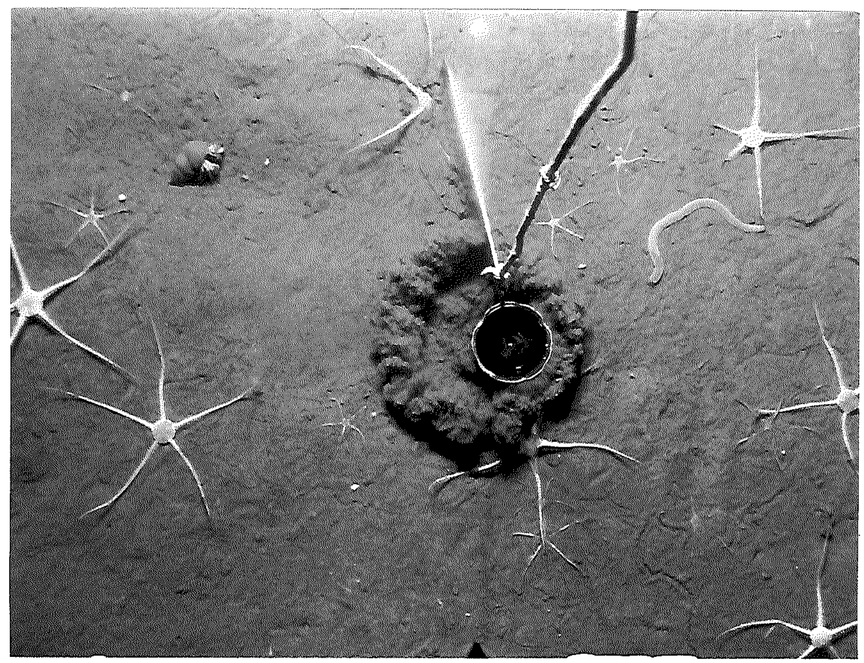


Photo 157 (46°49.9'N. 44°49.85'W, 142 m)
Near the centre of Flemish Cap, east of the Grand Banks of Newfoundland, bedrock outcrops with large boulders occur. These stable substrates have the heavy encrustations of undisturbed areas. Although there are numerous individuals of each species attached to the bedrock, the individual organisms are not large. The muddy-sand sediment adjacent to the outcropping is soft enough for burrowing anemones such as Cerianthus. Also included are colonial, branching bryozoans of several types, and encrusting sponges and tunicates.

Photo 158 (46°30.08'N, 45°30.41'W, 305 m)
In this area of southwest Flemish Cap there does not appear to be an accumulation of fine-grained sediments, as these fractions have been winnowed by currents, producing a gravelly lag. Very little biogenic growth is observed, suggesting that the currents are too strong to provide a suitable environment for most organisms (contrast with Photo 160 from northern Flemish Cap). There is some degree of colonisation by very small organisms, perhaps hydroids or tunicates. The anemones seen are probably deep water species. A snake-like nemertean worm, a highly motile carnivore, is also visible in the lower part of the photograph.

Photo 159 (46°48.7'N, 44°48.5'W, 136 m)
This photo from the southern part of Flemish Cap near the shallowest area, shows a cobble-pebble lag with sand bottom. Burrowing organisms have brought a patch of the subsurface sand matrix to the seabed. Numerous brittle stars can be seen on the cobbles and pebbles, in the interstices between them, and in the vicinity of the large burrow openings and pits in the sandy area. Gastropods, a small sea star and sponges are also present. The obvious disturbance of the sediment by the burrow maker appears to have triggered some response by the brittle stars, as ten small ophiuroids can be seen in the immediate vicinity of the burrows.

Photo 160 (47°21.1'N, 44°57.4'W, 180 m)
The substrate in this environment on the northern flank of Flemish Cap is fine-grained sand with occasional large boulders, probably of the Adolphus Sand formation. These boulders provide a solid surface for a well developed sessile community of sponges, branching and encrusting bryozoans, hydroids, sea pens and tunicates. Such a community indicates a constant supply of current-borne food. Numerous small, carnivorous brittle stars (Ophiura sp.), and burrowing deposit feeding anemones can be found on the muddy sand substrate. Vertical tubes of a sabellid polychaete protrude from the surface, together with arms of suspension feeding brittle stars. The presence of a rich and active infauna is evident from the trails and pellets over the surface.

Photo 157

Photo 159

Photo 158

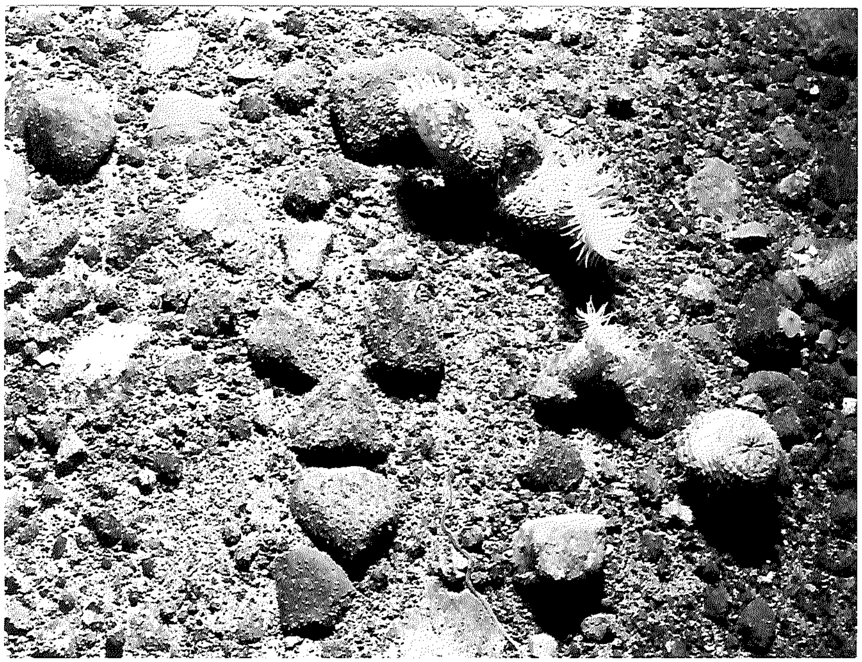


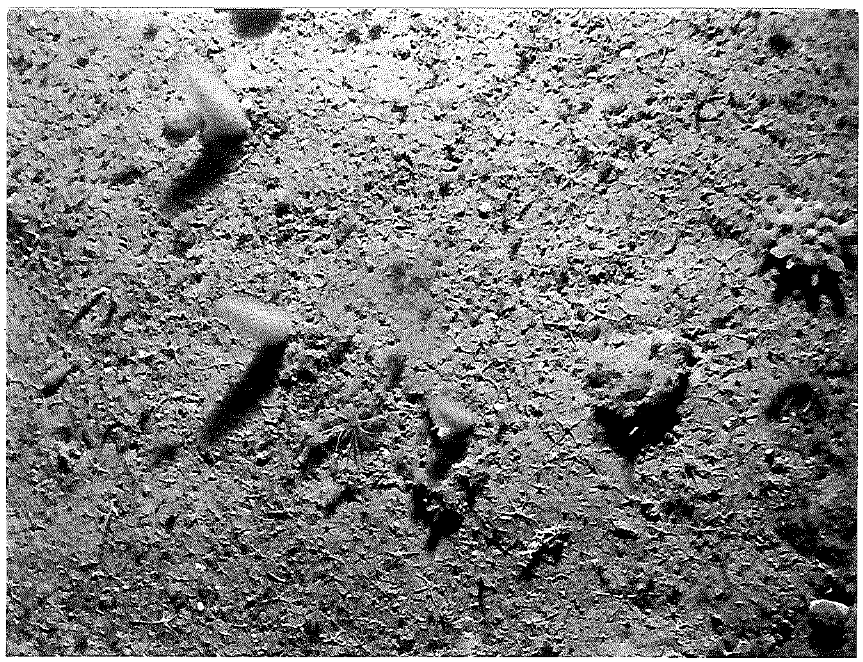
Photo 160

Photo 161 (46°44.84'N, 45°15.09'W, 218 m) At this depth on the western edge of Flemish Cap, the environment is similar to that encountered at similar depths on the flank of Grand Bank. The substrate in general is fine clayey or silty sand, probably of the Adolphus Sand formation. The dense distribution of small, deposit feeding, scavenging brittle stars makes them the most obvious and abundant epifauna. They feed on small organisms in the tubes and pits which give the bottom its textured appearance. The seabed surface is covered with faecal pellets and large and small mounds made by burrowing organisms. Vertical tubes are also visible, probably belonging to suspension feeding sabellid polychaetes. The sediment is probably heavily reworked by the infauna.

Photo 162 (47°23.58'N, 45°14.82'W, 233 m) This photo is similar to Photo 161 and suggests that a similar environment exists on the northwestern edge of Flemish Cap. However, the seabed hosts a slightly different fauna. Here, sponges, sea pens and burrowing anemones compete for space with the numerous small brittle stars and create a more diverse community. It should be noted that, as in Photo 161, close-up examination of the photograph shows that the entire seabed is covered with tiny brittle stars, probably of the Ophiura-type (approximately 2000 are to be seen in this picture). Numerous tubes, minute pits and faecal pellets attest to an abundant infaunal population of invertebrates, particularly polychaetes.

Photo 161

Photo 162



particularly evident in Photo 5. Careful examination of Photo 161 shows a high density of brittle stars. Some of the small black dots on the photo are shadows cast by the brittle stars when they are slightly elevated above the seabed, and others represent burrow openings.

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Index 1. Index of Biological Terms used to Describe Features Shown in Photographs.

Index 2. Index of Geological Features Shown in Photographs.

Index 3. Index of Geographical Locations Shown in Photographs.

Appendix 1. Relevant Information Pertaining To Scotian Shelf Photographs

Photo	Cruise	Station	Gravel%	Sand%	Silt%	Clay%	Mud%	Source
1								STRONG/BUZETA, FUNDY BEAR
2								STRONG/BUZETA, FUNDY BEAR
3								STRONG/BUZETA, FUNDY BEAR
4								STRONG/BUZETA, FUNDY BEAR
9	DAWSON 73.003	9						AGC
10	DAWSON 73.003	117						AGC
11	DAWSON 73.003	8						AGC
12	KAPUSKASING 69.016	315						AGC
13	PANDORA 85.057 PISCES IV	Dive 1604						AGC
14	DAWSON 82.005 CO	(CTD3)						AGC
15	KAPUSKASING 69.016	232						AGC
16	KASUSKASING 69.016	232						AGC
17	KAPUSKASING 69.016	216						AGC
18	HUDSON 71.014	14						AGC
19	DAWSON 82.005 CO	(CTD3)						AGC
20	DAWSON 82.005 CO	(CTD3)						AGC
21	KAPUSKASING 69.016	220	0.10	96.00	1.50	2.60		AGC
22	KAPUSKASING 69.016	220	0.10	96.00	1.50	2.60		AGC
23	KAPUSKASING 69.016	229	0.00	1.60	53.90	44.60	7.60	AGC
24	HUDSON 71.014	6						AGC
25	GEONAUTICS LTD. 1982	24						AGC
26	GEONAUTICS LTD. 1982	21						AGC
27	GEONAUTICS LTD. 1982	32						AGC
28	GEONAUTICS LTD. 1982	32						AGC
29	NEW KISKEARD 1967	?						DREA
30	KAPUSKASING 69.016	223	60.00	40.00	0.00	0.00	0.00	AGC
31	HUDSON 71.014	19						AGC
32	HUDSON 71.014	15	0.00	1.00	44.24	54.70		AGC
33	SS 3 i41	j20						DFO St. Andrews
34	DAWSON 77.001	?						C. Majka
35	HUDSON 79.011	Camera 6						AGC
36	HUDSON 79.011	Camera 7						AGC

Photo	Cruise	Station	Gravel%	Sand%	Silt%	Clay%	Mud%	Source
37	KAPUSKASING 69.016	267	0.00	58.40	16.90	24.80	3.75	AGC
38	KAPUSKASING 69.016	224	0.00	70.00	19.00	11.00		AGC
39	KAPUSKASING 69.016	221	0.10	87.50	5.50	7.00		AGC
40	KAPUSKASING 69.016	231						AGC
41	QUEST 78.Q68	4						AGC
42	DW Crs 7	i41 j16						DFO St. Andrews
43	DAWSON 77.001	43						C. Majka
44	QUEST 78.068	2						AGG
45	KAPUSKASING 69.016	222	12.30	86.00	0.30	1.20	0.00	AGC
46	HUDSON 83.019	5						AGC
47	KAPUSKASING 69.016	219	11.50	83.50	1.00	4.00		AGC
48	KAPUSKASING 69.016	219	11.50	83.50	1.00	4.00		AGC
49	HUDSON 76.016	9A						AGC
50	HUDSON 71.014	10						AGC
51	HUDSON 76.016	10C						AGC
52	HUDSON 71.014	4						AGC
53	DAWSON 84.005	BRUTIV Dive 2						AGC
54	HUDSON 83.019	3						AGC
55	HUDSON 83.019	?						AGC
56	QUEST 78.Q68	2						DREA
57	KAPUSKASING 69.016	310						AGC
58	KAPUSKASING 69.016	226						AGC
59	HUDSON 83.019	3						AGC
60	HUDSON 84.029	1						AGC
61	DAWSON 84.005	BRUTIV Dive 3						AGC
62	DAWSON 84.005	BRUTIV Dive 3						AGC
63	DAWSON 84.005	BRUTIV Dive 2						AGC
64	DAWSON 84.005	BRUTIV Dive 1						AGC
65	HUDSON 83.019	1						AGC
66	HUDSON 83.019	2						AGC
67	KAPUSKASING 69.016	227						AGC
68	NEW LISKEARD 1967							DREA
69	DAWSON 84.005	BRUTIV Dive 5						AGC
70	DAWSON 84.005	BRUTIV Dive 5						AGC

Photo	Cruise	Station	Gravel%	Sand%	Silt%	Clay%	Mud%	Source
71	DAWSON 84.005	BRUTIV Dive 5						AGC
72	DAWSON 84.005	BRUTIV Dive 5						AGC
73	MV TEM 1986	Hunky Dory 9-29						Texaco Canada Resources
74	MV TEM 1986	Hunky Dory 9-29						Texaco Canada Resources
75	MV TEM 1986	Hunky Dory 12-24						Texaco Canada Resources
76	MV TEM 1986	Hunky Dory 12-24						Texaco Canada Resources
77	GEONAUTICS LTD. 1982	9						AGC
78	GEONAUTICS LTD. 1982	9						AGC
79	MV TEM 1986	Hunky Dory 6-19						Texaco Canada Resources Ltd.
80	MV TEM 1986	Hunky Dory 8-40						Texaco Canada Resources Ltd.
81	PANDORA 81.050	PISCES IV Dive 1051						AGC
82	PANDORA 81.050	PISCES IV Dive 1053						AGC
83	PANDORA 81.050	PISCES IV Dive 1051						AGC
84	PANDORA 81.050	PISCES IV Dive 1053						AGC

Appendix 2. Relevant Information Pertaining To Grand Banks of Newfoundland Photographs.

Photo	Cruise	Station	Gravel%	Sand%	Silt%	Clay%	Mud%	Source
5	HUDSON 75.009	1A						AGC
6	HUDSON 83.033 BRUTIV Tow 4 File 102							AGC
7	PANDORA 81.054 PISCES IV Dive 1074							AGC
8	PANDORA 81.054 PISCES IV Dive 1074							AGC
85	HUDSON 85.005	20						AGC
86	HUDSON 85.005	20						AGC
87	HUDSON 85.005	20						AGC
88	HUDSON 85.005	20						AGC
89	RV MARINUS 1987	A-8						E. Dawe
90	HUDSON 78.012	453						AGC
91	HUDSON 78.012	232						AGC
92	HUDSON 78.012	621						AGC
93	HUDSON 85.005	21	27.50	66.50	6.00	0.00		AGC
94	HUDSON 77.011	33						AGC
95	HUDSON 77.011	28						AGC
96	HUDSON 77.011	28						AGC
97	HUDSON 86.017	10	0.00	96.15	0.00	3.85		AGC
98	HUDSON 86.017	5	0.00	97.94	0.00	2.06		AGC
99	HUDSON 77.011	7	7.23	44.73	36.75	11.30		AGC
100	HUDSON 77.011	5						AGC
101	HUDSON 73.006	171	0.00	8.70	58.80	32.40		AGC
102	HUDSON 73.006	200						AGC
103	HUDSON 85.005	23						AGC
104	HUDSON 85.005	23						AGC
105	PANDORA II 81.054 PISCES IV Dive 1071							AGC
106	HUDSON 78.012	543						AGC
107	PANDORA II 81.054 PISCES IV Dive 1073							AGC
108	HUDSON 78.012	522						AGC
109	HUDSON 78.012	523						AGC
110	HUDSON 73.006	234	16.70	82.60	0.35	0.35		AGC
111	HUDSON 73.006	242	11.80	87.20	0.50	0.50		AGC
112	HUDSON 86.017	19						AGC

Photo	Cruise	Station	Gravel%	Sand%	Silt%	Clay%	Mud%	Source
113	HUDSON 85.005	1	0.80	98.10	1.10	0.00		AGC
114	HUDSON 87.014	11						AGC
115	HUDSON 85.005	3	79.20	19.90	0.90	0.00		AGC
116	HUDSON 85.005	5						AGC
117	HUDSON 85.005	15	1.00	95.90	3.10	0.00		AGC
118	HUDSON 87.014	27						AGC
119	HUDSON 87.014	29						AGC
120	HUDSON 85.005	11	0.00	87.30	9.00	3.70		AGC
121	HUDSON 83.033 BRUTIV Tow 7 File 154							AGC
122	PANDORA II 85.057 PISCES IV Dive 1							AGC
123	HUDSON 83.033 BRUTIV Tow 8 File 174							AGC
124	PANDORA II 85.057 PISCES IV Dive 3							AGC
125	HUDSON 87.014	29						AGC
125	HUDSON 87.014	29						AGC
127	PANDOARA II 85.057 PISCES IV Dive 1							AGC
128	PANDORA II 85.057 PISCES IV Dive 4							AGC
129	HUDSON 77.011	23						AGC
130	HUDSON 86.017	14						AGC
131	HUDSON 87.014	25						AGC
132	HUDSON 86.017	13						AGC
133	HUDSON 73.006	238	66.80	32.70	0.25	0.25		AGC
134	HUDSON 73.006	21	74.70	21.10	1.70	2.60		AGC
135	HUDSON 73.006	226						AGC
136	HUDSON 86.017	19						AGC
137	HUDSON 77.011	24						AGC
138	HUDSON 77.011	24						AGC
139	HUDSON 77.011	24						AGC
140	NO INFORMATION AVAILABLE							AGC
141	HUDSON 73.006	221	38.50	61.30	0.10	0.10		AGC
142	HUDSON 86.017	15						AGC
143	HUDSON 73.006	221	8.90	49.90	41.20	7.35		AGC
144	HUDSON 85.005	2						AGC
145	HUDSON 83.033 BRUTIV Tow 2 File 20							AGC
146	HUDSON 83.033 BRUTIV Tow 2 File 2							AGC
147	HUDSON 83.033 BRUTIV Tow 7 File 150							AGC

Photo	Cruise	Station	Gravel%	Sand%	Silt%	Clay%	Mud%	Source
148	HUDSON 85.005	1	0.80	98.10	1.10	0.00		AGC
149	HUDSON 80.010	16	1.70	98.04	0.11	0.15		AGC
150	HUDSON 80.010	3	0.06	99.94	0.00	0.00		AGC
151	WILFRED TEMPLEMAN 27 1985	6						M. Hutcheson
152	WILFRED TEMPLEMAN 27 1985	6						M. Hutcheson
153	HUDSON 86.017	1						AGC
154	HUDSON 75.009	21	0.00	86.50	9.92	3.58		AGC
155	HUDSON 75.009	27						AGC
156	HUDSON 85.005	18	0.00	32.10	41.70	15.10		AGC
157	HUDSON 75.009	1						AGC
158	HUDSON 75.009	5						AGC
159	HUDSON 77.011	21						AGC
160	HUDSON 77.011	17						AGC
161	HUDSON 75.009	3						AGC
162	HUDSON 75.009	17						AGC