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Bulletin of the Fisheries Research Board of Canada

Morphology and Sediments of the Gulf of St. Lawrence

D. H. Loring - D. J. G. Nota

BULLETIN 182
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Environment Canada
Fisheries and Marine Service

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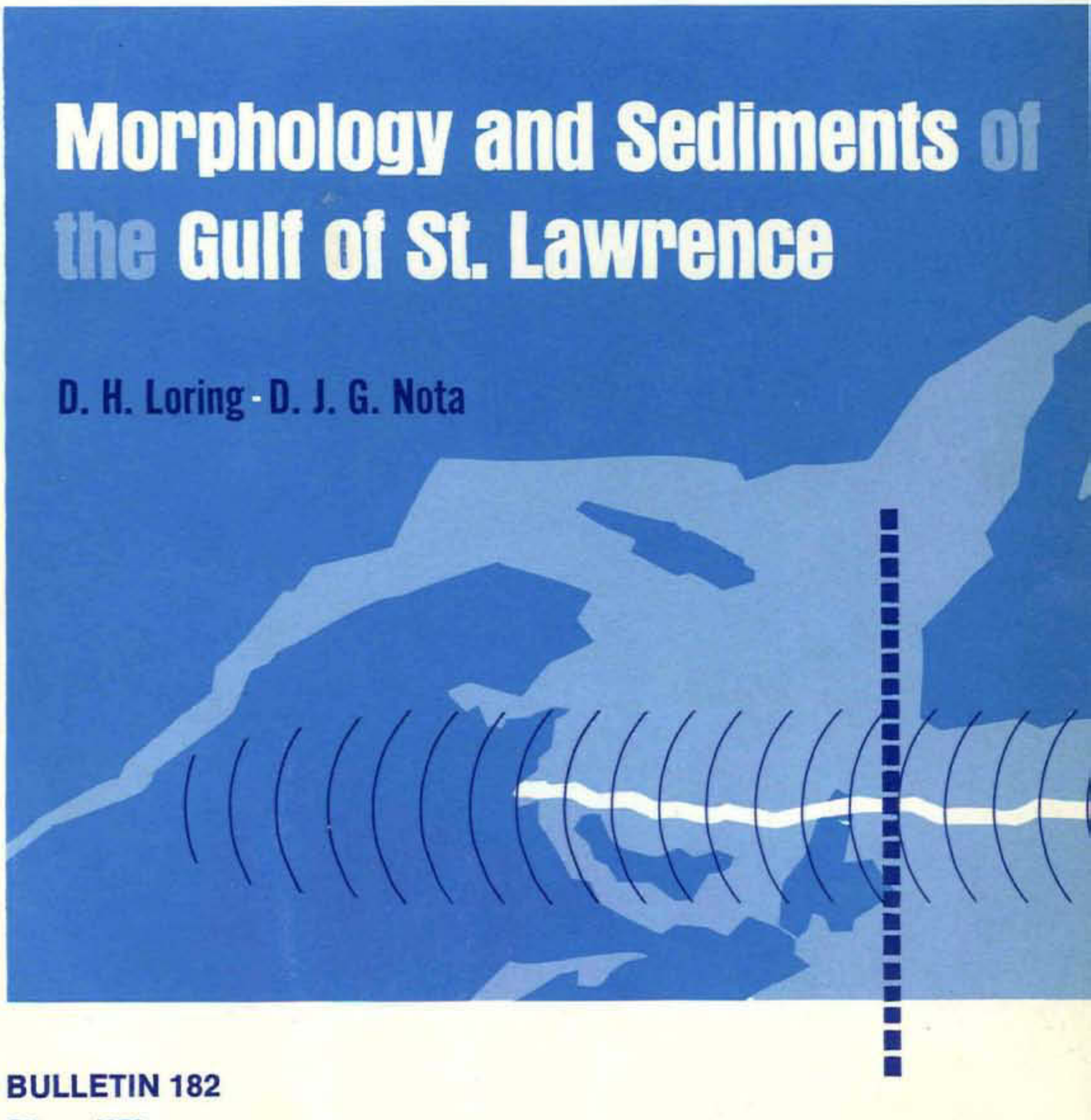

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MORPHOLOGY AND SEDIMENTS OF THE GULF OF ST. LAWRENCE

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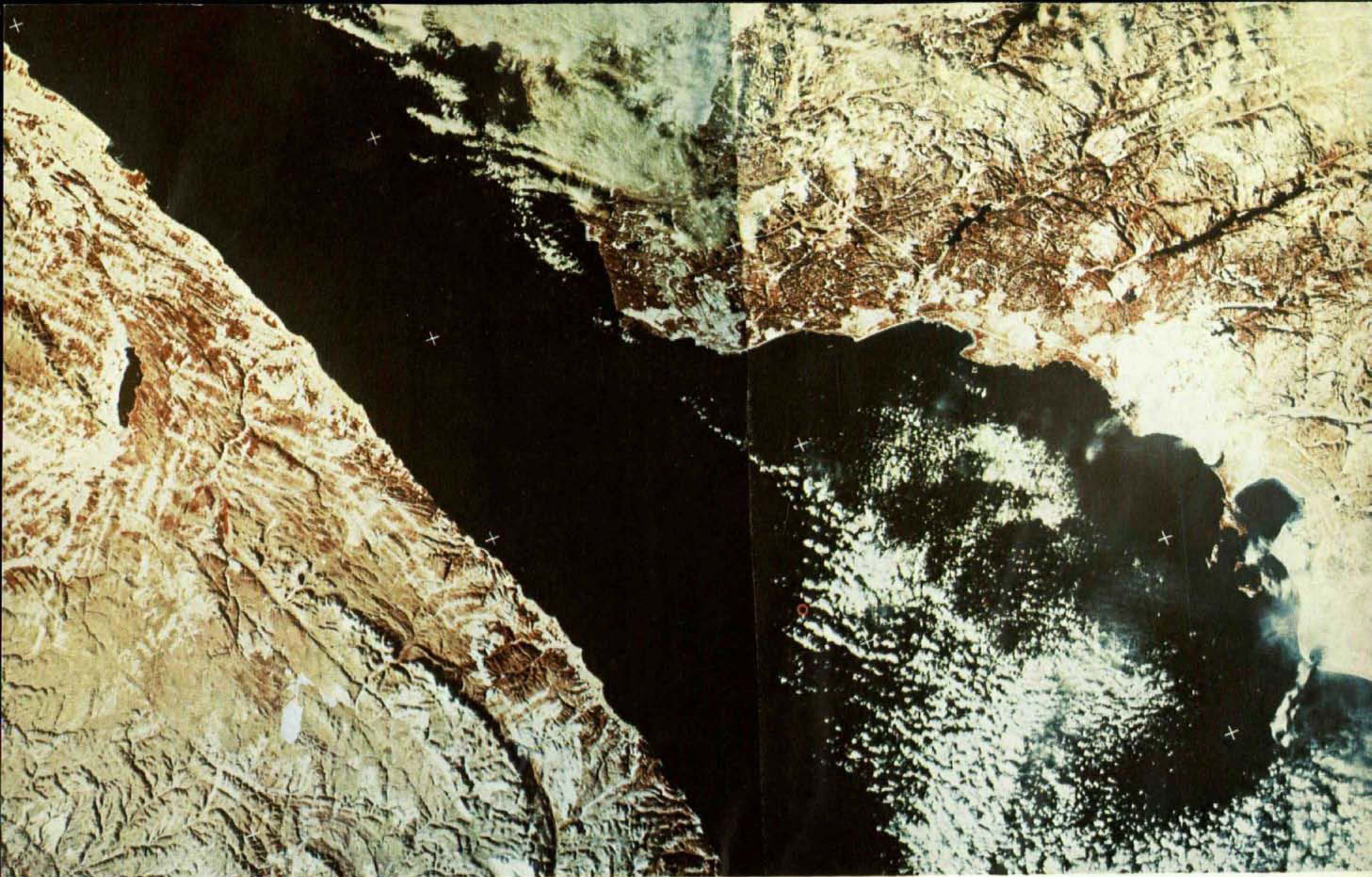

Earth Resources Technology Satellite (ERTS) view of the St. Lawrence Estuary and Gulf (Nov. 30, 1972). The scale is ~1:1,000,000.

BULLETIN 182

Morphology and Sediments of the Gulf of St. Lawrence

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Abstract

This report describes and assesses the submarine morphology and the characteristics of the sediments (lithology, grain size, mineralogy, and chemistry) of the Gulf of St. Lawrence and the marine estuary of the St. Lawrence River.

The Gulf of St. Lawrence is an inland sea of triangular shape which occupies an area of approximately 96,000 square miles. It has an irregular submarine topography composed of long trough-shaped valleys and shelves of varying widths and relief. Acoustical and sampling data indicate that the submarine topography is controlled by the lithology and structure of the underlying bedrock and an uneven cover of unconsolidated sediments. Fine-grained sediments referred to as pelites occupy the floors of the major troughs and shelf valleys and sediments of coarser grain sizes (sands and gravels) form the cover on the trough slopes and the adjacent shelves. Continuous seismic profiles and sediment cores from various parts of the Gulf reveal that glacial drift occurs beneath the surface sediments in many parts of the Gulf. Along the southern edge of the Laurentian Trough adjacent to the Magdalen Shelf these glacial sediments form a thick wedge composed of a series of coalescing fans. Mineralogical and chemical data indicate that the sediments have been derived from underlying sedimentary rocks (calcareous and noncalcareous) as well as from crystalline rocks of the Canadian Shield to the north and west and that Wisconsin glaciations have been the most important single factor in controlling the dispersal pattern of terrigenous material in the Gulf.

The geological, morphological, and sedimentological data indicate that the main stages in the development of the present morphology and sediments in the Gulf are (1) the formation of a preglacial landscape, (2) modification of the landscape by repeated glaciations during the Pleistocene Epoch, (3) late-glacial (late-Wisconsin) ice readvances and retreats, and (4) modification of the relict glacial morphology and sediments by postglacial changes in sea level and by present depositional conditions. At the present, specific sedimentary environments of deposition, active redistribution and nondeposition of terrigenous material occur in the Gulf.

Synopsis

CHAPTER 1 — INTRODUCTION

The Gulf of St. Lawrence is a Canadian marginal sea which occupies an area of approximately 96,000 square miles. This report describes and assesses the submarine morphology and the characteristics of the sediments (lithology, grain size, mineralogy, and chemistry) in the Gulf of St. Lawrence and the marine estuary of the St. Lawrence River, and is accompanied by detailed bathymetric and surface sediment maps (Charts 1 and 2, in pocket). The study was undertaken to provide a broad appraisal of the sedimentary environment of the Gulf and its late-glacial and postglacial history. It is a synthesis of geological and geochemical data collected and interpreted over the past 10 years from bottom grab samples, core samples, echograms, continuous seismic profiles, side-scan sonargrams, and underwater photographs.

CHAPTER 2 — PHYSIOGRAPHIC AND GEOLOGIC SETTING

The Gulf of St. Lawrence and Estuary of the St. Lawrence River is bordered to the north by the highland edge of the Canadian Shield (Laurentian region) consisting almost entirely of mixed crystalline rocks of Precambrian age with only minor amounts of sedimentary rocks. In the west, the St. Lawrence Lowlands, which are underlain by unfolded sedimentary rocks, border the estuary, and extend seaward with remnants reappearing as islands and narrow coastal lowlands along the northern and eastern margins of the Gulf. The south side of the lower St. Lawrence Estuary and the southern and eastern margins of the Gulf are enclosed by the highlands, uplands, and lowlands of the Appalachian region of Canada and are developed on mixtures of crystalline rocks and folded and unfolded sedimentary rocks. All of these regions have a complex geological, tectonic, and erosional history which extends over the greater part of geological time. The main elements of the landscape as we now recognize them appear to have evolved by sequential terrestrial erosional processes in Mesozoic and Cenozoic times, the most important features of which are (1) the formation of planation surfaces on the highland areas (Mesozoic); (2) dissection of the planation surface in Cenozoic times; (3) the evolution of cuesta-like landscapes on lowland areas, now partly submerged beneath the Gulf, and (4) the establishment of a major valley system, extending from the Great Lakes to Cabot Strait, on less resistant rocks situated between the crystalline rocks of the Canadian Shield and the folded sedimentary rocks of the Appalachian region. During the Pleistocene Epoch, continental ice sheets from the north and local highland glaciers modified the details of the preglacial topography of the land areas adjacent to the Gulf and left a thin layer of glacial sediments on the uplands and thick deposits in the lowlands. As the ice receded, the sea invaded the adjacent coastlines of the Gulf and created temporary inland seas in the upper parts of the St. Lawrence River (the Champlain Sea) and Saguenay River (Laflamme Sea) into which late-glacial sediments accumulated. As the coast adjacent to the Gulf recovered from the weight of the ice, the land rose, the seas withdrew, and the present climatic, drainage, and oceanographic conditions became established.

CHAPTER 3 — CLIMATE AND OCEANOGRAPHY

A number of important physical and chemical factors contribute to the present sedimentary environment in the Gulf of St. Lawrence. The climate which ultimately controls the nature of the geomorphic and weathering processes varies from subarctic in the northern part of the Gulf to a warmer, humid, continental type in the southern and western parts. Dissolved and suspended inorganic and organic matter in fresh waters is supplied (~475,000 ft^3/sec) to the Gulf from numerous rivers draining into it and from precipitation in the form of rain and snow. Two thirds (367,000 ft^3/sec) of this is supplied by the St. Lawrence River which extends inland for almost 2000 miles and has a drainage area of almost a half a million square miles. This river contributes ordinary calcium bicarbonate water and other dissolved substances (total dissolved load about 160 ppm) to the Gulf but very little solid material for its drainage area. The other rivers contribute varying amounts of dissolved substances to the Gulf with the lowest amounts of dissolved material being derived from rivers draining the chemically resistant crystalline rock areas such as the Canadian Shield and the most being contributed by rivers draining the areas of less resistant sedimentary rock and industrial areas. The Gulf is a marine body of water with salinity ranging up to 35‰ and contains small amounts of suspended matter. The oceanographic conditions are characterized by at least three water masses of differing temperatures and salinities and a complex estuarine type of current and circulation patterns (tidal and nontidal). In addition the Gulf has a winter ice cover.

CHAPTER 4 — SUBMARINE GEOMORPHOLOGY

Long, deep, trough-shaped submarine valleys with water depths between 200 and 600 m form the most conspicuous features of the submarine topography (Chart 1, in pocket) in the Gulf. The largest of these is the *Laurentian Channel* or *Trough*, 200–540 m in depth, which is about 668 naut. miles (1240 km) long and from 20 (37 km) to 50 naut. miles (92.5 km) wide. It extends from a position off the mouth of the Saguenay fjord in the St. Lawrence Estuary through the Gulf and across the continental shelf to the shelf edge. Southeast of Anticosti Island this main trough is joined discordantly by two others: The Anticosti Trough or Channel, 200–300 m deep, which enters from the northwest; and the Esquiman Trough or Channel, 200–300 m deep, which enters from the northeast. The main features of the surface morphology of these troughs are their relatively straight, steep sides and their broad, undulating floors which contain a number of large, elongated depressions as much as 100 m deep. In detail the sides usually have a hummocky microrelief and the floors are usually smooth except for the occasional floor ridges. In addition there are several submarine fans or spurs along the valley sides. Submarine platforms or shelves with water depths less than 200 m border the troughs and are of varying widths and relief. In the St. Lawrence Estuary, narrow shelves referred to as the Les Escoumins and Gaspé slope gently outwards to a break in slope at about 100 m. In the Gulf, the shelves have been divided into (1) the North Shore which extends from Sept Îles to Cape Whittle; (2) the Quebec–Labrador Shelf which extends from Cape Whittle to the Strait of Belle Isle; (3) Anticosti Shelf adjacent to the Island; (4) the Newfoundland Shelf, which lies along the west coast of Newfoundland; and (5) the Magdalen Shelf which occupies the southern embayment of the Gulf. The first two shelves are narrow and are characterized by a narrow, rough inner coastal shelf area separated, in part, from wider outer shelves or banks by elongated shelf valleys. The Anticosti Shelf is a submarine continuation of Anticosti Island and the Newfoundland Shelf is a gently seaward-sloping plain which widens southward along the west coast of Newfoundland. The Magdalen Shelf is the largest shelf with an area of about 30,000 square miles. It has a rather distinct topography composed of long but fairly shallow (water depths 10–200 m) shelf valleys along its western and eastern margins as well as smaller ones in the central shelf area, and elevated areas or banks and smaller platforms in the central shelf.

Acoustical and sampling data indicate that the submarine topography is controlled by the lithology and structure of the underlying bedrock and an uneven cover of unconsolidated sediments. The main valley system was established as part of a preglacial drainage system by sequential fluvial erosion along lines of weakness in the underlying bedrock of differing structures (folded, unfolded, faulted), origins (sedimentary, metamorphic, and locally igneous), and ages (Precambrian–Permian) in Mesozoic and Cenozoic times. This left the more resistant rocks and structures to form the adjacent upland or shelves in the northern and southern parts of the Gulf on which cuesta landscapes developed. During the Pleistocene Epoch, the fluvial valleys were modified into glacial troughs by ice masses which repeatedly filled them. The troughs were formed by glacial erosion which widened and straightened the valley walls and deepened their floors as well as by the deposition of an uneven cover of glacial sediments over the bedrock surface. Additional morphological features such as thick fan deposits of glaciomarine sediments were preserved along the valley sides in late-glacial times beneath a layer of till. Although the shelves were glaciated, the ice failed to modify more than the details of the preglacial drainage valleys. It left a nearly continuous but relatively thin till cover over the bedrock surfaces. Postglacial changes in sea level have resulted in the formation of submarine terraces and the modification of the relict glacial landscape through the reworking of glacial deposits and the deposition of recently supplied material in the trough and shelf valleys.

CHAPTER 5 — SURFACE AND SUBSURFACE SEDIMENTS

The Gulf sediments are classified and mapped according to their dominant (>30% by weight) and minor (5–30%) grain-size components (gravel, sand, and pelite), calcium carbonate content, sorting, and origin. Additional characteristics such as color, subdivision of sand and pelite-size grades, and acoustical reflecting characteristics have also been used to differentiate sediment units. Four main lithological units each with various subdivisions are recognized in the Gulf: viz., pelites, sands (coarse–medium- and fine-grained), gravels, and glacial drift. The surface distribution of these units (see Chart 2, in pocket) is, in general, controlled by the submarine topography. Fine-grained, dark greenish-grey pelites (particles <.05 mm) and calcipelites which contain >5% $CaCO_3$ occupy the deep central parts of the troughs as well as some shelf valleys. These sediments are the last sediment addition and form a smooth cover on the trough floors up to 40 m thick. In the upper St. Lawrence Estuary, a relict pelite has also been identified. The pelites grade laterally into pelites containing 5–30% sand-size material (sandy pelites). Sandy pelites and their calcareous equivalents occupy the sides and lower slopes of the troughs as well as the headward parts of the main troughs and floors of some shelf valleys. With increasing sand contents, the sandy pelites grade upwards into very sandy (>30%) pelites on the upper slopes of the major troughs. Locally, glacial drift, which usually occurs as subsurface deposits, outcrops or is near the surface along the upper slopes of the troughs. The shelf sediments are characterized by an abundance of material from the coarse size grades and form an intermittent cover over the bedrock. In the northern part of the Gulf, the shelf sediments consist mainly of poorly-sorted coarse-to-medium grained calcareous (calcarenites) and non-calcareous sands containing varying amounts of gravel and pelite, and various types of gravel deposits. These include deposits of limestone and dolomite gravels (calcirudites) around Anticosti Island and on the outer Quebec-Labrador Shelf as well as shell gravels in the Strait of Belle Isle. In contrast, the sediments in the southern Gulf (Magdalen Shelf) are usually better sorted and distributed than those found on other shelves. They consist of gravels, and well-to-poorly sorted coarse-to-fine grained sands containing varying amounts of gravel and pelite. In general, the grain size of the sediments decreases with increasing water depths away from the shorelines and bank tops, with the finest sediment sizes accumulating in the shelf valleys and depressions, to form deposits of sandy and very sandy pelites quite different to those found in the major troughs.

Sediment cores reveal the general vertical and lateral changes in the lithology of the subsurface sediments. They show in many places a twofold and sometimes threefold zonation. The top layer is usually a pelite or sandy pelite or their calcareous equivalent which represents the last (postglacial) sediment addition. Beneath this layer is usually a glacial till composed of a poorly-sorted admixture of gravel, sand, pelite, and carbonate detritus and debris. In the western and northern Gulf, the till layer is usually grey whereas in the southern part of the Gulf, the till is reddish-brown in color. These tills vary widely in their lithological and petrographic characteristics depending on the parent rocks from which they were derived. The tills are underlain in places by glaciomarine sediments. Glaciomarine sediments make up the bulk of the submarine fan deposits along the southern edge of the Laurentian Trough and have been found in single places in the floor of the Laurentian and Esquiman troughs. Seismic data indicate that glaciomarine sediments in the fan deposits are also underlain by unconsolidated sediments having the reflecting characteristics of till, but these have not yet been sampled. Shells and fragments of various shells have been recovered from the glaciomarine sediments at the bottom of the till layer and from the top of the till deposits. Radiocarbon dating of this material has been used to distinguish the depositional periods for these sediments.

Chapter 6 — Grain-Size Frequency Distributions

Grain-size data from 500 samples have been classified using Q_1MdQ_3 diagrams and cumulative grain-size frequency distribution curves. It was found that the sediments could be divided into a limited number of principal grain-size types and that these types were characteristic of the environments of deposition. The areal distribution of the grain-size types revealed a definite relationship with the morphology of the sea floor. The sediments of the northern Gulf have been grouped into three main types of size-frequency distribution (See Fig. 46–50). Two types of pelite distribution (Types 1 and 2) and one type of sand distribution (Type 3) were established. The sediments from the Laurentian Trough system (Type 1) are bimodal, viz., mixtures of well sorted pelite and poorly sorted sand; these sediments clearly demonstrate the importance of recent ice-rafting in the environment. The size distributions of Type 2 are also pelite distributions, but are relict, most likely from the Champlain Sea episode. They are mainly characterized by a very high clay content and occur between Quebec City and the mouth of the Saguenay River. The sediments from the shelf areas and slopes adjacent to the troughs have been classified as Type 3; they are composite sediments that cover a wide range of size grades. The sand part of these deposits points to local reworking under marine conditions of an originally unsorted deposit (moraines and tills).

The majority of the sediments from the southern Gulf (see Fig. 51–55) are of coarser grain-sizes when compared to those of the northern Gulf; they have been grouped into three types (Types 4, 5, 6). Type 6 refers to the bank areas, Type 5 is from the transitional areas between the banks and protected shelf valleys, and Type 4 is from the shelf valleys. In fact, these sediments together form one continuous series. The bank sands (well-sorted medium-grained sands with a little coarse material) gradually become finer (indices 222, 333, 334, etc.) and finally merge into the fine sandy pelites from the shelf valleys (indices 570, 670). In general, the southern Gulf area represents an environment of active reworking and redistribution, with the finer sizes being winnowed from the bank tops and redeposited on the adjacent lower slopes and in protected shelf valleys.

Chapter 7 — Dispersal and Sources of Terrigenous Detritus

Mineralogical and chemical studies of the sand-size material reveal the pattern of Pleistocene glaciation in the area. The sediments of the Laurentian Trough system have been derived essentially from the complex crystalline igneous terrain of the Canadian Shield and are referred to as the Laurentian suite. They are characterized by the abundance of amphiboles and pyroxenes in the heavy fraction and about 60% of feldspars in the light fraction (Fig. 59 and 61). Essentially the sediments from the southern Gulf (Magdalen Shelf) are composed of erosional products, derived from the regolith of the underlying Palaeozoic bedrock, with material from the Laurentian suite superimposed. Detrital material from the Shield is dispersed south and east to the shorelines of New Brunswick, Prince Edward Island, and Cape Breton. Isoconcentration lines for minerals characteristic of the Laurentian suite (such as amphiboles) and of elements (such as iron) which mainly reside in these ferromagnesium minerals give evidence that the Laurentide ice carried with it detrital material from the Canadian Shield when it invaded the southern Gulf area with lobes through the preglacial drainage system and spilled thinly over the remainder of the shelf (Fig. 65 and 68). During and after the postglacial transgression some reworking and redistribution occurred while under present conditions some material from the adjacent shorelines is still being added by ice-rafting. The most important single factor affecting the mineral dispersal pattern, however, has been the extensive Wisconsin glaciation with Laurentide Ice.

A few X-ray analyses reveal that the clay-size material is composed of rock flour (amphiboles, pyroxenes, and feldspar) with only minor amounts of clay minerals. Chemical analysis of 18 selected samples from the Gulf also reveals that most of the material $<2\mu$ is chemically immature and is supplied from the St. Lawrence drainage basin (Canadian Shield portion). Small but significant amounts of the clay-size fraction are more chemically mature and appear to derive from local sedimentary sources in the southern Gulf as well as from sources outside the Gulf. A plot of the Na/K ratio (Fig. 71) along the length of the Laurentian Trough from the estuary to Cabot Strait reflects the seaward decrease in the chemically immature material and the corresponding rising influence of the chemically mature material on the chemistry of the clays.

CHAPTER 8 — GEOCHEMISTRY

The Gulf sediments may also be regarded as a mixture of organic and inorganic material that has arrived at the site of deposition as solid particles (detritus) or has been incorporated from solution in a variety of ways. The geochemistry of the major elements indicate that Si, Al, Ti, K, Na, Mg, Ca, and to a lesser extent Fe and Mn have entered the depositional basin structurally combined in detrital silicate and carbonate minerals. Within the Gulf, Si varies between 21.0 and 42.3%, Al between 1.7 and 9%, Ti between 0.07 and 0.76%, K between 0.54 and 3.15%, Na between 0.56 and 2.8%, Mg between 0.14 and 3.52%, Fe between 0.61 and 5.72%, Ca between 0.20 and 25.2%, and Mn between 0.07 and 0.27% with sediment texture and location. These textural and regional variations in major elemental concentrations are mainly determined by the nature, abundance, grain size, and provenance of the host minerals of these elements.

Chemical partition of the major elements into their detrital and nondetrital contributions reveals that most of the major elements accumulate at the same rate as detrital sedimentary material and that small but significant quantities of K, Na, Fe, Mn, and Ca are incorporated into the sediments in a variety of ways such as precipitation, sorption onto suspended matter, and extraction by living organisms in response to present physicochemical conditions in the Gulf.

The organic fraction usually makes up less than 5% of the sediments and is derived from living organisms and the organic compounds formed by the decay of plant and animal matter. Most of the organic component has reached the sediments as solid particles and in the dissolved form as well as from within the marine area. It is preserved in the greatest concentrations in the quiet deep central parts of the major troughs and shelf depressions where it has been deposited from suspension along with the fine-grained inorganic sediments.

CHAPTER 9 — DEPOSITIONAL HISTORY

The geological, morphological, and sedimentological data indicate that the main stages in the development of the morphology and sediments of the Gulf of St. Lawrence as we now know it are (1) the formation of a preglacial landscape (2) the modification of this landscape by repeated glaciations during the Pleistocene Epoch (3) late-glacial (late-Wisconsin) erosion and deposition (4) modification of the relict glacial morphology and sediments by postglacial changes in sea level and by present depositional conditions.

The late-glacial history of the Gulf as recorded by the stratigraphy of the sediment cores and acoustic structure of the unconsolidated sediment deposits involves (Table 19) the initial retreat of the glaciers from the Laurentian Trough system onto the adjacent shelves and shorelines (~14,500–13,000 years BP), glaciomarine sedimentation which formed a series of coalescing fans along the edge of the Magdalen Shelf and thin deposits elsewhere in the troughs (~13,000–10,200 years BP) and the deposition of a till cover during a subsequent readvance of ice into marginal marine to open marine water of the troughs <10,200 years BP. Radiocarbon data suggests that this late ice had withdrawn by 8700 years BP or earlier and postglacial conditions were being established with the accumulation of pelites in the troughs and shelf valleys, reworking of shelf deposits, and the formation of submarine terraces at various levels on the shelves. Lithological and foraminiferal core data indicate the oceanographic conditions varied from marginal marine to open marine during the accumulation of the deepwater pelites until the present depositional conditions were established. At the present, specific sedimentary environments of deposition, active redistribution, and nondeposition occur in the Gulf. These include the active deposition of the deepwater pelites in the deep central parts of the major troughs, the active deposition of sandy and very sandy pelites in the shelf valleys, the offshore bank areas of active sediment sorting and redistribution, the nearshore and coastal areas of active reworking and redistribution, and the areas of essentially nondeposition characterized by large areas of uncovered bedrock and relict deposits of sands and gravels.

1

Introduction

The importance of understanding the physical and biological environments of the Gulf of St. Lawrence has long been recognized. The Gulf is the most important embayment in the Canadian coastline (Fig. 1). It is a triangular-shaped inland sea covering 96,000 square miles ($\sim$250,000 km^2) connected to the Atlantic Ocean by the Strait of Belle Isle and Cabot Strait and to the interior by the St. Lawrence River. Bordered by five eastern provinces, it provides direct access from the ocean to the urban and industrial heartland of Canada. Since Jacques Cartier first entered the Gulf in May 1534, it has been the principal pathway for men to explore, colonize, and develop Canada. From it comes one quarter of Canadian fish landings both by weight and value.

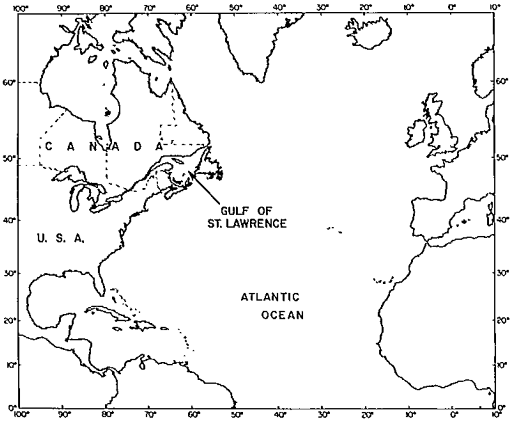

FIG. 1. Location of the Gulf of St. Lawrence on the east coast of Canada.

This report describes and assesses the marine geological environment of the Gulf of St. Lawrence including the St. Lawrence Estuary. It contains a synthesis of geological and geochemical data collected and interpreted over the past 10 years and is accompanied by detailed bathymetric and surface sediment maps (Charts 1 and 2, in pocket). Most of this study deals with the geomorphology, surface sediments (lithology, mineralogy, and chemistry), and present depositional conditions, but several studies have also been made of the bedrock geology and the stratigraphy of the unconsolidated sediments. These studies are regional and of a reconnaissance nature in the sense that they have been designed to obtain acoustical and sampling data on the morphology and basic properties of the sediments from the whole Gulf. This approach was used to provide a broad appraisal of the sedimentary environment of the Gulf and its late-glacial and postglacial history.

The report and maps which accompany it are intended for those interested in the Gulf of St. Lawrence and especially for those engaged in economic activities. For the fishermen and biologists the maps might be used to find the relief and composition of the sea floor that are most suitable for or related to a particular fish, shellfish, or bottom organism. For those interested in pollution control, the text (Chap. 8) deals with the partition of the major elements in the Gulf sediments into detrital and nondetrital phases, as well as the areas of deposition and sources of sediments. Marine and petroleum engineers will find information on the relief and texture of the sea floor at potential cable, pipe, and well sites as well as some information on the subsurface structure. For earth scientists this study is intended to illustrate the characteristics of glacial-marine sediments and their response to the present physical and physico-chemical environment.

Initially, the geological setting of the Gulf between the glaciated crystalline rocks of the Canadian Shield and the sedimentary rocks of the Appalachian region, and the northern climatic conditions set this region apart from most other sedimentary environments that have been studied in recent years. These other areas such as the Gulf of Mexico, the sea off southern California, the Orinoco delta, Guiana Shelf, the Rhône delta, the Niger delta, and the Persian Gulf mostly occur in unglaciated subtropical or tropical regions with sedimentary environments influenced by large supplies of terrigenous material (delta areas). More recently, the realization that the Gulf receives the waste products from over 60% of the Canadian population has added another dimension to the study of the sedimentary environments in the Gulf.

Geographical studies of the Gulf of St. Lawrence began in 1534, with its discovery and exploration by Jacques Cartier who gave the name *Baye Saint Laurens* to a large bay on the north shore of the Gulf now known as Ste. Geneviève. The latinization and misplacement of this name offshore as *Sinus S. Laurentii* on the Mercator Map of 1569 resulted in the eventual extension of this local name to the entire Gulf and River. Bathymetric data for the Gulf were accumulated in the early days from the many soundings taken by lead line initially by Cartier, and later by other explorers, traders, fishermen, and during the early French and English military expeditions. Since it was customary to arm the sounding leads with tallow, the first small samples of the bottom were obtained and recorded on navigation charts. With the advent of the echo sounder, continuous bathymetric observations and profiles of the sea floor were produced for navigation and fishing charts that added immensely to the hydrographic coverage of the Gulf.

Studies of the submarine physiography of the Gulf began with the work of Spencer (1890 and 1903) and was carried on by Goldthwait (1924), Johnson (1925), Cooke (1930), Shepard (1931), and MacNeil (1956). The results of these studies will be discussed elsewhere in this report. Knowledge of the regional sediment conditions prior to 1961 is scarce. Up to this time only scattered sediment observations and chart notations had been made. Since 1961, the authors have made a series of systematic studies to assess the regional marine geological environment of the Gulf of St. Lawrence. The results of some of these studies have been published separately from time to time, but as more data accumulated it was felt that an overall picture of the sedimentary environment in the Gulf should be presented including reference to studies carried out by other workers in related fields such as the adjacent land geology, oceanography, and marine geophysics.

The interpretations in this report are based on the collection and analysis of bottom grab and core samples, echograms, side-scan sonargrams, continuous seismic profiles, and underwater photographs, obtained between 1961 and 1971 using a variety of field and laboratory methods.

Methods and Materials

This section outlines the main features of the methods used in the collection and analysis of the data. Readers interested in the technical details of these methods are referred to the appropriate reference or authors.

Collection of Data

Acoustical and sampling data were obtained in the River and Gulf of St. Lawrence on board CNAV *Sackville* (see cruise reports S-56, 1961; S-62, 1962; S-75, 1963; S-79, 1964; BIO-27-65, 1965); CSS *Kapuskasing* (July 1965; BIO-13-66, 1966; BIO-09-66, 1966; BIO-28-68, 1968); CSS *Hudson* (BIO-24-67, 1967); CNAV *Bluethroat* (BIO-20-67); CSS *Baffin* (1965). On these cruises, sounding lines and sample stations were selected initially on the basis of the submarine morphology and later in combination with a preliminary sedimentological map as the sea floor data accumulated. Navigational control for the location of sounding lines and samples was achieved primarily by DECCA and LORAN; in areas without this coverage (pre-1963), celestial navigation and dead reckoning was used, and radar was often used near land to establish positions.

Acoustical data on the topography and nature of the sea floor was obtained from echosounding, oblique echo ranging, and continuous seismic profiling. Use was also made of the available bathymetric information. Depending on the ship, a Mark V Precision Depth Recorder (PDR), and Kelvin Hughes echosounders (Model 26 and Model J) were used to obtain echograms showing the relief and nature of the surface and near-surface (acoustically transparent) sediments of the sea floor (see Loring 1962 for details). Additional sounding information was also obtained from the original sounding rolls and field sheets of the Canadian Hydrographic Service, particularly those from the CSS *Baffin* surveys of 1968 and 1969 in the northeastern part of the Gulf.

During a cruise on board CSS *Kapuskasing* in 1965, a Kelvin Hughes oblique sonar was used to map the sea floor in parts of the Magdalen Shelf. This equipment was similar to that described by Chesterman et al. (1958, 1967) and employed by Stride (1959, 1961). It provided a continuous record of acoustic reverberations from a 800-yard (720-m) wide strip of the bottom. Variation in the intensity of the marking on the records could, given adequate calibration and standardization of the equipment, be interpreted as indicative of the composition and microtopography of the sea floor. Continuous seismic profiling to determine the subsurface structure and composition of the sea floor in the Laurentian Trough were carried out using a Bolt Associates Air Gun (Model 600A) and on the Magdalen Shelf using a 160 Joule Huntec Model 2A Hydrosonde Sparker.

About 1500 sediment samples have been collected from various parts of the Gulf (Chart 3, in pocket). This sampling program was designed to obtain a regional coverage of the sedimentary environment in the area. For this reason, the location and density of the sampling stations were based on a preliminary morphological map and later in combination with a sedimentological map as has been mentioned before. In practice it meant that more samples were required from the shallow water areas or shelves, which had a complicated sediment pattern, than from the troughs with their nearly consistent sediment cover.

Bottom grab samples (0.01–3 kg) of the sediments were obtained for the most part using a modified Van Veen (0.1 m^2) grab and stored in plastic bags under refrigeration until returned to the laboratory. The samples were numbered consecutively on each different cruise so a sample number such as BIO-24-67, station 10, refers to sample 10 of a Bedford Institute of Oceanography Cruise number 24 in 1967. For earlier cruises such as S-75, the S refers to a cruise by CNAV *Sackville* at the time when cruises were being numbered consecutively for each ship used for oceanographic studies. Core samples up to 65 ft ($\sim$20 m) were obtained using standard piston corers with weights of 350 lb ($\sim$160 kg) and 1200 lb (545 kg); plastic liners 1½ inches in diameter and up to 20 ft long were used with the 350-lb core and 3½-inch liners up to 70 ft long were used with the 1200 lb core. When liners were not available, the core samples were extracted from the core barrels on board, logged, wrapped, and stored in aluminum or iron tubes until opened for study. In a few cases, short cores of about 6 ft ($\sim$2 m) were obtained using a light weight gravity corer. In addition to these sampling devices, an underwater sampler was used to obtain small ($<$0.1 kg) samples of the sea floor during sonar surveys. For specialized samples on the Magdalen Shelf, a 1500 lb (680 kg) sand corer, similar to that described by Van den Bussche and Houbolt (1964), and a box sampler similar to that described by Bouma and Marshall (1964) were used to obtain selected sand samples.

Bottom photographs of selected areas were also obtained using an EG & G bottom camera.

Field observations of fresh sediment samples included estimates of sediment color (Munsell rock color chart 1971) and gross lithology, together with some measurements of *p*H and E*h* (Beckman Model -G- *p*H–E*h* Meter) and oxygen activity (KCNS/K_3 $Fe(CN)_6$ method of Jackson (1958, p. 354–357) for selected samples. Water samples for the determination of temperature, salinity, *p*H, dissolved oxygen, and turbidity were collected and analyzed at selected stations and at various depths. In addition some *in situ* measurements of turbidity were made with a Secchi disc at selected stations during daylight hours and with a shallow water ($<$50 m) Hydrowerkstatten transmissometer.

Shoreline samples for mineralogical studies were collected from the Magdalen Islands, Prince Edward Island, Cape Breton Island, Nova Scotia, New Brunswick, and Gaspé Peninsula in 1965 and 1966, as well as from the St. Lawrence River, the North Shore, and Anticosti Island in 1968.

Data Analysis

Acoustical Data — In the laboratory, sounding records were studied, interpreted, and reduced manually in most cases to a scale suitable for plotting and presentation. It should be noted that not all records presented have a uniform exaggeration because the horizontal scale of the echograms varied with differences in the speed of the paper passing through the recorders and changes in ship speed whereas the vertical scale remained fixed. These differences were partly compensated for by an attempt to maintain a consistent ship speed and rate of recording as far as possible. The use of different sounding instruments also contributed to the lack of uniformity amongst some records presented in this report. Sonargrams were recorded on a modified facsimile recorder, photographed, interpreted, and prepared for presentation with the relevant data (for details see Gilbert et al. 1966 and Loring et al. 1970). The information on the continuous seismic records was first interpreted visually and then reduced to constant scale with the aid of a pantograph with independently vertical and horizontal scales. Since the acoustical information pertaining to the upper (sea floor) part of the records was often hidden by the recording of the bubble pulse of the seismic display, echograms obtained simultaneously with these records were used to provide the surface and near surface (< 10 m) information.

Sedimentological Analyses — Initially the sediment samples were sorted and split after their water content had been determined. A representative sample for sedimentological analyses was prepared by separating the material >2 mm from the finer material. Material >2 mm was set aside for petrological analyses. The analyses for particle size distributions were carried out by the normal combined sieve–pipette method developed and standardized for sedimentological investigations of the Landbouwhogeschool, Wageningen, Netherlands. The samples were treated with 10% H_2O_2 on a steam bath and with 0.2-N HCl at room temperature to remove organic matter and carbonate. A solution of sodium phosphate was used as a dispersing agent. The results of the analyses have been illustrated as phi-indices diagrams and cumulative curves on arithmetric probability papers as used by Doeglas (1946 and 1968) for his extensive studies on the relation between size-frequency distribution and environment of deposition.

Mineralogical analyses were carried out after separation into a heavy and light fraction. The light minerals were identified by a combined method of staining and the use of immersion liquids (Nota and Bakker 1960). The method of heavy mineral analysis applied has been described in detail in various publications (Doeglas 1960; Van Andel 1950; Nota 1968). However, to prevent destruction of minerals like apatite, biotite, and olivine, the samples were not boiled in concentrated HCl and HNO_3 but only treated with $Na_2S_2O_4$. Of each slide, about 150 transparent grains were identified and their frequencies were given as a percentage of the whole. The analyses exclude the opaque minerals. The fraction used for the heavy and light mineral analysis ranges from 0.5 to 0.05 mm. Fractional mineral analyses were also made on a number of selected samples (see Chap. 7). Since gravels, sands, and pelites generally will be transported quite independently, the conclusions on the sources of the sand fraction will not necessarily apply to those of the gravels and pelites.

Most of the samples contain heavy minerals in sufficient quantities to carry out a normal counting. There is no seaward limit of heavy mineral occurrence and even the deepwater pelites yield sufficient heavy minerals for analysis. This is in contrast to the seaward boundary for the occurrence of heavy minerals that Van Andel (Van Andel and Postma 1954) found in the area of fine-grained pelites in the center of the Gulf of Paria. One reason for the lack of such a boundary in the St. Lawrence region is the prominent factor of ice-rafting. The other reason is that in the majority of the samples, the quantity of heavy minerals is high; in many cases it amounts to 10% of the insoluble residue (of the material coarser than 50μ). This high ratio of heavy to light minerals has to be considered as a source characteristic. The mineralogy of the clay-size fraction (<0.002 mm) was determined by measurements obtained from a Noralco high angle X-ray diffractometer (Cu–Kα radiation) and a Philips Powder Camera.

Chemical Analyses — Samples used for chemical analyses were first washed with distilled water to remove soluble sea salts using the method described by El Wakeel and Riley (1961). Prior to 1965 quantitative chemical analyses of samples for the major element oxides of silicon, aluminium, titanium, sodium, potassium, manganese, iron, magnesium, and calcium were made using the Rapid silicate analytical scheme (colorometric) described by Riley (1958) with the modifications described by Loring and Lahey (1965). After 1965, the major elements in the sediments were determined by atomic absorption using a Perkin-Elmer Model 303 atomic spectrophotometer.[1] Ferrous iron was determined by the method of Groves (1937) but ceric sulphate was used instead of $KMnO_4$.

In addition to the normal chemical techniques outlined above, a number of samples were treated according to the technique described by Hirst and Nicholls (1958) to evaluate the detrital and nondetrital contributions to the total elemental content. These sediments were treated for 24 hr with 25%v/v acetic acid which removes any elements that are loosely held. The residue of this extraction was used to determine the detrital contributions. Additional determinations on selected samples were made to investigate the partition of iron and manganese among the soluble phases. Dithionite ($Na_2S_2O_4$) was used to remove amorphous and crystalline iron oxides and iron sorbed by sediment particles following the method described by Mehra and Jackson

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[1] The rock samples G1 and W1 were used as internal standards for the analyses. Replicate analyses (12) of G1 had the following standard deviations and coefficients of variation for the various elements: Si — 0.41, 1.2; Al — 0.15, 2.0; Ti — .025, 14.2; Na — 0.10, 3.9; K — 0.16, 3.6; Mg — 0.01, 5.7; Mn — .001, 4.2; Fe — 0.08, 5.8; Ca — 0.03, 2.6.

(1958). Hydroxylamine-hydrochloride (1% solution) was used to remove exchangeable Mn^{+2}, easily reducible manganese oxides, and iron sorbed by the sediments. Both treatments leave the lattice structure of the silicate minerals intact and do not attack the resistant oxides such as ilmenite and hasumannite (McKeaque and Day 1966; Heintze and Mann 1951). Iron and manganese in the dithionite and hydroxylamine-hydrochloride filtrates were determined by atomic absorption using a Perkin-Elmer Model 303 atomic spectrophotometer. Separation of the individual size fractions was carried out after dispersion in 0.16-N NH_4 (OH).

Calcium carbonate in 675 sediment samples from the estuary and Gulf was determined by digestion in 4-N HCl using the technique described by Van Schuylenborgh (1961) and Loring and Lahey (1963). Readily oxidizable organic matter was determined using the wet oxidation method by chromic acid with H_2SO_4 heat of dilution described by Walkey (1947). The effect of chloride was prevented by leaching and the use of Ag_2SO_4 in the digestion mixture.

Radiocarbon^{14} dates reported in this book have been determined by the Radiocarbon Laboratory, Geological Survey of Canada, Ottawa, Ont.

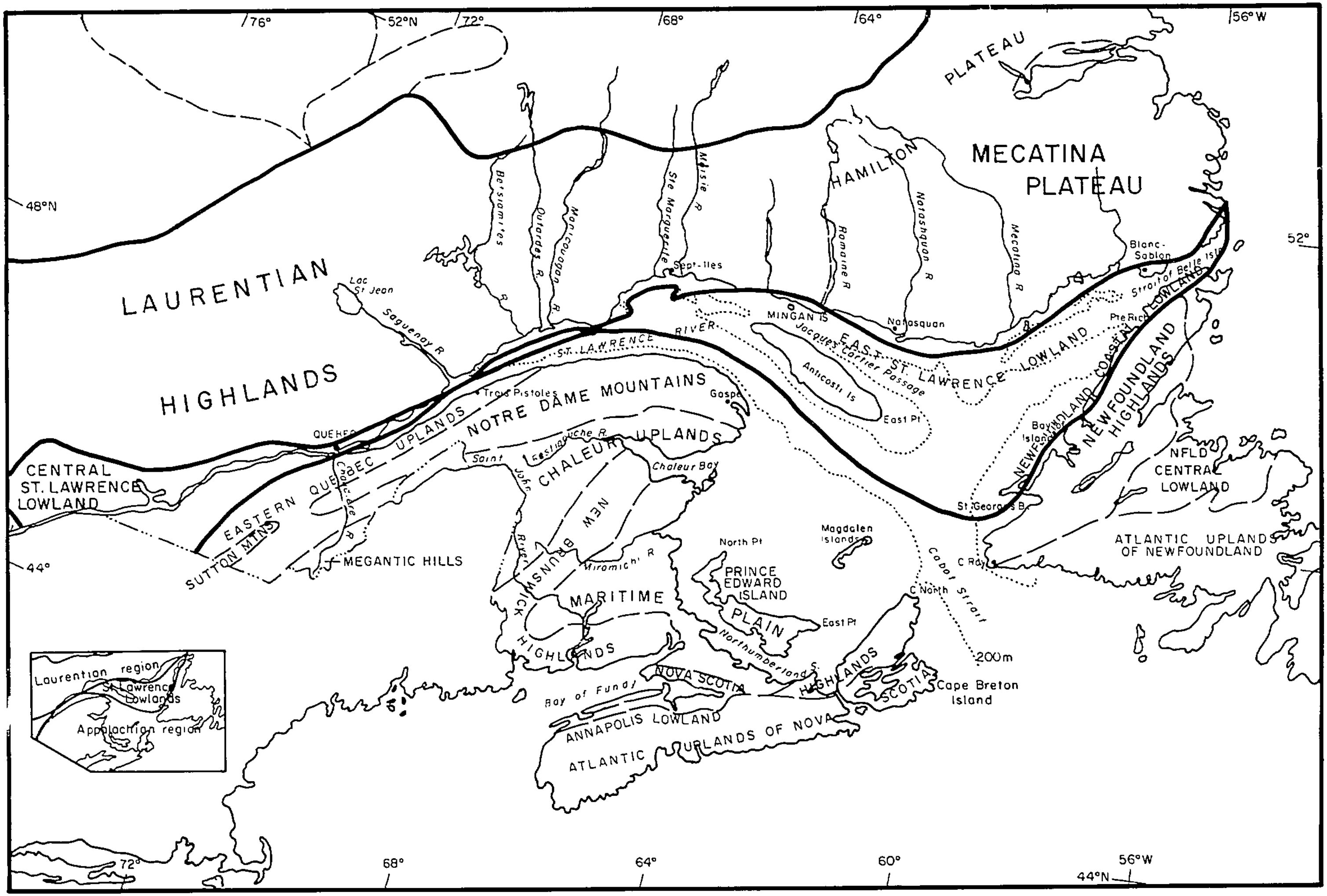

FIG. 2. Physiographic regions of eastern Canada (modified from Geol. Surv. Can. Map 1254A).

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Physiographic and geologic setting

The segment of eastern Canada, which includes the River and Gulf of St. Lawrence, comprises a number of physiographic regions: the Laurentian region (Canadian Shield), the St. Lawrence Lowlands, and the Appalachian region (Fig. 2, insert map). These regions, which exhibit distinct topographic, geologic, and tectonic characteristics, form the setting for the marine geologic investigations.

The Laurentian Region

This region comprises uplands and highlands that rise abruptly above the north shore of the St. Lawrence Estuary and Gulf to form the south and southeastern border of the Canadian Shield. It is subdivided into the Laurentian Highlands, which border the Estuary and Gulf from Quebec City to Sept Îles, and the Mécatina Plateau, which extends north and east from Sept Îles to the Strait of Belle Isle. The whole region is an immense rocky plateau with an uneven rolling surface. Most of the plateau lies at about 2000 ft elevation but some broad areas have summits at 3000 ft and in a few places 4000 ft (Fig.3).[2] Along

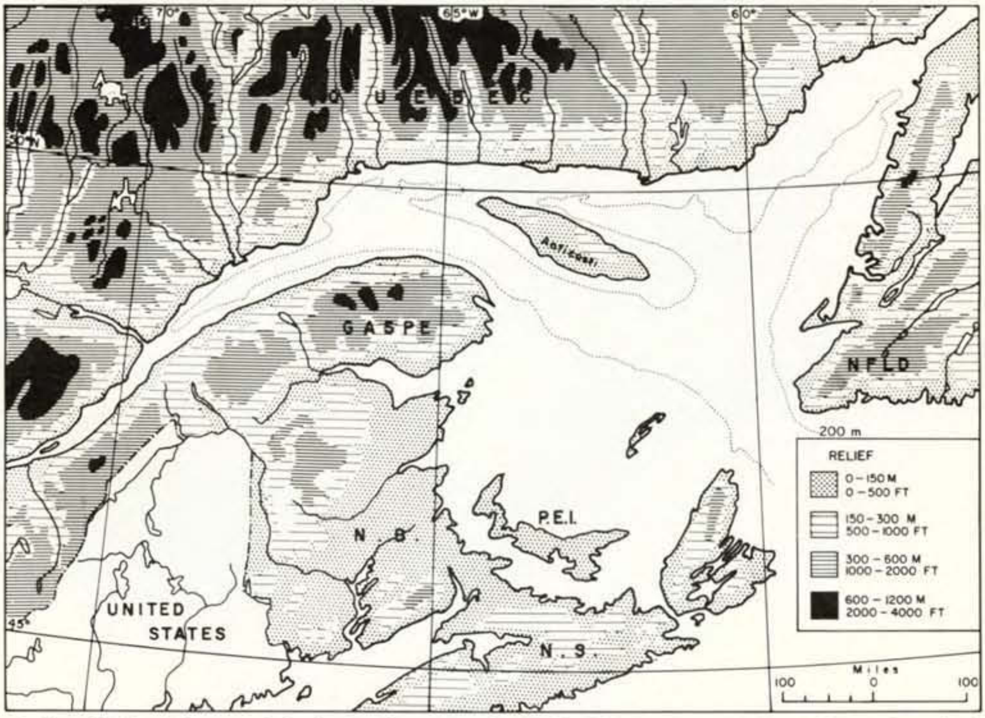

FIG. 3. Simplified relief map of the land adjacent to the Gulf of St. Lawrence (adapted from Canada Atlas Map 10).

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[2] The detailed relief of the region in meters is shown in Chart 1.

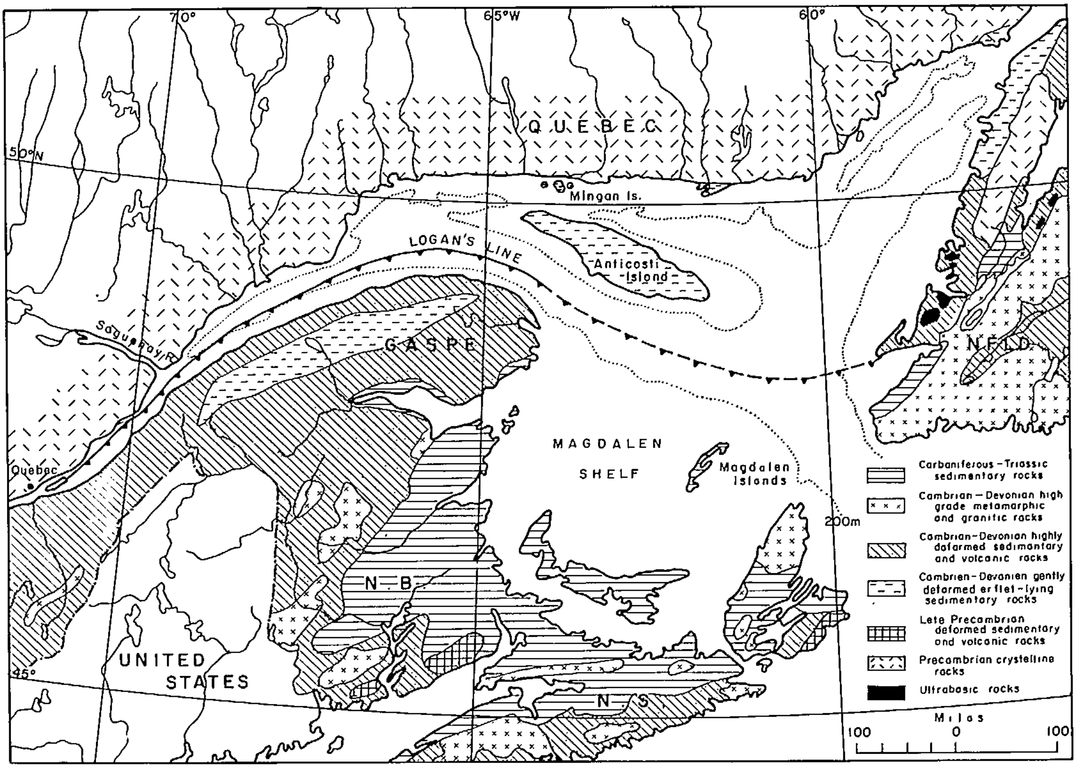

FIG. 4. Simplified geological map of the land adjacent to the Gulf of St. Lawrence (modified from Neale et al. 1961).

the margin of the estuary, the southern edge of the plateau is usually formed by a steeply rising escarpment from 800 to 1500 ft high. At the foot of the escarpment lies a narrow coastal lowland along the north shore of the Gulf. The edge of the escarpment is deeply and, in places, widely incised by a number of long rivers draining the interior of the plateau, of which the Saguenay, Betsiamites, Manicouagan, Outardes, and Romaine are the largest (Fig. 2). As a result of this dissection this border has a mountainous appearance when viewed from the Estuary and Gulf. The interior also has a mountainous appearance with accordant summits over broad areas which represent old erosional surfaces (Ambrose 1964).

Beneath an intermittent veneer of unconsolidated sediments, the plateau is underlain by igneous and metamorphic rocks of Precambrian age (>600 million years ago) such as granites, granodiorites, anorthosites, gneisses, and schists. A few outliers of Paleozoic sedimentary rocks occur in the basin of Lake St. Jean at the head of the Saguenay River, along the southern margin adjacent to the estuary, the north shore of the Gulf opposite Anticosti Island, and the Strait of Belle Isle (Fig. 4).

Tectonically, the Shield has been a fairly stable mass since Precambrian times and the crystalline rocks which partly comprise it constitute the basement on which younger sedimentary strata to the south rest (Fig. 5). It was not folded to any great extent by later mountain building movements but rather underwent broad downward and upward movements that permitted the deposition and erosion of sediments along its margins in Paleozoic times (600–225 million years ago). After uplift at the close of Paleozoic or early Mesozoic times, the whole region was above sea level and undergoing erosion (Poole et al. 1970).

The present surface of the Laurentian Plateau represents an exhumed pre-Paleozoic erosional surface that has a complex history (Wilson 1903, 1918; Cooke 1929, 1930, 1931; Blanchard 1931, 1932; Ambrose 1964).

The Shield was apparently peneplained and the valley system was cut into the bedrock before the Paleozoic era and later it was partly covered with Paleozoic sedimentary rocks (mostly limestones and shales of mid-Ordovician age). During Mesozoic and Tertiary times streams stripping the Shield of its cover rocks apparently exhumed the margin of the Shield and the old deep stream valleys, some of which are incised up to 1500 ft into the edge of the plateau. Along the lower margin of the plateau where cover rocks still exist, such as on the north shore adjacent to Anticosti Island, valleys occupied by rivers flowing down the regional slope on crystalline rocks now appear to pass directly into the preglacial valley system developed on the Paleozoic cover rocks.

Following this period of deep erosion and dissection of the plateau came the continental glacial period of the Pleistocene Epoch with southerly advances and northerly retreats of great masses of ice. The whole region was apparently glaciated by ice sheets moving south as well as west and east from centers in the interior (Prest 1970). As a result, the preglacial topography and drainage system was slightly modified by glacial erosion and deposition (Fig. 6). Further to the south ice masses also contributed to the development of the present morphology and sediments in the estuary and Gulf as well as in the land areas beyond (Chap. 4 and 5).

About 12,500 years ago the ice sheet had withdrawn to the north shore of the estuary and Gulf and to the interior about 7000 years BP when it finally wasted away in central Labrador. As the ice withdrew from the north shore of the estuary and Gulf, it initiated a series of complex recessional stages along its margins (see Prest 1970). The main features of these withdrawal stages, except for some local readvances, were: (1) the opening of the St. Lawrence River valley between the Laurentian Highlands and the Gaspé Peninsula to allow the marine waters of the Gulf to flow into the interior and form a large inland sea, the Champlain Sea (Hitchcock 1861) (~11,800–9500 years BP) with its accompanying sedimentation and (2) a later opening of the Saguenay River valley through which the marine waters entered the basin of Lake St. Jean to form the Laflamme Sea between 10,250–8700 years BP (Elson 1969a). The marine submergence of these areas as evidenced by old strand

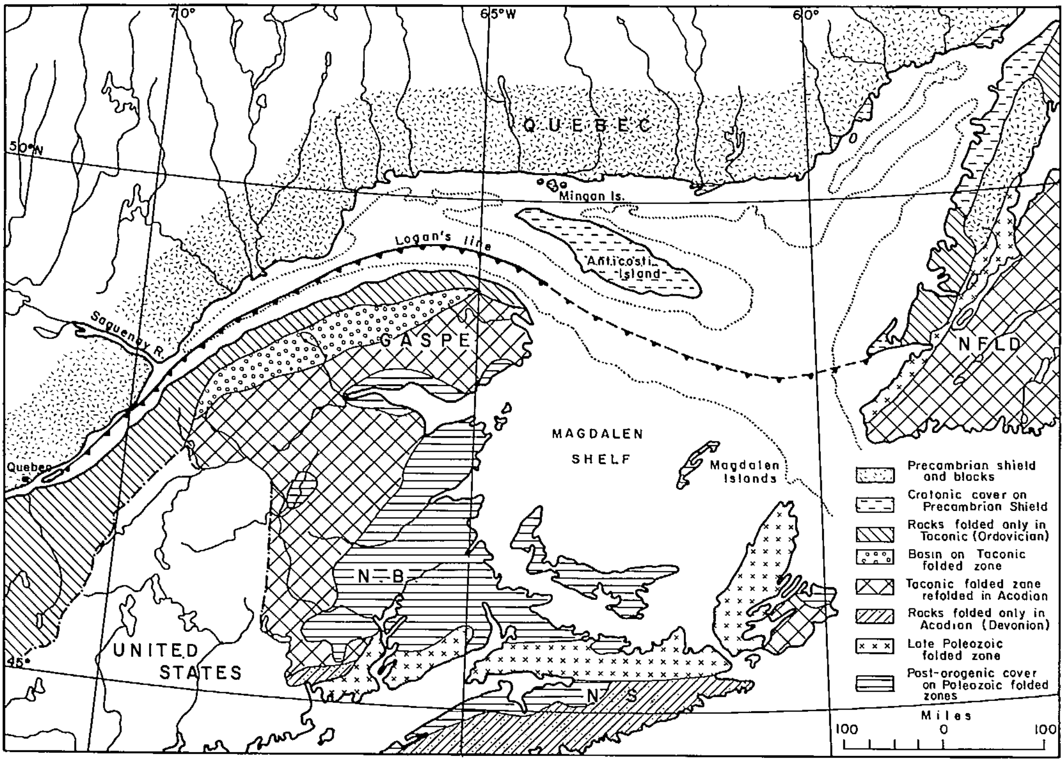

FIG. 5. Simplified tectonic map of the land adjacent to the Gulf of St. Lawrence (modified from Neale et al. 1961).

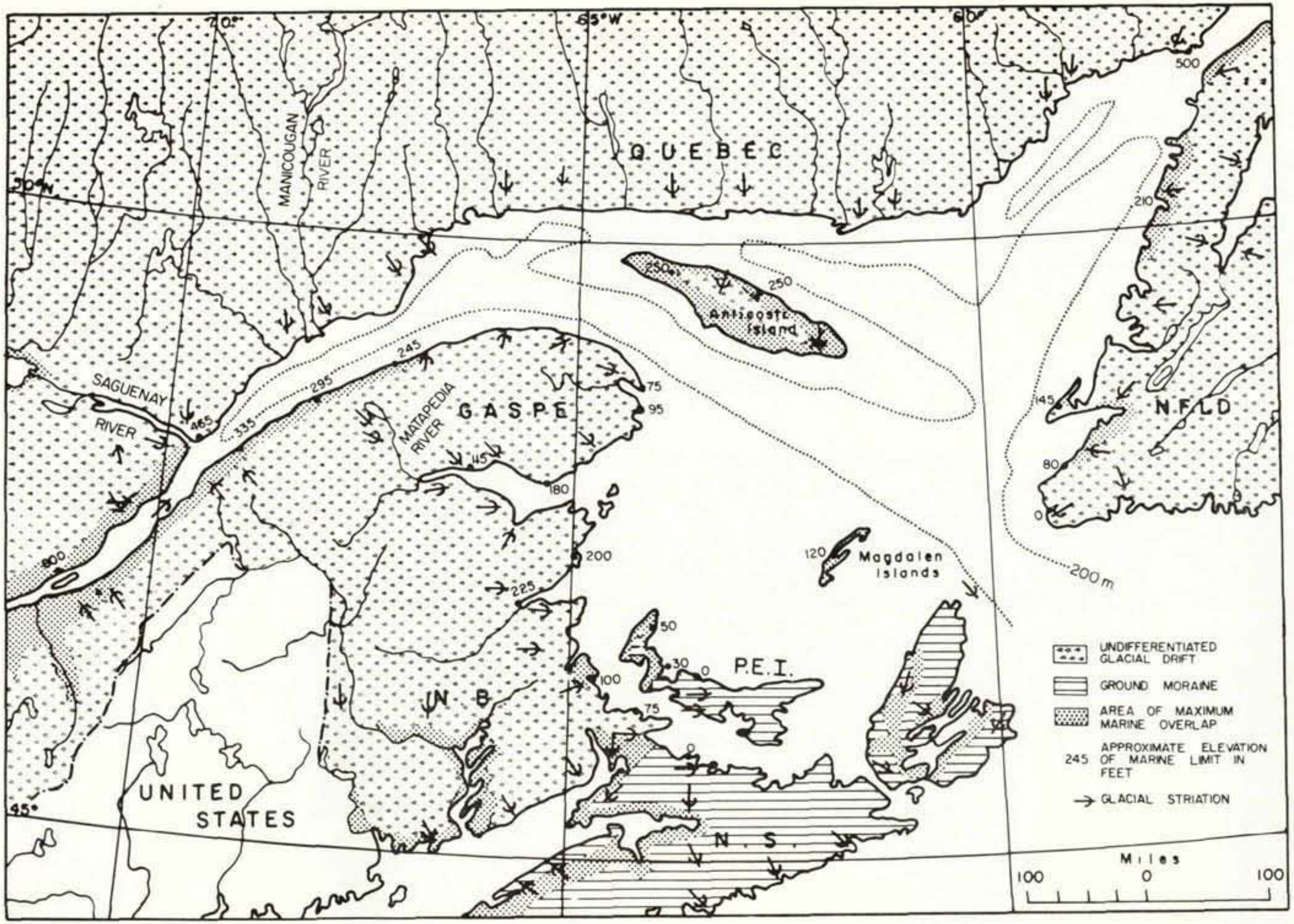

FIG. 6. Simplified glacial map of the Gulf of St. Lawrence region (modified from Geol. Surv. Can. Map 1253A).

lines ranges from 300 to 600 ft. As the depressed crust recovered from the weight of the ice masses, the land rose with the result that these seas were gradually forced back into the Gulf and the present drainage was established.

St. Lawrence Lowlands

The St. Lawrence Lowlands border the Laurentian region on the southeast and extend from the west end of Lake Huron northeasterly to the Strait of Belle Isle (Fig. 2, insert map). It comprises three units: the west St. Lawrence Lowland, the central St. Lawrence Lowland, and the east St. Lawrence Lowland, of which the latter two are of most interest to this study. The lowlands are floored by unfolded Paleozoic strata and the west and central lowlands are plain-like areas, whereas the east lowland contains, in part, a major submarine valley system and, in part, a shallowly submerged cuesta landscape.

Central St. Lawrence Lowland

The central St. Lawrence Lowland includes the area between the Ottawa and St. Lawrence rivers and straddles the St. Lawrence River as far east as Quebec City.

South of the Laurentian Plateau the V-shaped plain of the central lowland extends on either side of the river from the vicinity of Quebec City to the western Quebec boundary and an arm of the lowland continues up the Ottawa River. The surface of the plain is nearly flat at an altitude of 0–500 ft above sea level except for some isolated hills known as the Monteregian Hills which rise from 500 to 1000 ft above the plain east of Montreal. Below Montreal, the land bordering the river does not exceed 100 ft in elevation but farther back rises to heights of nearly 300 ft above sea level as it reaches the hilly country of the Appalachian region to the south and east.

The lowland is underlain by Paleozoic (Cambrian–Ordovician) strata in its western part near Quebec City. Although the rocks are essentially flat lying they have been warped into an elongated syncline that overlaps the Precambrian crystalline rocks of the Canadian Shield along its northern boundary. To the southeast they abut against an extensive fault zone which runs northeasterly from Lake Champlain to Quebec City and up the St. Lawrence River valley. This fault zone, which is known as Logan's Line (Logan 1863, p. 234, 296) or "the Appalachian front," separates the nearly horizontal Paleozoic strata of the lowlands from the highly folded rocks of the Appalachian region to the southeast (Fig. 4).

East St. Lawrence Lowland

The east St. Lawrence Lowland extends through the St. Lawrence River valley and estuary northeast of Quebec to the Strait of Belle Isle and the west coast of Newfoundland. The submerged part of the lowland forms the floor of the river, estuary, and northern Gulf whereas the unsubmerged parts include Anticosti Island, the Mingan Islands, the north shore adjacent to these islands, several small areas along the north shore to the Strait of Belle Isle, and the Newfoundland Coastal Belt.

The physiography of the submerged parts of the lowland is discussed in Chapter 4, so only the pertinent features of the unsubmerged parts are mentioned here.

Anticosti Island is about 140 miles long with a maximum width of 35 miles. It is a partly submerged, southerly dipping cuesta with a steep north-facing escarpment between 400 and 600 ft high, parallel to the north coast of the island. In general, most of the western and northeastern parts of the island vary in elevation between 300 and 700 ft, whereas the greatest altitude of 850–1000 ft is reached in the southeastern part of the island. The entire island is characterized by a rugged immature topography in which northward flowing rivers are short and occupy deep preglacial valleys, whereas southward flowing rivers are longer and bordered by gently sloping valleys in their lower reaches.

The northern scarp face and southern dip slope are terraced. More than twenty terraces have been recorded (Twenhofel and Conine 1921), with the highest at an elevation of 400 ft. Along the steep northern side the terraces are narrow whereas those on the south side may be several miles wide. Although mostly covered with unconsolidated glacial and postglacial sediments, terraces above the 250-ft level are the result of bedrock control, whereas those below have mainly been formed by marine erosion during a period of higher sea level (Bolton and Lee 1960).

The *Mingan Islands*, of which there are 27, lie 20 miles north of Anticosti and also form part of a cuesta landscape, which is now partly submerged. They have steep northward facing scarps and southerly dipping backslopes that were eroded in preglacial times and later submerged to form the Jacques Cartier Passage (see Chap. 4).

The *Newfoundland Coastal Belt* extends along the west coast of Newfoundland and includes the Port au Port Peninsula. Most of the region is less than 400 ft high although the top of the Port au Port Peninsula has a height of 1160 ft. It is formed by a strip of nonresistant, mainly unfolded Paleozoic strata that dips towards the west.

The rocks of the St. Lawrence Lowlands were deposited along the southern margin of the Shield during Lower and Middle Paleozoic times. They remained undeformed on a relatively stable platform, known as the St. Lawrence Platform (Poole 1967), despite the intensive mountain building activity which affected the rocks of the Appalachian region to the south and southeast (Fig. 5).

Since Paleozoic time the rocks of the St. Lawrence Lowlands have been deeply eroded by rivers, and major valleys have been established in more easily eroded rocks such as shales. This erosion has left the more resistant rocks, such as the dolomites and limestones of the lowlands and the resistant rocks of the Laurentian (crystallines) and Appalachian (folded sedimentary) regions, to form the adjacent uplands and highlands drained by narrow tributary valleys connected to the broad open main valleys.

In the central lowland the overall effect of the differential erosion of resistant and nonresistant rocks is illustrated by the presence of the narrow lowland near Quebec City between the crystalline Shield rocks to the north and the folded Appalachian rocks to the south, and the exposure through differential erosion of the plug-like masses of alkaline igneous rocks that form the Monteregian Hills. Some of these rise more than 1000 ft above the surrounding lowland. In the eastern lowland differential erosion of relatively hard and soft strata has resulted in (1) the formation of the lowland which occupies the floor of the River and Gulf north and east to the Strait of Belle Isle and (2) the evolution of a cuesta landscape in the northern part of the Gulf, of which Anticosti Island and the Mingan Islands are unsubmerged remnants.

Deep preglacial bedrock valleys are present in the various parts of the western St. Lawrence Lowlands (Scott 1967). All these valleys were apparently tributaries to a major valley system that extended southeast from Georgian Bay to Lake Ontario and formed part of the preglacial St. Lawrence or Laurentian river system.

Between Montreal and Quebec the preglacial Laurentian river was most likely not far from the course of the present St. Lawrence River, and was joined by tributaries that drained the Laurentian Highlands and the Appalachian regions (MacPherson 1967). Recent subsurface drilling (Simard 1971) indicates that the preglacial bedrock surface of the St. Lawrence River in this area lies between 10 and 330 ft below present sea level and is covered by a variable thickness of glacial and postglacial sediments. Preglacial tributary bedrock valleys have also been detected beneath glacial drift to the south and north of the present St. Lawrence River (Tremblay and Hobson 1962; Freeze 1964; Prest 1970). East of Quebec City the course of the Laurentian river undoubtedly followed the submarine extension of the present St. Lawrence River valley through the estuary across the Gulf (see Chap. 4). It was probably joined by tributaries draining the Shield and the Appalachian region and from upland remnants of the lowlands which developed on the more resistant Paleozoic rocks now partly submerged.

The total thickness of rocks removed by the preglacial erosion is not apparent, except that the exposure of the Cretaceous igneous stocks which make up the Monteregian Hills, suggests that the region has been lowered by more than 1000 ft since that time. The present distribution of the Paleozoic strata also indicates that the greatest thicknesses have been removed from areas adjacent to the Shield, in the St. Lawrence valley, and in its submarine extension in the Gulf.

During the Pleistocene Epoch continental glaciers advancing from the interior of the Shield moved over the lowlands, further eroding the rocks, modifying the preglacial topography, and burying it beneath a thick layer of glacial sediments. The complex glacial and postglacial history has been well summarized by Prest (1970) and need not be repeated here except for a few comments.

The thick unconsolidated deposits in the lowlands represent (1) glaciation before and during the Wisconsin stage; (2) marine invasion during the recessional phases of glaciation; and (3) fluvial deposition during the withdrawal of the seas from the area.

At least two main stages of glaciation took place: one more than ~65,000 years ago (early-Wisconsin stage), and another between ~65,000 and 12,500 years BP (late-Wisconsin stage). These stages are separated by a nonglacial interval and have been recognized from the glacial deposits in the St. Lawrence valley (Gadd 1960). After the recession of the glaciers from the western side of the Appalachian Highlands, about 12,700 to 11,800 years BP, marine waters invaded the St. Lawrence, Ottawa, and Champlain valleys (LaSalle 1966; Gadd 1964; Lee

1962; and Elson 1969a) to form the body of the marginal marine and brackish water known as the Champlain Sea. Marine silts, clays, and sands that were deposited in the Champlain Sea now form a thick deposit on the floor of the lowland and part of the river floor below Quebec City. After most of the ice masses had retreated northward, between 9500 and 8000 years BP, the land surface which had been depressed by the weight of the ice rose differentially and caused the Champlain Sea to withdraw eastwards from the lowland through the present St. Lawrence valley. As the marine waters receded the sea was replaced in progressive stages by brackish and then freshwater and fluvial drainage systems that eventually worked their way into some of their old preglacial patterns (MacPherson 1967). Sediments removed during this period were eventually deposited in some parts of the River and Gulf (see Chap. 4 and 5).

The Appalachian Region

The south side of the St. Lawrence River and the southern and western Gulf are bordered by the Appalachian region of Canada. This region occupies that part of the province of Quebec that lies southeast of the Logan's fault (Fig. 4), and the provinces of New Brunswick, Nova Scotia, Prince Edward Island, and Newfoundland.

The region is subdivided into a large number of physiographic units (Fig. 2). The physiography is dominated by a well-developed planation surface[3], most likely a peneplain of Cretaceous age, which is highest in the northwest and slopes gently southeastward to the Atlantic Ocean. The various subdivisions consist of highlands, uplands, and lowlands formed in Mesozoic and Cenozoic times by differential erosion of resistant and less resistant rocks. Some of these regions are described briefly below.

Quebec Appalachians

The south side of the St. Lawrence Estuary is bordered by the uplands and highlands of the Gaspé Peninsula. In the southwestern part near Quebec City, the region is known as the eastern Quebec Uplands and consists of a single range of hills about 200 miles long with a breadth of 30–50 miles. These uplands rise to almost 2000 ft above sea level. For another 150 miles to the east the hills continue to rise to form the eastern extension of the Nôtre Dame or Shickshock Mountains of the Gaspé Peninsula with elevations up to 4000 ft. The top of this mountain range has a relatively flat surface, deeply dissected by streams, which forms part of the general planation surface sloping south-eastward to the ocean. This high plateau is surrounded by a lower one at an elevation of 1000–1500 ft on its north side. To the south there is a similar plateau referred to as the Chaleur Uplands, developed on Paleozoic limestones and sandstones. The edges of the plateau are deeply dissected by numerous rivers. The river valleys are mainly steep-sided and narrow, and their floors are in many places 1000 ft below the neighboring uplands and mountains (Dresser and Denis 1944).

The north shore of the region is smooth and arcuate with few indentations, whereas the eastern and southeastern shorelines are irregular and are characterized by an alternation of numerous small peninsulas, bays, and coves. These shorelines apparently resulted from the partial "drowning" of the rock structure forming the Gaspé Peninsula (see below) in which the north shore parallels the arcuate trend of the sedimentary belts and the south shore obliquely truncates the rock structure (see Johnson 1925, p. 20–23).

Most of the rocks of the Quebec Appalachians are Paleozoic in age and have a dominant northeasterly trend which swings eastward in the Gaspé Peninsula. They can be divided into three major structural belts — northern, central, and southern (Neale et al. 1961). The northern belt is 10–30 miles wide and extends the full length of the region. Its northern boundary is marked by Logan's Line (Fig. 5) which parallels the Gaspé Peninsula offshore. The rocks are mainly slates of Lower and Middle Ordovician age that were tightly folded and fractured in the Taconic orogeny (~440 million years ago) at the close of the Ordovician period and thrust against the platform sedimentary rocks to the north, forming Logan's Line. The central belt is underlain by Silurian and Devonian limestones and sandstones. This area was folded in the Acadian orogeny (~350 million years ago) at the close of the Devonian period into a broad synclinorium having a general plunge to the east. The southern structural belt is 20–80 miles wide. It is underlain by shales, limestone, and quartzites of Ordovician–Devonian age that were folded in the Taconic orogeny and later refolded in the Acadian orogeny. Along the coast a narrow strip of Carboniferous sandstones and

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[3] Planation surface is used in the text instead of peneplain or pediplain because of the controversy surrounding the use of these terms (King 1967, p. 151 and 167; Thornbury 1969).

shales separates the most resistant rocks of the uplands from Chaleur Bay.

Maritime Appalachians

South and east of the Gaspé Peninsula the Gulf is bordered by the lowlands of New Brunswick, Nova Scotia, and the highlands of Cape Breton (Fig. 2). The lowlands together with Prince Edward Island and the Magdalen Islands including the surrounding sea floor form a single physiographic unit referred to as the Maritime Plain on which elevations seldom exceed 600 ft. They are underlain by generally flat-lying Permo-Carboniferous sandstones, shales, and some coal measures through which, particularly on the Magdalen Islands, small bodies of volcanic rocks protrude to form prominent hills (Weeks 1963; Sanchargin 1964). Although these rocks are essentially flat-lying, they occupy a broad basin which plunges gently to the northeast. Differential erosion of this structure has produced a cuesta-like landscape of which Prince Edward Island represents an unsubmerged remnant.

The coastline forms a large semicircle around the rim of the southern Gulf of St. Lawrence (see Fig. 2) and mainly reflects the partial submergence of the lowlands. Differential erosion of the relatively weak Carboniferous rocks along the shores has produced a variety of shore forms in which the structural pattern of the coastal rocks has been etched in response to wind, wave, and current patterns (see Chap. 3). Such a pattern may be seen from the southwestern shore of Prince Edward Island along which the alternating headlands and bays have resulted from the differential erosion of minor folds with the bays representing the erosion of anticlines and headlands representing the partial erosion of synclines (Johnson 1925, p. 65). In contrast the leeward shores (north and east), such as the east coast of New Brunswick and the north shore of Prince Edward Island, contain a variety of wave built forms such as baymouth bars, spits, wide sandy beaches, and tombolos formed by longshore currents which sweep along these coastlines. The overall pattern of the coastlines, such as in the southwesterly facing crescent form of Prince Edward Island, may be said to reflect the adjustment of the coastal landforms to the prevailing winds. In general, the southerly and westerly facing shores are eroded by waves and their erosional products are deposited offshore. In contrast, the northerly and easterly facing shores are eroded by waves striking them obliquely and the erosional products so produced are transported by longshore currents and retained inshore to build constructional forms.

The Cape Breton Highlands have a plateau-like surface with elevations ranging between 1300 and 1500 ft and is deeply dissected along its edge by streams. The northwestern coast of the highland is relatively steep and straight with few indentations. It is believed to be a resurrected peneplain shoreline (Johnson 1925, p. 27). Although the plateau surface has often been described as part of the old dissected Cretaceous peneplain, Johnson (1925, p. 29) suggested that part of this southerly tilted surface is a pre-Carboniferous erosional surface which has been exhumed from beneath a cover of Carboniferous rocks during succeeding periods of erosion in Tertiary times.

The highland is mainly underlain by granitic and metamorphosed rocks of pre-Carboniferous age. A narrow coastal strip of soft Carboniferous rocks separates the harder, resistant rocks of the highland from the sea in the southeastern corner of the Gulf.

The eastern margin of the Gulf touches on the highlands, uplands, and lowlands of western Newfoundland (Fig. 2). From the Strait of Belle Isle southwards to Bonne Bay and the Port au Port Peninsula, the Gulf is bordered by the Newfoundland Coastal Belt and the Port au Port Peninsula which rises above the shoreline to a height of 1000 ft. Between the two uplands, the Gulf touches the foot of the Long and Serpentine mountain ranges with elevations varying from 600 to 2000 ft. The top surface of these mountain ranges is nearly flat and is believed to represent an old erosional surface.

These highland areas are bounded by steep slopes facing the Gulf to the west and their top surface slopes from about 2000 ft in the west to about 700 ft in the east. The gradient from east to west is about 6 ft per mile, and carried over to Gaspé at the same rate, is in close agreement with the high plateau of the Shickshocks. Beneath the top surface several lower erosional surfaces (at 1300–1700 and 500–1000 ft) have been recognized by various workers (Twenhofel and MacClintock 1940; Smith 1958; and Riley 1962).

South of the Port au Port Peninsula is a narrow coastal lowland referred to as the St. Georges Lowland and the Anguille Mountains at the entrance to the Gulf.

The most striking feature of the west coast of Newfoundland is the presence of deep fjord valleys which extend inland between high walls for up to 20 miles to the mouths of the rivers draining the interior highlands. These rivers, of which the Humber is the longest, have deeply dissected the western edge of the Newfoundland Highlands.

The coastal lowlands are underlain by relatively undeformed Paleozoic sedimentary rocks which fault against Precambrian crystalline rocks or highly-folded Paleozoic rocks of the highland area. The lowland area in St. Georges Bay is underlain by Permo-Carboniferous rocks which form the northeastward extension of the Carboniferous rocks of the Maritime Plain.

The stratigraphic and tectonic history of the Appalachian region is characterized by the complex interplay of various tectonic elements which need not be dealt with here except to refer the interested reader to the work of Poole (1967); Poole et al. 1970; and Sheridan and Drake (1968) and to the generalized geological and tectonic maps shown in Fig. 4 and 5. It is sufficient for the reader to be aware that no rocks younger than late Paleozoic or early Permian have been detected within the borders of the Gulf, except for the Cretaceous and Jurassic igneous intrusions in the central St. Lawrence Lowland and on Anticosti Island.

It is likely that the erosional pattern of the region as we now know it began to form in late Paleozoic times when rifting occurred beneath the continental mass to the east, and North America separated from Europe and Africa. Although the continental edge of the Appalachian region remained in a stable position of relative to .inland sites, North America continued to move westward from the site of the original break along the mid-Atlantic ridge (Emery et al. 1970). In terms of the gross effects of plate tectonics, the region is part of an Americo-trailing edge coast (that is, part of a trailing edge of a continent with a collision coast) and as a result actively modified by the depositional products and the erosional effects from an extensive area of high interior mountains (Inman and Nordstrom 1971).

The present landscape of the Appalachian region evolved with minor interruptions by sequential terrestrial erosional processes in Mesozoic and Cenozoic times. The most important features are: (1) the formation of the planation surfaces of the highlands; (2) dissection of the planation surface as it was tilted to the southeast when the continental margin subsided in Cenozoic times; (3) the evolution of cuesta landscapes on the lowlands of the northern and southern Gulf; and (4) the extension of the St. Lawrence preglacial drainage system from Cabot Strait to the Great Lakes.

The well-developed but deeply-dissected highland planation surface that dominates the region was apparently completed by late Cretaceous–early Tertiary times and its erosional products deposited on the Atlantic continental shelf and slope to form the Cretaceous coastal plain. Part of the Cretaceous planation surface may also represent an exhumed pre-Carboniferous peneplain. This erosional cycle was apparently followed by uplift in early–middle Tertiary times so that a second surface (at the 1000–1500-ft level) of the Chaleur Uplands, the New Brunswick and Newfoundland highlands, was developed in which the more resistant Paleozoic strata formed the upland erosional surfaces, and the less resistant strata such as the Permo-Carboniferous sandstones and shales formed the lowlands. The present valley system, which dissects the uplifted surface, represents the youngest cycle of erosion. According to Alcock (1935), two stages of development are recognized in the stream valleys of the Chaleur Bay area, a mature topography which was produced in the early and middle part of the Pliocene, and a youthful topography which developed through renewed uplift in late-Pliocene times in which the stream valleys entrenched into the edge of the plateau and below the highland surfaces. Studies by Riley (1962) and Smith (1958) also suggested the erosional surfaces of western Newfoundland indicate successive stages of uplift during Tertiary times. Studies of the stratigraphy and structure of the sediments on the continental shelf and slope (Bartlett and Smith 1971; Emery et al. 1970) indicate that the Mesozoic and Tertiary drainage systems were similar to those of today, and fairly constant sediment supplies without major tectonic upheavals were maintained from the land areas throughout these periods.

Before and during the Wisconsin stage of the Pleistocene period the whole area was covered by ice masses which moved south and east from the Shield into the areas occupied by the river and Gulf and local ice caps which formed on the highlands of the Gaspé Peninsula and the New Brunswick highlands (Flint 1951; Prest and Grant 1969). The local glaciers were most active before and after the advance and retreat of the continental ice sheets, and local readvances from highland centers into the Gulf in late-glacial times played a signficant part in the morphological development of some parts of the Gulf (see Chap. 9). In general, the highland areas were left with an intermittent veneer of drift, whereas the lowland areas have an almost continuous cover of ground moraine (Fig. 6).

The pattern and timing of the retreat stage of the ice from the whole area, and the pattern of postglacial submergence have been described by Prest and Grant (1969) and Prest (1970). They suggest that the ice withdrew from the region between 16,000 and 7000 years ago. As the ice withdrew it was accompanied by the intermittent postglacial submergence and emergence of the border of the southern Gulf. The apparent change in sea level varied from zero along a line between Prince Edward Island and the southwestern corner of Newfoundland, to about 250 ft on the Gaspé Peninsula. The present level has been established gradually during the last 7000 years.

3

Climate and oceanography

Climate

Climatic conditions ultimately determine the nature of the geomorphic and weathering processes. Precipitation effects chemical alterations of terrigenous material and also removes the resulting products (detrital particles and dissolved material) from the site of weathering. Temperature controls the rate of chemical reactions in the weathering processes.

The land areas adjacent to the St. Lawrence River and Gulf lie in a humid microthermal climatic province — Province "D" of the climatic zone classification of Köppen (see Straller 1970, Chap. 8). It is a rain–snow climate with cold winters having a mean temperature of its coldest month below 26.6°F and its warmest month above 50°F. This province may be further subdivided into two main climatic regions, referred to as a subarctic region, and a humid continental region with cool summers and no dry season (see Fig. 7).

The subarctic climatic region covers: (1) the

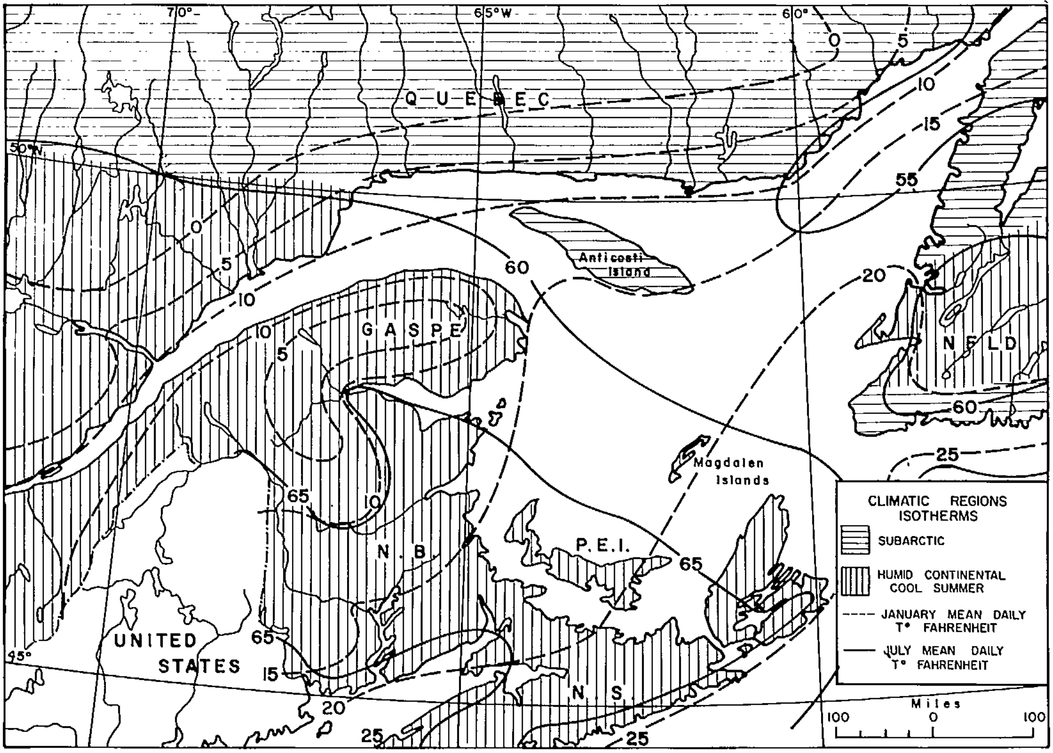


Fig. 7. Climatic regions and isotherms of the Gulf of St. Lawrence region (modified from Canada Atlas Maps 21 and 30).

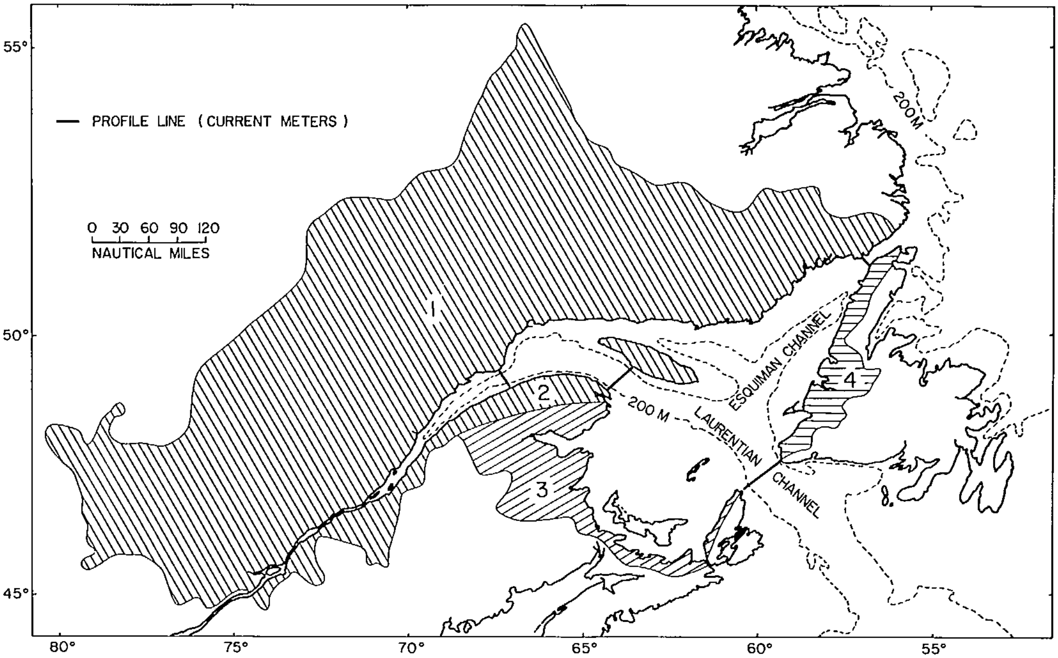


FIG. 8. Major drainage basins of eastern Canada (modified from Trites 1971). Drainage basins: 1, St. Lawrence (north); 2, St. Lawrence (south); 3, Maritime Appalachian; 4, Newfoundland Appalachian.

area along the north shore of the Gulf east of Sept Îles, and the interior of Quebec and Labrador to the north and east, (2) Anticosti Island, and (3) most of the Newfoundland Highlands. These areas are characterized by cold, snowy (100–150 inches), long (160–200 days of snow cover) winters with an average January temperature between 0 and 20°F. The summers are cool, wet, and short (only 1–3 months) having a mean temperature above 50°F (mean July temperature 55–60°F). The total precipitation for this area varies from 30 to 40 inches with 16–20 inches of this occurring in the period from June to November.

This region supports a boreal forest composed mainly of coniferous trees such as balsam, fir, and spruce, which grow on poor soils of the podzol and humic podzol groups developed from a thin cover of glacial drift (chap. 2). Shallow peat bogs and barrens are also common because of the poor drainage in this region (Rowe 1959).

In contrast, the Laurentian Highlands adjacent to the north shore of the St. Lawrence River and Estuary west of Sept Îles, the St. Lawrence Lowlands and the Appalachian region, with the exceptions noted previously, lie in the humid continental climatic region. This region has a slightly warmer (mean January temperature between 5 and 25°F) shorter (80–160 days of snow cover) winter with less snow (60–100 inches) than the subarctic region. The summers are mild with at least 4 months having a temperature above 50°F (mean July temperatures about 65°F). Total annual precipitation for this region varies from 38 to 55 inches with the highest values being recorded from the Atlantic coast of Nova Scotia and Newfoundland.

This region supports a more varied type of forest than the subarctic region and is characterized by mixed coniferous (fir, spruce, pine, etc.) and deciduous (maple, oak, elm, etc.) forest regions (Rowe 1959). The extent to which these forest regions occur in any given part of this region depend on the local microclimates, topography, and soil materials which are mainly podzols developed from the various glacial tills (Chap. 2).

Drainage

It has been estimated that the Gulf of St. Lawrence receives an average freshwater input of 474,537 ft.^{3}/sec from the rivers draining into it (Trites 1971). The St. Lawrence River is the largest single contributor of fresh water (approximately two-thirds of the total) with a discharge of about 367,000 ft.^{3}/sec at Quebec City according to Parde (1948). The drainage area of the St. Lawrence River is about 500,000 square miles of which 250,000 square miles lie in the Province of Quebec (Fig. 8). This area is drained by 13 rivers of more than 100 miles long, including the three and four tributaries of the Saguenay and Ottawa rivers, respectively. On the south side, four main rivers enter the St. Lawrence River and all are upwards of 100 miles long with the Richelieu 210 miles long (Table 1).

The southern Gulf receives the drainage from the Chaleur Bay Uplands, the New Brunswick Highlands, and the lowlands and highlands of Nova Scotia through a number of rivers of which the longest are the Restigouche (~50 miles long with a drainage area of 2900 square miles), the Miramichi (~130 miles long with a drainage area of 4900 square miles), and the Margaree (~38 miles long with a drainage area of 449 square miles). The eastern Gulf receives the drainage of the western slopes of the Newfoundland Highlands through numerous rivers of which the largest is the Humber River system which is about 75 miles long and has a drainage area of 2800 square miles.

In addition to rivers, the Gulf receives fresh water from rain and snow which, according to an estimate made over a 12-month period by Trites (1971), amounted to an average of about 83,555 ft^3/sec (total precipitation–evaporation).

Freshwater Chemistry

The chemical composition of the fresh water supplied to the Gulf by the St. Lawrence River and two of its tributary rivers (the Saguenay on the north and the Richelieu on the south), and the Miramichi River entering the southern Gulf are given in Table 2. The most abundant cations and anions (expressed in ppm) are calcium and bicarbonate indicating that the fresh waters entering the Gulf from these sources are ordinary calcium bicarbonate waters, some of which are dilute in the rivers draining the Canadian Shield (the Saguenay) and the highlands of New Brunswick (the Miramichi).

TABLE 1. Some major rivers of the St. Lawrence drainage basin.

River	Approximate length (statute miles)	Drainage area (square miles)[a]
Northshore		
Ottawa	685	55,560
St. Maurice	325	16,448
Saguenay	475	30,000
Bersimis	240	6,400
Outardes	270	7,200
Manicouagan	310	19,100
Ste. Marguerite	130	—
Moisie	210	7,350
Romaine	270	5,475
Natashquan	220	6,170
Southshore		
Chaudière	120	2,328
St. Francois	165	3,682
Richelieû	210[b]	8,523

[a] Drainage areas derived from Water Research Paper 119, Department of Northern Affairs, Ottawa.

[b] Only 75 miles in the Province of Quebec.

TABLE 2. Analyses[a], in parts per million, of water from rivers draining into the Gulf of St. Lawrence.

River	Constituents (*ppm*)									
	HCO_3^{-1}	SO_4^{-2}	Cl^{-1}	F^{-1}	NO_3^{-1}	Ca^{+2}	Mg^{+2}	$Na^{+1}+K^{+1}$	Fe^{+3}	SiO_2
St. Lawrence at Levis, Que.	84	20	16	–	0.4	28	5.8	Na^{+1} 8.0 K^{+1} 1.1	0.02	1.7
Saguenay River at Riverbend, Que.	6.1	3.1	0.5	–	0.6	3.6	1.5	–	0.20	3.0
Richelieu River at St. John's, Que.	43.3	12.0	1.6	–	0.52	15.6	4.1	3.6	0.05	6.6
NW Miramichi River at Red Bank, N.B.	6.7	4.8	0.70	–	0.84	5.5	2.4	3.1	0.16	5.0

[a] Data from Leverin 1947.

Dissolved and Suspended Loads

The total dissolved load of the St. Lawrence River is about 160 ppm according to Leverin (1947), whereas its tributaries and the Miramichi River carry smaller amounts of dissolved solids (Table 3). The dissolved load is markedly less (<50 ppm) in rivers such as the Saguenay and the Miramichi which drain the chemically resistant rocks of the Canadian Shield and the New Brunswick Highlands than in those such as the St. Lawrence and the Richelieu which drain less resistant sedimentary rocks.

The St. Lawrence River transports one of the least amounts of sediment per square mile of drainage area (~8 tons/square mile) of any major river of the world. This is due partly to the presence of the Great Lakes which form huge settling basins, and partly to the present climatic conditions, and the geology of its drainage basin (Holeman 1968). Although there is little data on the suspended matter entering the Gulf, data collected from the St. Lawrence River at Montreal during 1968 show that the concentration of suspended matter varies daily and seasonally from 3 to 24 ppm in relation to variation in discharge rates.

In relation to the 58 major rivers of the world, the St. Lawrence River ranks 14th in the drainage area, 11th in average discharge rate, but only 35th in its yearly suspended load (Inman and Nordstrom 1971).

On the average, the amount of suspended matter transported by the St. Lawrence River over a year is ~10,700 tons per day. In a year this is enough to supply each square mile of the Gulf with 41 tons of suspended matter. If only the depositional areas in the Gulf are considered, the suspended matter supplied amounts to about 98 tons per square mile. In contrast, the Mississippi transports about 2 million tons of suspended matter per day (Inman and Nordstrom 1971).

The composition of the suspended matter in the river has not been studied in detail, but preliminary analyses indicate that it is composed of 37.5% organic matter and 62.5% inorganic material (Water Quality Division, Department of the Environment, 1970).

Oceanography

Marine Water Masses

The waters of the Gulf, Estuary, and the River as far west as the bridge at Quebec City are marine with the salinity ranging up to $35^{0}/oo$. In the open Gulf they usually vary between $26^{0}/oo$ and $35^{0}/oo$. Oceanographic conditions are complex in the Gulf and estuary as a result of the mixing of water masses of acutely contrasting temperature and salinity (Hachey et al. 1956).

In terms of vertical temperature distribution the Gulf waters usually have a threefold zonation in summer (Fig. 9). During the summer months, there is a warm (8–18°C) surface layer, beneath which is an intermediate cold water layer that usually has temperatures of 4°C to less than 1°C extending to a depth of about 190 m, and finally a deep relatively warm (4–6°C) water layer which has a temperature maximum at 200–300 m. The two upper layers undergo seasonal varia-

TABLE 3. Dissolved and suspended loads of selected rivers draining into the Gulf of St. Lawrence.

River	Drainage area (*10^3 square miles*)	Average discharge[a] (*10^3 cfs*)	Total dissolved solids (*ppm*)	Total suspended load[b] (*ppm*)	Suspended load (*10^4 ton/year*)	Geology of source area
St. Lawrence at Levis, Que.	498	367	160	8.4	389	Sedimentary + igneous + metamorphic
Saguenay River, Que.	30	52	20	2.3	15.1	Igneous + metamorphic
Richelieu River at St. John's, Que.	8.5	11.4	87.4	8	11.5	Sedimentary
Miramichi River, N.B.	.49	3.9	32.3	2.2	1.1	Igneous + metamorphic

[a] Discharge rates derived from Water Research Paper 119 and Surface Water Data Report (1968) for Atlantic Provinces (Dept. E.M.R., Ottawa) and Parde (1948).

[b] Data from Leverin (1947) and Ann. Hydr. Qual. des Eaux (1968), Dept. Nat. Res., Québec.

tions and due to strong mixing become nearly one thermally during the winter months. The temperature maximum at the deep layer may vary seasonally from 4 to 6°C.

In terms of vertical salinity distribution the warm surface layer is usually composed of low saline water (26⁰/oo–32⁰/oo), and the cold water layer has a salinity range of 32⁰/oo to 34⁰/oo. In the deep warm layer, however, the salinity seldom varies from 34.6⁰/oo by more than 0.2⁰/oo.

Water Chemistry

From a geochemical viewpoint the important characteristic of the water chemistry in the Gulf is the oxygen content and the *p*H of the waters. Generally, the waters are well oxygenated and the concentration of dissolved oxygen decreases with depth (L. M. Lauzier 1965 personal communication). At the surface the dissolved oxygen content is about 8 ml/liter, whereas near the bottom it varies from 7.5 ml/liter in the shallower parts to 1.8 ml/liter in the deeper parts. Nowhere is the bottom water stagnant.

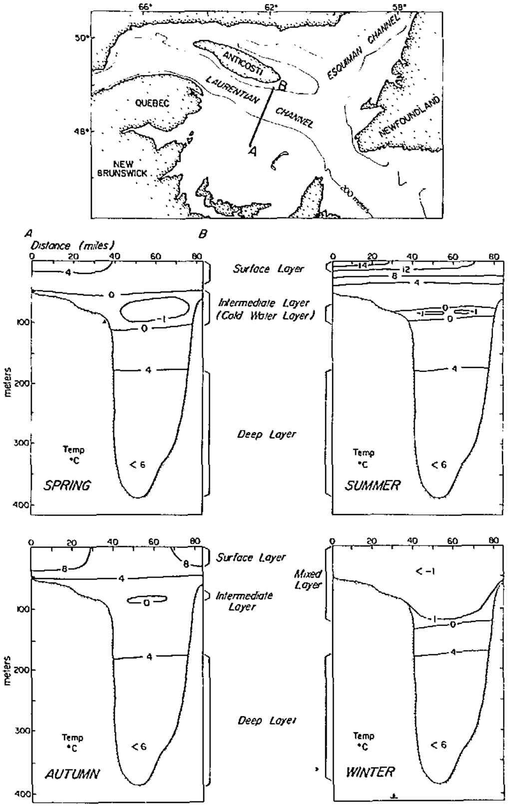


FIG. 9. Seasonal (spring–winter) variations in the thermal structure of the water layers in the Laurentian Channel (modified from Lauzier 1960).

The *p*H of the water ranges from 7.6 to 8.0 (MacIntyre 1965). The *p*H is highest in the surface waters and lowest near the sediment–water interface.

Suspended Matter

Although the concentrations and distribution of the suspended matter in the marine waters of the Gulf have not been studied in detail, preliminary measurement on water transparencies (Secchi disc, and light-scattering photometer) and suspended loads have been made by various workers.

Secchi disc measurements by Nota and Loring (1964) during July 1962 reveal considerable variation in the surface water transparencies in the estuary and Gulf (Fig. 10). Such measurements showed that: (1) the lowest transparencies (maximum turbidity) occur in the estuary between Quebec City and the mouth of the Saguenay River where strong mixing of fresh and saline waters takes place; (2) below the Saguenay the turbidity of the waters decreases with transparencies increasing to 10–15 m in depth; (3) transparencies in the estuary and western Gulf vary from 10 to 15 m with the exception of a higher turbid area (5–10 m) adjacent to the north shore of the Gulf, opposite Anticosti Island; and (4) southeast and northeast of Anticosti Island as far as Cabot and Belle Isle straits, the waters are clearer with a transparency greater than 15 m. These variations in water transparencies reflect the mixing of the relatively turbid, less saline St. Lawrence River outflow, and the outflow of rivers entering from the adjacent areas with the clear, incoming, saline oceanic waters.

Light-scattering photometric measurements which determine the decrease in the intensity of scattered light through a cell of known length (T units per m) are shown in the vertical distribution of suspended particles in the Gulf during July 1961 (Cook 1962) (Fig. 11).

A profile across Cabot Strait shows: (1) the outflowing surface water on the south side of the Strait has a low turbidity; (2) the intermediate cold layer which has an outward flow along the southern side of the Strait (see Circulation) is more turbid than the surface layer and has a high turbidity core (~6 units) at a depth of 100 m, whereas on the opposite side of the Strait there

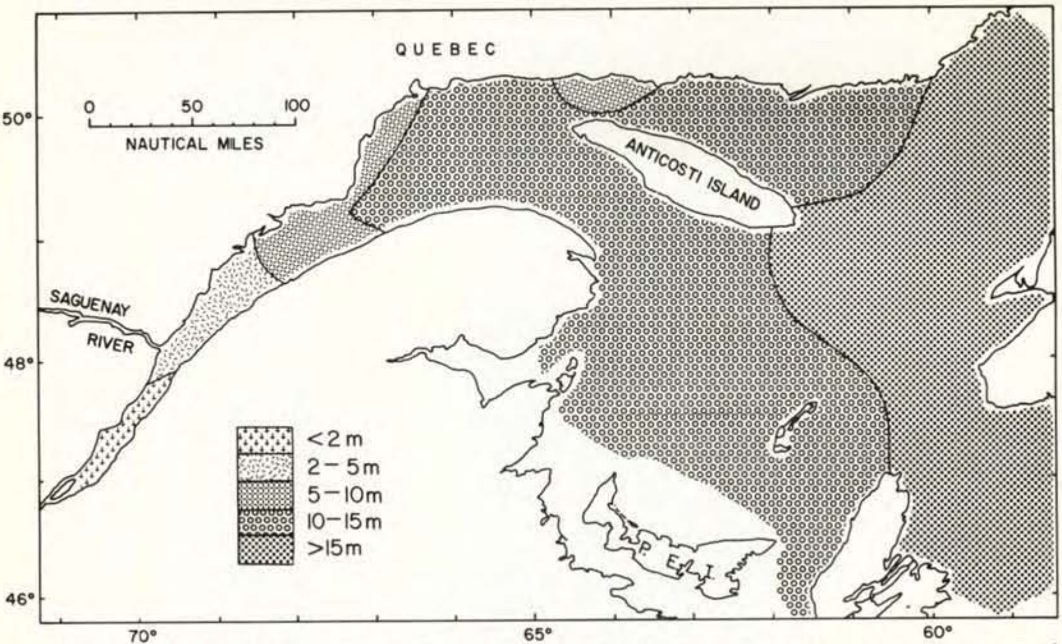


FIG. 10. Transparency of the water in meters according to Secchi disc measurements (modified from Nota and Loring 1964).

is a less turbid (<2 units) inflow of water; (3) the warm inflowing bottom water near the south side of the Strait is also turbid with a high turbidity core of between 350 and 400 m, whereas the bottom waters on the northern side are much less turbid. In contrast, a section across the Gaspé Passage shows that the surface and intermediate layers have little turbidity, but the inflowing bottom water has a high turbidity core between 275 and 300 m along the northern side of the Passage. In the estuary between the Gaspé coast and Pte. des Monts the water to depths of 100 m is fairly clear. Below 100 m the turbidity increases towards the bottom with the maximum turbidity occurring near the south side of the estuary at a depth of 275 m.

These measurements suggest that suspended matter is being transported out and into the Gulf, and the amount is related to the nature and behavior of the various water masses in the Gulf. The general distribution pattern of suspended matter inferred from these measurements has been generally confirmed by the work of D'Anglejean (1969 and 1970) which is discussed below.

Preliminary measurements by D'Anglejean (1969) at various locations showed that the concentration of *suspended matter* in the water column varies from 0.3 to 1 ppm.

In Cabot Strait the concentration of suspended matter in surface layers ranged from 0.3 to 0.4 ppm with 10–15% of the material being of inorganic origin. Between 150 and 350 m, the intermediate cold layer (Fig. 9) contained similar concentrations of suspended matter but a much higher proportion (25–30%) of inorganic matter. Below 350 m, in the warm bottom waters the concentration of suspended particulate material ranges from 0.6 to 0.7 ppm with the inorganic fraction comprising 45% of the total. D'Anglejean calculated that the net outflow of suspended matter amounted to 4500 tons/day whereas the daily inward net flow amounted to 1100–2000 tons of material from outside the Gulf. Analyses of data from the Gaspé Passage suggested that the net inflow of suspended matter in this area amounts to 4000–5000 tons/day, almost four times the inflow at Cabot Strait. It is believed that the additional inflowing material is derived from sources within the Gulf.

In addition D'Anglejean found that slightly higher concentrations (1–2 ppm) of suspended material were present in the southern Gulf and were related to the water circulation pattern in this area.

Mineralogical analyses of the suspended matter revealed that the inorganic fraction was composed of quartz, amphiboles, illite, and chlorite which is similar to the mineralogical composition of the clay fractions (<2 μ) of the recent marine sediments in the Gulf (Chap. 7 and Nota and Loring 1964).

Circulation

Although the surface currents and circulation patterns have been investigated in the Gulf of St. Lawrence by various workers over the past 10 years, only the general features of them are known to any extent, and these have been summarized by Trites 1971.

Current measurements have been undertaken across Cabot Strait, Gaspé Passage, the St. Lawrence Estuary at Pte. des Monts, Strait of Belle Isle, and near Rimouski (Farquharson 1962, 1966; Farquharson and Bailey 1966; Forrester 1967). Current data from the estuary and Gaspé Passage show that there is an outflow of surface water along the Gaspé coast referred to as the *Gaspé Current* which is mostly confined to the upper 25–50 m, and an inflowing water current beneath the outflow with its core about 100 m below the surface. This inflowing water reaches the surface to the north adjacent to Anticosti Island (Fig. 12). In Cabot Strait the strongest currents are associated with a distinct seaward-moving layer which occupies most of the southern and central part of the Strait, whereas the inward flow is concentrated below the outflow and in a narrow band along the north side of the Strait adjacent to Newfoundland. The water entering the Gulf is apparently deflected to the right and flows northeastwards along the west coast of Newfoundland. In the Strait of Belle Isle, oceanic water moves into the Gulf along the north side of the Strait and follows along the north side of the Gulf. Some of this water passes through Jacques Cartier Passage and becomes involved in a counter-clockwise circulation.

Circulation patterns have also been studied

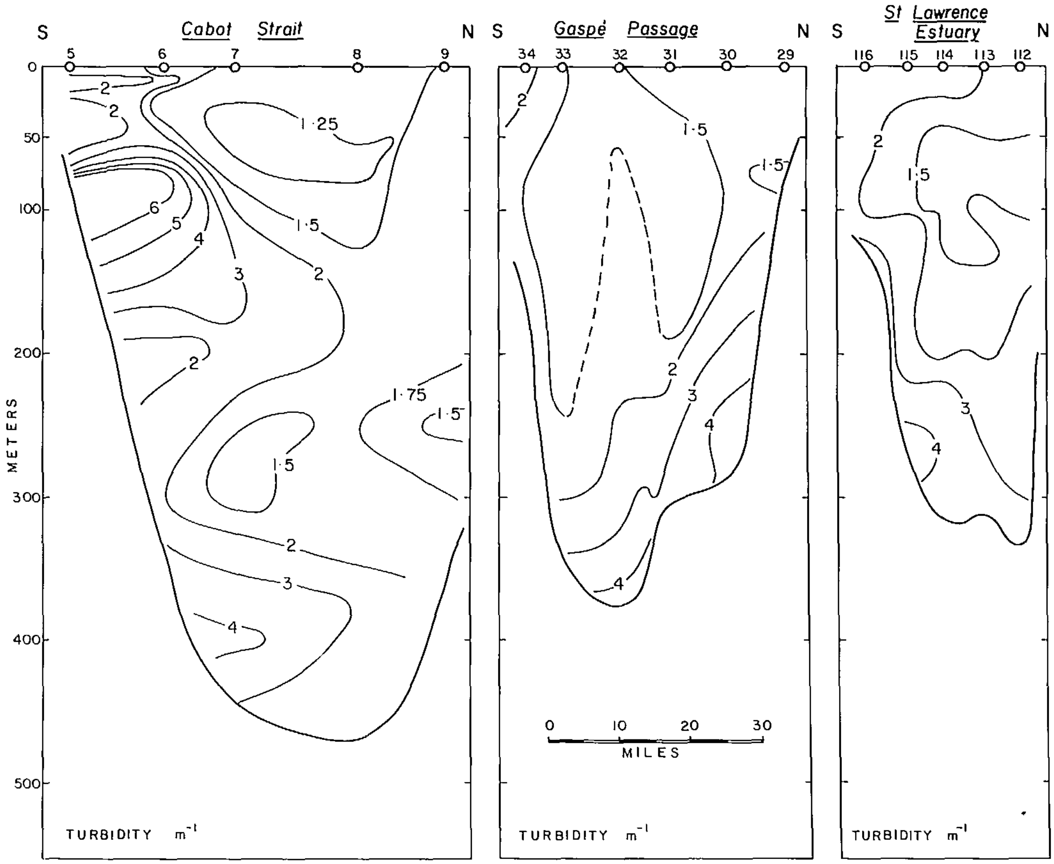


FIG. 11. Turbidity of the water along selected sections of the Laurentian Trough according to light-scattering measurements (data from Cook 1962).

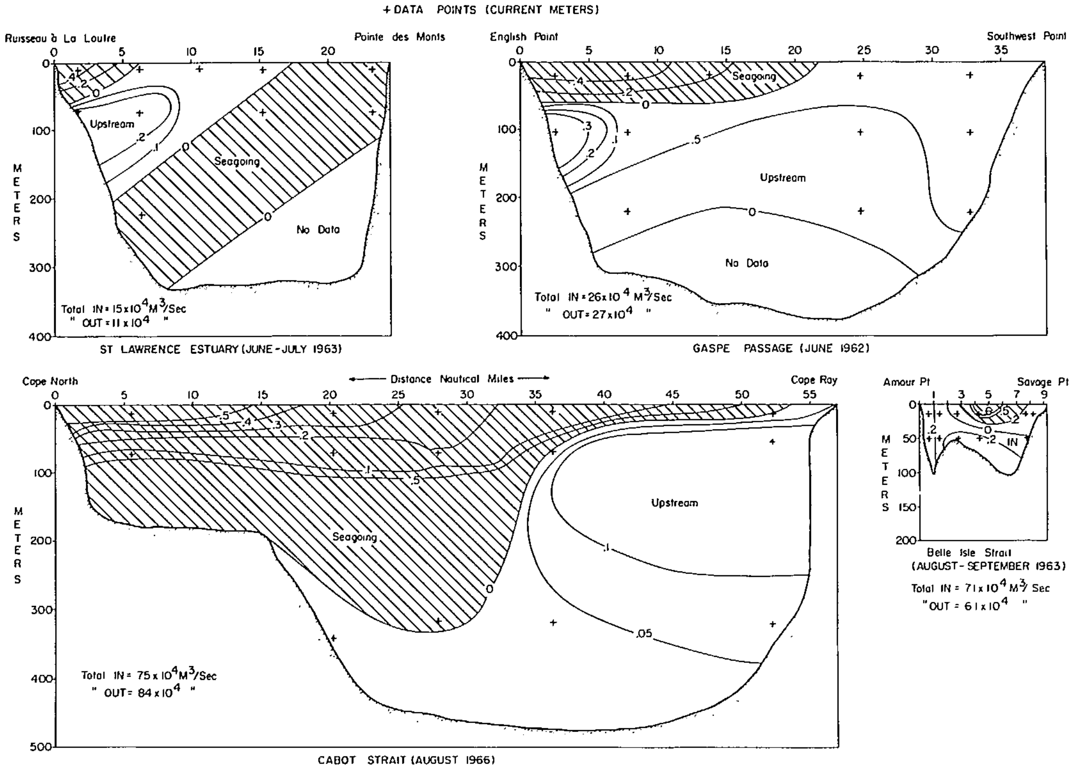


FIG. 12. Residual currents through three cross sections (shown in Fig. 8) of the Laurentian Trough and one section of the Strait of Belle Isle (from Trites 1971).

from the use of drift bottles (Bumpus and Lauzier 1965; Lauzier 1967), and parachute drogues have been used by other workers (Blackford 1965a; Trites 1968). From these data Trites (1971) has proposed a summer circulation pattern which is shown in Fig. 13. The main features are: (a) a general two-way flow in both Cabot and Belle Isle straits; (b) a counter-clockwise circulation pattern in the Gulf; and (c) the "Gaspé current" which begins to develop in the Rimouski–Pte. des Monts area and extends along the entire length of the Gaspé coast. The highest speeds are found in the Gaspé current and in the outflow through Cabot Strait, reaching values of 10 to 20 miles/day (21–42 cm/sec).

Theoretical circulation models based on simplified equations of motion in which wind was considered the primary driving force have produced a similar circulation pattern to that in Fig. 13 (Blackford 1965b, 1966). As a result it has been suggested (Trites 1971) that both wind and freshwater discharge are the most important factors in producing the large scale surface layer circulation in the Gulf. In addition, wind-generated waves play an important role in determining the coastal morphology of the region.

Near-bottom current measurements, which are so important to an understanding of the distribution of recent surface sediments in the Gulf, are rather limited, but useful results have been obtained from the use of seabed drifters (Lauzier 1967) in the southern Gulf (Fig. 14). The most important features shown by these data are: (a) an inward flow along the 100–200-m contours on the northern side of Cabot Strait; (b) a counter-clockwise drift off Chaleur Bay and the northeastern coast of New Brunswick, with a return drift along the western and northern edges of Orphan Bank; (c) a southeasterly drift along the 100–200-m contours at the edge of the Magdalen Shelf, towards Cabot Strait; (d) a northeasterly drift along the shore of Cape Breton Island; (e) a general convergence towards the southern end of the Magdalen Islands from a large area of the central shelf; (f) upwelling along the northeastern coast of New Brunswick and the mainland side of Northumberland Strait;

and (g) along the north coast of Prince Edward Island. The residual bottom currents based on the seabed drifters appear to be mostly in the range of 0.3–0.7 miles/day or 0.6–1.5 cm/sec (minimum values). The relation between the distribution of various sediments and bottom currents will be discussed in Chapters 5, 6, and 9.

Tides and Tidal Currents

The semidiurnal and diurnal (daily) tides from the North Atlantic Ocean are propagated through Cabot Strait (Farquharson 1962), and counterclockwise around the Gulf. These are illustrated in Fig. 15 which shows the semidiurnal lunar tidal constituent (M_2) and the diurnal constituent (K_1). There are two amphidromic points for the M_2 constituent — one near the northwest coast of the Magdalen Islands and a second near the western end of the Northumberland Strait where the tidal wave progresses around a point or center of little or no tide. In most areas of the Gulf the semidiurnal constituent dominates (Fig. 15). Tidal ranges increase rapidly towards the St. Lawrence River with a mean range of 13 ft near Quebec City.

Tidal currents seldom exceed 0.5 knots (26 cm/sec) except in locally confined areas such as the St. Lawrence Estuary and Cabot, Belle Isle, and Northumberland straits. In Cabot Strait tidal streams are generally in the order of 1 knot (52 cm/sec) with greater speeds being reached in Northumberland Strait. These tidal streams may play an important role in the erosion, transport, and deposition of recent marine sediments in the southern Gulf (Loring et al. 1970; Kranck 1971).

Ice

Each year in the River and Gulf considerable quantities of sediments are ice-rafted from the shorelines by the sea and the shorelines are modified by the action of surface ice (Nota and

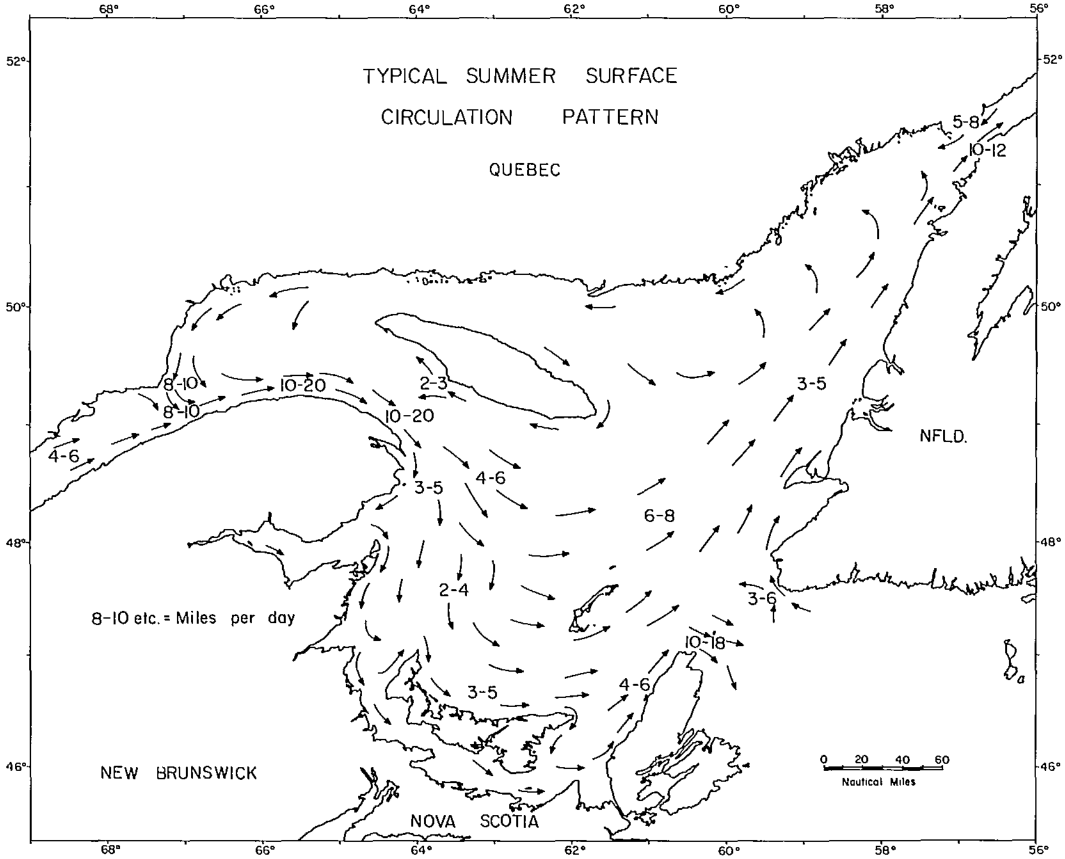


FIG. 13. Surface water circulation pattern in the Gulf of St. Lawrence during summer (from Trites 1971).

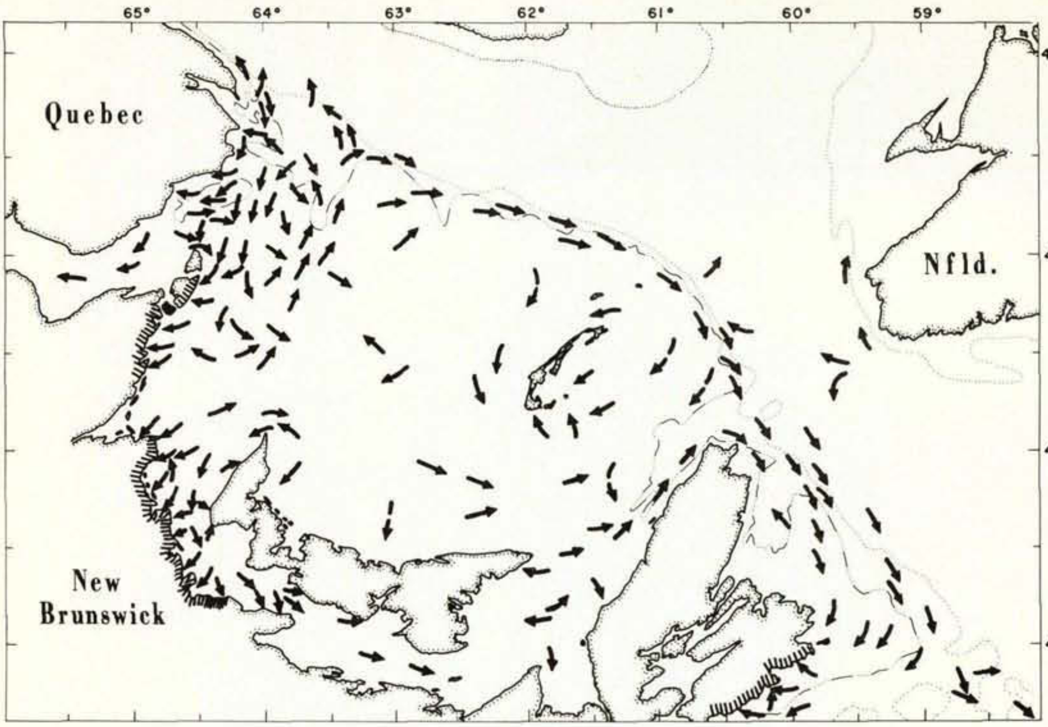


FIG. 14. Inferred residual bottom drift in the southern Gulf of St. Lawrence (from Lauzier 1967).

Loring 1964; Dionne 1968). Ice in varying concentrations is present in the River and Gulf for several months each year and arises from three sources (El Sabh 1969): (a) Labrador ice that enters through the Strait of Belle Isle; (b) ice from the St. Lawrence River and Estuary; and (c) ice fields which are locally formed in the Gulf.

The general features and decay of the ice cover during the winter and spring months is depicted in Fig. 16 from data compiled by Matheson (1967) over a 5-year period. It may be seen that in December ice starts to form in sheltered areas. During January the ice concentration increases rapidly although the region west of Newfoundland remains unfrozen due to the influx of water through Cabot Strait. By the last week of January the southwestern and central parts are covered by heavy ice from the River and Estuary. The ice is transported seaward through Cabot Strait as the winter progresses. Ice concentrations along the north shore of the Gulf and south shore of Anticosti generally tend to be lower because of the prevailing offshore winds. The offshore movement of ice in these areas is an important means of transporting any incorporated shore material into the offshore regions of the Gulf (see Chap. 5 and 6). Major ice concentrations usually last until April when a rapid breakup starts because of spring warming. During this period most of the sediments incorporated into the ice at the shoreline and transported throughout the Gulf are deposited. Ice is retained longest in the southern part of the Gulf and Strait of Belle Isle.

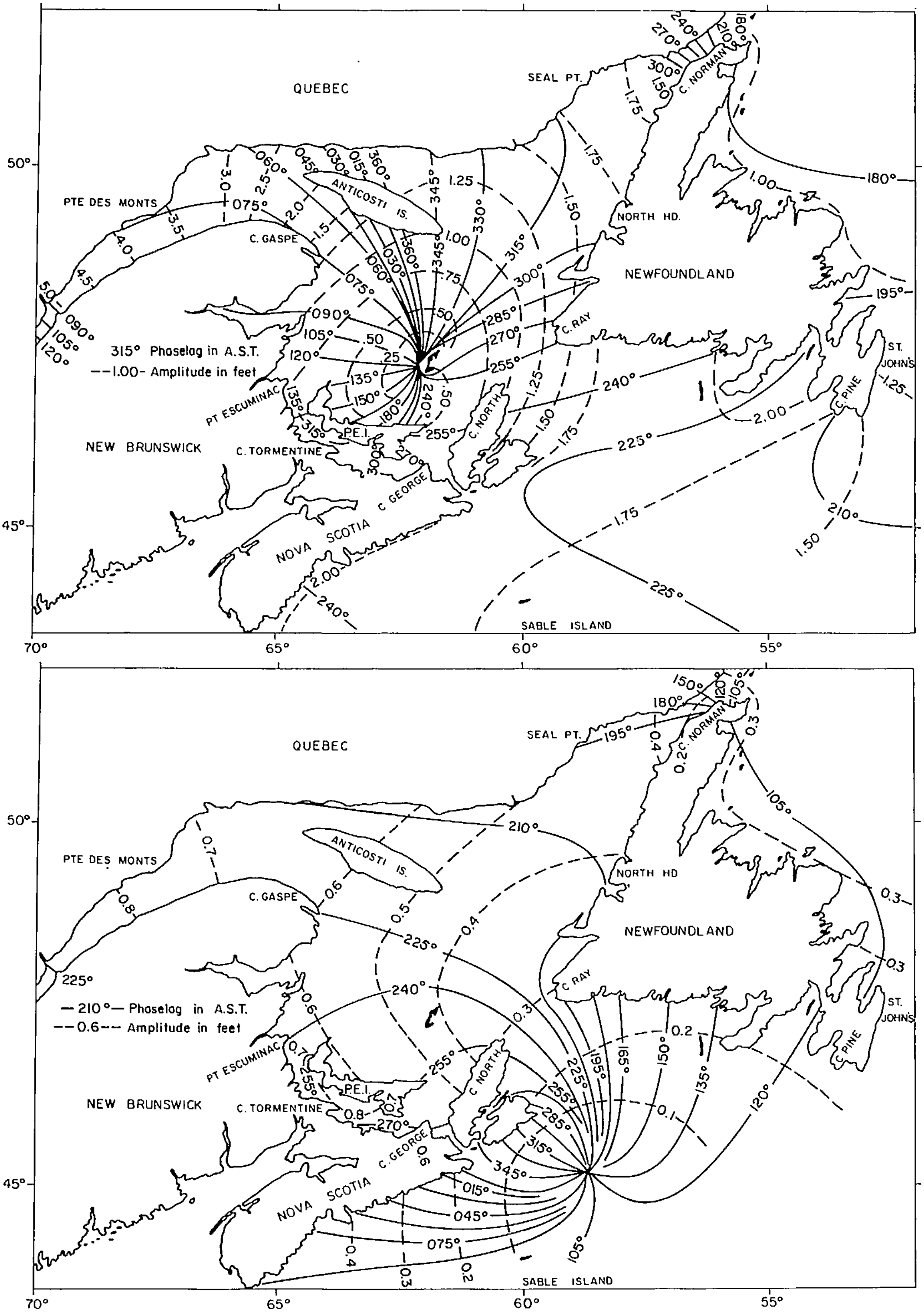


FIG. 15. (*Top*) Semi-diurnal lunar tidal constituent, M_2; (*bottom*) lunisolar diurnal tidal constituent K_1 in the Gulf of St. Lawrence (after Farquharson 1962).

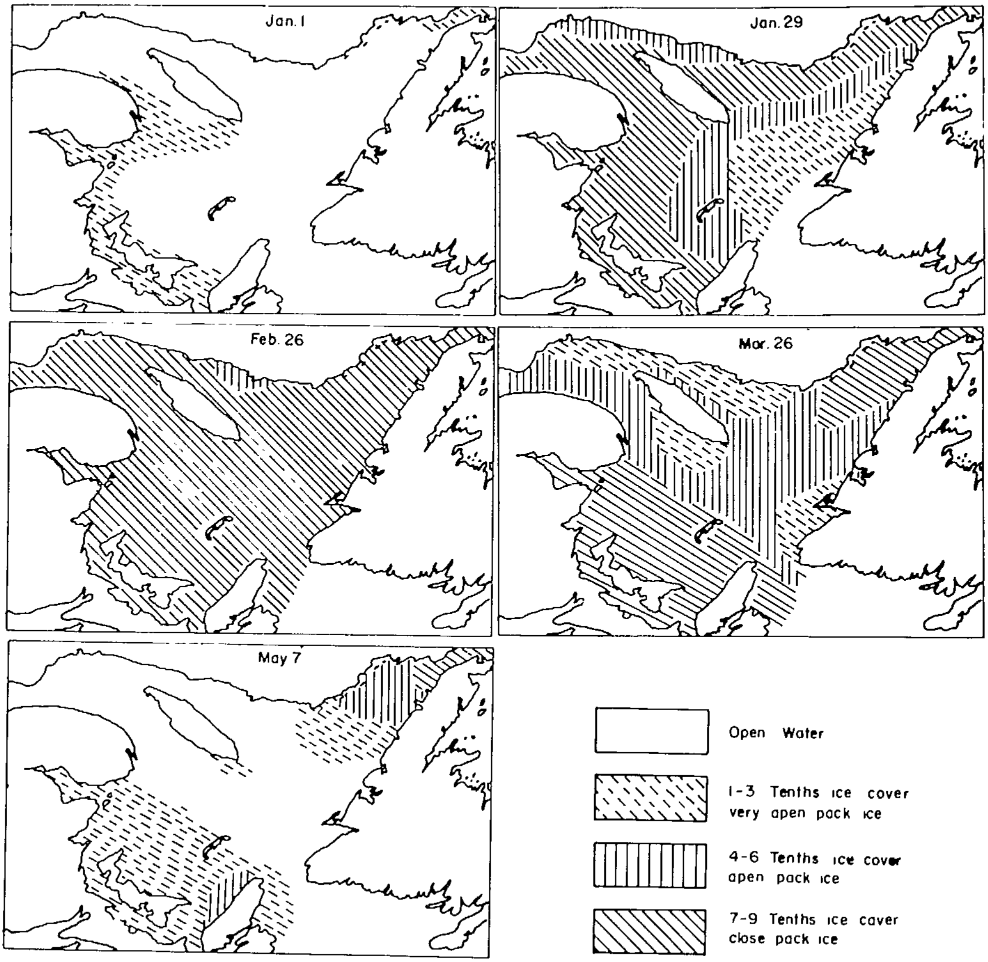


FIG. 16. Average ice concentrations in the Gulf of St. Lawrence (modified from Matheson 1967).

4

Submarine geomorphology

The Gulf of St. Lawrence has an irregular submarine topography composed of long deep valleys and shallow platforms or shelves (Fig. 17). Water depths are less than 600 m (~330 fath) with one quarter of the area shallower than 55 m (~30 fath) and less than one-fifth deeper than 275 m (~150 fath).

The topography is developed on the seaward extension of two physiographic units: The St. Lawrence Lowlands and the Maritime Plain (Fig. 2).

The submerged portion of the St. Lawrence Lowlands extends northeast from Quebec City and occupies the narrow estuary of the St.

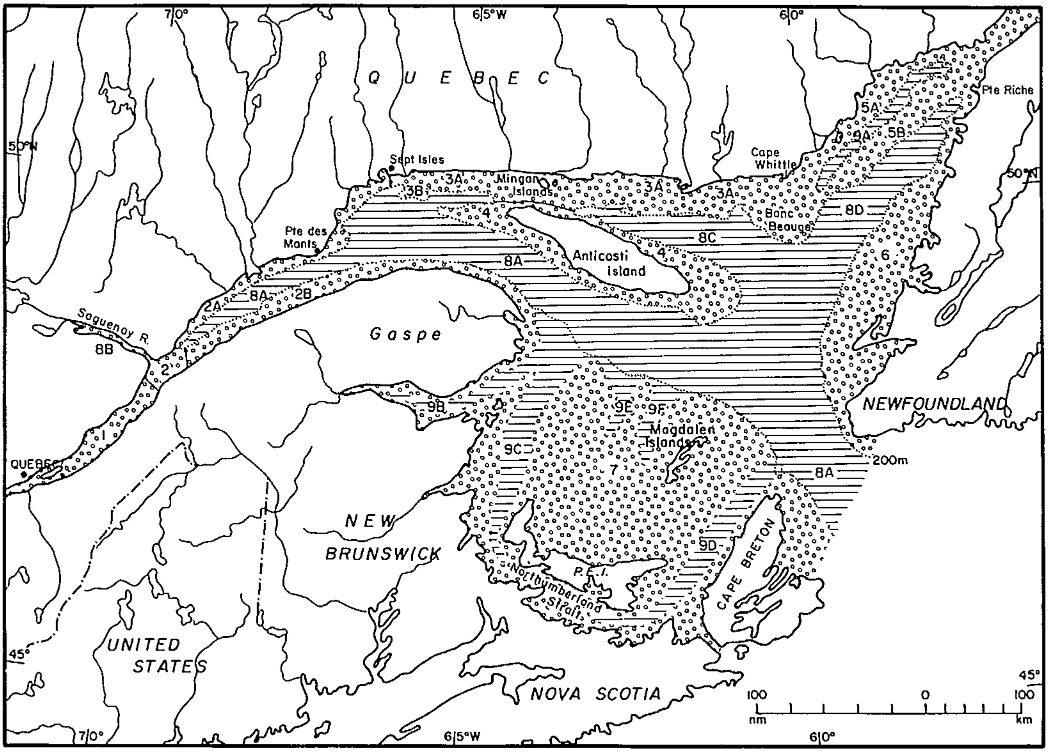


FIG. 17. Physiographic divisions of the Gulf of St. Lawrence. Shelves (water depth <200 m): 1, St. Lawrence River floor; 2, St. Lawrence Estuary shelves; 2A, Les Escoumins Shelf; 2B, Gaspé Shelf; 3, North Shore Shelf; 3A, Inner Shelf; 3B, Outer Shelf; 4, Anticosti Shelf; 5, Quebec–Labrador Shelf; 5A, Inner Shelf; 5B, Outer Shelf; 6, Newfoundland Shelf; 7, Magdalen Shelf. Submarine troughs (water depths >200 m): 8, Laurentian Trough system; 8A, Laurentian Trough; 8B, Saguenay Fjord; 8C, Anticosti Trough; 8D, Esquiman Trough; 9, Shelf valleys (water depth <200 m); 9A Mécatina Trough; 9B, Chaleur Trough; 9C, Shediac Trough; 9D, Cape Breton Trough; 9E, Western Bradelle Trough; 9F, Eastern Bradelle Trough.

Lawrence River and the northern part of the Gulf. It is deeply dissected into a system of long submarine valleys, referred to as the Laurentian Trough system, and less deeply submerged remnants which form submarine platforms or shelves of varying width and relief. In the northern Gulf this topography has the appearance of a cuesta-like landscape of which Anticosti and the Mingan Islands are the largest unsubmerged remnants (see Chap. 2).

The Maritime Plain occupies the southern embayment of the Gulf. It forms a broad, semicircular, shallow submarine area known as the Magdalen Shelf and is underlain by nearly horizontal rocks of Permo-Carboniferous age. The shelf is indented by fairly shallow valleys and depressions, and is broken by low rising ridges and banks. Upland remnants of this submerged lowland, the seaward extension of the Carboniferous lowlands of New Brunswick and Nova Scotia, protrude above water to form several islands, the Magdalens and Prince Edward Island being the largest. Beyond the edge of the shelf, an eroded edge of the lowland forms part of the Laurentian Trough: the trunk valley of the system.

Laurentian Trough System

Dimensions and Physical Characteristics

The dimensions and physical characteristics of the Laurentian Trough, its tributary valleys, and some of the major shelf valleys are summarized in Table 4.

The Laurentian Channel or Trough is the long, deep trough-shaped valley which forms the most conspicuous feature of the submarine topography in the St. Lawrence Estuary and Gulf (see Bathymetric Chart 1, in pocket). It originates near the mouth of the Saguenay River in the shallower reaches of the St. Lawrence Estuary 103 naut. miles below Quebec City. From here, the deep broad course of the valley can be easily traced bathymetrically northeastward through the estuary, beyond which it bends smoothly to the southeast, between Anticosti Island and the Gaspé Peninsula. It crosses the Gulf, and continues through the Cabot Strait to its terminus at a depth between 500 and 600 m at the edge of the continental shelf southeast of Newfoundland.

The trough has relatively straight steep walls and a broad hummocky floor with widths up to 50 naut. miles (average ~30 naut. miles). Elongated depressions occur in the floor along its entire length (668 naut. miles, 1240 km) which range from 1 naut. mile (1.85 km) to 103 naut. miles (191 km) in length and from 40 m (~22 fath) to about 100 m (~55 fath) in depth.

After the initial sharp descent of the headwall from 100 m to about 240 m (131 fath) water depths are consistently greater than 300 m (164 fath) and over much of the floor are greater than 400 m (~219 fath). Depths of up to 535 m (292 fath) are reached in a large floor depression near Cabot Strait.

Within the Gulf, the Laurentian Trough has three main tributary valleys which join it discordantly: The Saguenay, the Anticosti, and the Esquiman. Several smaller shelf valleys are also confluent with this system (Fig. 17).

The fjord-like valley occupied by the Saguenay River joins the main trough discordantly near its head. It is a long (~50 naut. miles) narrow (1–3 naut. miles) valley with straight and highly polished rock walls ranging in height from 366 m above to 300 m below sea level. Bevelled spurs are common. Elongated deep basins with depths to 300 m, separated by narrow shallow (<100 m) sills, occur along its entire length. At its mouth lies a deep inner basin, with water depths of 300 m, which is separated from the head of the main trough by a narrow shallow (40 m) sill.

Southeast of Anticosti Island the main trough is joined discordantly by the Anticosti Channel from the northwest (Chart 1, in pocket) and by the Esquiman Trough from the northeast.

The Anticosti Trough or Anticosti Channel originates in about 120 m of water at the eastern end of Jacques Cartier Passage. Between Anticosti Island and the North Shore of the Gulf, it takes the form of an elongated depression, approximately 145 naut. miles long, which varies in width from 3 naut. miles to a maximum of 38 naut miles (70 km). Water depths are consistently greater than 200 m and depths of 296 m have been recorded in one of the many floor depressions. Beyond Anticosti Island, the trough opens and bends to the south, to join the northern wall of the Laurentian Trough at a depth of ~300 m about 65 naut. miles east of Anticosti.

The Esquiman Trough, the northeastern tributary, originates in 100 m of water about 5 naut. miles off Pte. Riche on the northwestern coast of Newfoundland. At its head, it has an initial width of 10 miles and a floor depth of 240–260 m. Thence, it widens to about 32 naut. miles (between the 200-m contours, see Chart 1) as it continues to the southwest for a distance of 120 miles between the Newfoundland and the Quebec–Labrador shelves. Water depths are

TABLE 4. Dimensions and physical characteristics of the Laurentian, Saguenay, Anticosti, and Esquiman troughs and some major shelf valleys.

Dimensions and physical characteristics	Troughs				Shelf valleys		
	Laurentian	Saguenay	Anticosti	Esquiman	Chaleur Trough	Shediac Trough	Cape Breton Trough
Key number Fig. 17	8A	8B	8C	8D	9B	9C	9D
Length naut. miles (*km*)	668(1240)	50(93)	145(270)	120(222)	108(200)	143(265)	162(300)
Depth at head (*m*)	100	100	120	100	20	20	20
Max. width (naut. miles)	50	4	38	32	15	27	16
Max. depth (*m*)	535	300	296	345	200	180	180
Depth at terminus (*m*)	550	40 (sill)	300	300	120	120	200
Gradient (*m/km*)	0.36	–	0.67	0.90	0.50	0.38	0.60
Nature of long profile	Continuous series of basins along the length						
Max. wall height (*m*)	~300	~180	~180	~180	80	40	120
Character of transverse profile	Predominantly trough-shaped						
Nature of wall material[a]	A, B, C	–	B, C	B, C	B, C	B, C	B, C
Nature of core sediment from axis	Pelite cores with glacial till and glaciomarine sediments						
Relation to river valleys[b]	A	A	B	B	A	B	B

[a] Nature of wall material: A = crystalline rock dredged; B = sedimentary rock dredged; C = unconsolidated sediment.
[b] Relation of trough head to river valleys: A = definite connection; B = no connection.

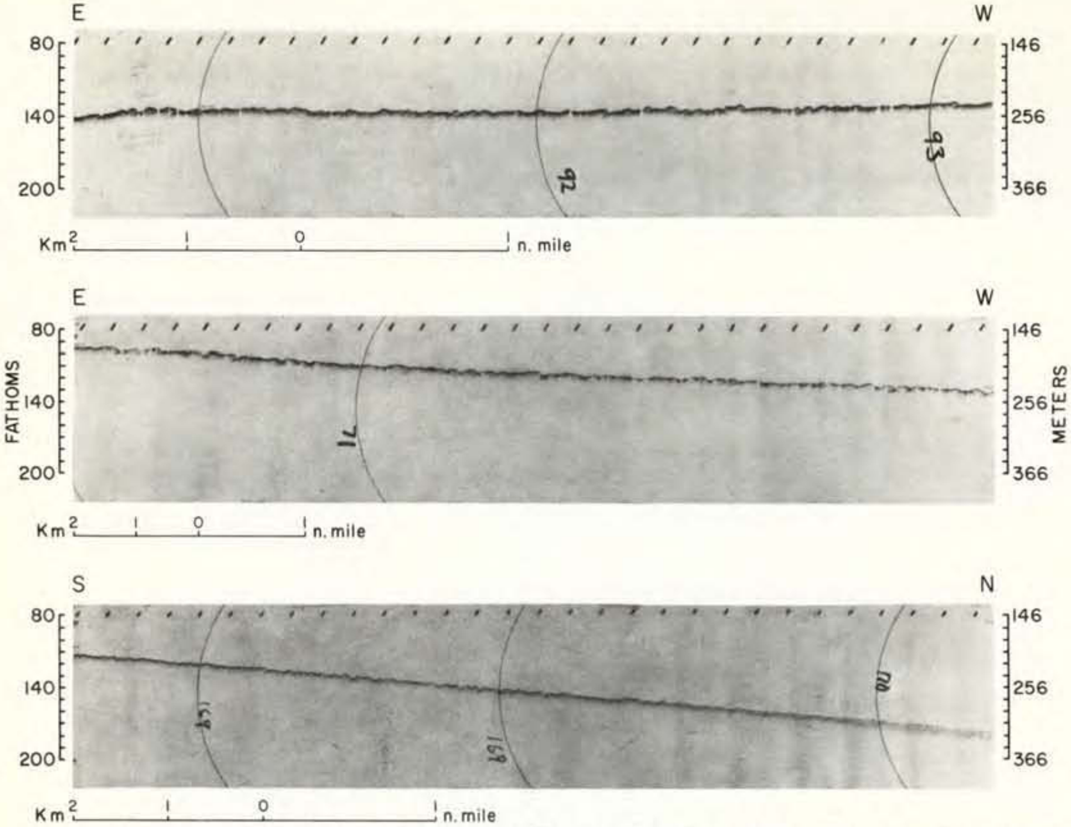


FIG. 18. Echograms showing the hummocky unmodified till surface on the slopes of the Laurentian Trough adjacent to: (*top*) Anticosti Shelf; (*middle*) Newfoundland Shelf; (*bottom*) Magdalen Shelf.

greater than 200 m and depths of 344 m (~188 fath) are recorded in one of its many floor depressions and along the western side. In the inter-trough area between Banc Beaugé and the Newfoundland Shelf the northern wall is lower, the floor is narrower and the southern wall is flatter so that only a trace of the original valley curves to the south for another 30 naut. miles to join the wall of the main trough (Chart 4 in pocket, echoprofiles, 17, 20, and 21).

Surface morphology

Although each of the troughs exhibits some variety in form, their surface characteristics are typical of fluvial valleys modified by glacial erosion and deposition, and later by postglacial sea level rises and recent depositional conditions (Charts 1 and 4) (Shepard 1931; Nota and Loring 1964; Shepard and Dill 1966.)

The main features attributed to glacial erosion and deposition include: relatively straight walls, discordant valley junctions, bevelled spurs (particularly the Saguenay fjord valley), a series of large elongated depressions on the floors of the trunk and tributary valleys (Charts 1 and 4, profiles 13, 24, and 25), and the *U-shaped* profile formed by a broad base (up to 48 naut. miles) of moderate irregularity (Chart 4, echoprofiles 1–12). In addition, there is a wide (~40 miles) submarine fan which descends from the shelf-slope break at 120 m, to the trough floor at 440 m between the Gaspé Peninsula and Orphan Bank on the Magdalen Shelf (Chart 1). This is the surface expression of a thick wedge of unconsolidated glaciomarine sediments which lie along the southern side of the trough (Chart 5, in pocket, seismic profiles 3, 4, 5, 6, and 7). In the northern part of the Gulf another long tapering submarine spur descends south from Banc Beaugé and separates the submarine traces of the Anticosti and Esquiman troughs (Charts 1 and 4, echoprofiles 20, 21, and 24 at Stn. 45). This ridge which is illustrated in Fig. 20 is composed of glacial sediments and is believed to be a medial moraine (see Chap. 5 and 9).

In small-scale details, the actual echogram

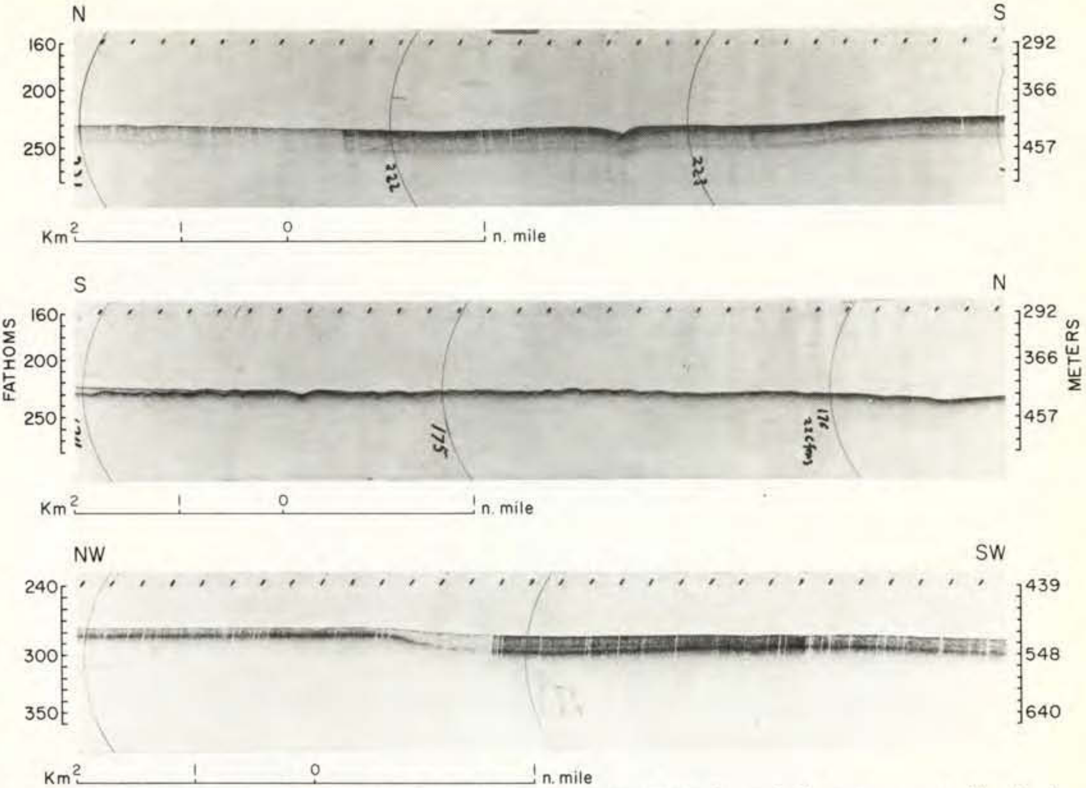


FIG. 19. Echograms from the northern Gulf of St. Lawrence. (*Top*) Acoustically transparent pelites in the Laurentian Trough (from profile 2, Chart 5, in pocket); (*middle*) hummocky till surface (*center*) thinly covered (*left margin*) with acoustically transparent pelites in the Laurentian Trough (from profile 3, Chart 5, in pocket); (*bottom*) longitudinal section of the Laurentian Trough in Cabot Strait showing the acoustically transparent pelites (from profile 10, Chart 5, in pocket).

traces show that the trough slopes adjacent to the Magdalen, Anticosti, and Newfoundland shelves have a distinctive moraine-like microrelief (local relief ±5 to 15 m) composed of broad (0.1–3 naut. miles) asymmetrical, rough-surfaced hummocks and depressions covering the slopes below 120 m(see Fig. 18 and Chart 4, echoprofiles 7, 10, 21). This local relief continues downward to the floor and beyond to form the floor relief or passes beneath a smooth cover of acoustically transparent sediments, in which the hummocks occasionally reappear as low-rising ridges. (Chart 4, echoprofiles 4, 8, 9, 11, 20, 24, 25, and Fig. 19 and 20). Sub-bottom reflections from 3 to 40 m beneath the floor and adjacent lower slopes indicate that acoustically transparent sediments are ponded between and underlain by this rough-surfaced hummocky relief in many parts of the trunk and tributary valleys (Chart 4, echoprofiles 1 to 24).

Sampling data (see Sediments, Chap. 5) indicate that the rough microrelief of the slope and floor represents a moraine topography constructed of glacial till essentially unmodified on the slopes but slightly modified on the floor by ponding of acoustically transparent postglacial pelites in depressions on its rough surface. Above about 110 m along most of the adjacent slopes, the rough moraine microrelief changes into fairly smooth surfaces composed of sediments having the textural characteristics of drift reworked by marine processes.

These surfaces unite to form a broad sloping terrace-like feature between the 100 and 200 m level (see Fig. 21). The transition in relief, and the sediment texture at the shelf-slope break is believed to represent the lowest level at which sediments were modified by the postglacial marine transgressions. (See Present Depositional Conditions, Chap. 9).

Subsurface morphology

The subsurface morphology of the Laurentian Trough and its tributary valleys is controlled by

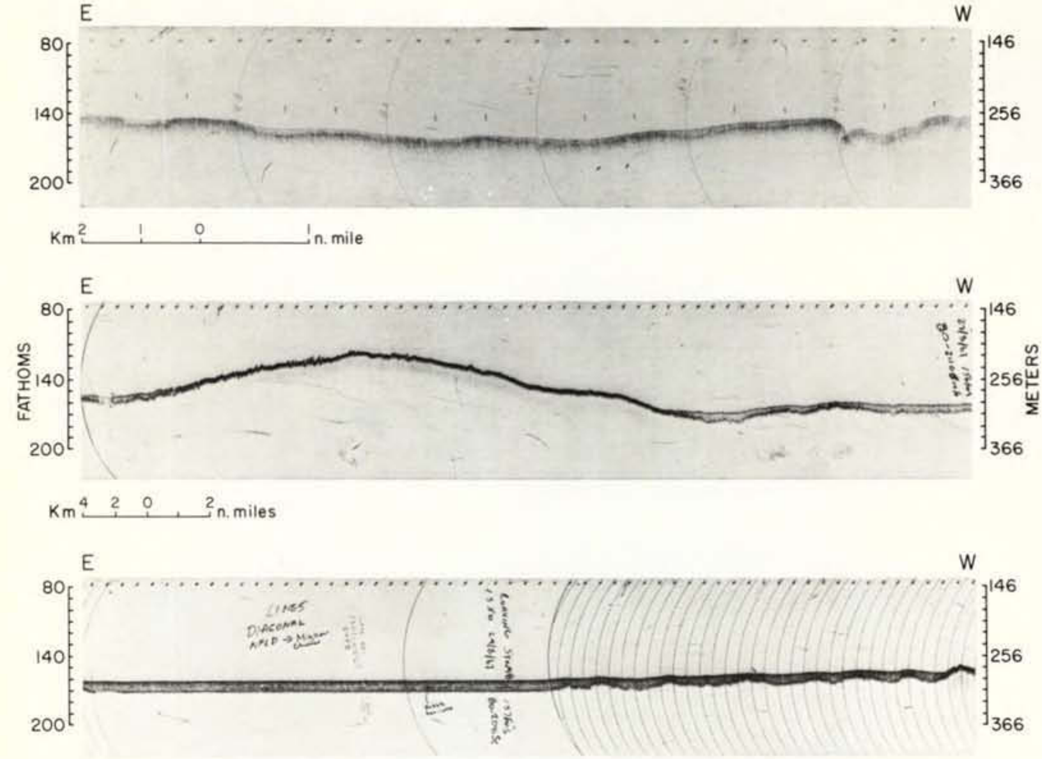


FIG. 20. Echograms showing various features of the tributary troughs. (*Top*) Floor of the Esquiman Trough with a layer of acoustically transparent pelites; (*middle*) moraine ridge south of Banc Beaugé and acoustically transparent pelites covering the rough till subsurface of the Anticosti Trough (from profile 21, Chart 4, in pocket); (*bottom*) floor of the Anticosti Trough showing pelites covering the rough till subsurface.

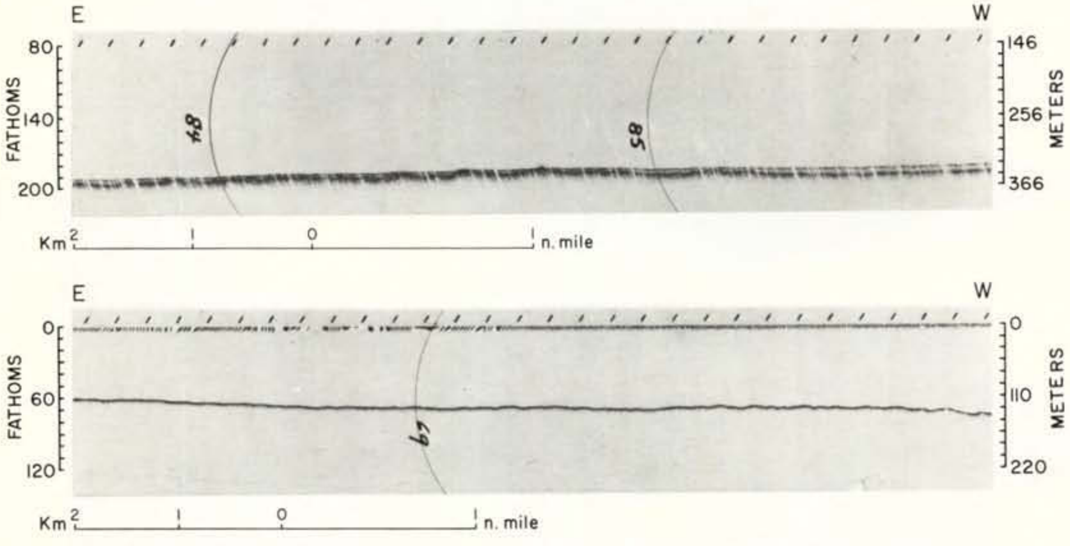


FIG. 21. Echogram showing (*top*) the seaward traces of the Esquiman Trough (Fix. 84) and the Anticosti Trough (Fix. 85) between Newfoundland and Anticosti Island; and (*bottom*) the change between modified and unmodified till surfaces about 1 km west of Fix 69 on the Newfoundland Shelf.

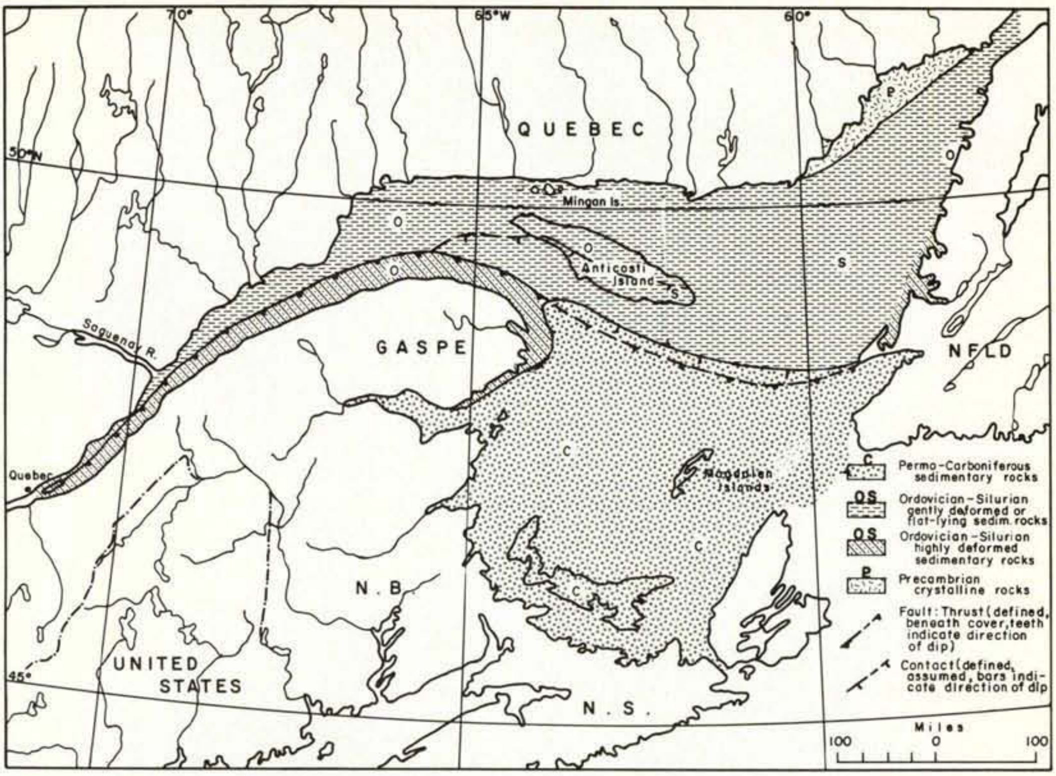


FIG. 22. Simplified bedrock geology of the Gulf of St. Lawrence.

the structure and lithology of the underlying bedrock and by the nature of the unconsolidated sediments.

Bedrock geology — A simplified map of the bedrock geology of the sea floor is shown in Fig. 22. The Precambrian unit on this map includes all the crystalline rocks that outcrop along the southeastern edge of the Shield and form the basement. These rocks occur offshore along the inner part of the Quebec–Labrador Shelf. Elsewhere, except in the very nearshore waters (unmapped) along the north shore of the estuary and Gulf, they are overlapped to the southeast by Paleozoic sedimentary rocks.

Ordovician to Silurian rocks of the St. Lawrence Platform (Poole 1967) occupy the northern part of the estuary and Gulf. These rocks consist mainly of limestones, calcareous shales, and sandstones and dip gently to the south and east. They are exposed above water on the Mingan Islands where they are Lower to Mid-Ordovician in age, and on Anticosti Island where they form a Mid-Ordovician to Upper-Silurian conformable sequence (see Chap. 2). Along the north shore of the Gulf from the mouth of the Saguenay to Cape Whittle, and along the line of the Mécatina Trough (Fig. 17) they fault against or overlap the Precambrian crystalline rocks. In the northern part of the St. Lawrence Estuary these rocks are most likely of Middle Ordovician age and fault against highly folded Ordovician rocks which make up the coastal exposures along the north coast of the Gaspé Peninsula. The fault zone which separates them is believed to be the eroded edge of the Appalachian Front or "Logan's Line." In the subsurface profiles (Chart 5, in pocket, seismic profile 1 and 2) these strata and the fault zone seem to disappear beneath a cover of younger sediments as they are traced south-eastward down the Laurentian Trough (seismic profiles 3, 6, etc.).

South of Anticosti, the northern part of the Laurentian Trough is apparently occupied by Silurian strata which are overlapped near the center by younger sediments. In the northeastern part of the Gulf, however, the data indicate that the Mid-Paleozoic strata (mostly Silurian) are warped into a synclinal structure, the axis of which is parallel to and east of the center of the Esquiman Trough (Chart 5, seismic profile 11).

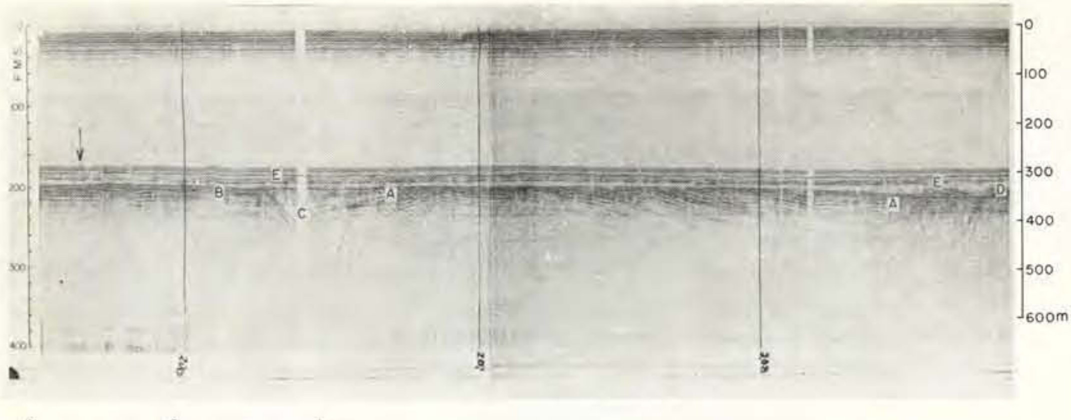


FIG. 23. Logan's Line: North–south seismic record about 7 naut. miles (13 km) in length from Section 1, Chart 5, in pocket: (A) folded Ordovician strata; (B) undeformed Ordovician–Silurian strata; (C) Logan's Line or the eroded edge of the Appalachian Front, and (E) glacial and postglacial sediments resting on a "planed" bedrock surface.

Along the inshore part of the Newfoundland Shelf these rocks fault against or overlap Ordovician or older strata exposed along the coast (Chap. 2).

Permo-Carboniferous rocks comprising red sandstones and shales occupy the southern part of the Laurentian Trough, the southeast corner of the Gulf including Cabot Strait and most of the Magdalen Shelf. To the north they appear to overlap the Silurian strata without the occurrence of any major dislocation.

No younger rocks have been identified on the sea floor of the Gulf, although some workers (King and MacLean 1970), on the basis of their investigations outside the Gulf, have speculated on a former occurrence of Tertiary rocks within this region.

Continuous seismic profiles (Chart 5, profiles 1–11) reveal that the Laurentian Trough is underlain by an uneven and overdeepened bedrock surface which developed across rocks of different structure, lithology, and age. The bedrock surface is almost always obscured by unconsolidated sediments which have filled irregularities in the surface in some places, (seismic profile 2, Chart 5) and in others have formed structures of considerable dimensions (seismic profiles 3 and 6).

Between the Gaspé Peninsula and the North Shore Shelf, the southern wall and part of the floor is underlain by folded rock (profile 1, Chart 5). These rocks are presumably Appalachian front sedimentary types of Ordovician age, that fault against gently southerly dipping stratified rocks, which are presumably sedimentary rocks of Ordovician age that occur on the sea floor about 16 naut. miles ($\sim$30 km) from the Gaspé coast. It is believed that the contact between these rocks represents the submerged eroded edge of the Appalachian front or "Logan's Line," (Fig. 23). Further to the southeast (seismic profile 3, Chart 5) this fault contact disappears, apparently beneath a thick cover of younger sedimentary rocks. North of the fault zone, in profile 1, (Chart 5) the sedimentary rocks conform to the northern slope of the trough and underlie most of the North Shore Shelf. Near the coast, they seem to overlap Precambrian crystalline rocks of the Canadian Shield.

Although seismic data are not available, it is believed from the land geology that the Laurentian Trough between Pointe des Monts and its head off the mouth of the Saguenay River has a similar bedrock geology to that shown in profile 1 (Chart 5). Gently deformed or flat lying Paleozoic strata (Mid-Ordovician) form the northern part of the trough floor and the eroded edge of the folded Appalachian rocks forms the southern part of the floor and the adjacent wall (Fig. 22).

Recent seismic surveys (Simard 1971) along and across the south channel of the St. Lawrence River near Ile aux Coudres reveal that the preglacial bedrock surface has an irregular relief which varies from 12 to more than 160 m below sea level. It is composed of steeply dipping rocks of Lower Ordovician age (Sillery Formation, Dresser and Denis 1944). The bedrock in this

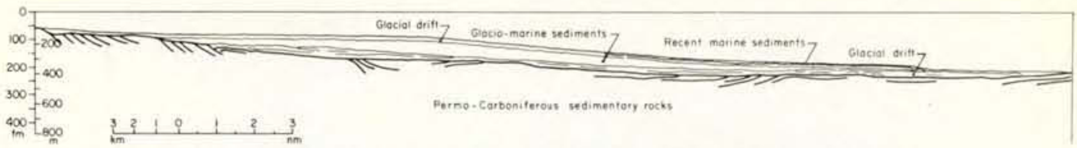


FIG. 24. Geological interpretation of part of seismic profile 3, Chart 5, in pocket.

area is overlain in some places by a glacial till up to 10 m thick. On top of the till is a thick layer of unconsolidated Champlain Sea and Recent (Holocene) sediments.

Between the Magdalen shelf and Anticosti Island (Chart 5, seismic profiles 3, 6, 8) the bedrock surface is apparently eroded across stratified rocks of presumably Permo-Carboniferous age that occur along the southern wall and part of the floor. In some places such as those shown in seismic profile 6 (Chart 5), terrace-like features are cut into the bedrock surface in the southern wall. Near the center of the trough, these rocks appear to overlap southward-dipping strata of presumed Silurian age which form the bedrock surface on the northern part of the floor and slope adjacent to the Anticosti Shelf.

Between the Magdalen and the Newfoundland shelves, the trough, as well as the adjacent shelves, appear to be underlain by gently rolling stratified sedimentary rocks of presumed Permo-Carboniferous age (Chart 5, seismic profiles 9 and 10). The bedrock surface in this area truncates the structure on the southern wall and part of the floor, whereas on the northern slope it nearly parallels the dip of the strata (Chart 5, profile 9).

In Cabot Strait, the undulating bedrock surface is formed by gently rolling stratified rocks that assume a seaward dip towards the southeastern end of the section, and a short section of strongly folded strata (Chart 5, profile 10). The gently folded rocks appear to overlap the folded zone and are most likely of Permo-Carboniferous age. The folded zone may represent an outcrop of older strata similar to the nearby Precambrian rocks of St. Paul Island, off the northern tip of Cape Breton.

The continuous seismic profiles also show that the bedrock surface on the floor is "planed off" (eg. profile 8) in some places, and in other places such as in the Dètroit d'Honguedo (Gaspé Passage) and Cabot Strait, it is overdeepened (profiles 2 and 10). The "planed" bedrock surface and the "overdeepened" areas, which usually coincide with the oval depressions shown on the bathymetric chart (Chart 1) indicate that glacial erosion has also been involved in the development of the bedrock surface.

Deposits of unconsolidated sediments — The bedrock surfaces are overlain by a nearly continuous cover of unconsolidated sediments. Over most of the floor and slopes, the cover fills irregularities in the surface and is less than 100 m thick. Along the southern side of the trough, a

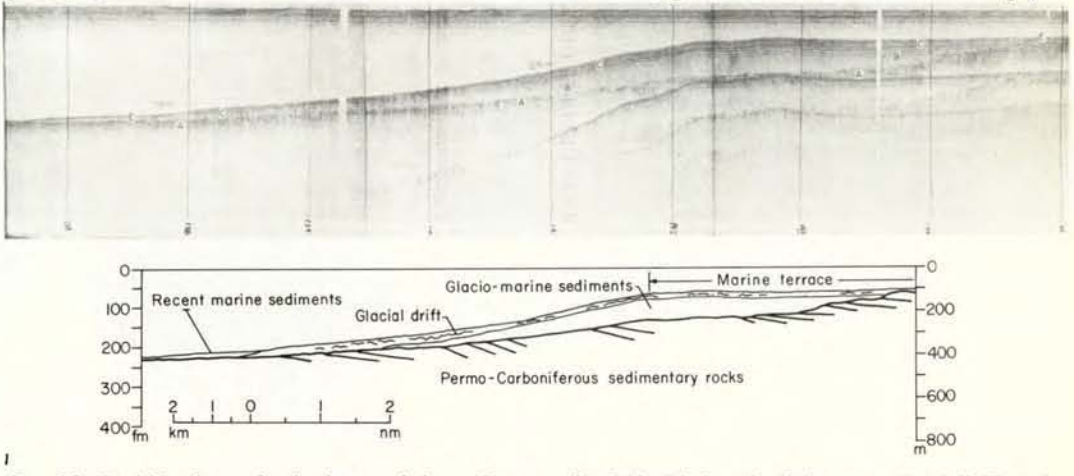


FIG. 25. (*Top*) North–south seismic record about 13 naut. miles (24 km) in length off the eastern Bradelle Trough. (from Section 6, Chart 5, in pocket): (A) eroded bedrock surface; (B) homogeneous glaciomarine sediments; (C) reddish-brown sandy till, and (E) recent marine sediments. (*Bottom*) Interpretation of seismic record.

thick wedge (~150 m) of stratified glaciomarine sediments determines the present valley form (see Chart 5, profiles 3–7, Fig. 24 and 25).

The continuous seismic profile (Chart 5, profile 3) across the fan-shaped submarine spur between Gaspé and Orphan Bank reveals a thick wedge of unconsolidated sediments on top of a sloping bedrock surface. In longitudinal section (southwest–northeast), it consists of three topographic parts (Chart 4, echoprofile 7 and Fig. 24): (1) a broad gently sloping terrace between the 120- and 180-m contour with a maximum sediment thickness of 150 m; (2) a more steep, almost straight front slope between 180 and 360 m with a maximum sediment thickness between 110–128 m, and (3) a gently undulating sheet or apron at the front of the slope to its toe at ~400 m with sediment thickness of 35 to 110 m. In transverse section (seismic profile 4, Chart 5) it is a lens-shaped body ~40 naut. miles across with a maximum thickness of 145 m. All these parts have a hummocky surface relief, although at the foot of the slope this relief is buried beneath acoustically transparent sediments (see middle echogram, left margin, Fig. 19). Internal reflections indicate that the wedge is composed of a layer of sediments 35 to 80 m thick, which is nearly acoustically transparent and homogenous, sandwiched between two thinner and nearly continuous layers, 18–25 m thick, with rough-textured reflecting characteristics. Sampling data indicate that the top layer is glacial drift and the thick underlying layer is glaciomarine in origin (Chap. 5 and 9). The origin of the layer above the bedrock surface has not been established, although the reflecting characteristics suggest that it is glacial drift.

This wedge of unconsolidated sediments extends along the shelf edge for about 85 miles (Chart 5, seismic profiles 5–7) and is composed of a series of coalescing fans. In the deposit off the mouth of the eastern Bradelle Trough (profile 6, Chart 5, and Fig. 25) the topographical and lithological construction is similar (cf. profile 3) but the bottom drift layer is absent, the front face is steeper, the apron less extensive, and the toe is reached at a depth of 420 m on the floor 6 naut. miles from the terrace edge. Further to the southeast the sediment body wedges out against the shelf edge.

The bedrock geology of the floor of the Saguenay River is not known directly, but the presence of undeformed Paleozoic strata (Mid-Ordovician) in the basin of Lake St. Jean at the head of the river suggests that this valley may also be floored by rocks of Mid-Ordovician age. Most of these may have been removed during a pre-glacial erosion cycle (see Chap. 2). The linearity of the valley as a whole, however, is partly controlled by faulting (Kumarapeli and Saull 1966).

No information is available on the thickness of the unconsolidated sediments that mantle its undulating floor. However, the glaciated characteristics of the fjord itself suggest that the bedrock floor is partly covered by glacial sediment, some of which may form the sills found at its mouth and along its length.

Although seismic data are not available from all parts of the tributary valleys, a profile (Chart 5, profile 11) across the junction of the Anticosti and Esquiman troughs shows that the area is underlain by stratified bedrock presumably of Silurian age. These rocks dip towards the center of the trough and form a broad synclinal structure. The bedrock surface conforms to this structure and is overlain by a continuous but relatively thin (<50 m) cover of unconsolidated sediments. The upper reaches of the Anticosti and Esquiman troughs consist of bedrock depressions in Paleozoic strata which overlap the Precambrian rocks of the Canadian Shield along the edge of the north shore of the Gulf, and along the inner edge of the Quebec–Labrador Shelf (see Fig. 22). They are overlain by a relatively thin (<50 m) but nearly continuous cover of glacial and postglacial sediments.

Origin of the Laurentian Trough system

Since 1890, four different proposals have been advanced to explain the origin of the Laurentian Channel or Trough: fluvial erosion, glacial erosion, erosion by turbidity currents, and faulting. A fluvial origin was first proposed by Spencer (1890, 1903) and later supported by Goldthwait (1924) and Johnson (1925). A glacial origin was advocated by Shepard (1931) who considered that its present form was mainly due to the modification of a fluvial valley by glacial erosion and deposition. These conclusions were later supported in full by the work of Nota and Loring (1964) who also discounted the argument of MacNeil (1956) for a turbidity current origin of the trough. A tectonic origin was suggested by Press and Beckman (1954) and later by Kumarapeli and Saull (1966) who proposed that the trough was a rift valley system similar to that found in East Africa. Recent work by Sheridan and Drake (1968), Nota and Loring (1964), and King and MacLean (1970) has demonstrated that the Laurentian Trough is a linear erosional feature that has been modified by glacial erosion and deposition.

Morphological development

The present configuration of the Laurentian Trough and its tributary valleys can be explained by the following sequence of events, the detailed evidence of which is presented in succeeding chapters.

The acoustic and sampling data indicate that the Laurentian Trough and its major tributary valleys are deep erosional valleys cut into rocks of different age, structure, and lithology, that form part of the seaward extension of the preglacial St. Lawrence or Laurentian River system (Chap. 2). In this system, the Laurentian Trough forms the seaward extension of the old St. Lawrence River valley across the Gulf to the edge of the continental shelf. Some of its tributary valleys are still connected to some of the drowned valleys of the present drainage (Chap. 2). Such a drainage pattern as depicted in Fig. 26 and 27 would suggest that the preglacial Laurentian River(s) between Quebec and the Gulf would have been guided and confined between the Laurentian Highlands to the north and the northeasterly trend of the uplands and mountains of the Gaspé Peninsula to the south. This part of the valley probably would have received the drainage of the Laurentian Highlands through the preglacial valleys of the Saguenay, Bersmis, Manicouagan, and Moise rivers, as well as from the Appalachian region through the preglacial valleys of the Yamaska, St. Francis, Nicolet, Bécancour, and Chaudière rivers (Chap. 2). From the estuary to Cabot Strait, the Laurentian river would have received the drainage indirectly from the Laurentian Highlands through the drainage system of the cuesta landscape of the northern part of the Gulf (see North Shore Shelf). It would also have received the drainage of the western edge of the Newfoundland Highlands through the Esquiman Channel, and the southern Gulf through a number of rivers cutting across the Magdalen Shelf from the Quebec and Maritime Appalachian region (see Magdalen Shelf).

The submerged part of the valley system appears to be well adjusted to the lines of structural and lithological weakness in the bedrock of the region. In the estuary, the Laurentian

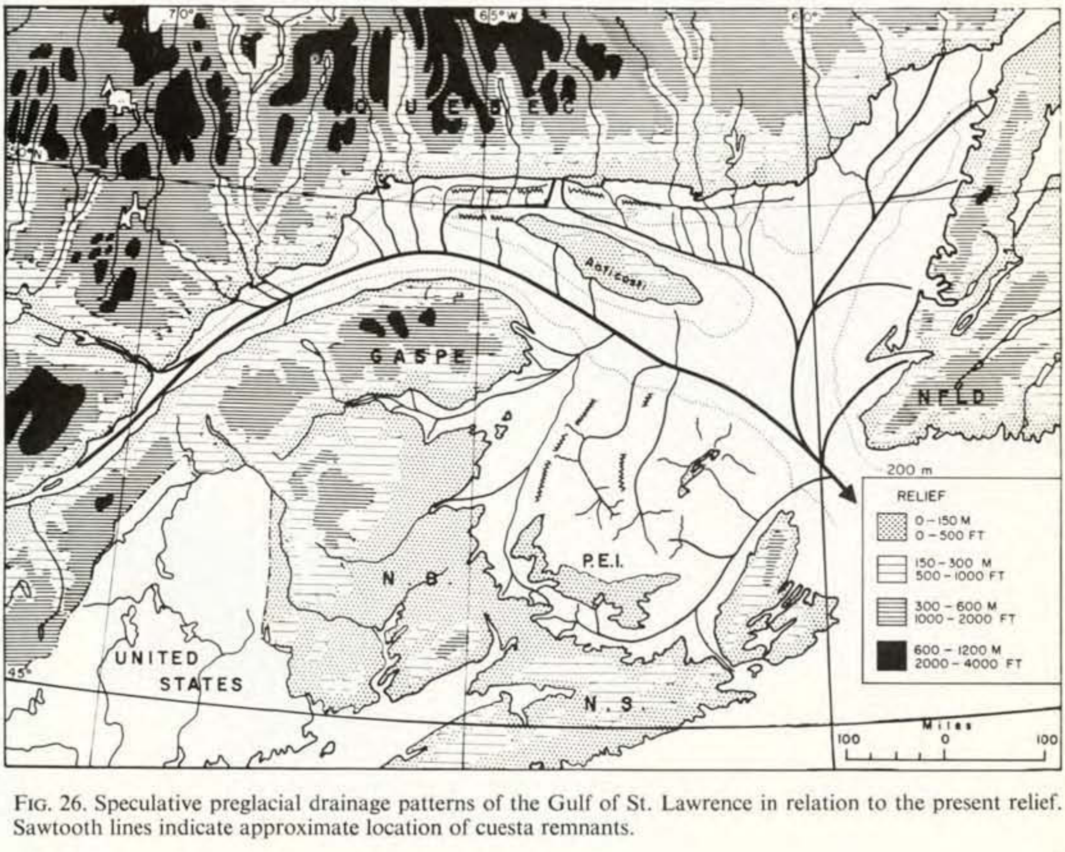


FIG. 26. Speculative preglacial drainage patterns of the Gulf of St. Lawrence in relation to the present relief. Sawtooth lines indicate approximate location of cuesta remnants.

FIG. 27. Speculative detailed preglacial drainage in the northern central Gulf of St. Lawrence in relation to the present bathymetry (after CHS chart 801). Arrows indicate probable direction of flow, and the line thicknesses reflect relative importance of the drainage channels. The drainage divide in Jacques Cartier Passage is marked by the dashed line and the remnants of the cuestas by the sawtooth lines.

Trough is essentially a longitudinal fault contact erosional valley that has been opened along two lines of weakness; the faulted contact zone (Logan's Line) between the folded and unfolded Mid-Paleozoic strata, and the down-faulted contact between the unfolded Paleozoic strata and the crystalline rocks of the Laurentian Highlands. From the estuary to Cabot Strait, the major valley appears to have developed by differential erosion along the south and easterly dipping contact between the Mid-Paleozoic and Upper Paleozoic strata. Since the valley appears to have migrated into the Permo-Carboniferous sandstones and shales, they seem to have been less resistant to erosion than the Silurian strata.

The preglacial bedrock control on the development of the Anticosti and Esquiman troughs is part of the evolution of the cuesta landscape of the North Shore and Quebec–Labrador shelves and is discussed in conjunction with them (see later pages).

The preglacial valley system apparently represents the youngest state in the development of the major physiographic features of the region which have evolved since early Tertiary times (Chap. 2). During the Tertiary, the major features were formed by the partial dissection of the "Cretaceous planation surface" (Chap. 2) as it was gradually and intermittently tilted to the southeast by subsidence along the continental margin (Emery et al. 1970). By the late Tertiary, the major valleys apparently became entrenched below the lowland surface in the belts of relatively weak (lithologically and structurally) Paleozoic rocks which already partly occupied elongated depressions in the surface of the Precambrian basement rocks (Haworth et al. 1972). The latest period of valley entrenchment appears to be in late Pliocene to early Pleistocene times as is evidenced by the land geology and by the presence of eroded Tertiary strata on the floor of the Laurentian Trough outside the Gulf (King and MacLean 1970; Bartlett and Smith 1971; McIver 1972).

During the Pleistocene, the fluvial valleys were modified into glacial troughs by ice masses which repeatedly filled them. The glacial geology of the surrounding land area (Fig. 28) indicates that they were initially invaded by three main ice lobes which later coalesced when the individual troughs were overridden but separated again when the ice withdrew from the region. The main ice lobe apparently entered the trough from the north side near the mouth of the Saguenay and Manicouagan rivers, from whence one portion flowed down the Laurentian Trough overriding parts of the Magdalen Shelf, and eventually out through Cabot Strait. Another portion flowed up the trough towards Quebec City until it was confluent with a portion of the lobe occupying the Saguenay valley (Dresser and Denis 1944). Part of the central lobe also appears to have overridden the southeastern side of the trough and eventually pushed down the Matapedia valley and entered Chaleur Bay, beyond which it became confluent with the ice occupying the Laurentian Trough.

A second major ice lobe must also have moved eastward through the Anticosti Trough, north of Anticosti Island. The island, lying in the path of the ice coming from the north, probably formed a barrier for the basal ice and deflected it in an eastward direction before the island itself was overridden. A third lobe flowing south and east from the highlands of Labrador entered the Esquiman Trough and also modified its fluvial topography. As this lobe pushed south and west, it became confluent with the Anticosti lobe (from the north and west) south of what is now Banc Beaugé, and with the Laurentian lobe at the southern end of the Newfoundland Shelf.

Since the density of ice is about 0.9 even a valley glacier of some 600 m thickness would have been thick enough to scoop the valley bottom without floating, but the pressure on the substratum would be so small that a much thicker ice tongue was probably involved. In fact, there is considerable evidence (McGerrigle 1952) to indicate that the Gaspé Peninsula with elevations up to 1300 m was overridden by ice.

Glacial erosion by these ice masses, controlled by the preglacial topography, resulted in the widening, deepening, and straightening of the valley walls as far to the southeast as the mouth

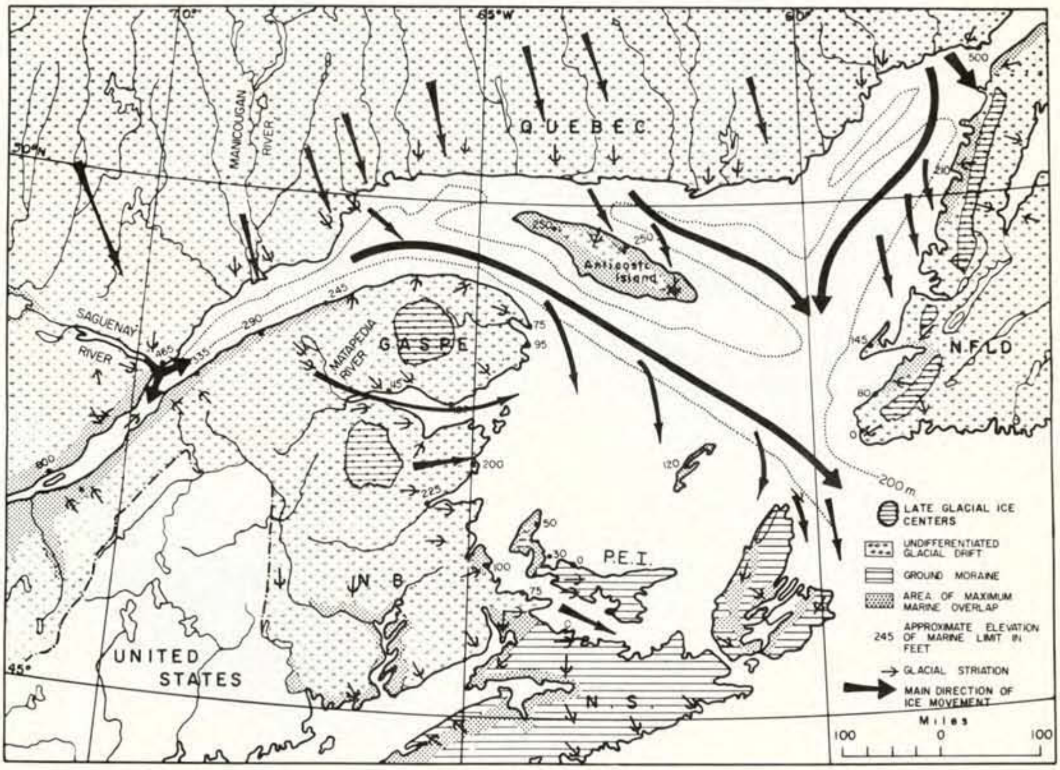


FIG. 28. Speculative flow pattern of the major (large arrows) and minor (smaller arrows) ice lobes in the Gulf of St. Lawrence during the Wisconsin glaciation. Approximate location of late-glacial centers is also shown. Data for the glacial geology of the land area is mainly based on Can. Geol. Surv. Map 1253A (1970). (see Fig. 6).

of the Laurentian Trough at the edge of the continental shelf. In the narrower parts of the valleys, such as in the Gaspé Passage and Cabot Strait, increased erosion caused by the more rapid flow required for ice to pass through these narrows, apparently resulted in the overdeepening of the bedrock surfaces in these areas.

Uneven deposition of glacial till from the ice, unevenly charged with debris and detritus, and from streams that flowed in or under the ice, resulted in the production of an irregular glacial landscape over most bedrock surfaces. Local glacio-fluvial activity began to modify the glacial topography at the end of the Pleistocene period when the ice began to melt and flotation occurred. Additional morphological features such as moraines and thick fans of glaciomarine sediments buried by thin glacial tills were also produced during the retreat stages of the continental ice, and by the readvances of local ice masses when the continental ice had almost withdrawn from the Gulf (see Late-Glacial History, Chap. 9).

Changes in sea level have resulted in the formation of submarine terraces along the edge of the adjacent shelves above the 110 to 100 m isobath (see Surface Morphology). The modification of the glacial landscape has also occurred through the reworking (erosion and redeposition) of the glacial deposits on the adjacent shelves, and deposition of material from the adjacent coastal areas, and from the St. Lawrence drainage system in depressions on the slopes and floors of the trough (see Present Depositional Conditions, Chap. 9).

Submarine Shelves

The submarine valleys in the estuary and Gulf are bordered by shallow (water depth usually <200 m, and in most cases <100 m) submarine platforms or shelves of varying widths and relief (Fig. 17). Geographically these may be divided into the following:

1. Shelves of the St. Lawrence Estuary
2. North Shore Shelf
3. Anticosti Shelf
4. Quebec–Labrador Shelf
5. Newfoundland Shelf.
6. The Magdalen Shelf

Shelves of the St. Lawrence Estuary

The Laurentian Trough merges into the floor of the St. Lawrence Estuary just below the mouth of the Saguenay River. Most of the floor is fairly shallow between the head of the trough and Quebec City, with small elongated islands separating a deeper northern side (water depths to 160 m) from the shallower (water depths less than 20 m) southern one (Chart 1, in pocket).

The Laurentian Trough is bordered by two narrow shallow shelves (Les Escoumins and the Gaspé) from its head to the mouth of the estuary (Fig. 17, 2A and B). These shelves vary in width from less than a mile to as much as 7–8 naut. miles. Their even surfaces usually slope gently towards the axis of the trough, to a break in slope around 20–100 m. The Gaspé Shelf is developed mainly along the southeastern shore near the head of the trough, along which it decreases in breadth seaward. On the northwest shore the shelf referred to as Les Escoumins Shelf has a very limited breadth (usually less than 8 naut. miles).

At the mouth of the estuary, the shelves remain narrow (<5 naut. miles) along the Gaspé Coast and along the north coast towards Sept Îles. These shelves usually have a smooth sediment surface broken occasionally along the north shore by outcrops, and there is little evidence to suggest shelf incisement except near Sept Îles. About 10 miles west of Sept Îles, echograms taken parallel to the shelf-slope break, at about 120 m show that the outer edge is rough and incised by narrow (0.2-0.7 naut. miles) steep-walled channels with depths 35–55 m below the surrounding floor. These channels have a common base level of 175 m, and at least one of them can be traced across the shelf to the mouth of the St. Marguerite River which provides some evidence of shelf cutting in this area at a period of lower sea level.

North Shore Shelf

The shelf broadens east of Sept Îles and has a rough basin-and-bank topography which, generally, extends eastward through Jacques Cartier Passage along the North Shore to Cape Whittle, a distance of 225 naut. miles (Fig. 17 and Chart 1).

The shelf topography consists of an inner shelf bordering the coast, an area of longitudinal and transverse depressions within the shelf, and a single or double outer bank region. Because of the length of this shelf, it is discussed in three sections as follows:

1. Between Sept Îles and Jacques Cartier Passage, the inner shelf bordering the coast is 4–5 miles wide and terminates at the 100-m contour. Immediately seaward and parallel to the inner shelf is a series of deep elongated depressions 2–5 naut. miles wide with water depths of 180 m. Beyond and parallel to these depressions, is a series of banks with a minimum water depth of

60 m which are separated from each other by short deep transverse channels. At the western end, the outer channel and bank system is double with the inner banks and depressions separating a large offshore bank from the coast. Small peak-like banks also occur in water depths between 100 and 220 m at the western end of the shelf off Sept Îles (Chart 1 and Fig. 29). These peaks are about 900–1200 m wide at their base and taper to about 90 m wide at the tops which rise about 55–75 m above the sea floor. Although no additional data is available, the geology of the adjacent land (Faessler 1942; Twenhofel 1931) suggests that these peaks may represent inliers of Precambrian rocks protruding through a thin cover of Paleozoic sediments. Further east the outer shelf is occupied by a narrow (10 naut. miles) elongated (47 naut. miles) basin-shaped depression which heads towards Jacques Cartier Passage. Water depths near the center of this depression are greater than 200 m and depths to 231 m have been recorded in its floor.

Acoustical and sampling data indicate that the inner banks are bedrock elevations on which there is a continuous but relatively thin cover of coarse sediments, and that the outer bank at the western end of the shelf has a thicker and more continuous sediment cover (see Chart 5, seismic profile 1, northern end). Fine-grained marine sediments are ponded in the intervening "lows" parallel and transverse to the banks.

2. Between the north shore and Anticosti Island the shelf is about 20 miles wide. In this region, the inner shelf encloses a group of 27 islands, known as the Mingan Islands, that lie along the north shore for a distance of about 45 miles. These islands, which are 1–3 miles wide, are separated from each other by narrow north–south channels with water depths of 120 m. They are underlain by limestone rocks dipping gently to the south and are part of a dissected cuesta ridge whose escarpment is to the north and whose dip slope is to the south (Chap. 2). South of the islands a saddle-shaped rise or divide in the sea floor (with maximum water depths of 110 m) separates them from Anticosti Island. The divide also serves to separate the western shelf depression from the head of the Anticosti Trough to the east.

3. Along the remainder of the coast the shelf is less than 15 miles wide and like that to the west has an irregular and rugged relief. It is characterized by a nearly continuous series of inner and outer depressions and banks parallel to the coast, and has a serrated edge along the 100-m contour. The banks have a minimum water depth of 30–60 m and are separated by short and deep transverse depressions. Some of the banks rise above the water to form the multitude of islets found near the coast.

Although the shelf is covered with glacial debris and some recent marine sediments (see Sediments), the present shelf topography appears to represent a cuesta landscape of which some remnants protrude above water as islands.

Anticosti Shelf

The broad platforms which form the western and eastern submarine extension of Anticosti Island and the narrow reefs enclosing its northern and southern coasts are easily observed from the bathymetry (see Chart 1).

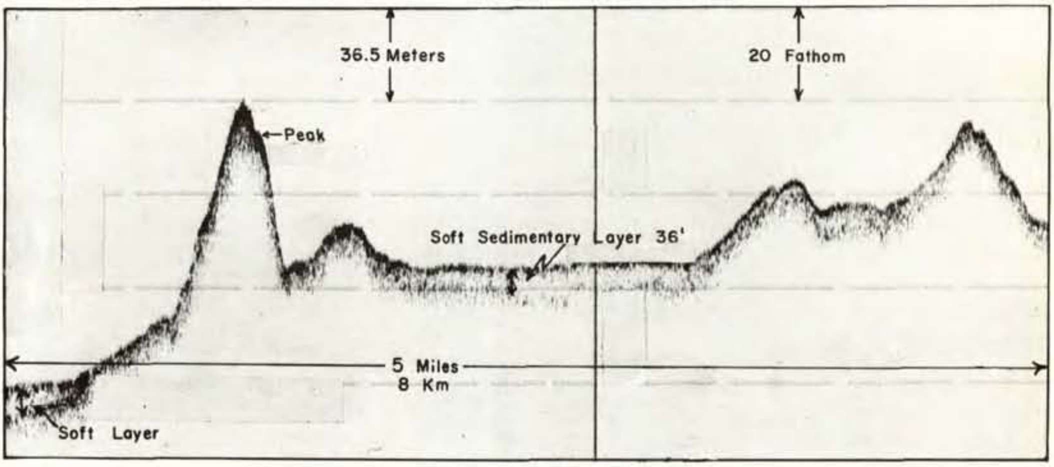


FIG. 29. Echogram from a section south of Sept Îles, Que., showing peak-like banks rising above the sea floor.

At the western end of Anticosti Island a gently sloping submarine platform tapers westwards for 36 naut. miles. It is 3–16 naut. miles wide and is formed by a series of banks, of which Parent is the largest, and separated by short transverse channels along its length. Water depths over the banks range from 50 to 100 m (about 27 to 55 fath), whereas the intervening lows have depths of 140 m (about 77 fath). In transverse profile, the ridge has a cuesta shape with a relatively steep northern face, a fairly smooth gently-sloping top and a gentle southward slope. Bottom samples indicate that it is covered with limestone debris and detritus.

The shelves adjacent to the steep cuesta face on the northern side and to the dip slope of the southern side of the island are narrow and rarely exceed 5 miles in breadth. They consist of limestone bedrock which slopes sharply to a shelf-slope break at about 100 m (~55 fath).

In contrast, the submarine extension of the island's structure to the east forms a broad gently-sloping platform about 30 miles wide. This shelf has little local surface relief and reaches a shelf slope break at 100–120 m about 30 miles from the shore (Chart 4 in pocket, echoprofiles 11 and 21). It is mainly a limestone platform on which lies a veneer of calcareous gravel, sand, and pelite.

The acoustical and sampling data suggest that the North Shore and the Anticosti shelves represent a preglacial hogback and cuesta landscape developed by stream erosion on gently southerly and easterly tilted Ordovician and Silurian strata (Twenhofel 1928).

The nature and extent of the preglacial drainage system developed in these regions was first recognized by Twenhofel (1931). Detailed inspection of the bathymetry suggested that channels between the various banks along the coast represented breaching of the cuesta ridges by streams flowing from the north (resequent streams), whereas the inner and outer longitudinal depressions represented erosion by streams (subsequent) parallel to the strike (see Fig. 26 and 27). In this drainage system one major stream apparently flowed south across the ridges, and then turned west through the central shelf depression and then around the end of the submarine extension of Anticosti to join the preglacial Laurentian valley. Another main stream apparently flowed east of the saddle-shaped rise in the sea floor between Anticosti and the Mingan Islands and followed the course of the preglacial Anticosti Trough around the edge of the Anticosti Platform to join the Laurentian River to the southeast. Between Anticosti Island and Newfoundland it was joined by another river(s) from the northeast referred to as the Esquiman River(s).

The east river would have received its drainage from the streams of the north shore of the Gulf and from the Mingan Islands eastward to Cape Whittle, the tributaries of which are responsible for the dissection of the eastward extending cuesta ridges consisting mostly of Lower Ordovician dolomites. This river apparently would have also received the drainage from the north slope of the eastern part of Anticosti Island. Similarly, the west river most likely received the drainage of the north shore of the Gulf eastward to Sept Îles. The rivers draining the north slope in the western part of Anticosti Island would also have flowed into the west river. These erosional valleys were later modified by the glacial erosion and postglacial deposition that also affected the tributary valleys of the Laurentian Trough.

Quebec–Labrador Shelf

A large flat-topped offshore bank with minimum water depths of less than 60 m, known as Banc Beaugé, marks the junction of the North Shore Shelf and the Quebec-Labrador Shelf (Fig. 17 and Chart 1). This bank is an important feature of positive relief, for it is the top surface of a tapering gently sloping submarine spur which, from the bathymetry (Chart 1), can be traced southward for 25 naut. miles to a depth of about 260 m. This spur separates the traces of the Anticosti and Esquiman troughs between Anticosti Island and the Newfoundland Shelf (see Chart 4, echoprofiles 20, 21, and 24, as well as Fig. 20 and 21). Although the origin of the bank and spur are not fully known, sampling data suggests that the ridge represents a medial moraine deposited on top of a bedrock elevation (see Subsurface Sediments).

Beyond Cape Whittle, the shelf widens to about 35 naut. miles and extends northeast to the coast of Newfoundland, obliquely dividing the northeastern part of the Gulf. It has a very complex basin-and-bank topography consisting of a narrow inner shelf bordering the Quebec–Labrador coast to the Strait of Belle Isle and elongated depressions parallel to the coast between the inner shelf and the outer shelf or bank region (see Chart 4, echoprofiles 14–18).

The inner shelf is 2–10 naut. miles wide and terminates in water depths of approximately 100–120 m. It contains many islets of Precambrian rock and numerous banks which are separated by deep transverse channels with water depths up to 100 m running into coastal inlets.

Immediately seaward of the inner shelf and parallel to it is a series of deep elongated depressions of which the largest and deepest is known as the Mécatina Trough (Huntsman et al. 1954) (See Chart 4, echoprofile 16). This depression is more or less continuous along the inner shelf for about 100 naut. miles and is 6 to 10 naut. miles wide. Elongated deep floor depressions with depths to 250 m and separated by narrow sills with depths sometimes less than 100 m occur almost continuously along its length. The outer shelf which separates the Mécatina Trough from the Esquiman Channel is 5–30 miles wide and stretches almost from Cape Whittle, on the north shore of the Gulf, to Riche Point on the Newfoundland coast and northward to the entrance to the Strait of Belle Isle. The outer shelf consists of a series of uneven to smooth surfaced banks with water depths less than 100 m and locally less than 40 m. These banks are dissected by transverse and longitudinal valleys with depths up to 200 m (Chart 1). In cross profile the outer banks have a cuesta-like appearance with steep northwesterly faces and smooth to uneven southeasterly backslopes (Fig. 30).

Acoustical and sampling data indicate that the outer shelf is covered with glacial debris of calcareous and igneous origin and some recent marine sediments. It is underlain by Lower to Mid-Paleozoic strata which dip to the southeast. The inner depressions also contain glacial debris and some calcareous marine sediments. The inner shelf is underlain by Precambrian Shield rocks on which there is a thin veneer of glacial and postglacial sands and gravels. The contact between the Precambrian basement rocks and the gently deformed Paleozoic strata is marked by the line of the Mécatina Trough (Fig. 22).

The preglacial drainage of the northeast part of the Gulf apparently followed similar lines of development to that of the North Shore Shelf, in which a broad cuesta-like landscape was

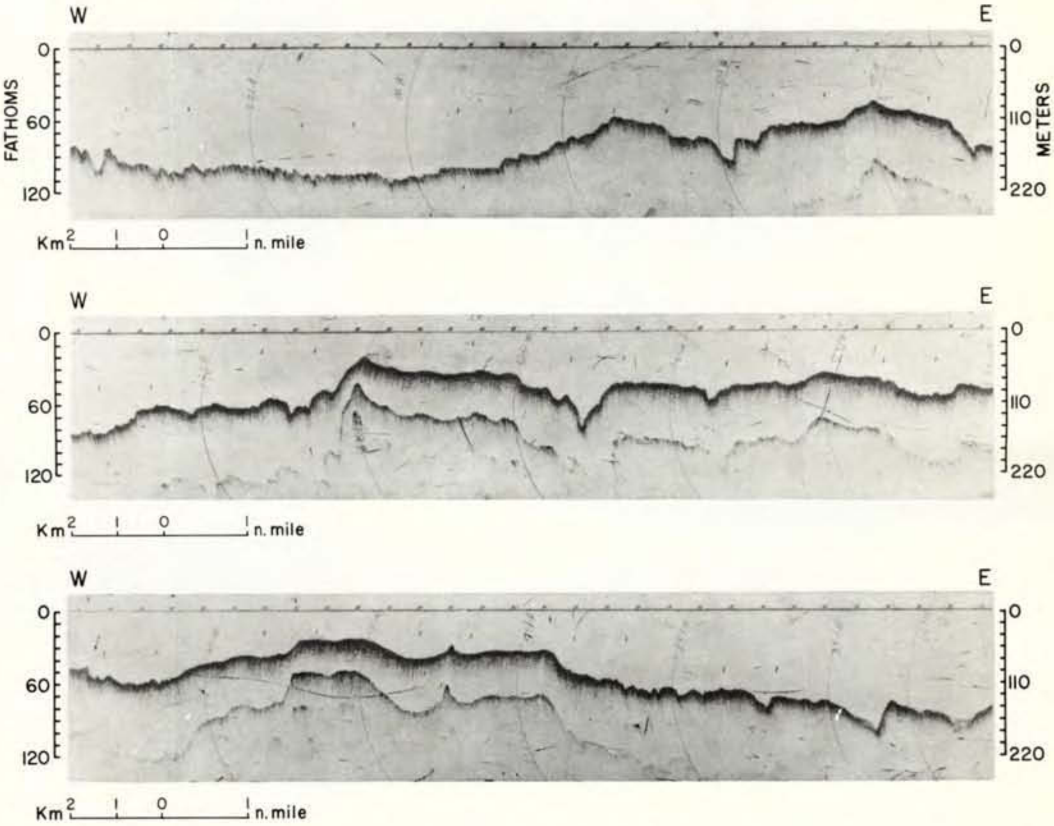


FIG. 30. Cross section of the Mécatina Trough *(top)* and the outer Quebec–Labrador Shelf *(middle and bottom)* with an incised cuesta-like slope to the east.

formed. Geophysical data show (Sheridan and Drake 1968) that a saddle-shaped rise in the bedrock, which strikes northwest-southeast, occurs in the Strait of Belle Isle. This would probably have formed an ancient drainage divide between the watershed of the preglacial river drainage to the Gulf and that flowing into the Atlantic to the northeast.

In the Gulf, the contact between the crystalline Shield rocks of the inner Quebec–Labrador Shelf and the Paleozoic strata of the outer bank and shelf area, may have been eroded by rivers flowing down the eastern slope of the coast and along the contact from Eskimo Bay southwesterly towards the present Mécatina Trough. South of Mécatina Island, this channel appears to turn southward to join the Esquiman Channel.

The outer banks and the Esquiman Trough are part of a synclinal valley of Cambrian–Ordovician strata trending to the southwest. It is suggested that the preglacial rivers followed the axis of this syncline and received the drainage from the northwestern flank of the cuesta as well as the drainage from the western part of Newfoundland. Apparently, erosion of the synclinal valley proceeded more rapidly than that along the Mécatina Trough as the Esquiman Valley is much more deeply incised than the former.

Newfoundland Shelf

The shelf bordering the fjord coast of western Newfoundland is less than 10 naut. miles wide at the head of the Esquiman Trough off Pte. Riche and remains so southward for another 40 naut. miles. Beyond, it widens gradually to 30 naut. miles before it decreases in width to less than 10 naut. miles by the incursion of the Port-au-Port Peninsula. From here to Cape Ray, the shelf remains narrow and rarely exceeds 5 naut. miles wide.

It is mainly an undulating plain sloping gently to the shelf-slope break around 100–120 m (Fig 21) and is broken occasionally nearshore by broad low-rising banks with minimum water depths of 30 m (Chart 4, profiles 17, 20, 21). A rough floor with a local relief of ±15 to 30 m is usually confined to the narrow parts of the shelf at its northern and southern end (see eastern part of echoprofile 12, Chart 4), and at the entrances to the coastal fjord valleys of which the Bay of Islands is the largest.

Sampling data (Chap. 5) indicate that most of the shelf above 120 m is covered with reworked glacial material with some recent marine sediments being ponded in shallow shelf depressions. It is underlain by seaward-dipping platform rocks, presumably of Paleozoic age, that either fault against or overlap strongly folded strata along some parts of the adjacent coastline (Fig. 22).

Magdalen Shelf

The Magdalen Shelf is a shallow submarine area of 30,637 square miles (79,350 km^2) formed by the seaward extension of the Carboniferous lowlands of New Brunswick and Nova Scotia (Chart 1). It lies southwest of the Laurentian Trough and occupies the broad semicircular embayment which surrounds Prince Edward Island and the Magdalen Islands, between the Gaspé Peninsula and Cape Breton Island. Its western side extends into Chaleur Bay and its southeastern corner into St. Georges Bay. Water depths on the shelf are usually less than 100 m (~55 fath) but depths up to 200 m (~110 fath) are found in some valleys and depressions.

The shelf on the whole is a plain which slopes gently from the south towards a shelf-slope break along the Laurentian Trough at 100–200 m with a gradient of 0.44–0.84 m/km. In detail, the shelf surface has an irregular relief composed of low-rising elevated areas or banks and shallow and elongated depressions or valleys (Fig. 31). Five principal morphological units can be recognized on the shelf, of which three are features of positive relief. These are: (1) a broad submarine terrace crowned by the Magdalen Islands, (2) a central area studded with banks and traversed by shallow valleys, (3) submarine extensions of coastal headlands, (4) long narrow valleys along its western and eastern margins, and (5) a terraced and indented shelf edge.

A broad submarine terrace surrounding the Magdalen Islands is the most conspicuous feature of positive relief in the eastern part of the shelf (Fig. 31 and 32). Its base, outlined by the 34-fath (62-m) contour, encircles the islands at distances of about 30–35 naut. miles from their western and eastern coasts and from 10–25 naut. miles to the north and south of the islands. On the western and eastern sides (Chart 6, profile 1) echoprofiles taken reveal that the terrace surfaces are gently inclined (1.1 m/km) to the terrace break between 62–70 m and are smooth with only local areas of irregular relief (±20 m). In contrast, the terrace surface to the north and south of the islands is rough with pronounced ridges and depressions interspersed with stretches of smooth ground (Chart 6, echoprofiles 4 and 17). Acoustical (seismic) and sampling data (see Sediments) indicate that the whole terrace is a broad anticlinal arch formed from gently sloping

Paleozoic bedrock. In areas of irregular relief, the bedrock is at or near the surface, whereas in the smooth areas of the terrace it is overlain by a thin cover of unconsolidated sediments.

The central part of the shelf is studded with low rising banks and shallow depressions. The main features of positive relief are Bradelle, Bennett, Pieter, and Orphan Banks (Chart 1, Fig. 31 and 32). *Bradelle Bank*, about 40 miles west of the Magdalen Islands, occupies about 250 square miles and is elongated in a northwest–southeast direction. It is situated between two shallow shelf valleys referred to as the *Western* and *Eastern Bradelle troughs* and rises gently from its base at 33 fath (60 m) to form a wide, nearly flat-topped bank with minimum water depths of 25 fath (46 m) (Chart 6, echoprofiles 5, 6, 12, and 13). The top and sides of the bank are fairly smooth but irregularities in relief attributable to bedrock exposures are found near the base. *Bennett Bank* is an elongated area of positive relief about 20 miles long and 6–9 miles wide at the shelf edge north of Bradelle Bank. It rises from 50 fath (90 m) to its elongated flat-topped surface with a minimum water depth of 31 fath (57 m). *Orphan* and *Pieter banks* are found in the northwestern part of the shelf. They have almost circular smooth flat-tops with

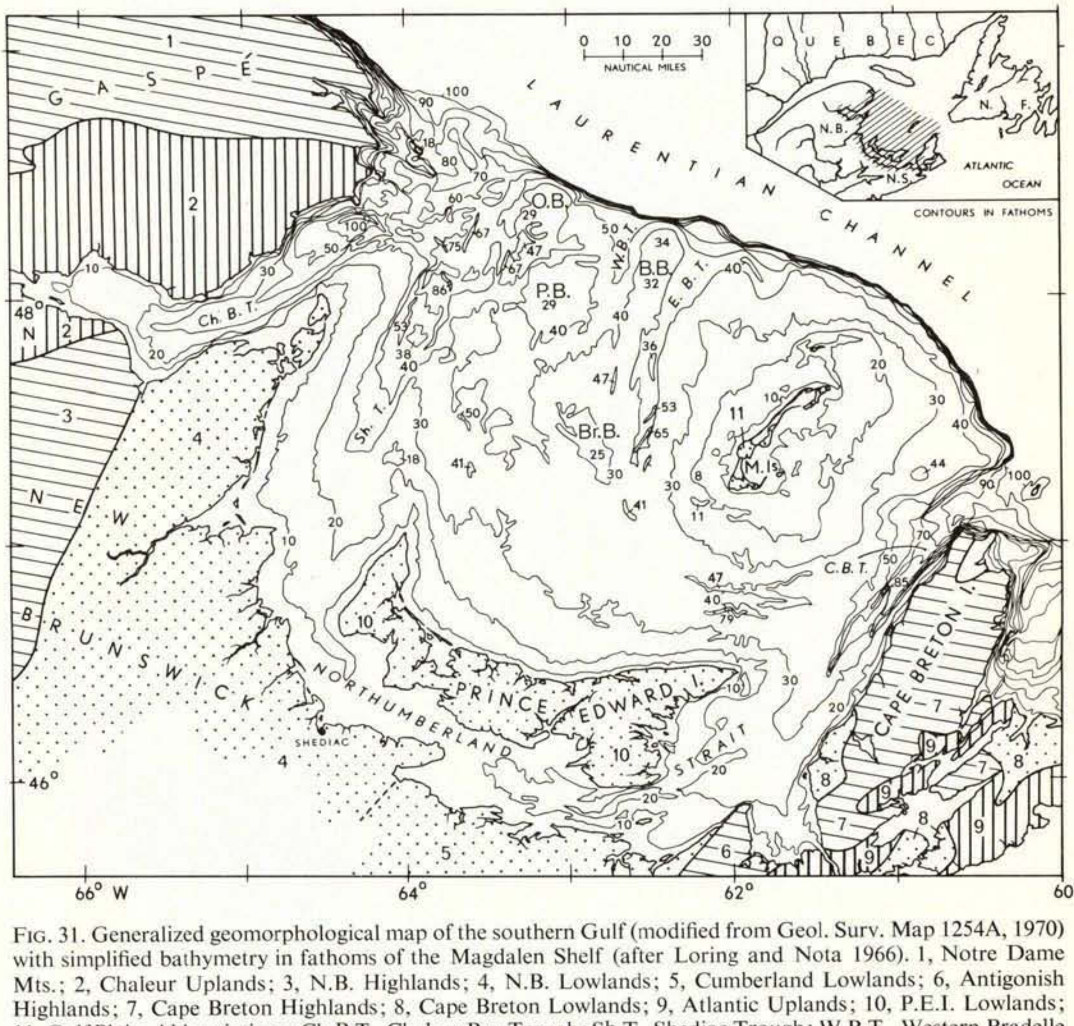


FIG. 31. Generalized geomorphological map of the southern Gulf (modified from Geol. Surv. Map 1254A, 1970) with simplified bathymetry in fathoms of the Magdalen Shelf (after Loring and Nota 1966). 1, Notre Dame Mts.; 2, Chaleur Uplands; 3, N.B. Highlands; 4, N.B. Lowlands; 5, Cumberland Lowlands; 6, Antigonish Highlands; 7, Cape Breton Highlands; 8, Cape Breton Lowlands; 9, Atlantic Uplands; 10, P.E.I. Lowlands; 11, Gulf Plain. Abbreviations: Ch.B.T., Chaleur Bay Trough; Sh.T., Shediac Trough; W.B.T., Western Bradelle Trough; E.B.T., Eastern Bradelle Trough; C.B.T., Cape Breton Trough; M.Is., Magdalen Islands; Br.B., Bradelle Bank; O.B., Orphan Bank; P.B., Pieter Bank; B.B., Bennett Bank.

minimum water depths of ~55 m, and gently inclined sides except for the relatively steep northern and northwestern slopes of Orphan Bank (Chart 6, echoprofile 14). Acoustical and sampling data indicate that these banks represent submerged mesa-like bedrock elevations on which there is a nearly continuous but relatively thin sediment cover.

Around the western rim of the shelf, the submarine extensions of North Point, Prince Edward Island, and the Shippigan Peninsula form the most conspicuous features of positive relief. The gently sloping submarine ridge extending from North Point curves from north to northeast as it continues offshore for 40 naut. miles to a depth of 32 fath (58 m), beyond which its continuation to the shelf edge is marked by a series of small low rising banks separated by shallow depressions (Fig. 32). It is 8–16 naut. miles wide. Transverse profiles (Chart 6, echoprofile 7) show that it has an asymmetrical shape formed by a relatively steep western slope, a broad nearly flat top and a more gently inclined eastern slope. Continuous seismic profiles indicate that it is a stratified bedrock structure, presumably Permo-Carboniferous sandstone, with an apparent easterly dip, on which there is a nearly continuous and relatively thin cover of sediments (Chart 7, seismic profile 2). The submarine extension of the Shippigan Peninsula, beyond Miscou Island, forms an asymmetrical broad submarine nose 8–20 naut. miles wide, plunging gently to the northeast for 25 naut. miles to a depth of 44 fath (~80 m). Its asymmetrical shape is formed by a relatively steep northwestern face, a nearly flat top, and a more gently inclined southwestern slope. Echograms and samples indicate that it is also a bedrock structure on which there is an intermittent veneer of sediments.

The shelf is incised by a number of well-defined (20–200 m) trough-shaped valleys along its

FIG. 32. Detailed bathymetry map (in fathoms) of the southern Gulf (Magdalen Shelf) after Loring and Nota (1966).

western and eastern margins and by shallower and broader ones in the central part. In addition, two small deep sinuous valleys occur between Prince Edward Island and the Magdalen Islands (See Charts 1 and 6 and Fig. 32, echoprofile 4).

In the northwestern corner, a trough-shaped submarine valley about 10–15 naut. miles wide, referred to as the *Chaleur Trough*, extends seaward for 108 naut. miles from the mouth of the Restigouche River through Chaleur Bay. It joins the slope of the Laurentian Trough at a depth of about 65 fath (119 m) off the Gaspé Peninsula. Off Gaspé it is joined from the south by a long curving submarine valley, 8–27 naut. miles wide, referred to as the *Shediac Trough*. According to the bathymetry this trough begins in 10 fath (18 m) of water in the western part of Northumberland Strait (Chart 6, echoprofile 7 and 8). In the eastern part of the Strait, another submarine valley begins in about 10 fath (18 m) of water. This valley, referred to as the *Cape Breton Trough*, is 5–16 naut. miles wide and extends to the northeast and along the coast of Cape Breton Island to join the Laurentian Trough at a depth of 110 fath (~200 m) (Chart 6, echoprofiles 9 and 10). It is poorly defined and shallow for the first 20 miles of its course, beyond which it becomes well-defined and much deeper (45–110 fath, 82–200 m) off the northwest coast of Cape Breton. In the central shelf, two shallow valleys, referred to as the *Western* and *Eastern Bradelle troughs* extend in a northeasterly direction to join the Laurentian Trough discordantly at a depth of 60–65 fath (Chart 6, echoprofiles 12, 13, and 14). These valleys are less than 10 naut. miles wide and have water depths between 32–65 fath (~60–120 m) except in isolated rimmed floor depressions where depths of 87 fath (160 m) have been recorded.

The troughs are underlain by stratified bedrock, presumably of Permo-Carboniferous age. These bedrock surfaces are overlain in most places by 2 to 70 m of unconsolidated sediments (Chart 7, seismic profiles 1, 2, 4, and 5).

Although the valleys appear to be part of a former drainage system, now submerged, neither in transverse profile nor in longitudinal profile do they now greatly resemble stream-carved valleys. Instead, they all contain an assemblage of features usually found in valleys modified by glacial erosion and deposition (Loring and Nota 1966). They have relatively straight walls (particularly the Chaleur and Cape Breton troughs), a trough-shape with a wide irregular base (Chart 6, echoprofiles 9 and 10), longitudinal profiles (echoprofiles 11 and 15) characterized by reversed slopes resulting from a series of rimmed floor depressions along their length, of which the largest and deepest (~200 m) is found in the Chaleur Trough, oval-shaped floor elevations (particularly in the Shediac and Cape Breton troughs) and discordant valley junctions with the Laurentian Trough. Some of these shelf valleys contain glacial drift on their floors which is partly buried beneath recent marine sediments and which gives rise to an irregular subsurface relief beneath a smooth cover of acoustically transparent sediments (Chart 7, seismic profiles 1–5).

In addition, the two sinuous valleys between Prince Edward Island and the Magdalen Islands, which are elongated in an east-west direction, resemble melt water tunnel valleys or *Rinnenseen* (Loring and Nota 1966). The northern one is about 30 naut. miles long; the southern one extends for 15 naut. miles. On the western side they are separated from each other by a ridge, while in the east they are partially interconnected. The width of each valley is about 2½ miles. These valleys show an irregular, rather than a graded, long profile which is the result of a series of isolated deep basins in their floors. The deepest of these basins is over 82 fath (150 m) in depth and is found in the southern valley (Chart 6, echoprofile 4). The position of the basins gives a somewhat sinuous course to the valley.

The valley slopes have little or no sediment cover. They are composed of reddish-brown friable sandstone similar in lithology to the bedrock exposed along the adjacent coast of Prince Edward Island and elsewhere along the shelf. At the eastern end, the bedrock surface is overlain by a relatively thin layer of stratified sediments. These valleys are thought to have formed by the erosion of melt water streams in drainage tunnels at the base of a glacier. This ice must have been thick enough to have provided the hydrostatic pressure necessary to erode sizable gorges in the bedrock. Meltwater erosion may also be responsible for some of the overdeepened (up to 87 fath, 160 m) parts of the eastern Bradelle Trough (Fig. 32, and Chart 6, echoprofile 12) and the outer part of the Shediac Trough.

The shelf edge lies between 44 and 110 fath (80 and 200 m of depth). It is relatively straight adjacent to the northern and northeastern sides of the Magdalen terrace and in front of the shelf banks, but it is deeply indented at the mouths of the major shelf valleys and to a lesser extent at the discordant junctions of the western and eastern Bradelle troughs with the Laurentian

Trough. Below about 55 fath (100 m), the edge is marked by an inclined terrace-like surface that slopes toward a shelf-slope break (Chart 6, echoprofiles 2, 16, and 17). The shelf edge is narrow where it is bounded by the bank fronts but is wide and gently inclined where it follows up the mouths of the intervening shelf valleys. The line of the break along the shelf is relatively straight in front of the banks, but it is bulged outwards in front of the shelf valleys.

Echograms (Chart 6, profiles 16 and 17) reveal that parts of the terrace surface and the slope below the break have intervals of irregular relief (±15–30 m) composed of broad asymmetrical hummocks and depressions. Bottom samples show that these features are constructed of sediments having the textural characteristics of glacial drift. The upper part of the terrace and the ascending slopes backing it are usually smooth and have a continuous cover of sand and gravel. The transition between modified and unmodified morainal topography at between 77 and 60 fath (~140–110 m) is considered to represent the lowest level at which the glacial deposits have been reworked during the late-glacial–postglacial transgressions and regressions. The slope break usually occurs between 60 and 77 fath (110–140 m) in front of the banks and at the mouths of the western and eastern Bradelle troughs, but it is deeper 110 fath (~200 m) at the mouths of the major shelf valleys. Continuous seismic profiles (Chart 5, seismic profile 6) and sampling show that the terrace for the most part has been built out, mainly in front of the shelf valleys, on a relatively narrow bedrock platform and gently sloping bedrock surface.

Morphological Development

The present upland surfaces suggest that the relative sea level was at one time higher to the land than at the present (see Chap. 2). The submarine topography also shows that for part of the time sea level was lower than today and the region was dry land. A complex drainage system which developed during this low-level stage was later modified by Pleistocene erosion and deposition.

The submerged portions of the coastal lowlands which form the submarine shelves and parts of their attendant valley system indicate a long history of repeated emergence of the land relative to the sea. Along the north shore of the Gulf and the northern part of the Gulf the submarine lowlands have been identified as a cuesta-like landscape developed on gently seaward-dipping rocks of Cambrian-Silurian age, the preglacial drainage of which was determined by their lithology and structure (see Fig. 26). The Newfoundland Shelf is also the submarine extension of a coastal lowland developed on seaward dipping stratified rocks of Ordovician-Silurian age.

The Magdalen Shelf represents a submarine extension of the Carboniferous lowlands of New Brunswick and Nova Scotia. Geophysical studies (Sheridan and Drake 1968) indicate that the relief of the Magdalen Shelf is developed on an asymmetrical basin of Permo-Carboniferous rocks. This basin is slightly tilted to the southeast and the rocks occupying it have been broadly warped into a synclinorium which plunges to the northeast.

Johnson (1925, p. 56), after a careful study of the shorelines and the existing charts of the southern Gulf, concluded that the western and central regions represented the partial submergence of an eroded, broad, shallow northeasterly plunging syncline of Permo-Carboniferous rocks. Furthermore, he suggested that differential fluvial erosion of the gently inclined strata had developed an asymmetrical upland or cuesta landscape, the steeper side of which faced southwestward while the backslope descended gently to the north and east. Later drowning left Prince Edward Island as an unsubmerged upland remnant of this landscape and the Northumberland Strait as a drowned inner lowland which had developed on less resistant strata.

On Prince Edward Island, the cuesta ridge of resistant strata flattens and swings around to the north and east and has its submarine extension off North Point. Thence, it can be traced northeasterly as a curving submarine ridge to the edge of the shelf near Orphan Bank (see Fig. 31 and 32). Similarly, Northumberland Strait has a westerly and northerly extension in the Shediac Trough which lies between the New Brunswick coast and the submarine extension of the cuesta ridge.

Careful inspection of the bathymetric data also suggests that there is another partly-preserved ridge of resistant strata north of Prince Edward Island and west of the Magdalen Islands, which has its highest remaining elements in Bradelle and Bennett banks. These banks are separated from the submarine extension of the Prince Edward Island ridge to the west and the Magdalen platform to the east by the western and eastern Bradelle troughs. Where the rocks are almost horizontal, mesa-like bedrock features have been formed and are now represented by the flat-topped banks such as Orphan and

Bradelle. In the eastern part of the shelf, the submarine platform around the Magdalen Islands is a surface expression of a dome-like elevation formed by an anticlinal arch of bedrock (Sheridan and Drake 1968, fig. 13). Along its eastern margins, the Cape Breton Trough is underlain by more strongly folded Permo-Carboniferous rocks, the fold axes of which strike northeasterly and apparently plunge to the northeast. The acoustical data (Chart 7, seismic profiles 4 and 5) indicate that the trough is an erosional feature which has probably been developed along the structural trend of these folds by differential erosion.

Since the lowlands are beneath an upland erosional surface believed to be Cretaceous in age, (discussed in Chap. 2), the development of these areas may be regarded as beginning in early Tertiary times and continuing through succeeding periods of differential uplift and fluvial erosion to the beginning of the Pleistocene.

The preglacial bedrock valleys of the Magdalen Shelf (Fig. 26), some of which are still connected to modern river systems such as the Restigouche, show that the shelf was traversed by northeasterly flowing rivers which became well adjusted to the broad structure of the shelf. The preglacial drainage system has been recognized by Johnson (1925), Cooke (1931), and Loring and Nota (1966). The Chaleur Trough was apparently traversed by the seaward extension of the Restigouche and the Matapedia River systems, which drain the highlands of New Brunswick and the Gaspé. These are now deeply incised into the edge of the adjacent highlands and uplands. The preglacial Miramichi River, draining the highlands of New Brunswick, apparently curved to the north and followed the line of the Shediac Trough, which is an old inner lowland developed on relatively weak strata between cuesta ridges.

According to Cameron (1962) an ancient drainage divide extended between Cape Tormentine, N.B. and Borden, P.E.I. Rivers flowing down the regional slope from the highlands of New Brunswick (Chart 1) turned to the north and west and followed the course of the Shediac valley. This valley also probably received the drainage from adjacent points in Prince Edward Island. North of the Shippigan Peninsula, the drainage became confluent with the rivers flowing through the Chaleur Trough. Together they joined the Laurentian Trough southeast of the tip of the Gaspé Peninsula.

The easterly flowing rivers, which initially joined Northumberland Strait east of the ancient drainage divide, also had a well-developed system of tributaries. According to Cameron, the ancient course of the Parrsboro River found its way north and eastward into the eastern end of Northumberland Strait and flowed with other rivers along the course of the Cape Breton valley (trough) to reach the Laurentian Trough to the northeast (Loring and Nota 1966). In the central shelf, small rivers which occupied the western and eastern Bradelle valleys (troughs) flowed northeasterly to join the Laurentian Trough.

During the Pleistocene epoch, the entire shelf was presumably covered by ice sheets. The Laurentian ice invaded the shelf with ice tongues extending into the main channels of the preglacial drainage system. Laurentide ice also spread over the remainder of the shelf (Chap. 7), although it may have been effectively blocked from some parts by ice moving out from local highland centres. Glaciation failed, however, to modify more than the details of the local relief with the exception of the tunnel valleys which formed during a recessional stage of the ice from the shelf. There is also no indication that the activity of the ice has left major depositional features on the shelf. It was responsible in part, however, for the thick wedge of unconsolidated sediments occurring along the edge of the shelf adjacent to the Laurentian Trough.

The postglacial transgression has modified the glacial morphology and deposits through reworking, sorting and deposition, and caused some marine planation. One indication of this action is given by the broad submarine terrace developed in places between 100 and 140 m along the shelf edge. This terrace probably marks a modification at the shelf edge which began during a standstill in the postglacial to late-glacial transgressions and which continued through changes in sea level. Other (higher) stands at sea level are recognized by the broad terrace developed at 28–34 fath (51–62 m) around the Magdalen Islands and in the coastal areas of Prince Edward Island and those recognized by Kranck (1972) in Northumberland Strait (see Chap. 9).

Recent depositional processes have also modified the glacial topography through active erosion and transport of sediment areas on top of the banks and deposition in the troughs and intervening "lows" between the banks.

5

Surface and subsurface sediments

Surface Sediments

This chapter is devoted to a description of the sedimentary units and their general lithology. The lithology of the surface sediments (top few centimeters) and their regional distribution reflects the present depositional conditions and also, to a certain extent, the depositional conditions that have been effective earlier. Since the nature of the sediment cover is very different for the Laurentian Trough system and the adjacent shelves, these areas will be considered in separate parts.

About 1500 surface samples from the floor of the estuary and Gulf have been collected and examined. The sediment descriptions are largely based on examination of the samples under a binocular microscope. However, in order to provide a basis for comparison, about 500 of the samples (150 from the Laurentian Trough and 350 from the Magdalen Shelf) have been analysed to determine the particle distribution, and about 675 to determine the carbonate content. The sediment distribution for Northumberland Strait has been interpreted from sample data provided by K. Kranck, Bedford Institute. Since the sediments in that area are not discussed in this chapter, the reader is referred to a detailed sediment map CHS chart 4023 G 1972 and report prepared by Kranck (1971).

The limits and names of the size grades used in this chapter are: *gravel*, for particles coarser than 2 mm; *sand*, for particle diameters between 2 and 0.05 mm (sometimes subdivided into coarse sand (1–0.5 mm), medium sand (0.5–0.25 mm), fine sand (0.25–0.05 mm), or very fine sand (.125–0.05 mm). For material smaller than 0.05 mm, the term *pelite* is used instead of *mud*. Pelite is composed of *silt* particles between 0.05 mm and 0.002 mm, and *clay* particles less than 0.002 mm in diameter. The term *calcirudite* is applied to calcareous material over 2 mm in diameter; *calcarenite* is calcareous material of sand size, and calcareous material smaller than 50 μ (0.05 mm) is referred to as *calcipelite*.

The nomenclatural system used to describe the texture of the sediments is similar to that of Nota (1958). Components representing less than 5% by weight of the total sediment are not considered. Those representing between 5 and 30% are indicated by an adjective (sandy) and those over 30% qualify as nouns (sand). If two components represent more than 30%, the finer-grained component is indicated by a noun, the other by an adjective with the adverb "very," e.g. "very sandy pelite" and not "very pelitic sand." In this chapter the term calcipelite is also applied to pelites having a carbonate content that ranges between 5 and 30% by weight. The advantage of this system of nomenclature is that the 30% limit can be more easily determined in thin sections or by means of a binocular microscope than the 50% limit which is so commonly used.

The colors of the sediments are recorded according to the Rock Color Chart distributed by the Geological Society of America (1971). Most of the colors were estimated when the samples were fresh and wet, except for core samples which were dry or partly dry when the color was recorded.

The distribution of the sediments is given in the form of a map (Chart 2, in pocket) for the whole area. The regional variations in grain size, carbonate content, and textural characteristics of the samples obtained from the different traverses, as well as the bathymetric information, were used as a basis of its construction. It is obvious, however, that large areas still exist in which the sampling density is low (Chart 3, in pocket) so that *sediment boundaries should be regarded as approximate*.

Although the actual sediment composition can be given only for the precise location of the samples, reference to the echoprofiles (Chart 4, in pocket) will give a clear overall picture of the surface sediment distribution in each region. Interpretations of oblique sonar records and bottom photographs can also be used to show the sediment pattern, particularly on the Magdalen Shelf.

Many of the sediment descriptions have also been recorded in the form of figures. Therefore, in reading the text, frequent reference to the relevant figures is recommended.

Laurentian Trough system (Northern Gulf)

The regional variation in the composition of the surface sediments in the Laurentian Trough system and its adjacent shelves is shown by the accompanying sediment map (Chart 2, in pocket). A series of profiles has also been constructed from the echograms and sampling data to show the relation between submarine topography and sediment composition in various parts of the trough (Fig. 33).

From the sediment map and echoprofiles, it may be seen that, in general, the sediment distribution is controlled by the submarine topography: fine-grained sediments (pelites and sandy pelites) occupy the floors of the troughs, and sediments of increasing grain size (very sandy pelites, pelitic sands, sands, gravels, and locally glacial drift) form the cover on the slopes and the adjacent shelves.

In addition, it should be noted that calcareous debris and detritus form an important component of the sediments occupying the trough system east of the St. Lawrence Estuary (Fig. 34). Carbonate contents are less than 5% in the following areas: from Quebec City to the mouth of the estuary, in the nearshore areas of the North Shore Shelf with the exception of the area opposite Anticosti Island, the inner Quebec–Labrador Shelf, the inshore area of the Newfoundland Shelf, and the Magdalen Shelf with the exception of the area adjacent to the Gaspé Peninsula. Carbonate contents greater than 5% occur along the Gaspé coast, around Anticosti Island, in the Laurentian Trough to the south and southeast of the island, and in the northeastern part of the Gulf. Furthermore, the pattern displayed by the regional distribution of carbonate indicates two dispersal centers of the calcareous material (See Chap. 7).

Megascopic and microscopic examination reveal that detrital limestone particles of gravel, sand, and pelite size are the main source of carbonate in the sediments, except in the Strait of Belle Isle, where shell fragments are also present in sufficient amounts to form shell gravels (map unit 4c, Chart 2, in pocket).

Pelitic material is the predominant constituent of most of the fine-grained surface sediments on

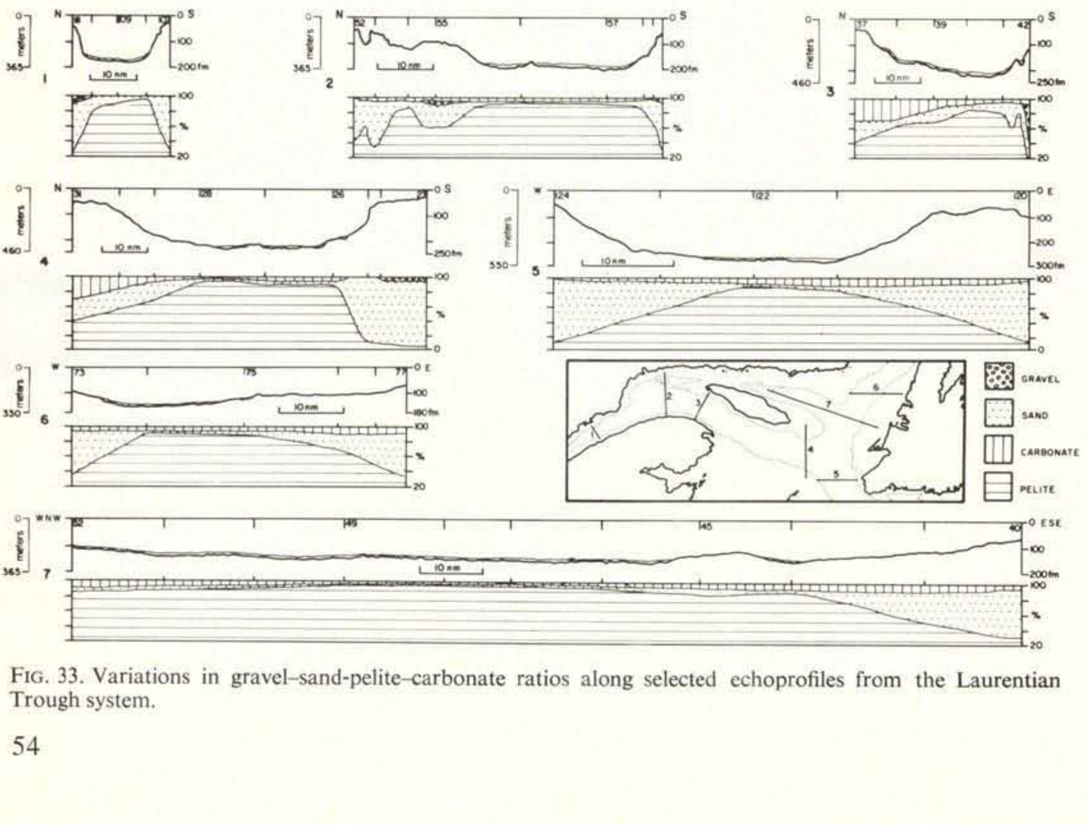


FIG. 33. Variations in gravel–sand-pelite–carbonate ratios along selected echoprofiles from the Laurentian Trough system.

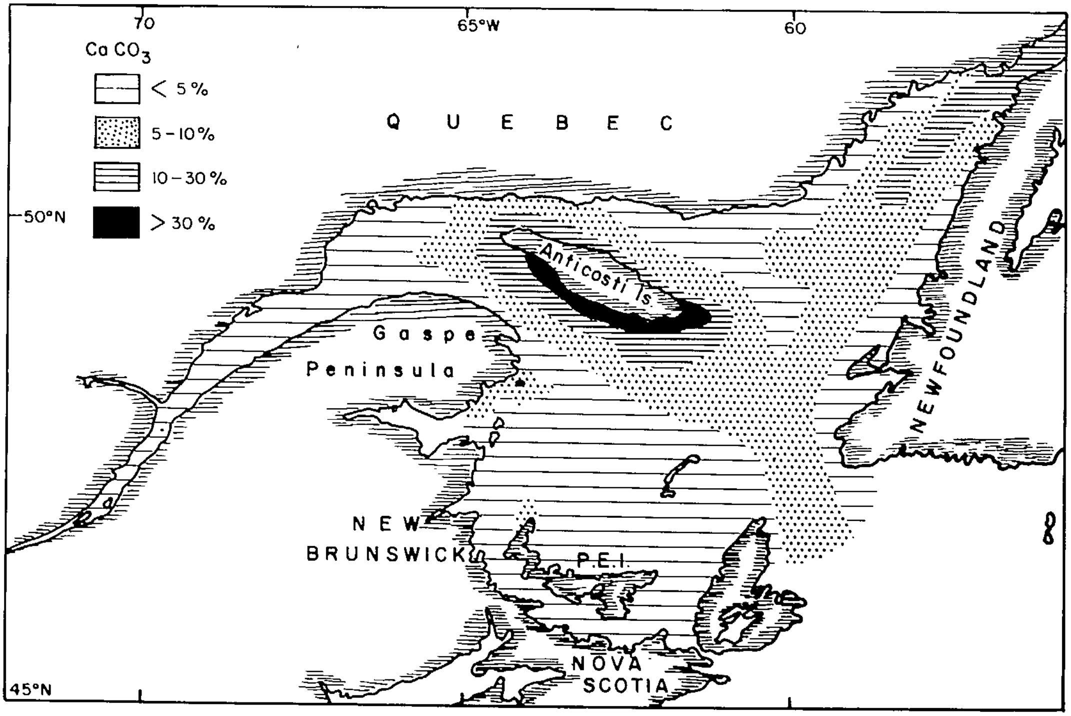


FIG. 34. Regional distribution of calcium carbonate ($CaCO_3$) in the surface sediments of the Gulf of St. Lawrence.

the floors and slopes of the Laurentian, Anticosti, and Esquiman troughs. In these sediments, variation in the silt and clay content of the pelites is one of the distinguishing characteristics of the different pelite deposits in the troughs, viz., deepwater, protected basin, and relict; whereas variation in the amount of material coarser than 50 μ separates sandy pelites from the very sandy pelites on the slopes of the trough (Fig. 33). In addition, the carbonate content of the sediments (Fig. 34) separates noncalcareous pelites in the estuary from calcareous pelites or calcipelites elsewhere in the troughs.

Pelite and calcipelite (Map Units 1 and 1a) — Pelite and calcipelite form the top sediment cover over most of the floor and lower slopes of the Laurentian Trough in water depths usually greater than 280 m (~153 fath) and in the Anticosti and Esquiman troughs at water depths usually between 180 and 300 m (~98–164 fath). These sediments which are acoustically transparent vary in thickness from 1 to 40 m. The greatest thickness of the pelite layer, which forms the most recent sediment addition, is found in the large depressions in the trough floors with a maximum thickness of 40 m being recorded from the large floor depression in the Laurentian Trough near Cabot Strait. Elsewhere the deposits thin out over the floor rises and ridges which separate the depressions, and towards the sides of the troughs (see Chart 4, in pocket). The echograms show that pelite deposits have formed a more or less level surface over a rough undulating topography by filling the subsurface irregularities (see Figs. 19 and 20). Core samples and continuous seismic profiles show that the rough surface on which the thin cover of pelites has been deposited is mainly constructed of sediments having the textural characteristics of glacial drift.

The deepwater pelites and calcipelites are very soft sediments with a water content of about 60% by weight. They are dark greenish-grey (5GY 4/1) a few millimeters below the sediment–water interface, whereas at the interface they are a dark yellowish-brown (10 YR 4/2). Oxidizing conditions prevail at this interface, whereas below it reducing conditions prevail. The *p*H of these sediments varies between 6.89 and 8.12. The clay content is usually between 45 and 65% and the silt content ranges from 30 to 50% by weight. In the calcipelites, the carbonate content varies from 5 to 20%. Percentages of material coarser than 50 μ generally amount to only a few percent and increase as these sediments merge into sandy pelites. The coarse material which sometimes includes pebbles and boulders is more or less homogeneously mixed with the pelite, although in some cores (see Subsurface Sediments) the coarse material is concentrated at certain levels. The coarse-grained material (2–0.05 mm) in the pelite is composed of feldspar, quartz, accessory heavy minerals, and rock fragments, but in the calcipelites, which occupy the deep central parts of the Laurentian Trough south and east of Anticosti Island, as well as the Anticosti and Esquiman troughs, the coarse material is mainly composed of gravel- and sand-size limestone particles (see Chap. 7). The granulometrical composition of the pelites indicates that the pelite-size material has been deposited recently from suspension and that the coarse material is mainly derived from the adjacent shorelines by ice-rafting (see Chap. 6).

Deposition of very silty pelites and calcipelites in the shelf valleys and in depressions surrounding the trough has also formed protected basin deposits (not differentiated on Chart 2). The most extensive deposits of this type are found in the large protected basin east–southeast of Sept Îles, in the elongated depressions near the coast of Labrador (Mécatina Trough) and in St. George's Bay, Newfoundland. The main features of these sediments are their high silt content (45–60%) and lower clay content (<50%). The high silt content of these sediments is believed to result from the presence of bottom currents which are of sufficient strength to prevent the accumulation of clay-size particles as the dominant constituent.

The other type of pelite deposit is found at or near the surface beneath a thin cover of sand and gravel on the south side of the upper St. Lawrence Estuary below Quebec City (Map Unit 1b). Throughout this area, the characteristic deposit is a homogeneous stiff, light olive-grey (5 Y 6/1) heavy pelite.

The distinctive features of these sediments are their stiffness (water content about 40%) and the very high clay content which is usually between 80 and 90%.

The differences in texture between these pelites and those found elsewhere in the troughs indicate that the stiff pelites are not recent deposits but relict from former environmental conditions (Nota and Loring 1964). As such they are important in deducing the earlier depositional history of this area (see Chap. 9).

Sandy and very sandy pelites (Map Units 1c and 1d) — Coarser-grained sediments enclose the deepwater pelites throughout the trough system (see Chart 2). With decreasing water depth these sediments show a decrease in pelite content, particularly in the amount of clay-size particles, and a corresponding rise in the percentage of material coarser than 50 μ (see Fig. 33).

Sandy pelites (Map Unit 1c) border and sometimes divide the pelite deposits in the trough floors, and cover the lower slopes. They also cover most of the floor in the Laurentian Trough in the estuary, the floor in the headward parts of the Anticosti and Esquiman troughs, and the floor of the Saguenay fjord. With increasing sand and silt content, the sandy pelites usually merge with the very sandy pelites on the upper slopes.

The very sandy pelites (Map Unit 1d) are found on the trough slopes, and in some parts of the adjacent shelves. They occur in water depths between 20 and 220 m in the upper part of the Laurentian Trough, but in the lower part near Cabot Strait they sometimes extend to a depth of 460 m (Fig. 33, line 5). In the Anticosti and Esquiman troughs they are usually found in water depths between 100 and 300 m. They have their most extensive coverage on the slopes surrounding the eastern half of the Anticosti Shelf, on the rough hummocky slopes adjacent to the Newfoundland Shelf, and around Banc Beaugé.

Subbottom reflections indicate that the thickness of the sandy pelites varies from 0 to 15 m but the very sandy pelites are mostly acoustically opaque at the energy level of the conventional echosounder. Continuous seismic profiles and core samples show that the sandy pelites are underlain at depth by glacial drift, whereas the glacial drift surface is usually less than 3 m beneath the very sandy pelites on the trough slopes.

These sediments are usually dark greenish grey (5 GY 4/1) and uncompacted. The sandy pelites contain 30 to 55% clay-size material, whereas in the very sandy pelites, the clay content is much lower and ranges between 7 and 35%. Sand-size material, which makes up 5–30% of the total in the sandy pelites and more than 30% in the very sandy pelites, contains the whole spectrum of sand-size grades and is usually very poorly sorted (see Chap. 6). The sand-size carbonate component, which comprises 5–30% of the total in the sediments from the central and eastern Gulf, is composed of limestone and dolomite particles and minor amounts of shell fragments. In the sandy pelites the coarse-grained component is mainly supplied from the adjacent shorelines by ice-rafting. In the very sandy pelites, however, most of the coarse-grained material as well as part of the pelite component has been supplied by the reworking of the rough glacial drift surface on which they rest (see Depositional History, Chap. 9). In some places this reworking process is still occurring.

Gravelly pelite and gravelly sandy pelites (Map Units 1e and 1f) — Gravelly pelite (Map Unit 1e) and gravelly sandy pelites (Map Unit 1f) are poorly sorted sediments that occur mainly in water depths between 100 and 300 m on the slopes surrounding the eastern end of Anticosti Island, at the head of the Anticosti Trough, and along the inner Quebec–Labrador Shelf (Chart 2, in pocket). At the eastern end of Anticosti Island the gravel- and sand-size material is composed mainly of limestone and dolomite fragments derived partly from the underlying bedrock, and partly from the reworking of a grey calcareous glacial till which thinly mantles the bedrock in this area (see Fig. 18). The pelite component which dominates the sediments is derived in part from the till and in part from suspension. It is considered that these units like map units 1d and 3e mainly represent modified glacial drift.

Glacial drift (Map Unit 5) — Glacial drift is used in this report as a stratigraphic term for Pleistocene glacial deposits, whereas the terms *till*, *glaciomarine*, and *glaciofluvial* are used in the petrological sense (see Subsurface Sediments and Chap. 6).

The glacial deposits in the Gulf are the oldest unconsolidated sediment units and form an uneven cover on top of the bedrock. They are covered mostly by Recent postglacial marine sediments in the troughs and on the adjacent shelves, except for local outcrops along the edge of the Magdalen Shelf (Chart 2). These deposits usually vary in thickness from 3 to 30 m but, where they fill depressions in the bedrock, are as much as 100 m thick. Since the drift mainly occurs as a subsurface deposit, it will be described in the section dealing with the subsurface sediments except where it outcrops on the Magdalen Shelf.

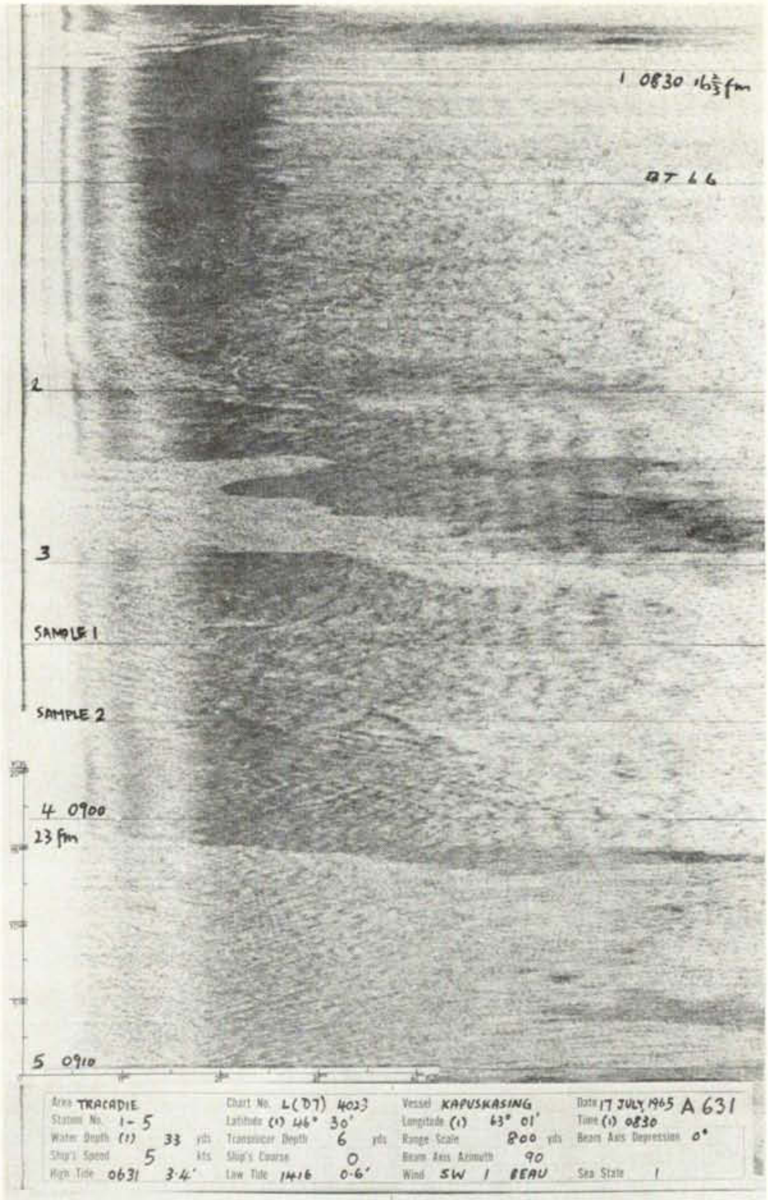
Western, Northern, and Eastern Shelves

An abundance of material from the coarser size grades is the main feature of the sediments covering the western, northern, and eastern shelves adjacent to the troughs (see Chart 2).

The coarser-grained deposits may be classified mostly as pelitic sands (Map Unit 3b and 3e), sands containing varying amounts of gravel (Map Unit 3d and 3c), and various types of gravel deposits (Map Unit 4, 4a, 4b, and 4c). Locally, accumulations of fine-grained material have formed the protected basinal type of pelite deposit in the shelf depressions and valleys. In addition, deposits of calcirudite (Map Unit 4a) and calcarenite (Map Unit 3a) are formed from an abundance of calcareous material of gravel and sand size on the Anticosti Shelf, in Jacques Cartier Passage, North Shore Shelf, and on the series of broad submarine banks extending through the northeast part of the Gulf to the Strait of Belle Isle (outer Quebec–Labrador Shelf). In the Strait itself the floor is covered mostly with a peculiar deposit composed entirely of igneous rocks and large barnacle (*Balanus hameri*) shells (Map Unit 4c).

Bottom profiles (see Fig. 33) clearly reveal the relation between rough shelf topography and sediments. The topographic highs or banks show concentrations of coarser size grades while the intervening lows and valleys contain an enrichment of pelitic material.

The textural characteristics of the sands and pelitic sands are mostly similar to those described for the poorly sorted, very sandy pelites on the upper slopes of the trough as they differ only in the relative proportions of pelite, sand, and gravel-size material in them. Well to fairly well sorted sands, containing small amounts of pelite ($<5\%$), are uncommon and are found mostly in the nearshore areas and in the southern Gulf (see Magdalen Shelf). The gravel-size component of the shelf deposits, like that present in some of the slope and floor sediments, varies not only in amount but also in size and composition. All sizes of particles are found including boulders. In general, gravels from the north side of the Gulf, including the Labrador coast, are mainly composed of igneous rocks and metamorphic rocks (granites, syenites, gabbros, anorthosites, various gneisses, and quartzites) except in the vicinity of the Mingan Islands, Anticosti Island, and along the outer part of the Quebec–Labrador Shelf where limestone and dolomites are found in the samples. The concentration of gravel-size limestone and dolomite material from Anticosti and the northeastern Gulf has previously been mentioned (Map Unit 4a). On the south side of the St. Lawrence Estuary and on the Newfoundland Shelf, the



Area	TRACADIE	Chart No.	L(D7) 4023	Vessel	KAPUSKASING	Date	17 JULY 1965 A 631
Station No.	1-5	Latitude (1)	46° 30'	Longitude (1)	63° 01'	Time (1)	0830
Water Depth (1)	33 yds	Transducer Depth	6 yds	Range Scale	800 yds	Beam Axis Depression	0°
Ship's Speed	5 kts	Ship's Course	0	Beam Axis Azimuth	90		
High Tide	0631 3·4'	Low Tide	1416 0·6'	Wind	SW 1 BEAU	Sea State	1

FIG. 35. Sonargram record showing patches of gravel (dark irregular tones) with sand, and sand thinly covering the bedrock (lighter tones interspersed with faint lineations) just north of Prince Edward Island. The area shown by this record is about 3½ naut. miles by 800 yards (720 m). The transmission line is located at the left margin with a profile of the sea floor immediately adjacent to it.

gravels are a mixture of rocks of similar lithology to those on these coasts and to those from the northern part of the Gulf.

The coarse-grained deposits on the shelves adjacent to the troughs are considered to be mostly relict glacial drift material that has partly been reworked, resorted, and redistributed during the period of postglacial transgressions (see Chap. 9).

Magdalen Shelf (Southern Gulf)

Glacial erosion and deposition together with sealevel changes and recent depositional conditions have produced a complicated sediment cover of variable thickness and extent over the Magdalen Shelf (Chart 2). This cover rests upon, and is frequently broken by, an irregular bedrock surface composed mainly of Permo-Carboniferous sandstone (Loring and Nota 1966).

Four main lithological units are recognized on the Shelf, viz., glacial drift, gravels, sands, and pelites. Subdivisions of the latter three units are differentiated on the basis of their minor (5–30%) components. In addition, the sands have been qualified on their grain size (coarse- to medium-grained, fine-grained, and very fine-grained) and degree of sorting (poorly sorted and fairly well sorted to well sorted). Carbonate detritus does not form an important component in these sediments as the $CaCO_3$ content is less than 5%, except in a small area in the northwestern part of the shelf adjacent to the Gaspé Peninsula.

Glacial drift (Map Unit 5a) — A layer of reddish-brown glacial drift characterized by a rough hummocky surface is exposed on or near the terrace surface along the edge of the Laurentian Trough and on the floor ridges in the Shediac and Cape Breton troughs. Drift also forms a rough-surfaced subbottom deposit of varying thickness over the bedrock surface in the shelf valleys and in several places on the central shelf. The drift has been reworked, resorted, and redistributed by sealevel rises and recent depositional processes into a variety of sediments in most of the shelf areas that have water depths less than 100 m. Core samples (see Subsurface Sediments) show that the drift is a reddish-brown till composed of a poorly sorted mixture of gravel, sand, and pelite. Petrographic and mineralogical analyses (see Chap. 7) indicate that the drift consists of minerals and rock fragments derived from the underlying bedrock, and minor amounts of material carried from outside the shelf area.

Gravels (Map Units 4 and 4b) — On the shelf, gravel with occasional sand patches and sandy gravels (Map unit 4b) form a thin discontinuous cover which rests upon and is frequently broken by a rough bedrock surface on large areas of the sea floor between Prince Edward Island and the Magdalen Islands. (profile 4; Chart 6, north of Prince Edward Island (Fig. 35), on the submarine extension of North Point, Prince Edward Island, on the western flank of the Shediac Trough (echoprofile 8, Chart 6), and north of the Magdalen Islands. These deposits usually occur in water depths between 20 and 70 m (~10–38 fath) and are surrounded by a thicker cover of sands with varying amounts of gravel. In several places the sand is gradually encroaching on the gravel fields (Fig. 36). Outside of these areas, local gravel fields of smaller extent are also found where bedrock is at or near the surface, and on the shelf banks such as Bradelle and Orphan banks. On the banks, sand and granule-size (4–2 mm) material have been winnowed out of older glacial deposits and the gravel-size material has been left as "lag deposits."

FIG. 36. Large and small rock fragments mainly reddish-brown sandstones with an intermittent veneer of sediments on the sea floor north of Prince Edward Island. Note by the apparent deposition of sediment in the upturned shells, the encroachment of sediment over the pebbles, cobbles, and boulders. Photograph represents an area of about 1.5 x 1.2 m and was obtained at a depth of 55 m at station 84, S-75 (46°48′N,62°37′W).

The gravel consists of pebbles, cobbles, blocks, and sometimes boulders mixed with small amounts of sand. It is composed mainly of reddish-brown friable sandstone of similar lithology to the bedrock surface on which it rests.

Rocks foreign to the shelf such as the crystallines (granites, gneisses, basic igneous rocks), quartzites, and limestone occur, however, in significant, and in some places predominant quantities, especially in gravel areas in the northern part of the shelf (see Chap. 7). The foreign rocks are usually better sorted (32–64 mm) than the local material and often have the "flat iron" shape usually associated with glacially transported material. Coralline or other encrustations occurring on one side of the local and foreign rocks indicate, however, that neither has been transported recently but that the material belongs to relict glacial and residual deposits (Fig. 37).

FIG. 37. Lag gravel deposit composed of glacially transported rocks foreign to the shelf area and some local bedrock fragments on the sea floor northwest of the Magdalen Islands. Photograph represents an area of about 1.5 × 1.2 m and was obtained at a depth of 55 m at station 25, S-75 (47°59′N, 61°38′W).

Sand associated with the gravels is brownish-red to greyish-brown, coarse- to medium-grained (2–0.25 mm) and usually poorly sorted in the large gravel-covered areas in which little or no sediment accumulation is now taking place. In contrast, the sands are medium- to fine-grained and fairly well to well sorted in areas near the edges of some large gravel fields as well as in the gravel fields that lie on shelf banks such as Bradelle Bank. On these banks active redistribution of sediments is taking place (see Chap. 9).

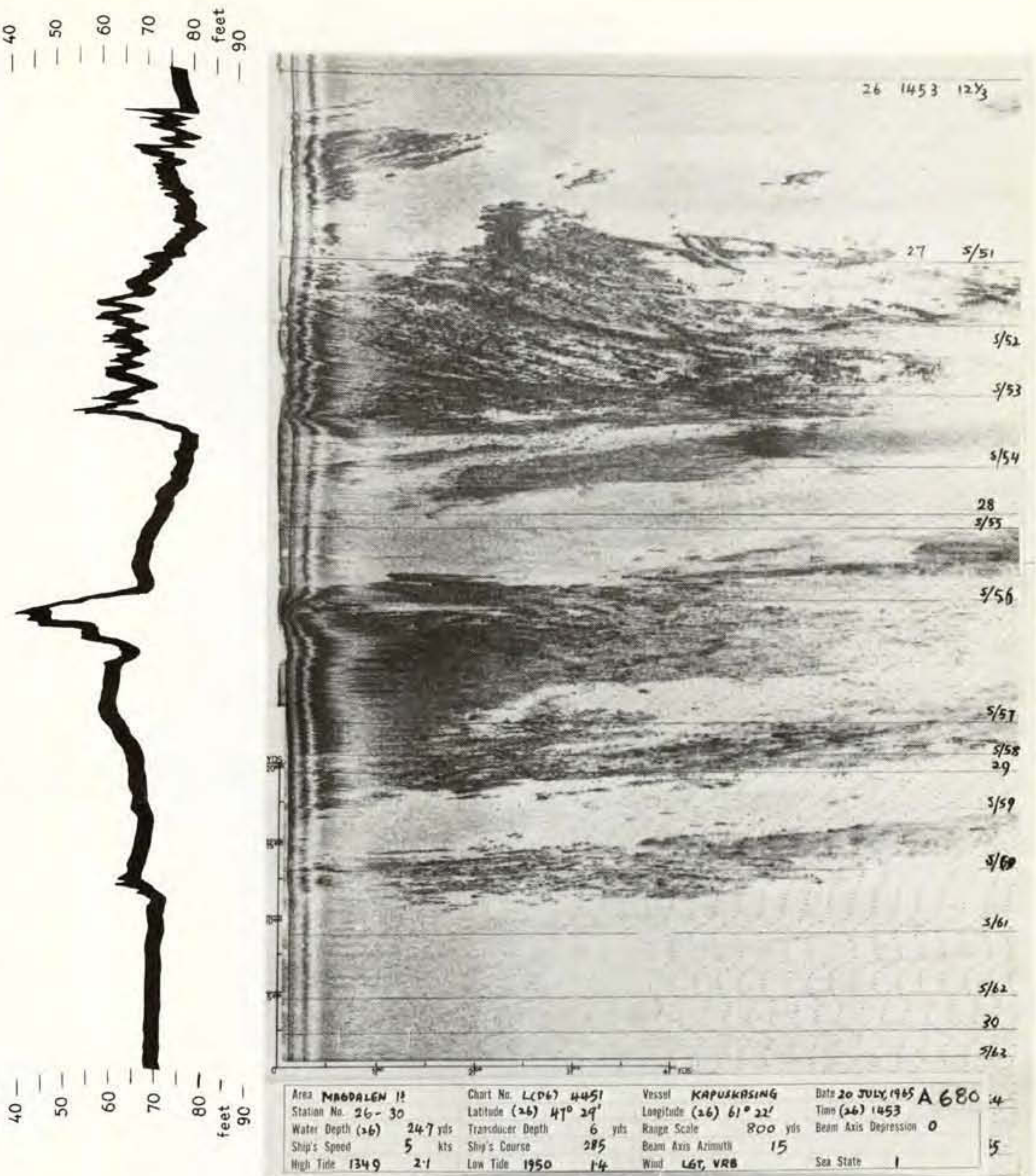
Sands (Map Units 3 and 2) — Outside the large gravel areas, the sediment cover is thicker and more nearly continuous with only local exposures of bedrock. It consists mainly of sand with varying amounts of gravel- and pelite-size material. The shelf sands have been differentiated on the following basis: (1) grain size (coarse- to medium-grained, 2–0.25 mm in diameter; and fine-grained, 0.25–0.05 mm in diameter; and very fine-grained, 0.125–0.05 mm); (2) sorting (poorly sorted and fairly well sorted to well sorted); and (3) the minor components (5–30%) with which they are associated. The sands are composed of mineral and rock fragments (feldspathic quartz sands with rock aggregates) derived from the underlying bedrock and small but significant amounts of material from outside the shelf area (see Chap. 7).

Coarse- to medium-grained sands (Map Unit 3) are the dominant constituent of the sediment cover in many parts of the shelf. They have a wide variation in their degree of sorting, color, thickness and contain varying amounts of gravel and pelite.

Gravelly, fairly well sorted to well sorted reddish-brown to greyish-brown sands (Map Unit 3c) form a thin but nearly continuous sediment cover in water depths less than 60 m (~33 fath) off the north coast of Prince Edward Island, the New Brunswick coast, on top of Bradelle Bank (Fig. 38), and on the inner part of the terrace near the western, northern, and northeastern coasts of the Magdalen Islands. In some places near the Magdalen Islands these sands also occur between bedrock outcrops (Fig. 39). The occurrence of sand waves in some of these areas, such as on Bradelle Bank, indicates that these are areas in which active reworking, resorting, and redistribution of old glacial deposits are taking place (see Fig. 40).

FIG. 38. Gravelly well to fairly well sorted reddish–brown to greyish–brown sand (Map Unit 3c) on top of Bradelle Bank. Photograph (1.5 × 1.2 m coverage) was obtained at a depth of 44 m at station 90, BIO-27-65 (47°26′N,62°55′W).

In contrast, gravelly, poorly sorted reddish-brown to greyish-brown, coarse- to medium-sands (Map Unit 3d) occur in essentially nondepositional environments (see Chap. 9), such as in the deeper waters north of Prince Edward Island, off Kouchibouguac Bay, New Brunswick, in the tongue between the Shediac and Chaleur Bay troughs, the lower bank slopes,

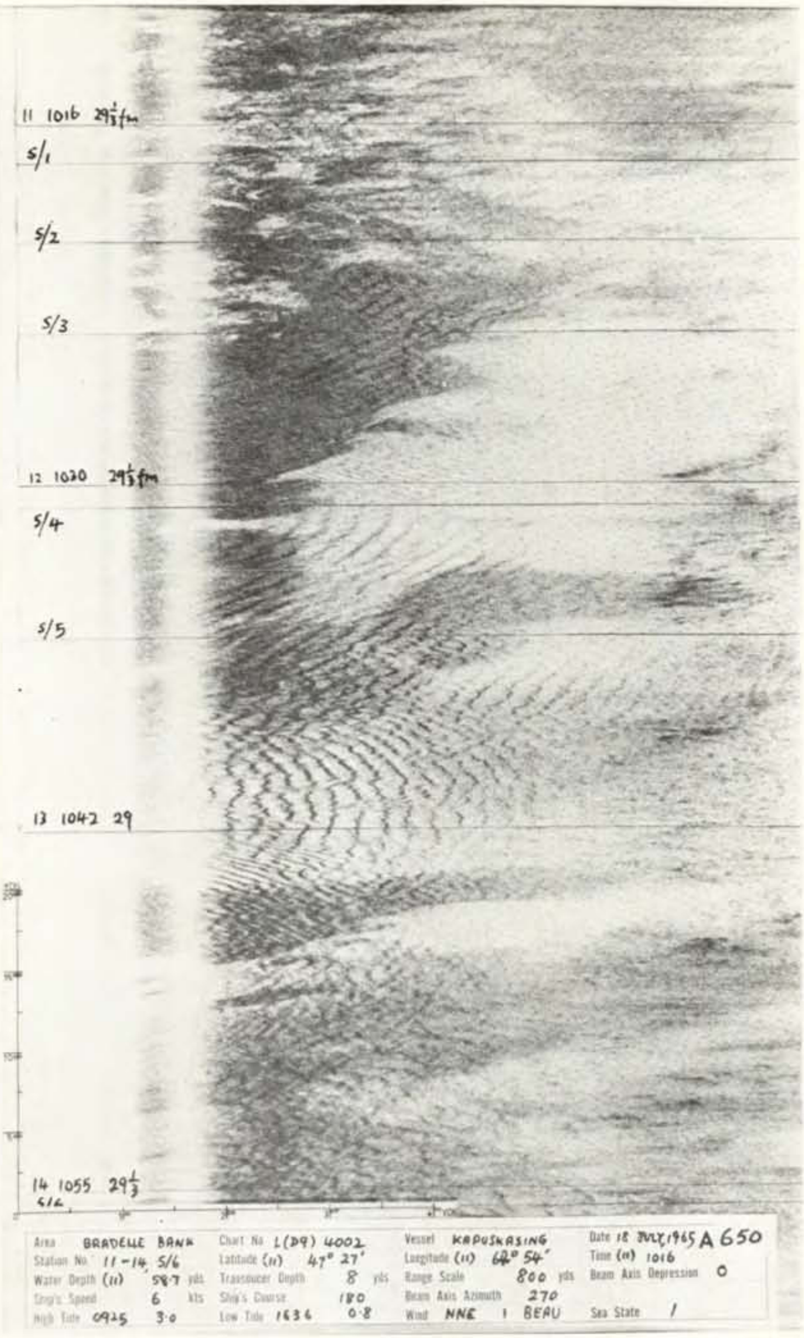


Area MAGDALEN I!	Chart No. L(D6) 4451	Vessel KAPUSKASING	Date 20 JULY, 1965 A 680
Station No. 26- 30	Latitude (26) 47° 29′	Longitude (26) 61° 22′	Time (26) 1453
Water Depth (26) 24·7 yds	Transducer Depth 6 yds	Range Scale 800 yds	Beam Axis Depression 0
Ship's Speed 5 kts	Ship's Course 285	Beam Axis Azimuth 15	
High Tide 1349 2·1	Low Tide 1950 1·4	Wind LGT, VRB	Sea State 1

FIG. 39. Two large and several smaller rock formations protruding above a flat sandy bottom near the east coast of the Magdalen Islands. Acoustic record of about 3½ naut. miles by 800 yards. The lettered horizontal lines across the record indicate the location of underway bottom samples. The transmission line is located at the left hand margin, with a profile of the floor immediately adjacent to it. Echogram obtained simultaneously with sonar record is also shown.

and on the western edge of Magdalen terrace. They also occur at the western and eastern ends of the tunnel valleys between Prince Edward Island and the Magdalen Islands, and along the west coast off Cape Breton. These sands are of residual and glacial origin (see Chap. 6 and 7).

Poorly sorted admixtures of gravel (>5%), pelite (>5%), and greyish-brown, coarse- to



Area	BRADELLE BANK	Chart No	L(D9) 4002	Vessel	KAPUSKASING	Date	18 JULY 1965 A 650
Station No	11-14, S/6	Latitude (11)	47° 27'	Longitude (11)	64° 54'	Time (11)	1016
Water Depth (11)	58.7 yds	Transducer Depth	8 yds	Range Scale	800 yds	Beam Axis Depression	0
Ship's Speed	6 kts	Ship's Course	180	Beam Axis Azimuth	270		
High Tide 0925	3.0	Low Tide 1636	0.8	Wind	NNE 1 BEAU	Sea State	1

FIG. 40. Gravel patches (dark even tones), sand (light even tones), and sand waves (alternating dark and light regular pattern) on Bradelle Bank. The area of sea floor covered by this record is about 3½ naut. miles by 800 yards (720 m). The location of underway bottom samples is indicated by the S-lettered horizontal lines across the record. Note that sand wave pattern in this record is an oblique westward view.

medium-grained sands (Map unit 3e) are found in areas where the glacial drift has been slightly reworked at the junction of the Shediac and Chaleur troughs, as well as on the floor ridges in the Cape Breton Trough off Cheticamp (Cape Breton Island).

Fine-grained (0.25–0.05 mm) sands (Map Unit 2) form the predominant constituent of the sediment cover on the shelf in the intervening lows between shelf banks, the upper slopes of the shelf valleys, and lower slopes along the shelf edge. They are usually well sorted (<30% >200 μ and the fraction between 50 and 100 μ is less than 30%) and mixed with varying amounts of gravel and pelite. Grain-size analyses indicate that the sands have been mainly winnowed out of the coarser sediments on the banks and elevated areas and redeposited in response to the present current regime (see Chap. 6).

Fine-grained well sorted sands (Map Unit 2) occur in the deeper waters between Bradelle Bank and Prince Edward Island, the western and eastern slopes of Bradelle Bank, at the edge of the Shelf, and in a narrow band at the eastern end of the tunnel valleys.

Very fine (<30% >125 μ) well sorted sands (Map unit 2a) form a large body about 10 miles wide that extends eastwards for 20 miles from the 20 m (~10 fath) line across the terrace east of the Magdalen Islands. These sands are enclosed by coarser sediments to the north and south, and eastwards they merge with the pelitic fine sands (Map unit 2b) on the western slope of the Cape Breton Trough. Grain-size analyses suggest (see Chap. 6) that these sediments represent the redeposition of fine-grained sand and silt winnowed out of coarser-grained deposits and transported in response to the present current regime.

Southwest and west of Bradelle Bank the fine sands are mixed with pelite (Map Unit 2b), the percentage of which increases toward the Shediac Trough to form a large body of slightly pelitic (5–15%) sands which grade into pelitic fine sands (5–30%). The pelitic fine sands also form a narrow zone on the eastern slope of the Shediac Trough. Pelitic fine sands also occupy the headward part of the Shediac Trough between Prince Edward Island and the New Brunswick coast, and a narrow zone along the western side of the trough. In the central shelf they are found in the deepest parts of the eastern Bradelle Trough and in the tunnel valleys between Prince Edward Island and the Magdalen Islands. On the eastern side of the shelf, pelitic fine sands form most of the sediment cover between Prince Edward Island and Cape Breton and along the western flank of the Cape Breton Trough.

Fine-grained well sorted sands containing minor amounts (5–30%) of gravel have a much wider distribution than the fine sands themselves (Map Unit 2c). They occur intermixed with the fine sands between Bradelle Bank and Prince Edward Island (Map unit 2–2c) at the mouth of the western and eastern Bradelle troughs, the slope above the shelf break, and the northeastern outer edge of the Magdalen terrace, as well as in a narrow zone between the fine and coarse- to medium-sands at the eastern end of the tunnel valleys.

Pelites (Map Unit 1) — Pelite (material <50 μ) is the predominant constituent, (>30%) of the sediment cover on the floors and lower slopes of the shelf valleys. Variation in the amounts of sand in these sediments gives rise to both sandy and very sandy pelites on the shelf (Map Unit 1c and 1d). Unlike the Laurentian Trough no extensive deposits of pelite without any additional sediment component (> 5%) have been mapped in the shelf valleys with the exception of a pelite deposit inferred from Kranck's data at the eastern entrance to the Northumberland Strait. The granulometry and mineralogy of these sediments indicate that they have been derived partly from the winnowing of adjacent relict shelf sediments (see Chap. 6 and 7).

In the Shediac Trough, very sandy pelites and sandy pelites occupy a narrow (2–8 mile) zone in the center of the trough parallel to but 25 miles off the New Brunswick coast. This zone, which is about 60 miles long, is enclosed at both ends and on the sides by a variety of coarser-grained sediments. The fine-grained sediments are brownish-red to brownish-grey and are composed of pelite with varying amounts of sand. The percentage of sand increases laterally towards the sides as well as toward the head and seaward parts of the trough. The pelite component, which makes up 55–80% of the total, has a silt content between 70–90% and clay content of 10–30%. The sand is generally very fine-grained (125 to 50 μ) and is well sorted (<5% > 125 μ). Occasional pebbles, however, are found in some of the samples.

These pelites form the last sediment addition in the trough as they overlap and are underlain by older deposits. Echograms reveal that these sediments form a nearly continuous acoustically transparent smooth cover on the trough floor, between 1 and 15 m thick, that rests upon and is broken by a rough surface of older unconsolidated sediments and/or bedrock (cf. echoprofiles 7 and 8, Chart 6, and seismic profiles 1 and 2, Chart 7). Sediment cores, ranging in length from 2 to 6 m, obtained from the floor ridges show that the very sandy pelites are underlain by a hard poorly sorted reddish-brown mixture of gravel, sand, and pelite having the textural characteristic of the glacial till that is found elsewhere on the shelf (see Subsurface Sediments). Subbottom reflections recorded by the continuous seismic profiler indicate that in some places as much as 30 m of this material rests upon an eroded bedrock surface in the central part of the trough.

In the Chaleur Trough, sandy pelites form an almost continuous cover on the lower slopes and floor of the trough. These sediments are similar in texture to those found in the Shediac Trough. Some, however, that occur near the north side of the trough adjacent to the Gaspé Peninsula, carry significant amounts of calcareous material (> 5%) to form the calcareous sandy pelites outlined on the map. Subbottom reflections indicate that these sediments, which are the last addition to the trough, are about 3 m thick on the sides and as much as 18 m thick in the deep floor depression (> 180 m, ~100 fath) at the outer part of the trough. They are apparently underlain by glacial sediments but these older deposits have not yet been penetrated by coring.

Extensive deposits of pelite are also found in the Cape Breton Trough. They form an almost continuous sediment cover of very sandy pelites (Map Unit 1d) on the slopes below 80 m (~44 fath) and between floor ridges. Laterally they grade into coarser-grained sediments (pelitic fine sands, etc.). On the surface they are brownish soft sediments in which pelite is the dominant grade size containing 10–30% clay-size material. The sand-size component which makes up 10–40% of the total is very fine grained (125–50 μ) and is well sorted (less than 5% > 125 μ). Occasional pebbles, however, were found in some of the samples.

Echograms of various parts of the trough floor show that most of the sediments are acoustically opaque although several small patches of acoustically transparent sediments, 3–10 m thick, occur adjacent to the long and narrow (1–2 miles) floor ridge which bisects the trough floor for 20 miles of its length off Cheticamp, Nova Scotia (profiles 9 and 10; Chart 6).

The pelite cover which forms the last sediment addition rests upon, and in some places is broken by, either glacial drift or an irregular bedrock surface (see Subsurface Sediments).

Subsurface Sediments

Although this chapter deals mainly with the nature and distribution of the surface sediments, a limited number of sediment cores have been obtained from the Gulf of St. Lawrence (Fig. 41). These have been used to assess the vertical and lateral changes in the subsurface lithology. The locations of the cores were selected on the basis of the morphological and acoustical (echosounding and seismic) data (Chap. 4).

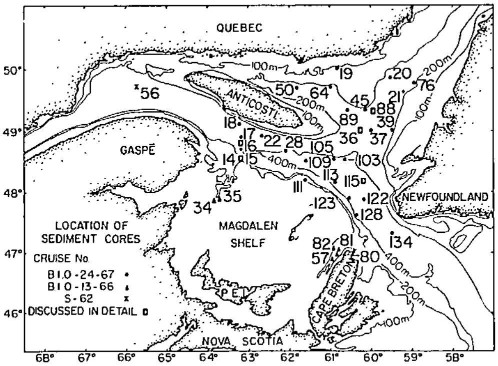


FIG. 41. Location of sediment cores discussed in text from the Gulf of St. Lawrence.

Sediment cores ranging in length from 1 to 12 m from the various parts of the region (Fig. 41) reveal in many places a twofold and sometimes threefold zonation (Fig. 42 and 43). The top layer is usually of grey pelite or calcipelite (Map Unit 1 and 1a), or sandy pelite or its calcareous equivalent (Map Unit 1c or cal. 1c). Beneath this layer in some places is a poorly sorted sediment having the textural characteristics of glacial till and composed of varying proportions of gravel, sand, pelite, and carbonate detritus (see Chap. 6). In the western and northeastern part of the Gulf, this material is usually grey, whereas in the southern part it is usually reddish-brown. These till-like sediments vary widely in their lithological and petrographic characteristics depending upon the parent rocks from which they were derived (Fig. 44). The lithological sequence is closely related to the microrelief of the sea floor (see Chap. 4, Fig. 19–20). In areas with a hummocky floor, the top pelite layer is often very thin (< 1 m) or absent, e.g. cores 16, 17, 29, 103, 113, 122, 123, 45, 37, 39, 76, 19, 57, (BIO-24-67), whereas

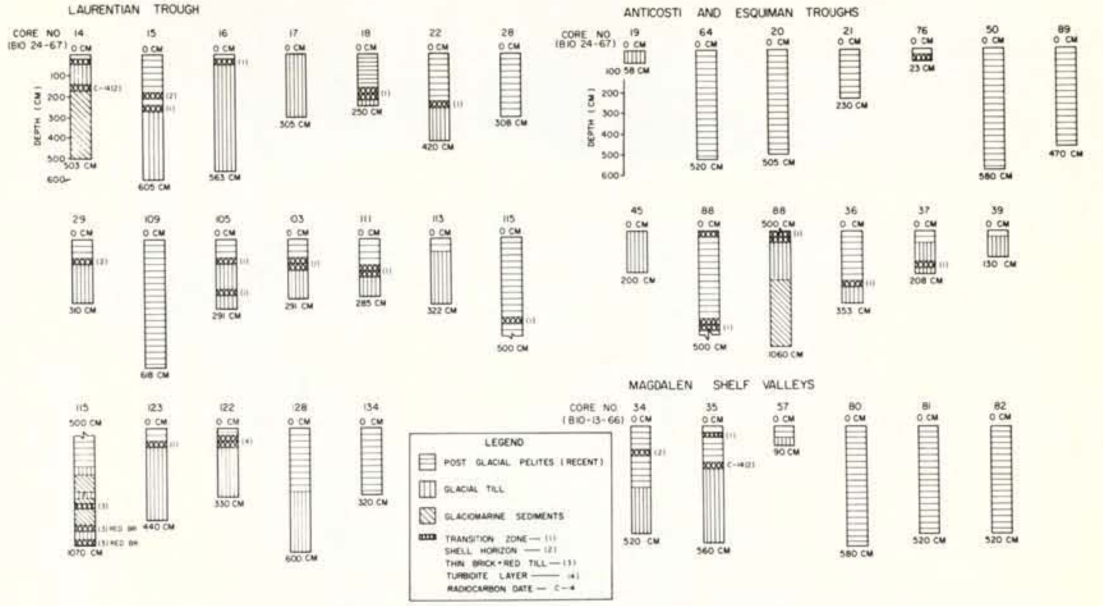


FIG. 42. Generalized stratigraphy of sediment cores (for location see Fig. 41).

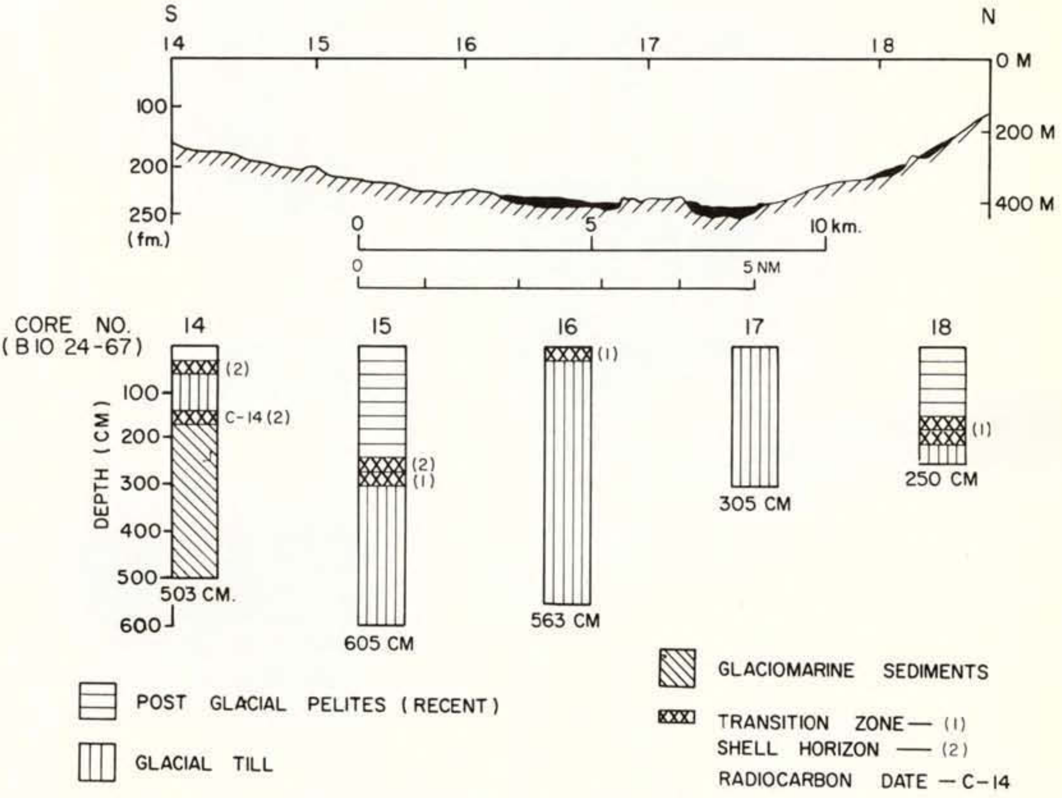


FIG. 43. Stratigraphy of cores from the fan deposits in relation to the topography of the Laurentian Trough (see echo profile 8, Chart 4, in pocket).

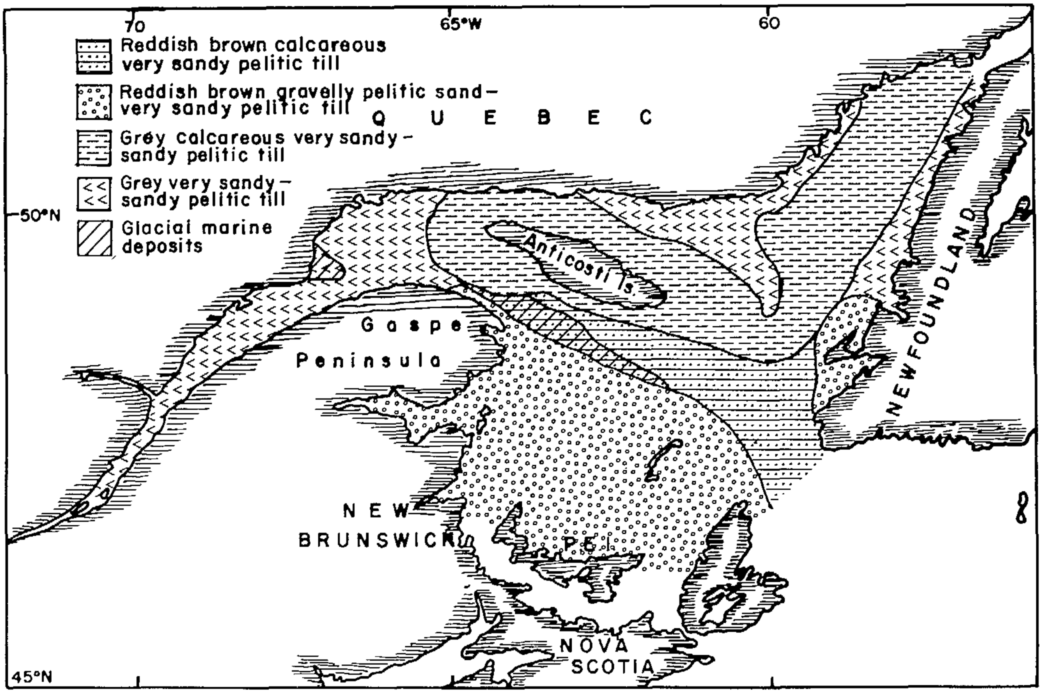


FIG. 44. Approximate distribution of till deposits in the Gulf of St. Lawrence. Boundaries are only very approximate because these units occur mainly as subsurface deposits.

in the floor depressions, the cores do not penetrate the glacial sediments beneath because of the thickness of the pelite layer, e.g. cores 109, 64, 50, 20, 21, 89 (BIO-24-67).

At several locations (cores 14, 88, and 115; BIO-24-67) the cores have a threefold zonation: the till horizons being underlain or interbedded with sediments having the textural characteristics of glaciomarine sediments. (see Chap. 6).

Laurentian Trough system

Presented in the following paragraphs are some of the details of the lithological sequences in the cores from given areas such as (1) the western part of the Laurentian Trough which includes the Détroit d'Honguedo (Gaspé Passage) and the area between the Magdalen Shelf and Anticosti Island; (2) the eastern part of the Laurentian Trough system which includes parts of the Anticosti and Esquiman troughs; and (3) the Magdalen Shelf valleys.

West of Anticosti Island, core samples from a ridge which breaks through the acoustical transparent layer near Station S-62-56 (Fig. 33, profile 2) indicate that the surface pelites are underlain by rather stiff light grey pelitic sediments full of angular sand grains and pebbles. These sediments have the characteristics of till. Most of the coarse material appears to have been derived from the Canadian Shield and probably represents the source and nature of the tills that occur beneath the pelites in the other parts of the estuary.

A series of sediment cores taken across the Laurentian Trough from a site near Orphan Bank on the Magdalen Shelf to a location at the edge of the Anticosti Shelf (see Chart 4, profile 8) reveals the nature of the subsurface lithology of the thick wedge of unconsolidated sediment. This wedge covers the bedrock along the edge of the Laurentian Trough adjacent to the Magdalen Shelf for a distance of 85 naut. miles and extends up to 28 naut. miles from the shelf edge. It was seen in Chap. 4 that this feature originated from the coalescence of fan-shaped bodies lying off the mouths of the submerged shelf valleys. The lithological sequence of several cores is shown in Fig. 43 in relation to their topographical location.

Sediment cores up to 6 m long were obtained along this section and show the main features of the subsurface lithology. The first of these (core 14) is 503 cm long and was obtained at a depth of 198 m (~108 fath), and shows a threefold zonation. Lithologically, the top layer, about 33 cm thick, varies from a grey pelitic sand to a very sandy (30–40%) pelite. Beneath it is the transitional zone of 30 cm, containing a few shell fragments, that separates the top layer from a reddish-brown poorly-sorted mixture of scattered pebbles, sand (40–60%), and pelite having the textural characteristics of a till (Map Unit 5a). This layer is about 100 cm thick and contains scattered fragments of red sandstone similar in lithology to the adjacent shelf bedrock. Beneath the till at 153 cm is a thin (~7 cm) shell horizon from which a Carbon-14 date was obtained (see Depositional History). Below this layer at approximately 160 cm the lithology changes to a greyish-brown very sandy (30–40%) pelite which also contains fragments of red sandstone similar to those found in the overlying till.

Mineralogical analyses reveal that these horizons contain an assemblage of heavy and light minerals similar to that found elsewhere in the southern Gulf (Loring and Nota 1969). A few benthic foraminifera are also found at some levels. The granulometry, presence of shell fragments and foraminifera found in this core suggest that these sediments have been deposited in a marginal marine environment.

Core 15, the second of these cores, is 605 cm long and was obtained from the front face of the fan at a depth of 293 m (160 fath). It has a twofold zonation. The top layer of 261 cm thick is composed of a grey soft pelite which contains scattered pebbles. Below a thin shell layer at the contact, the pelite is underlain by reddish-brown sediment similar in lithology and composition to the till found in Core 14.

Core 16, the third of these cores, is 563 cm long and was obtained from the apron of the fan at a depth of 348 m (190 fath). It also has a similar zonation to that of Core 15 but with a thin (20 cm) layer of grey sandy pelite. Separated from the top layer by a transition zone 20 cm thick, the remainder of the core consists of reddish-brown sandy pelite and gravelly sandy pelite which is calcareous (>5% $CaCO_3$) at some levels. The depositional history of the lithological sequence in this core is discussed in Chap. 9.

Core 17 is 305 cm long and was obtained near the toe of the fan at a depth of 384 m (210 fath). The core consists of reddish-brown till except for a thin (less than 10 cm) layer of modified till at the top. The till grades from a poorly sorted, calcareous sandy-gravelly pelite to a sandy (10–40%) pelite or calcareous sandy pelite containing scattered rock fragments. Foraminifera found at various intervals in this core confirm that this material was also deposited in a marginal marine (coastal) environment (see Chap. 9).

The acoustical data (Chart 5, seismic profiles 3–7) indicate that the till layer usually varies in thickness from 20 to 30 m although in a few places it must be as thin as 1 m, as shown in Core 14. The homogeneous sediments beneath the till range to 100 m thick and wedge out at the top and bottom of the fan deposit. These changes in the lithological sequence reflect significant changes in the depositional events during late-glacial and Recent (Holocene) times (see Chap. 9).

Sediment cores from the area southeast of Anticosti Island show in many places a twofold zonation (Cores 22 to 134, Fig. 42). The top layer is usually a calcareous pelite or sandy pelite which represents the postglacial addition (see Surface Sediments). The bottom layer is usually a reddish-brown till-like deposit. It contains varying amounts of marine foraminifera, which indicates that this material has accumulated in a marginal marine environment. The pelite layer is usually homogeneous but in Core 109 (618 cm long) which was obtained at a depth of 427 m (~234 fath) in the Laurentian Trough, a distinct clay-rich horizon is found between the 420 and 500 cm interval of the core. At this interval the clay content varies between 74 and 76% in contrast to a clay content between 60 and 64% in other parts of the core and less fine silt (16–2 μ) is present. As a result this horizon has a much higher $<2\ \mu/2\text{–}16\ \mu$ ratio than the normal pelites and is similar to the values for the relict pelites (see Map Unit 1b). This may reflect changes in the depositional history of the pelites in the Gulf (see Chap. 9).

The most complete lithological sequence from this area is shown in Core 115 (BIO 24-67) obtained in the area between the Magdalen and Newfoundland shelves. The top 400 cm of this core is composed of light olive-grey (5Y6/1)[4] soft pelites similar in lithology to those described as deepwater pelites. Beneath this interval, a gradual change takes place in the color of the pelites. At 450 cm the pelite is yellowish-brown (10YR6/2) and from 450 cm the pelite is light brown (5YR6/4). At a depth of 680 cm a sharp change in lithology occurs which marks a definite change in the depositional environment. The sediments beneath 680 cm are poorly sorted gravelly, very sandy pelites which contain several distinct

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[4] Core colors were mostly recorded from dry or partly dry samples.

brick-red (10R4/6) calcareous horizons. This sequence which extends to the bottom of the core appears to represent the deposition of till in a marine environment. In this sequence, the distinct brick-red horizons seem to be similar to those described by Connolly et al. 1967. It is considered that this till sequence is related to the upper till on top of the fans, which are partly buried by the deepwater pelites, along the edge of the Magdalen Shelf adjacent to the Laurentian Trough. The interpretation of this sequence is given in Chap. 9.

An interesting sequence was also found in Core 122 taken at a depth of 510 m in Cabot Strait (Fig. 42 and 45). On top of till deposits and underneath a thin (0–15 cm) cover of recent deepwater pelites, a layer of approximately 65 cm was found, composed of coarse-grained sands with varying amounts (5–50%) of pelite. The most apparent feature within this layer is the graded aspect, i.e. a decrease upwards in the maximum diameter of the fine gravel and sand components. The data from the mechanical analysis show that the total layer is a twofold sequence. It is suggested that these graded beds represent deposition from turbidity-like currents, which probably have originated from the resedimentation of material deposited in a floating shelf ice zone in the manner described by Carey and Ahmad (1960).

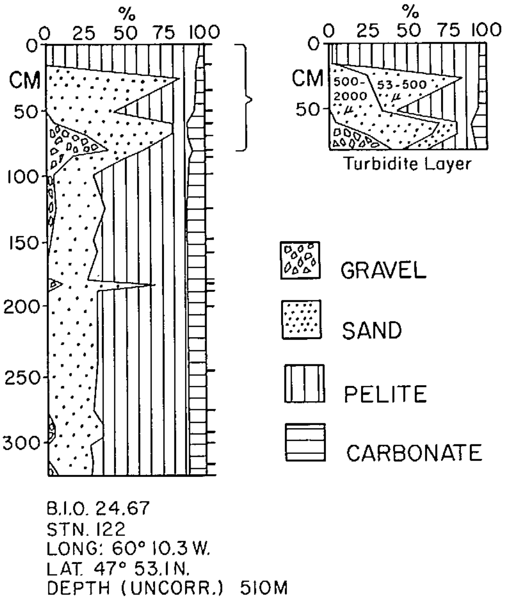


Fig. 45. Lithology of core 122 showing the vertical distribution of gravel, sand, pelite, and carbonate material as well as the granulometric composition of the turbidite layer.

Sediment cores 64, 20, 21, 50, and 89 in the Anticosti and Esquiman troughs are mainly composed of calcipelite. Till was found in a few cores from the slopes adjacent to the North Shore Shelf (Core 19), the Newfoundland Shelf (Core 76), and in cores 45 and 88 near the submarine extension of Banc Beaugé (Fig. 17, Chap. 4). On the slope of the North Shore Shelf, the till in core 19 is a poorly sorted very sandy (50%) grey pelite containing crystalline material derived from the Canadian Shield. In contrast, the till from the slopes adjacent to the Newfoundland Shelf is a calcareous sandy (27%), gravelly (11%), pale yellowish-brown to grey pelite containing fragments of limestone and dolomite similar in lithology to the bedrock underlying the sea floor and adjacent coastline (see Chap. 2 and 4) as well as crystalline material from the Shield.

A core (45, Fig. 42) from near the top of the submarine ridge separating the traces of the Anticosti and Esquiman troughs at depths of 248 m (~136 fath) is composed of grey-brown pelitic gravelly (40%) sand having the characteristics of noncalcareous till. The rock fragments are mainly crystalline material apparently derived from the Canadian Shield. The composition of the material in this ridge confirms that this ridge is a glacial moraine, mostly like a medial moraine, that probably developed between ice lobes that occupied the Anticosti and Esquiman troughs at one stage in the Pleistocene period.

Core 88, obtained about 15 miles to the east of the site for Core 45, shows a threefold zonation. This core, which is 1060 cm long and taken from a depth of 274 m (~150 fath), has a top layer, about 460 cm thick that consists of grey calcipelite. Beneath a transitional zone about 90 cm thick is a calcareous, gravelly (5–20%) sandy pelitic till which is greyish-orange-pink (5YR7/2). The till horizon is about 200 cm thick and is underlain by a calcareous sandy pelite containing less gravel (<9%) which is light olive-grey. The foraminiferal and lithological data indicate that this interval represents a glaciomarine sediment deposited under more favorable climatic and warmer water conditions than the overlying till (see Chap. 9 for a discussion of the depositional history of this sequence). Microscopic examination of the till and layers of glaciomarine sediment reveals that most of the coarse-grained material is derived from the Shield (crystalline material), with lesser amounts derived from the local bedrock and the coastlines of Newfoundland (sedimentary rocks). Sediment cores east of Anticosti Island such as cores 36, 37, and 39 also show the twofold zonation mentioned for the other cores.

Shelf valleys

Cores 34, 35, 81, and 82, (BIO-13-66) have also been obtained from some of the shelf valleys such as the Shediac and Cape Breton troughs on the Magdalen Shelf. In these valleys, the lithological sequence generally revealed by these cores is similar to that found in the Laurentian Trough system (viz: a pelite surface layer underlain by a till).

In the Shediac Trough, cores (Stn. 34 and 35) about 6 m in length obtained from the floor ridges in the trough show a twofold zonation in which sandy pelites or very sandy pelites form the surface layer and reddish-brown till forms the lower part of the cores.

Shell horizons have been found at the contact (Fig. 42, core 35) and in the grey pelite layers (core 34) from which enough material has been recovered for C^{14} dating (see Chap. 9).

In the Cape Breton Trough, the pelite cover either rests upon or is broken by glacial drift or an irregular bedrock. Continuous seismic profiles (profiles 3, 4, and 5; Chart 7) obtained transverse to the trough reveal that the long narrow ridge dividing the floor is a bedrock elevation on which lies a thin sediment cover. Sediment cores (Stations 54, 57, profiles 9, 10, Chart 6) obtained from the upper slopes of the ridge show that beneath the thin layer of very sandy pelite, the cover is composed of reddish-brown partly reworked glacial drift similar in texture to that found elsewhere on the shelf. In the depressions on either side of the ridge, the very sandy pelite deposits rest upon stratified sediments (presumably sand and gravels) and, in turn, according to seismic reflections, most probably are underlain by glacial drift which fills the depressions in the bedrock surface beneath. On the flanks the pelites are underlain by glacial drift, which is partly stratified and of variable thickness, filling an irregular sloping eroded bedrock surface (see seismic profile 4, Chart 7) composed of Upper and Lower Carboniferous rocks. The bathymetry of the area strongly suggests that the bedrock and till cover together form a drumlin, probably of the crag and tail type (Chart 1, bathymetric map).

In the Cape Breton Trough, sediment cores up to 7.6 m long obtained from the pelites in the center of the trough also show a twofold zonation, which differs from that described earlier for the cores that penetrated the pelite layer. The top layer, 1–1.8 m thick, is composed of brownish soft pelite that contains very fine sand and some gravel (see Surface Sediments), whereas the underlying material is a dark grey to black (N1-N3) very fine sandy pelite. The dark color (N3) of the sediments is very striking. It is assumed to be due to the presence of finely disseminated iron monosulphide since the sediment reverts to a brownish color when exposed to air. Chemical analyses of selected samples indicate that they contain 0.8–2.7% organic carbon, 2–4% calcium carbonate, and less than 0.5% acid soluble sulphide sulphur.

In summary, the lithological sequence revealed by the cores appears to represent the deposition of glacial sediments during the advance and retreat of the continental ice masses and during the readvances of local glaciers into a marginal marine environment in late-glacial times. The cores also provide evidence of the depositional conditions of the Recent (Holocene) sediments (see Chap. 9).

6

Grain-size frequency distributions

Mechanical analyses of over 500 samples have been carried out to determine the regional textural variations (see Sediments) and to identify the characteristic grain-size frequency distribution types throughout the region. It is possible to interpret such an extensive collection of data in several ways in order to establish the relation between grain-size frequency distribution and environment of deposition. One system of classification is to express the characteristics of the grain-size frequency distributions as a set of statistical measures; another is to illustrate the results of the mechanical analyses as cumulative curves and to use a graphic classification that is based on the shape of the curves. Both systems will be used in this report. Emphasis, however, will be placed on the graphic method, because the cumulative curves convey more details and their shapes often show characteristic relations with certain environments. For the graphic classification, the results of the analyses have been plotted on probability paper having an arith-

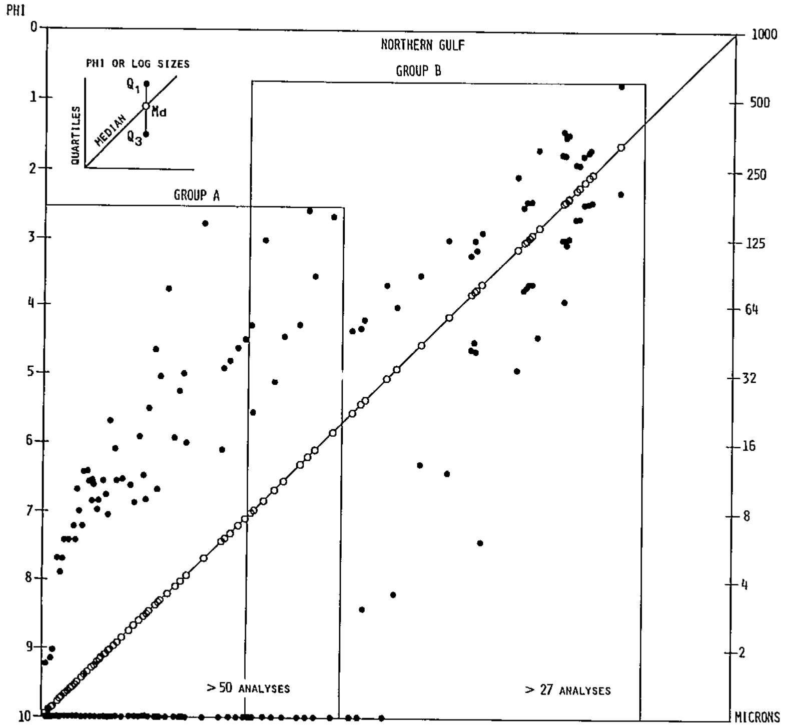
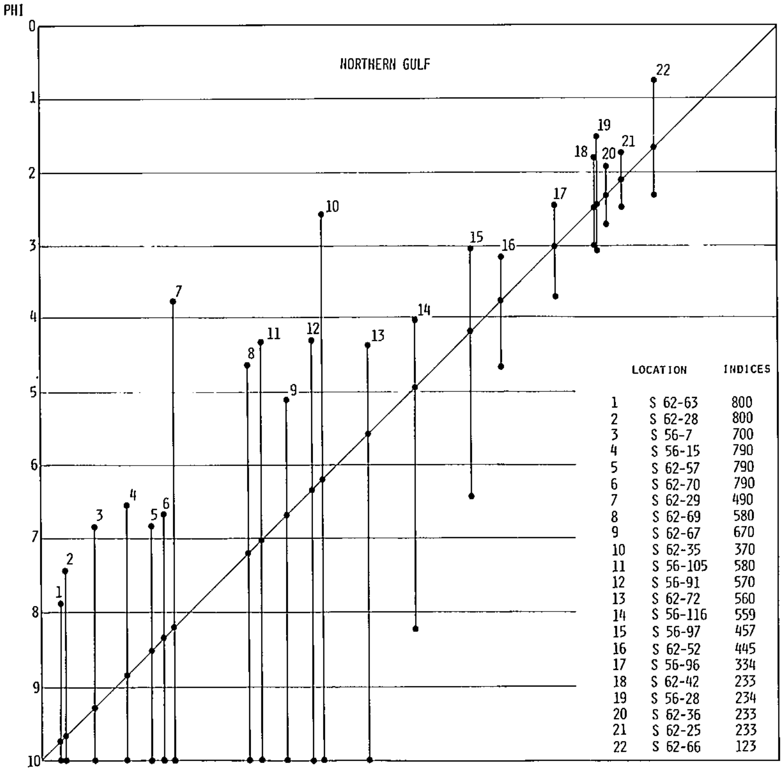


FIG. 46. Q_1MdQ_3 diagram for samples from the northern Gulf of St. Lawrence. Group A represents samples from the Laurentian Trough and Group B those from adjacent shelf areas.



	LOCATION	INDICES
1	S 62-63	800
2	S 62-28	800
3	S 56-7	700
4	S 56-15	790
5	S 62-57	790
6	S 62-70	790
7	S 62-29	490
8	S 62-69	580
9	S 62-67	670
10	S 62-35	370
11	S 56-105	580
12	S 56-91	570
13	S 62-72	560
14	S 56-116	559
15	S 56-97	457
16	S 62-52	445
17	S 56-96	334
18	S 62-42	233
19	S 56-28	234
20	S 62-36	233
21	S 62-25	233
22	S 62-66	123

FIG. 47. Q_1MdQ_3 diagram with indices for selected samples from the northern Gulf of St. Lawrence.

metical size scale (Doeglas 1946). The same system for representation was used in a previous study of the Gulf of St. Lawrence (Nota and Loring 1964) and also in the studies of the sediments of the continental shelf off the Orinoco delta (van Andel and Postma 1954; Koldewijn 1958; Nota 1958) and of the Rhône delta (Kruit 1955).

The grain-size data have also been classified using diagrams in which the median and quartile measures have been plotted on graph paper with a Wentworth phi scale that is widely used in North America. Doeglas (1968, 1971) has shown that diagrams and indices based on Wentworth phi values of Q_1, Md, and Q_3 can be used for textural classification and for distinction of environments (Fig. 46 and 47). Graphically the value of the median is plotted on the diagonal of the diagram, the value of Q_1 vertically above and that of Q_3 vertically below the point of the median. The values of the indices are obtained by rounding off the phi values for Q_1, Md, and Q_3 to integer phi units; for a positive phi-value to the next higher positive unit and for negative values to the next higher negative unit. The Wentworth grade 1000–500 μ is assigned number 1 and the grade 2000–1000 μ becomes $\bar{1}$; the value 0 is used for the grades below 2 μ (above phi 9) in order to restrict the indices to unit values. In the few cases that one of the parameters falls on phi 0.00, the index value is assumed to be plus 1.

The grain-size frequency distribution types from the northern and southern Gulf will be discussed separately. The Q_1MdQ_3 diagrams will be discussed first, followed by a description of the cumulative grain-size frequency curves.

Northern Gulf (Laurentian Trough System and adjacent shelves)

The *Q_1MdQ_3 diagrams* from samples throughout the northern Gulf are represented in Fig. 46 and 47; in Fig. 46 the Q_1MdQ_3 values of a series of some 80 samples are given, while in Fig. 47 some selected samples of the same series have been presented with their indices; numerical data are given in Table 5. The sample locations are shown in Fig. 48. The samples from Fig. 46 are

TABLE 5. Size-frequency distribution data of selected samples from types 1, 2, 3.

Location	Grain-size curve type no.	>420 µ	300 – 420	210 – 300	150 – 210	105 – 150	75 – 105	50 – 75	32 – 50	16 – 32	8 – 16	2 – 8	<2 µ
S 62–63	1							1.2	1.8	3.5	7.0	26.7	59.8
S 62–28	(group A in Q_1MdQ_3 diagrams)	0.9	0.6	0.8	0.8	0.9	0.8	0.6	2.3	5.7	4.9	22.7	59.0
S 56–7		0.6	0.4	0.7	0.8	0.9	1.2	1.1	4.5	8.0	8.3	20.5	53.0
S 56–15		1.4	0.5	0.7	0.7	0.8	0.8	0.8	4.3	8.7	11.3	21.9	48.1
S 62–57		1.0	0.6	0.7	0.7	0.6	0.5	0.6	2.2	7.2	14.1	25.0	46.8
S 62–70		1.6	0.8	0.8	0.9	0.7	0.5	0.5	3.4	7.8	11.9	23.5	47.6
S 62–29		6.3	3.5	4.2	4.7	3.7	2.6	2.0	6.7	6.7	6.1	14.8	38.7
S 62–69		5.9	3.0	3.2	3.3	2.7	1.8	1.5	7.2	11.6	9.4	13.2	37.2
S 62–67		2.8	1.1	1.2	1.1	0.9	1.1	2.5	13.1	17.8	11.4	13.4	33.5
S 62–35		12.1	6.0	5.4	6.3	6.1	3.9	1.7	5.0	2.7	4.3	11.3	35.2
S 62–1 F	2							2.7	3.6	1.8	2.2	7.7	82.0
S 62–1 C								1.6	4.3	3.8	3.2	8.0	79.1
S 56–56 E								1.0	2.2	4.9	5.5	9.3	77.1
S 62–3 E								0.7	1.1	1.1	1.1	3.9	92.1
S 62–2 A								0.2	2.7	1.5	2.7	11.7	81.2
S 62–2 Y								0.3	1.7	1.4	1.1	5.5	90.0
S 56–105	3	2.0	0.7	0.9	1.0	5.4	9.8	5.8	10.5	6.5	7.9	11.6	37.9
S 56–91	(group B in Q_1MdQ_3 diagrams)	5.2	2.0	2.3	2.7	3.1	5.1	5.2	9.9	12.1	9.6	14.5	28.3
S 62–72		1.8	0.7	0.8	1.2	2.2	7.6	10.3	19.9	9.4	6.1	10.2	29.8
S 56–116		0.7	0.5	0.7	1.0	1.9	5.7	9.0	20.0	12.8	5.9	9.7	32.1
S 56–97		5.3	3.1	4.8	7.7	7.7	14.1	10.8	13.9	6.0	3.5	10.3	12.8
S 62–52		3.5	2.8	3.8	5.0	10.4	24.5	16.6	16.7	5.4	2.6	3.1	5.6
S 56–96		8.4	5.4	6.1	14.1	30.2	12.7	4.7	3.7	3.7	1.1	1.8	8.1
S 62–42		15.2	9.4	16.9	26.0	14.2	5.4	2.0	1.7	0.9	0.9	2.0	5.4
S 56–28		19.3	10.9	14.6	21.5	13.9	4.8	2.1	2.3	2.6	0.3	3.3	4.4
S 62–36		3.9	10.1	38.4	25.8	10.1	2.6	0.9	1.0	1.0	0.5	2.5	3.2
S 62–25		5.9	20.9	35.5	25.1	6.2	3.2	1.1	0.3	0.3	0.3	0.5	0.7
S 62–66		35.0	18.6	20.7	17.8	3.8	1.2	0.7	1.0	0.2	0.2	0.4	0.4

from *two different areas;* the samples from Group A are from *the Laurentian Trough* and those from Group B are from the areas adjacent to the trough, viz., *the nearshore shelf areas.* The sediments from the Laurentian Trough have the third quartile on the base line of the diagram and their medians are smaller than 50 µ. These sediments represent the deepwater pelite deposits, described in Chap. 5, and their first quartiles indicate that they may contain a substantial amount of sand-size material. The distances between the Q_1 and Q_3 values may amount to more than 6 phi units, which confirms that the pelites are poorly sorted. Some selected samples from Group A are illustrated in Fig. 47 with their indices (see also Table 5). The majority of the samples of Group B have their Md values in the sand grades, although there is

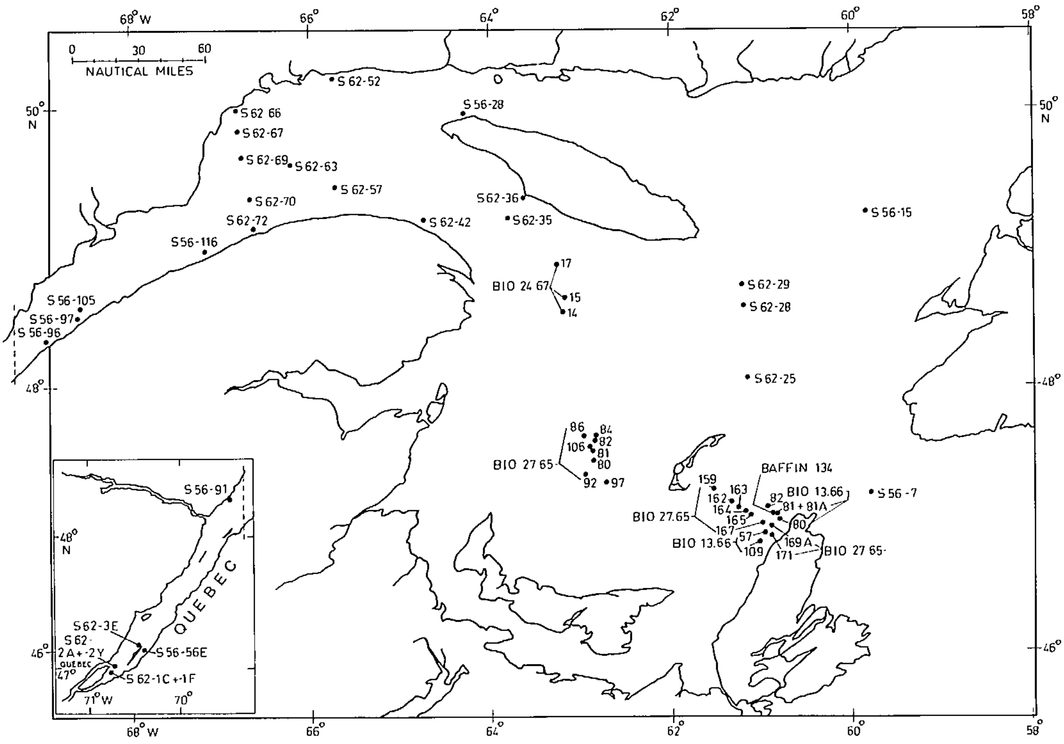


FIG. 48. Location of individual samples referred to in figures and text.

some overlap between the boundaries of Groups A and B. The bands of quartile points are narrower for the sediments of Group B when compared with those from Group A; they show that the sands generally are better sorted than the deepwater pelites (see also their indices in Fig. 47). It should be emphasized, however, that the Q_1MdQ_3 diagrams account for only 50% of the grain-size distribution and hence do not take into account the tails of the curves (cf. Fig. 49). The bands of quartile measures widen where the sediments of Groups A and B merge. Some selected samples from Group B are illustrated in Fig. 47 and their numerical data are given in Table 5.

The study of the *grain-size frequency distribution curves* revealed that a limited number of principal grain-size types occur. Comparison of the cumulative curves of the sediments from the northern Gulf shows that *three main types of size-frequency distributions* may be distinguished. Two types of pelite distributions (Types 1 and 2) and one type of sand distribution (Type 3) were established. Representative examples of each type are given in Fig. 49. The curves which have been classified as Type 1 represent samples from the Laurentian Trough system (cf. Group A, Fig. 46). These pelites contain up to 60% clay and usually about 35% silt. The sand portion (particles > 0.05 mm) of these curves forms an almost horizontal straight line and thus represents a poorly sorted distribution. The sandy pelites of Type 1, e.g. curves 3, 5, and 7, Fig. 49, are composite sediments and are mixtures of two simple sedimentary components, viz., pelite which is supplied in suspension, and poorly sorted sand which is supplied independently from the pelite. Nota and Loring (1964, p. 217) concluded that *recent ice-rafting* was a prominent factor in the area of investigation, because of the climatic conditions of the area (Chap. 3) and was responsible for the coarse unsorted sand addition to the pelites.

The curves from Type 2 are also pelite distributions. They represent samples from the stiff light-grey (5Y 6/1) pelite, found between Quebec City and the mouth of the Saguenay (see Chart 2, unit lb). The size frequency distributions of Type 2 are mainly characterized by a very high clay content, with percentages usually between 75 and 90%. These sediments have not been illustrated in Fig. 46 because of their extremely

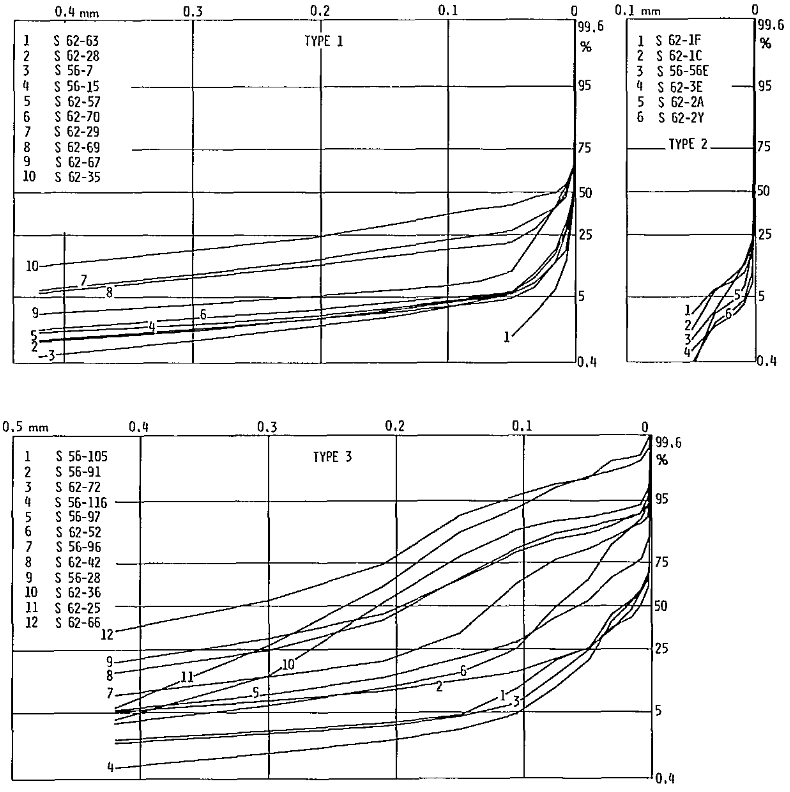


FIG. 49. Cumulative grain-size curves from sediments in various parts of the northern Gulf: Type 1 represents samples from the Laurentian Trough; Type 2 refers to relict pelites from the area between Quebec City and the Saguenay River; Type 3 represents samples from the shelf areas and slopes adjacent to the troughs.

fine-grain sizes (indices 000). As was mentioned previously (Chap. 5), these pelites are considered as not recent but deposited during an older cycle of sedimentation.

The sediment Types 1 and 2 (and 3, discussed below) differ rather widely in the ratios between the percentages of the <2 μ and 2–16 μ material and fall into two groups. In Fig. 50 the first group (indicated by the dots) represents samples from the pelitic deposits in the Laurentian Trough system, from the central-deep (deep-water pelites) as well as from the nearshore shallow areas with (very) sandy sediments. The second group (indicated by small triangles) refers to samples from the stiff light grey pelites, in the area between Quebec City and the Saguenay. The almost constant granulometrical composition of the material <16 μ for the majority of the pelite deposits (for widely diverging percentages <2 μ) is characteristic for the sediments of Group 1. Nota and Loring (1964) concluded that the constant granulometrical composition can be explained only by assuming that a homogeneous (at random) composition of the flocculated sus-

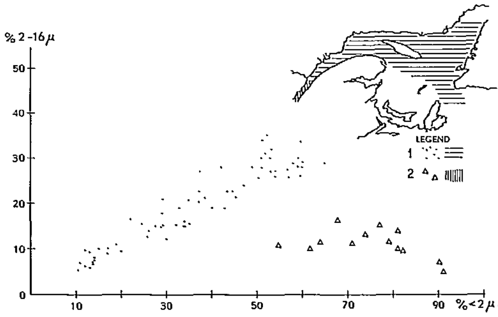


FIG. 50. The relationship between percentages <2μ and 2–16μ in samples from the northern Gulf. Group 1 refers to recently supplied pelites; Group 2 refers to late-glacial pelites. Note: The mechanical analysis of all samples excluded carbonates and organic matter.

pended material has been formed when it is finally deposited. The tidal-current system in the Gulf in combination with the great depth of the Laurentian Trough system creates favorable conditions to mix thoroughly all the suspended material that gets into it before it is finally deposited.

The pelites from the second group (Fig. 50) have no constant ratios and on the average have exceptionally high contents of the grade <2 μ. These sediments appear to have accumulated in a restricted body of water that was almost completely free of electrolytes. In such an environment sorting can affect the finest size grades so that they remain for a long time in suspension before finally settling in stagnant bodies of water, such as lakes (for details see Nota and Loring 1964, p. 218–220). Consequently these sediments are considered to be *relict*, or remnant from a different earlier environment and most likely represent sediments from the Champlain Sea episode (Chap. 9).

The curves which have been classified as Type 3 (Fig. 49) represent relatively shallow water samples from the shelf areas and slopes adjacent to the troughs. Most of these curves cover a wide range of size grades and therefore are not well-sorted deposits. However, in samples 7, 8, 9, 10, and 12, a curvature convex upwards to the right at the coarse end can be discerned in the size range between about 100 and 250 μ. This means that the coarse tail greater than approximately 300 μ does not belong to the same size distribution. The sediments from Type 3 are considered to have mainly derived from more or less reworked Pleistocene drift (moraines and tills). The composite character of these curves is formed by the mixing of three simple components. They are: (1) pelite (a minor component) deposited as recently supplied suspended material from nearby (for example, from tills) or supplied from a long distance; (2) a sand component in the size range between about 60 and 300 μ: its sorted character at the coarse-grained part of the grain-size curve points to local reworking under marine conditions of an originally unsorted deposit, most probably of glacial origin (moraine or till); (3) a coarse-grained addition forming the tail of

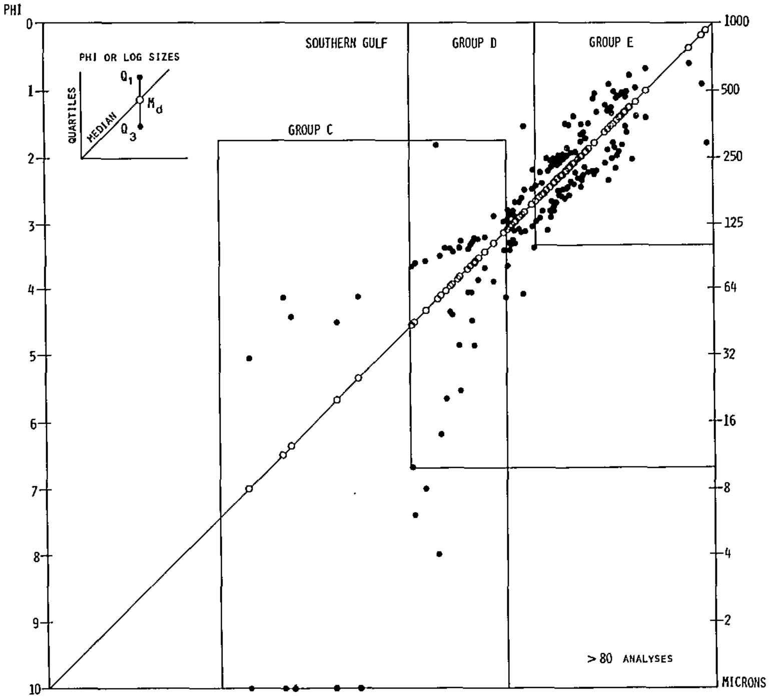
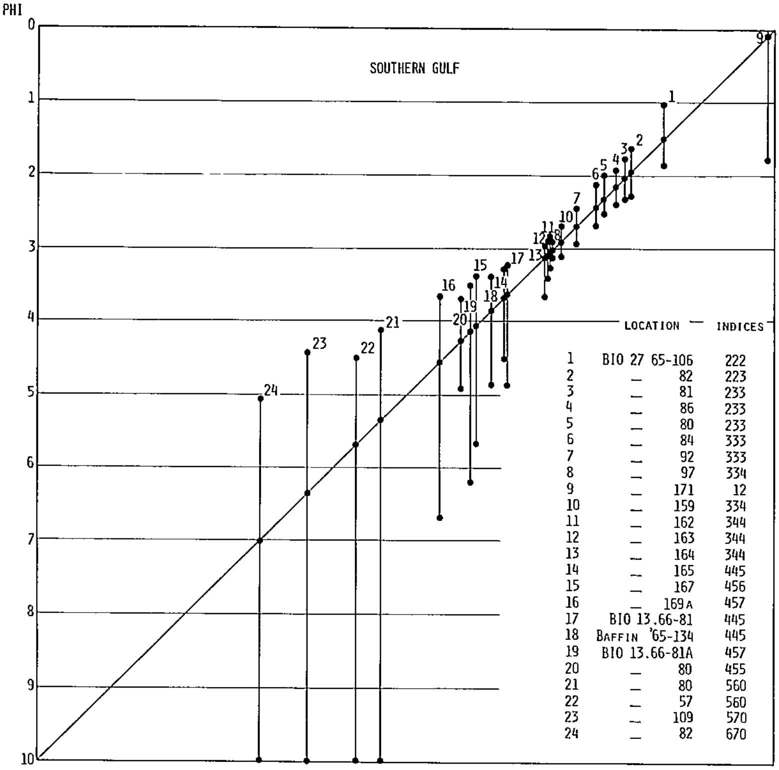


FIG. 51. Q_1MdQ_3 diagram for samples from the southern Gulf; Group C refers to samples from the shelf valleys, Group D to those from the transitional areas between the valleys and the banks, and Group E refers to those from the bank areas.



	LOCATION —	INDICES
1	BIO 27 65-106	222
2	— 82	223
3	— 81	233
4	— 86	233
5	— 80	233
6	— 84	333
7	— 92	333
8	— 97	334
9	— 171	12
10	— 159	334
11	— 162	344
12	— 163	344
13	— 164	344
14	— 165	445
15	— 167	456
16	— 169A	457
17	BIO 13.66-81	445
18	BAFFIN '65-134	445
19	BIO 13.66-81A	457
20	— 80	455
21	— 80	560
22	— 57	560
23	— 109	570
24	— 82	670

FIG. 52. Q_1MdQ_3 diagram with indices for selected samples from the southern Gulf. For sample locations see Fig. 48.

the size-frequency distribution curves: it covers the material supplied by ice rafting and/or a lag deposit from a layer underneath.

It appears that reworking and redistribution of the Type 3 sediments has occurred during the postglacial transgression and may be taking place now under present conditions in certain areas, in relation to the morphological expression of the sea floor.

Southern Gulf (Magdalen Shelf region)

The majority of the sediments obtained from the southern Gulf are of coarser grain sizes, viz., sand, patchy gravels, and their admixtures (see Chart 2). Pelite deposits have been found only in the protected shelf valleys, viz., the Cape Breton Trough, the Shediac Trough, the Chaleur Trough, etc. (Chart 2).

Three groups of sediments are represented in the *Q_1MdQ_3 diagrams* (Fig. 51 and 52). These are (E) from *the bank areas*, (D) from *the transitional areas between the banks and protected shelf valleys*, and (C) from *the shelf valleys*. In fact these sediments together form one continuous series. The bank sands become gradually finer (indices 222, 223, 233, 333, 334, etc., Fig. 52) and finally merge into the pelites from the shelf valleys (indices 570, 670) with increasing Md phi-values. The bank sands often are very well sorted and not skewed (222, 333) or well sorted and slightly skewed (233, 334). Sample 9 (near the western coast of Cape Breton, Fig. 52) with a coarse unsorted tail of gravel size (not determined) represents a lag deposit. Similar lag deposits are found in deeper water north of Prince Edward Island, near the Magdalen Islands, and on the banks near the shelf edge. Generally, the coarseness and better sorted character of the sediments from the southern Gulf when compared to those of the northern Gulf indicates that the environment of the southern Gulf is of a higher energy level. This is especially true when the bank sediments of the southern Gulf are compared with the sediments of the other shelf areas adjacent to the Laurentian Trough system (see Fig. 46 and 47). The predominantly strong northerly winds with their longer fetch, and stronger swell make the area more exposed for reworking under present conditions. Essentially, the combined action of wave turbulence and currents (residual and tidal) on the banks result in the sorting and transport of the sediments even when the currents themselves are too weak to erode the material. It should be also noted from the Q_1MdQ_3 diagrams that the pelites from the shelf valleys are not as fine grained when compared to the deepwater pelites of the Laurentian Trough system and the 'coarse tail' remains finer.

Comparison of the *cumulative frequency distribution curves* of these southern Gulf deposits reveals that *three principal types of size-frequency distributions* can be distinguished which characterize the surface and near surface sediments. Two other types have been found in layers underneath the surface sediments; they will be discussed at the end of this section.

The sediments which have been found in the Cape Breton Trough appear to be characteristic for shelf valleys (Fig. 53 and Table 6, Type 4).

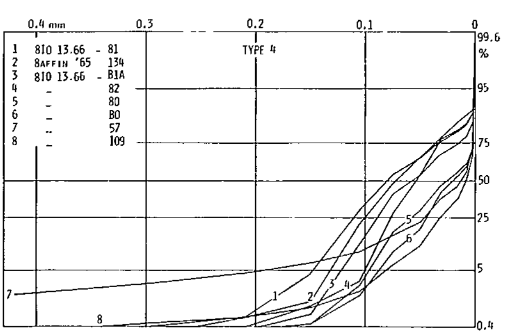


FIG. 53. Cumulative grain-size curves (Type 4) of shelf valley sediments in the Cape Breton Trough. For sample locations see Fig. 48.

These sediments are fine sandy pelites; occasional gravel-size material, however, is found in some of the samples as a result of ice-rafting. The difference between the pelites of the shelf valleys from the southern Gulf and the deepwater pelites of the northern Gulf is striking. The sand fraction of the southern Gulf pelites, in contrast to the northern Gulf pelites, is very fine-grained and well-sorted. Most of the sand- and silt-size material lies between about 20 and 100 μ, and the amount of sand coarser than 120 μ usually is less than 5%. The percentage of clay-size material ($<2\ \mu$) amounts to about 30% by weight within the trough. It decreases away from the center of the trough and there is also a slight increase in the maximum diameter of the particles (up to 150 μ approximately; Fig. 54). Core profiles in the trough show only slight variations (obviously due to lamination) and are continuous up to at least 5 m.

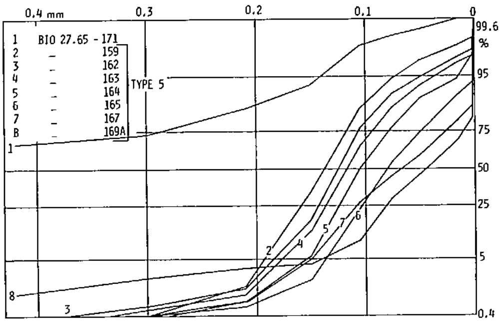


FIG. 54. Type 5 series of cumulative curves depicting the changes in grain-size distributions from the Magdalen terrace to the Cape Breton Trough. This series is characteristic of the grain-size changes that take place in the transitional environments. For sample locations see Fig. 48.

It should be noted that Curve 7, Fig. 53, has a coarse unsorted tail. This sample was obtained at a location where glacial till is found near the surface. Therefore, it is considered as a reworked till (Curve 1, Fig. 54).

Another difference between the deepwater pelites from the Laurentian Trough system and the fine sandy and very sandy pelites from the Cape Breton Trough (as well as from the other shelf valleys) is that the latter show size-frequency distributions with a less pronounced tail at the coarse end of the curves. This indicates that the addition of coarse unsorted material by ice-rafting is less compared to the sediments in the northern Gulf and implies that the ice-rafting processes in the northern Gulf have a stronger and more widespread impact on the depositional conditions than they have in the southern Gulf. An explanation for this difference is found in the pattern of ice movements in the region (see Chap. 3, Fig. 16; see also Chap. 7, Fig. 59).

The relation between the sediments from the Cape Breton Trough and those from the adjacent shelf area is illustrated in Fig. 54. The series of size-frequency distributions from a traverse from the Magdalen Islands to the Cape Breton coast is considered to depict the characteristic transition from the nearshore shallow waters of the Magdalen terrace into the Cape Breton Trough (samples 2–8, Fig. 54) as well as to the nearshore waters of Cape Breton (sample 1). Figure 54 reveals (1) a gradual decrease in the sand-size component in the direction of the center of the trough (samples 2–8); (2) a gradual

TABLE 6. Size-frequency distribution data of selected samples from types 4, 5, and 6.

Location		Grain-size curve type no.	>420μ	300–420	210–300	150–210	105–150	75–105	50–75	32–50	16–32	8–16	2–8	<2μ
BIO 13.66	stn 81	4	0.1	0.1	0.5	3.7	25.3	25.2	11.1	9.8	5.4	2.7	4.9	11.2
Baffin '65	134	(group C in	0.2	0.2	0.3	0.7	20.1	26.2	19.1	18.7[a]		4.2[b]		10.3
BIO 13.66	81^{A}	Q_1MdQ_3 diagrams)	0.1	0.1	0.1	0.5	11.7	28.0	14.1	13.5	6.6	3.6	6.9	14.8
BIO 13.66	82		0.1	0.1	0.2	0.7	2.2	24.4	26.9	22.3	5.1	2.8	3.8	11.4
BIO 13.66	80		0.1	0.1	0.1	0.2	2.2	14.5	12.7	16.4	10.6	5.2	10.3	27.6
BIO 13.66	80^{+}		0.1	0.1	0.1	0.2	1.3	7.9	9.2	22.5	12.7	6.4	11.9	27.6
BIO 13.66	57		1.9	1.1	1.5	2.3	2.9	6.5	6.4	14.1	9.4	10.2	16.4	27.3
BIO 13.66	109		0.3	0.2	0.2	0.3	1.1	4.2	5.5	13.7	12.1	13.2	17.7	31.5
BIO 27.65	stn 171	5	67.9	5.5	12.5	7.4	5.2	0.6	0.2	0.3		0.2		0.2
	159	(group D in	0.1	0.3	1.3	32.3	52.1	8.5	2.7	1.2		0.5		1.0
	162	Q_1MdQ_3 diagrams)	0.3	0.4	0.9	16.3	58.8	14.3	3.9	2.7		0.7		1.7
	163		0.2	0.4	0.6	11.8	54.0	19.5	6.6	3.9		0.8		2.2
	164		0.1	0.2	0.5	4.9	45.1	27.1	11.8	4.7		3.4		2.2
	165		0.2	0.2	0.3	1.5	21.3	31.9	19.2	15.9		3.3		6.2
	167		0.1	0.3	0.4	4.4	22.0	17.8	14.9	21.0		6.2		12.9
	169^{A}		1.3	1.1	1.0	0.6	5.8	20.2	16.1	23.5		12.4		18.0
BIO 27.65	stn 106	6	32.0	35.2	25.6	5.8	0.5	0.1	0.2	0.2		0.2		0.2
	82	(group E in	8.2	23.0	41.9	20.1	5.1	0.5	0.1	0.5		0.1		0.5
	81	Q_1MdQ_3 diagrams)	3.2	20.6	47.1	23.2	4.6	0.4	0.1	0.3		0.2		0.3
	86		1.2	11.4	48.3	30.6	6.5	0.6	0.1	0.3		0.3		0.7
	80		1.5	11.1	29.7	46.6	9.6	0.6	0.1	0.2		0.3		0.3
	84		1.1	5.8	29.7	42.5	16.0	1.7	0.5	0.4		0.6		1.7
	92		0.4	1.0	9.7	47.8	34.3	3.4	0.9	1.0		0.3		1.2
	97		0.4	0.6	1.4	14.2	73.6	5.5	1.0	0.9		0.7		1.7

[a] 50–16 μ.

[b] 16–2 μ.

+Core sample depth, 286–292 cm.

increase in the clay content in the same direction; (3) the fairly well-sorted character of the sand-size material progressively becoming better as well as finer with increasing water depths; (4) the coarse tail, attributed to ice-rafting (see above) is poorly developed, except Curve 8, Fig. 54. This series clearly indicates that (a) the gradual decrease in grain size towards the center of the trough reflects the present active reworking and redistribution (winnowing of the 'fines') of the available sand on the shelf area, thus obviously contributing to *the accumulation of the fine sandy components in the trough under present conditions;* (b) the influence of ice-rafting seems mainly restricted to the nearshore areas. In contrast, Curve 1, Fig. 54 is very poorly sorted, and was obtained nearshore in an area where glacial till was near the surface. Therefore this sample most likely represents a lag deposit, derived from the reworking of a till. In summary, it should be emphasized that the conclusions stated above are considered to apply not only to the remainder of the Cape Breton Trough and adjacent shelf areas, but also to the depositional conditions in the other shelf valleys and intervening lows between the banks.

A series of size-frequency distribution curves from the area of Bradelle Bank is represented in Fig. 55 (Type 6, Table 6). This bank area was selected for a detailed acoustical and sampling survey (Loring et al. 1970) because it represents one of the more exposed areas of positive relief (minimum depth about 46 m, 25 fath) in which specific environmental conditions might be encountered. The sonar surveys showed that the bank has a patchy distribution of lag gravel deposits and sandwave fields. The size-frequency distribution curves of the sands, as represented in Fig. 55, show that the sand grades range from about 100 to over 500 μ; and that clay particles are nearly absent. A little (up to 2–4%) coarse material (> 2 mm) also appeared to be part of these deposits. The shape of the curves suggests that these sediments have developed in varying degrees corresponding to the present current regime. In Fig. 55, Curve 1, derived from a sample obtained on top of the bank, is the coarsest-grained of the series, while Curve 8, from a sample on the lower slopes of the bank (in deeper water) is the finest grained. The area with its sediments is considered to represent *an environment of active reworking and redistribution*, again with the finest sand sizes being winnowed from the bank tops and redeposited in the adjacent lower slopes and less exposed shelf areas. Although no bottom current data are yet available, the presence of granules in the rippled sand fields suggests that granules as well as sand are periodically in transport, which implies that strong bottom currents must occasionally occur. Echograms, sonargrams, and bottom samples indicate that similar reworking and redistribution occur on the other banks under present conditions (Chap. 5, Sediments).

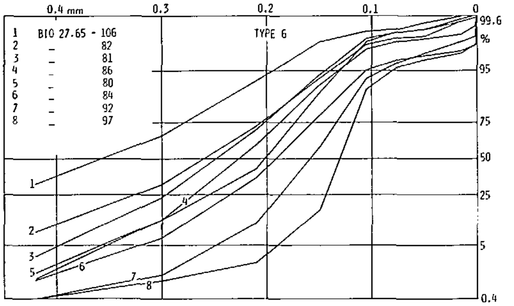


FIG. 55. Variation in cumulative curves (Type 6) of surface sediments from the top to the lower slopes of Bradelle Bank showing the decrease in grain-size with increasing water depth. For sample locations see Fig. 48.

Echograms, bottom samples, and underwater photographs have revealed (see surface sediment map and echograms) that in large areas north of P.E.I., northwest of the Magdalen Islands, very near the east coast of the Magdalen Islands, and off the east coast of New Brunswick bedrock is exposed through an intermittent veneer of sand and gravel (Loring et al. 1970, and Chap. 5). These areas are considered as *essentially nondepositional.* The patchy distribution of sand and gravel and the general unsorted character of these sediments suggest that they are mainly residual deposits (see Fig. 52, sample 9).

Figure 56 shows size-frequency curves from three sediment types which have been sampled as *subsurface deposits;* Q_1MdQ_3 diagrams have not been presented because of the limited number of samples. Curve 1 of this series (Fig. 56) represents a stratified reworked till deposit from Station 14 (Fig. 42); the convex upwards middle part of the curve suggests reworking under marine conditions, while the coarse tail is probably due to ice-rafting, or stratification. In Fig. 56, Curves 2–5 represent till deposits found in the core samples (Fig. 42 and 43) which are characterized by their unsorted character. The clay content in the samples varies between about 18 and 30%.

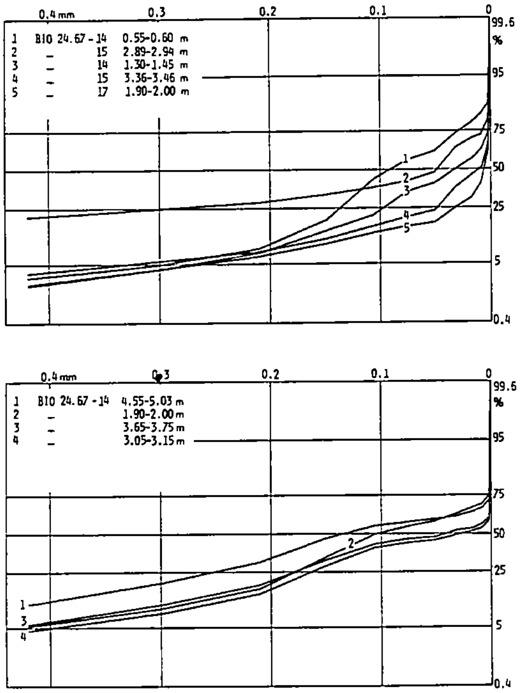


FIG. 56. Cumulative curves of the subsurface sediment types. (*Top*) Grain-size curves of modified till (Curve 1) and unmodified till at the edge of the Magdalen Shelf. For location of samples see Fig. 48, 41, 42.
(*Bottom*) Grain-size curves of glaciomarine sediments.

For analytical reasons the curves do not include the material coarser than 500 μ, but varying amounts of material larger than 2 mm occur in these samples (see Chap. 5 and 9).

Figure 56 also shows a series of size-frequency distributions that are referred to as glaciomarine sediments from the fan deposits (Core 14, BIO-13-67, Fig. 43) along the edge of the Magdalen Shelf. Although their exact depositional environment is not altogether apparent, the curves show some characteristics that differentiate these from the other types in the area. The main characteristics are (1) a high ratio for the $<2\mu/<16\mu$ size grades (approximately 0.8); (2) a convex upward middle section of the curve; (3) an unsorted coarse-grained addition. The high $<2\mu/<16\mu$ ratios suggest the influence of freshwater, practically free of electrolytes, such as meltwater, while the convex section indicates a tendency to a defined maximum size; the coarse unsorted tail in these homogeneous unstratified sediments is probably due to ice-rafting. No information on the size-frequency distributions of similar deposits seems available. The authors suggest tentatively that these deposits have accumulated relatively rapidly, as meltwater deposits in a restricted marginal marine environment in which material was also supplied by floating ice. The stratigraphical position of these deposits suggests the end of the Alleröd time or at the beginning of the Younger Dryas as the most probable time for the readvance of the ice fronts (see Chap. 5 and 9).

7

Dispersal and sources of the terrigenous detritus

Sediments are not only the product of transport and deposition but also of their provenance. This chapter deals with the basic information required to establish the regional distribution of the sediments and the supply lines to their sources. In this chapter emphasis has been laid upon the mineralogical analysis of sand-size material, since this is the size-grade most widely distributed over the whole region.

The Carbonates

The regional variations in carbonate contents have been discussed (Chap. 5). Reference is made to Fig. 33 and 34. Summarizing, the available data show *two main sources of carbonate material*, viz., the area of the Strait of Belle Isle and the area around Anticosti Island. In the area of Strait of Belle Isle the carbonate concentrates are related to the presence of Paleozoic limestones and dolomites which outcrop on the sea floor (Chap. 4); locally, large amounts of shell fragments are also responsible for the high carbonate contents (Chart 2). The situation around Anticosti Island is different. The general picture is that the highest carbonate contents occur in the samples from nearshore areas around Anticosti (>30%) while carbonate contents decrease away from the island. Anticosti Island is composed mainly of limestone and other calcareous sedimentary rocks. Limestone particles of gravel and sand size can be recognized in grab and core samples from the area around the island. The distribution pattern of the carbonates around Anticosti also demonstrates the prominent influence of ice-rafting as a dispersing agent under present conditions (see Chap. 6). The predominance of the northerly winds, which control the ice movements seems clearly reflected (Nota and Loring 1964) in the sediment patterns.

The Gravels

The analyses of gravel-size material had to be restricted to a very limited number of sampling sites (approximately 40), because not enough material was available for accurate counts. Counts have been made only from the southern Gulf, because of the relative abundance of gravel-size material in the samples from that region. The fraction analyzed is between 5 and 20 mm and counts were made of 200 particles per sample.

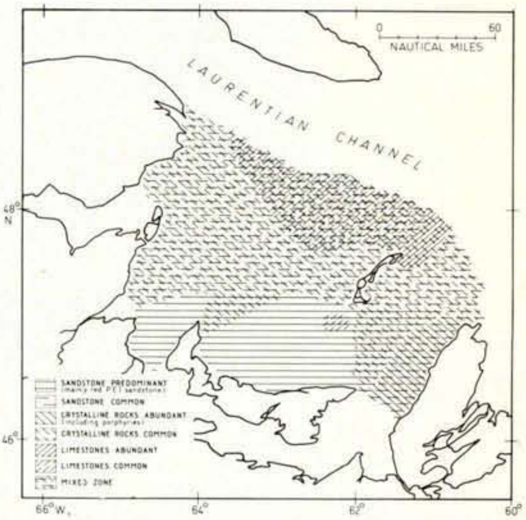


FIG. 57. Distribution pattern of gravel associations in the southern Gulf of St. Lawrence (Magdalen Shelf).

The distribution of the gravel associations can be outlined briefly as follows (see Fig. 57). The shelf area adjacent to Prince Edward Island is characterized by the dominance of the red sandstone similar in lithology to that found on the adjacent coast with minor admixtures of quartz and quartzite pebbles, near the eastern and western ends of the island. More to the north and northwest of Prince Edward Island there is an increase in rock fragments foreign to the area, viz., crystallines (of various kinds), quartzites, and grey sandstones. North of the Magdalen Islands, the gravel association is mainly characterized by limestones and crystallines, while in the Cape Breton Trough crystallines predominate. Samples off the eastern coast of the Magdalen Islands show an abundance of porphyritic crystallines and other crystallines.

Although the data is limited, it may be suggested that *there has been a supply of rock fragments foreign to the shelf from the north and northwest*. The presence of crystalline rock fragments in the pelites of the Cape Breton Trough, however, suggests that they have been supplied from the adjacent Cape Breton coastline by recent ice-rafting.

The Sands

Sand is the size grade most widely distributed over the area studied; consequently, the grouping of the sediments according to their mineralogical composition has been based mainly on the analyses of the sands. As usual in sedimentary petrological research, the mineralogical analysis of the sands has been carried out after separation into a light and a heavy fraction. The mineralogical analysis was not, as in many cases, confined to the heavy fraction. Differences in heavy mineral content between mineral assemblages can result in an over-representation of one of the assemblages. It was found that the additional data from the light mineral analysis was necessary for a balanced interpretation of the distribution and source of the mineral assemblages.

Before dealing with the results of the minerallogical analyses, the summing up of a few general considerations seems worthwhile.

(1) The mineral composition of the sediments in a depositional basin will be largely determined by the nature of the rocks in the source region. However, weathering of unstable minerals (in the source areas, during transport or after deposition) and selective sorting during transport, might modify the composition relationship between the source rocks and the depositional site.

(2) Mineralogical analysis provides quantitative results based on mineralogical data rather than geological evidence. The technique of mineralogical analysis and the interpretation of its results, however, should be tied in with the geomorphological and sedimentological evidence of the depositional basin.

(3) The mineralogical investigation in the area is concerned almost entirely with the surface sediment layer (between 0 and 10 cm). Under present conditions, ice-rafting is considered to be a prominent factor and this mode of transportation always results in haphazard distribution of unsorted material, mostly causing a minor coarse addition to fine sediments (Nota and Loring 1964). This specific textural character of the ice-rafted sediment necessitates the investigation of the nonfractionated sample (50–500 μ). The possible influence of sorting upon the mineral composition can be evaluated by fraction analysis of some selected samples from the distinctive mineral associations. A fraction analysis of all samples is not warranted.

(4) Over 350 heavy mineral counts and some 250 light mineral counts have been carried out from selected locations. The number of grains counted per mount was 150. When in the course of the mineralogical examination the patterns of dispersal of the mineral assemblages had been established and were found to correlate well with the geomorphological and sedimentological evidence, it was decided to extend the investigation to more sampling sites with the aid of the more automatized and hence less time-consuming chemical analysis, to confirm and define more precisely the dispersal patterns established by the sedimentary petrological analysis. The additional use of chemical analysis is warranted since differences in mineralogical composition are also displayed by differences in the chemical composition of the sands. It should be emphasized, however, that in a study such as the present one, a proper mineralogical analysis should precede the chemical. The interpretation of the chemistry of the sands in terms of distribution and provenance is most hazardous unless the host minerals and their general dispersal patterns have been identified.

Some preliminary results of the mineral analysis of the area have been mentioned in previous publications of the authors (Nota and Loring 1964; Nota 1968; Loring and Nota 1969). Most of the information from the mineral analysis is represented in tables and figures which are largely self-explanatory. The accompanying text has been limited to the necessary comment to avoid lengthy discussions and too much repetition. In reading the following discussion, frequent reference to the relevant figures and tables is strongly recommended.

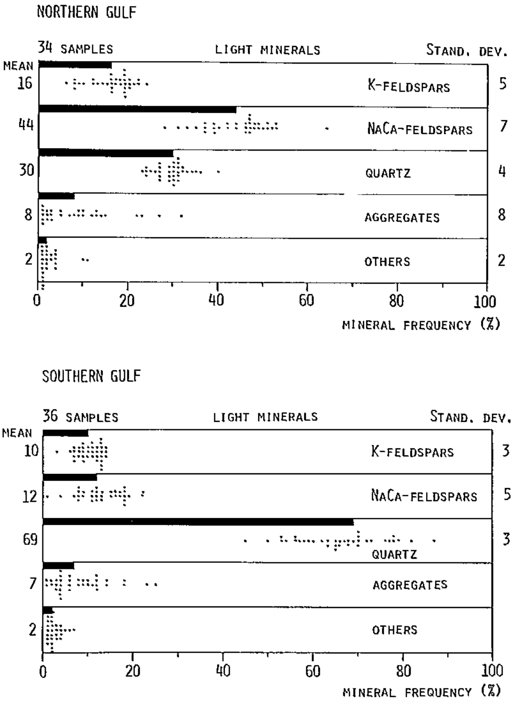


FIG. 58. Light mineral frequencies from samples of the northern ($n = 34$) and southern ($n = 36$) Gulf. Dots represent mineral frequencies per sample; the narrow horizontal black columns indicate the mean values.

Mineral assemblages

Fig. 58 and 59 show the results of the investigation of the *light fraction* expressed as mutual percentages. The overall picture of the light mineral distribution shows the existence of two main regions, each having a characteristic light mineral composition. Also the average ratio of light to heavy minerals is strongly contrasting (see Fig. 60). This separation based on the light mineral analysis clearly differentiates the Laurentian Trough system in the north from the semicircular Magdalen Shelf in the south. *In broad environmental terms it suggests* that the sands on the Magdalen Shelf (southern Gulf) apparently are largely polycyclic and composed of local erosional products mainly derived from the underlying and intermittently exposed Paleozoic bedrock while in the Laurentian Trough system (northern Gulf) the sands have to be considered essentially as fresh immature Pleistocene and postglacial detritus that has accumulated in the basin. *This concept of bipartition of the greater St. Lawrence region* has been discussed earlier and will be frequently referred to because it is an essential feature in the present investigation. In addition the presence of relatively high concentrations of aggregates (10–20%) in the beach and bedrock samples from the shores of Gaspé, New Brunswick, P.E.I., and Cape Breton and in the adjacent coastal waters seem to reflect the localized effects of ice-rafting in the southern Gulf, i.e. material from these areas is only ice-rafted a short distance offshore (see Chap. 6).

In fact the picture of mineral dispersal is more complex, as can be inferred from the investigation of the *heavy minerals*. Comparison of heavy mineral counts from the northern Gulf with counts from the southern Gulf shows striking differences (Fig. 60, 61, 62, and Table 7). It reveals that the heavy mineral composition is fairly uniform in the northern Gulf with a high percentage of total heavy fraction (average 8.7%) and abundance of unstable minerals like amphiboles (32–66%) and pyroxenes (16–43%). These features and the markedly fresh appearance of the mineral grains, the nearly total absence of altered material and low amounts of stable minerals like tourmaline, zircon, anatase, and rutile indicate that the sediments from the northern Gulf represent a first-cycle product. This is confirmed by the associated light mineral suite with an average of 44% of plagioclase, 16% potash feldspar, and 30% quartz (Fig. 58). Nota and Loring (1964) thus concluded *that the sediments of the Laurentian Trough system have been derived essentially from the complex crystalline igneous terrain of the Canadian Shield.* Extensive Wisconsin glaciation by which glacial drift of a homogeneous distributive province was widely distributed, and recent ice-rafting by which material along the shorelines is picked up and spread over the entire region are considered as the major causes of the uniformity of the mineral assemblage throughout the area. This mineral assemblage characteristic for the northern Gulf will henceforth be referred to as the *Laurentian suite.*

The mineralogical analysis of samples throughout the southern Gulf (Fig. 60) shows: (1) low concentrations (average 1.5%) of heavy minerals; (2) high frequency of opaques (average 51%), both as primary minerals and as alterites; (3) more stable minerals; (4) lower frequencies for the amphiboles and pyroxenes; and (5) larger frequency ranges for the dominating mineral species. The latter is expressed by comparison of the standard deviations which are given in the figures concerned. This inhomogeneity can be traced back to the existence of at least three mineral assemblages in the area of the southern

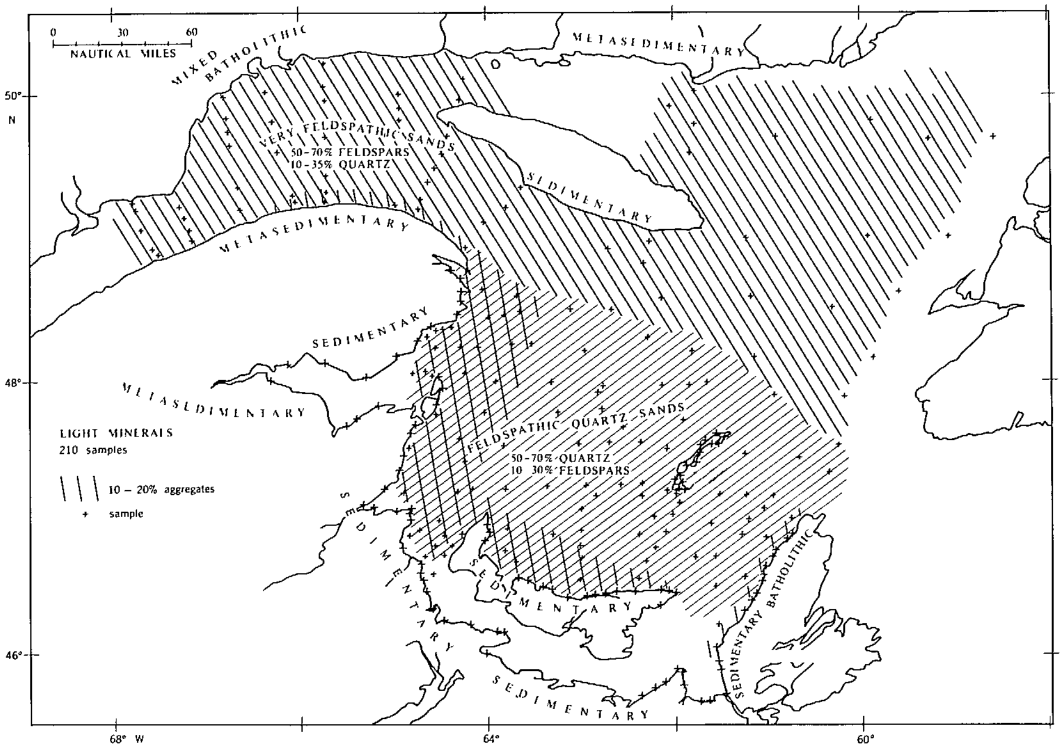


Fig. 59. Distribution of light mineral assemblages (quartz, feldspar, and aggregates) in the Gulf of St. Lawrence sediments. Representative sample locations are indicated by the plus signs.

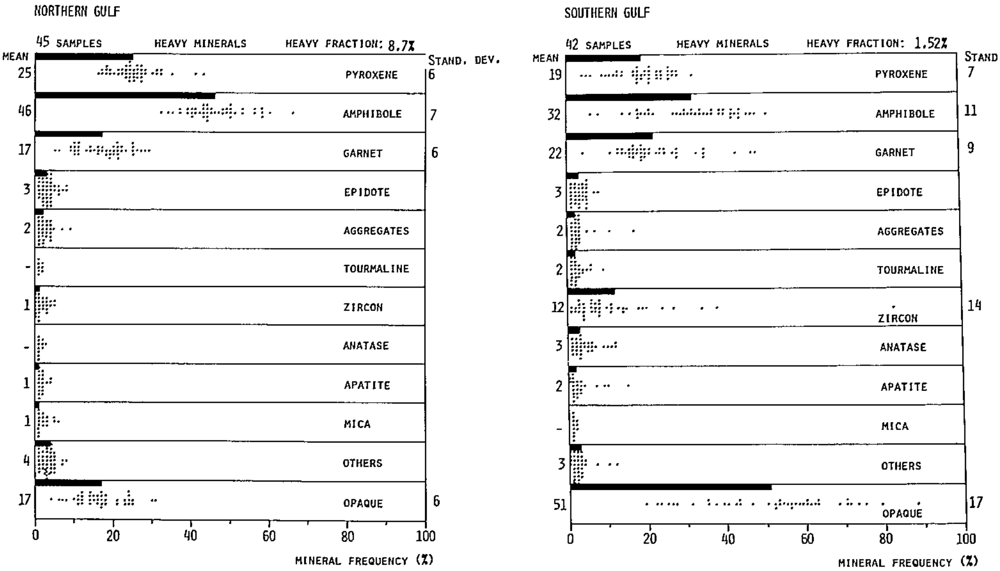


Fig. 60. Heavy mineral composition and frequency in the sands (500–50μ) from northern and southern Gulf of St. Lawrence sediments. Representation same as Fig. 58.

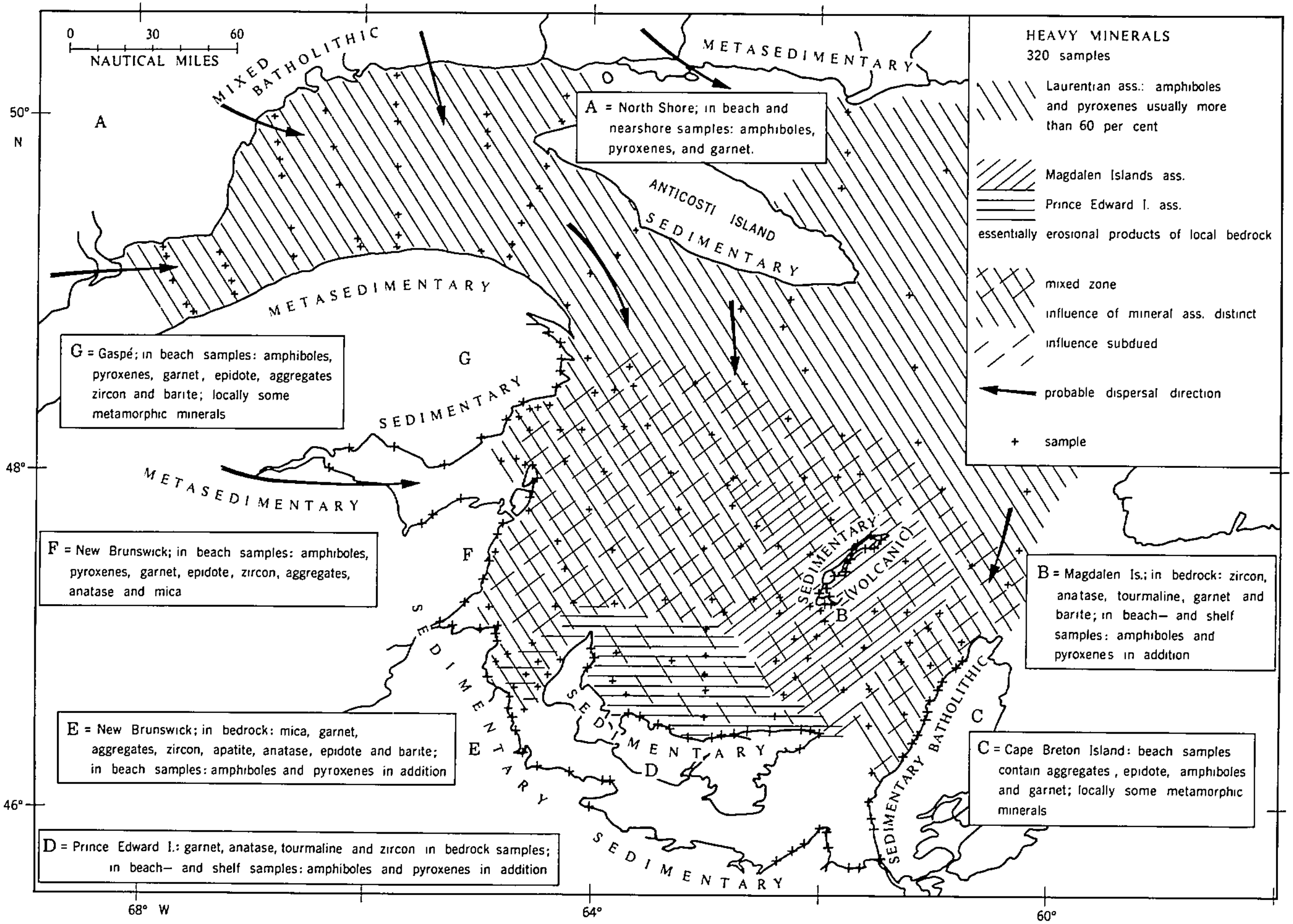


FIG. 61. Dispersal pattern of heavy mineral associations in the Gulf of St. Lawrence and their relation to the composition of beach and bedrock samples. Letters such as E and F refer to sampling areas. Sample locations (plus signs) are also shown.

TABLE 7. Heavy and light mineral assemblages from the northern and southern Gulf, grade 50–500 μ.

	Northern Gulf													
	S 56–23	S 56–26	S 62–37	S 62–39	S 62–63	S 56–35	S 56–108	S 56–93	S 62–48	S 62–57	S 62–64	S 62–75	S 62–76	S 56–7
Heavy minerals														
Pyroxene[a]	12	16	16	10	6	9	15	12	21	12	13	13	19	11
Hypersthene	16	37	16	8	10	8	13	15	20	11	11	8	11	12
Amphibole	46	28	48	47	49	58	48	50	39	44	51	42	45	44
Garnet	16	6	10	20	17	10	16	11	9	26	19	21	21	17
Epidote	2	4	1	6	5	–	2	3	3	1	2	8	2	2
Aggregates	3	2	3	2	2	3	2	3	4	2	–	1	–	1
Tourmaline	–	–	–	–	2	–	–	–	–	–	–	1	–	–
Zircon	–	3	1	1	–	–	2	–	1	1	1	1	–	1
Anatase	–	–	1	–	1	–	–	1	–	–	–	–	–	1
Rutile	–	–	–	–	–	1	–	–	–	–	–	–	–	–
Apatite	1	–	–	2	–	4	–	1	–	–	–	1	–	4
Mica	–	1	1	–	2	3	–	2	–	–	–	2	–	–
Other minerals	4	3	3	4	6	4	2	2	3	3	3	2	2	7
Opaque	26	28	17	8	16	7	7	8	18	12	14	4	6	21
% heavy fraction	9.1	13.5	10.5	10.3	11.9	14.7	11.1	7.8	9.7	9.7	12.6	14.0	10.7	2.6
Light minerals														
Quartz	31	29	30	33	27	28	28	24	23	30	29	31	31	48
Potash Feldspars	17	6	11	9	15	13	18	22	12	19	16	19	19	18
Plagioclase Feldspars	43	64	44	44	52	53	47	49	39	42	53	46	47	23
Aggregates	6	1	14	10	6	5	6	3	15	8	2	2	2	11
Other minerals	3	–	1	4	–	1	1	2	11	1	–	2	1	–

	Southern Gulf										
	S 62–25	S 75–14	S 75–60	S 75–16	S 75–54	S 79–176	S 79–169	S 75–46	S 79–216	S 79–236	Baffin 134
Heavy minerals											
Pyroxene[a]	11	9	12	13	6	4	1	10	13	7	6
Hypersthene	13	8	10	13	12	5	1	17	13	14	16
Amphibole	35	17	26	32	42	27	13	40	42	37	27
Garnet	25	19	16	28	16	19	27	16	17	20	13
Epidote	2	1	–	–	1	10	5	4	5	5	4
Aggregates	9	1	–	–	–	17	7	1	1	–	–
Tourmaline	2	7	3	–	1	4	8	1	–	2	1
Zircon	1	31	22	13	18	7	17	6	4	11	19
Anatase	–	4	8	–	2	2	15	3	–	1	7
Rutile	–	2	1	–	–	–	–	1	–	–	2
Apatite	–	–	1	–	–	–	4	–	1	1	2
Mica	–	–	–	–	–	4	–	–	–	–	2
Other minerals	2	1	1	1	2	1	2	1	4	2	1
Opaque	38	71	55	56	37	73	82	60	26	39	59
% heavy fraction	2.5	0.49	0.91	0.51	1.04	0.21	0.84	1.30	2.34	1.00	0.73
Light minerals											
Quartz	70	76	68	76	81	57	60	62	62	70	69
Potash Feldspars	7	11	12	8	11	8	6	13	7	9	13
Plagioclase Feldspars	12	7	16	11	3	13	17	10	16	18	11
Aggregates	11	4	3	4	4	18	12	12	12	3	6
Other minerals	–	2	1	1	1	4	5	3	3	–	1

[a] Not including hypersthene.

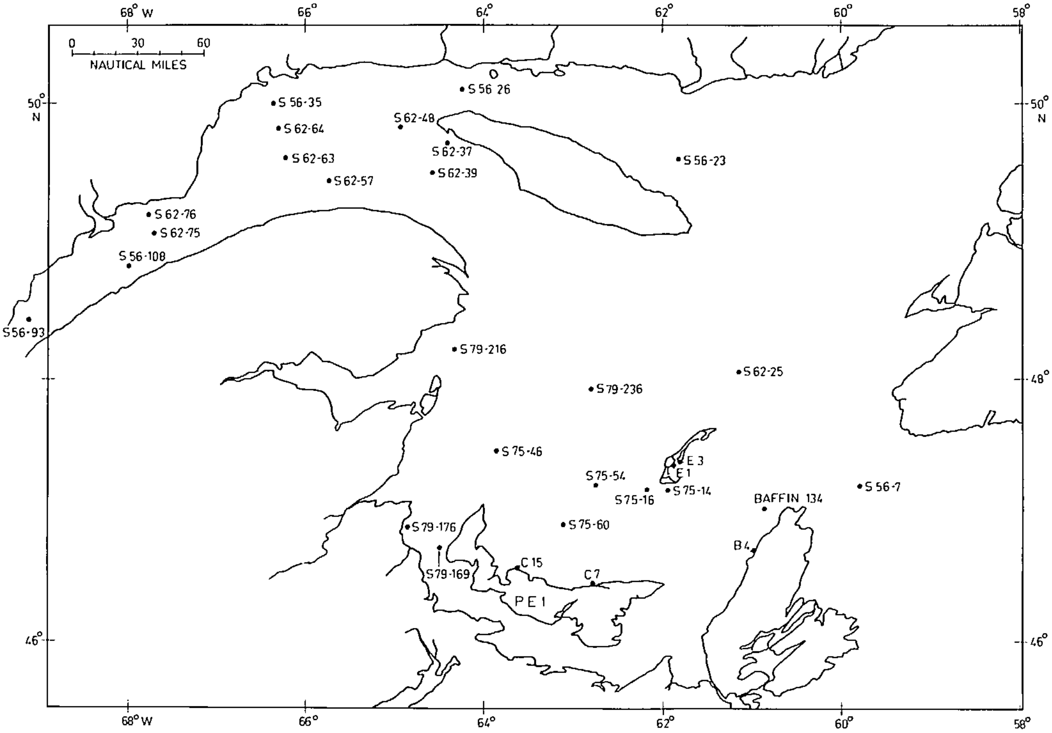


FIG. 62. Location of samples recorded in Table 7 and used for fractional heavy mineral analyses in Fig. 66 and 67.

Gulf, viz., the *Magdalen Islands association* which occurs around the Magdalen Islands, the *Prince Edward Island association* from the nearshore areas of P.E.I., and a third, less pronounced *mixed assemblage* for the remainder of the shelf. In fact, each of these three assemblages represents a mixture of at least two mineral associations (Fig. 61). Beach samples as well as bedrock samples from the shorelines have been used to establish the sources and regional distribution of the relevant mineral associations.

The Magdalen Islands heavy mineral association (Fig. 63) is characterized by the following mean (M) values (%) for 18 samples: 24 for pyroxenes, 23 for amphiboles, 24 for garnet, 13 for zircon, and by the regular presence of minerals like tourmaline and anatase. A marked difference with the Laurentian suite is the significant presence of stable minerals of which zircon is the most frequent. A glance at Fig. 61 and Table 8 reveals that bedrock samples from the Islands contain these minerals in fairly high quantities but generally lack pyroxenes and amphiboles. In some shoreline samples close to local exposure of volcanic rocks, high amounts of augite (58–69%) are found. These augites, however, are predominately brownish (titaniferous) and thus differ from the greenish augites found in the northern Gulf sands. It is noteworthy that the bedrock contains a distinctive type of garnet (subrounded, etchy) which is also found in the shelf samples from the southern Gulf, but there admixed with the angular and markedly fresh and clear garnet from the Laurentian suite. The available information of both the heavy and light mineral data leads to the conclusion that the Magdalen Islands mineral suite is largely the erosional product of the regolith that mantles the local bedrock, intermixed with a varying amount of material foreign to the area. The foreign material is easily recognized as representing detritus from the Laurentian suite.

A comparable situation is met in the nearshore areas north of Prince Edward Island. The data from Fig. 61 and 63 reveal: (1) differences between the P.E.I. heavy mineral association and that of the Magdalen Islands; (2) a close relationship between P.E.I. bedrock samples and beach and shelf sands from the P.E.I. association, though the characteristic Laurentian com-

Table 8. Average heavy mineral composition of beach sand and bedrock samples bordering the Gulf, grade 50–500 μ.

Area	No. of samples	Probable main source	Pyroxene[a]	Amphibole	Garnet	Epidote	Aggregates	Tourmaline	Zircon	Anatase	Rutile	Apatite	Mica	Other minerals	% Heavy fraction	Opaque
Shore and nearshore samples (northern Gulf)	12	Shield rocks	25	52	12	3	2	–	2	–	–	1	–	3	10.4	17
Magdalen Islands	15	Pal. sandstones intermixed with local volcanic rocks	17	23	29	4	3	2	14	1	1	–	–	6	1.1	58
Near volcanic rocks	3		56	16	3	5	5	3	8	2	–	–	–	2	0.8	48
Bedrock samples	4		–	–	8	–	1	6	66	10	9	–	–	–	0.9	55
Cape Breton Is.	21	Mixed sedimentary and batholithic	3	19	11	18	41	1	–	1	–	–	2	4	5.1	44
Prince Edward Is. (North Shore)	19	Paleozoic sandstones	3	7	31	2	8	19	4	22	–	2	–	2	0.6	68
Bedrock samples	5		–	1	26	1	2	13	17	19	3	4	12	2	0.7	79
N.B. Coast (Cape Tourmentine–Miramichi Bay)	16	Paleozoic sandstones	3	14	19	7	22	10	3	4	1	7	8	2	0.7	73
Bedrock samples	13		–	3	13	3	10	9	8	9	–	9	32	4	0.6	80
N.B. Coast (Miramichi Bay to Campbellton and Chaleur Bay)	7	Paleozoic sandstones batholithic	9	19	24	9	14	4	5	6	1	3	3	3	2.0	72
Bedrock samples	4		–	2	8	1	9	9	10	32	1	9	14	5	0.5	58
Eastern Gaspé coast	16	sedimentary, metamorphic, batholithic	15	18	12	13	20	1	5	4	–	1	2	9	1.2	68

[a] Including hypersthene.

ponents (amphiboles and pyroxenes in great abundance) are lacking in the bedrock. The heavy mineral evidence thus indicates that the beach and shelf sands around P.E.I. are largely of local bedrock origin, but appear to be mixed with material from the Laurentian suite. Here again, the etchy subrounded bedrock garnet is easily distinguished from the fresh subangular

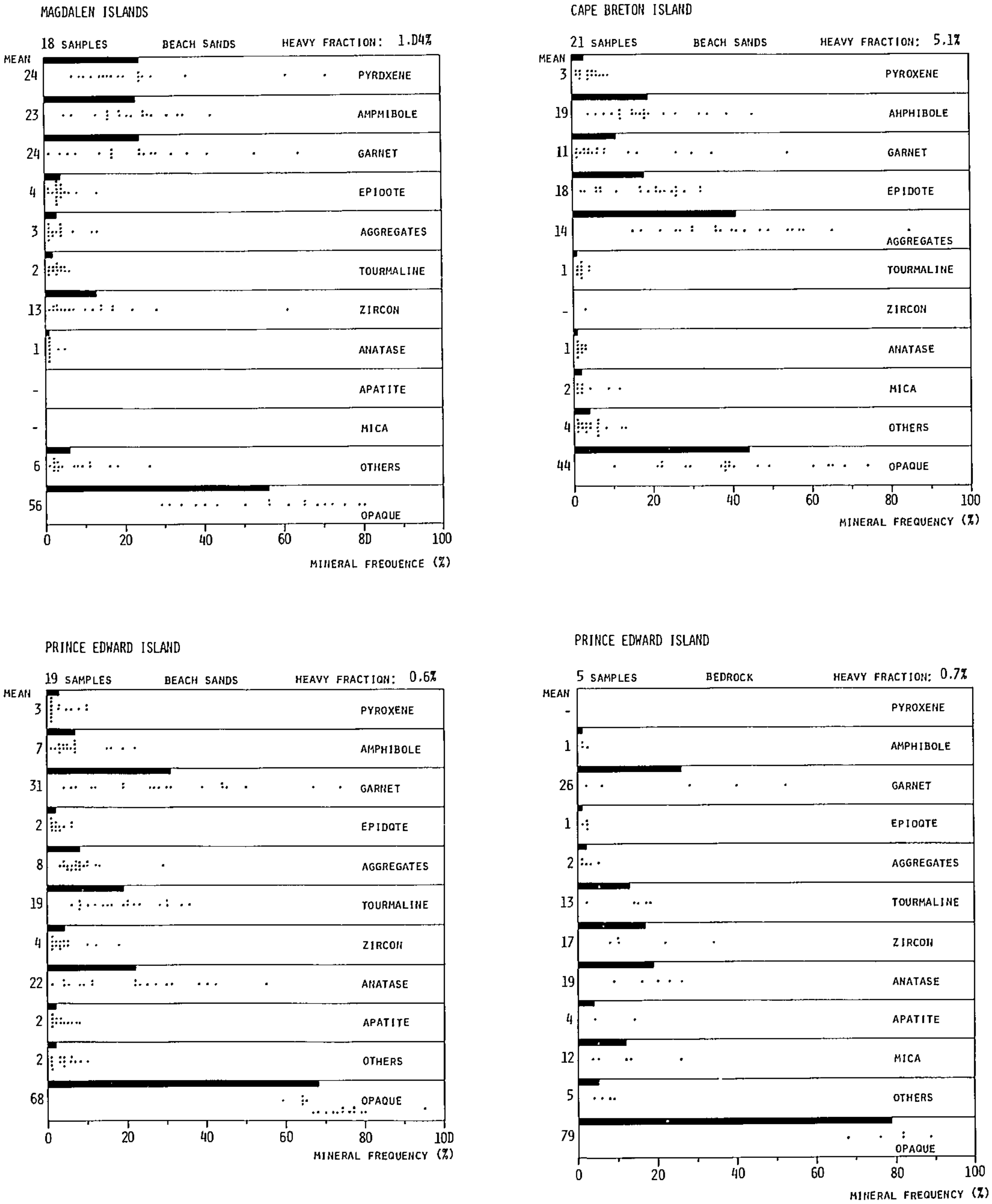


FIG. 63. Heavy mineral composition and frequency in beach sands from the Magdalen Islands, Cape Breton Island, as well as beach and bedrock samples from Prince Edward Island.

northern Gulf garnet. The light mineral data are limited (five samples), but agree with the heavy mineral evidence. The quartz content of the bedrock samples is somewhat lower (49–73%) but the quartz content normally increases for the erosional products and the feldspar content decreases.

Similar parallels could be drawn for the rela-

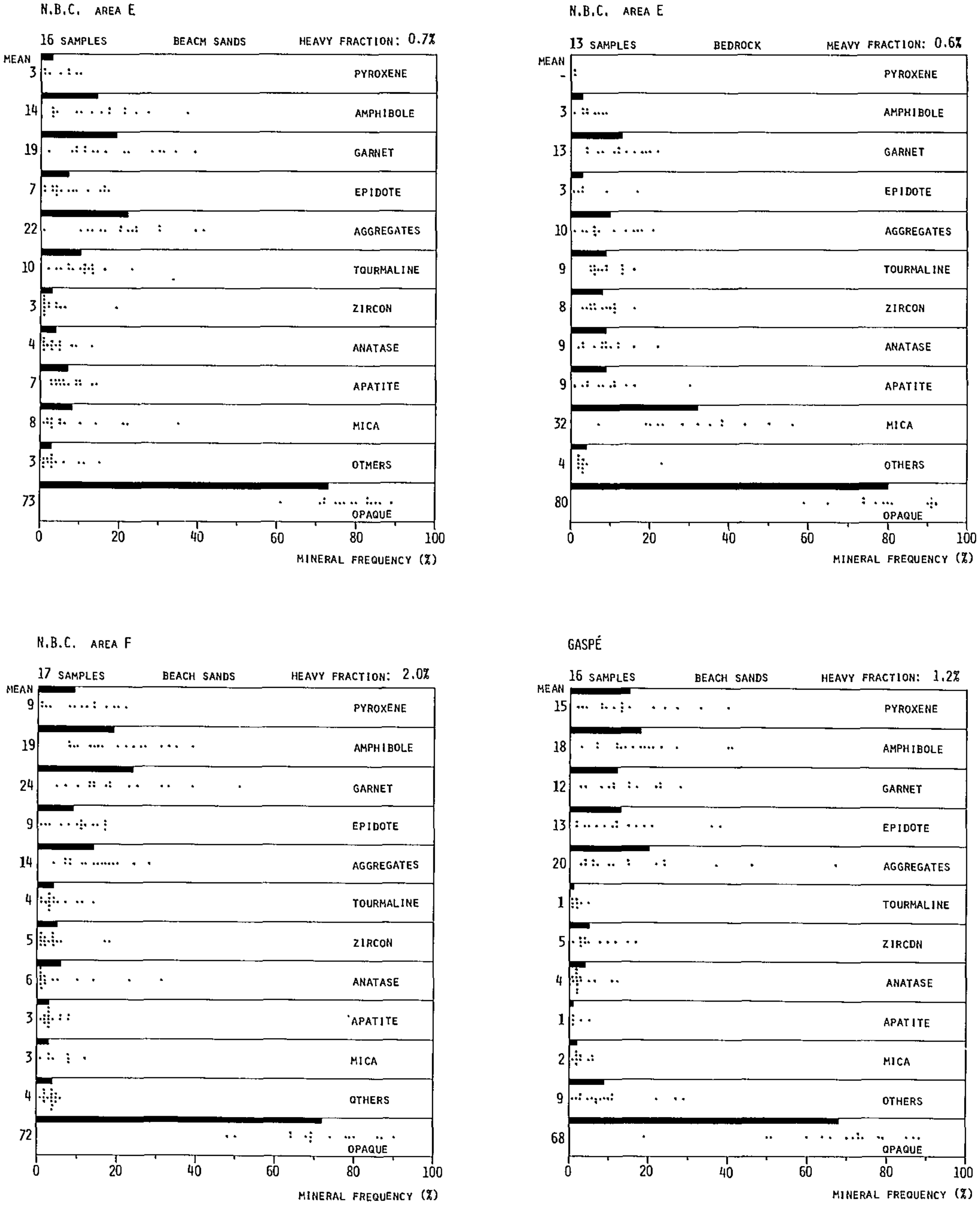


FIG. 64. Heavy mineral composition and frequency in beach and bedrock samples from the E part (Fig. 61) of the New Brunswick coast (N.B.C.) as well as beach sands from the F part of the New Brunswick coast and the Gaspé coast.

tion between shoreline samples from Cape Breton and New Brunswick and the adjacent shelf areas (see Fig. 64). The available data as represented in the relevant figures and tables, however, is largely self-explanatory. Therefore, to obviate lengthy discussions, the reader is urged to make a careful inspection of the data.

Essentially the sediments from the southern Gulf are composed of erosional products, derived from the regolith of the underlying Paleozoic bedrock, with material from the Laurentian suite superimposed. The heavy fraction analysis clearly reflects the Laurentian influence because those sediments with relatively high heavy mineral content have been mixed with local material, which contains only low concentrations of heavy minerals. Similarly, the light fraction of the local bedrock dominates the light mineral composition of the southern Gulf sediments.

In broad terms of regional mineral distribution, an increase in the amounts of minerals belonging to the Laurentian suite is the major characteristic of the sediments lying outside of the boundaries of the Magdalen and Prince Edward Island associations. The increasing influence of the Laurentian suite is shown by the increase in the amounts of amphiboles (up to 60%) and pyroxenes in the heavy fraction. In general, it is strongest in the sediments occurring in the western and northwestern part of the southern Gulf. Heavy minerals characteristic of the Laurentian suite are also easily detectable in the sediments from the western entrance of Northumberland Strait, nearshore areas of Prince Edward Island and New Brunswick, and in the Cape Breton Trough. In detail, the iso-concentration lines (see Fig. 65; see also Chemistry of the sands) of minerals characteristic for the Laurentian suite (such as amphiboles) reveal that in general the concentrations of these minerals are highest along the axis of the shelf valleys. These values decrease from north to south in the shelf valleys, as well as laterally. Although recent ice-rafting is considered as a prominent factor for erosion and deposition throughout the whole region, these data can definitely not be accounted for in this manner. Hence, this dispersal pattern supports the geomorphological evidence for Wisconsin glaciation of the southern Gulf before local re-advances in late-glacial time (see Chap. 9). It confirms that the ice carried with it detrital material from the Canadian Shield area to the north when it invaded the southern Gulf shelf area with lobes through the preglacial drainage system and spilled thinly over the entire shelf. During and after the postglacial transgression, both the foreign and local material have been reworked and locally redistributed, while under present conditions it can be expected that some material is still being added from the shorelines by ice-rafting. *It is evident, however, that the most important single factor affecting the mineral dispersal pattern has been the Wisconsin glaciations by Laurentide ice.* Sand dispersion from the major distant source area — the Canadian Shield — appears not to have been entirely along the longitudinal axis of the Laurentian basin but more radial in a southerly direction, and to a great extent determined by the morphological characteristics of the depositional site (see Fig. 28).

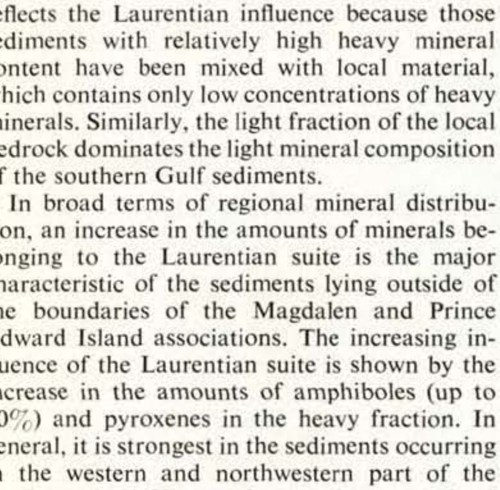


FIG. 65. Iso-concentration lines for amphiboles showing concentrations in general are highest along the axis of the shelf valleys; this pattern supports the geomorphological evidence for Wisconsin glaciation by Laurentide ice.

Finally, the question whether the distinction between the heavy mineral assemblages is due to differences in the coarseness of the sand or to differences in the source of the material, should be examined. It is a well-known fact that zircon usually occurs in fine grains and that frequencies of this mineral therefore are generally higher in fine-grained sediments. It is possible that a single unsorted parent material can be separated by sorting into a coarse and fine-grained sediment each having a different mineralogical composition. With a view to these considerations, some selected samples from the northern Gulf and the southern Gulf, as well as from adjacent shorelines were subjected to a fraction analysis (see Fig. 62 for sample locations). From these samples sieve fractions of the 420–210, 210–105, and 105–50 μ grades were examined. The results of the fractional analysis can be represented in various ways; in this report simple bar diagrams are used (see Fig. 66). The mineralogical variations with different size grades can be easily evaluated by comparing the percentages of the various mineral species in each grade. Comparison between samples representative of the various mineral assemblages shows that the compositional differences cannot be ascribed to granular variations. Therefore, it may be concluded that the differences between the heavy mineral assemblages as defined here do not represent varieties caused by sorting of a single parent material, but have to be explained in terms of provenance. This does not mean, however, that sorting effects are absent. The data from Fig. 66 show that sorting effects may cause important variations within each assemblage. On the other hand it is shown that sediments from the southern Gulf (e.g. S79-236) can be recognized as mixtures between Laurentian material (e.g. S62-39) and the erosional products of Paleozoic bedrock (e.g. Magdalen Islands, sample E3). Similar relations exist between bedrock samples from the Magdalen Islands and from Prince Edward Island and their respective beach sands and nearshore shelf samples. The Cape Breton Island samples are set apart mainly by the abundance of aggregates (Fig. 67, Table 8).

Geochemistry

The chemical composition of the sands (500–50 μ fraction) reveals that the regional differences in mineralogical composition are also displayed by regional differences in chemical composition (Table 9). In Table 9 the relatively low silicon and high aluminum (average Si/Al: 5.0) together with the high sodium and potassium contents of the northern Gulf sands reflects their relatively low quartz and high feldspar contents (Fig. 58). In addition, the relatively high Fe and Mg contents of these sands are indicative of the high concentration of ferromagnesium minerals in the northern Gulf sands (Fig. 60). Similarly, the high silicon and low aluminum contents (average Si/Al: 14.6) of the southern Gulf sands reflect their high quartz and low feldspar content, and low concentrations of iron and magnesium are indicative of their low concentrations of Fe and Mg bearing minerals. In contrast, the Newfoundland Shelf sands which contain mixed mineralogical assemblages (Laurentian and local metamorphic and sedimentary) are somewhat intermediate in chemical composition between the northern Gulf and southern Gulf sands.

Regional differences in the mineralogical–chemical maturity of the sands are also indicated

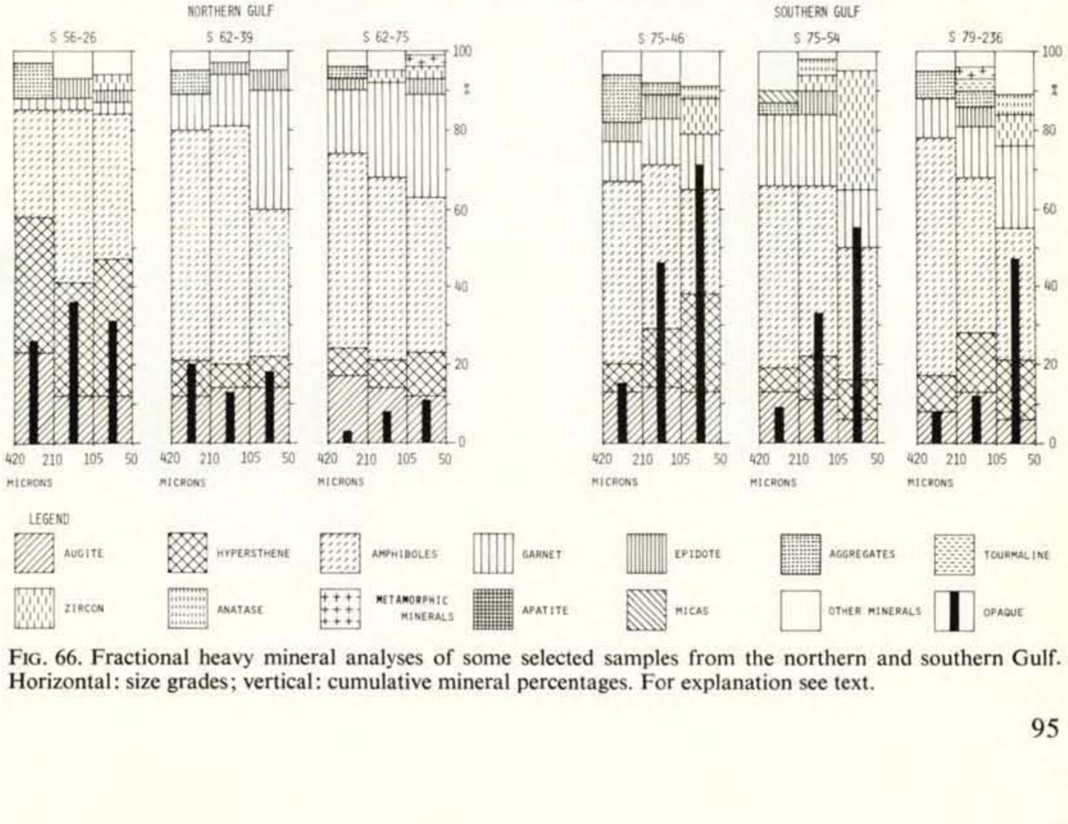


FIG. 66. Fractional heavy mineral analyses of some selected samples from the northern and southern Gulf. Horizontal: size grades; vertical: cumulative mineral percentages. For explanation see text.

by the sodium/potassium (Na/K) ratio (Table 9). The immature northern Gulf sands have a high Na/K ratio (~1.04) whereas the mature southern Gulf (Magdalen Shelf) sands have a low Na/K ratio (average 0.59 or less). The sands from the Newfoundland Shelf on the other hand contain a large proportion of immature material as they have an average Na/K ratio of 1.04.

In the southern Gulf, the differences in chemical composition are also reflected in the mineralogical differences of the sands resulting from the intermixing of varying amounts of immature (Laurentian suite) with the more mature southern Gulf material. For example in Table 9, the higher elemental values and Na/K ratios of the sands in the troughs, compared to the sands belonging to the Magdalen association, are due to the influence of the immature material on the chemical as well as the mineralogical composition of the trough sands.

Since the chemical composition reflects the mineralogical composition of the sands, regional variations in elemental composition may be used to infer the dispersal pattern of the host minerals of these elements (Loring and Nota 1969). One such example is displayed by the contoured geographic distribution of iron, depicted in Fig. 68. These isoconcentration lines show that high iron contents occur along the axis of the Shediac Trough and decrease laterally in concentration towards the New Brunswick coast and the southeastern part of the shelf. Since iron mainly resides in the ferromagnesium minerals, this pattern confirms that detrital material rich in the ferromagnesium minerals, such as amphiboles (Fig. 65) has been dispersed southward along the axis of the Shediac Trough and laterally across the shelf. Similarly, the low iron contents (<0.5%) of the sands around the Magdalen Islands reflect the dispersal of the bedrock erosional products low in ferromagnesium minerals.

Regional variations in aluminum contents and the sodium/potassium ratios show small but significant changes in the shelf sands from which the dispersal pattern of the aluminosilicate minerals, the host minerals of aluminum, and that of sodic feldspar relative to potash feldspars plus micas, the main host minerals of sodium and potassium, may be inferred (Fig. 69 and 70).

In these dispersal patterns, high aluminum concentrations coincide with the configuration of the Shediac Trough and decrease in concentration from north to south along the trough axis as well as laterally. Similarly, the Na/K ratios are highest in the northwestern part of the shelf and in the Shediac Trough they decrease towards

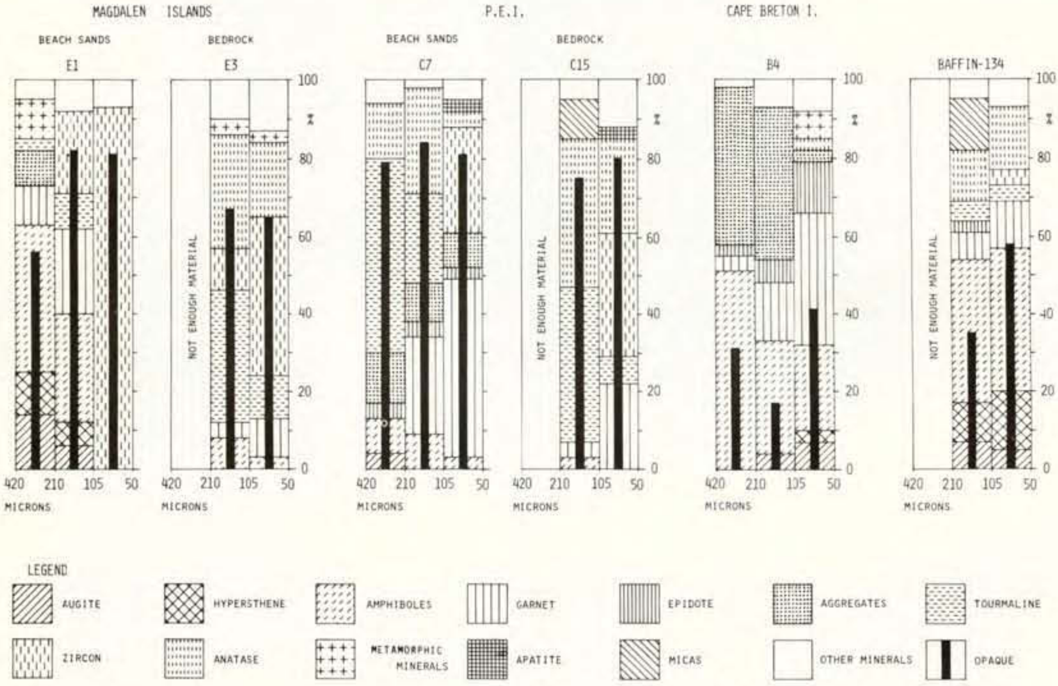


FIG. 67. Fractional heavy mineral analyses of some selected beach sands. For sample location see Fig. 62.

TABLE 9. Average Si, Al, Ti, Na, K, Fe, Mn, Mg, and Ca Contents (percent except parts per million for manganese) and elemental ratios for Gulf sands.[a]

Area	Mineralogical Suite	No. of Samples	Si	Al	Ti	Na	K	Fe	Mn	Mg	Ca	Si/Al	Na/K	Mn/Fe
Northern Gulf	Laurentian	123	31.42	6.27	0.34	2.14	2.06	2.51	554	1.07	3.79	5.0	1.04	0.022
Newfoundland Shelf	Mixed	9	37.40	3.97	0.32	1.32	1.27	1.69	413	0.98	1.56	9.4	1.04	0.024
Southern Gulf (Magdalen Shelf)	Mixed	239	42.10[b]	2.89	0.17	0.88	1.48	1.02	202	0.33	0.54	14.6	0.59	0.020
	Magdalen Ass.	83	–	2.13	–	0.57	1.20	0.57	121	–	–	–	0.48	0.021
	PEI Ass.	18	–	3.78	–	1.32	2.00	1.55	254	–	–	–	0.66	0.016
(Shediac Trough)	Mixed	45	–	4.05	–	1.38	1.50	1.93	319	–	–	–	0.92	0.016
(Cape Breton Trough)	Mixed	15	–	3.69	–	1.33	2.03	1.61	415	–	–	–	0.66	0.026

[a] Determined by atomic absorption technique.
[b] Average of 3.

the New Brunswick coast, as well as toward the eastern and southern parts of the shelf with the lowest values (<0.3) occurring on Bradelle Bank and around the shorelines of the Magdalen Islands.

These patterns reflect the declining influence of the Laurentian material, rich in aluminosilicate minerals, mainly plagioclase feldspars, on the chemical composition of the sands, and the corresponding rise in the amounts of local bedrock material, low in aluminosilicate minerals, southward along the axis of the Shediac Trough, and laterally towards the coast of New Brunswick, Bradelle Bank, the Magdalen terrace, and the southeastern corner of the shelf.

From the foregoing considerations, it is clear that small but significant regional changes occur in the light mineral composition. These follow the general migration routes of the detrital material inferred from the dispersal patterns of the heavy minerals on the shelf. Together the dispersal patterns of the heavy and light minerals reflect the pattern of Wisconsin glaciation in the southern Gulf.

The Clays

A few mineralogical analyses (~10) have been made of clay-size fractions (<1 μ) from surface samples obtained in the Laurentian trough system. Semi-quantitative X-ray studies (Diffraction, powder methods) by R. Schoorl, (Wageningen) reveal that the mineralogical composition of the clay fraction is essentially uniform and consists of plagioclase feldspar, amphibole, chlorite, hydrous mica, kaolinite, smectite, and quartz. Additional X-ray analysis will be necessary for a satisfactory regional appraisal and hence the discussion of the results is limited.

The presence of plagioclase feldspar (mainly oligoclase) and amphibole indicates that some of the clay-size material is mineralogically immature and represents "rock flour" derived mainly from the crystalline rocks of the Canadian Shield (Nota and Loring 1964). Since the mineralogical composition of the clay-size material in the recent sediments is similar to that found in suspension (Chap. 3), it appears that immature (mineralogically and chemically) material is still being supplied to the Gulf from the adjacent

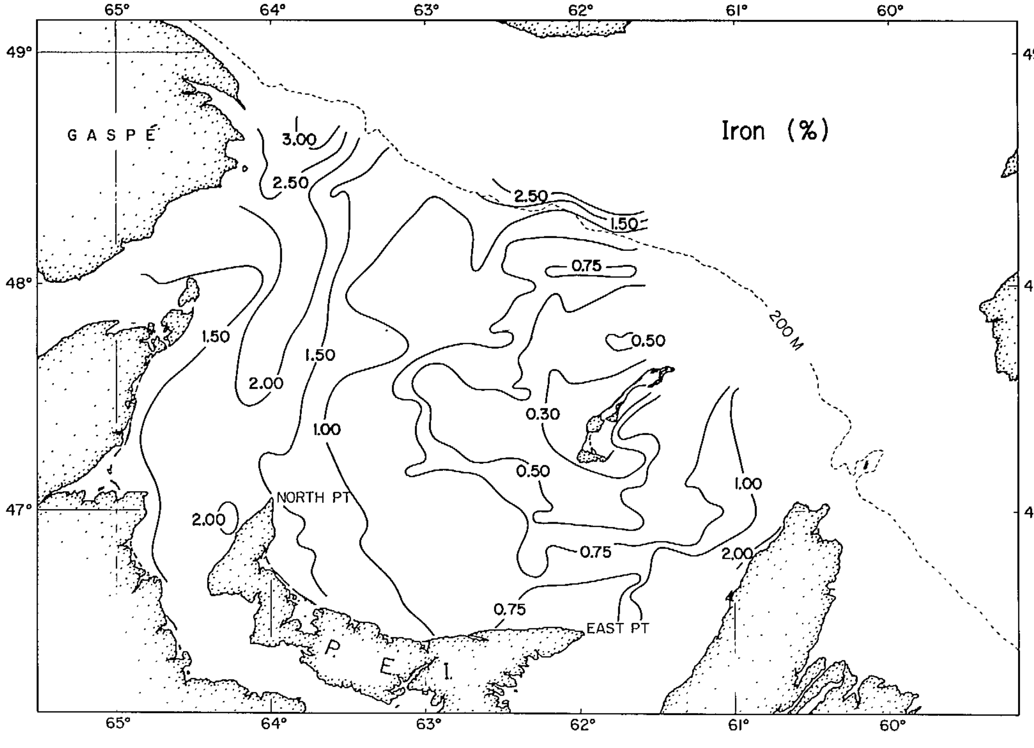


FIG. 68. Regional distribution of iron contents (%) in sands from the southern Gulf of St. Lawrence sediments.

land areas under the present climatic conditions.

The chemical composition of the clay-size material (<2 μ) in the sediments from different parts of the Gulf reveals small but significant differences in composition that is not apparent from the preliminary mineralogical studies of this material.

Table 10 records the average major element composition and elemental ratios of the <2 μ fraction in 18 samples from the Gulf and the average major element composition of the <5 μ fraction of 57 sediments from the Scotian Shelf reported by Hoffman (1970). From this table it may be seen that, compared to the Scotian Shelf clays, the Gulf clays are higher in Si, Na, K, Fe, Mn, Mg, and Ti and lower in Al and Ca concentrations, and have higher Si/Al, Na/K, Ti/Al and lower Ca/Al, Mn/Fe, and Mg/Fe ratios. These differences suggest that the Gulf clays contain a higher proportion of "rock flour" or undecomposed aluminosilicate minerals such as plagioclase feldspar, and amphiboles than the Scotian Shelf clays and are more chemically immature.

Within the Gulf major elemental concentrations and element ratios also show small but significant regional variations that may be attributed to the occurrence of clay-size material from different source areas. From Table 10 it may be seen that the clay-size material from sediments in the upper Laurentian Trough usually have slightly higher Si, Na, K, Ti, Fe, Mn, and Ca concentrations, lower Mg/Fe ratios, and higher Si/Al and Na/K ratios than the material from Cabot Strait, the Esquiman Trough, and the Magdalen Shelf valleys. Essentially, the higher Na/K ratios and elemental concentrations of the former indicate that the material from the western and northwestern part of the Gulf is more chemically immature than found elsewhere and has been in part derived from the igneous and metamorphic rocks of the Shield. The more chemically mature material of the sediments in the south and southeastern parts of the Gulf has the chemical characteristics of being derived, at least in part, from local sedimentary rocks. Some of the mature material may also be derived from outside the Gulf as it is similar in many aspects to the composition of the clay-size material in the seaward part of the Laurentian Trough reported by Hoffman (1970) (Table 10).

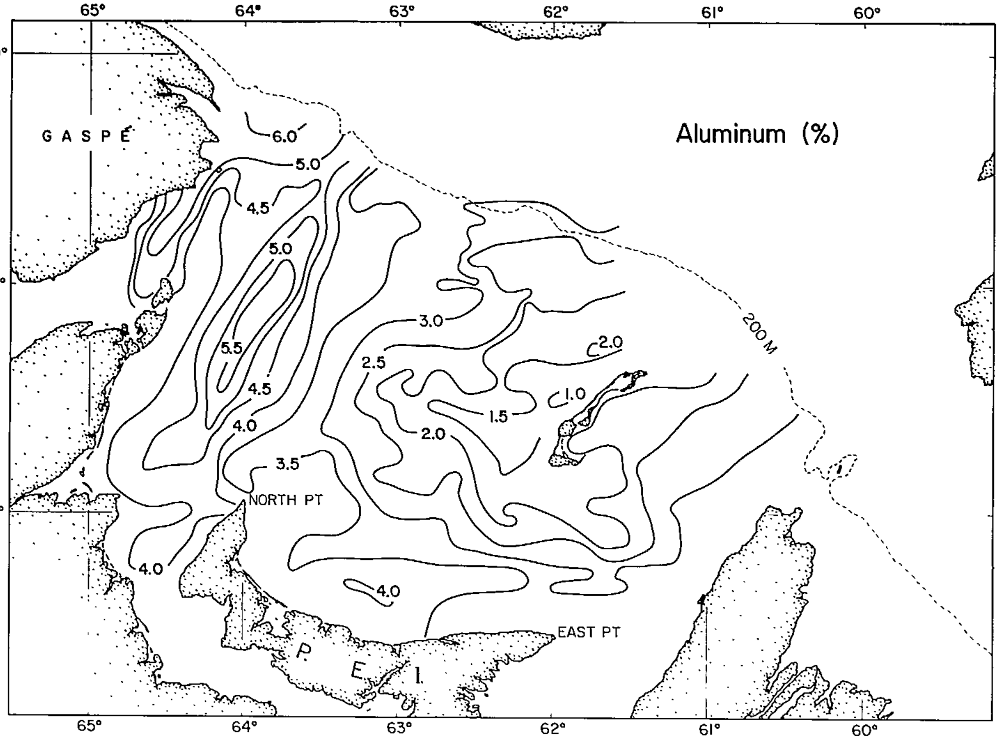


FIG. 69. Regional distribution of aluminum (%) in sands from the southern Gulf of St. Lawrence sediments.

Table 10. Average major elemental concentrations (percent by weight except parts per million for manganese) and ratios of clay size material from the Gulf of St. Lawrence and Scotian Shelf.

	Si	Al	Si/Al	Na	K	Na/K	Fe	Mn	Mn/Fe	Mg	Mg/Fe	Ca	Ca/Al	Ca/Mg	Ti	Ti/Al
Average of 18 clay size fractions ($<2\mu$)[a] from the Gulf (This report)	25.80	8.70	2.97	1.30	2.96	0.44	6.45	744	0.011	2.19	0.34	1.08	0.12	0.49	0.53	0.061
Average of 57 clay size fractions ($<5\mu$) from Scotian Shelf (Hoffman 1970)	23.00	9.08	2.53	0.57	2.55	0.22	4.75	649	0.014	1.85	0.39	1.30	0.14	0.70	0.49	0.054
Average of 12 clays from the upper and middle part of Laurentian Trough and from the Anticosti Trough	26.24	8.52	3.08	1.49	3.04	0.49	6.78	824	0.012	2.23	0.33	1.26	0.15	0.56	0.59	0.069
Average of 4 clays from the lower Laurentian Trough (Cabot Strait) and the Esquiman Trough	25.22	9.05	2.79	0.98	2.93	0.33	6.26	659	0.011	2.34	0.37	0.83	0.09	0.35	0.44	0.049
Average of 2 clays from the Magdalen Shelf	25.65	9.05	2.83	0.75	2.52	0.30	4.82	438	0.009	1.71	0.35	0.47	0.05	0.27	0.35	0.039
Average of 3 clays from the Laurentian Trough outside the Gulf (Hoffman 1970)	23.80	8.68	2.74	0.77	2.75	0.28	4.62	619	0.013	2.13	0.46	2.78	0.32	1.31	0.43	0.050

[a] Detrital fraction, see Chap. 8.

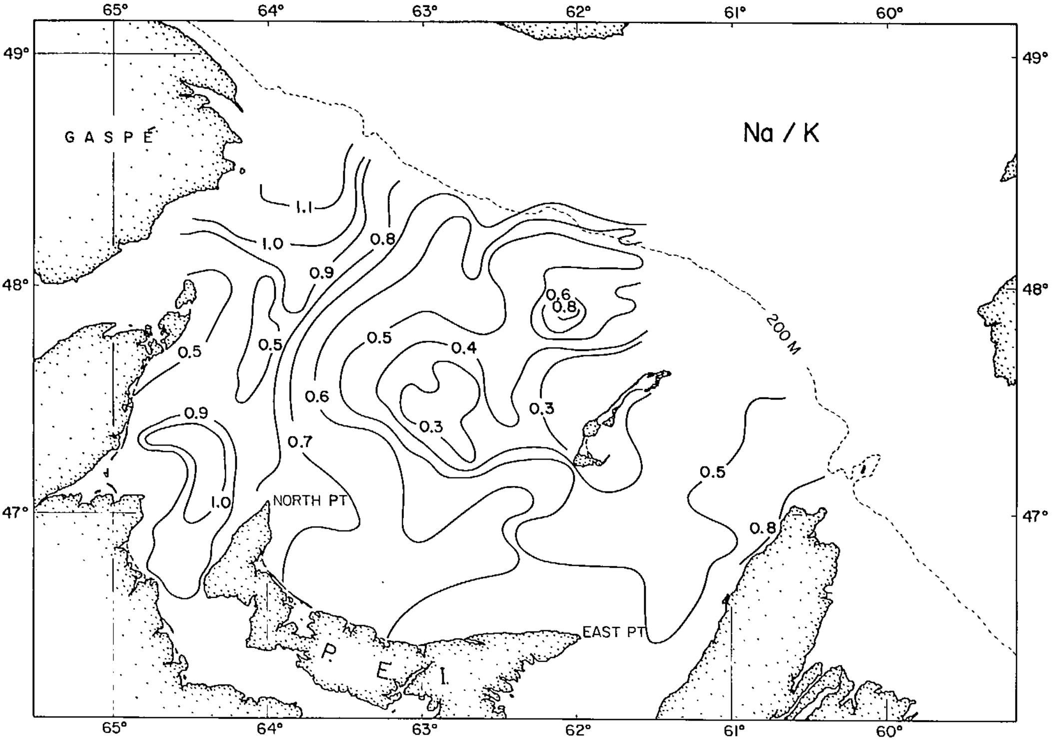


FIG. 70. Regional variation of sodium/potassium (Na/K) ratios in the sands from the southern Gulf of St. Lawrence sediments.

The change in the nature of the clay-size material along the length of the Laurentian Trough from the estuary to Cabot Strait and beyond is illustrated by the variation in the Na/K ratio (Fig. 71). In this figure, Na/K ratios greater than or equal to 0.50 are considered to be indicative of the most chemically immature clay-size material in the region, and Na/K ratios less than 0.3 are considered to be indicative of the most chemically mature material. It may be seen that the Na/K ratios gradually fall (0.55–0.36) from the estuary to Cabot Strait and sharply in the clays from just outside Cabot Strait beyond which they rise slightly. This pattern suggests that the amount of immature material declines and the proportion of mature material rises from the estuary to Cabot Strait. Beyond, the material appears to be the most mature (Na/K ratio <0.3). A similar fall in the Na/K ratio of the material in the size fraction of 16–2 μ is also indicated in this diagram because there is a constant <2/16–2μ ratio in the material being supplied to the sediments from suspension (Chap. 6).

Consequently, it appears that immature clay-size material derived from the St. Lawrence drainage area is transported seaward in response to the present circulation pattern (see Chap. 3) and in so doing, some is deposited in the estuary. The remainder in suspension becomes increasingly diluted and mixed with more

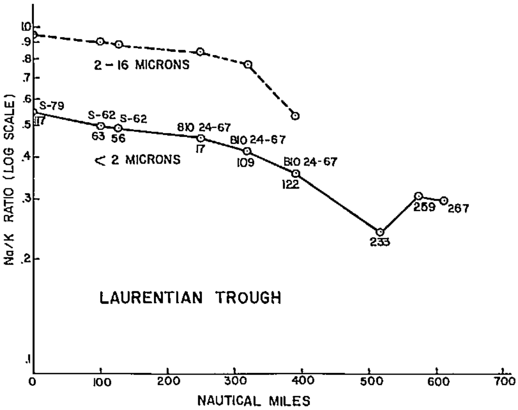


FIG. 71. Seaward decrease in the Na/K ratios of the clay (<2μ) and fine silt (2–16μ) fraction of sediments along the axis of the Laurentian Trough. For sample locations see Fig. 76.

mature material derived from local sedimentary sources on the coasts adjacent to the southern Gulf, on the Magdalen Shelf, and from material brought in through Cabot Strait. Some of the mixed material is transported out of the Gulf through Cabot Strait (see suspended load, Chap. 2) and some remains in the Gulf to be eventually deposited in response to the present current regime in the Magdalen Shelf valleys, in the southeastern part of the Laurentian Trough, and the Esquiman Trough. Not all of the clay-size material has been recently supplied in suspension from the adjacent land as some has undoubtedly derived through the reworking of glacial and older postglacial deposits (Chap. 9).

Finally, it is of interest to note the dispersal pattern of chemically immature clay-size material from the north and west is similar in many respects to that inferred from the dispersal pattern of the chemically immature Laurentian sands through the estuary and Gulf, with the notable exception that the sands are derived from sources within the Gulf, whereas part of the clay-size material may have originated from outside the Gulf

8 Geochemistry

Sediments may be regarded as a mixture of inorganic and organic material that has arrived at the site of deposition as solid particles (detritus) or has been incorporated into the sediments from solution in a variety of ways, i.e. nondetrital (Kryinne 1948, Nicholls 1958).

In the Gulf sediments, detrital material quantitatively dominates the nondetrital material and determines the broad chemical features of the sediments. Most of the chemical constituents such as silicon, aluminum, and sodium are structurally combined in the rather limited number of detrital silicate minerals such as quartz, feldspar, and heavy accessory minerals; the secondary minerals such as the clays and the amorphous compounds of iron and manganese that comprise the inorganic fraction of the sediments (Chap. 7). The principal factors controlling the content of such constituents and their host minerals are usually the nature of the detrital material supplied and the physical conditions of sedimentation. This does not imply that the material undergoes no significant changes as it accumulates to form a sediment. Insofar as it is out of equilibrium in the chemical environment of deposition, it will undergo chemical changes tending towards an equilibrium condition (Nicholls and Loring 1960, 1962: Loring and Nota 1968).

A small but geochemically important fraction of the total of the various elements also occurs as readily exchangeable or absorbed ions. The elements in this fraction represent mainly material that has been initially leached from the source rocks by weathering or supplied in dissolved form from industrial sources, transported in true solution, and incorporated into the sediments in a variety of ways such as precipitation, absorption, or extraction by living organisms. The main factors controlling the distribution of the individual elements in the nondetrital fraction are the nature of the dissolved material supplied to the area, and the physical, chemical, and biological conditions in the depositional areas.

The organic fraction usually makes up less than 5% of the Gulf sediments and is derived from certain living organisms and the organic component formed by the decay of plant and animal matter, the end product of which is sometimes referred to as "humus." The organic material has reached the sediment as solid particles and in the dissolved form from the land as well as from within the marine area, although the differentiation between the two pathways is difficult to determine chemically once they have been incorporated into the sediment.

This chapter examines the factors governing the abundance and distribution of the major elements comprising the inorganic matter in the sediments, and the relative contributions of the detrital and nondetrital fractions to the total major element content of some selected sediments. In interpreting the variation in elemental contents and ratios consideration is given to such factors as the lithology, grain size, mineralogy, and provenance of the sedimentary material, the physical conditions of sedimentation, and the physico-chemical environment in which the material has accumulated. The distribution of organic matter is also discussed.

To avoid repetition of detailed geochemical discussions on the many possible mechanisms responsible for the incorporation of some elements such as manganese into the sediments, the appropriate references will be given.

Average Chemical Composition of the Sediments

The average contents of the major elements and their ranges in concentration in the various sediment types are recorded in Table 11. The main points of interest are the differences in the average contents of silicon (Si), aluminum (Al), titanium (Ti), sodium (Na), potassium (K), iron (Fe), manganese (Mn), calcium (Ca), magnesium (Mg) and elemental ratios between the various

TABLE 11. Chemical composition (percent except parts per million for manganese) of marine sediments from the Gulf of St. Lawrence.

Sediment no. of samples	All sands (81)		Northern Gulf sands (52)	Southern Gulf (Magdalen Shelf) sands (20)	Nfld. Shelf sands (9)	Calcarenites (35)		Pelites (51)		Calcipelites (63)		Total sample (230)
Constituent	Avg	Range	Avg	Avg	Avg	Avg	Range	Avg	Range	Avg	Range	Avg
Si	32.0	23.5 –42.3	29.2	38.0	35.0	26.3	10.5 –36.2	26.4	22.6 –30.2	26.1	21.0 –34.1	28.6
Al	6.25	1.7 – 9.0	7.61	3.66	4.10	5.27	2.2 – 8.0	7.50	5.9 – 8.4	6.59	4.3 – 7.7	6.42
Ti	0.39	0.14– 0.76	0.45	0.27	0.32	0.32	0.07– 0.64	0.46	0.34– 0.72	0.40	0.21– 0.53	0.40
Na	1.84	0.41– 2.88	2.26	1.03	1.25	1.50	0.62– 2.40	1.96	1.00– 2.89	1.53	0.52– 2.21	1.59
K	2.01	1.05– 2.71	2.29	1.56	1.39	1.91	0.54– 2.94	2.41	1.09– 3.15	2.16	1.51– 2.68	2.04
Fe	3.01	0.61– 5.33	3.81	1.42	1.91	2.59	0.90– 5.42	4.53	3.12– 5.72	3.55	1.65– 5.25	3.39
Mn	514	170–880	592	333	467	472	280–580	736	430–2670	635	340–1200	591
Mg	1.08	0.14– 2.72	1.29	0.45	1.25	1.55	0.85– 3.16	1.84	0.92– 2.70	1.96	1.04– 3.17	1.55
Ca	2.06	0.20– 5.35	2.62	0.57	2.11	5.79	1.30–25.2	2.48	1.55– 3.88	3.70	2.12– 8.40	3.16
Elemental ratios												
Si/Al	5.1		3.8	10.3	8.5	5.0		3.5		4.0		4.5
Na/Al	0.29		0.30	0.28	0.31	0.29		0.26		0.23		0.25
Na/K	0.92		1.00	0.66	0.90	0.78		0.82		0.71		0.78
K/Al	0.32		0.30	0.43	0.34	0.36		0.32		0.33		0.32
Fe/Al	0.48		0.50	0.39	0.47	0.49		0.60		0.54		0.53
Mn/Fe × 10^{-1}	0.17		0.16	0.24	0.24	0.18		0.16		0.18		0.17
Fe/Mg	2.79		2.95	3.16	1.53	1.67		2.46		1.81		2.19
Mg/Al	0.17		0.17	0.12	0.30	0.29		0.24		0.30		0.24
Mg/Fe	0.36		0.34	0.32	0.65	0.60		0.41		0.55		0.46
Ca/Al	0.33		0.35	0.15	0.52	1.10		0.33		0.56		0.49

sands (sands and calcarenites, Chart 2, Map Units 2, 3) and the pelites (pelites and calcipelites Map Unit 1, except Map Unit 1d). Examination of Table 11 reveals that on the average, the sands contain more Si, Al, Ti, Na, K, Fe, and Mn, and less Mg, and Ca, than the calcarenites. These differences reflect the dilution of the silicate material (quartz plus the aluminosilicate minerals) by the detrital carbonate fraction of the calcarenites. This is by no means entirely obvious except for the big difference in Ca/Al ratios between the sands and calcarenites (0.33 vs. 1.10) because the average sand content is derived from sands from different areas having strongly varying chemical composition. The sands also contain more Si and less Al, Ti, K, Na, Ca, Mg, Fe, and Mn and have higher Si/Al ratios than the pelites. These differences reflect the relative decrease in quartz which is a major source of silicon and the corresponding rise in the amounts of aluminosilicate minerals, the major source of Al, Na, K, Ti, Mg, and Fe, with decreasing grain size of the sediments. The pelites contain more Si, Al, Ti, Na, K, Fe, and Mn and less Ca and Mg than the calcipelites, which are higher in Ca and Mg due to the dilution of the silicate minerals by the carbonate component in the calcipelites. On the whole, these differences demonstrate that the chemical composition of the various sediments reflects the mineralogical composition of the detrital fraction and that chemical composition and texture are not independent variables. For this reason it is necessary to make comparisons between texturally equivalent sediments, or size fractions, if regional variations in chemical composition in the estuary and Gulf are to have any significance.

Abundance and Regional Distribution of the Major Elements

In the sediments: Si varies between 10.5 and 42.3%, Al between 1.7 and 9.0%, Ti between 0.07 and 0.76%, Na between 0.41 and 2.89%, K between 0.54 and 3.15%, Fe between 0.61 and 5.72%, Mn between 0.017 and 0.267%, Mg between 0.14 and 3.17%, and Ca between 0.20 and 25.2% with sediment texture and location (Table 11 and Fig. 72–75). From the distribution patterns displayed by the elements and elemental ratios, it may be seen that the greatest regional variations in concentration occur between the different shelf areas and that the least variations occur in the sediments occupying the Laurentian Trough system.

The highest concentrations of Al, Ti, Na, K, Fe, and Mn occur in the sandy sediments on the shelves of the estuary, the North Shore Shelf, and on the inner part of the Quebec–Labrador Shelf and the lowest concentrations in the sands of the Magdalen and Newfoundland shelves (Table 11 and Fig. 72–75). In contrast, the highest concentrations of Si (Fig. 72) occur in the sands of the Magdalen and Newfoundland shelves and the lowest occur in the northern Gulf sands and the calcarenites of the Anticosti Shelf (cf. Table 11). Total Ca and Mg on the other hand, are highest in concentration in the calcarenites of the Anticosti Shelf and in the northeastern part of the Gulf near the entrance to the Strait of Belle Isle (Fig. 75) whereas, the lowest total Ca and Mg values are found on the Magdalen Shelf. Essentially these differences in concentrations reflect the differences in relative proportion of quartz and aluminosilicate minerals in sands from the different areas due to difference of provenance as well as to the dilution effect of detrital carbonate particles (Chap. 7).

These regional changes in the relative proportions of quartz and aluminosilicate minerals and carbonate in the sediments are illustrated by the regional variations in the Si/Al ratios (Fig. 72) i.e. the high Si/Al ratios on the Magdalen Shelf area represent the high quartz and low aluminosilicate mineral content of the sediments in this area and the lower values elsewhere represent the dilution of quartz in varying degrees by the other components. Similarly, the relative regional changes in the nature of the feldspar components (Na bearing plagioclase and K bearing orthoclase) and mica are reflected by the regional variations in the Na/K ratios (Fig. 73, cf. Fig. 59).

In the Laurentian Trough system, the regional variability in major elemental concentrations is less than on the shelves due to the more uniform sources and provenance of the surface sediments (Chap. 7). The distribution patterns reveal that the highest concentrations of Si, Al, Ti, K, Na, Fe, and Mn usually occur in the pelites of the estuary and that slightly lower concentrations occur in the calcipelites of the southeastern part of the Laurentian, Anticosti, and Esquiman troughs. Total Ca on the other hand, is highest in the calcipelites in trough areas adjacent to the Anticosti shelf, whereas Mg has its highest concentration in the pelites and calcipelites occupying the floor depressions in the troughs.

On the whole, the regional distribution pattern of the individual elements reflects the regional differences in the texture and nature of the detrital material (Chap. 7) and to a certain extent the distribution in the nondetrital phase of the sediments. The degree to which the detrital and nondetrital phases control the distribution of the

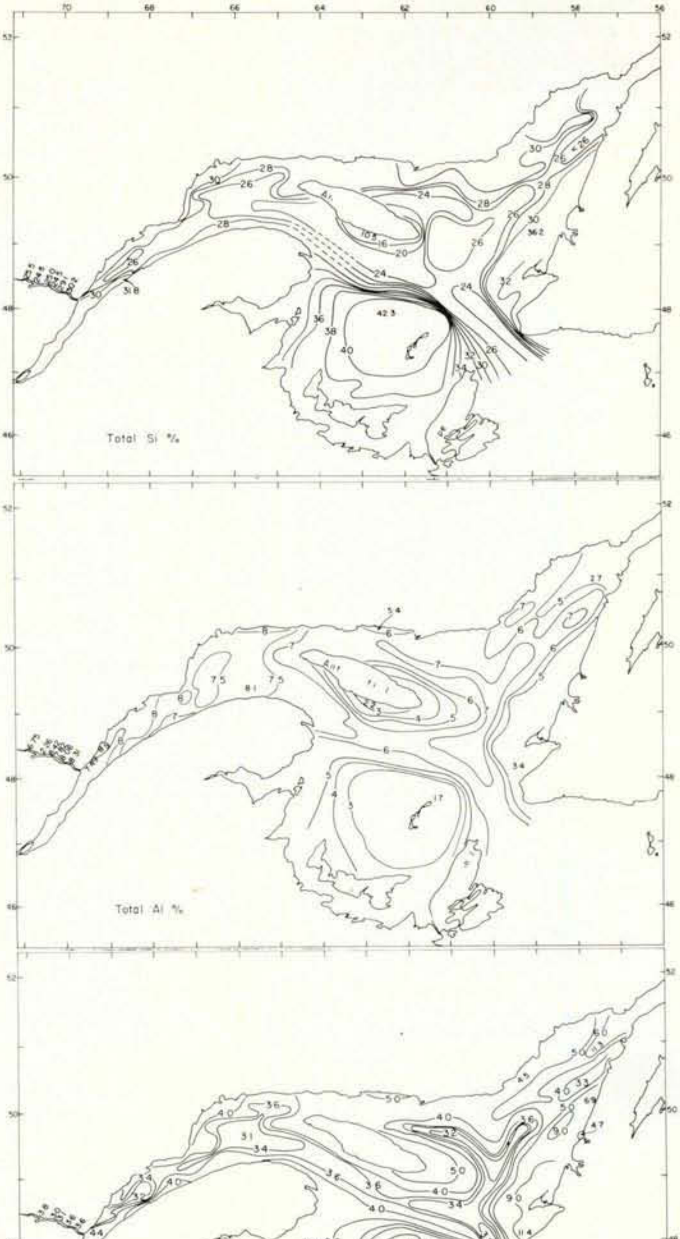


FIG. 72. Regional distribution of silicon, aluminum, and silicon/aluminum ratios in the Gulf of St. Lawrence sediments (230).

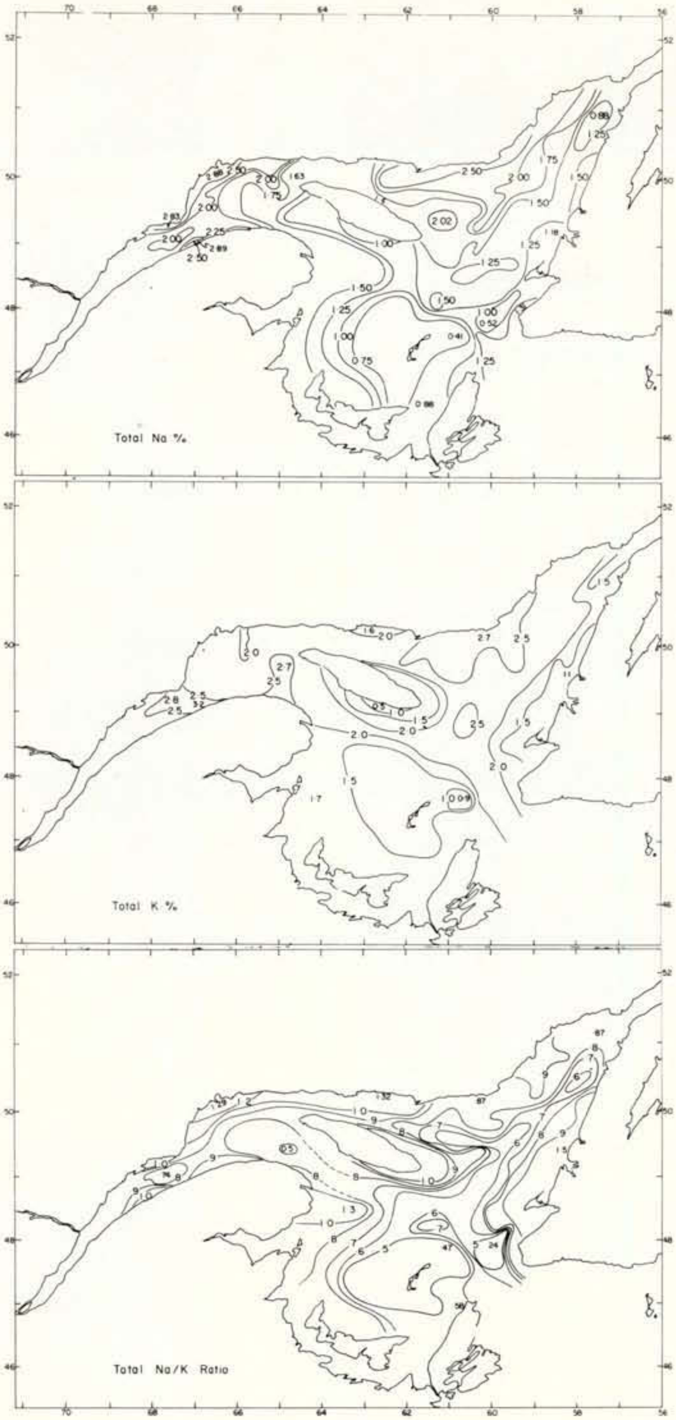


FIG. 73. Regional distribution of sodium, potassium, and sodium/potassium ratios in the Gulf of St. Lawrence sediments (230).

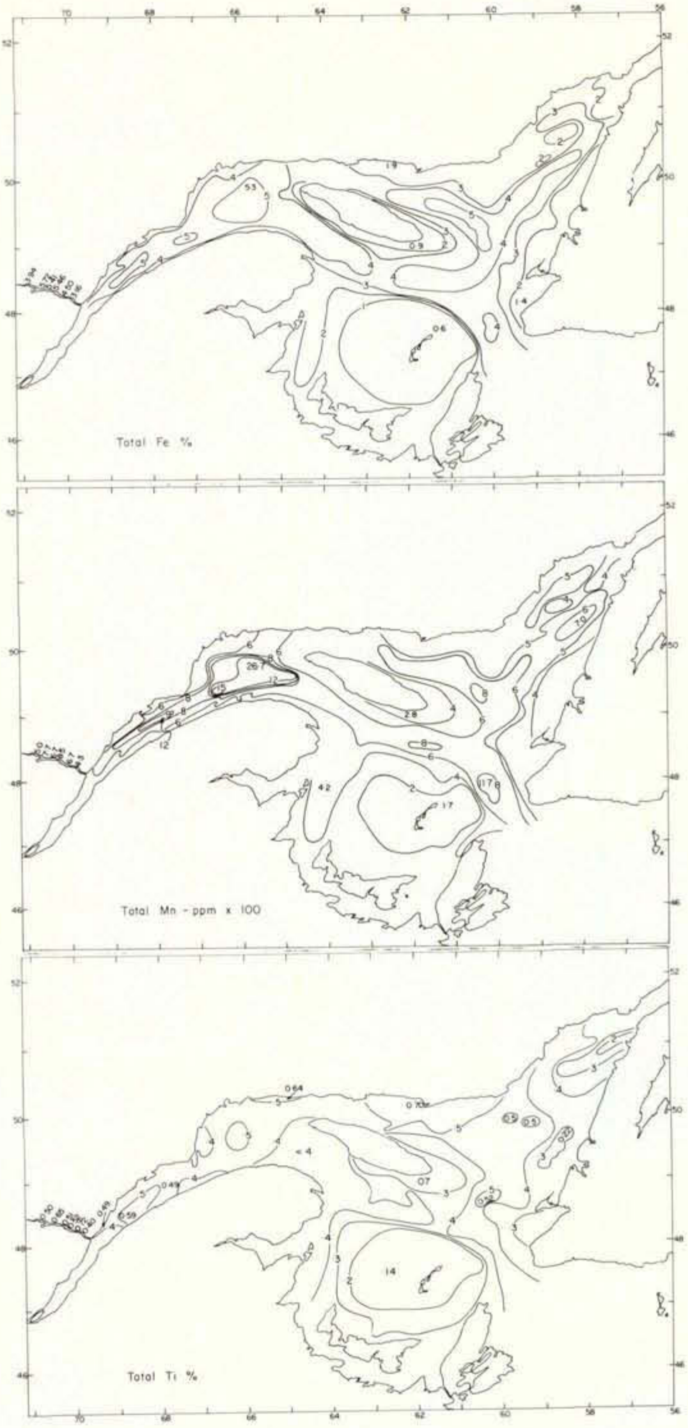


FIG. 74. Regional distribution of iron, manganese, and titanium in the Gulf of St. Lawrence sediments (230).

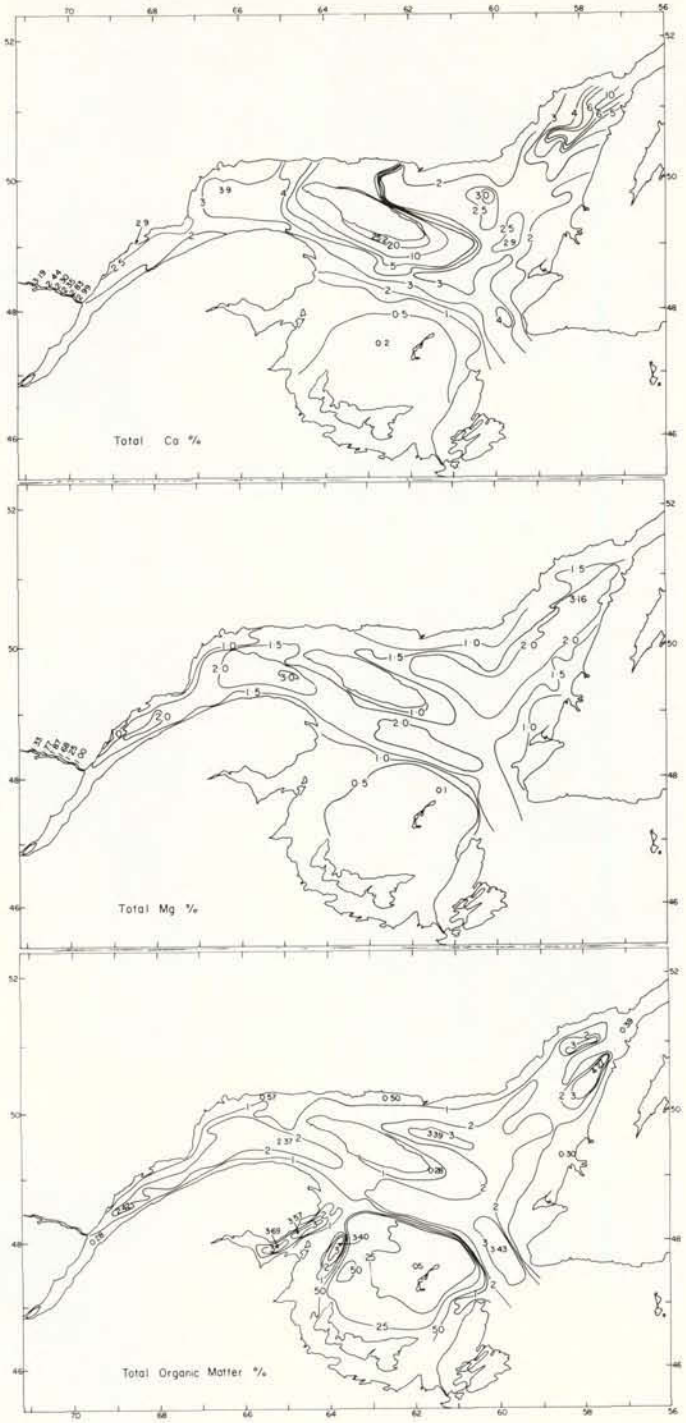


FIG. 75. Regional distribution of calcium, magnesium, and total organic carbon matter in the Gulf of St. Lawrence sediments (230, except 186 for .o.c.m).

TABLE 12. Absolute major element contents of the detrital and nondetrital fractions in percent, except parts per million for manganese, from 18 Gulf of St. Lawrence sediments. For sample locations see Fig. 76.

				BIO24	BIO24	BIO20	BIO27					BIO24	BIO24	BIO24	BIO24	Baffin	BIO24	BIO24	BIO24
		S–79	S–62	–67	–67	–67	–65	S–79	S–62	S–62	S–62	–67	–67	–67	–67	–65	–67	–67	–67
Element		113	59	57	100	5	172	117	64	63	56	17	108	109	122	96	51	74	35
		3b[b]	1c	Cal 3b	3b	1d	1d	1	1	1	1	Cal 1c	Cal 1c	1a	1a	1a	1	1	Cal 1d
Al	*x*[a]	0.55	0.72	0.08	0.26	1.81	1.15	0.97	0.99	1.27	1.03	0.65	0.28	1.65	1.10	0.88	1.15	1.14	0.27
	y	7.60	7.40	6.20	4.80	5.67	4.69	8.30	8.00	8.00	8.20	7.70	7.00	7.70	7.74	7.16	7.80	8.20	6.60
Fe	*x*	0.66	0.90	0.32	0.35	2.11	2.87	1.09	0.56	0.56	0.71	0.41	0.28	0.58	0.66	0.81	0.66	0.57	0.54
	y	2.55	3.47	2.99	2.46	2.19	1.84	5.27	4.91	5.35	5.66	4.53	4.00	5.22	4.36	4.01	5.50	5.58	3.38
K	*x*	0.11	0.36	0.04	0.17	–	–	0.61	0.68	0.99	0.78	0.47	0.20	0.99	–	–	0.74	0.89	0.18
	y	1.65	2.26	2.10	1.67	1.62	1.74	2.68	2.70	2.77	2.75	2.48	2.57	2.63	2.27	2.04	3.05	2.90	2.85
Na	*x*	0.33	0.36	0.32	0.17	0.30	0.29	0.79	0.68	0.99	0.71	0.47	0.16	1.24	0.15	0.15	0.90	0.98	0.14
	y	2.62	2.11	2.20	1.36	1.56	1.05	1.93	1.75	1.73	1.70	1.86	1.76	1.38	1.21	1.43	1.89	1.49	1.82
Mg	*x*	0.44	1.44	0.32	2.96	3.32	4.02	1.58	2.10	2.25	2.26	2.01	2.03	3.22	2.12	4.69	2.87	4.39	3.21
	y	1.02	1.23	0.76	0.84	0.64	0.57	1.71	1.78	1.82	1.80	1.49	1.42	1.75	1.50	2.20	1.70	1.99	1.22
Mn	*x*	142	640	77	1148	1750	2553	1455	2358	2120	10996	2266	476	2375	3102	1026	443	1098	688
	y	571	504	609	375	269	305	728	688	789	970	596	537	652	567	515	741	630	470
Ca	*x*	0.76	2.88	31.65	13.30	9.35	14.63	2.06	13.02	11.20	10.41	20.59	24.39	9.32	14.63	17.37	7.38	8.29	22.40
	y	2.69	1.82	2.00	0.86	0.46	0.41	1.68	1.64	1.56	1.49	1.59	1.42	1.11	0.41	1.22	1.73	1.26	1.43

[a] *x* = Absolute amount in nondetrital fraction; *y* = Absolute amount in detrital fraction.

[b] Sediment type: 1, pelite; 1a, calcipelite; 1c, sandy pelite; 1d, very sandy pelite; 3b, pelitic sand; Cal, calcareous.

Table 13. Detrital and nondetrital contributions for 18 sediments from the Gulf of St. Lawrence, in percent except parts per million for manganese. Sample location shown in Fig. 76.

Element		S–79 113	S–62 59	BIO24 –67 57	BIO24 –67 100	BIO20 –67 5	BIO27 –65 172	S–79 117	S–62 64	S–62 63	S–62 56	BIO24 –67 17	BIO24 –67 108	BIO24 –67 109	BIO24 –67 122	Baffin –65 96	BIO24 –67 51	BIO24 –67 74	BIO24 –67 35
Al	*n*[a]	0.05	0.08	0.02	0.03	0.06	0.04	0.16	0.16	0.18	0.16	0.11	0.07	0.20	0.15	0.12	0.14	0.14	0.06
	d	6.90	6.60	4.70	4.20	5.48	4.52	6.90	6.70	6.90	6.90	6.40	5.30	6.80	6.68	6.18	6.80	7.20	5.10
Fe	*n*	0.06	0.10	0.08	0.04	0.07	0.10	0.18	0.09	0.08	0.11	0.07	0.07	0.07	0.09	0.11	0.08	0.07	0.12
	d	2.59	3.08	2.25	2.18	2.12	1.78	4.40	4.11	4.59	4.79	3.77	3.02	4.59	3.76	3.46	4.83	4.90	2.63
K	*n*	0.01	0.04	0.01	0.02	–	–	0.10	0.11	0.14	0.12	0.08	0.05	0.12	–	–	0.09	0.11	0.04
	d	1.50	2.01	1.58	1.48	1.57	1.68	2.24	2.26	2.38	2.32	2.06	1.94	2.31	1.96	1.76	2.68	2.54	2.22
Na	*n*	0.03	0.04	0.08	0.02	0.01	0.01	0.13	0.11	0.14	0.11	0.08	0.04	0.15	0.02	0.02	0.11	0.12	0.03
	d	2.38	1.88	1.66	1.20	1.51	1.01	1.61	1.47	1.48	1.44	1.55	1.33	1.21	1.04	1.23	1.66	1.31	1.42
Mg	*n*	0.04	0.16	0.08	0.34	0.11	0.14	0.26	0.34	0.32	0.35	0.34	0.50	0.39	0.29	0.64	0.35	0.54	0.71
	d	0.93	1.09	0.57	0.74	0.62	0.55	1.43	1.49	1.56	1.52	1.24	1.07	1.54	1.29	1.90	1.49	1.75	0.95
Mn	*n*	13	71	19	132	58	89	240	382	301	1700	353	117	288	425	140	54	135	152
	d	519	448	458	332	260	294	608	576	677	820	495	405	573	489	444	651	553	366
Ca	*n*	0.07	0.32	7.85	1.53	0.31	0.51	0.34	2.11	1.59	1.61	3.48	6.00	1.13	3.00	2.37	0.90	1.02	4.95
	d	2.44	1.62	1.51	0.76	0.44	0.40	1.40	1.37	1.34	1.28	1.32	1.07	0.98	0.72	1.05	1.52	1.11	1.11

[a] *n* = nondetrital contribution; *d* — detrital contribution.

Table 14. The detrital and nondetrital contributions as percentages of the total elemental content.

Element	S–79 113	S–79 117	S–62 64	S–62 63	S–62 56	S–62 59	BIO24 –67 17	BIO24 –67 109	BIO24 –67 108	BIO24 –67 122	Baffin –65 96	BIO24 –67 74	BIO24 –67 51	BIO24 –67 57	BIO20 –67 5	BIO27 –65 172	BIO24 –67 35	BIO24 –67 100	Avg
										% Detrital									
Al	99.28	97.73	97.67	97.46	97.73	98.80	98.31	97.14	98.70	97.80	98.10	98.09	97.98	99.58	98.92	99.12	98.84	99.29	98.36
K	99.34	95.73	95.36	94.44	95.08	98.05	96.26	95.06	97.49	–	–	95.85	96.75	99.37	–	–	98.23	98.67	96.62
Na	98.76	92.53	93.04	91.36	92.90	97.92	95.09	92.90	97.08	98.11	98.40	91.61	93.79	95.40	99.34	99.02	97.93	98.36	95.75
Fe	97.74	96.07	97.86	98.29	97.76	96.86	98.18	98.50	97.73	97.66	96.92	98.59	98.37	96.57	96.80	94.68	95.64	98.20	97.36
Mn	97.56	71.70	60.13	69.22	32.54	86.32	56.38	66.55	77.59	53.50	76.03	80.38	92.34	96.02	81.76	76.76	70.66	71.55	73.32
Mg	95.88	84.62	81.42	82.98	81.28	87.20	78.48	79.79	68.15	81.65	74.80	76.42	80.98	87.69	84.93	79.71	57.23	68.52	79.54
Ca	97.21	80.46	39.37	45.73	43.90	83.51	27.50	46.45	15.13	19.36	30.70	52.11	62.81	16.13	58.67	43.96	18.32	33.19	45.25
										% Nondetrital									
Al	.72	2.27	2.33	2.54	2.27	1.20	1.69	2.86	1.30	2.20	1.90	1.91	2.02	0.42	1.08	0.88	1.16	0.71	1.64
K	.66	4.27	4.64	5.56	4.92	1.95	3.74	4.94	2.51	–	–	4.15	3.25	0.63	–	–	1.77	1.33	3.38
Na	1.24	7.47	6.96	8.64	7.10	2.08	4.91	7.10	2.92	1.89	1.60	8.39	6.21	4.60	0.66	0.98	2.07	1.64	4.25
Fe	2.26	3.93	2.14	1.71	2.24	3.14	1.82	1.50	2.27	2.34	3.08	1.41	1.63	3.43	3.20	5.32	4.36	1.80	2.64
Mn	2.44	28.30	39.87	30.78	67.46	13.68	43.62	33.45	22.41	46.50	23.97	19.62	7.66	3.98	18.24	23.24	29.34	28.45	26.68
Mg	4.12	15.38	18.58	17.02	18.72	12.80	21.52	20.21	31.85	18.35	25.20	23.58	19.02	12.31	15.07	20.29	42.77	31.48	20.46
Ca	2.79	19.54	60.63	54.27	56.10	16.49	72.50	53.55	84.87	80.64	69.30	47.89	37.19	83.87	41.33	56.04	81.68	66.81	54.75

TABLE 15. Ratios of the absolute amounts in the nondetrital fraction to the absolute amounts in the detrital fraction.

Element	Ratio	S–79 113	S–79 117	S–62 64	S–62 63	S–62 56	S–62 59	BIO24 –67 17	BIO24 –67 109	BIO24 –67 108	BIO24 –67 122	Baffin –65 96	BIO24 –67 74	BIO24 –67 51	BIO24 –67 57	BIO20 –67 5	BIO27 –65 172	BIO24 –67 35	BIO24 –67 100
Mn	x/y	.25	2.00	3.43	2.69	11.34	1.27	3.80	3.64	.89	5.47	1.99	1.74	.60	.13	6.51	8.37	1.46	3.06
Fe	x/y	.26	.21	.11	.10	.12	.26	.09	.11	.07	.15	.20	.10	.12	.11	.96	1.56	.16	.14
Al	x/y	.07	.12	.12	.16	.13	.10	.08	.21	.04	.14	.03	.14	.15	.01	.32	.24	.04	.05
Mg	x/y	.43	.92	1.18	1.24	1.26	1.17	1.35	1.84	1.43	1.41	2.13	2.21	1.69	.42	5.19	7.05	2.63	3.52
Ca	x/y	.28	1.23	7.94	7.18	6.99	1.58	12.95	8.40	17.18	35.60	14.24	6.58	4.27	15.82	20.33	35.68	15.66	15.47
Na	x/y	.13	.41	.39	.57	.42	.17	.25	.90	.09	.12	.10	.66	.48	.15	.19	.28	.08	.12
K	x/y	.07	.23	.25	.36	.28	.16	.19	.38	.08	–	–	.31	.24	.02	–	–	.06	.10

TABLE 16. Absolute major element contents (percent except parts per million for manganese) in various size fractions of the detrital fraction and in the nondetrital fraction for three representative sediments.

Element	Detrital fraction						Nondetrital fraction	Detrital total	Total
	>500 μ	500–53 μ	53–37 μ	37–16 μ	16–2 μ	<2 μ			
				Station S–79 113; Pelitic sand					
Si	36.00	33.40	30.60	31.60	31.30	26.00	–		
Al	7.10	7.40	7.80	8.40	8.00	9.20	.55		
Ti	.69	.49	.38	.61	.30	.13	–		
Na	2.61	2.70	2.56	2.97	2.68	1.99	.33		
K	1.67	1.52	1.49	1.91	2.30	3.03	.11		
Fe	.80	2.47	4.51	3.00	3.59	6.81	.66		
Mn	170	530	980	675	635	825	142		
Mg	.30	.91	1.48	1.08	1.36	2.23	.44		
Ca	2.05	2.71	3.54	3.15	2.52	1.70	.76		
				Station BIO–24–67 17; Sandy calcipelite					
Si	32.20	32.50	33.10	32.50	32.30	28.50	–		
Al	7.30	6.70	6.40	6.50	7.70	8.40	.65		
Ti	.55	.63	.55	.50	.38	.15	–		
Na	2.64	2.24	2.00	2.08	2.11	1.35	.47		
K	2.27	1.85	1.86	2.01	2.52	2.92	.47		
Fe	2.08	3.30	3.32	2.48	3.55	6.44	.41		
Mn	215	590	550	440	545	740	2266		
Mg	.58	.91	1.00	.90	1.27	2.18	2.01		
Ca	2.41	2.12	1.73	1.46	1.67	1.09	20.59		
				Station S–62 56; Pelite					
Si	–	34.00	–	32.30	31.30	26.00	–		
Al	–	6.20	–	7.70	8.00	8.40	1.03		
Ti	–	.49	–	.52	.58	.54	–		
Na	–	2.58	–	2.50	2.24	1.44	.71		
K	–	1.90	–	2.12	2.54	2.94	.78		
Fe	–	3.00	–	3.01	3.68	6.79	.71		
Mn	–	792	–	710	660	1130	10996		
Mg	–	.87	–	.97	1.28	2.12	2.26		
Ca	–	2.13	–	2.23	1.98	1.26	10.41		

Contributions of the various size fractions (detrital) and nondetrital fraction to the total elemental contents (% except ppm for Mn) of the three sediments

Station S–79 113; Pelitic sand									
Si	2.17	21.74	2.62	.72	1.12	1.37	–	29.74	29.74
Al	.43	4.82	.67	.19	.29	.48	.05	6.88	6.93
Ti	.01	.20	.05	.01	.02	.03	–	.32	.32
Na	.15	1.75	.22	.07	.09	.10	.03	2.38	2.41
K	.10	.99	.13	.04	.08	.16	.01	1.50	1.51
Fe	.05	1.60	.38	.07	.13	.36	.06	2.59	2.65
Mn	10	345	84	15	22	43	13	519	532
Mg	.02	.59	.13	.02	.05	.12	.04	.93	.97
Ca	.12	1.77	.30	.07	.09	.09	.07	2.44	2.51
Station BIO–24–67 17; Sandy calcipelite									
Si	3.11	6.00	0.52	1.08	4.37	10.39	–	25.47	25.47
Al	.71	1.24	.10	.22	1.04	3.06	.11	6.37	6.48
Ti	.02	.07	.01	.02	.08	.20	–	.40	.40
Na	.26	.42	.03	.07	.28	.49	.08	1.55	1.63
K	.22	.34	.03	.07	.34	1.06	.08	2.06	2.14
Fe	.20	.61	.05	.08	.48	2.35	.07	3.77	3.84
Mn	21	109	8	14	73	270	383	495	878
Mg	.06	.16	.02	.03	.17	.80	.34	1.24	1.58
Ca	.23	.39	.02	.05	.23	.40	3.48	1.32	4.80
Station S–62 56; Pelite									
Si	–[a]	.31	–[a]	1.31	7.16	14.58	–	23.36	23.36
Al	–	.06	–	.31	1.83	4.71	.16	6.91	7.07
Ti	–	.00	–	.02	.13	.30	–	.45	.45
Na	–	.03	–	.10	.51	.80	.11	1.44	1.55
K	–	.02	–	.09	.57	1.64	.12	2.32	2.44
Fe	–	.03	–	.12	.84	3.80	.11	4.79	4.90
Mn	–	7	–	29	151	633	1700	820	2520
Mg	–	.01	–	.04	.29	1.18	.35	1.52	1.87
Ca	–	.02	–	.09	.45	.70	1.61	1.26	2.87

[a] Not enough sample for analyses.

major elements has been determined and is described in the following text.

Chemical partition

In addition to the determination of the total elemental contents in a large number of sediments, about 18 sediments of different textural characteristics and from different locations (Fig. 76) were treated with an acetic acid solution (25% v/v). This enables detrital and nondetrital contributions to be evaluated. The acetic acid removes only the major elements which are held in carbonates, easily soluble amorphous compounds, and/or loosely held in ion-exchange positions and assumed to have been removed from solution by absorption, by co-precipitation, or by direct precipitation. This treatment leaves the lattice structure of the silicate minerals intact and does not attack the resistant iron and manganese oxides such as hematite, ilmenite, and hausmannite (McKeaque and Day 1966; Heintze and Mann 1951; Hirst and Nicholls 1958). Unfortunately, the acetic acid technique does not account for all elements which may have been originally derived from solution, but due to recrystallization of the host minerals, have become incorporated into lattices and, therefore, resistant to acetic acid, e.g. elements present in sedimentary pyrite.

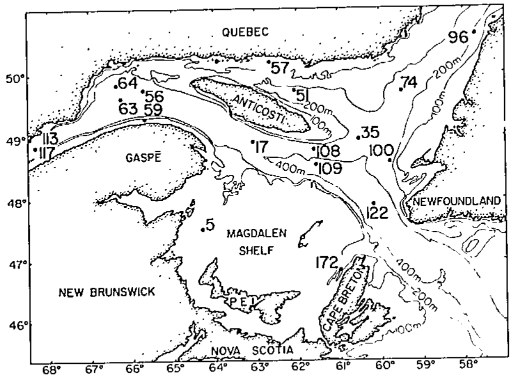


FIG. 76. Location of samples used for the determination of the detrital and nondetrital elemental contributions.

After removal of the acid soluble fraction, analyses of the different elements in the individual size fractions (500–53, 53–37, 37–16, 16–2, and less than 2 μ) of the detrital fraction were made to evaluate the textural and regional variation of the elements in this fraction.

The elements for which nondetrital and detrital contributions have been evaluated are Al, Na, K, Fe, Mg, Mn, and Ca; the detrital contribution (d) being derived by adding the contribution (absolute concentration (y) × percentage of the size fraction in the sample) that each size fraction makes to the total detrital fraction. Detrital and nondetrital contributions to the major element contents of the 18 samples and related data are given in Tables 12–16.

Inspection of the detrital–nondetrital contribution expressed as a percentage in Table 14 reveals that the *detrital character* of the elements on the average decreases in the order of Al >Fe >K >Na >Mg >Mn>>Ca. Si and Ti are not mentioned because they are strictly detrital. On this basis, the elements may be divided into several groups.

Group 1: Elements in this group have 100% of their total element content contributed by the detrital fraction. Silicon and titanium are the only elements in this group.

Group 2: This group contains Al, Na, K, and Fe which have between 91 and 98% of their total contents (average >96%) contributed by the detrital fraction.

Group 3: This group contains Mn, Mg, and Ca which have 15–97% of their total content (average 45–79%) in the detrital fraction depending on the texture and location of the sediment.

From this data, it is evident that the geochemistry of the elements in group 1 and 2 is essentially determined by the source, nature, and distribution of the detrital material, whereas the elements in group 3 have, in some places, a nondetrital character (Table 15) (x/y ratio >1). The nondetrital character of calcium and magnesium may be only apparent because these elements are mainly derived from the dissolution of detrital limestone and dolomite particles (Chap. 5 and 7). Manganese, on the other hand, appears to have nondetrital characteristics which vary with grain size (compare Station 113, pelitic sand, with Stations 56 and 64, pelites, Tables 12 and 13). The abundance, distribution, and source of the elements in various size fractions and in the detrital and nondetrital fractions are discussed separately.

Detrital Fraction — The total amount of any individual element in the detrital fraction depends on the absolute content in each size fraction and the contribution that each size fraction makes to the total amount (Table 16).

Chemical analyses of absolute concentrations in the individual size fractions show that the average absolute concentrations of Si decrease and those of Al, K, Fe, Mn, and Mg increase

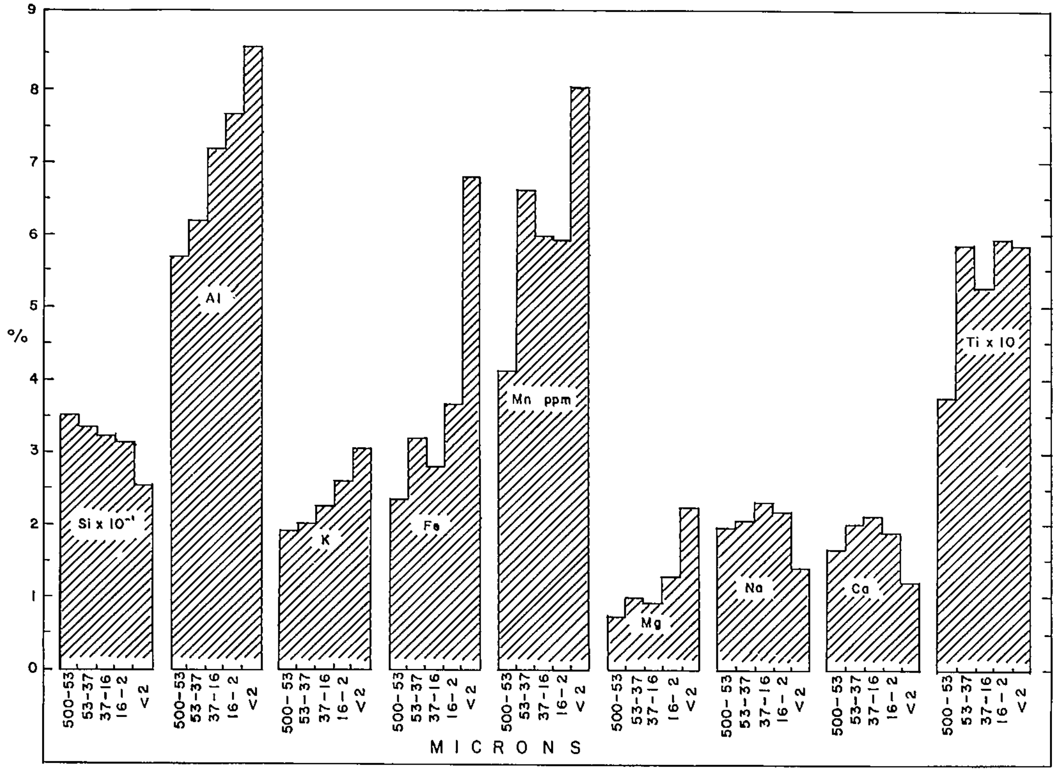


FIG. 77. Average elemental contents of the various size grades in the detrital fractions.

gradually or sometimes step-wise with decreasing grain size of the fractions so that the highest concentrations of all these elements except Si occur in the clay-size fraction (Fig. 77). In contrast, the average concentrations of Na and detrital Ca are highest in the silt- and sand-size fractions and the lowest in the clay-size fraction. The lowest Ti concentrations occur in the sand-size fraction and the highest in the silt-size fraction particularly the 53–37 μ fraction which is also slightly enriched with detrital Fe and Mn, and the clay-size fraction.

Consideration of these elemental concentrations in the various fractions and the contribution that each fraction makes to the total elemental content of the various sediments accounts for the relation between total chemical composition of the various sediments and texture noted in Table 11. For example, the sands generally have higher Si contents because of the relatively higher concentration of Si in the sand-size fraction and the high proportion of this fraction in sediments of this type. Similarly, pelites are usually lower in Si and higher in the other elements (Table 16). Exceptions to this are for the elements such as Ca and Mn in some sediments (e.g. Stations 122 and 108 for Ca and Stations 56 and 64 for Mn) whose total elemental content is mainly derived from the nondetrital fraction (Table 14).

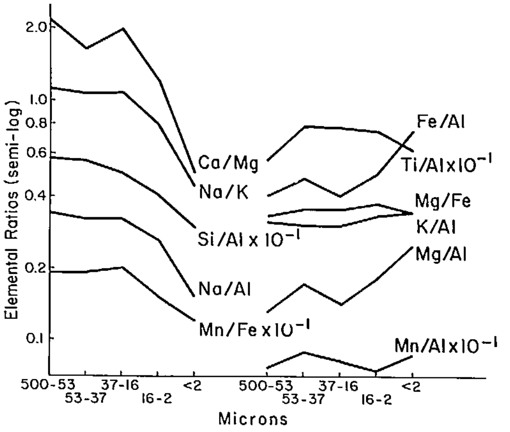


FIG. 78. Variation of elemental ratios with decreasing size grades in the detrital fractions.

TABLE 17. Major constituents of the common light and heavy minerals in the Gulf sediments.

Mineral	Major constituent	Mineral	Major constituent
Quartz	Si	Heavy minerals	
Feldspars			
Orthoclase	K, Al, Si	Augite[a]	Ca, Mg, Al, Si
		Hypersthene	Mg, Fe, Si
		Hornblende[a]	Mg, Fe, Ca, Na, Al, Si
Plagioclase			
Albite	Na, Al, Si	Garnet[a]	Ca, Mg, Fe, Al, Si
Oligoclase	Na, Ca, Al, Si	Olivine[a]	Mg, Fe, Si
Andesine[a]	Ca, Na, Al, Si	Tourmaline	Ca, Mg, Fe, B, Al, Si
Anorthite[a]	Ca, Al, Si	Zircon	Zr, Si
		Anatase	Ti
		Rutile	Ti
Mica			
Muscovite	K, Al, Si	Titanite	Ca, Ti, Si
Biotite[a]	K, Mg, Fe, Al, Si	Apatite	Ca, P, F
		Ilmenite	Fe, Ti
		Magnetite[a]	Fe
Clays			
Kaolinite	Al, Si		
Illite[a]	K, Al, Si		
Chlorite[a]	Mg, Ca, Fe, K, Al, Si		
Calcite	Ca		

[a] Minerals containing manganese as a trace constituent.

Most of the elements in the detrital fraction occur as constituents in the crystal lattices of the rock-forming minerals found in the Gulf sediments (see Table 17).

Since the chemical composition of each size fraction reflects its mineralogical composition, the textural variations in elemental concentrations and elemental ratios in Fig. 77 and Fig. 78 can be ascribed to variations in the abundance, characteristic grain size, and nature of their host minerals in these fractions. One example of this may be seen in the decrease of Si concentrations and rise in aluminum concentrations with decreasing grain size in Fig. 77. This reflects the fall in the quartz concentrations and the corresponding rise in the concentrations of the aluminosilicate minerals between the sand-silt size grades and the clay-size fractions. The extent to which these changes take place between the individual size fractions is illustrated by the fall of the average Si/Al ratio with decreasing grain size (Fig. 78). Another example of geochemical interest is change in Na/K with grain size. The change of Na and K contents as well as the constancy of the K/Al, and the fall of the Na/K ratios with grain size indicate that Na-bearing minerals are depleted relative to K bearing minerals with decreasing grain size with the greatest loss in Na bearing minerals occurring in the clay-size fraction. Since sodium is preferentially lost relative to potassium in the weathering cycle (Rankama and Sahama 1950), these changes represent a change from chemically immature sand- and silt-size material to more chemically mature clay-size material having lower Na/K ratios (See Chap. 7). The data for Ti, Fe, Mg, Mn, and detrital Ca may also be interpreted in a similar way in terms of variations in abundance and grain size of their host minerals.[5]

Another point of interest is the difference or range in elemental contents in the same size fractions (Fig. 79). Since each fraction is texturally equivalent, these differences may be considered to represent the regional variations noted in the regional distribution patterns (Fig. 72–75). More than one comparison of the size fractions is needed because the sand- and silt-size fractions have a different provenance and mode of transport and deposition than the clay-size fraction of the same sediments (Chap. 7). These differences in turn are determined by such factors as the source rocks, nature of the weathering process, mode of transport from the weathering site, and the physical conditions of sedimentation.

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[5] e.g. Mg resides mainly in the amphiboles, pyroxenes, and garnets in the sand and silt fractions whereas chlorite is one of the main host minerals for Mg in the clay fraction.

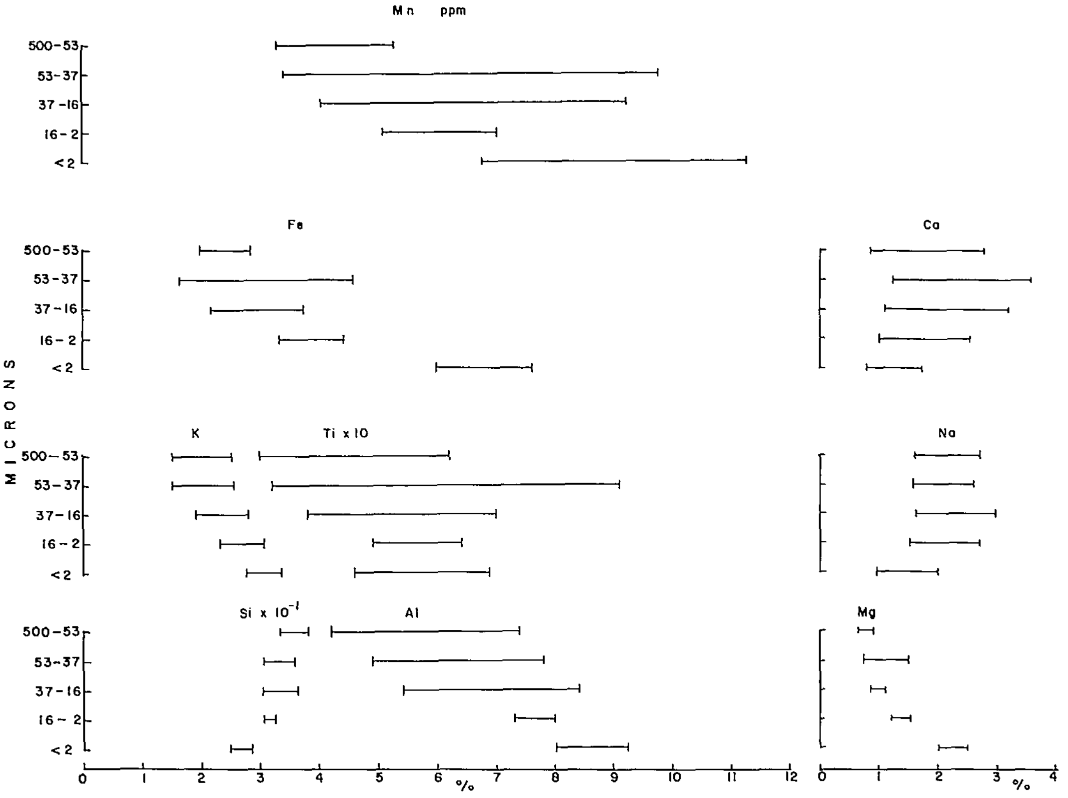

FIG. 79. The spread of elemental contents within the indicated size grades of the detrital fractions.

In summary, the nature of the detrital fraction dominates the broad chemical features of the sediments. The variation of most of the major elements with the grain size of the sediments is accounted for by the variation in the nature, abundance and characteristic grain size of the host minerals with which they are mostly structurally combined. The geographic variations in elemental contents within texturally equivalent sediments or size grades are determined by regional differences in mineralogical composition.

Nondetrital fraction — The nondetrital fraction forms a small but geochemically important fraction of the sediment.

In the sediments, the nondetrital (acetic acid soluble) character of the elements is the reverse of the detrital character viz., Ca > >Mn >Mg > >Na >K >Fe >Al (Table 14 and 15). The absolute concentrations and the contribution that each element makes to the nondetrital fractions (Table 12, 13, and 14) and their sources are summarized in the following text.

Silicon and *titanium* are strictly detrital elements since no measurable Si and Ti have been found in the nondetrital fraction. The main effect of the nondetrital fraction which includes that derived from $CaCO_3$ is to dilute the amounts of Si and Ti bearing minerals in the sediments. This dilution effect is particularly reflected in the low Si and Ti contents of the calcarenitic and calcipelitic sediments around Anticosti Island.

Small amounts of *aluminum* (0.4–2.9% of the total), and significant amounts of *potassium* (0.6–5.6% of the total) and *sodium* (0.7–8.6% of the total) are found in the nondetrital fraction with the highest amounts being derived from the pelitic sediments and the lowest from the sandy sediments. Nondetrital aluminum is apparently derived from the dissolution of precipitated sesquioxides or removed from "fresh" ferromagnesium minerals because the highest values of Al usually coincide with those sediments which contain high amounts of nondetrital Fe, Mn and Mg (Table 12). Nondetrital Na and K appear to represent the amounts of these elements sorbed on the surface of solid particles or released from edge and interlayer positions in the clay minerals. This would suggest that some ionic exchange reactions would occur between the Na and K in the seawater and the sediments (suspended and at the sediment–water interface). The extent to which this takes place is not known because of the limited amount of data available at this time and the possibility that some of the soluble Na and K represents traces of sea salts retained by the samples.

The difference between the total Fe/Al ratios (Table 11) of the sands (0.48) and the pelites (0.60) suggests that some *iron* in the sediments is derived from sources other than the detrital iron bearing aluminosilicate minerals. Since iron may occur in various oxidation states depending on its initial state in the sediments and the physiochemical condition under which iron bearing minerals accumulate, it is useful to know its distribution in the *ferrous* and *ferric state* in the sediments. In the sediments from the St. Lawrence Estuary, ferrous iron (Fe^{+2}) is the predominant state of iron with concentrations ranging from 1.34 to 2.38% (average 2.15%), whereas the ferric iron (Fe^{+3}) content varies between 0.88 and 3.18% (average 1.59%) (Loring and Nota 1968). Regionally, the Fe^{+3}/Fe^{+2} ratios increase with decreasing grain size. Ferrous iron contents remain relatively constant and show no relation to the sediment texture and location in the estuary. The distribution of ferric iron, however, is related to the changes in the texture. Low Fe^{+3} values usually occur in the sands and the sandy pelites of the nearshore areas, whereas the higher values are usually associated with the deepwater pelites from the central part of the trough, presumably because of the excess iron in the ferric state in these fine-grained sediments at the sediment–water interface.

Table 14 indicates that only small amounts of iron (1.4–5.32% of the total) are present in the acetic acid soluble fraction of the sediments and are not apparently directly related to sediment texture. The iron in this fraction is presumably derived from the removal of small amounts of iron from the fresh ferromagnesium minerals in the sandy sediments, from ionic exchange positions in the pelitic sediments, and from the carbonate component of the calcarenites and calcipelites. These amounts do not, however, account for the differences in total Fe^{+3}/Fe^{+2} ratios with grain-size changes.

A stronger chemical attack using dithonite ($Na_2S_2O_4$) to remove amorphous and crystalline iron oxides as well as the iron sorbed by sediment particles revealed that 3–16% of the total iron was accounted for with the highest amounts being removed from the pelites and the lowest from the sandy sediments. The chemical evidence which is discussed in detail by Loring and Nota (1968), suggested that the dithonite soluble iron was derived from iron oxide coating on particles deposited from suspension and as a result of the oxidation of undecomposed detrital material at the sediment water interface. Apparently the iron oxide coating is also present on the suspended particles when they are transported into the depositional basin. The oxide coating is apparently retained and additional oxide coatings added to the particles in the well-oxygenated waters in the Gulf. After deposition the retention of the iron in this state and the formation of additonal oxides depends on the length of time the material remains in contact with the oxygenated bottom waters before it is buried.

Manganese is strongly nondetrital in character in the fine sediments. whereas in the sandy sediments it has all the characteristics of a detrital element (Table 14 and 15).

High amounts of manganese (2.4–67.5% of the total) occur in the nondetrital fraction with the highest amounts being derived from the pelites (20–68%) and the lowest from the sandy sediments (<20% of the total). The absolute concentrations of Mn in this fraction ranges from 77 ppm to 10,996 ppm with the lowest concentrations occurring in the nearshore sandy sediments (e.g. Station 113, S-79, Station 57-24-67) and the highest in the pelites (Stations 56, 63, 64, S-62, Station 74, BIO-24-67) in the central parts of the Laurentian Trough system (Fig. 76 and Table 12). The contribution that these fractions make to the total Mn content of any one sediment varies from 13 to 1700 ppm with the highest amounts being contributed to the total Mn content of the pelites and calcipelites and the lowest to the sandy sediments (Table 16). These amounts are similar to those derived from a group of estuary sediments by a selective hydroxyamine-hydrochloride treatment (Loring and Nota 1968).

The results indicate that the proportion of nondetrital Mn in the sediments is one of the most important factors in determining the abundance and regional distribution pattern of total Mn in sediments of the Laurentian Trough system, as shown in Fig. 74. The main sources of nondetrital Mn are exchangeable Mn^{+2}, easily reducible Mn oxides and Mn occluded in the lattices of the carbonate minerals.

The chemical evidence (see Loring and Nota 1968 for details) suggests that not much dissolved manganese is incorporated into the sediments at the sediment–water interface in conjunction with an iron colloid aquate as has been suggested by Goldberg and Arrhenius (1958) for the incorporation of Mn in deepsea clays. This is because the relatively high rate of sedimentation for the pelites limits the time that the active interface is exposed to sea water. In fact, the relatively rapid sedimentation rate appears to have prevented the accumulation of high concentrations of manganese which would lead to the formation of manganese or ferromanganese nodules. Conditions seem to be favorable on the banks where sedimentation rates are much lower but no Mn coated pebbles or coarse sand grains were observed as they have been observed elsewhere under similar conditions (Manheim 1965).

It appears, however, that most of the nondetrital Mn is derived from Mn oxide coatings on particles, and a large part of the Mn in the pelites has entered the depositional basin as oxide films on suspended material. Since detrital minerals cannot lose Mn in oxygenated waters because it is nearly all structurally combined or present as insoluble oxides (Groot 1963), the Mn oxides are apparently retained on the suspended material and at the sediment water interface. Below the interface, however, Mn is probably mobilized in the reduced state under the reducing conditions present below the sediment interface and in the presence of ferrous iron. There is no evidence to suggest that very much Mn is contributed by the detrital carbonate fraction in the sediments as there is no obvious correlation between the amounts of soluble Mn and calcium in the suite of samples studied. Furthermore, the total amounts of manganese in the calcipelites and in the calcarenites are less than those in their noncalcareous equivalents. Consequently, the carbonate fractions appear to influence the distribution of manganese only as a dilutant that depresses the manganese contents of the silicate fraction and the amorphous compounds in relation to the carbonate concentration in the sediments.

From 4 to 43% of the total *magnesium* is located in the nondetrital fraction (see Table 14). The absolute concentration of soluble Mg ranges from 0.44 to 4.39% which represents a contribution of 0.04 to 0.71% to the total magnesium contents of the individual sediments (Table 13). The highest contributions to the total Mg contents are made in the calcareous sediments and the lowest in the noncalcareous sediments. Nondetrital Mg is derived from the particles of limestone and dolomite dissolved by the weak acid attack and Mg removed from the lattices of unstable ferromagnesium minerals, and exchange positions of the clay minerals, particularly chlorite. Since the highest amounts of soluble Mg are usually associated with sediments having the high concentrations of soluble calcium, carbonate material is the main source of Mg, whereas the lower and more variable amounts are found in the noncalcareous sediments which are mainly derived from ferromagnesium minerals, exchange positions, and from the carbonate shell fragments. Because of the variability in the abundance and nature of the carbonate minerals within all the sediments it is difficult to assess the full extent to which magnesium undergoes ionic exchange reactions at the sediment–water interface.

Between 2.8 and 85% of the *calcium* in the group of sediments examined is found in the nondetrital fractions of the sediments. (Table 14). The absolute concentrations of the soluble calcium in this fraction range from 0.76 to 31.65%, which represented a contribution of 0.07–7.85% to the total calcium in the sediments (Tables 12 and 13). Nondetrital calcium is mainly derived from the dissolution of particles of limestone and dolomite found in these sediments although minor amounts may have been contributed to this fraction by shell fragments, from exchange positions within the clay minerals, and from calcium phosphate minerals. Consequently, the distribution of detrital carbonate throughout the central and northeastern part of the Gulf controls the geochemistry of calcium in these areas (Fig. 34, Chap. 5). The dispersal pattern of nondetrital calcium as well as that of detrital calcium carbonate reflect the pattern of glacial erosion and deposition as well as ice-rafting in this area (see Nota and Loring 1964 and Chap. 5).

Organic matter

Easily oxidizable (cold H_2SO_4) organic carbon matter (organic carbon × 1.72) varies from 0.12 to 5.79% with sediment texture and location in the estuary and Gulf, (Fig. 75 and 80).

The lowest concentrations (less than 1%) occur in the sandy sediments occupying the shelves and upper slopes (water depths less than 250 m) of the trough (Fig. 80). Intermediate values (1–2%) occur in the very sandy and sandy pelites on the middle and lower slopes of the main troughs and shelf valleys. A high concentration of organic matter (2-5%) occurs in the deepwater pelites on the floors of the troughs, with the highest concentrations (3–5%) occurring in the most central and deepest areas of the troughs. The

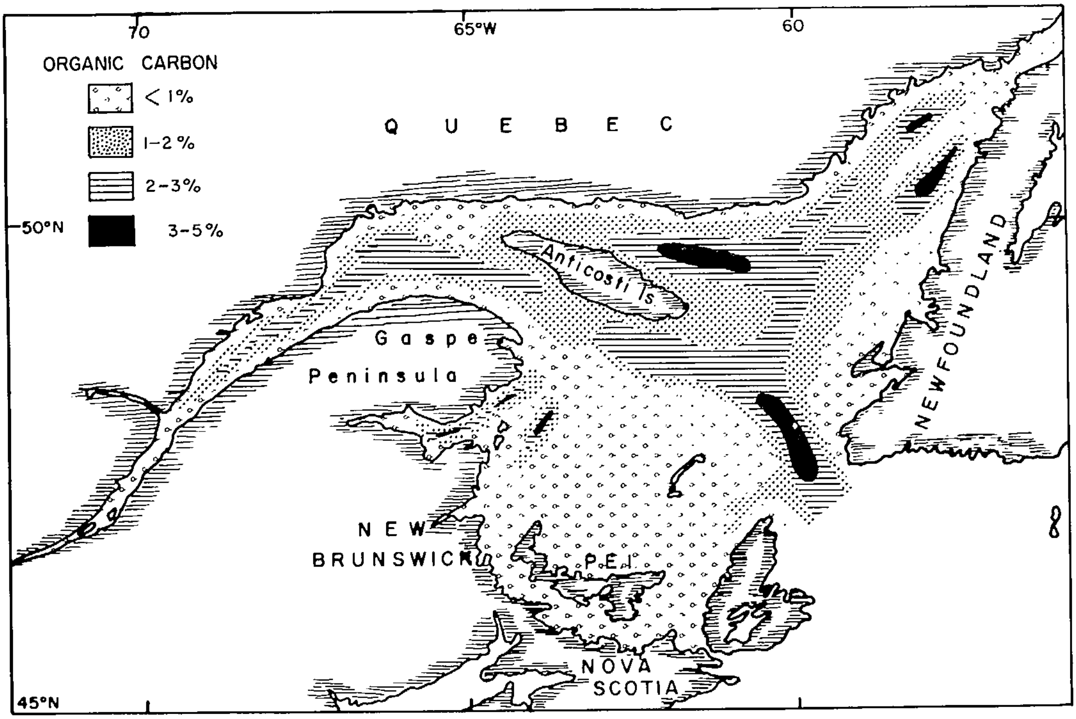

FIG. 80. Regional distribution of organic carbon matter in Gulf of St. Lawrence sediments in percent by weight of dry sample.

high organic anomalies are found: (1) in one of the deep floor depressions of the Laurentian Trough, near Cabot Strait, (2) at the head of the Esquiman Trough and in the Mécatina Trough, (3) in the Chaleur Bay and Shediac troughs and (4) in the Saguenay fjord.

The distribution of organic material is evidently related to sediment texture. Figure 81 shows that the percentage of organic carbon matter increases with increasing clay content of the sediments. Furthermore, analysis of the absolute concentrations in the sand and silt-size grades in a few samples selected from the organic rich areas confirm that the amount of organic carbon matter usually increases with decreasing size grades with the highest concentrations occurring in the clay-size fraction. A notable exception is found in sediments from the Saguenay fjord where organic carbon matter is highest in the sand-size fraction. The reason for this is attributed to the presence of wood fibers in the sand-size fraction of the sample from this area. In the other samples, however, it is evident that the organic content mainly depends on the absolute concentration in the silt- and clay-size fraction, and the contribution that this fraction makes to the total sample.

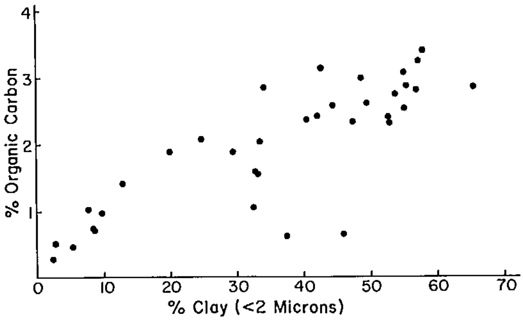

FIG. 81. Relation between percent organic carbon matter and percent clay ($<2\mu$) in surface sediments (35) from the Laurentian Trough system.

The accumulation and retention of organic matter in the sediments apparently depends on the present depositional conditions and the rates of organic productivity. The close relationship between sediment texture and location indicates that the maximum accumulation of organic matter, which has a low settling velocity, occurs from suspension along with recently supplied suspended fine sediments in the quietest areas on the floors of the submarine troughs. Evidently, some areas of the trough floor, because of their central location and distance from the major outflow of the St. Lawrence River, are the most favorable places for the collection of the organic matter, as well as for the slow deposition of the finest sediments. Apparently, other parts of the trough floor near steep slopes and near to the outflow of the St. Lawrence River have higher rates of sediment deposition which tend to dilute the associated organic matter.

Similarly, the low concentration of organic matter along the upper slopes and on the elevated areas of the shelves can be attributed to the more turbulent conditions that prevent the deposition and retention of very much suspended organic as well as fine-grained inorganic material in these areas.

It is difficult to assess the contribution of the *in situ* biomass or rate of organic productivity to the residual organic material in the sediments as very little is known about its abundance and regional distribution. Table 18 compares the average organic matter with the values for other marine sediments. On the average the St. Lawrence pelites have higher organic matter contents than the sediments in the Gulf of Mexico and the Gulf of Paria, but about half the values found in areas with very high organic productivity such as the Baltic Sea and the Gulf of California. The zones of high organic matter within the pelites, however, have comparable values to those found in other areas of higher organic material mentioned above.

Although relatively high rates of organic productivity may occur in some parts of the Gulf, it is not possible to distinguish between the material supplied in suspension from the adjacent land areas and the material produced in situ. At the present, it appears that the physical conditions of sedimentation determine the organic content. For example, a recent study of the distribution of *Clostridium botulinum* Type E in the sediments (Laycock and Loring 1972) shows that *botulinum* spores supplied to the coastal areas from the adjacent land are transported and deposited along with fine-grained inorganic material in certain areas in response to the present current regime. Although this illustrates the supply lines for some of the organic material in the sediments, it does not shed any significant light on the degree of formation of *in situ* organic matter.

TABLE 18. Average organic matter content (percent) and range for various sediments from the Gulf of St. Lawrence and comparison with results derived by other workers.

Location	Organic matter (%) Avg	Organic matter (%) Range
Gulf of California—slope sediments (Van Andel 1964)	6.20	1.37–13.1
Gulf of California—basin sediments (Van Andel 1964)	4.44	0.69– 6.9
Gulf of Paria sediments (Van Andel & Postma 1954)	1.22	0.1 – 1.4
Gulf of Mexico sediments (Trask 1953)	0.63	–
Baltic Sea sediments (Debyser 1961)	4.44	3.98– 8.3
Peru–Chili Trench sediments (Trask 1961)	3.32	0.3 –16.5
Northern Gulf sands (39)	1.14	0.40– 2.06
Southern Gulf (Magdalen Shelf) sands (100)	0.45	0.28– 0.68
Newfoundland Shelf sands (9)	0.23	0.02– 0.52
Calcarenites (27)	1.17	0.39– 2.59
Pelites (40)	2.32	0.46– 5.79
Calcipelites (46)	2.33	0.65– 4.27

Future studies may in fact reveal that there is little relationship between sites of high productivity and areas in which high amounts of organic matter are preserved. It may well be that areas containing the least amounts of organic material, such as the shelves, are the areas in which the highest organic productivity is taking place, but because of the physical and chemical conditions, the environment is not suited for the preservation of the organic matter produced *in situ*.

9 Depositional history

The geological, morphological, and sedimentological data indicate that the region has evolved through a complicated sequence of events.

The purpose of this chapter is to present the general conclusions that may be reached on the succession of depositional events and the present sedimentological conditions in the Gulf of St. Lawrence. Although our data mainly relate to the late-glacial (late-Wisconsin) and Recent depositional history of the area, we can also recognize some of the major features of earlier stages in its development. A synthesis of this data and its interpretation are summarized in the following text.

The main stages in the development of the region are:

1, The preglacial morphological development which was mainly determined by the structure and the lithological weaknesses of the bedrock in the Gulf (Chap. 2 and 4).

2, Modification of the preglacial landscape by repeated glaciations during the Pleistocene which particularly resulted in the formation of the trough-shaped submarine valleys (Chap. 4).

3, Late-glacial erosion and deposition which is still mainly responsible for a number of features of the present surface morphology in many parts of the region (Chap. 4 and 5).

4, Submergence of part of the area by postglacial rises in sea level which resulted in some modification of the glacial morphology and sediments on the upper slopes of the troughs and on adjacent shelves (Chap. 4, 5, and 6).

5, Present depositional conditions that are modifying the relict glacial morphology and its sediments so that an equilibrium with the present environmental conditions may eventually be established (Chap. 5).

There is considerable evidence to indicate that the St. Lawrence Lowland adjacent to the Canadian Shield has existed as a depression extending from the east coast into the interior for the greater parts of geological time (Chap. 2). In periods of continental uplift, it is probable that this lowland would have always been occupied by river systems which would have received the drainage from the adjacent highlands (see Chap. 2 and Ambrose 1964).

The presence in the region of a preglacial landscape developed through mainly fluvial erosional cycles most probably under arid or semi-arid climatic conditions is indicated by the well-developed cuesta topography with its accompanying drainage system in the northern and southern parts of the Gulf, and by the presence of the well-established major Laurentian valley system which apparently developed along the lines of structural (e.g. Logan's line) and lithological weaknesses in the bedrock. Since there is no apparent evidence for a previous cover of Cretaceous and Tertiary sediments, this landscape as we now recognize it was most likely formed during the dissection of a Cretaceous planation surface in Tertiary times.

During the Pleistocene Epoch, the whole area was glaciated and the preglacial drainage valleys were modified into glacial troughs by the ice which repeatedly eroded them and filled them with sediments (Chap. 2 and 4). Erosion by these ice masses, strongly controlled by the preglacial bedrock topography, resulted in the widening and straightening of the valley walls and deepening of their floors. Uneven deposition of glacial sediments produced an irregular glacial landscape over most of the Gulf floor. Additional morphological features such as moraines, and thick wedges of glaciomarine sediments buried by glacial tills were also brought about by the advance and retreat of the Laurentide ice sheet and by the readvance of local ice masses when the Laurentide ice had almost withdrawn from the Gulf.

Although glacial deposits belonging to earlier glaciations (>40,000 years ago) have been reported on land in the St. Lawrence Lowlands (Gadd 1960) and in Cape Breton (Mott and Prest 1967; Newman 1971), no deposits older than late-Wisconsin (>20,000 years BP) have been identified in the Gulf; any earlier deposits seem to have been lost. The presence of only a relatively thin layer of unconsolidated sediments on the floor of the Laurentian Trough and its tributary valleys (Chap. 4) is probably due to the removal of some or all of these old glacial and interglacial deposits during the last major glaciation. In fact, the accumulation of a thick layer of unconsolidated Cenozoic sediments at the foot of the continental slope discovered by Emery et al. (1970) below the mouth of the Laurentian Trough may represent in part the dumping ground for some of these sediments bulldozed out of the trough during the preceding glaciations.

Depositional Conditions

Laurentian Trough system

A number of features in the region record the depositional history of the late-glacial period in the Laurentian Trough and its tributary valleys. These features include: (1) the presence of the thick wedge of unconsolidated sediment consisting of coalescing fans along the edge of the Magdalen Shelf; (2) unmodified till deposits on the slopes and floor of the troughs which have a characteristic hummocky topography. In some places, these deposits occur directly beneath a cover of postglacial pelites; (3) the occurrence of relict pelites which have been deposited in late-glacial times.

The fan deposits adjacent to the Magdalen Shelf consist of a thick layer of homogeneous sediments overlain by a till and, in at least one place, underlain by another till (see Chap. 4, Chart 5). The lithological details of this deposit are illustrated by core 14 in Fig. 42 and 43. This core, which is 503 cm long, contains a shell horizon in the homogeneous sediments immediately below the till. A 5-g sample of the shell material (whole and fragments of *Macoma* sp.) dated by the Geological Survey of Canada (G.S.C. date 1528) yielded a date of 10,200 ± 440 years BP.

The Carbon-14 date allows certain deductions to be made on the sequence of events in the Gulf in relation to the subdivision of late-glacial times elsewhere. The date correlates approximately with the Younger Dryas stage of the European stratigraphers (Van der Hammen and Vogel 1966), which in Europe was a cold phase with a subarctic climate and readvances of ice sheets. It also correlates with the date of a late-glacial readvance referred to as the St. Narcisse readvance which overode Champlain Sea sediments in the eastern part of the St. Lawrence Lowlands (LaSalle 1966).

The sedimentological and paleontological data indicate that the shell horizon and the deposits beneath were formed by sedimentation in marginal marine waters under a cover of floating ice and fairly close to the front of a live advancing or retreating ice margin standing in water. This period of glaciomarine sedimentation was most likely fairly rapid along the edge of the Magdalen Shelf and apparently took place prior to the deposition of the dated shell horizon but not later than 14,000 years BP because of the presence of late-Wisconsin Laurentide ice in the Laurentian Trough (Prest 1970). The stratigraphic position of the top of this deposit may then be placed, in European terminology in the Alleröd Stage, which was a temperate interstadial immediately before the Younger Dryas, whereas the lower levels of the deposit may relate to pre-Alleröd times (Table 19).

In addition, a seismic profile of part of this deposit (Chart 5, Fig. 24 and 82) shows that the glaciomarine sediments (B, Fig. 82) just before (3 naut. miles or 5.5 km) they wedge out against the shelf, overlie a sequence of unconsolidated sediments with apparent foreset bedding (A, Fig. 82) which in turn eventually terminates at the base of a morainal ridge. Although the stratification may be due to ice pushing, these deltaic-like deposits may also be due to the deposition of sediments during an early warm phase of the Alleröd when the ice fronts were farther from the Shelf. If so, the glaciomarine sediments covering the deltaic deposit may be the result of increased sediment deposition as the ice fronts began to advance in the beginning of the Younger Dryas.

The reddish-brown till above the glaciomarine deposits (C, Fig. 82) indicates that there was a significant glacial readvance over the shelf edge and into the Laurentian Trough as far as the north slope of the trough. This readvance was most likely from the southwest because of the petrographical characteristics of the till (see Chap. 5). Although the dated horizon indicates that the time of the readvance might be any time <10,200 years BP, *it is concluded that this readvance should be correlated with the St. Narcisse readvance of LaSalle and others in the Maritime region in Younger Dryas time because no evidence has been found for a younger glacial readvance in the entire region.*

The depositional conditions for the tills, which vary in thickness from 1 to 30 m, are reflected

TABLE 19. Summary of late-glacial and postglacial events in the Gulf of St. Lawrence

	Time	Glacial history in the Gulf of St. Lawrence region	Characteristic trough deposit(s)	Major depositional agent(s)	Planktonic Foraminifera		Related stages in St. Lawrence Lowlands	Years BP approximately
Holocene	Postglacial	Final decay of ice masses Postglacial transgression	Deepwater pelites	Marine water with sporadic ice rafting	Arctic-subarctic (coastal and oceanic waters)		Establishment of the present day St. Lawrence drainage system	9500 years–present 8660 ± 280 years BP (core 35)
Pleistocene	Late-glacial[a] Younger Dryas	Ice readvances from local highland centers (valley and Piedmont glaciers) and development of extensive shelf ice (grounded and floating) over most of the Gulf	Submarine tills (subglacial, mainly reddish-brown and grey calcareous)	Ice Terrestrial, grounded, and floating shelf ice in a marine environment	Arctic (coastal and oceanic waters)	Champlain Sea Episode	St. Narcisse readvance	10,800–10,200 years BP (LaSalle 1966) < 10,220 ± 440 years BP (core 14)
	Alleröd: Late Alleröd	Deterioration of climate: regrowth of local ice caps on land and the development of shelf and pack ice over the Gulf	Glaciomarine sandy–very sandy pelites with rock fragments	Ice Ice rafting, icebergs, floating shelf ice in a marine-meltwater environment	Subarctic-northern temperate-northern subtropical (coastal-oceanic waters)		Ice recession to north shore of St. Lawrence River	11,800–10,800 years BP (Elson 1969)
	Middle & Early Alleröd	Ice recession to and beyond the shores of the Gulf. Dissected ice mass on P.E.I. and southern Gulf. Semi-isolation of independent ice masses on adjacent highlands	Time and type of deposition not precisely established, probably includes: deltaic glacio-fluvial outwash deposits. Relict pelites (inner St. Lawrence Estuary)	Ice-meltwater Fresh water			Initiation of Champlain Sea Episode	12,700-11,800 years BP
	Pre-Alleröd	Initial deglaciation of the Gulf region with the withdrawal of ice up the Laurentian Trough from Cabot Strait to Saguenay River. Initial transgression	Not known except for glacial deposits above bedrock surfaces (seismic profiles)				Ice recession to or behind St. Antonin Moraine and Highland Front Moraine	14,500–12,700 years BP (Prest 1970)

[a] Subdivision of late-glacial times according to European stratigraphy (Van der Hammen and Vogel 1966), North American equivalents described by LaSalle (1966).

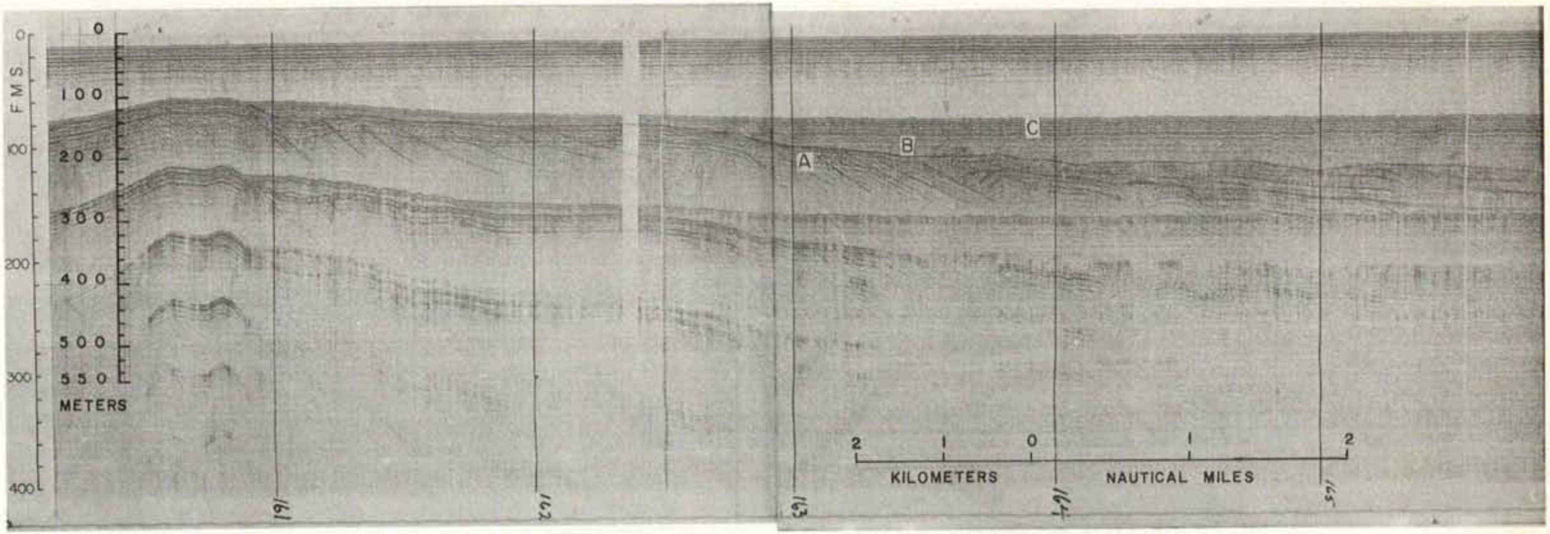

FIG. 82. Reproduction of seismic record (seismic profile 3, Chart 5, in pocket) from the edge of the Magdalen Shelf showing (A) deltaic-like forset beds overlain by (B) glaciomarine sediments which have been covered by (C) till.

by the lithological and foraminiferal characteristics of the sediments in Core 16 (BIO-24-67) obtained at a depth of 348 m near the distal end of the fan deposit (see Fig. 42 and 43). The lithological sequence consists of a grey sandy pelite (0–20 cm) and a brownish-red till (20–563 cm)

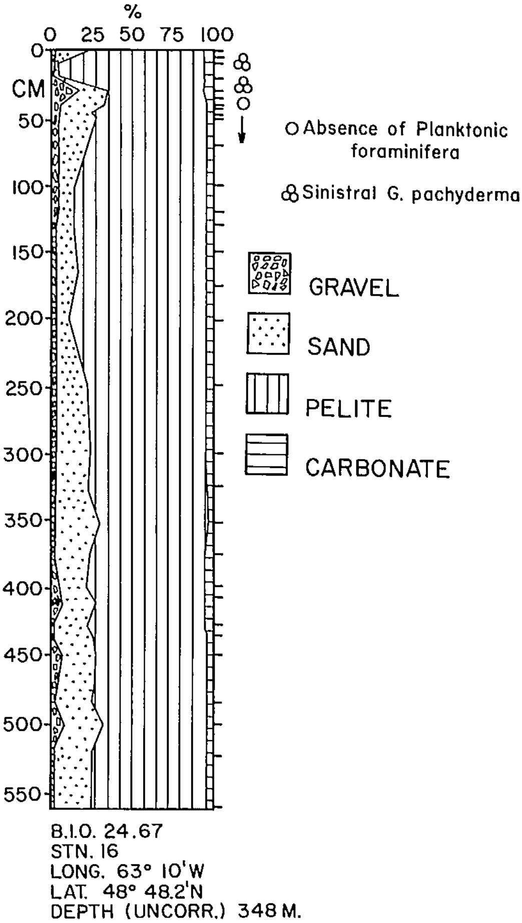

FIG. 83. Lithology of Core 16 (BIO-24-67) showing variation in the gravel, sand, pelite, and carbonate composition in relation to changes in planktonic foraminifera. For core location see Fig. 41.

Foraminiferal data (supplied by G. Vilks, Bedford Institute, Dartmouth, N.S.) from this core and others provides additional evidence of environmental changes in the region during the accumulation of these and other core sediments. The foraminiferal interpretation is based mainly on the occurrence, nature, and abundance of planktonic foraminifera. The presence of abundant planktonics is usually regarded as indicating deposition in an oceanic environment (undiluted marine waters), whereas the scarcity or absence of planktonic species in sediments is usually regarded as deposition in a marginal marine environment (diluted marine waters) usually with rapid sedimentation rates and/or a total thick ice cover that does not permit their existence (Ericson et al. 1964; Vilks 1970).

Variation in the nature and abundance of several species of planktonic foraminifera and the coiling direction of one of these (*G. pachyderma*), are considered to reflect changes in the water temperatures due to changes in the nature and circulation pattern of the water masses, as well as climatic conditions that were prevalent during the accumulation of the sediments. Briefly, sinistral (left coiling) *Globigerina pachyderma*, a high arctic species, is considered to reflect deposition from cold Labrador current water (Arctic water); the presence of dextral (right coiling) *G. pachyderma*, *G. bulloides*, *G. inflata*, and *G. quinqueloba* is usually considered to reflect deposition from warmer North Atlantic slope waters of the subarctic and northern subtropical regions (Bé et al. 1971). Under present environmental conditions (Chap. 3) the surface sediments in the Gulf contain sinistral *G. pachyderma* except in the Cabot Strait area where dextral *G. pachyderma* and *G. bulloides* also occur. Hence, increase of North Atlantic slope water species relative to sinistral *G. pachyderma* represents the effect of increasing water temperature, and vice versa.

In Core 16, (Fig. 83) there are no planktonic foraminifera between the 560 cm (bottom) and 40 cm in the till, and at some intervals only a few benthonics are present. The conclusion is that this till resulted largely from direct and probably relatively rapid deposition from ice, in a marginal marine environment. The top 20 cm of the grey sandy pelite is characterized by the presence of a few Arctic planktonic foraminifera (sinistral *G. pachyderma*) and an assemblage of benthonics that reflects the present depositional conditions.

In summary, the lithological record from the coalescing fans is considered to represent (see also seismic profiles): (a) Alleröd deposits (viz., delta-like deposits with glaciomarine sediments on top) which reflect the gradual deterioration of the climate, preceding the Younger Dryas readvance, (equivalent to the St. Narcisse readvance); (b) the presence of a shell horizon which has been dated as 10,220 ± 440 years BP; and (c) the deposition of a till cover in Younger Dryas time that represents direct deposition from ice during a glacial readvance in this area. In some places this late-glacial sequence has a veneer of postglacial (Holocene) recent marine pelites.

A sequence of glaciomarine till, and postglacial sediments is also found in cores from other parts of the Gulf (see Chap. 5, Fig. 42). Since the number of cores is limited it should be emphasized that only the major features of the depositional history in the remainder of the Gulf have been recognized. These features are illustrated by the lithology and paleontology of three cores viz., cores no. 88, 36, and 115, Fig. 84 (locations shown in Fig. 41). In Core 88, obtained south of Banc Beaugé, the lithological sequence is (1) a calcareous gravelly sandy pelite from 1060 cm (bottom) to about 740 cm; (2) a calcareous very sandy, to (very) gravelly pelite (till) interval, between about 740 cm and 540 cm; (3) a calcareous sandy (gravelly) pelite between 540 and 450 cm which probably forms a transition zone to (4) a calcareous pelite from 450 cm to the present surface of the sea floor.

Foraminiferal data reveal the presence of warmwater (North Atlantic slopewater) planktonic species (*G. bulloides*, *G. quinqueloba*) in the interval between 1060 and 840 cm; but at a depth of 790 cm sinistral *G. pachyderma* occurs and no warmwater planktonic foraminifera are found. Most probably, this indicates that cooling off in the area began in the time preceding the till deposit found between about 740 and 540 cm. The till deposit is characterized by the absence of planktonic and scarcity of benthonic foraminifera, except at 640 cm where sinistral *G. pachyderma* are found. This implies that rapid sedimentation (with some kind of dumping from floating ice) has been characteristic for this depositional site in a marginal marine environment with perhaps a continual ice cover and restricted oceanic influence.

The transitional zone (540–450 cm) contains a few planktonic forams (sinistral *G. pachyderma*) and a few benthonics at 540 cm and 515 cm, but planktonic foraminifera are absent and benthonics scarce in the remainder of the zone. In the sequence between 450 cm and the top of the core, a few sinistral *G. pachyderma* are present between 450 and 50 cm; above 50 cm, sinistral *G. pachyderma* become more abundant and a few dextral *G. pachyderma* also appear in the core. Consequently, it is inferred that the waters became more open marine in nature as these sediments accumulated and that a warming trend in the waters that were initially cold occurred during the accumulation of the last 50 cm of sediments. The interpretation of this sequence is that (a) the lower levels (to about 790 cm) represent glaciomarine Alleröd deposits; (b) the till (740–540 cm) represents deposition during a Younger Dryas glacial readvance in this part of the Gulf; (c) the transitional zone represents the retreat of the ice; and (d) the sequence above 450 cm represents postglacial (Holocene) deposition. Although the Champlain Sea might have extended through the beginning of the Holocene (Preboreal), no evidence for such sediments has been found in this core.

The coarse fraction analysis reveals throughout the core section that the petrographical components referred to as the Laurentian suite in Chapter 7 distinctly indicate a northern source (mainly Canadian Shield) for the sand- and gravel-size material. *This means that a Younger Dryas readvance also came from a northern direction.* Once again, it should be emphasized, however, that this interpretation is tentative and concerns only the major trends in the depositional sequence; further, that a detailed study of the faunal content in these sediments will undoubtedly reveal a more complicated record of the environmental history, which will certainly have been greatly influenced by a varied sequence in oceanographic conditions in the area.

Compared to the core section of Station 88, Core 36 has a reduced sequence. In this case, till deposits occur from 350 cm (bottom) to about 260 cm, and the transitional zone occurs between about 260 and 220 cm. The upper 220 cm are considered to represent postglacial sediments. The till deposit (350–260 cm) is considered to represent deposition of material from a floating ice sheet during the Younger Dryas readvance. The coarse fraction analysis of the till in Core 36 reveals that sand- and gravel-size material is similar to that in Core 88 and is dominantly angular crystalline material of northern (mainly Canadian Shield) origin (See Chap. 7). Some crystalline limestone and dolomite particles, most likely from Anticosti Island and the North Shore, were also observed in the coarse fraction. As was observed in Core 88, the lack of reddish-brown sandstone particles in the till of Core 36 excludes a southern source for the till.

In general, the foraminiferal sequence throughout the core can be correlated with that of Core 88. In the till horizon (350–260 cm) Arctic marine planktonic foraminifera (*G. pachyderma*) are present in abundance in the calcareous (very) sandy gravelly pelite horizons at 350–340 cm, and at 275 cm, and in the sandy pelite interval at 300 cm, but North Atlantic slopewater planktonic species also occur at 320 cm and both

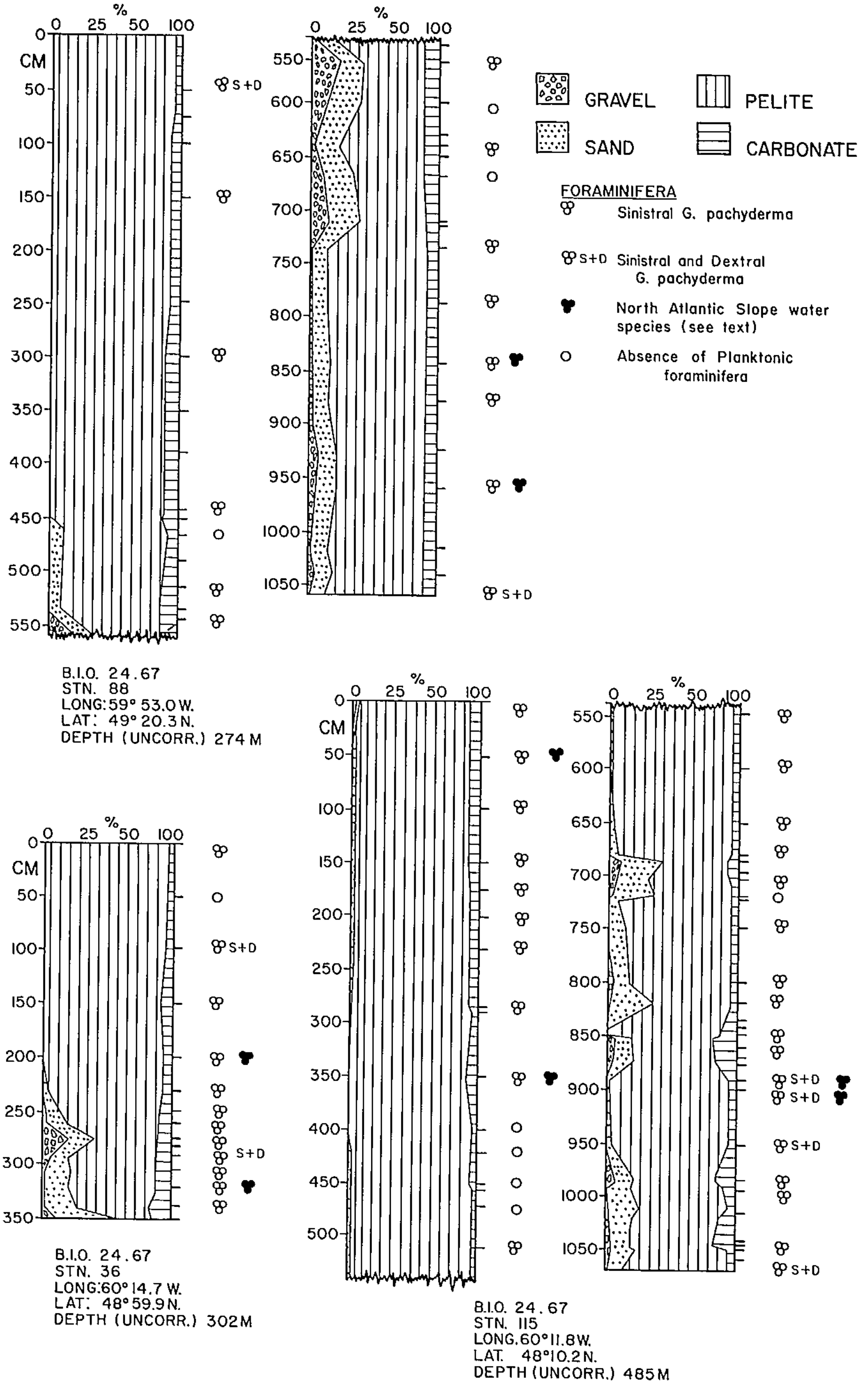

FIG. 84. Lithology of cores 88, 36, and 115 (BI0-24-67) showing variation in the gravel, sand, pelite, and carbonate composition in relation to changes in planktonic foraminifera. For core locations see Fig. 41.

dextral and sinistral *G. pachyderma* occur in abundance at 290 cm. The alternation of Arctic planktonics with those usually associated with warmer North Atlantic slope waters suggests that there were temperature changes in marine waters during the deposition of the till such as might occur with an oscillation in a floating ice margin due to the incursion of warmer waters. Some evidence for these changes in the ice margin can be deduced from the fact that the horizons rich in North Atlantic species contain little gravel (<5%), whereas those richest in Arctic planktonics contain up to 20% gravel. The transitional zone (260–220 cm) is characterized by a cold water sinistral *G. pachyderma* and a few benthonic forams. In contrast, the postglacial sequence (220–0 cm) shows an alteration between horizons rich in Arctic planktonics (150 cm) and those rich in mixed Arctic and North Atlantic slopewater species (200 and 100 cm). Above 100 cm no planktonic foraminifera have been found except in the surface layer. This sequence apparently reflects an alternation of cold and warmer marine waters during the accumulation of the first 120 cm of the postglacial sequence as the oceanographic conditions adjusted to changing climatic regimes until the present day conditions were established during the deposition of the last 100 cm of sediment. It should be noted that sediments at this location (Fig. 41) would be sensitive to any changes in the influx of Atlantic waters through Cabot Strait and influx of Labrador current waters into the Gulf through the Strait of Belle Isle. (see Chap. 3, Fig. 12 and 13).

The core from Station 115 (Fig. 42 and 84) has characteristics which differentiate it from the core sections from Stations 88 and 36. The core was obtained some 50 naut. miles to the south of Core 36 in the vicinity of Cabot Strait and this location undoubtedly influenced its depositional sequence.

In general, the bottom part of the core, from 1060 cm to about 680 cm represents a well-developed sequence of till deposits, whereas the remaining sediments represent the postglacial sequence. The brick-red horizons within the till sequence (see Chap. 5) are very striking. The coarse fraction analysis of the brick-red layers as well as of the other till material revealed the predominance of detritus from brownish-red colored sandstone, similar in lithology to those which outcrop in many places on the Magdalen Shelf (Fig. 22). Needham et al. (1969) isolated Upper Carboniferous palynomorphs from similar horizons in a core from Cabot Strait. They considered the Carboniferous rocks on the Magdalen Shelf to be one of the source areas for the brownish-red to brick-red sediments in their cores as did Conolly et al. (1967). Although the present authors do not exclude such a source area, the relatively high carbonate content of the red sandstone gravels particularly of the brick-red horizons (up to 18% carbonates) should not be neglected. The present study has revealed that the sediments of the Magdalen Shelf are low in carbonate, whereas the area around St. George's Bay (southwestern Newfoundland) is characterized by the presence of calcareous brownish-red Permo-Carboniferous sandstones as well as extensive outcrops of reddish and grey limestone (Riley 1962). Therefore, St. George's Bay should also be considered as a likely source area for the reddish-brown till in this core.

The four well-developed till layers (intervals roughly between 1060 and 960; 890 and 850; 840 and 800; 720 and 680 cm, respectively), in general, have the foraminiferal characteristics observed in the tills from the other cores: the presence of a few Arctic planktonics and usually only a few benthonics. These data suggest rapid deposition of tills in a marginal marine environment with an extensive ice cover. In terms of the model of glacial marine sedimentation, the authors refer to the marginal zone of the floating ice as discussed by Carey and Ahmad 1960, and Aalto 1971. Within the till sequence, the interval between about 950 and 900 cm contains some North Atlantic slopewater species similar to those described for Core 36 and a relatively rich mixed benthonic fauna (Fig. 84). These species probably reflect deposition during an oscillation in the ice margin due to an incursion of warmer oceanic water into the Gulf through Cabot Strait, an incursion that apparently extended at least to the vicinity of Core 36. The till sequence between 1060 (bottom of core) and about 680 cm on the whole, however, is considered to correlate with the Younger Dryas observed in other parts of the region. It is apparent from the previous discussions that the sequence above the till (from 680 up to surface) represents Holocene deposition.

Between 680 and 350 cm, however, fluctuations in the foraminiferal content have been observed which are related to an alternating sequence of various environmental stages (680–420 cm cold; 420–400 cm discontinuity; 350 cm warmer) before the present day oceanic conditions were achieved. The foraminiferal record between 350 cm and the surface shows an increase of sinistral *G. pachyderma* towards the top of the core along with the occurrence of a few dextral *G. pachyderma* at about 50 cm. This sequence is similar to the upper part of Core 88 and probably reflects the warming trend in marine waters as the present-day oceanographic conditions were reached during the deposition of the last 50 cm of sediments at this site. It is of interest to note that Needham et al. (1969) isolated various spores and pollen types from reddish-brown glaciomarine sediments, and the grey postglacial recent marine sediments from a 10 m core (V16–240) obtained in Cabot Strait. In this core, which had a similar lithological sequence to that described for Core 115, the pollen and spores in the reddish-brown glacial sediment was made up almost entirely (96%) of Upper Carboniferous palynomorphs and a few percent (~4%) non-arboreal pollen (NAP). In the brown transitional sediment (430 cm below the surface) Upper Carboniferous palynomorphs made up 27% of the identified grains with the remainder being NAP (17%) and arboreal (AB) pollen (55%) with *Pinus* as the dominant species (24%). In contrast, the postglacial grey pelites about 200 cm below the surface contained no Upper Carboniferous palynomorphs, 17% NAP, and 83% aboreal pollen which was dominated by *Pinus* (58%). These changes in the palynology of the sediments reflect the Permo-Carboniferous rock sources of the brownish-red glacial sediments and support the planktonic evidence for climatic changes during the accumulation of the sediments. In fact, the changes in the non-arboreal pollen and arboreal pollen may also reflect the sudden amelioration of the climate in mid-postglacial time as recorded by palynologists in the *Pinus* maximum in some parts of the adjacent land areas (Livingstone 1968).

The relict pelites (Map Unit 1b, Chap. 5) that occur on the floor of the St. Lawrence River below Quebec City are believed to have been deposited in late-glacial times. Their high clay content, and granulometry support the view that there was progressive sorting during their deposition from suspension in a freshwater environment (Nota and Loring 1964). Such conditions prevailed during the initiation of the Champlain Sea episode when the retreating ice masses were still separating meltwater lakes from the marine water flooding up the St. Lawrence Estuary and River or finally at the last stage in the Champlain Sea episode when the marine water was replaced by the fresh waters as the crustal rebound exceeded the eustatic rise in sea level. Our data are not sufficient to determine the exact time of their deposition, but provide enough evidence to classify them as being deposited during a freshwater phase of the Champlain Sea episode. Pelites, having similar characteristics to the relict pelites, have also been found in the Laurentian Trough near the bottom of Core 109 (BIO–24–67, Fig. 42). Consequently, they may represent the deposition of suspended fine-grained material in an environment that contained a high proportion of meltwater, early in postglacial times.

Magdalen Shelf

The glacial events in the Laurentian Trough and its tributary valleys were interconnected with those on the Magdalen Shelf. In this region, the situation between the beginning of regional deglaciation and the Younger Dryas readvance appears to be one in which ice from the local highland centers still remained on or near the coasts. During late-glacial time a partly dissected ice mass apparently remained over most of central and eastern Prince Edward Island at least on the adjacent shelf, as far north as Bradelle Bank, and perhaps on the Magdalen Islands. On Prince Edward Island the presence of a late-glacial ice mass which had localized movements is reflected by the presence of extensive glacio-fluvial deposits and an interconnected system of eskers (Prest 1970). On the Magdalen Shelf the acoustical and sampling data relating to this situation include the disorganized knob and basin topography north of Prince Edward Island (Fig. 32), the presence of tunnel valleys, glaciofluvial deposits, and the poorly sorted unmodified relict sediments to the north of Prince Edward Island (see Chap. 4 and 5). The margin of this ice at one time in its recessional stage is probably marked by the tunnel valleys (Chap. 4), and their orientation suggests that the ice stood on the shelf with an arced front facing east, north, and west.

This late ice mass apparently developed as the ice withdrew from the outer shelf and the sea began to invade the shelf initially along the axis of the Cape Breton and Shediac troughs, and separated the ice on the central shelf from ice on the adjacent coasts. As the ice retreated from the central shelf towards Prince Edward Island, marine waters spilled over the lower parts of the central shelf, perhaps to a depth of about 60 m below present sea level, and initiated the formation of the well-developed submarine terrace, with local areas of well-sorted sands and bedrock pebbles, around the Magdalen Islands. In the Cape Breton Trough, the initial rise in sea level was apparently rapid because there was only slight modification of the surface till on the drumlin-like feature in the trough off Cheticamp, Nova Scotia.

During the retreat of the ice, and before and during the initial transgression, it is likely that meltwater sediments were carried out of the receding ice margin, transported along the course of the shelf valleys, and deposited over the shelf edge to initiate the formation of the large deposit of coalescing fans of glaciomarine sediments. Along the last retreating ice front, meltwater streams apparently formed the tunnel valleys by eroding the soft sandstone bedrock in the Eastern Bradelle Trough and between Prince Edward Island and the Magdalen Islands, and deposited glaciofluvial sands and gravels in the Cape Breton Trough to the east.

Although Prest (1970) considered that the ice mass astride Prince Edward Island and the adjacent shelf had disappeared by 12,500 years BP, it seems more likely that some ice remained later owing to the colder climate in the later Alleröd and Younger Dryas times, expanded, and then melted in situ after these periods.

In late Alleröd and Younger Dryas times the local highland ice on the Gaspé Peninsula apparently expanded in the form of valley and piedmont glaciers and spread north and west to the southern border of the Laurentian Trough, as is indicated by the transport of erratic boulders (McGerrigle 1952), as well as eastward toward Orphan Bank and the edge of the shelf. It is apparent that the local ice mass on the shelf also expanded toward the shelf edge at this time. As the ice approached the edge, detritus, and debris washed out from the front of advancing ice and from floating and grounded shelf ice, were deposited in the front of the western shelf valleys in a marginal marine environment to form the remainder of the thick layer of glaciomarine sediments. Eventually (< 10,200 years BP) the ice advanced over the edge and into the trough. This resulted in the uneven deposition of submarine tills over the glaciomarine sediments. Similar readvances from the north shore of the Gulf and from western Newfoundland also appear to have occurred, as demonstrated by the stratigraphy of the cores. At the maximum of this readvance, ice filled these parts of the Laurentian Trough and the heads of the tributary valleys. The deeper areas of the central and southeastern Gulf were most likely covered by floating ice sheets, which eventually deposited the thin tills interbedded with glaciomarine sediments, during oscillations in the margin of the ice sheets. Although data for this readvance are scanty on the land, Grant (1970a, b) reports local westerly readvances of glaciers from the highlands of Newfoundland, through the fjord valleys of western Newfoundland, into the sea at about 10,900–10,100 years BP. There is no definite evidence of a readvance into the Cape Breton Trough (Newman 1971). Hickox (1962), on the basis of a dated peat horizon of 10,710 ± 210 years BP between two tills from Port Hood Island, Cape Breton, suggested, however, that a younger till was deposited by ice readvancing from a center located on the highlands of Cape Breton, and perhaps was also contemporaneous with a local readvance in western Nova Scotia.

Late-Glacial and Postglacial Changes in Sea Level

The relative sea level in late-glacial time is not known with any certainty, but evidence for a fall in sea level preceding the Younger Dryas readvance has been found in the St. Lawrence lowlands by LaSalle (1966) and Elson (1969b). Grant (1970) suggests that sea level had fallen about 18–35 m prior to the highland readvance in northwestern Newfoundland. Immediately preceding the Younger Dryas, the dated shell horizon and the foraminiferal assemblages on the edge of the Laurentian Trough apparently accumulated in a marginal marine environment comparable to an inner shelf environment of today. Acoustical data from the same deposit indicates that the highest depositional level of the glaciomarine sediments now rests about 60 fath (110 m) below present sea level. At this period, the world-wide sea level is believed to have been about 60 m below the present sea level (Milliman and Emery 1968). Kranck (1972) reports a possible level about 35–45 m lower than present at the eastern end of the Northumberland Strait at this time. Consequently, sea level in parts of the shelf at this time was probably somewhere between 110 and 35 m below the present level, perhaps 60 m; the approximate level of the Magdalen terrace.

The pattern of submergence and re-emergence of the land adjacent to the Gulf is more complicated than was suggested by Elson (1969a, b) and Prest (1970) because of the lack of data on the differential effects of late ice masses on crustal rebound, the eustatic rises in sea levels, and the apparent variation in sea levels before, during, and after the Younger Dryas readvances. Although the details of these sea level changes are beyond the scope of this work, the following succession of events is recognized: (1) initial transgression in those regions that first became ice free; (2) regression following the isostatic uplifting of the land, and preceding the Younger Dryas readvances; (3) a new transgression in the border zone of the late ice and adjacent areas, a transgression that was eustatic and is referred to as the *postglacial transgression*; and (4) a final regression caused by the decreasing rates in eustatic rise in sea level while the isostatic land uplifting continued. Sea levels have apparently been rising along the east coast for the last 5000 years because of subsidence of the crust (Grant 1970c).

The data presented in Chap. 4 and 5 pertains to several features related to postglacial rises in sea level. Sediment cores from the lower slopes of the troughs and on the floors, show that the tills deposited in Younger Dryas times are directly overlain by fine-grained deepwater pelites deposited from suspension which contain only small amounts (<5%) of coarse-grained material. This material could have been derived only from the adjacent shorelines by sporadic ice-rafting (see Chap. 7). Since these sediments must have been laid down in deep ice-free water under marine conditions, they represent sediments deposited during and after the postglacial rise in sea level. The variation of foraminiferal content and composition in them reflect the changing environmental (oceanographic) conditions during their deposition.

Additional information on the late-glacial and Holocene events is also recorded in one of the cores from the Magdalen Shelf valleys by the stratigraphy of Core 35 (BIO-13-66), obtained between till ridges on the floor of the Shediac Trough at a depth of 95 m (52 fath). This core which was 560 cm long penetrated through a veneer of light olive-grey sandy pelite (0–38 cm), a pelite layer (38- ~180 cm), and into reddish-brown gravelly pelitic sands and very sandy pelite tills containing a distinct shell horizon below the pelite layers (see Fig. 41, 42, and 85).

The foraminiferal content from the top to the bottom was homogeneous; there were no planktonic foraminifera and only a few benthonic species of a similar nature to those found under present day shelf conditions.

The shell horizon, however, yielded some important information. About 10 g of shell material was obtained from the 200–220-cm interval and was composed of whole shells of *Macoma calcarea* and fragments of *Balanus* (sp.) and *Hemithiris psittacea* (identified by Dr F. Wagner, Bedford Institute of Oceanography). A 4-g sample of *M. calcarea* yielded a Carbon^{14} date (G.S.C. Date 1608) of 8,660 ± 240 years BP.

The lithology and dated shell horizons allow certain deductions to be made on the depositional sequence in the Shediac Valley that might also be applicable to the events interpreted from the cores described previously from other parts of the Gulf.

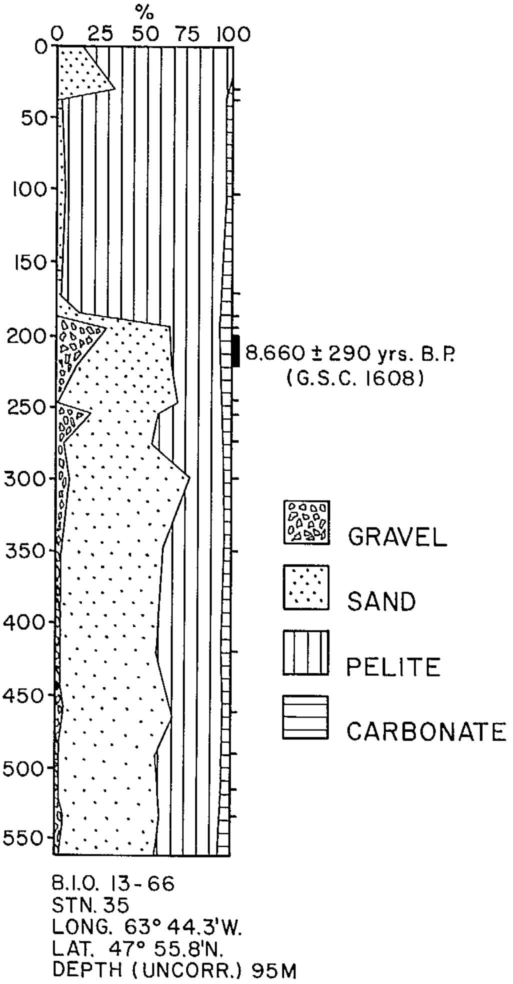

FIG. 85. Lithology of Core 35 (BIO-13-66) showing variation in the gravel, sand, pelite and carbonate composition, as well as the location of the dated shell horizon. For core location see Fig. 41.

The brownish-red till-like sediments just beneath the shell horizon have the lithological appearance of being slightly reworked by marine processes, most likely during the initial postglacial transgression. These sediments occur on the valley floor at an elevation lower than a lag gravel zone on the valley side that marks the zone of intensive marine reworking of glacial till. The till depth (97 m), lack of strong reworking between 97 and 60 m, and the fairly sharp transition to intensely reworked glacial till suggest that the initial transgression was rapid between 97 and 60 m. The absence of marine planktonic foraminifera in these sediments also suggests that they were modified in a marginal (coastal) marine environment. The dated shell horizon implies that a change in the depositional pattern occurred about 8700 years BP. It also implies that the Younger Dryas advance and retreat referred to previously must have occurred in this area between 10,220 years BP, (bottom of till, Core 14) and 8700 years BP (top of till, Core 35) and that the retreat was followed by the postglacial marine transgression.

Although the pelite–till contact could easily be erosional, it undoubtedly marks at least the beginning of the Holocene deposition of grey pelites in the shelf valleys, and perhaps the beginning of the recent circulation and depositional pattern in the Gulf as a whole. The lithology of the grey pelites between 180 and 38 cm indicates deposition in deep *ice-free* marginal marine waters, whereas a decrease in water depth and the effect of the present day shelf depositional conditions is reflected in the deposition of the sandy pelite layer towards the top of the core in the interval between 38 and 0 cm. The deposition of the pelites also implies that after ~8700 years the water depth increased significantly on the shelf, and the St. Lawrence River drainage began to determine the circulation and depositional pattern in the Gulf.

The data from the shelf edges also relates to the postglacial sea level rises, as they show that above the 100–120 m level the hummocky drift surface has been almost completely modified, the drift has been reworked into various types of gravel and sands, and wide sloping terrace-like surfaces have been formed by marine processes.

Since there is little evidence for an extended stillstand at the 100–120 m level around the shelf edges, such as the presence of well-defined shoreline features (sand bars, etc.), it is suggested that sea level may not have stood at this depth for any length of time before the sea transgressed across the shelves with the retreat of the late ice. In fact, the fairly consistent level of the transition along the shelf edge may have been formed in part by active reworking by marine processes in much shallower water, for example, 60–35 m below present sea level, during the post-glacial rise. This reworking apparently continued throughout the rise in sea level, but its intensity decreased with time.

Present Depositional Conditions

The distribution of the surface sediments and their morphological expression reflect the present depositional conditions and, to a certain extent, the depositional conditions that have been in effect earlier in the Gulf of St. Lawrence. This section delineates the specific sedimentary environments of deposition, nondeposition, and active redistribution in the region and explains their present-day significance. In reading the text, reference should be made to Fig. 86 which shows the areas in which these sedimentary environments are found as well as to the bathymetrical and surface sediment maps (Charts 1 and 2, in pocket). In referring to environmental and surface sediment maps, however, it should be emphasized again that boundaries between units are approximate only and transitions are gradual.

The distribution of the deepwater pelites indicates that the deep central parts of the Laurentian, Anticosti, and Esquiman troughs are areas in which active deposition of fine-grained inorganic and organic material takes place. The suspended fine-grained material is supplied to these depositional sites from the St. Lawrence drainage area, from adjacent coastal areas, from active reworking of older sedimentary deposits, and perhaps from outside the Gulf (Chap. 7). It is deposited in response to the present current regime at sites having little or no bottom turbulence which are usually the deepest and most central parts of the troughs. In addition, the sediments in active depositional areas contain a minor amount of coarse-grained unsorted detritus supplied from the adjacent (mainly northern) shorelines by ice-rafting.

The deepwater pelites are apparently in equilibrium with the present environment. Echograms (Chap. 4) show that the pelites have developed their own morphological expression by filling in and levelling off for the most part the old, hummocky glacial surface. The maximum thickness of these postglacial pelites has been recorded as 40 m. The rate of pelite accumulation or deposition for this area is not known, however, with any certainty. The foraminiferal studies of core samples indicate that the environmental conditions and depositional rates have varied throughout the deposition of the postglacial pelites to such an extent that an average depositional rate would not be significant.

In the northern Gulf, the shelves, in general, are characterized by poorly sorted coarse-grained surface sediments that appear to have

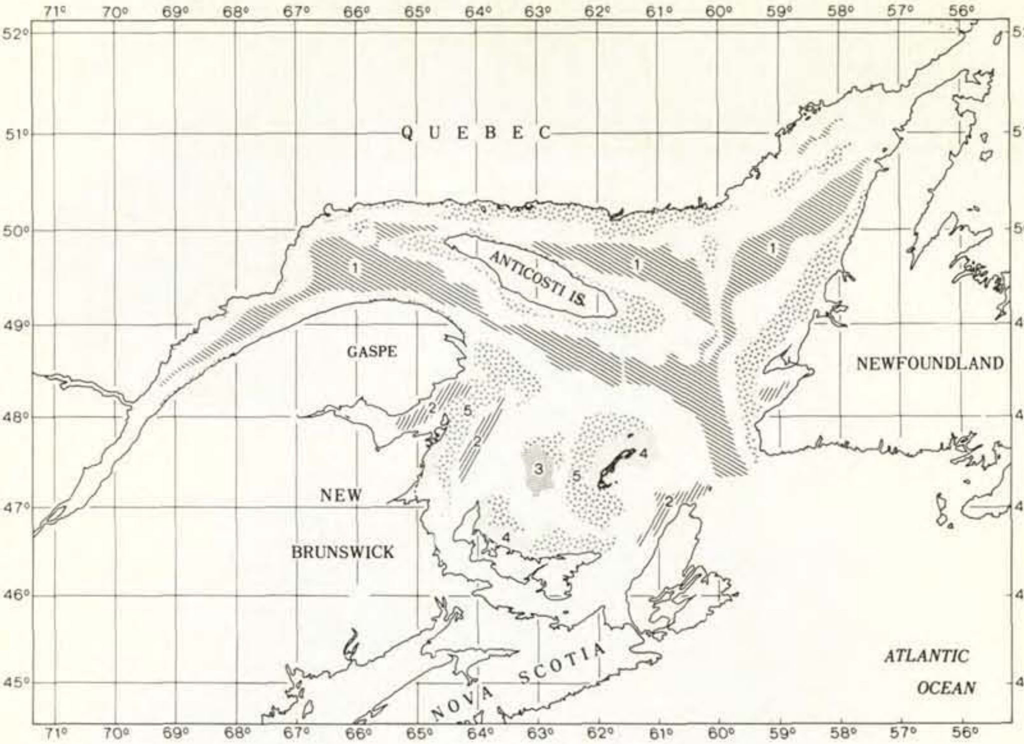

FIG. 86. Sedimentary environments of the Gulf of St. Lawrence: environments of deposition; (1) active deposition of deepwater pelites, (2) active deposition of fine grained sandy and very sandy shelf valley pelites; environments of active redistribution; (3) offshore areas of active reworking and redistribution, (4) nearshore and coastal areas of active reworking and redistribution; nondepositional environments, (5) areas of essentially nondeposition with local reworking and formation of lag deposits; transitional environments occur in the blank areas.

been derived from Pleistocene deposits. These have been reworked to varying degrees during the postglacial transgression (see Chap. 6), with the accumulation of fine-grained sediments (silty pelites) restricted to the protected basins and shelf valleys. The morphology and sediments are largely relict, in the sense that they are remnants from an earlier environment, although locally the sediments may be set in motion periodically and redistributed over restricted areas. In Fig. 86 these areas have been indicated as essentially nondepositional.

The granulometrical composition of the stiff light olive-grey (5 Y 6/1) heavy pelites from the area below Quebec City indicates that they are not being deposited at the present time but are residual from former conditions. They apparently accumulated in fresh water during the Champlain Sea episode in late-glacial time and now seem to be largely subject to erosional conditions (Fig. 10, Chap. 3).

The southern Gulf (Magdalen Shelf) has an irregular relief and is characterized by the presence of elevated areas and trough-shaped valleys as the major morphological features. In general, the topography has the characteristics of a submerged cuesta landscape developed on low dipping sedimentary rocks; Bradelle Bank, Orphan Bank, Bennett Bank, Pieter Bank, and some other banks represent submerged mesalike bedrock elevations. Morphological, mineralogical, and geochemical data indicate that the entire shelf was covered with ice sheets during Wisconsin glaciation (Chap. 7).

The surface sediment map shows a more varied sediment distribution pattern for the Magdalen Shelf. The majority of the sediments are sands and gravels and their admixtures. The mineralogical analysis has shown that these sediments are essentially the erosional products derived from the underlying Paleozoic bedrock intermixed with varying amounts of detrital material foreign to the shelf.

Pelite deposits have been found only in the major troughs, viz., in the Cape Breton Trough, in a relatively narrow elongated area of the Shediac Trough, and in the Chaleur Trough. Special reference is made to the sandy and very sandy pelites in the Cape Breton Trough because they have a specific depositional environment which appears to be similar to the other shelf valleys and adjacent shelf areas. Acoustical and sampling data transverse to the shores of Cape Breton show that the percentages of pelite in the sediments increases with increasing water depth. The sand component is very well sorted and very fine grained (100–50 μ) with less than 5% coarser than 120 μ. A distinct tendency for a decrease in the sand-size particles in the direction of the center of the trough has also been observed (Fig. 54, Chap. 6). The size-frequency distributions of the samples from this area show that the sands are of marine origin and have been supplied to the trough in suspension. The adjacent shelf areas to the west and northwest of the Cape Breton Trough are considered to be the source for the fine sand component of the sandy pelites which accumulate under present conditions. Similar processes of recent deposition occur in the Shediac Trough and adjacent areas as well as in the intervening lows between banks, such as in the western and eastern Bradelle Troughs. Fine sand mixed with varying amounts of pelite appears to have been winnowed out of the coarser sediments on the banks and deposited in these lows in response to the present current regime. Differences in depth, current action, and source routes account for the differences in grain size and in the extent of these deposits.

Acoustical and sampling data from elevated areas such as Bradelle Bank reveal that the sediments are largely a product of reworking and active redistribution (Loring et al. 1970). Most of Bradelle Bank was found to be covered with fine- (0.250–0.125 mm) to medium-grained (0.50–0.25 mm) sands with local gravel fields. Near the edge of the bank some bedrock exposures have been found. A sonar survey detected the presence of sand waves. Mechanical analyses of samples from these areas show fairly well-sorted sands with a medium diameter of 250 μ with about 2% granules (2–4 mm). It is assumed that the sand waves are formed from sand- and granule-size material that is still being winnowed out from the glacial and local regolith material and is migrating in response to the present conditions. Simultaneously, the transport of sand leaves behind lag deposits of coarse material that form the local gravel fields. The configuration of the sand waves observed suggests that sediment transport is from east to west, coinciding with the direction of residual bottom current inferred from the recovery of the seabed drifters in this area. Such a process might also be responsible for the accumulation of the pelitic fine sands to the west of Bradelle Bank.

Large areas, such as the sea floor north and west of the Magdalen Islands, and to the north of Prince Edward Island, have sandstone bedrock exposed through a thin sediment cover of (mainly local) sand and gravel. Sonar surveys reveal that the distribution of the sands and gravelly sands is discontinuous and very irregular. The irregular bottom topography in these areas, especially north of Prince Edward Island, appears greatly influenced by the bedrock surface. Consequently, sediment and morphology are indicative of essentially nondepositional conditions, although reworking and some redistribution may occur locally in the nearshore waters (see Fig. 86).

As was pointed out earlier, it is believed that the ice caps remained during the initial transgression in the area north of Prince Edward Island. The detailed bathymetrical map (Fig. 32) of this area reveals an irregular sea floor topography with knolls and basins, which is usually described as knob and basin topography. Such surface expressions are considered to result from slight oscillations in an ice front and appear to coincide with the nearby presence of tunnel valleys. The lack of substantial quantities of debris to cover the underlying bedrock suggests that the presence of ice masses apparently freshened the topography without deposition of significant amounts of glacial drift.

Similar nondepositional conditions prevail in the shelf areas adjacent to the New Brunswick coast. In addition, the area with hummocky topography off Chaleur Bay (Chart 6, in pocket; echo profile 14) is veneered with reworked glacial drift. Reworking and redistribution have not been sufficient to conceal the relict glacial morphology.

In summary, the complicated distribution pattern of the surface sediments in the southern Gulf indicates that (1) active deposition of fine sandy pelites occurs in the protected shelf valleys, in the intervening lows between the banks, and on the upper slopes of the shelf edge from nearby sources; (2) active reworking, redistribution, and winnowing occurs on exposed areas of positive relief such as Bradelle Bank, and some other banks forming (rippled) sand fields and lag gravel deposits; (3) essentially nondepositional conditions prevail in the areas off the north coast of Prince Edward Island, off the northeast coast of New Brunswick, and off the Magdalen Islands; this is illustrated by the presence of large areas of uncovered bedrock and relict deposits of sands and gravels.

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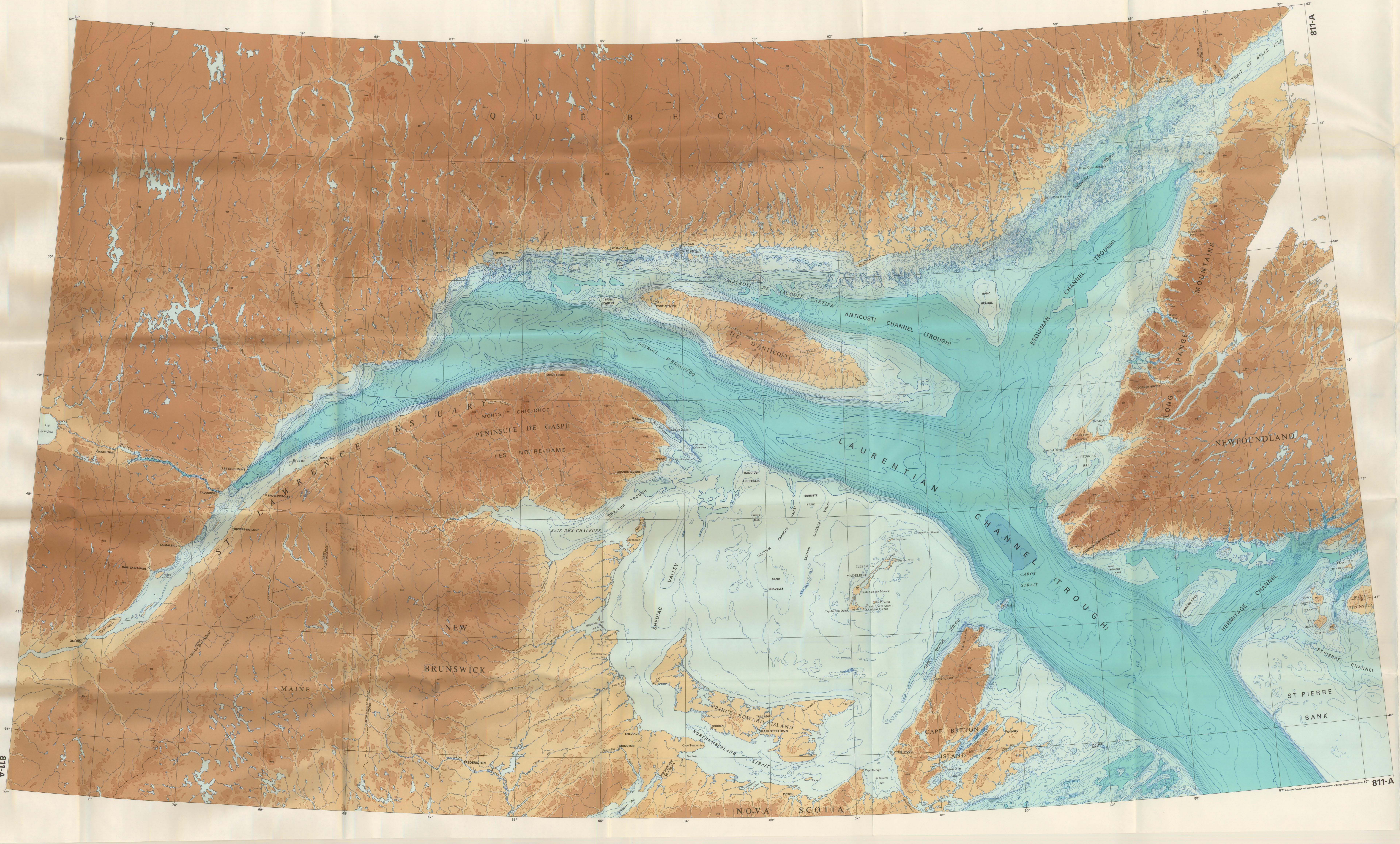

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CANADA

BATHYMETRIC CHART

GULF OF ST. LAWRENCE

Cartography by the Canadian Hydrographic Service

CONTOURS IN METRES

Scale 1:1 000 000

Projection : Lambert Conformal
(43° N. and 49° N.)

Scale of Nautical Miles 0 25 50 75

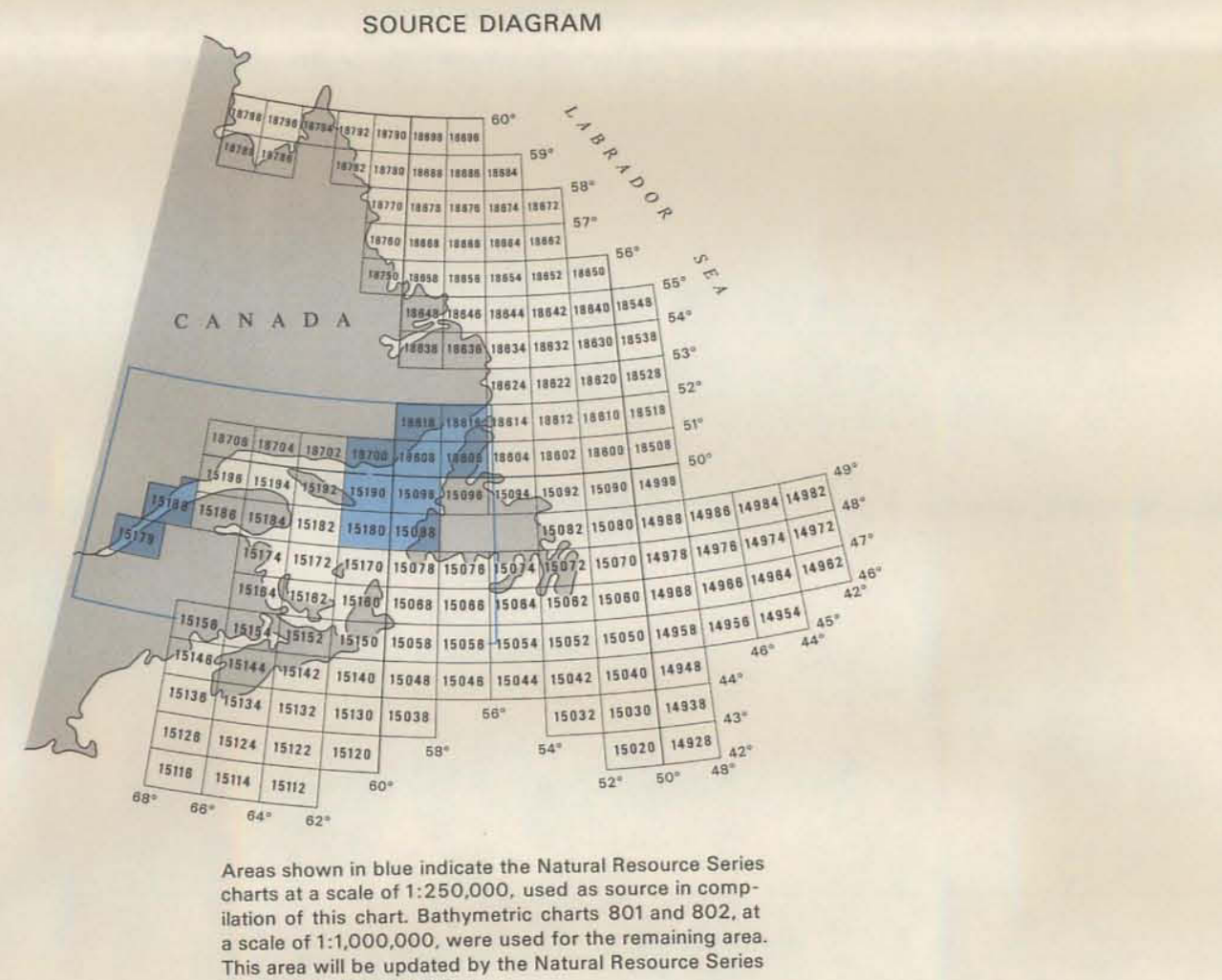
Scale of Statute Miles 0 25 50 75

Scale of Kilometres 25 0 25 50 75

ELEVATIONS AND DEPTHS IN METRES

- 1500
- 1000
- 500
- 200
- 100
- SEA LEVEL
- 100
- 200
- 500

SOURCE DIAGRAM



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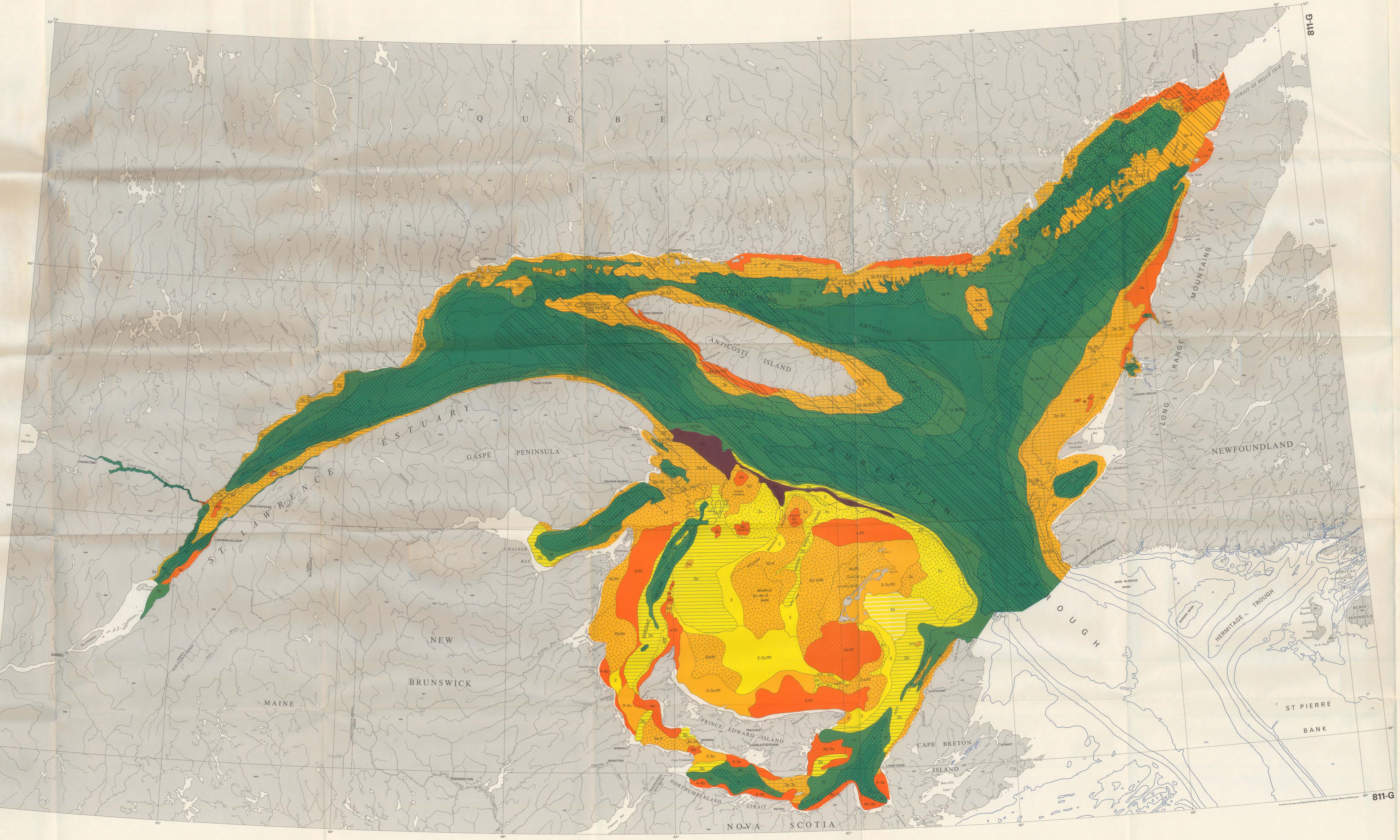

DISTRIBUTION OF SURFACE SEDIMENTS

GULF OF ST. LAWRENCE

Geology by Dr. Douglas H. Loring, Marine Ecology Laboratory, Dartmouth, N.S.
and Dr. Dirk J.G. Nota, Landbouwhogeschool, Wageningen (The Netherlands).

To accompany Fisheries Research Board of Canada Bulletin:
Morphology and Sediments of the Gulf of St. Lawrence.

DEPTH CONTOURS AND ELEVATIONS IN METRES

Natural Scale 1:1 000 000

Projection : Lambert Conformal

Scale of Nautical Miles

Scale of Statute Miles

Scale of Kilometres

LEGEND

PELITE

1	Pelite
1a	Calcipelite
1b	Relict Pelite
1c	Sandy Pelite
1d	Very Sandy Pelite
1e 1f	Gravelly Pelite; Gravelly Sandy Pelite

SAND

2	Well to fairly well sorted fine Sand
2a	Very fine Sand
2b	Pelitic fine Sand
2c	Gravelly fine Sand
3	Coarse-medium grained Sand
3a	Calcarenite
3b	Pelitic poorly sorted Sand
3c 3d	Gravelly well sorted Sand; Gravelly poorly sorted Sand
3e	Gravelly Pelitic Sand, mostly reworked equivalent of 5

GRAVEL (PEBBLES, COBBLES, BOULDERS)

4	Gravel with occasional sand patches
4a	Calcirudite
4b	Sandy Gravel
4c	Shell Gravel

GLACIAL DRIFT, USUALLY ASSOCIATED WITH A DISTINCTIVE HUMMOCKY RELIEF

5a 5b	Reddish brown drift derived mainly from Permo-Carboniferous rocks; Red to grey drift, usually calcareous, derived mainly from Pre-Carboniferous Paleozoic rocks, sometimes from Pre-Cambrian rocks.

BEDROCK NEAR OR AT THE SURFACE

R1	Mostly reddish brown friable sandstone of Permo-Carboniferous age.
R2	Paleozoic sedimentary rocks, mainly calcareous, of Ordovician-Silurian age.
R3	Pre-Cambrian rocks of the Canadian Shield.
▨	Calcareous; greater than 5% $CaCO_3$ by weight

NOTES

Data for Northumberland Strait derived from Kranck (1971: Map 4023-G).

Fractional notations are used where surface units are thin; upper numbers apply to thin or discontinuous surface units, the lower numbers to the principal underlying units.

Colour tints and symbols as used in the legend represent the first component only when referring to the unit identifications on the chart.

SEDIMENT CLASSIFICATION

Sediment Size Grades and Particle Diameters			Nomenclature Critical Limits of the various components are 5% and 30% by weight.				
Size Grade	Calcium Carbonate Equiv.	Particle Diameter (mm)	<5% by Weight	5-30% by Weight	5-30% $CaCO_3$ by Weight	>30% by Weight*	>30% $CaCO_3$ by Weight
Pelite	Calcipelite	<0·05	Not Named	Pelitic	Calcareous and /or Calcipelitic	Pelite	Calcipelite
Clay	-	<0·002	"	-	-	-	-
Silt	Calcipelite	0·002-0·05	"	-	-	Pelite	-
Sand	Calcarenite	0·05 - 2·0	"	Sandy	Calcareous and /or Calcarenitic	Sand	Calcarenite
Very Fine Sand	"	0·05 - 0·125	"	"	"	Very Fine Sand	"
Fine Sand	"	0·125 - 0·25	"	"	"	Fine Sand	"
Medium Sand	"	0·25 - 0·5	"	"	"	Medium Sand	"
Coarse Sand	"	0·5 - 2·0	"	"	"	Coarse Sand	"
Gravel	Calcirudite	>2·0	"	Gravelly	Calcareous and /or Calciruditic	Gravel	Calcirudite

*If two components represent more than 30% each, the finer grained component is indicated by its noun, the other with an adjective with the adverb "very" e.g. very sandy pelite and not very pelitic sand. The term calcipelite is also extended to include calcipelitic pelite.

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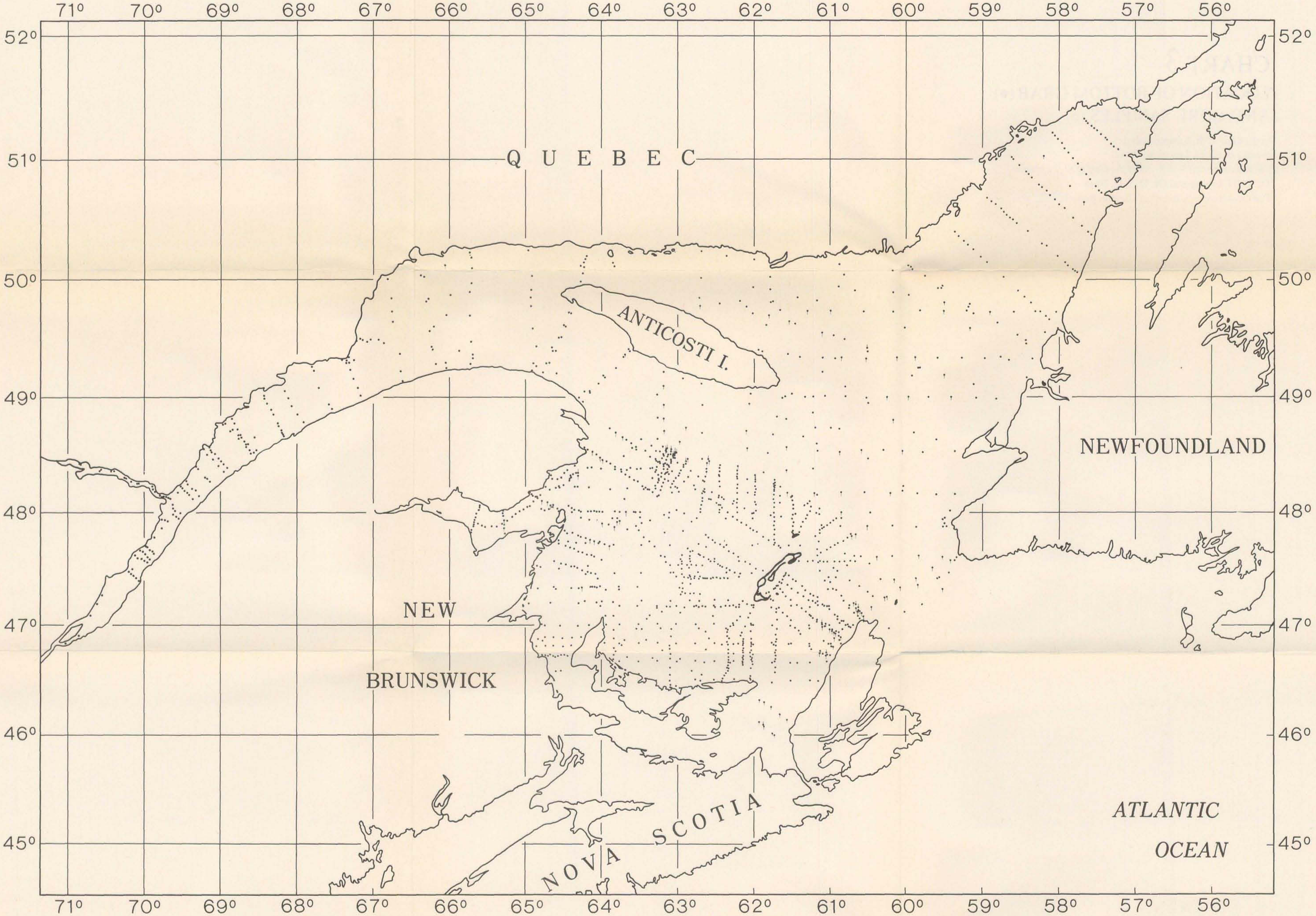
CHART 3

LOCATION OF BOTTOM GRAB (•) AND CORE SAMPLES (♀)

in the Gulf of St. Lawrence and
estuary of the St. Lawrence River.
"*Morphology and Sediments of the Gulf of St. Lawrence*"
Dr. D. H. Loring and Dr. D. J. G. Nota
Fisheries Research Board of Canada Bulletin 182



71°
70°
69°
68°
67°
66°
65°
64°
63°
62°
61°
60°
59°
58°
57°
56°
52°
51°
50°
49°
48°
47°
46°
45°
QUEBEC
ANTICOSTI I.
NEWFOUNDLAND
NEW
BRUNSWICK
NOVA SCOTIA
ATLANTIC
OCEAN

CHART 4
NORTHERN ECHOGRAM CHART

Continuous echograms from the northern
Gulf of St. Lawrence with interpretation
of the nature of the sea floor.
"*Morphology and Sediments of the Gulf of St. Lawrence*"
Dr. D. H. Loring and Dr. D. J. G. Nota
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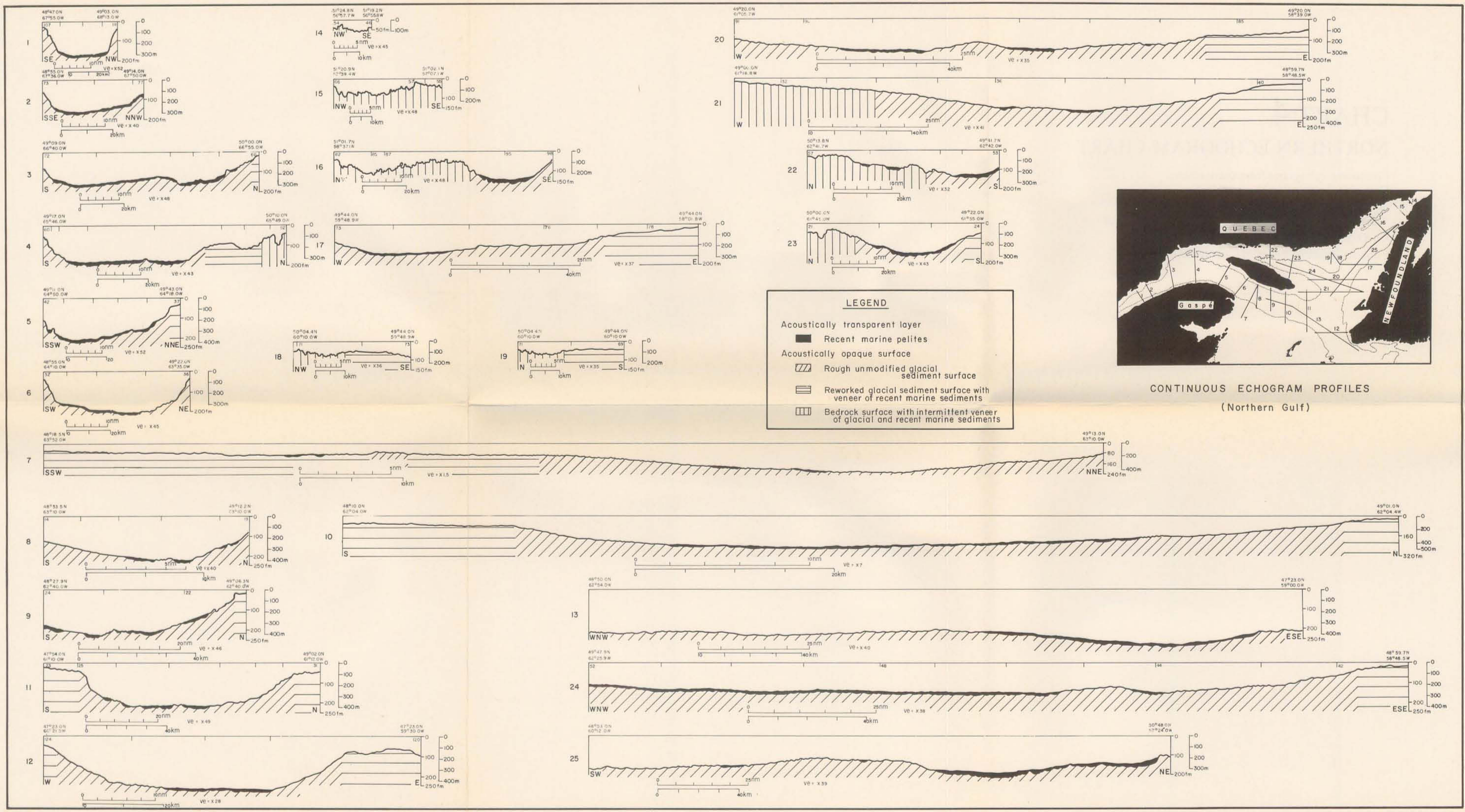

CONTINUOUS ECHOGRAM PROFILES

(Northern Gulf)

CHART 5

NORTHERN SEISMIC CHART

Continuous seismic profiles from the
northern Gulf of St. Lawrence.
"*Morphology and Sediments of the Gulf of St. Lawrence*"
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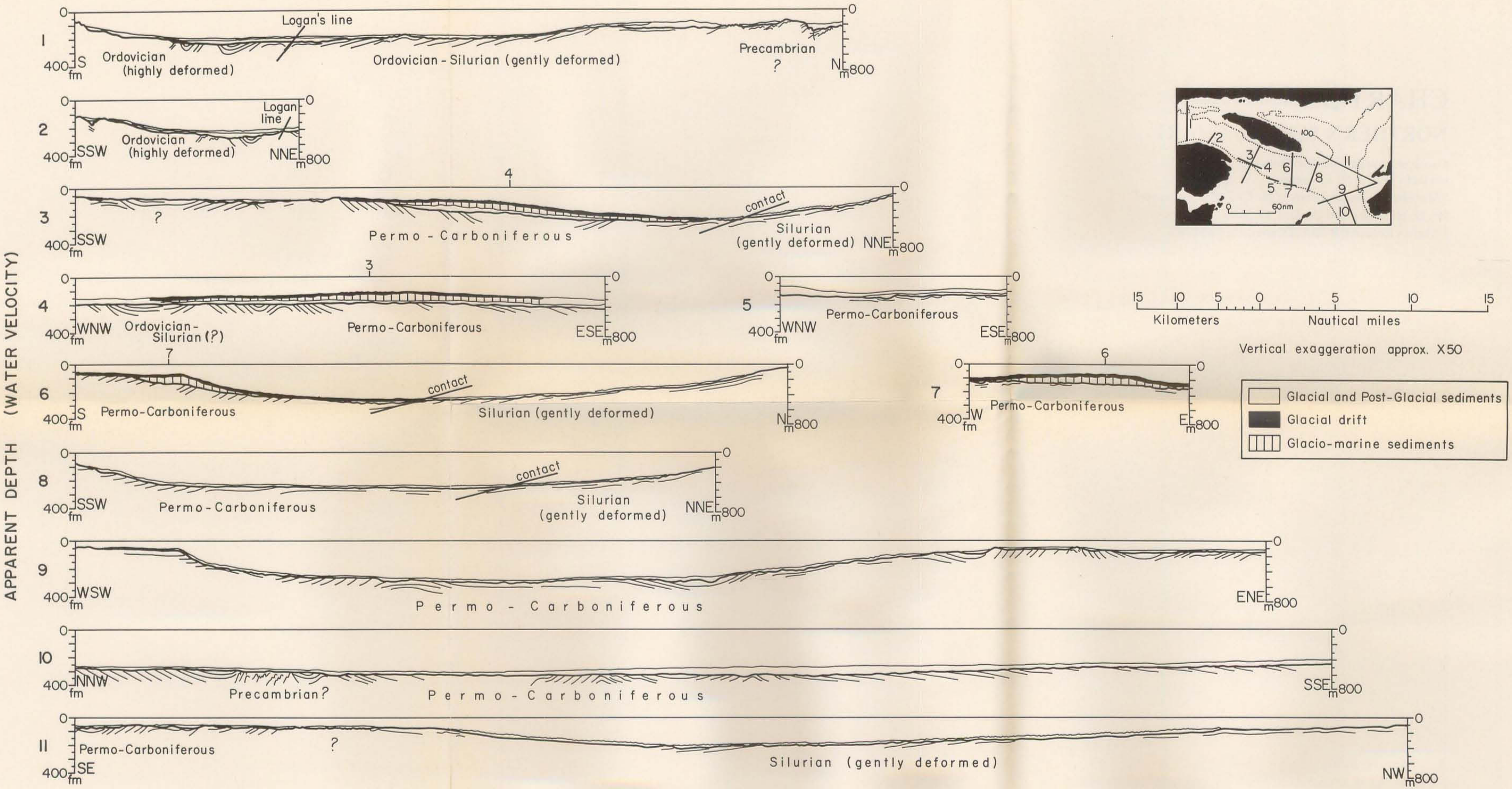
Fisheries Research Board of Canada Bulletin 182



CONTINUOUS SEISMIC PROFILES (Northern Gulf)

CHART 6

SOUTHERN ECHOGRAM CHART

Continuous echogram profiles of the
southern Gulf (Magdalen Shelf) with
interpretation of the sea floor.

"*Morphology and Sediments of the Gulf of St. Lawrence*"
Dr. D. H. Loring and Dr. D. J. G. Nota
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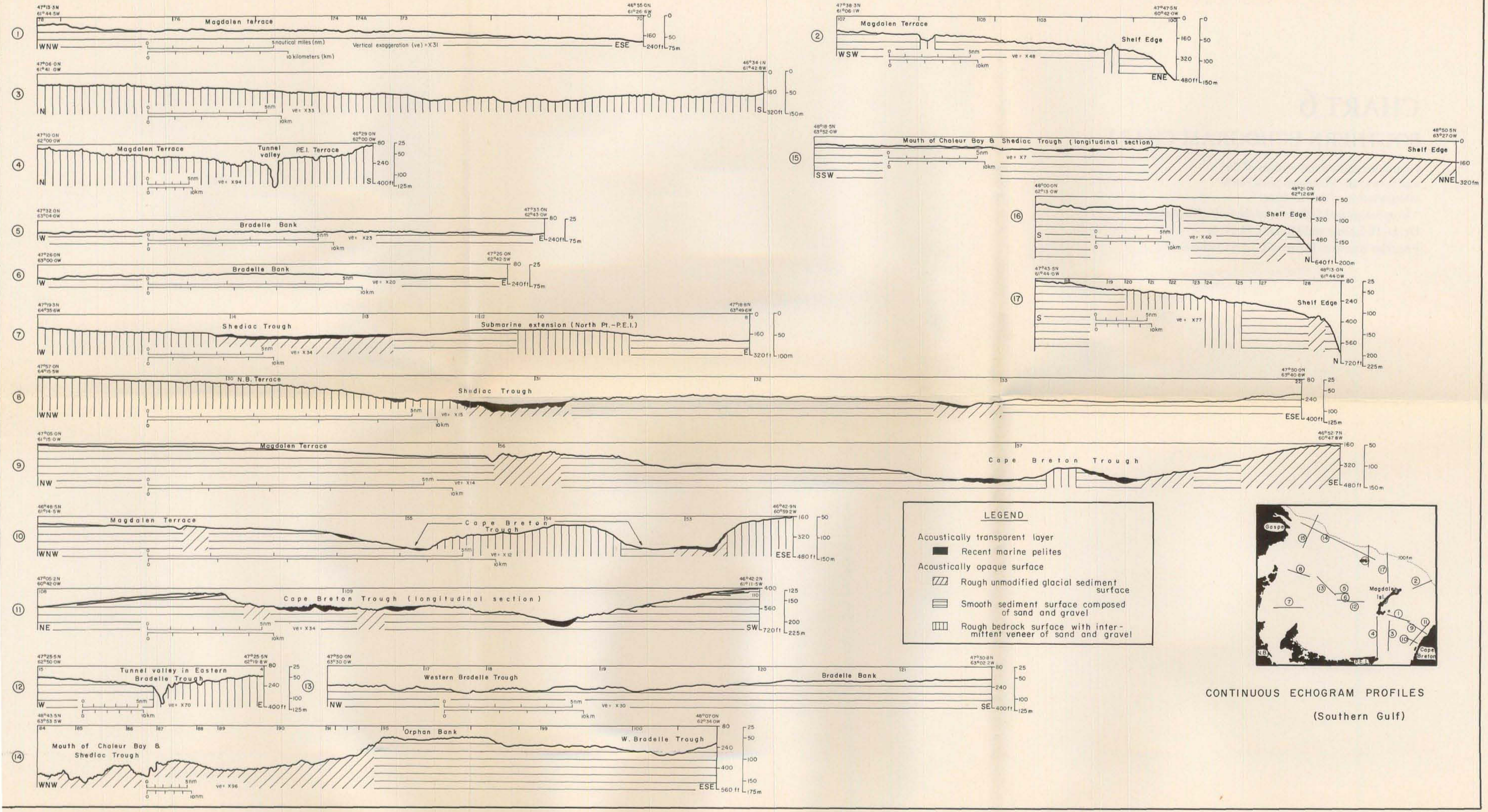

LEGEND

Acoustically transparent layer
- ■ Recent marine pelites

Acoustically opaque surface
- ▨ Rough unmodified glacial sediment surface
- ☰ Smooth sediment surface composed of sand and gravel
- ▥ Rough bedrock surface with intermittent veneer of sand and gravel

CONTINUOUS ECHOGRAM PROFILES

(Southern Gulf)

CHART 7

SOUTHERN SEISMIC CHART

Continuous seismic profiles of the
southern Gulf (Magdalen Shelf)
"*Morphology and Sediments of the Gulf of St. Lawrence*"
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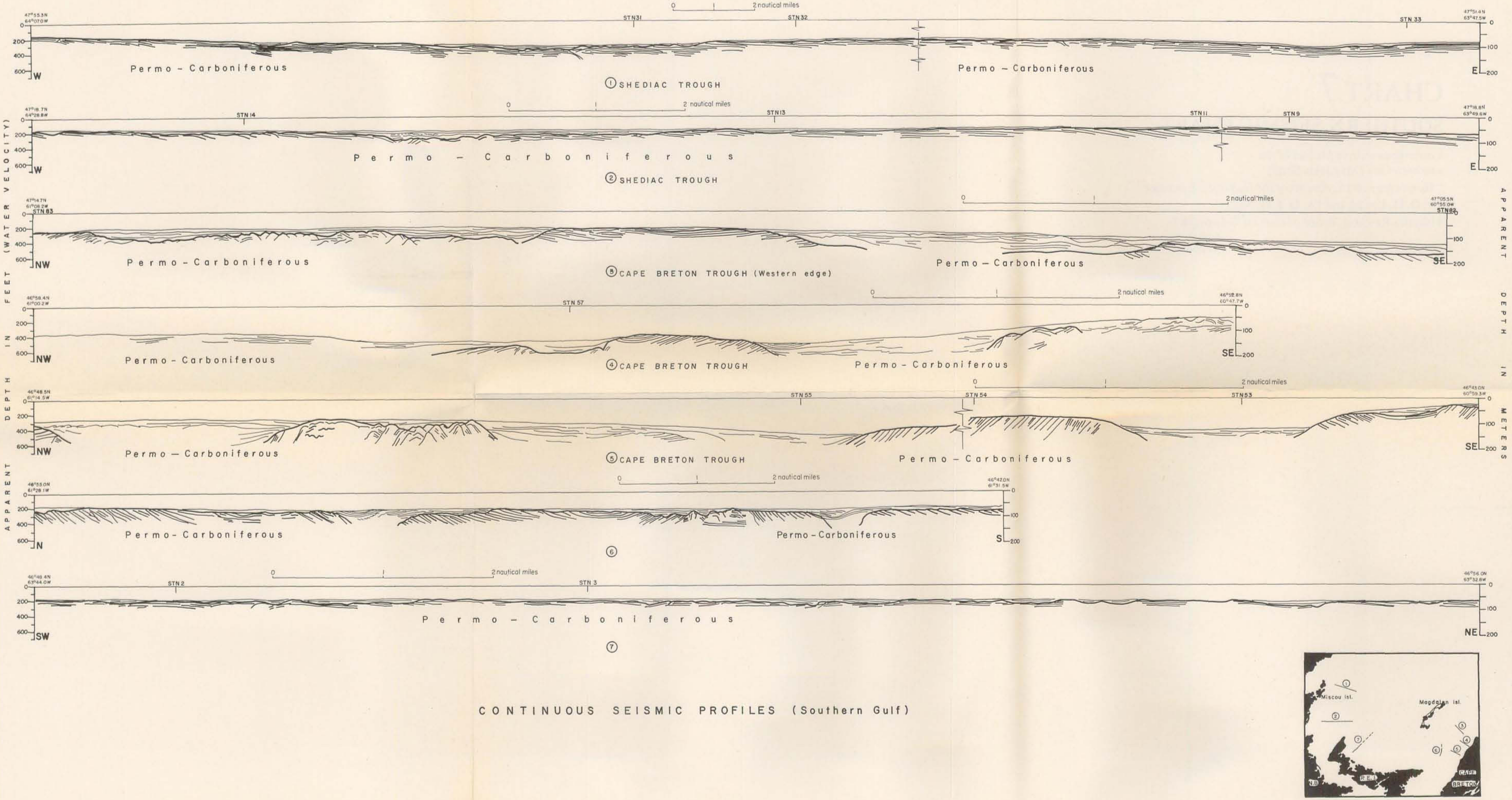
Fisheries Research Board of Canada Bulletin 182



CONTINUOUS SEISMIC PROFILES (Southern Gulf)