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geology of the scotian shelf

by Lewis H. King and Brian MacLean
geological survey of canada

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GEOLOGY OF THE SCOTIAN SHELF AND ADJACENT AREAS

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Dartmouth, N. S.

ABSTRACT

The geology of the Scotian Shelf and adjacent areas falls into four major divisions: the Acadian Basin, the acoustical basement, the east coast geosyncline, and the Sydney Basin. The rocks of the coastal areas around the Bay of Fundy, eastern and southern Nova Scotia, and southern Newfoundland belong primarily to the Appalachian province. These rocks are overlain, farther seaward on the continental shelf, by a younger Mesozoic–Cenozoic sequence.

The offshore geology was interpreted on the basis of structural and stratigraphic relationships from seismic reflection data; acoustical reflectivity; adjacent shore geology; data from 10 exploratory wells and a few dredge samples; and gravity, magnetic, and seismic refraction data.

This report and accompanying map 812H complement the deeper subsurface studies arising from the current search for offshore oil and gas. Moreover, the study outlines the areas of occurrence of Pennsylvanian strata, which are in part coal bearing, and of older rocks, which may contain economic mineral deposits.

RÉSUMÉ

Le plateau continental Scotian et les régions adjacentes font partie de quatre grandes divisions géologiques: le bassin Acadien, le socle « acoustique », le géosynclinal de la côte est et le bassin de Sydney. Le roc des zones côtières de la baie de Fundy, de l'est et du sud de la Nouvelle-Écosse et du sud de Terre-Neuve appartient principalement à la province des Appalaches. Plus loin des côtes, il est recouvert d'une séquence secondaire–tertiaire–quaternaire plus jeune.

L'interprétation géologique des fonds sous-marins est fondée sur des relations structurales et stratigraphiques établies à partir des données de la sismique-réflexion, de la réflexion acoustique et de la géologie du littoral contigu, des données obtenues de 10 puits d'exploration et de quelques échantillons de dragage ainsi que de celles de la sismique-réfraction et des études gravimétriques et magnétiques.

Le présent rapport ainsi que la carte 812H qui l'accompagne s'ajoutent aux études du sous-sol profond accompagnant la recherche actuelle de pétrole et de gaz sous la mer. De plus, il indique les zones à strates pennsylvaniennes renfermant en partie du charbon, ainsi que les zones de rocs plus anciens, pouvant receler des dépôts minéraux avantageux du point de vue économique.

INTRODUCTION

This report accompanies Map 812H (Chart 1, in pocket), Geology of the Scotian Shelf and Adjacent Areas. It is the first of a planned series of marine bedrock maps of the sub-Pleistocene surface, and is designed to extend the geological coverage of the land areas across our continental shelves. The onshore and offshore geology around the Bay of Fundy, eastern and southern Nova Scotia, and southern Newfoundland is shown on the map. The rocks in these areas belong primarily to the Appalachian province. These rocks are overlain farther seaward on the continental shelf by a younger sequence of strata which have no counterparts on mainland Nova Scotia except for a few small outliers along the Schubenacadie and Musquodoboit river valleys. Their closest landfall is Cape Cod and adjacent islands along the New England coast. South of Cape Cod they underlie the Atlantic Coastal Plain and continental shelf along the eastern seaboard of the United States.

The study is based primarily on an examination of high resolution seismic profiler records collected by the Bedford Institute of Oceanography from 1964 to 1973. In addition to seismic records, this interpretation is based on the various geological features on the adjacent shore, on data from 10 exploratory wells and from dredged samples, from gravity and magnetic maps, and from seismic refraction data. Although much of the map is a detailed account of the geology of the sub-Pleistocene surface and can serve as a base for future geological studies of Canada's east coast, overall it is considered a reconnaissance map because of the remote sensing techniques used for the collection of most of the data. A shallow-drilling program would benefit the study of the

geology at the sub-Pleistocene surface because bedrock sampling is made difficult by the extensive unconsolidated cover.

The geological map and stratigraphic data from our study complement the deeper subsurface studies necessary in the current search for offshore oil and gas. Moreover, the study outlines the areas of occurrence of Pennsylvanian strata, which are probably coal bearing, and of older rocks, which may contain economic mineral deposits.

PREVIOUS WORK

The geology of the land areas of Atlantic Canada has been studied for about 150 yr and is the subject of many publications. The land geology has been reviewed by Alcock (1947), Weeks (1958), and Poole et al. (1970). The following account is a review of previous studies relating to the geology of the Scotian Shelf and adjacent marine areas.

Early work on samples from the offshore area was by Verrill (1878), Upham (1894), and later Dall (1925), who reported on floats of Tertiary age recovered from the Grand Banks, Scotian Shelf, and Georges Bank. Cushman (1936) and Stephenson (1936) described material of Cretaceous age recovered during fishing operations on Banquereau and Georges Bank. Sable Island was studied by MacDonald (1883, 1884, 1886), who reported on its origin and dynamic nature, and by Patterson (1894), who speculated on the subsurface nature of the banks. Goldthwait (1924) included a description of the island in a report on the physiography of Nova Scotia.

The origin of the Bay of Fundy and Gulf of Maine was a subject of interest and controversy for many years. Upham (1894) and Johnson (1925) suggested that the Bay of Fundy was a graben and on the basis of prominent submarine scarps Johnson postulated the occurrence of a southwesterly trending fault (Fundian Fault) in the Gulf of Maine parallel to the Maine coast. He also suggested an extension of the Acadian Triassic basin into the Gulf of Maine. Johnson thought that Georges Bank represented a cuesta developed on coastal plain strata and not formed of glacial debris as was suggested by some previous workers. He, and later Koons (1941, 1942), believed that the Bay of Fundy and Gulf of Maine had been formed by fluvial erosion followed by submergence and that glacial erosion was a minor factor. Shepard (1930, 1931a) recognized the presence of deep basins and U-shaped features and considered that the Bay of Fundy and Gulf of Maine originated through glacial erosion, possibly along a glacial river system. This view was shared by Chadwick (1948, 1949). Shepard supported Johnson's conclusions as to the cuesta form of Georges Bank, but considered its present shape largely due to glaciation, and in 1934 Shepard et al. extended these conclusions to the outer banks of the Scotian Shelf. Stetson (1936, 1949) described samples of coastal plain strata dredged from submarine canyons on the south side of Georges Bank. Murray (1947) reported on the bathymetry of the Gulf of Maine. Seismic refraction investigations of a reconnaissance nature were conducted by Drake et al. (1954, 1959), gravity studies were carried out by Worzel and Shurbet (1955), and a detailed seismic reflection, magnetic, and hydrographic survey of the northern part of the Gulf of Maine was carried out by Malloy and Harbison (1966). Magnetic data from the Bay of Fundy, eastern Gulf of Maine, and Scotian Shelf were published in the Geological Survey of Canada Ship Magnetometer and Aeromagnetic Series (1958–1968) and in reports by Bower (1962) and Hood (1966a, 1966b). The Canadian Hydrographic Service survey in 1964 provided additional magnetic field coverage in the vicinity of Grand Manan Island together with gravity data (Haworth 1974a). Uchupi (1965) published a comprehensive series of colored charts relating the topography of the seabed and land areas between southern Nova Scotia and Florida. Using continuous seismic techniques, Robertson (1964) surveyed submarine canyons on Georges Bank, Emery and Uchupi (1965) investigated Georges Basin and Georges Bank, Uchupi (1966) and Tagg and Uchupi (1966) demonstrated the extension of the Triassic basin beneath the Gulf of Maine, Swift and Lyall (1968a) investigated Triassic strata in the Bay of Fundy, and Ballard and Sorenson (1968) examined Georges Basin and Northeast Channel. Most of the seismic reflection studies concluded that preglacial erosion played an important part in the physiographic development of the Gulf of Maine. Schlee and Pratt (1970) concluded that gross bedrock types could be inferred from a study of the gravel fraction recovered in dredge hauls, and Kane et al. (1972) related gravity and magnetic evidence to lithology and structures. Ballard and Uchupi (1972) interpreted the Triassic troughs to be tectonic basins within a Carboniferous–Triassic rift system, and Emery and Uchupi (1973) considered that Triassic rift structures probably formed an important tectonic unit of the Gulf of Maine.

The application of modern marine techniques to the Scotian Shelf commenced with seismic refraction studies by Officer and Ewing (1954) and Press and Beckmann (1954). Later, refraction studies were conducted in the Sable Island area by Willmore and Tolmie (1956) and Berger et al. (1965) and in other areas of the shelf by Barrett et al. (1964) and Berger et al. (1966). Dainty et al. (1966), Ewing et al. (1966), and Keen and Loncarevic (1966) studied the deep crustal structure of the eastern seaboard of Canada using refraction techniques. King (1967b, 1970), from seismic reflection data and bottom samples, confirmed the cuesta form of the outer banks and the occurrence of glacial deposits on the inner parts of the shelf, and concluded (King et al. 1974) that the present shelf morphology mainly eroded through glacial erosion and that glacial modification was minimal. The magnetic studies by Bower (1962) and Hood (1966a, 1966b) referred to previously, together with the work of McGrath et al. (1973), covered the Scotian Shelf. Gravity studies by Loncarevic (1965) revealed the presence of the Orpheus Anomaly on the eastern part of the Scotian Shelf. Ewing and Hobson (1966) investigated the anomaly area by seismic refraction techniques; and refraction, gravity, and magnetic data were utilized by Loncarevic and Ewing (1967) in the construction of a model. King and MacLean (1970a) demonstrated the relationship between the Orpheus Anomaly and an extensive fold belt on the eastern part of the shelf, and postulated an association with a major eastward extension of the Cobequid–Chedabucto Fault System. Samples of Tertiary strata recovered by dredge from The Gully, east of Sable Island, were described by Marlowe (1965, 1967, 1969) and Marlowe and Bartlett (1968). King et al. (1970) described samples of Cretaceous strata recovered by dredge from a site 100 km north-northwest of Sable Island. The locality was later investigated from a submersible (King and MacLean 1970b). In a major contribution, Sheridan and Drake (1968) discussed the geology underlying the Gulf of St. Lawrence, eastern Scotian Shelf, and Newfoundland and Labrador shelves. The continental slope, rise, and abyssal plain seaward of Nova Scotia were investigated by Uchupi (1969) and Emery et al. (1970), using seismic reflection, gravity, and magnetic data. Keen et al.

(1970) described the continental margin off eastern Canada and presented additional gravity data for the Scotian Shelf and Grand Banks. Diapiric structures were reported from continuous seismic reflection studies north of Sable Island (King and MacLean 1970c) and in the Laurentian Channel (Keen 1970; Webb 1973). In 1968 the first exploratory well on the Scotian Shelf was drilled on Sable Island to a depth of 4 600 m and the stratigraphic succession was described by Magnusson (1970). McIver (1972), in a major contribution based on information from exploratory wells and processed seismic data, proposed a stratigraphic framework and described the succession underlying the Scotian Shelf. Sherwin (1973) discussed the geology and hydrocarbon potential of the Scotian Shelf and Grand Banks. Analysis of commercial seismic and well data is in progress and is leading to an improved stratigraphic analysis of the section underlying the Scotian Shelf (Wade 1974; Jansa 1974; Williams 1974). From seismic reflection studies and correlation with well data, King et al. (1974) recognized four unconformities within the Mesozoic–Cenozoic succession underlying the Scotian Shelf. Results of sea bottom gravity studies conducted on the Scotian Shelf were reported with accompanying charts by Stephens et al. (1971) and Stephens and Cooper (1973), and with natural resource gravity and magnetic maps of the Orpheus area by Haworth (1974b). Haworth and MacIntyre (1975) provided a major regional compilation of gravity and magnetics at a scale of 1:1,000,000 for the Atlantic provinces' offshore areas. Discussions on the physiography of the Scotian Shelf were included in reports by Shepard et al. (1934), Berger et al. (1966), King (1967b, 1970), Cok (1970), MacLean and King (1971), Drapeau and King (1972), and Williams et al. (1972). The possible role of plate tectonics in the geomorphic evolution of the Atlantic Provinces was examined by King (1972).

Early studies of the Laurentian Channel were based on bathymetric data, and Spencer (1890, 1903), Upham (1894), Goldthwait (1924), and Johnson (1925) suggested a subaerial origin for the feature. Shepard (1931b) considered the present form of the Laurentian Channel to be due principally to glacial erosion, possibly along a preglacial river system that had experienced some structural control. A structural origin was suggested by Gregory (1929), Keith (1930), and Hodgson and Doxsee (1930) from studies relating to the Grand Banks earthquake. Nota and Loring (1964) supported Shepard's (1931b) contention of a glacial origin for the Laurentian Channel from their studies in the Gulf of St. Lawrence, and considered structural control along a preglacial valley system to be important. Kumarapeli and Saull (1966) proposed a structural origin for the feature, and McNeil (1956) suggested it may have been developed through the action of turbidity currents. Keen and MacPherson (1963) investigated the problem, utilizing magnetic data, and found no evidence for a structural origin for the Channel. Sheridan and Drake (1968) reached a similar conclusion, as did King and MacLean (1970d), who concluded from seismic reflection studies that the outer part of the Laurentian Channel was developed by glacial erosion along a preglacial drainage system.

The physiographic, sedimentary, and structural framework of eastern North America and beneath the western North Atlantic was recently reviewed and analyzed by Emery and Uchupi (1973) and Keen (1974), and the reader is referred to these studies for an appreciation of the broad geologic setting of the map-area.

METHODS AND CONTROL

The geology of the Scotian Shelf and adjacent areas was interpreted on the basis of structural and stratigraphic relationships and acoustical reflectivity as revealed by a study of 16,800 km of high resolution continuous seismic reflection profiles (see Map 812H for control), 2300 km of deep processed seismic records, bedrock control from adjacent land geology, released well data, dredged samples, and published gravity, magnetic, and seismic refraction data. Additional gravity and magnetic data were acquired in the Bay of Fundy, Gulf of Maine (Watts and Haworth 1974), and Laurentian Channel (Haworth et al. 1972) with shipborne equipment in conjunction with seismic reflection surveys in those areas.

The early seismic reflection profiles were obtained with a system in which an EG&G International 2500-J sparker was the acoustic source, but a Bolt Associates Model 600 air gun fitted with a 16.4-cm ^{3} (1-in ^{3}) chamber was the acoustic source used for most of the survey. A 164-cm ^{3} (10-in^3) chamber was employed on lines in the Bay of Fundy and part of the Gulf of Maine, and a 656-cm^3 (40-in^3) chamber equipped with a pulse shaper was employed on some profiles in the Laurentian Channel. Firing rates ranged from 1-s intervals for the smaller chambers to 2-s intervals for the largest. The degree of penetration obtained with the different chambers was approximately equivalent, but the signal-to-noise ratio was improved with the heavier equipment. Operating pressures ranged from 1.05×10^6 to 1.40×10^6 kg/m^2 (1500 to 2000 psi). Survey speeds ranged from 7.4 to 14.8 km/h (4 to 8 kn). The other principal components for most of the Scotian Shelf and early Gulf of Maine surveys included Alpine and Bolt hydrophone arrays, a Krohn-Hite filter, and an Alden 419 precision graphic recorder. Many of these components were subsequently replaced, and the system utilized in the Bay of Fundy and parts of the Gulf of Maine and Laurentian Channel included a 4-section custom hydrophone, Geospace 4-channel amplifier, Krohn-Hite band pass filter, Philips Analog 7-channel tape recorder, and an EPC Model 4100 graphic recorder. The data being recorded on tape were monitored on line at a reduced scale with a second EPC recorder. Interpretation was facilitated by having the data available at both full and reduced scales. Echograms were obtained simultaneously with the seismic data using a Kelvin Hughes 26B conventional echo sounder, and were used to resolve the area within the bubble pulse on the seismic profiles. King (1967 a, b) described techniques for the interpretation of unconsolidated sediments from the echograms.

Following the interpretation of the data on the seismic records, the significant events were transferred to geological sections which were constructed at a reduced scale by means of a special pantograph with independently variable horizontal and vertical scales. This permitted the data to be reduced, adjusted to the required vertical exaggeration, and corrected for variations in ship speed. Profiles from the Scotian Shelf and several from the Gulf of Maine were treated in this manner. Since 1971, the data have been reduced to the desired horizontal and vertical scale by playback from magnetic tape using an EPC recorder in single-sweep mode.

On the Scotian Shelf, the ship was positioned with a Decca Mark V Navigator, whereas positioning in the Bay of Fundy and Gulf of Maine was achieved by a combination of Decca, Loran A, and satellite navigation.

PHYSIOGRAPHY

The Scotian Shelf and adjacent areas comprise the following physiographic features: Bay of Fundy, eastern Gulf of Maine, Georges Bank, Georges Basin, Northeast Channel, Scotian Shelf, and Laurentian Channel south of Cabot Strait. These features, and various ideas concerning their origin, have been discussed in many contributions (see Previous Work) and illustrated on various bathymetric charts, including the Canadian Hydrographic Service 800 Series. The latter series depicts the shape of the seabed and adjacent land areas by metric contours on a Lambert conformal projection. Charts 801 and 802 at a scale of 1:1,000,000 were used as the base for our geologic compilation, Map 812H, as well as for Fig. 1.

The offshore areas considered in this report fall within two major geomorphic divisions, the Appalachian Region and the submerged area of the Atlantic Coastal Plain. The latter is developed across the surface of the Mesozoic–Cenozoic succession and lies between the erosional edge of these sediments and the edge of the continental shelf. The Appalachian Region lies to the north encompassing the remainder of the map-area. High resolution seismic studies reveal that the present topography reflects fairly accurately the shape of the bedrock erosional surface; the Quaternary cover obscures only details in the shape of the bedrock surface. The history of the geomorphic development of the surface across the Appalachian area dates back to late Jurassic and early Cretaceous time when the drainage systems began to modify the landscape leading to its present maturely dissected configuration (King 1972; Williams et al. 1972). The surface across the submerged coastal plain was probably formed subaerially during Tertiary time (King et al. 1974). Both surfaces were subsequently modified to varying degrees by the continental ice sheet.

Bay of Fundy and Eastern Gulf of Maine

The Bay of Fundy and eastern Gulf of Maine fall within the Fundian lowlands, a part of the Carboniferous–Triassic lowlands of the Appalachian Region. Together they comprise an area of approximately 55,000 km^2 within the map-area. The bathymetric contours conform more or less to the shoreline expression of the Bay of Fundy and gradually deepen to Grand Manan Basin, a 220-m depression at the southwest end of the bay adjacent to Grand Manan Island and its surrounding shoals. The overall morphology reflects a former drainage system starting in the Minas Basin–Truro region of central Nova Scotia and continuing through the Bay of Fundy and into the Gulf of Maine along a broad axis defined by the Jordan and Crowell basins. These basins have a maximum depth of 300 m, are silled, and show some evidence of having been overdeepened by glaciation. The contours along the eastern margin subparallel the Nova Scotia coastline and their complexity indicates a rough bottom, but deeper in the basins the contours are smooth because of a blanket of fine surficial sediment. The origin of the Bay of Fundy and Gulf of Maine was the subject of a prolonged discussion by Powers (1916), Johnson (1925), Koons (1941, 1942), and Shepard (1930, 1942). The offshore studies in the Bay of Fundy by Swift and Lyall (1968b) provided strong support for Johnson's ideas that the present morphology reflects subaerial erosion later modified by glaciation.

Georges Basin and Northeast Channel

Georges Basin and Northeast Channel form part of the former drainage system described above and extend it to the edge of the continental shelf. These physiographic features are, however, part of the submerged Atlantic Coastal Plain and together are thought to represent a breachway across a large cuesta defined by the outer banks. Georges Basin is 377 m deep and has a well defined sill in Northeast Channel at approximately 230 m depth. The morphology of the bedrock surface in Georges Basin and Northeast Channel suggest that the former was extensively overdeepened by the continental ice sheet.

Georges Bank

Georges Bank is the seaward flank of the Gulf of Maine and is the westernmost bank of a chain of outer banks that runs from the shoals south of Cape Cod to the Grand Banks of Newfoundland. It is separated from Browns Bank by Northeast Channel. The southern part of Georges Bank has a smooth surface which slopes gradually to the edge of the continental shelf. The crest along the northern side of the bank within the 60-m contour is rough and characterized by a series of parallel shoals and troughs with superimposed sand waves of varying shapes (Uchupi 1968). The bank is part of the submerged Atlantic Coastal Plain and is considered by most workers to be a drowned cuesta of Cretaceous and Tertiary strata. It does not appear to have been glaciated during the Pleistocene (Emery and Uchupi 1965).

Scotian Shelf

The Scotian Shelf is bounded on the west by Georges Basin and the Northeast Channel and on the east by the Laurentian Channel. The shelf comprises an area of about 160,000 km^2 and varies in width from 125 km at the west end to 230 km at the east end. The shelf break occurs at a depth of about 140–180 m. On the basis of topography the shelf can be divided into three zones: an inner zone characterized by a rough topography, a central zone of isolated banks with intervening basins and valleys of various shapes, and an outer zone consisting of a series of wide, flat banks.

The inner zone borders Nova Scotia and extends seaward about 25 km to a depth of 100–120 m along the fall zone. This area of the shelf belongs to the tilted Atlantic Uplands, a geomorphic division of the Appalachian Region. Its surface bears many similarities to that of the adjacent land areas and reflects the degree of roughness of the underlying bedrock surface.

The central shelf is approximately 20 km wide at the western end and broadens to 140 km where it borders the Laurentian Channel. At the inner boundary of this zone a marginal trough runs the entire length of the shelf, varying from 40 to 50 km wide and generally from 145 to 180 m deep. West of 61°W the central zone is characterized by three broad basins: Roseway, LaHave,[1] and Emerald, with respective depths of 160, 270, and 290 m. The basins are separated by isolated mesas, whose tops are about 80–100 m below the surface (Roseway and Sambro banks). East of 61°W this zone is dissected by an east trending system of partly disconnected valleys with intervening ridges and chains of partly isolated banks (Middle, Canso, Misaine, and the western extension of Banquereau). Short tributary valleys within the major valley systems have a northerly orientation. The valleys, incised in the underlying bedrock, have been partly filled with unconsolidated sediments; thus the original diverse topography

[1] The Canadian Permanent Committee on Geographic Names decided the official name to be LaHave, May 26, 1975.

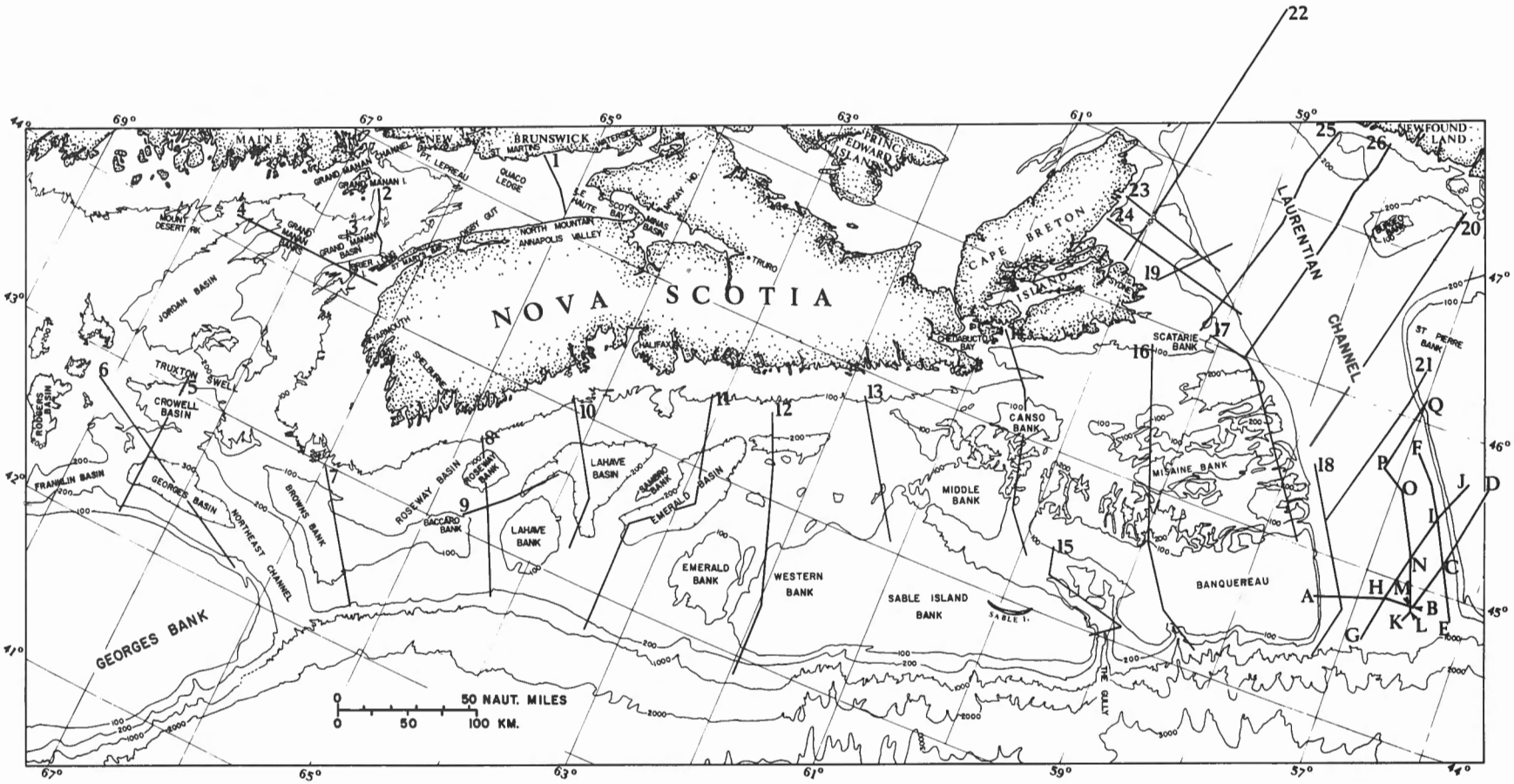

FIG. 1. Location chart for study area showing the generalized bathymetry and an index for the geological sections illustrated in the report.

now appears smoother and less continuous. They appear to represent a former drainage system. One such valley, The Gully, which separates Middle Bank and the western extension of Banquereau from Sable Island Bank at the edge of the shelf, is a modern submarine canyon Both the central and outer zones of the shelf belong to the submerged Atlantic Coastal Plain, which is subdivided into the Scotian Shelf uplands and lowlands (Williams et al. 1972).

The outer zone, an area of high relief, runs parallel to the shelf edge and is 50–75 km wide. Five broad, more or less flat-topped banks occur along this zone and are separated in three places by shallow saddlelike depressions which cut across the area of high relief from the basins to the shelf edge, and in one place by a submarine canyon. Browns, LaHave, Emerald, and Banquereau banks have respective minimum depths of 29, 71, 77, and 27 m while Sable Island Bank protrudes above sea level (Sable Island) to a height of 26 m.

The topography of the central and outer zones of the Scotian Shelf appears to be that of a partially dissected coastal plain, modified by glacial scouring and deposition, and further altered and reworked as a barrier coast during the Holocene transgression. A number of subaerial erosion periods have contributed to the pattern since early Tertiary time. The inner shelf, which is part of the Atlantic Uplands, has, like the Fundian lowlands, experienced a much longer history of geomorphic development.

Laurentian Channel

The Laurentian Channel is a broad troughlike depression that extends from the St. Lawrence River valley through the Gulf of St. Lawrence and across the continental shelf. Within the map-area, it divides the Scotian Shelf from the western part of the Grand Banks of Newfoundland. Where it crosses the continental shelf, the Laurentian Channel is a nearly straight trough, 95 km wide. A sill at a depth of about 410 m occurs at the southern end of the Channel; the depression behind the sill reaches a maximum depth of 535 m immediately north of Cabot Strait. Along the eastern bank of the Laurentian Channel south of Newfoundland, hanging valleys occur where Hermitage Channel and an unnamed depression northwest of Burgeo Bank enter the main channel at a depth of 300 m. Hermitage Channel consists of a series of elongate depressions gradually deepening to the northeast. The deepest, just outside the map-area (at 47°20′N, 56°35′W), has a maximum depth of 415 m, which is part of an enclosed depression 110 km long. Farther south, St. Pierre Bank forms the eastern boundary of the channel and has a very smooth and level surface with water depths generally between 40 and 80 m.

The northern half of the Laurentian Channel, as well as the adjoining bank areas east of Cape Breton Island and south of Newfoundland, falls within the Maritime Plain, a part of the Carboniferous–Triassic lowlands. The southern half falls within the coastal plain province. Regional considerations and the preservation of fluvial valleys in the Carboniferous, Cretaceous, and Tertiary rocks of the Laurentian Channel indicate that the ancestral St. Lawrence River system dates back at least to Early Cretaceous time (King and MacLean 1970d). Following this long depositional and erosional history, the continental ice sheet modified the channel to its present configuration. Shepard (1931b) was first to recognize the fjordlike character of the Laurentian Channel. The large silled basins along the floor of the trough, the submerged tributaries with their hanging valleys, and the straight parallel walls all attest to extensive erosion by a large and powerful glacier.

REGIONAL GEOLOGY

There is a marked contrast in detail between the land and offshore geology (Map 812H, in pocket). This is to some extent a function of the geology, but for many areas it reflects the difficulties inherent in marine geological mapping, especially over areas where acoustical basement outcrops at the sub-Pleistocene surface. In such cases the seismic profiler is of limited help and bedrock samples are difficult to obtain. The reconnaissance nature of the present survey, as indicated by the seismic control lines on the map, is also a limiting factor. Nevertheless, the map provides an appreciation of the offshore geology over an area of approximately 300,000 km^2, an area more than four times that of Nova Scotia.

The offshore region can be divided into four major geological units: (1) the Acadian Basin, an area of Triassic rocks in the Bay of Fundy and northern Gulf of Maine; (2) the acoustical basement, an area of Lower Paleozoic and older rocks which underlies the eastern and central part of the Gulf of Maine, as well as the inner zone of the Scotian Shelf; (3) the east coast geosyncline, an area of Jurassic, Cretaceous, and Tertiary strata which underlies the outer part of the Gulf of Maine and Georges Bank, the central and outer zones of the Scotian Shelf, and the outer part of the Laurentian Channel and (4) the Sydney Basin, an area of Carboniferous rocks east of Cape Breton Island.

The Table of Formations for the offshore area is given in Table 1.

Acadian Basin

The Acadian Basin contains most of the Triassic rocks that occur within the map-area except for small outliers on the shore of Chedabucto Bay and a possible extension of this deposit into the Orpheus basin. All known deposits are of continental origin and some contain interbedded basalt. In addition, a Triassic dike with a whole rock K/Ar date of 197 $\pm$ 32 million years (Larochelle and Wanless 1966) cuts across the Meguma Group and granitic rocks of southwestern Nova Scotia. Sherwin (1973) suggested that some Triassic sediments might be concealed beneath Jurassic and Cretaceous sediments on the Scotian Shelf, particularly within local fault-bounded basement depressions. The Acadian Basin is developed beneath the Bay of Fundy and northern Gulf of Maine, and the rocks are exposed subaerially along North Mountain (basalt, North Mountain Formation) and the Annapolis Valley (Wolfville and Blomidon formations) on the southeast side of the bay, around much of the Minas Basin shoreline, on the western two-thirds of Grand Manan Island (basalt), and in fault-bounded exposures along the New Brunswick coast at Point Lepreau (Lepreau Formation), St. Martins (Wolfville and Quaco formations), and Waterside (Wolfville Formation). Exposures of North Mountain Basalt also occur at Isle Haute and Quaco Ledge in the upper part of the bay. Basalt of the McKay Head Formation occurs locally between the Wolfville and Blomidon formations at McKay Head, and the Scots Bay Formation overlies the North Mountain Basalt in the area of Broad Cove on the shore of Scots Bay.

Powers (1916) provided the first detailed stratigraphic and structural account of the Triassic of this area, an account later modified by Klein (1962). Johnson (1925) recognized the extension of Triassic geology to the Gulf of Maine. Johnson's thorough morphological analysis of the Gulf of Maine, including his ideas regarding a Fundian fault system near the western margin of the Acadian Basin, and the relative

TABLE 1. Stratigraphic summary of rocks that occur in the offshore of the map-area; those that occur only on land are omitted from the summary. Some older sections are mapped as pre-Pennsylvanian acoustical basement in the offshore. Geographic localities are shown in italics. The Jurassic–Cretaceous boundary has been modified according to G. L. Williams (personal communication).

GEOLOGICAL AGE			ROCK UNITS			REFERENCE	
QUATERNARY			Sable Island Sand and Gravel		*Scotian Shelf*		King, 1970
			La Have Clay				
			Sambro Sand				
			Emerald Silt				
			Scotian Shelf Drift				
TERTIARY			The Gully Group	Banquereau Fm.	*Scotian Shelf*		McIver, 1972
CRETACEOUS				Wyandot Fm.			
				Dawson Canyon Fm.			
			Nova Scotia Group	Logan Canyon Fm.		Small Terrestrial Outliers *Central Nova Scotia*	
				Naskapi Fm.			
				Missisauga Fm.			
JURASSIC			Western Bank Group	Mic Mac Fm.			
				Verrill Canyon Fm.			
				Abenaki Fm.			
			Mohawk Fm.				
			Iroquois Fm.				
			Argo Fm.				
TRIASSIC			Fundy Group	Scots Bay Fm.	*Western Nova Scotia*	Lepreau and Quaco Fms. *Southern New Brunswick*	Klein, 1962
				North Mountain Fm.			
				Blomidon Fm.			
				McKay Head Fm.			
				Wolfville Fm.			
PERMIAN							Kelley, 1970 Barss and Hacquebard, 1967 Hacquebard, 1972
CARBONIFEROUS	Pennsylvanian	Stephanian	Pictou Group		*Maritime Provinces*		
		Westphalian	Cumberland Group				
			Riversdale Group				
		Namurian	Canso Group				
	Mississippian	Visean	Windsor Group				
		Tournaisian	Horton Group				
DEVONIAN			Granite Batholith				
SILURIAN			Torbrook Fm.		*Western Nova Scotia*	Mascarene Group *Southern New Brunswick*	Poole, Sanford, Williams, and Kelley, 1970 Taylor, 1969
			Kentville Fm. / New Canaan Fm.				
			White Rock Fm.				
ORDOVICIAN			Meguma Group	Halifax Fm.	*Mainland Nova Scotia*	St. John Group *Southern New Brunswick*	
CAMBRIAN				Goldenville Fm.		Several Cambrian Fms. *Cape Breton Island*	
PRECAMBRIAN			Morrison River Fm.		*Cape Breton Island*	Coldbrook Group *Southern New Brunswick*	
			Fourchu Group				
			George River Group			Green Head Group	

contributions of subaerial and glacial erosion to the geomorphic development of the area, has served as a framework and inspiration for modern marine geological studies in the Fundian region.

More recently, Swift and Lyall (1968a) showed through seismic reflection studies that the Acadian Basin north of Grand Manan was a broad open syncline, and provided additional evidence for the Fundian Fault. South of Grand Manan, Tagg and Uchupi (1966) and Uchupi (1966) defined three narrow Triassic troughs which were considered later to be tectonic basins within a Carboniferous–Triassic rift system (Ballard and Uchupi 1972), following some of Belt's (1968) ideas regarding Carboniferous geology of the Maritime Provinces. Ballard and Uchupi used refraction, gravity, and magnetic measurements by Drake et al. (1954), Malloy and Harbison (1966), and Kane et al. (1972) to suggest that the rift system might extend across the Gulf of Maine to the Boston–Narragansett basin complex. Wilson (1962) extended the Cabot Fault along a similar trend. Neale et al. (1961), Poole (1967), Belt (1968), and Webb (1969) discussed the broad structural and tectonic development of the region. The work of Stevenson (1960), Poole (1967), Loncarevic and Ewing (1967), and King and MacLean (1970a) led to the conclusion that certain structural and stratigraphic elements of the Acadian Basin could be extended across Nova Scotia to Chedabucto Bay and the Orpheus basin. A zone of east–west faulting along this trend extends across the Scotian Shelf (Glooscap fault system; see p. 13) and probably along the southern margin of the Grand Banks. It possibly was a major fault active during the opening of the Atlantic.

The Acadian Basin will be discussed under the following headings: the northeast section (the Bay of Fundy), the southeast flank, the southwest section (the northeast Gulf of Maine), the Glooscap fault system, and Carboniferous elements.

Northeast section — The study of offshore lithology and stratigraphy of the Acadian Basin is aided by Klein's (1962) study of the onshore geology. The Wolfville Formation was deposited in an alternating flood plain–alluvial fan environment, whereas the Blomidon Formation was deposited in a lacustrine environment. Limited exposures of the Scots Bay Formation at Broad Cove also represent a lacustrine environment. Klein postulated a tropical humid climate for the Maritime Provinces during deposition of the Triassic red beds.

Swift and Lyall (1968a) showed that the dominant structure of the Acadian Basin was a syncline conforming to the attitude defined on shore by the hook representing Cape Split and Cape Blomidon where the North Mountain Basalt dips 5–15° towards the synclinal axis. The syncline extends out

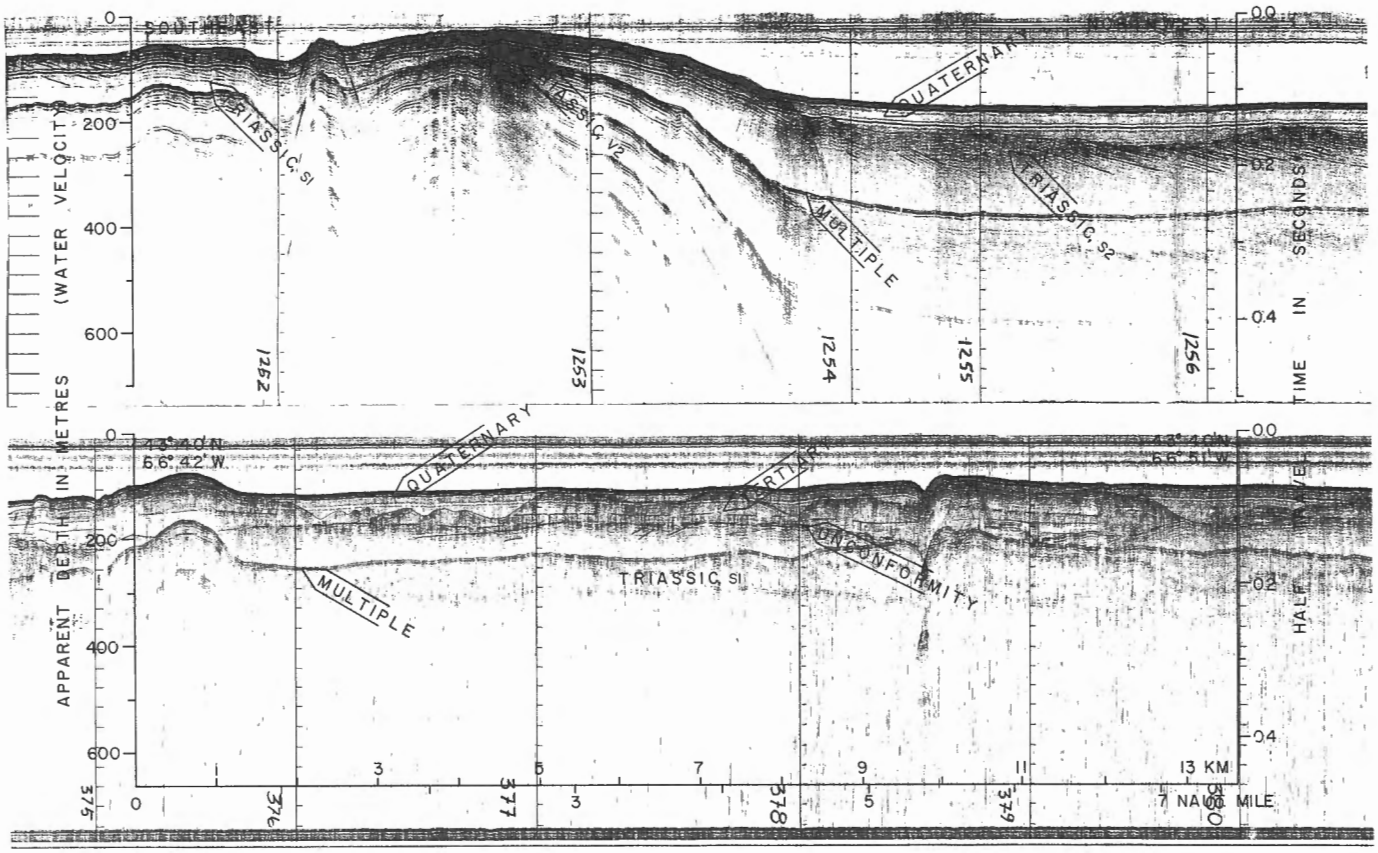

FIG. 2. *Upper*: continuous seismic reflection profile at points between 12 and 27 km along part of geological profile 3, Chart 2. The interpretation suggests the occurrence of the Blomidon–Wolfville formations (Triassic, S_1) at the southeast end of the profile overlain by the North Mountain Basalt (Triassic, V_2). The basalt is in turn overlain by the Scots Bay Formation (Triassic, S_2). The vertical exaggeration is approximately 6 times. *Lower*: continuous seismic reflection profile across strata that are interpreted as belonging to a Tertiary outlier 40 km west of Yarmouth. The Tertiary strata unconformably overlie sedimentary rocks of Triassic age. The vertical exaggeration is approximately 6 times.

of Scots Bay into Minas Channel, where its axis has been repeatedly offset by faults with a horizontal movement. The syncline plunges gently to the southwest and continues along the Bay of Fundy, becoming wider along its southern extension to Grand Manan Basin. At this point the axis of the fold shows an inflection around the shoals southeast of Grand Manan Island and then continues southwesterly. These structural and stratigraphic relationships are illustrated on Map 812H and in profiles 1–3, Chart 2 (in pocket).

In the Broad Cove area the North Mountain Basalt is capped by Scots Bay Formation consisting of a few meters of gray and purple beds of sandstone, claystone, and cherty limestone. Swift and Lyall (1968a) demonstrated that this formation thickened seaward; Map 812H shows its known extent offshore. Measurements along a seismic section (Chart 2, Profile 2) where the syncline reaches maximum width reveal a minimum thickness of 740 m (assumed velocity 3.0 km/s) for the Scots Bay Formation. Immediately south of Grand Manan the unit thickens to about 900 m (Chart 2, Profile 3). A part of the seismic record upon which Profile 3 is based is shown in Fig. 2 (*upper*). All seismic profiles show a well-defined and regular stratification in the Scots Bay Formation.

Swift and Lyall (1968a) also discovered a series of discontinuous faults that separate presumed Carboniferous from Triassic strata near the New Brunswick side of the basin. Where additional information was available, it was possible to show these faults on Map 812H in greater detail. The Carboniferous strata were more difficult to delineate because the profiling system was unable to penetrate Mississippian rocks; thus the narrow strip between the New Brunswick coast and the offshore Triassic was mapped as pre-Pennsylvanian acoustical basement. Much of this area could be underlain by Carboniferous strata, considering the distribution of these rocks along the adjacent shoreline. With the aid of aeromagnetic coverage and seismic profiles, we interpreted the fault system along the New Brunswick coast to be continuous with the Cobequid Fault along the north side of Minas Basin. The North Mountain Basalt follows and is at times incorporated into the fault zone as it cuts across the Bay of Fundy towards New Brunswick, but it appears to be downfaulted against the pre-Pennsylvanian unit approximately halfway across, 2.5 km west of Quaco Ledge. The North Mountain Basalt is not seen on the New Brunswick side beyond this point except possibly for the basalt occurrence on Grand Manan Island. Southwest of Quaco Ledge the fault appears to be well defined to 66°W where Swift and Lyall (1968a) assumed it to swing westerly and join obliquely with a fault off Point Lepreau. It might continue on a southwesterly course within Triassic rocks and join the faults at Grand Manan Island. A zone of disturbed strata along this course could represent the trace of a fault. This disturbed zone marks the northwest limit of the Fundy syncline in this area and thus provides additional evidence for the fault. Also, within the disturbed zone the aeromagnetic pattern shows greater variation, in contrast to the typically smooth signature of the Triassic sedimentary rocks. This discontinuity could mark the northwesterly limit of the Scots Bay Formation.

Bhattacharyya and Raychaudhuri (1967) recognized the Cobequid lineament in residual filtered magnetic maps of the Bay of Fundy. According to their magnetic interpretation, this lineament is divided into two parallel sub-blocks. East of 64°30′W the demarcation between subunits remains strong on the residual map but weakens on the filtered maps, suggesting that the fault dividing the units is shallow in the area. Southwestward, the southern subunit fades out within a shorter distance than does the northern unit. This suggests that vertical displacement along the boundaries of the subunits becomes more pronounced toward the west, but extrapolation was not carried beyond 66°W.

We believe, as did Swift and Lyall, that the fault zone along the New Brunswick coast is related to the Fundian Fault although the latter was thought to lie nearer the shore (Johnson 1925). Johnson based his argument for a fault-line scarp on linear escarpments bordering the partly submerged coastline, as well as on several prominent submarine scarps. He projected the system parallel to the Maine coast to about 70°30′W. The Triassic outliers along the New Brunswick coast are also fault bounded. The fact that the fault is discontinuous in certain areas does not detract from the argument for the existence of a major fault system. These discontinuities might occur between parallel faults that follow the major trends, a style that is apparent along this system as it crosses central Nova Scotia. The system might be further complicated by oblique faulting which also occurs on a regional scale in the area, as, for example, the offsets along North Mountain. The evidence strongly favours a half-graben origin for the Acadian Basin as postulated by Powers (1916).

Definite correlation of Triassic strata around the Bay of Fundy has not been achieved although Klein (1962) proposed a scheme on the basis of lithology. A modified correlation was proposed by Poole et al. (1970). Unfortunately, the seismic studies did not provide further evidence to assist in the solution of this problem. The Scots Bay Formation extends from Nova Scotia as far as the fault along the northwestern side of the Bay of Fundy, but a correlation with the strata to the north of the fault was not established. The Scots Bay Formation may extend into this area; on the other hand, the strata may be correlated with the Triassic units that occur along the New Brunswick shore. Therefore the strata north of the fault were mapped as undifferentiated Triassic on the basis of acoustical characteristics similar to those of adjacent strata of this age.

Stratigraphic thicknesses vary from a total of 760 m on the southeastern margin of the basin, including the North Mountain Basalt, to 1600 m at Point Lepreau on the New Brunswick side. In addition, 740 m of Scots Bay Formation are present in parts of the Bay. These values indicate that thicknesses of at least 2000 m of Triassic sediments may have been deposited in areas of the Bay of Fundy.

Southeast flank — The stratigraphic sequence of interbedded volcanics with the sediments in the Fundy Group provided an important key for the interpretation of the geology beneath the northeast Gulf of Maine and the Bay of Fundy. Seismic results show that the Wolfville and Blomidon formations continue from Annapolis Valley southerly along St. Mary's Bay to approximately 43°40′N, 70 km southwest of Yarmouth. At its southern extent this sequence is overlain unconformably by a younger unit of possibly Tertiary age. The overlying North Mountain Basalt can also be traced seaward along a similar trend, which essentially follows the trend of the eastern flank of the Fundy syncline. Its outcrop pattern is confirmed both by the aeromagnetic and shipborne magnetometer results. Approximately 15 km south of Brier Island the volcanic ridge is offset about 15 km to the northwest by an oblique fault. The pattern of offset is similar to the offsets at Brier Island, Long Island, head of St. Mary's Bay, and Digby Gut along North Mountain. The linear trend of the basalt then continues southwest for approximately 85 km to 43°40′N, 67°W. At this point the geologic relationships both

with respect to the basalt and the underlying Blomidon and Wolfville formations become uncertain.

In summary, the stratigraphic and structural integrity of the Fundy Group is maintained over a distance of 375 km from Truro to a point 35 km west of Yarmouth, along the entire eastern margin of the Acadian Basin half-graben. The Wolfville Formation unconformably overlies rock of either Cambro-Ordovician, Silurian, Devonian, or Carboniferous age along the entire boundary.

Southwest section — The line of demarcation between the northeast and southwest halves of the Acadian Basin occurs immediately northeast of Grand Manan Island. The southwestern part of the Acadian Basin differs dramatically in structural style from the northern, rather simple synclinal trough. Tagg and Uchupi (1966), and Uchupi (1966) recognized that basement irregularities separated the Bay of Fundy from the Gulf of Maine and continued into the latter. However, Triassic strata are continuous from the Bay of Fundy to the Gulf of Maine and extend southwest into Jordan Basin to approximately 43°30′N, 68°W. Tagg and Uchupi (1966) showed that the Triassic sedimentary rocks were separated by basement highs into three narrow troughs: (1) between Grand Manan Island and the mainland, (2) between the island and the Grand Manan Banks, and (3) south of the Grand Manan Banks.

Grand Manan Island and the shoals to the southeast show strong positive gravity and magnetic anomalies which probably reflect the Precambrian and Paleozoic structural framework. The magnetic contrast between these topographic highs and the surrounding sedimentary basins is well illustrated on the aeromagnetic map for the area (Geological Survey of Canada Aeromagnetic Series, Map 7033G, 1965) and the linear nature of these contacts along the northeastern and southeastern sides suggests faulting, with the Fundy Group downfaulted against the Grand Manan complex. The magnitude of the anomaly is approximately 350 gamma (Fig. 3). The free air gravity contours (Fig. 4) mimic the magnetic pattern and vary from a high of 30 mgal across the shoals immediately southeast of Grand Manan to a low of −10 mgal within a distance of 15 km to the northeast. A Bouguer correction for the difference in water depth does little to change this relationship. The compatibility of the magnetic and gravity data with the surface geology, mainly established by the high resolution seismic techniques, can be emphasized for the entire southern half of the Acadian Basin.

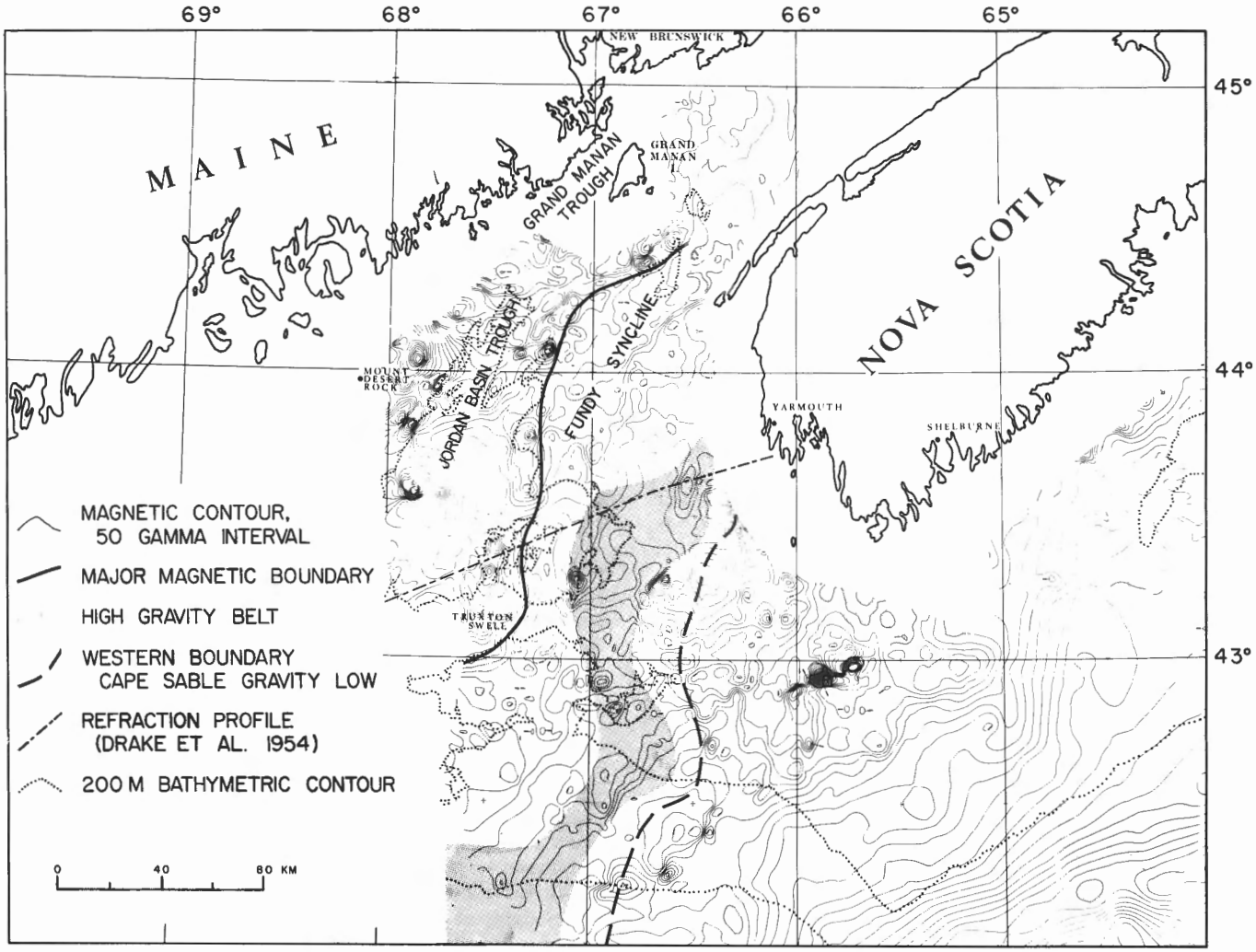

FIG. 3. Total field, shipborne magnetic data for eastern Gulf of Maine (after Canadian Hydrographic Service Natural Resource maps 15124-C, 15126-C, 15134-C, 15136-C, and 15146-C; compiled by R. T. Haworth, 1974). Generalized magnetic and gravity trends across the region are identified on the diagram.

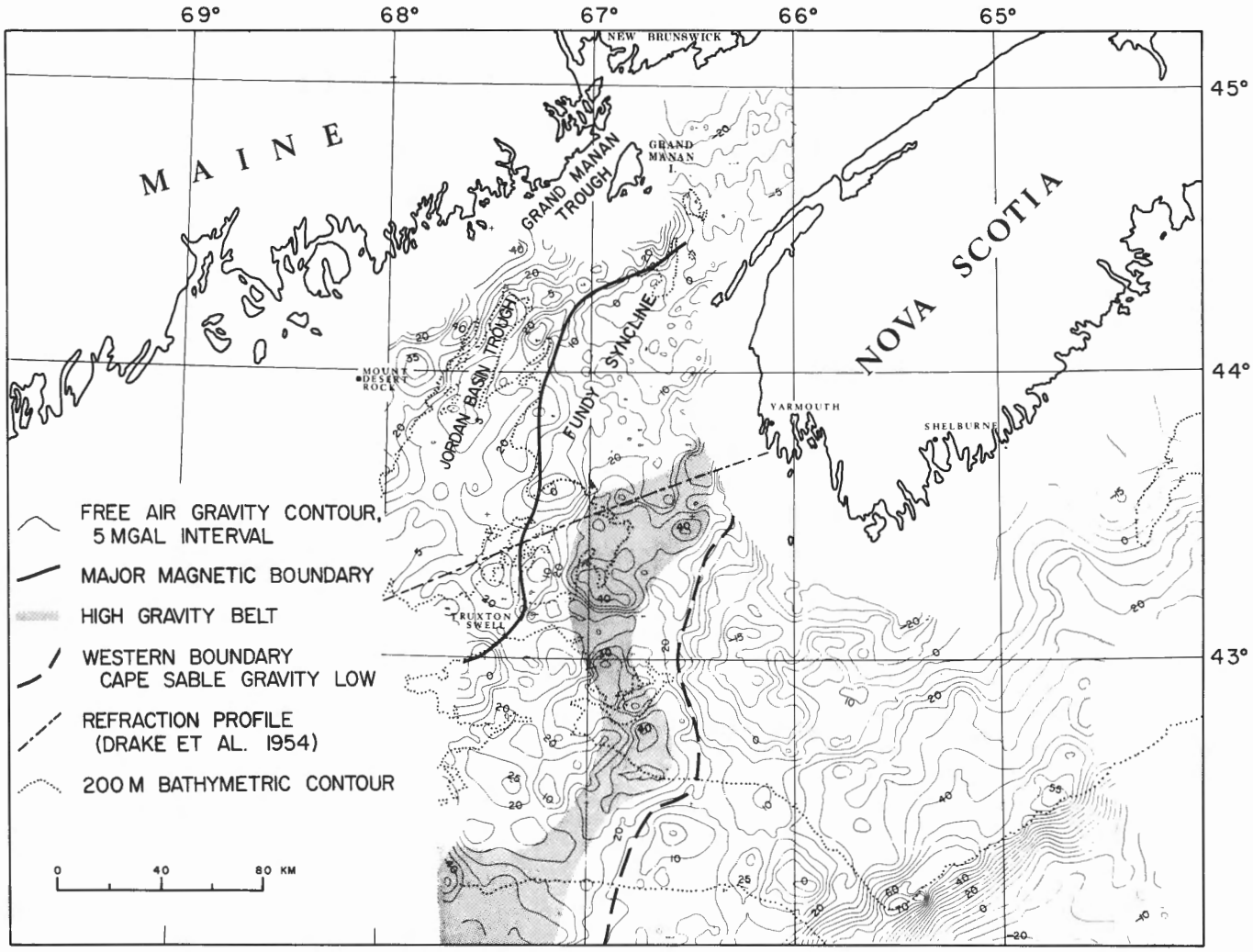

FIG. 4. Free air gravity anomaly data for eastern Gulf of Maine (after Canadian Hydrographic Service Natural Resource maps 15124-B, 15126-B, 15134-B, 15136-B, and 15146-B; compiled by R. T. Haworth, 1974). Generalized magnetic and gravity trends across the region are identified on the diagram.

All three studies emphasize the important trend from Grand Manan Island southwest to Mount Desert Rock along the northwest flank of Jordan Basin. At Grand Manan Island this trend is represented by faulted Triassic basalt, Silurian volcanics, and Precambrian metamorphics, but there are no sample data by means of which these occurrences can be extended along this trend. This topographic, magnetic, and gravity high separates the Triassic sedimentary troughs along Grand Manan Channel and along the northwest arm of Jordan Basin. In this report these features will be referred to as the "Grand Manan trough" and the "Jordan Basin trough" respectively (Fig. 3 and 4). The geophysical signature of the intervening high blends with the signature of the rocks along the inner shelf of the coast of Maine as the Mount Desert Rock area near 44°N and 68°W is approached.

The Jordan Basin trough is characterized by a smooth magnetic signature and low gravity values of from 5 to 10 mgal, which are terminated against a gravity and magnetic high at 43°30′N, 67°50′W. The high trends northwest–southeast, decreasing in intensity to the southeast, and divides Jordan Basin trough from another basin to the southwest recognized by Drake et al. (1954) from refraction data which showed a thickness of 490 m for a sedimentary layer with a velocity of 3.5 to 4 km/s. This basin appears to extend beyond 68°W. Reflection seismic profiles west of 68°W across the basin recognized by Drake et al. (1954) show a general smoothing of the bedrock surface in contrast with the adjacent basement surfaces, but internal reflectors were not observed because of the higher reflective character. Thus these rocks may be older and possibly of Carboniferous age, but were incorporated into the Acadian Basin through Triassic faulting.

A second major magnetic and gravity high occurs on Grand Manan Banks between the Jordan Basin trough and the southern extension of the Fundy syncline. It also finds expression through variations in the surface geology and topography and has a southwest–northeast trend that could include the shoals southeast of Grand Manan Island. A southerly branch from this trend runs parallel to the North Mountain Basalt on the eastern side of the basin and also has a positive gravity and magnetic expression. Initially this branch was thought to swing around the southern nose of the Fundy syncline and join the North Mountain Basalt, but this assumption was not borne out by the analytical results of dredge samples (Fig. 5). Very little basalt was recovered in the

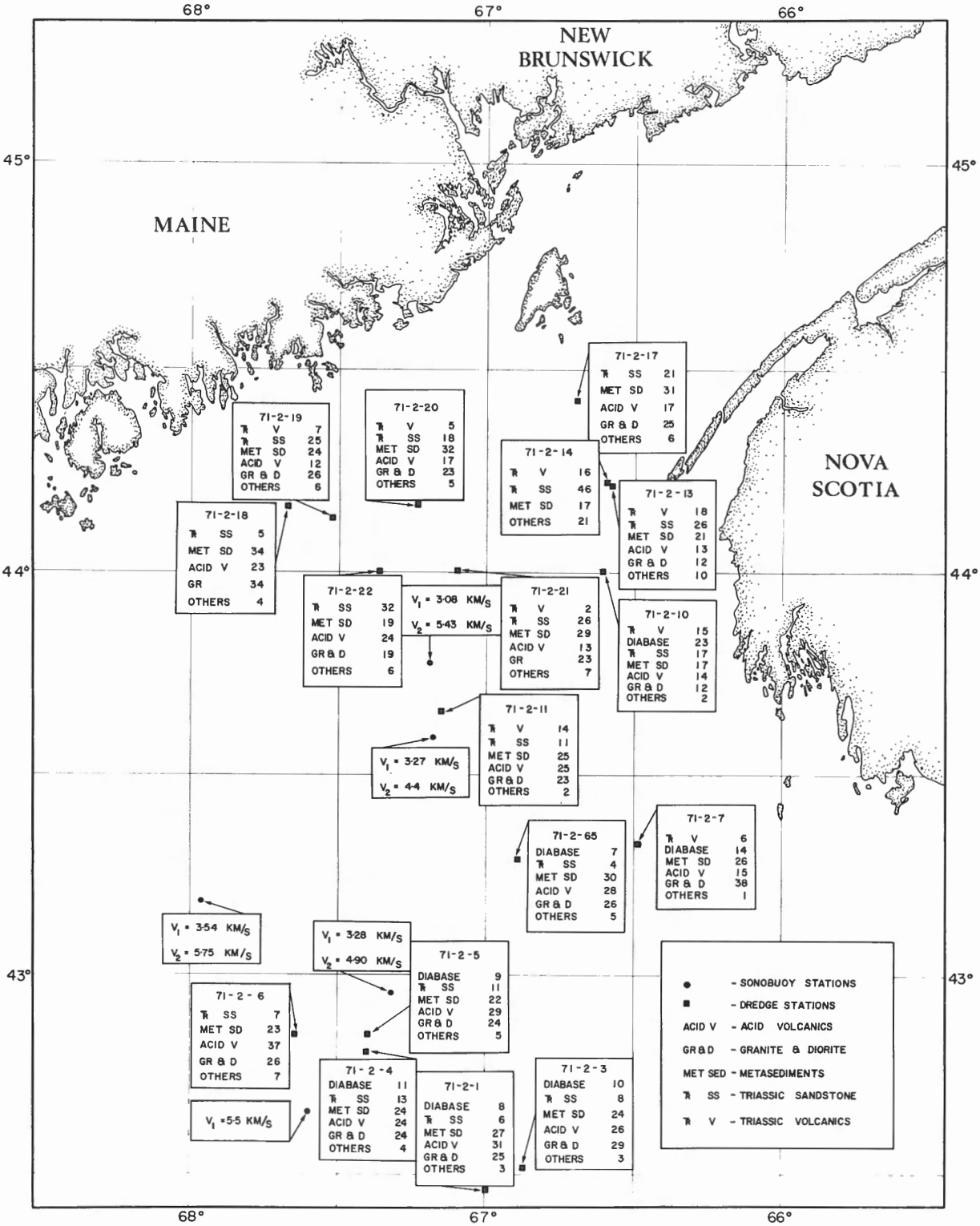

FIG. 5. Rock analyses and velocity data from dredge and sonobuoy stations. The samples represent the coarse fraction of glacial debris, and compositions are expressed as percent by number of particles present. The significance levels for Triassic sandstone and Triassic basalt were established at two control points overlying known occurrences of these rock types. Values of 10–15% for Triassic basalt and 15–20% for Triassic sandstone may indicate their occurrence at or near the sample point. Other rock suites indicated in the analyses represent composite designations (e.g. "metasediments" represents a variety of lithologies and ages) and significance levels are more difficult to establish. Possibly values of 25–35% for metasediments, acid volcanics, and granites would indicate their occurrence in the general area of the sample point. The velocity data were used in support of the seismic reflection data to separate sedimentary and basement rock types.

dredge samples of glacial debris west of the Fundy syncline and therefore the entire ridge has been mapped as pre-Pennsylvanian basement. It is possible that the pre-Pennsylvanian trend along the Grand Manan Banks represents a continuation of the poorly differentiated Precambrian–Lower Paleozoic rocks of Grand Manan Island.

These structural and stratigraphic relationships are illustrated on geologic section A-B, Map 812H, as well as on Chart 2, Profile 4. The faults are assumed to exist either on the basis of bedding attitudes with respect to the pre-Pennsylvanian acoustical basement, or on regional relationships and basin alignment supported by gravity and magnetic data. Although the structural styles of the Gulf of Maine and Bay of Fundy sections of the Acadian Basin appear to differ in detail, the idea of a discontinuous marginal fault system toward the western side of the entire Acadian Basin appears to be reasonably acceptable despite the fact that it does not take the form of a simple boundary fault as originally postulated by Johnson (1925).

At least 2300 m of Triassic sediments are present in the Jordan Basin trough (Chart 2, Profile 4) and about 900 m of Scots Bay Formation are present at the southern extremity of the Fundy syncline (Chart 2, Profile 2). The thicker sedimentary sequences at the western side of the Acadian Basin in the Gulf of Maine section are consistent with the greater thicknesses found on the New Brunswick side of the Bay of Fundy section along the downthrown side of the half-graben. The original sedimentation pattern in the Acadian Basin may have formed in two ways. On the one hand, the formation of a half-graben early in the history of the basin would explain the thicker section on the northern side of the basin. On the other hand, if the major faulting was a late factor in basin development, it is probable that the Triassic depositional boundaries originally extended well beyond the present limits of the basin. Faulting within the basin probably was related to the major rift system at the continental margin where continental breakup occurred in late Triassic to early Jurassic time. Some of the faulting occurred in late Triassic time (Poole 1967), but it is not known if faulting occurred concomitantly with sedimentation throughout most of the history of the basin.

Glooscap fault system — King and MacLean (1970a) discussed the Cobequid–Chedabucto Fault System that transects Nova Scotia from Chedabucto Bay to the north side of Minas Basin, and its possible extension to the west into the Gulf of Maine and to the east along the Orpheus basin on the Scotian Shelf and thence along the southwest margin of the Grand Banks. In the previous section we presented further evidence for its western extension beyond Grand Manan Island to at least 68°W. Additional evidence for its eastern extension across the Scotian Shelf is presented later in this report. Ballard and Uchupi (1972) also suggested that the fault extended into the Gulf of Maine and possibly into Massachusetts and Rhode Island. Because of the apparent magnitude of this fault system we herein propose an overall name for the feature: the Glooscap fault system,[2] and suggest that the previous nomenclature, such as the Fundian Fault and the Cobequid–Chedabucto Fault System be retained as divisions of the Glooscap system within limits of the geographic areas for which they originally were proposed.

[2] Glooscap was the culture hero of the eastern Algonquian tribes of the Maritime Provinces and adjacent parts of Maine, notably the Micmac, Malecite, and Passamaquoddy. Many features of the landscape were attributed to his actions.

In our original discussion we also suggested that the system might follow the Newfoundland Ridge and join with the Azores–Gibraltar Ridge. Auzende et al. (1970) proposed the name Newfoundland fracture zone for a zone of faulting that they recognized from seismic reflection studies along the Newfoundland Ridge. In view of this we further suggest that the name Glooscap fault system be applied to the part of the system that involves continental crust, and that the name Newfoundland fracture zone be used for the deepwater part of the system which appears to be a fossil transform fault involving oceanic crust. The Glooscap system is essentially Triassic and earlier, but evidence for faulting in Cretaceous time will be presented later in the report.

Carboniferous elements — Bell (1944) showed that Triassic rocks unconformably overlie folded and faulted Carboniferous clastic rocks in the Minas sub-basin in Nova Scotia, and that they are in fault contact with rocks of Carboniferous age on the flank of the Caledonian uplift along the New Brunswick coast. Bell included this Carboniferous basin underlying the Bay of Fundy, as well as the Cumberland sub-basin, with a larger geosynclinal area of Carboniferous sedimentation which he designated the Fundy Geosyncline. Poole (1967) extended the limits of the geosyncline along the Minas Basin–Chedabucto structural basin north of the Meguma Platform and included parts of Cape Breton Island, Prince Edward Island, and a narrow belt through western Newfoundland to White Bay. According to Poole, the geosyncline consists of a composite of individual troughs, basins, and intervening uplifted source areas which have had a complex history of vertical movement. Platforms bounding the geosyncline are covered with relatively undeformed rocks that grade into thicker, more deformed strata in the geosyncline. Belt (1968) visualized the area of mobility between the Meguma and New Brunswick platforms as a complex rift valley system and utilized the concept as a model for sedimentological studies. Ballard and Uchupi (1972) applied this concept to the Gulf of Maine and postulated a Carboniferous–Triassic rift system from the Bay of Fundy to the Narragansett Basin. On the other hand, Van de Poll (1972) preferred not to subdivide the total Carboniferous basinal area into tectonic elements because of the many uncertainties concerning the nature and extent of Carboniferous deformation.

Aside from the various ideas regarding the style of Carboniferous deformation, Poole, Belt, and Van de Poll all recognized the higher degree of deformation and metamorphism along a narrow belt that more or less coincides with the Glooscap fault system and appears to have served as a center for Triassic deposition. Van de Poll dated the zone of metamorphism as late Pennsylvanian to Triassic age. This zone may have been the site for even earlier motion in the form of large lateral translations as suggested by Webb (1969). Eisbacher (1969) provided evidence for some right-lateral, late Pennsylvanian displacement on the Cobequid Fault; however, this does not invalidate the stratigraphic evidence which indicates major vertical crustal movements in the form of grabens and half-grabens along the entire Glooscap fault system. We have discussed the involvement of Triassic sediments and volcanics in the Minas Channel close to Eisbacher's study area, in the seaward extension of the Cobequid Fault. This can also be recognized ashore along the Cobequid and Portopique faults (Weeks 1948). Possibly, the transcurrent motion that Eisbacher recognized might be associated with the metamorphic zone that developed before the Triassic faulting. King and MacLean (1970a) recognized a third

period of adjustment on the system which involved Cretaceous and early Tertiary sediments in the Orpheus basin and was accompanied by salt tectonism. They also noted that the latest motions might have been associated with plate adjustments in the Atlantic.

Acoustical Basement

Rocks were included in the acoustical basement because they have a high reflectivity and subsurface reflectors were not observed within this unit. It does not preclude the fact that some of the rocks within this division are of sedimentary origin, but there is a strong implication that sedimentary rocks present in this unit are of Mississippian age or older. This unit is useful for broad regional considerations between the older Paleozoic and Precambrian rocks and the younger Paleozoic rocks, but to differentiate and categorize the older unit gravity, magnetic, and refraction techniques, with lithologic and structural control from the adjacent shore geology, must be used.

When this approach is applied to the areas of the acoustical basement it can be divided into two major units: the offshore Meguma Group and its related rocks (€D), and the Pennsylvanian unit (pP) which is divided on a geographical basis into the east central Gulf of Maine basement (southwest of Yarmouth) and the Scatarie basement ridge east of southern Cape Breton Island. Narrow belts of pre-Pennsylvanian rocks also occur along the northwest boundary of the Acadian Basin, as well as around the Sydney Basin along the north coast of Cape Breton Island and along the south coast of Newfoundland.

Offshore Meguma Group and its related rocks — Rocks of the Meguma Group dominate the geology of Nova Scotia south of the Glooscap fault system. The group consists of the Upper Cambrian Goldenville Formation, composed of up to 5500 m of graywacke, quartzite, and slate, and the overlying Lower Ordovician Halifax Formation, composed of up to 3700 m of slate (Weeks 1965; Taylor 1967, 1969). Poole et al. (1970) summarized the work of Taylor (1965, 1969), Crosby (1962), and Smitheringale (1960) on four conformable formations: the White Rock, Kentville, New Canaan, and Torbrook, mixed clastic and volcanic assemblage, that conformably overlies the Meguma Group. The entire assemblage consists of quartzite, slate, and andesitic rocks that thicken from about 600 m in the northeast to nearly 6000 m near Yarmouth. These rocks represent almost continuous deposition from Cambrian to Devonian time and, during the Acadian orogeny of middle and late Devonian age, were isoclinally folded, metamorphosed, and intruded by granite. Metamorphic grades as high as the almandine–amphibolite facies occur in southwest Nova Scotia.

Schenk (1970), comparing the Meguma Group to models of flysch basins, concluded, from a dispersal pattern analysis, that the group may be an abyssal plain–continental rise complex derived from a large granitic craton to the southeast. On the basis of a plate tectonics model, Schenk (1971), following earlier suggestions by Wilson (1966), speculated that the Meguma Group was transported from the African to the American continent through continental collisions. Subduction at the plate margins was responsible for increased volcanism, telescoping of sedimentary and volcanic complexes, emplacement of granodioritic batholiths, and for the formation of the folded and metamorphosed Meguma platform.

The gravity field across the major part of the Meguma platform consists of a broad negative Bouguer anomaly with lowest values of −55 mgal in the central area west of Halifax (Fig. 6). This central negative anomaly was interpreted by Garland (1953) in terms of a large granite batholith.

The magnetic anomalies on the Meguma platform are related to isoclinal folds of the Goldenville and Halifax formations, and the high magnetic susceptibility of the latter. These provide the long linear anomalies described by Hood (1966a, 1966b), and depict the structural grain of the Meguma Group. In western Nova Scotia the magnetic lineations arise in part from the andesitic flows of the Whiterock Formation that are infolded with the Meguma Group (Bower 1962).

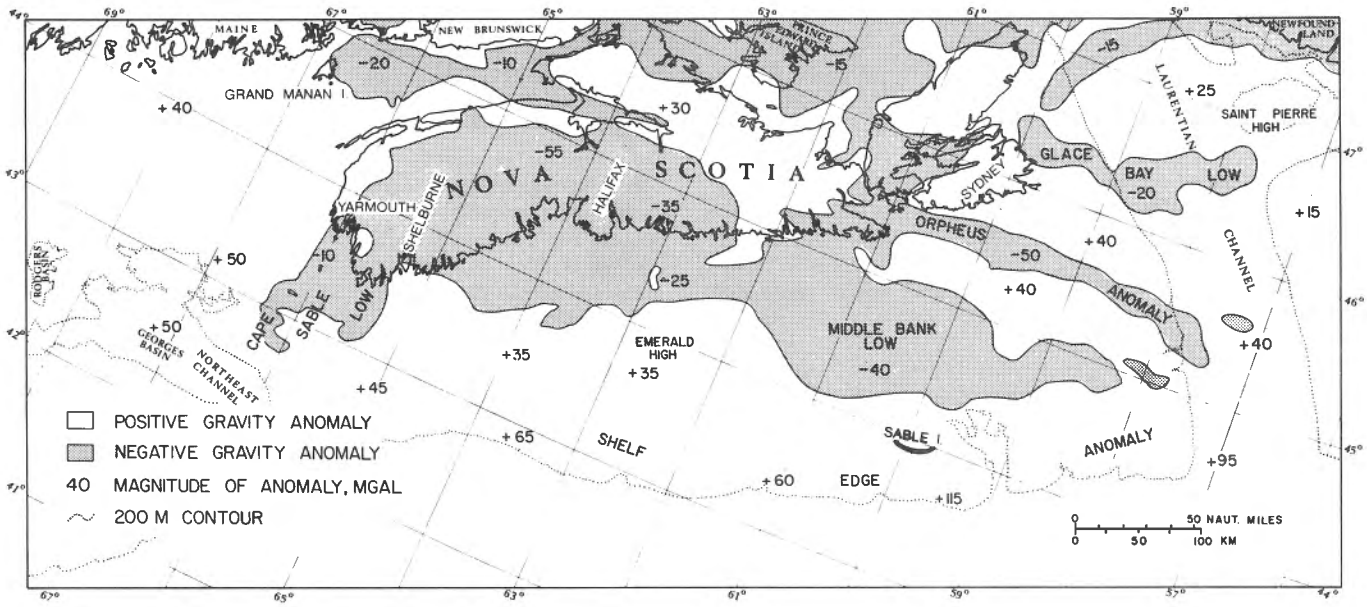

Fig. 6. Bouguer gravity anomaly map of the study area (after Garland 1953, Stephens et al. 1971, Stephens and Cooper 1973, and Haworth and MacIntyre 1975).

Offshore studies have assisted in defining the limits of the Meguma platform, and the probable extension of these basement rocks beneath the Mesozoic–Cenozoic section on the shelf (McGrath et al. 1973). Hood (1966a, 1966b) recognized that the characteristic magnetic pattern across the Meguma rocks can be traced offshore on the inner shelf immediately south of mainland Nova Scotia. These trends are apparent on the Aeromagnetic Series maps produced by the Geological Survey and run virtually parallel to the structurally controlled pattern of the Halifax Formation on the mainland. Hood (1966b) also outlined several granite bodies on the shelf from their magnetic patterns.

The gravity field of a large part of the Scotian Shelf south of the Orpheus basin shows the same broad characteristics and the same trend as the negative anomalies west of Halifax (Fig. 6). The main low occurs across Middle Bank (Middle Bank low, Stephens et al. 1971), and is attributed in part to a Devonian granite batholith. The magnitude and to some extent the shape of the anomaly may be influenced by the thickness of overlying sediments, particularly if salt is present. The trend of the northern boundary of this low is parallel with the Orpheus trend to the north, that is, parallel to the Glooscap fault system, although separated from the Orpheus negative anomaly by a strong belt of positive anomalies with maximum values of about 30–40 mgal. There is a continuous gravity gradient between the Middle Bank low and the increase in Bouguer anomaly to the southeast coincident with the shelf edge, thereby indicating that the edge of the body causing the Middle Bank low must be close to the edge of the shelf. Therefore the eastern end of the Meguma platform may extend along the southern side of the Glooscap fault system to the edge of the shelf.

West of the Middle Bank low the gravity field becomes positive with values to 35–45 mgal on Emerald (Emerald high), LaHave, and Baccaro banks (Stephens and Cooper 1973), and extends northerly to the present coastline south of Shelburne. The boundaries of the negative and positive anomalies maintain a trend parallel with the structural trends on the mainland. The reason for the prominent high south and east of Shelburne is not understood, but two offshore wells (Shell Mohawk B-93 and Shell Naskapi N-30) drilled on this positive area encountered a basement of granite and of Meguma schist and quartzite respectively, and so the anomaly does not represent a lithologic change from that typical of the Meguma platform.

The gravity and structural features in southwestern Nova Scotia trend farther to the south and are called the Cape Sable low (Fig. 6 and Map 812H). The negative anomaly associated with the granite batholith west of Halifax merges with the Cape Sable low and extends beyond Northeast Channel. Watts (1974) tested the granite hypothesis for the Cape Sable low with various models and found it to be a reasonable interpretation. The granite batholiths underlying the Cape Sable low and the central low west of Halifax may be joined at depth. At approximately 190 km south of Yarmouth the low terminates because of the abrupt increase in Bouguer anomaly at the shelf edge. The western boundary of the Cape Sable low extends southward along 66°30′W to 42°30′N, but another decrease in gravity along the same trend on the northern side of Georges Bank may indicate a further extension of the granite zone to the south (Fig. 4). A refraction line (Drake et al. 1954) that was run along a line normal to the western boundary of the Cape Sable low shows that the boundary coincides with the eastern flank of a deep trough in a subbasement layer. These relationships will be discussed in some detail in the following section.

The typical magnetic expression of linear anomalies across the Meguma rocks was also observed south of Yarmouth (Bower 1962). Bower's map shows that the trends are southerly, continuing to approximately 43°15′N, and appear to have been caused by the folded andesitic volcanics and Halifax slate occurring along the north–south structural trends in the Yarmouth area. At 43°15′N some of the trends change abruptly to a southwesterly direction, providing some evidence for faulting.

Pre-Pennsylvanian, east central Gulf of Maine — At present, a lithologic boundary between the rocks of the Meguma Platform and the pre-Pennsylvanian acoustical basement further west in the Gulf of Maine cannot be mapped. Magnetic lineations, typical of the Meguma platform, were not observed west of 66°45′W (Fig. 3), but this might be a result of wider track spacing when this area was surveyed. However, the gravity (Fig. 4), magnetic (Fig. 3), and refraction data (Drake et al. 1954) reveal trends that might be useful in defining, within broad limits, the western extent of the Meguma platform.

The western boundary of the Cape Sable low (Fig. 6) marks the western limit of the regional gravity low that runs through southwestern Nova Scotia and joins with the Middle Bank low. The gravity data for the eastern Gulf of Maine from this study (Fig. 4) and from Kane et al. (1972) provide regional coverage for most of the Gulf of Maine, and in general indicate a regional high gravity level. At the Maine coast, the regional field again assumes a low level. West of the Cape Sable low, the gravity field values increase and are accented by a belt of high anomalies of about 30–40 mgal free air (40–50 Bouguer), which is approximately 50 km wide and trends southerly. These anomalies are isolated and superimposed on a background field of 10–30 mgal free air (20–40 Bouguer).

Kane et al. (1972) noted for the central and western part of the Gulf of Maine that values of the Bouguer gravity field increase from the coastal areas of Maine toward the center of the Gulf of Maine. They reported a background gravity field of 15–25 mgal Bouguer with a superimposed complex group of positive and negative anomalies which taken together show a low-order northeast trend. Kane et al. (1972) interpreted this pattern as representing near-surface masses of felsic and mafic igneous and possibly sedimentary rocks, set in a matrix of metamorphic rocks that might be lower Paleozoic or even Precambrian in age.

Based on a comparison with Kane's results, the southerly trending high gravity belt west of the Cape Sable low appears to be significantly higher than the adjacent area to the west. This belt may be the western edge of the Meguma platform.

A refraction line (Drake et al. 1954) from Cape Ann, Massachusetts, to Yarmouth, Nova Scotia (see location in Fig. 3 and 4), showed that much of the Gulf of Maine is underlain at a shallow depth by a subbasement layer with a velocity of 6.0 km/s. Within the map-area this subbasement layer underlies the sedimentary basin at 68°W and 43°15′N. East of this basin the subbasement layer appears to outcrop at the seabed for a distance of 30 km and may be a more southerly continuation of the pre-Pennsylvanian trends along Grand Manan Banks, which, as suggested earlier, could be a Precambrian–lower Paleozoic complex.

Farther east along the refraction line the subbasement layer dips easterly along the line of section to form the western flank of a deep trough filled with 3 km of crystalline

basement rocks with a mean velocity of 5.13 km/s and a range of 4.5–5.5 km/s. These compare with measurements on the Meguma platform of 5.40–5.76 km/s for the first crystalline basement layer and 6.10–6.26 km/s for the second or major continental crustal layer (Dainty et al. 1966). The first basement layer was considered to be 5–10 km thick.

A comparison of the refraction section (Drake et al. 1954) with the gravity (Fig. 4) and magnetic (Fig. 3) data along the eastern Gulf of Maine shows that the western boundary of the Cape Sable low coincides with the eastern flank of a trough (Drake et al. 1954). The western edge of this trough, or area where the subbasement is exposed at the seabed, is correlated with the eastern limit of a highly anomalous magnetic zone that extends from the shoals southeast of Grand Manan Island, to Grand Manan Banks, thence south along 67°15′W to Truxton Swell (Fig. 3), where it swings to the southwest across Rodgers Basin (Kane et al. 1972).

The geophysical data support the existence of a major geological discontinuity in the Bay of Fundy, extending south across the central part of the area mapped as pre-Pennsylvanian basement near 67°W. On the western side of the discontinuity a Precambrian–lower Paleozoic complex may be present, possibly a continuation of the Avalonian trend (Zone H of Williams et al. 1972) from the Caledonia Highlands, through Grand Manan Island, and along the central axis of the Gulf of Maine. The eastern side of the discontinuity might represent the western edge of the Meguma platform (Zone I of Williams et al. 1972).

Dredge samples generally do not provide sufficiently reliable data for mapping definitive contacts, but their high volcanic content in this area (Fig. 5) is probably significant. Rocks of this type are common in the younger Silurian formations along the western exposure of the Meguma platform.

A fault-bounded sedimentary accumulation (undifferentiated Pennsylvanian to Jurassic in age) in Crowell Basin is superimposed on the pre-Pennsylvanian acoustical basement (Map 812H and Chart 2, Profiles 5 and 6). This basin is similar to the basin defined by refraction data at the western boundary of our map. Weak internal reflections were only noted on one profile across the basin; otherwise, it was recognized by its smooth surface that contrasted sharply with the rough surfaces on the adjacent basement rocks. Sonobuoy velocity data (Fig. 5) gave a near-surface velocity of 3.28 km/s for the rocks of the sedimentary basin contrasting with a velocity of 4.90 km/s for the basement, and a velocity of 5.5 km/s for the adjacent outcropping basement rocks. This basin was the only one found in this study; Ballard and Uchupi (1972) have described several similar basins to the west, as well as the Crowell Basin occurrence.

Pre-Pennsylvanian, Scatarie basement ridge — The Scatarie basement ridge was described by King and MacLean (1970a). It is an east trending ridge that extends from the southeast coast of Cape Breton Island, across Scatarie Bank and the Laurentian Channel to St. Pierre Bank. It is probably composed of Precambrian metasediments and volcanics, a Cambrian–Devonian suite of sediments and intrusives, and some overlying Mississippian sediments, because all of these occur along the southeast coast of Cape Breton Island. A 4.5-m core of basic volcanic rock was recovered from the basement ridge in 1973 using the Bedford Institute's shallow drill. The site is located 65 km east of Scatarie Island (Map 812H). The ridge divides a thick sequence of Mesozoic, Cenozoic, and probably Carboniferous rocks in the Orpheus basin to the south, from the Carboniferous rocks of Sydney Basin to the north. This ridge forms the sub-Pleistocene bedrock surface eastward to 58°W where it is overlain by Pennsylvanian and Tertiary sediments. Refraction data (Sheridan and Drake 1968) indicate that the ridge, in the center of the Laurentian Channel, has a relief of 2 km and is overlain by approximately 3.5 km of Mississippian and Pennsylvanian strata. Seismic velocities within the ridge range from 5.8 to 6.1 km/s (Ewing and Hobson 1966; Sheridan and Drake 1968). It is probably part of the Avalon Platform or Zone H of Williams et al. (1972). Haworth (1975) also suggested continuity between these zones by means of a prominent magnetic and gravity anomaly.

Mesozoic–Cenozoic Section — East Coast Geosyncline

The Mesozoic–Cenozoic section on Georges Bank and the Scotian Shelf, comprising Jurassic, Cretaceous, and Tertiary rocks, is a continuation of the succession underlying the Atlantic Coastal Plain and adjacent continental shelf that borders the mainland from the Gulf of Mexico to New England. King (1975) suggested that, because the succession is of geosynclinal dimensions, the major element might be referred to as the east coast geosyncline. This usage is herein continued and the sedimentary rocks within the geosyncline will be referred to as the east coast sediments rather than the coastal plain sediments as has been common in the past. The contact between the east coast sediments and the basement rocks of the Meguma platform occurs south of Nova Scotia about 50 km offshore, and is parallel to the coastline (Map 812H). Southeast of Cape Breton Island these rocks were deposited on the Scatarie basement ridge (Precambrian and Paleozoic rocks) and, in the Laurentian Channel, on rocks of Pennsylvanian age. The east coast sediments in the map-area fall into two structural categories: those sediments underlying most of Georges Bank and the Scotian Shelf that have a gentle regional dip of 0.5 to 1° to the south, and strata at the eastern end of the shelf in the Orpheus basin that are gently folded and generally faulted at the basin margin. Gently folded Jurassic strata also occur north of Georges Bank in Georges Basin. Before discussing the surface geology and shallow stratigraphy of these areas, a review of the subsurface geology and depositional framework of the east coast sediments will aid in providing a third dimension to the study.

Review of subsurface geology — The geological development of the margin of Atlantic Canada was discussed by King et al. (1975). Beginning in the late Precambrian and continuing throughout Paleozoic time the rocks of Atlantic Canada were deformed, metamorphosed, and intruded by granites as a result of the convergence of two major lithospheric plates (Wilson 1966; Schenk 1971). This sequence of events provided the platform upon which the continental part of our present margin was developed. In late Triassic to early Jurassic time rifting and sea-floor spreading commenced. These events led to the development of the Atlantic Ocean basin and the deposition of a thick sedimentary sequence of geosynclinal dimensions along its western margin, the east coast geosyncline. The geosyncline, underlying the continental shelf, rise, and abyssal plain, is still subsiding and receiving sediment. It can be divided into a miogeocline (King 1975) encompassing the Jurassic, Cretaceous, and Tertiary sequence underlying the continental shelf, and a eugeocline comprising strata of similar age underlying the continental rise and abyssal plain. The boundary between the miogeocline and eugeocline is in many areas represented by the modern and ancient continental slope.

The formation of the marginal geosyncline depended primarily on two physical processes. The marginal area (both oceanic and continental sides) subsided from thermal contraction following the thermal expansion and uplift associated with the initial rifting process. It was further depressed by the load of sediment being deposited along the margin.

Drake et al. (1959) noted a number of depocenters or deep basins and troughs on subsurface structural maps of the basement surface along the Atlantic margin. One such depocenter underlies the eastern part of the Scotian Shelf and rise and was named the Scotian basin (Jansa and Wade 1975). Figure 7 shows that this basin contains 10 km of sediment underlying the continental rise. The basin is over 8 km thick in the area of Sable Island and Banquereau, but thins rapidly to the west under Emerald, LaHave, and Browns banks. The Orpheus basin, along the Glooscap fault system, contains up to 6 km of sediment, a large part of which is east coast strata overlying Carboniferous strata. Sherwin (1973) noted that the greatest development and thickness of the east coast sequence occurred near the mouth of the ancestral St. Lawrence River and this system presumably supplied much of the sediment. This ancient drainage system possibly dates back to late Jurassic time (King and MacLean 1970d).

Petroleum exploration drilling activity on the Scotian Shelf (Mobil Oil Canada Ltd. and Shell Canada Ltd.) has provided much stratigraphic information. In a stratigraphic analysis of many of these data McIver (1972) proposed the framework and terminology for the east coast section, together with a description and geologic history of the stratigraphic units. McIver's analysis is included in Table 1 and the following summary of the stratigraphy and geologic history is extracted from his account. McIver's classification is based on rock units.[3]

[3] A revision of McIver's classification is being undertaken by Jansa (1974), Wade (1974), Williams (1974), Jansa and Wade (1975), and Williams (1975).

The oldest stratigraphic unit recognized is the Argo salt of early Jurassic age, with a thickness greater than 900 m. In some areas its basal contact is gradational through more than 50 m of interbedded anhydrite, halite, and shale. The distribution of salt is restricted to a number of sub-basins and appears to have initially accumulated in structural lows with later deposition spreading over wider areas of the shelf. Poorly sorted red beds were deposited under arid conditions at the basin flanks.

The Iroquois Formation dominantly consists of up to 200 m of brown, anhydritic dolomite and overlies the Argo salt. The sequence includes some salt and other evaporites at the base, overlain by the dolomite which in turn is overlain by minor amounts of limestone. The sequence represents a gradational change to normal marine conditions as the rift basin at the continental margin became larger and less restricted, and the Atlantic Ocean basin began to take shape. Overlying the Iroquois Formation is the Mohawk Formation, which consists of interbedded red and green sandstones, shales, and thin grey limestones. Its basal section might in part be equivalent to the Iroquois in updip areas. Lateral facies relations indicate that fluvial sands intertongue with marine shales and limestones. The restricted basins on the shelf were filled with sediment during Mohawkian time.

McIver grouped the formations which overlie the lowermost Jurassic units described above. The oldest such group is the Western Bank Group and it is entirely of Jurassic age. It consists of the Abenaki, Verrill Canyon, and MicMac formations. This represents a widespread marine transgression accompanied by the deposition of normal marine limestones and clastics. The Abenaki Formation is dominantly limestone and is over 900 m thick. It underlies and is in part equivalent to the MicMac and Verrill Canyon formations. It is subdivided into three members: (1) the basal Scatarie calcarenite sequence composed of oolites, coated pellets, algal plates, fossil fragments, and quartz grains cemented with sparry calcite; (2) the Misaine shale and argillaceous limestone sequence, wherein the shale is calcareous with interbedded lime mud, and the limestone is pelletoidal and laminated; and (3) the Baccaro

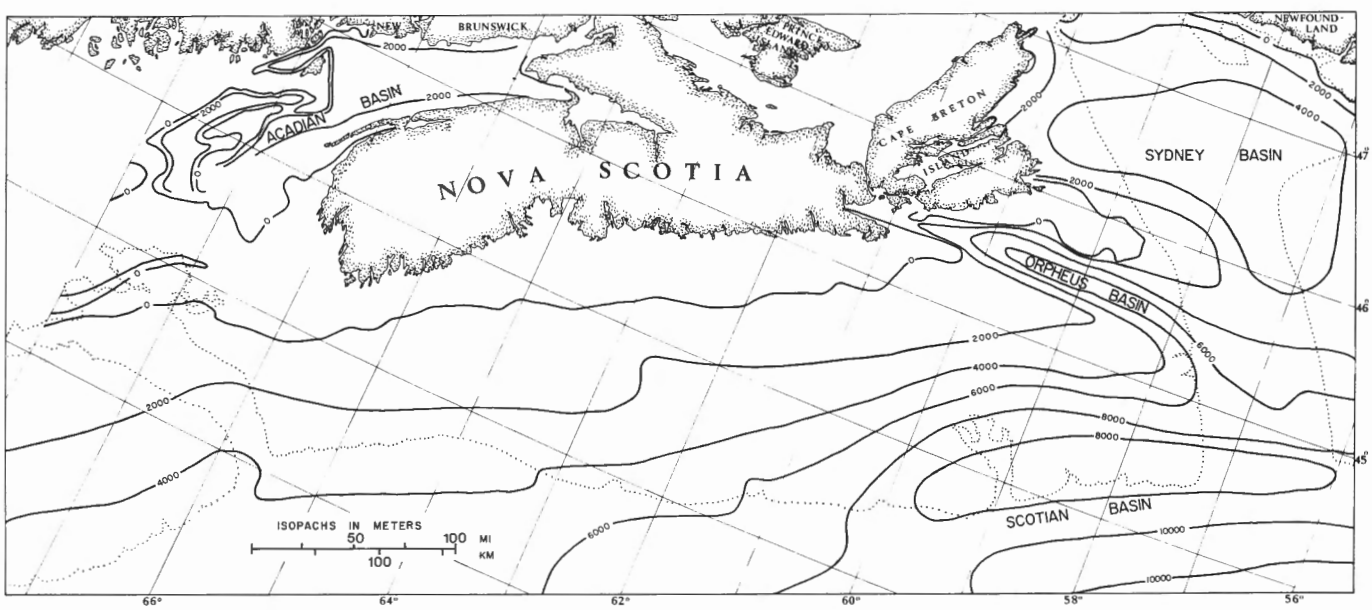

FIG. 7. Isopach map of sediments overlying the pre-Carboniferous basement surface (after Sherwin 1973).

massive limestone which is a dominantly high energy grainstone with shale and sand interbeds. The Abenaki Formation represents an outer shelf bank and is not a reef.

As the complex of Abenaki shelf edge banks developed, the MicMac Formation was deposited as a back-bank sequence of shale interbedded with carbonate muds and thin calcareous quartz sands. The unit is approximately 1200 m thick. Verrill Canyon Shale accumulated in the forebasins offshore from the Abenaki banks and is a normal marine shale. The shale has a maximum thickness greater than 600 m and is described as a medium grey to brown, carbonaceous, and splintery rock with thin interbeds of very fine sandstone and siltstone.

The Nova Scotia Group is a thick deltaic sequence of late Jurassic to early Cretaceous age.[4] It is characterized by terrigenous sandstone, which is particularly abundant in the eastern region of the shelf. The group is subdivided into three formations: the Missisauga, Naskapi, and Logan Canyon. The Missisauga Formation is dominantly sandstone with an updip facies of massive, thick sand units that grade into thinner sand units downdip and towards the western shelf region. The unit has a maximum thickness of 1100 m. Thin coaly and carbonaceous partings are common in both facies. The sand content is higher in the updip facies and the occurrence of interbedded shales more common in the downdip facies. The environmental spectrum in the Missisauga Formation ranged from fluvial to distributory channels on a marshy coastal plain, to deltaic fringe and shallow marine. The Naskapi shale is approximately 180 m thick and overlies the Missisauga Formation. The shale is gray to dusky red and carbonaceous. It has a sparse fauna and probably was deposited in a coastal environment. The overlying Logan Canyon Formation has a maximum thickness of 1000 m of alternating sandstone and shale. The vertical succession of sediments indicates that the sand influx gradually declined, and fauna in the interbedded shales records a gradual drowning of the Nova Scotia Group deltaic systems.

The Gully Group marks a change to deeper water sedimentation. It is subdivided into the Dawson Canyon, Wyandot, and Banquereau formations. The group spans Upper Cretaceous through Tertiary time. The Dawson Canyon Formation is up to 330 m thick over the central shelf, but in the downdip and western shelf areas it includes the shale facies of the Logan Canyon Formation and is thus much thicker. This formation is calcareous or marly towards the top and grades down through normal marine shale, becoming silty towards the base. A neritic to upper bathyal environment was probably quite consistent over much of the shelf. The Wyandot Formation overlies the Dawson Canyon and is probably the most distinctive lithologic unit on the shelf. It has a maximum thickness of 230 m and consists of white to gray chalk which grades laterally and vertically to marl. Deepwater sedimentation continued during deposition of the Banquereau Formation, but became shallower later in Tertiary time. The Banquereau has a maximum thickness of 1200 m and grades upward from calcareous muds and marls to noncalcareous silts and sands. The sands are generally argillaceous and glauconitic, but at the top of the section are medium-grained, well sorted, and clean.

[4] It is now thought that the Nova Scotia Group is entirely Cretaceous in age and that the Jurassic boundary lies between the MicMac and Missisauga formations (G. L. Williams, personal communication) (See Table 1).

Georges Bank and Scotian Shelf — The distribution of the east coast sediments on Georges Bank and the Scotian Shelf at the sub-Pleistocene surface is shown on Map 812H. The contacts were established from a study of high resolution seismic profiles with control from a few dredge samples from The Gully (Marlowe 1965, 1967, 1969) and a site north of Sable Island (King et al. 1970), and data from well history reports of the exploratory wells: Shell Onondaga E-84, Shell Naskapi N-30, Shell Oneida 0-25, Shell Mohawk B-93, Shell Abenaki L-57, Shell Missisauga H-54, Shell Wyandot E-53, Shell Argo F-38, Shell Fox I-22, Mobil Sable Island C-67; and Mobil-Tetco Dauntless D-35 (Shell Canada Ltd. 1970a–f, 1971a–c; Mobil Oil Canada Ltd. 1968, 1972). The rock units were recognized on high resolution seismic profiles by unconformable relations and differences in definition, nature, and frequency of seismic events depicting layered sequences, and by correlation with events on deep processed records (from a participation survey by Catalina Exploration Ltd., Regional Marine Seismic Reflection Survey, Scotian Shelf) that were tied to nearby exploratory wells.

Jurassic — Jurassic strata at the bedrock surface are confined mainly to the Georges Basin area except for a few salt piercement structures reported by Keen (1970), Webb (1973), and King and MacLean (1970c) in the Laurentian Channel and north of Sable Island. Rocks designated Pennsylvanian–Jurassic occur in the approach to Chedabucto Bay.

The Georges Basin occurrence was recognized as a distinct rock unit because the rocks were folded and truncated by an unconformity. The strata possibly are in fault contact with some of the adjacent basement rocks, but for the most part these strata were deposited on basement rocks (Map 812H, cross section C-D). Where the unit subcrops, the section is about 1000 m thick. The unit is Jurassic in age although it may include some early Cretaceous strata. The age of the unit was determined by correlating high resolution seismic data across Georges Basin with data from the Shell Mohawk B-93 well (Shell Canada Ltd. 1970d) by using a processed seismic profile (Catalina Exploration Ltd.) between the Mohawk well and Georges Bank. The unconformity at the top of the section is thought to be of early Cretaceous age (King et al. 1974). The unit is overstepped in part by both Cretaceous and Tertiary strata.

Two sections across Jurassic strata are shown in Chart 2, Profiles 5 and 6. In Profile 6 and Map 812H, cross section C-D, the strata are divided by a basement ridge of pre-Pennsylvanian rock that extends into the basin. In the northern part of the basin, beds flanking the ridge dip up to a maximum of 15°. These rocks may be in fault contact with basement rocks. The beds are regular and well defined as illustrated in cross section C-D and Fig. 8 (*lower*) along the section within the 67–82 km interval. Southeast of the basement ridge, the beds have a regional dip of approximately 1° to the south with local undulations characteristic of this unit. The Cretaceous beds, which have a more uniform dip, overlie the Jurassic strata unconformably. This contact is apparent at the eastern end of the section (Chart 2, Profile 5; Fig. 8, *upper*). Profile 5, which crosses the basin west of the basement ridge, indicates that minor folding is also present in this area and that there is some evidence of faulting at the 72–73 km interval.

The absence of Jurassic rocks at the sub-Pleistocene surface east of Georges Basin is a factor of the basement configuration (Fig. 7). The western third of the Scotian Shelf appears to have remained relatively high with respect to the Scotian basin to the east where the rates of subsidence and

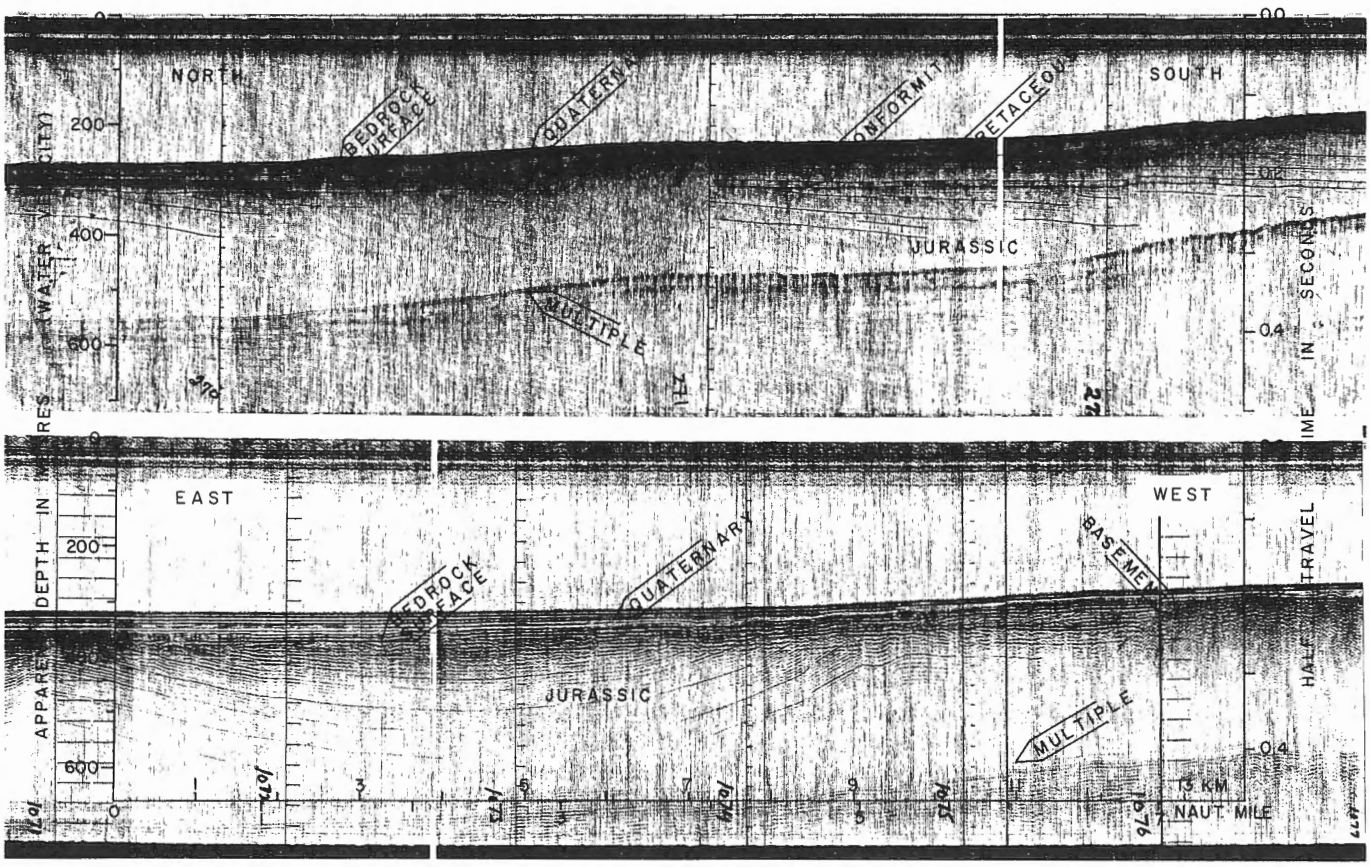

FIG. 8. *Upper*: continuous seismic reflection profile at points between 77 and 92 km along part of geological profile 5, Chart 2. The interpretation suggests the occurrence of Jurassic strata dipping gently seaward and overlain unconformably by a thin wedge of Cretaceous strata. The unconformity is thought to be Lower Cretaceous in age. The anomalous feature between 5.5 and 7.3 km may be a topographic high at the unconformity, or it may represent a pocket of gas. No seismic events can be observed below the surface of the feature. The vertical exaggeration is approximately 6 times. *Lower*: continuous seismic reflection profile at points between 67 and 82 km along part of geological profile 6, Chart 2. Folded Jurassic strata may occur in contact with acoustical basement at the north end of the profile. The structural nature of the contact is not clear but may in part be faulted. The vertical exaggeration is approximately 6 times.

sedimentation were much more rapid. Consequently, the thinner section of Cretaceous and Tertiary strata was eroded, exposing Jurassic rocks. As indicated by McIver (1972), the occurrence of Jurassic rocks in the subsurface on the shelf is widespread and the continuation of these strata into present day deepwater areas is indicated also by data from holes drilled by JOIDES Deep Sea Drilling Project (Ewing and Hollister 1972). In Hole 105 (34°54′N, 69°10′W), sufficient Jurassic sediments were deposited over the oceanic basalt to fill basement depressions and form a level sea floor. Jurassic strata are probably present overlying oceanic basement (Map 812H, cross section G; similar profiles by Emery et al. 1970) on the continental rise, but direct correlation with the Jurassic strata underlying the shelf along cross section E-F is not possible because of the presence of large diapiric structures as well as fossil continental slope underlying the upper continental rise. Cross section G was prepared from a processed seismic record run for the Bedford Institute of Oceanography by Catalina Exploration Ltd. (Grant and Manchester 1970).

Cretaceous — Cretaceous strata are exposed at the bedrock surface along much of the central shelf from Georges Bank to the Laurentian Channel, but this pattern is discontinuous where a veneer of Tertiary strata oversteps the sequence. Cretaceous rocks lie unconformably on Jurassic rocks in Georges Basin and beneath Georges Bank, but eastward along most of the shelf these rocks overstep the zero isopach of the Jurassic rocks and lie directly on the eroded quartzites and slates of the Meguma Group and intrusive Devonian granite. Exposures of Cretaceous rocks occur in the low-lying basin areas where erosion on the shelf was deeper during at least two previous erosional episodes. The seismic events representing bedding in the Cretaceous strata are generally strong, have a uniform dip, and can be followed for many kilometers. They presumably represent massive sandstone beds that are part of the Cretaceous deltaic sequence, and lithologic changes in the Dawson Canyon Formation. The Wyandot chalk is a particularly strong event and can be traced over a large area of the shelf. The zero isopach for the Wyandot Formation is indicated on Map 812H. The edge of this formation is erosional and in a few areas is overstepped by basal Banquereau strata (King et al. 1974). It is not known if this unconformity is a basin margin phenomena or if it extends deeper into the basin.

Eleven geological sections of the Scotian Shelf are shown in Charts 3 and 4 (in pocket), and photographs of representative seismic records appear in Fig. 9 and 10. These sections

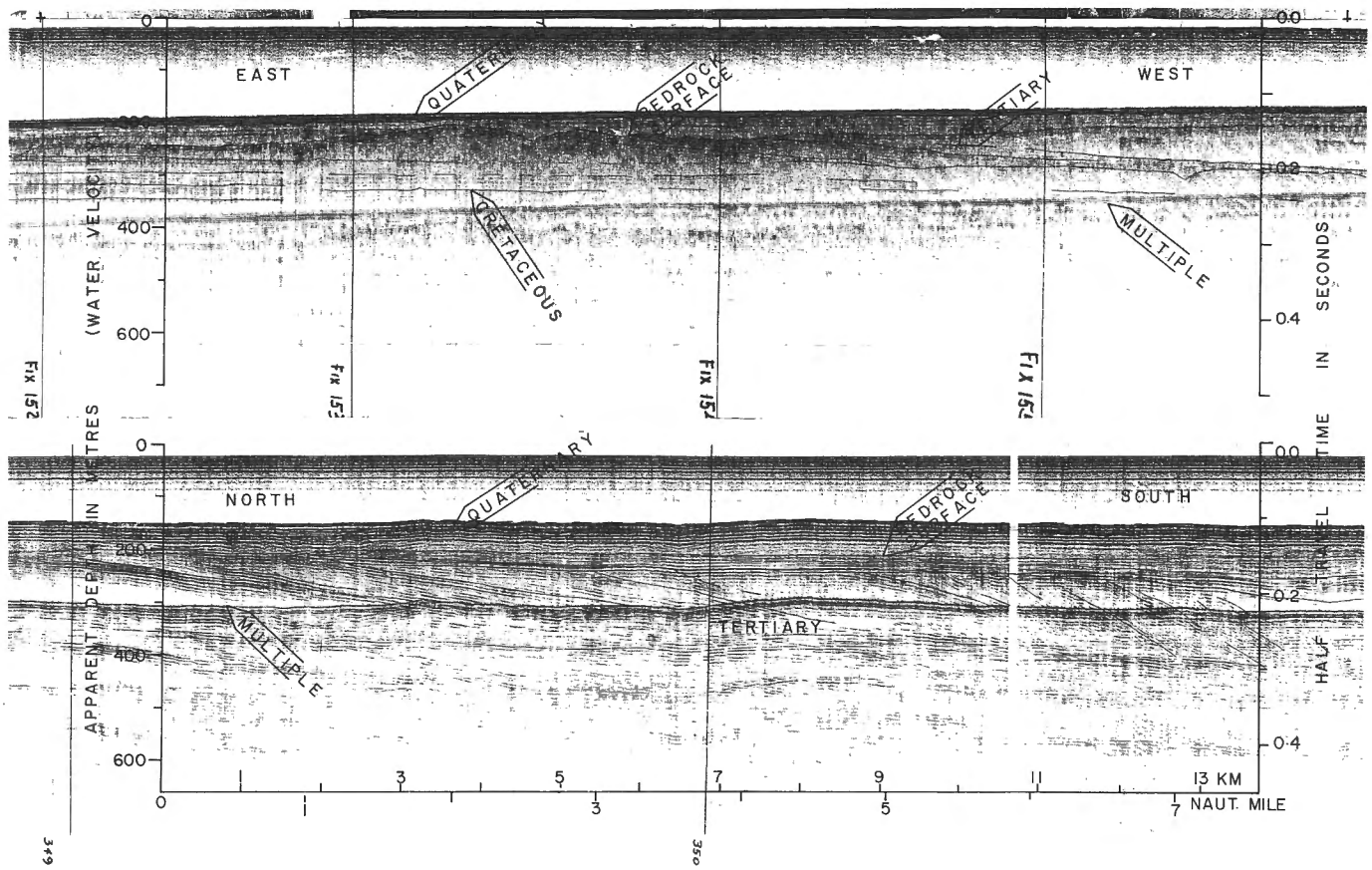

FIG. 9. *Upper*: continuous seismic reflection profile at points between 30 and 45 km along part of geological profile 9, Chart 3. The interpretation suggests the occurrence of well-bedded Cretaceous strata overlain at a slight angularity by Tertiary strata that show much less internal structure. The vertical exaggeration is approximately 6 times. *Lower*: continuous seismic reflection profile at points between 137 and 152 km along part of geological profile 11, Chart 3. The interpretation suggests the occurrence of a progradational sequence of Tertiary beds. The vertical exaggeration is approximately 6 times.

illustrate the relationship of the Cretaceous beds to the overlying Banquereau Formation of latest Cretaceous and Tertiary age, and the underlying rocks. Except for Jurassic beds at the western end of the shelf and Pennsylvanian beds at the north edge of the Orpheus basin in the Laurentian Channel, the underlying rocks generally constitute basement. Recognition of the Wyandot Formation was useful in the mapping procedure, as was the angular unconformity at the top of the sub-Banquereau Cretaceous beds. The age of the unconformity varies in many areas of the shelf because of the number of erosional cycles. On a few sections the unconformity, being overlain by basal Banquereau strata, can be considered late Cretaceous in age (King et al. 1974). The relationships are illustrated along the 100–116 km interval on Chart 3, Profile 11. In other areas of the shelf the overlying Banquereau beds are probably much younger and suggest a second period of overstepping in Tertiary time. Examples are shown on Chart 3, Profiles 9 and 10, near LaHave and Roseway banks.

Tertiary — The Tertiary and latest Cretaceous (Banquereau Formation) sediments are developed as a thin veneer or as erosional outliers on the underlying Cretaceous rocks in areas along the inner to central parts of the shelf. In these areas near the basin margin, the relationships appear to be unconformable. In a number of areas the Tertiary strata completely overstep the Cretaceous beds and form the zero isopach of the east coast sequence on the basement rocks on the shelf and Pennsylvanian rocks in the Laurentian Channel. In one area west of Yarmouth, Tertiary rocks overlie Triassic strata. The thickness of the Banquereau unit increases seaward to at least 2 km in some areas along the shelf edge, as revealed from well data and from interpretations of processed seismic records (Catalina Exploration Ltd. and Caravel Exploration Ltd.). A study of these records and high resolution seismic data shows that during deposition of the Banquereau Formation a number of progradational sequences developed across the shelf. The development of progradational beds is well illustrated on Chart 3, Profile 11, and Fig. 9 (*lower*) near the edge of the shelf, as well as on profiles from the Laurentian Channel. The seismic events representing the beds and surfaces are well defined. In many instances, stratification in the Banquereau Formation is variable. Some records show only a few acoustical events, for example along Chart 3, Profiles 7 and 8, but on others, especially in the Gully area, internal patterns show channels infilled with stratified units having local initial dips (Chart 4, Profile 15).

The channel and fill horizon appears to represent an extensive disconformity within the Banquereau Formation. When the spatial arrangement of the channels is considered through a study of all the seismic profiles of the area, the major channels can be correlated, indicating that the unconformity represents a former subaerially eroded surface, probably with

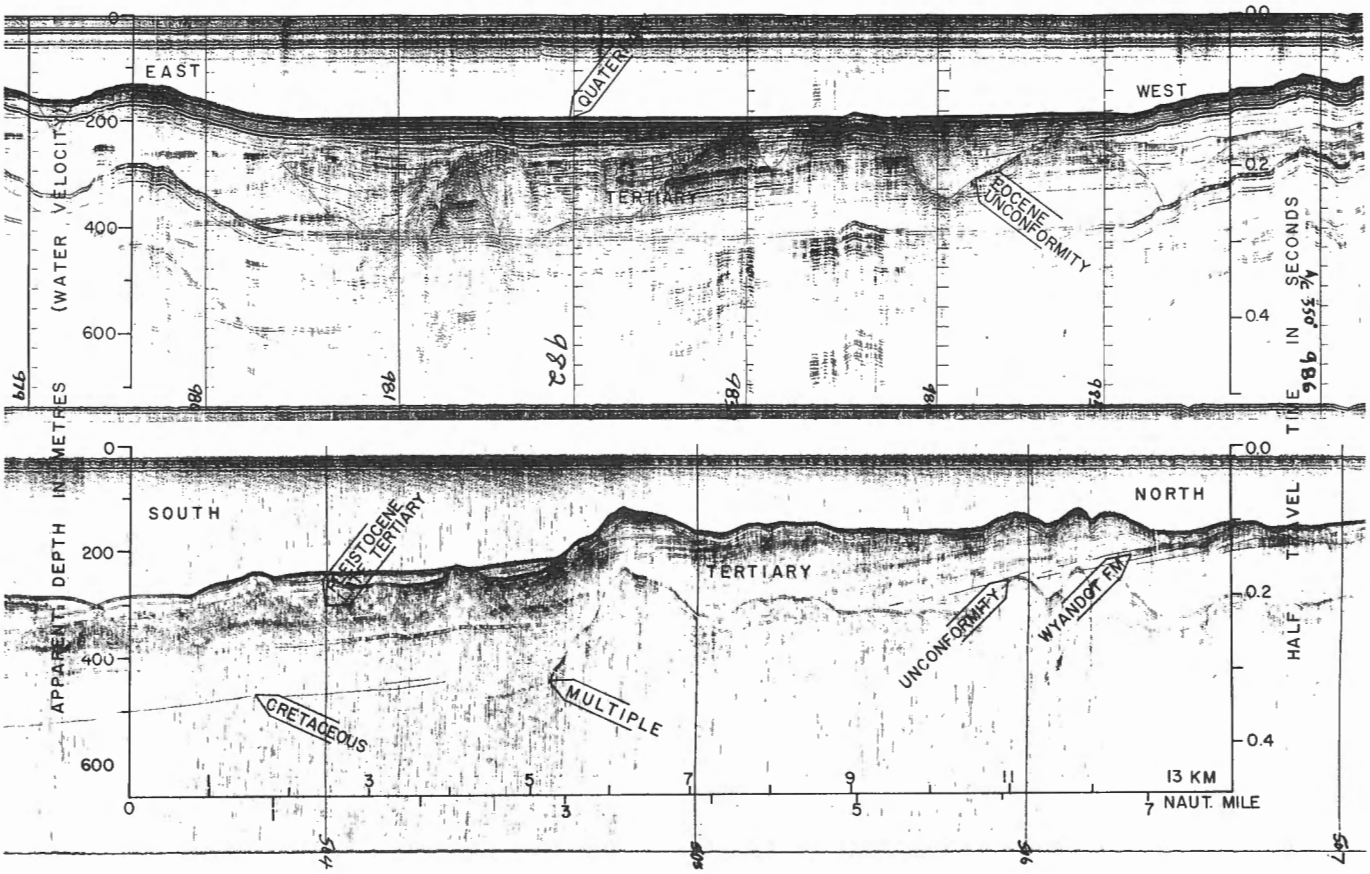

FIG. 10. *Upper*: continuous seismic reflection profile at points between 15 and 35 km along part of geological profile 15, Chart 4. Infilled, subaerial erosion channels possibly occur within Tertiary strata. The age of the unconformity may be Eocene. The vertical exaggeration is approximately 6 times. *Lower*: continuous seismic reflection profile at points between 94 and 113 km along part of geological profile 16, Chart 4. Cretaceous strata may be overlain unconformably by Tertiary strata. Note the strongly reflective Wyandot Formation. Channels are also in evidence within the Tertiary sequence as in the upper illustration. The vertical exaggeration is approximately 6 times.

some submarine canyon development near the edge of the former shelf. Correlation with data from the well history reports from Shell Missisauga H-54 (Shell Canada Ltd. 1970f) and Mobil Sable Island No. 1 (Mobil Oil Canada Ltd. 1968) suggests a late Eocene age for the unconformity (King et al. 1974). In the Gully area there are sufficient differences in the nature of the seismic data above and below the unconformity to divide the Banquereau Formation into an upper and lower unit, but the control was too widely spaced to map this division across the entire shelf.

The present bedrock surface is a Late Tertiary–Pleistocene unconformity (possibly of Pliocene age as determined from relationships in the Laurentian Channel) formed by fluvial and glacial processes. The Pleistocene and Recent unconsolidated cover is relatively thin, 0–200 m; consequently the present topography strongly reflects the underlying bedrock surface. Although in many areas this is the most conspicuous unconformity on the shelf, its configuration closely follows that of the Early Tertiary (Eocene) unconformity. This is more apparent on a regional basis than on the study of individual profiles. Both unconformities contributed significantly to the distribution pattern of Tertiary and Cretaceous rocks at the sub-Pleistocene surface.

King (1967b) described some of the larger geomorphic features of the shelf and indicated the cuesta development of the outer banks region and areas where it is thought to have been breached, for example, at The Gully and between Emerald and LaHave banks. Mesa developments, now recognized as isolated banks, are common on the shelf. A more youthful topography characterizes the area north and east of Sable Island where the process of canyon cutting and subaerial channeling was important. These larger landforms are believed to have been dominated by inheritance. Many forms recognizable at the latest erosional surface are inherited from the Early Tertiary period of erosion (King et al. 1974). Recognition of these large landforms is the best evidence supporting the existence of former fluvial drainage systems on the shelf.

Orpheus basin — Depocenters along the east coast geosyncline commonly cannot be recognized on the basis of near-surface studies and therefore have not been emphasized in this particular study. The Orpheus basin is different in this regard as considerable information was obtained from this area using high resolution seismic techniques. It extends from Chedabucto Bay seaward across the northeast section of the Scotian Shelf and into the Laurentian Channel.

Loncarevic and Ewing (1967) concluded that the Orpheus basin and its associated negative gravity anomaly are a consequence of a thick sequence of partly fault-bounded, low density strata including a thick section of salt. King and MacLean (1970a) suggested that the basin boundaries were

defined by a seaward extension of the Cobequid–Chedabucto Fault, a part of the Glooscap fault system, and noted mild folding of the Cretaceous strata within the basin (Chart 4, Profiles 16 and 17; Chart 5, Profiles 18 and 21; Chart 7, Profile GHNIJ; Chart 8, Profile KLMNOPQ; Chart 9, Profile ECIF (all in pocket). The limits of folding closely coincide with the areas of negative Bouguer gravity anomaly. They suggested that folding of the Cretaceous rocks resulted from late motion along the fault system, possibly in early Tertiary time or later, and recognized that salt tectonism was involved. An examination of a processed seismic record across the Orpheus basin substantiates the existence of a subsurface fault along the southern boundary of the basin. Futhermore, data from the well history reports on Shell Fox I-22 (Shell Canada Ltd. 1971c) and Shell Argo F-38 (Shell Canada Ltd. 1971b) confirmed the presence of Meguma (?) metamorphics at the southern side of the fault.

Sherwin (1973) and McIver (1972) also recognized faulting in the Orpheus basin, and Sherwin interpreted it as a graben structure. An examination of the high resolution seismic data indicates faulting in the Cretaceous strata at the northern boundary of the Orpheus basin along the southern flank of the Scatarie basement ridge and across the Laurentian Channel to its eastern bank (Chart 5, Profiles 20 and 21; Chart 8, Profile OPQ; Chart 9, Profile IF; and Fig. 11). Some of these profiles also indicate the existence of a number of piercement structures and possible salt ridges confirming some of Webb's (1973) observations in the Laurentian Channel.

Earlier conclusions (King and MacLean 1970a) regarding a Triassic fault origin for the Orpheus basin and subsequent movement along this system during Cretaceous and possibly early Tertiary time are still valid; however, a stronger influence of salt tectonism has been recognized. Late movement along the Glooscap fault system accounts for the faulting in the Cretaceous beds along the northern boundary of the Orpheus basin, and was probably responsible for some compressional folding accompanied by salt movement. As mentioned earlier, the Triassic faulting dominated by vertical motions probably

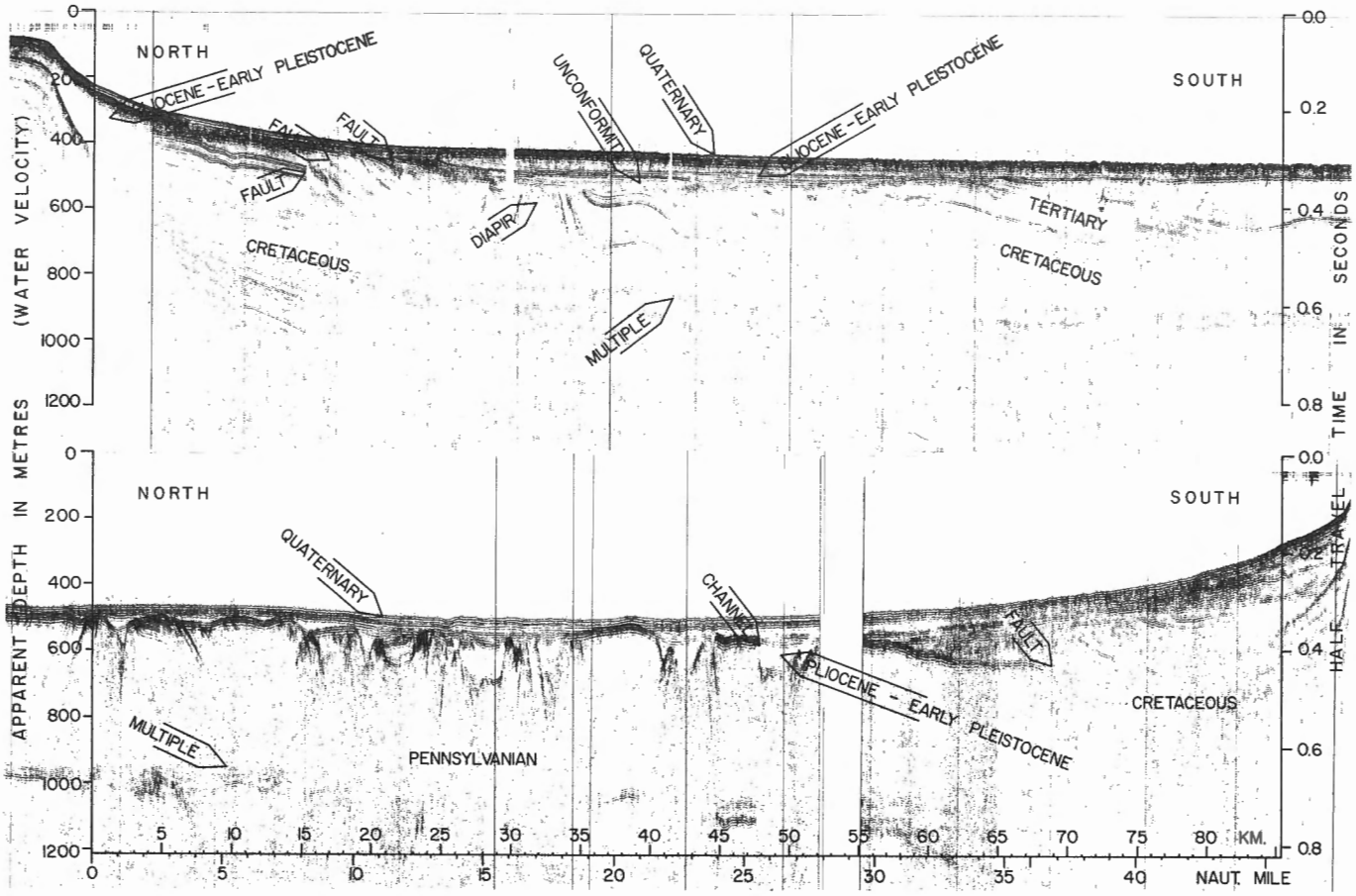

FIG. 11. *Upper*: continuous seismic reflection profile from 45°03.5′N, 57°07.0′W to 45°57.0′N, 56°50′W, at the eastern side of the Laurentian Channel. Faulted and folded Cretaceous strata may occur at the northern boundary of the Orpheus basin. The fault is an expression of the latest movement along the Glooscap fault system. The vertical exaggeration is approximately 25 times. *Lower*: continuous seismic reflection profile at points between 100 and 180 km along part of geological profile 20, Chart 5. Faulted and folded Pennsylvanian strata may occur in fault contact with Cretaceous strata. The fault at 69 km is part of the Glooscap fault system at the northern boundary of the Orpheus basin. The folded Pennsylvanian strata are part of the Carboniferous fold belt at the southern flank of the Sydney Basin. Channels at the Pennsylvanian surface are infilled with Pliocene–early Pleistocene sediment. Vertical exaggeration is approximately 25 times.

took place along an earlier fault system with mid-Devonian and Carboniferous expression of transcurrent motions (Webb 1969).

Laurentian Channel and western edge of Grand Banks — The east coast sediments continue across the Laurentian Channel and on to the Grand Banks. Shallow seismic coverage is useful in establishing detailed seismic stratigraphy in the upper part of this section from the Scotian Shelf to the Grand Banks. However, deep processed seismic records will be required in this area to provide a proper correlation between the Scotian Shelf and the Grand Banks to provide an understanding of the major geological differences that are now known to exist from studies of the exploratory wells in both areas.

Jurassic — Jurassic strata are not present in the near-surface section underlying the Laurentian Channel. Because they are present in the Orpheus basin (e.g. Shell Argo F-38; Shell Canada Ltd. 1971b) the northern boundary of Orpheus basin (most northerly fault across the Laurentian Channel, Map 812H) probably delineates the northern boundary of Jurassic strata underlying the Laurentian Channel.

Cretaceous — Cretaceous strata at the sub-Pleistocene surface in the Laurentian Channel occur as two isolated patches. These strata were identified by following Cretaceous seismic events from the Scotian Shelf and Grand Banks, although there was a short blind area caused by a thick Tertiary sequence on the Grand Banks side. The zero isopach is shown as a subsurface contact with Pennsylvanian strata on Map 812H. Cretaceous strata are overstepped by a thin sequence of Tertiary beds for about 30 km to the north.

The Cretaceous sequence overlies Jurassic rocks at depth in the Orpheus basin (Shell Canada Ltd. 1971b), but near the zero isopach was only observed on the shallow seismic data as unconformably overlying Pennsylvanian strata of the Sydney Basin. The unconformity between the Cretaceous and overlying basal Tertiary beds observed on the Scotian Shelf was not observed in the Laurentian Channel; however, a pronounced unconformity with younger Tertiary beds was noted (Chart 5, Profile 20 and 21; Chart 7, Profile NI; Chart 8, Profile NOPQ; and Chart 9, Profile CIF). The age of this unconformity is probably late Pliocene as discussed in the succeeding section. Because the Cretaceous beds within the Orpheus basin were folded and faulted as a result of salt tectonism and movement along the Glooscap fault system, the unconformity is conspicuous in the Laurentian Channel.

Faulting of the Cretaceous beds along the northern boundary of the Orpheus basin was observed on the shallow seismic profiles (Fig. 11; Chart 5, Profiles 20 and 21; Chart 8 at 118 km; Chart 9 at 113 km) in the Laurentian Channel and is shown as a defined surface and subsurface fault on Map 812H. The exact time of the latest faulting and folding is not clear because most of the evidence was removed by Pliocene and possibly earlier erosion across the Orpheus basin, but it may be of early Tertiary age or younger.

Tertiary — As on the Scotian Shelf, the Tertiary and latest Cretaceous beds thicken seaward from a thin veneer to approximately 2 km at the shelf edge. Near the zero isopach, only the uppermost part of the sequence (Pliocene–early Pleistocene unit) is represented, and these beds fill channels that were incised in Pennsylvanian and Cretaceous strata (Chart 5, Profile 20). The degree of overstepping on Pennsylvanian, Cretaceous, and older Tertiary beds is extensive, amounting to more than 100 km. Outliers of Tertiary–Pleistocene (?) cover rock to the north (Map 812H and Fig. 12) may extend the area of overstepping even farther. Most strata in the Tertiary sequence of the Laurentian Channel are well stratified, with progradational sequences well developed in a seaward direction (Chart 5, Profile 18).

The Mobil Tetco Dauntless D-35 well (Mobil Oil Canada Ltd. 1972, and G. L. Williams, personal communication) provides the best stratigraphic control for the Tertiary rocks of the Laurentian Channel. The well data and an interpreted shallow seismic section are shown in Chart 6, Profile AHMBCD. Miocene and Oligocene units can be traced into the channel, increasing in depth to an area east of the central axis of the channel. East of there these beds reserve dip and eventually outcrop on St. Pierre Bank. Chart 7, Profile GH, which intersects Chart 6, Profile AM, shows the attitude of the Miocene beds near the shelf edge. These relationships indicate a thick Pliocene section along the shelf edge.

A horizontally bedded unit with a maximum thickness of 300 m blankets the entire central and eastern area of the Laurentian Channel and overlies an unconformity near the top of the Tertiary section. This unit was considered to be Pliocene–early Pleistocene in age by using seismic stratigraphy to extend control into the Laurentian Channel from the Dauntless well (Chart 6). The Pliocene–early Pleistocene beds extend from the floor of the channel to the eastern bank (Charts 6 and 7), suggesting that the eastern bank was carved into these beds by the continental ice sheet; thus the beds are preglacial in age and were thicker and more widely distributed prior to the advent of glaciation. It might be the equivalent of the Tertiary–Pleistocene (?) cover rock indicated on Map 812H at Burgeo Bank and in the area of St. Paul Island. A sedimentary unit with similar boundary relationships also occurs along Halibut and Haddock channels on the Grand Banks (King and MacLean 1975). The upper surface of the Pliocene–early Pleistocene unit in the Laurentian Channel has a smooth surface that appears to be glacial pavement. The unit is overlain by glacial till, glacial-marine sediment, and Holocene and Recent clay and silt, collectively designated as the Pleistocene and Recent unit on the geological sections.

If the Pliocene–early Pleistocene age for the uppermost unit in the Laurentian Channel is correct, the unconformity that cuts across the rocks of Cretaceous to late Tertiary age, truncating beds, piercement structures, and faulted strata must be late Pliocene in age. Therefore, it is probable that the distribution of Tertiary rocks was much wider than the present zero isopach indicates. It is conceivable that the lowland areas across the Atlantic Provinces (the Carboniferous–Triassic lowland, physiographic division) were covered by Tertiary sediment and were later exhumed during the erosional period responsible for the development of the Pliocene unconformity.

In the Pennsylvanian, Cretaceous, and Tertiary sections of the Laurentian channel the effects of at least two periods of channeling are visible. Those channels at the surface of the Pennsylvanian rocks were indicated earlier (Chart 5, Profile 20) and are infilled with the Pliocene–early Pleistocene unit. Other channels occur at the surface of the Tertiary section near the mouth of the Laurentian Channel (e.g. Chart 5, Profile 18, at the 97–103 km interval, and profiles not illustrated). These channels may be about the same age as the channels incised in the Pennsylvanian strata and may be associated with the Pliocene unconformity. Another set of channels is present deeper in the Tertiary section (e.g. Chart 7, Profile GHNIJ, at the 50–80 km interval). Although the seismic

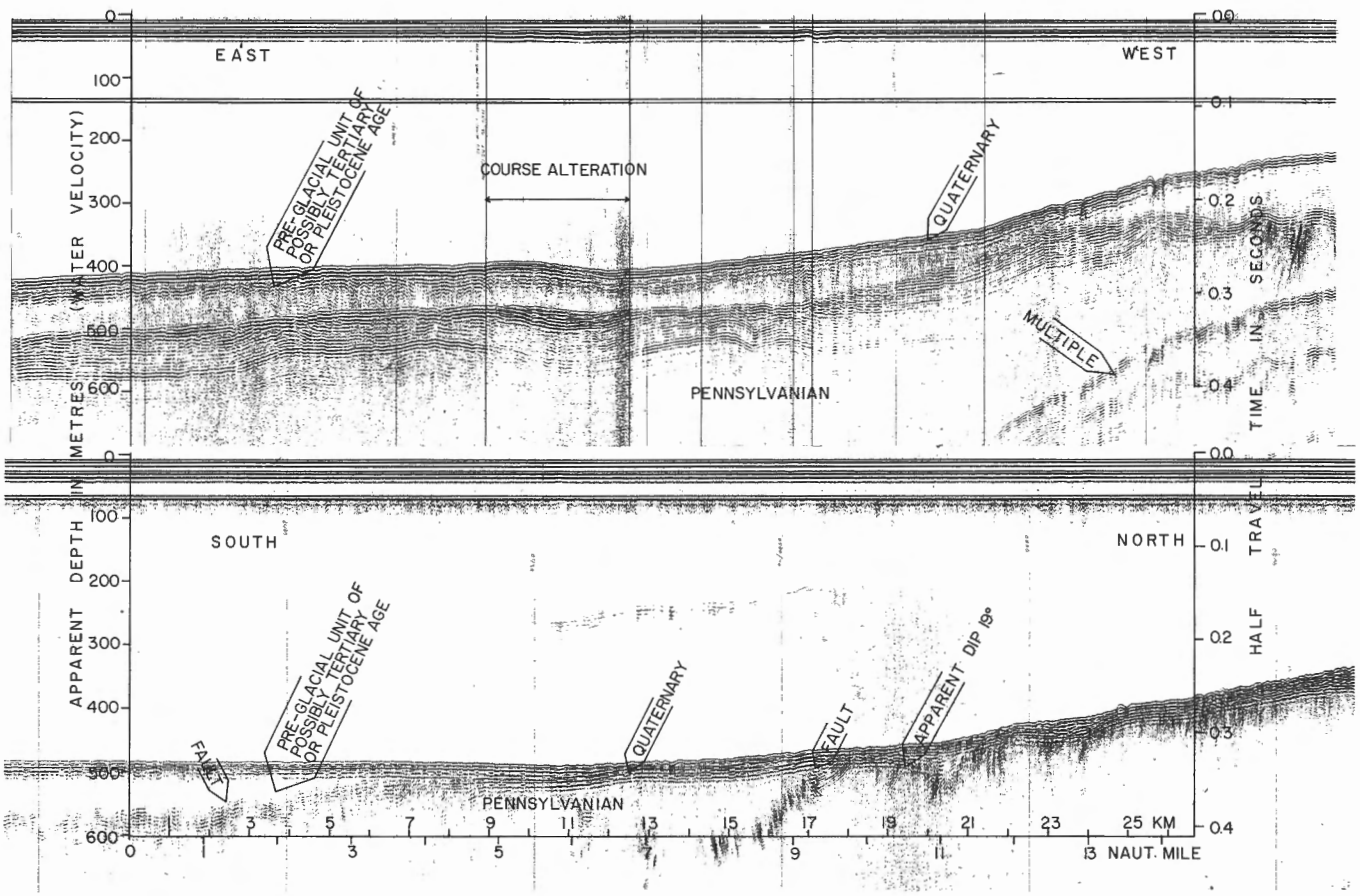

FIG. 12. *Upper*: continuous seismic reflection profile from 47°11.7′N, 59°55.0′W to 47°08.3′N, 60°09.2′W immediately south of St. Paul Island. Pennsylvanian strata may be overlain by a Tertiary–early Pleistocene (?) unit which extends from the base of the Laurentian Channel to the shelf surrounding St. Paul Island. The vertical exaggeration is approximately 16 times. *Lower*: continuous seismic reflection profile at points between 122 and 156 km along part of geological profile 22, Chart 10. Folded and faulted Pennsylvanian strata may be overlain at the south end of the profile by a Tertiary–early Pleistocene (?) unit. The fault at 2.5 km is the Aspy–Cape Ray Fault. The fault at 17 km represents the Cabot Fault. Vertical exaggeration is approximately 16 times.

evidence is not entirely clear, this set of channels could be associated with the Eocene unconformity that was discussed with regard to the Scotian Shelf.

Sydney Carboniferous Basin

Carboniferous strata, some of which are coal bearing, occur at the sub-Pleistocene surface over much of the area between Cape Breton Island and the south coast of Newfoundland, and constitute an offshore continuation of the Sydney Basin, one of the major Carboniferous sub-basins of the Atlantic Provinces. Bell's (1927, 1958) stratigraphic classification of the Carboniferous, still in general use, was significantly modified by Barss and Hacquebard (1967), Kelley (1970), and Hacquebard (1972). The classification, in Table 1, shows the lowest part of the section as late Devonian. Only three of the six major stratigraphic groups are exposed in onshore areas of the Sydney Basin: the Windsor, Canso, and Pictou. A more complete section will probably be found in the off shore areas. Carboniferous sediments of the Sydney Basin may also extend into the lower part of the section in the adjacent Orpheus basin because they are in fault contact with Cretaceous beds at the north edge of the basin.

The following description of the Sydney Basin rocks is summarized from Bell 1938. The Windsor Group of late Mississippian (Visean to early Namurian) age flanks the uplands surrounding the coalfield and unconformably overlies rocks that range in age from Precambrian to Devonian. The group is marine in origin and consists of up to 600 m of conglomerate, limestone, dolomite, gypsum, anhydrite, red shale, and sandstone. They are mainly shallow water deposits and include local alluvial fans of conglomerate.

The Canso Group, which is late Visean to late Namurian in age (transitional between the Mississippian and Pennsylvanian), occurs locally in two areas of the Sydney Basin with a maximum thickness of 400 m. The Canso is continental in origin and much of the group in this area was removed through erosion, and the contact with the overlying Pictou (Morien) Group is disconformable. The unit consists of dark gray siltstones and shales in the Cape Dauphin area, and chocolate shales and sandstone with some freshwater limestone in the Sydney area.

The overlying Pictou Group has a maximum thickness on land of 2000 m, of which the upper 1080 m contains coal seams of commercial significance. The sediments are fluvial and

fluviolacustrine in origin and are mainly gray and red sandstone, gray and red shale, some conglomerate, and thin bands of freshwater limestone.

In comparison to some of the other Carboniferous basins of Nova Scotia, e.g. the Cumberland and Minas basins, Bell considered that the Sydney Basin experienced a comparatively quiet tectonic development. The strata of the coalfield are flexed in open folds that trend easterly to northeasterly with prevailing dips on the flanking beds of 4–15°. In a few instances dips of 35–50° occur.

Seismic refraction studies between Cape Breton Island and Newfoundland (Sheridan and Drake 1968; Hobson and Overton 1973) indicate a sediment thickness in excess of 5000 m at the center of the basin. A compilation of these data by Sherwin (1973) shows the configuration of the basin (Fig. 7). Two groups of sediment velocities were recognized by Sheridan and Drake (1968) in the Sydney Basin, an upper layer of 3.2–4.3 km/s with a maximum thickness of approximately 1500 m and a lower layer of 4.5–5.5 km/s with a maximum thickness of almost 4000 m. The lower layer was thought to represent the seaward continuation of Mississippian strata, and the upper layer was considered to be a Pennsylvanian–Triassic unit.

A high resolution seismic reflection study (King and MacLean 1970d) from the Glace Bay area to the central part of the Laurentian Channel indicated that Pennsylvanian rocks continued offshore to the central part of the basin and correlated with the Pennsylvanian–Triassic unit of Sheridan and Drake (1968). Subsequent seismic studies have shown that Pennsylvanian rocks extend easterly from the Sydney area and flank the northern side of the Scatarie basement ridge to near 58°W where they overlie this ridge and continue southward beneath the Cretaceous and Tertiary cover along the axis of the Laurentian Channel to 45°45′N. The strata are downfaulted at the northern boundary of the Orpheus basin. Carboniferous beds south of the fault do not appear again on the high resolution profiles; however, refraction data (Sheridan and Drake 1968) indicate that the beds extend along the axes of the channel to the southern limit of the refraction line at 45°30′N. The boundary of the Pennsylvanian strata at the sub-Pleistocene surface is delineated on Map 812H and supported by representative geological profiles and photographs of seismic records (Chart 5, Profiles 19–21; Fig. 11; Fig. 12, *lower*; Chart 10, Profiles 22–26, and Fig. 13). The western edge of the Pennsylvanian strata follows the Cape Breton coast north of Cape Dauphin (46°21′N, 60°25′W)

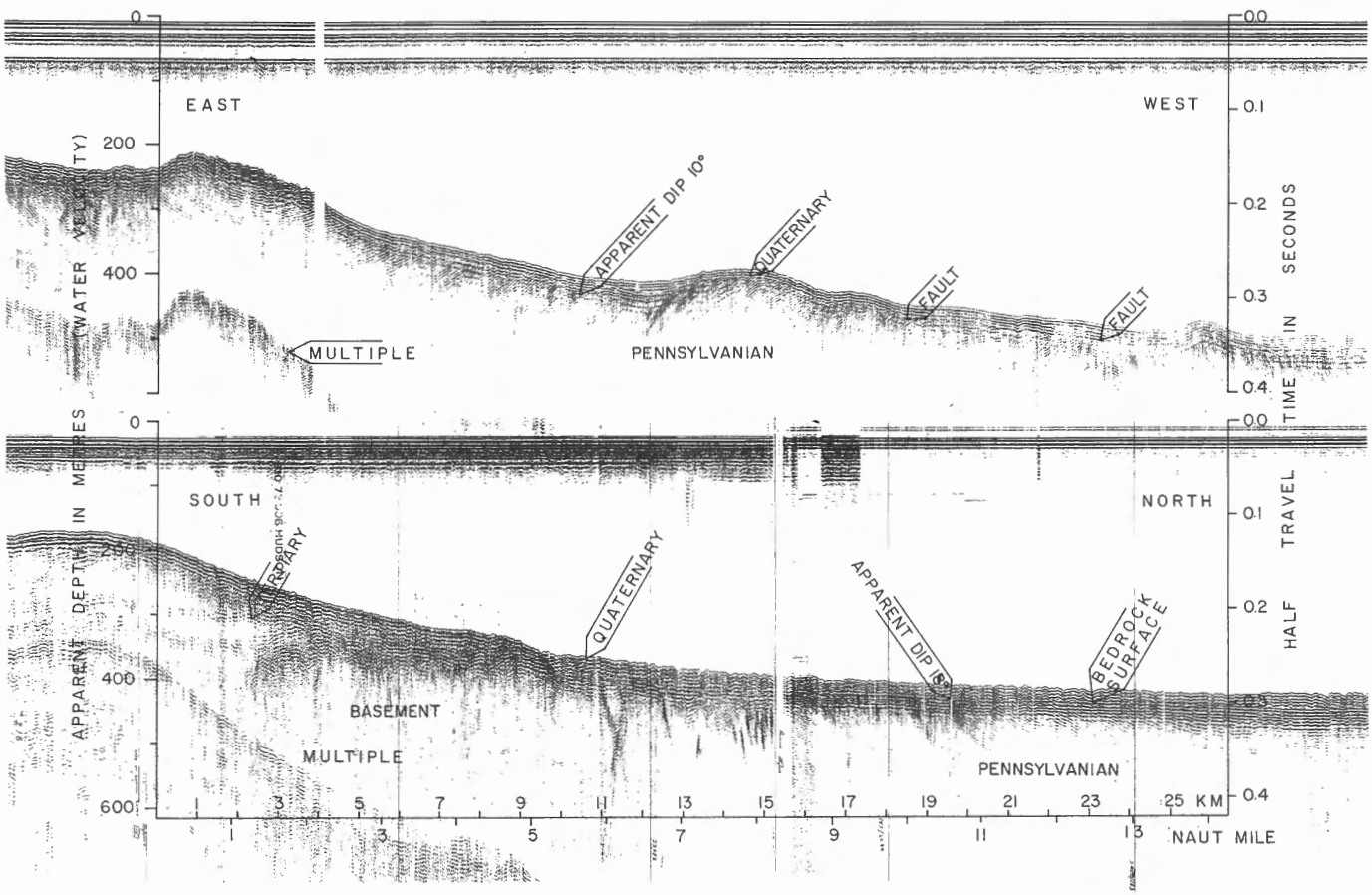

FIG. 13. *Upper*: continuous seismic reflection profile from 48°01.4′N, 59°33.7′W to 48°01.4′N, 60°02.2′W, in the Laurentian Channel west of St. George's Bay, Newfoundland. Folded and faulted Pennsylvanian strata may occur along the eastern flank of the Magdalen Basin. The vertical exaggeration is approximately 16 times. *Lower*: continuous seismic reflection profile from 45°53′N, 58°17′W to 46°12.8′N, 58°09.5′W at the edge of the Laurentian Channel east of Scatarie Island. Folded Pennsylvanian beds (part of the Carboniferous fold belt) may occur against the Scatarie basement ridge. To the south the ridge is overlain by Tertiary beds. The vertical exaggeration is approximately 16 times.

with a narrow strip of pre-Pennsylvanian acoustical basement between the boundary and the shoreline. The Pennsylvanian strata are sometimes in fault contact with the pre-Pennsylvanian unit. The distribution of Mississippian rocks along the shore indicates that much of the pre-Pennsylvanian unit in this area can be inferred to be Mississippian in age, but seismic reflection techniques have not been of any use in differentiating or mapping it. Pennsylvanian strata on the eastern side of the Sydney Basin lie within 5–10 km of the southern coast of Newfoundland. A basement ridge defined by refraction data connects Cape Breton Island and Newfoundland through St. Paul Island and separates the Sydney Basin from the Magdalen Carboniferous basin in the Gulf of St. Lawrence. The interpretation in Fig. 7 indicates the limits of the Sydney Basin at Cabot Strait. To the southeast, on the Grand Banks, the limits of Carboniferous strata are as yet undetermined. Interpretation of seismic records east of the map-area indicates that Pennsylvanian strata continue easterly in the nearshore area at least to Placentia Bay, and drilling data indicate the presence of these strata in Elf Hermine E-94 well (Elf Oil Exploration and Production Canada Ltd. 1972) and the presence of Horton, Eifelian–Tournaisian in age (Howie and Barss 1975), and Windsor strata in Amoco-IOE Gannet 0-54 (Amoco Canada Petroleum Company Ltd. 1972). These subsurface discoveries occur in basins that appear to be related to basement block-faulting (Amoco Canada Petroleum Company Ltd. and Imperial Oil Ltd. 1973). The relationship of these basins to the Sydney structural basin is as yet undefined.

Because of the sparse subsurface data in the offshore area, only a few broad statements can be made regarding development of the Sydney Basin. As shown in Chart 10, Profiles 22, 25, and 26; the structural style is relatively simple and, except for local folding, essentially saucer-shaped with the beds dipping towards the deeper and central parts of the basin. In view of the recent discovery of lower Horton strata on the Grand Banks in the Gannet well (Amoco Canada Petroleum Company Ltd. 1972) it is quite probable that sedimentation became established in the Sydney Basin in late Devonian time and the simple structure suggests a gradual subsidence, expansion, and filling of the basin. Very little is known of the pre-depositional basement topography. In contrast to the adjacent basins, the Orpheus and Magdalen basins, there is no evidence for salt tectonism and the development of piercement structures. Near the margin of the basin, the profiles commonly show an increase in the degree of folding with dips ranging from 10 to 25° (Chart 5, Profiles 20 and 21; Fig. 11, *lower*; Fig. 13, *lower*; Chart 10, Profiles 22–26). Occasionally the folding was beyond the limits of resolution of the seismic reflection system.

A marginal fold belt is present along the south side of the basin on the northern flank of the Scatarie basement ridge and in the central and eastern part of the Laurentian Channel where the ridge is not exposed (Chart 5, Profile 20, at the 100–140 km interval, and Profile 21 at the 10–30 km interval, and on profiles not illustrated). Land areas of the Sydney Basin in the Sydney area fall within this zone of marginal folding. The fold belt along the margin may have been the result of forces initiated by differential subsidence due to the sediment load or related to motion on possible subsurface boundary faults for which as yet there is very little direct evidence. Bell (1938) reported faults along contacts with crystalline basement, and two boundary faults where the Pennsylvanian rocks are downfaulted against Windsor strata and the basement rocks. Faults shown in Chart 10, Profile 23, at the 3-km point, and Profile 24, at the 11-km point, may represent the offshore continuation of a boundary fault at Cape Dauphin (46°21′N, 60°25′W). The Aspy fault along the south side of Cape North (47°00′N, 60°30′W) is important in defining the boundary of the Sydney Basin in Cabot Strait. Information from seismic reflection profiles across the strait is interpreted as showing the Aspy fault joining with the Cape Ray fault of Newfoundland (Map 812H; Chart 10, Profile 22, at the 130-km point; and Fig. 12, *lower*). The Cabot Fault, which Wilson (1962) projected along the northwest coast of Cape Breton Island to join with the Long Range Fault of the Codroy Valley of Newfoundland, appears to have a near-surface expression only across the eastern part of the Cabot Strait. These faults are associated with shallow basement structures and help to define the boundary between the Sydney and Magdalen basins.

Pennsylvanian strata are continuous, but faulted, from the Sydney to the Magdalen Basin, except for a small area of exposed basement around St. Paul Island. Folding at the south end of the Magdalen Basin is prevalent, probably as a consequence of both compressional forces and salt tectonism (Fig. 13, *upper*; and Map 812H).

A thin sequence of cover rock overlies the Pennsylvanian beds and is considered to be Tertiary–Pleistocene (?) in age (Fig. 12 and Map 812H).

The submarine extension of the Sydney coalfield has been a matter of intense interest from the point of view of future reserves. The Point Aconi Seam, the uppermost seam in the section, outcrops 25 km north of Sydney at the shoreline. This stratigraphic unit can be inferred thoughout most of the Sydney Basin from the seismic profiles, but the data are not sensitive to the detection of coal. In the center of the basin this unit is overlain by approximately 1200 m of additional strata making the total thickness of Pennsylvanian section in the basin about 3200 m. The uppermost part of the section on land is Stephanian in age (Barss and Hacquebard 1967), and so it is possible that some lower Permian strata might occur in the central part of the basin. The Point Aconi unit outcrops around the entire basin, flanking the Scatarie basement ridge across the Laurentian Channel, thence swinging to the north to cut across the end of Burgeo Bank. The strata north and northeast of Burgeo Bank were sampled with the Bedford Institute bedrock drill at two sites noted on Map 812H (47°20.9′N, 57°44.3′W and 47°13.7′N, 57°17.0′W). Two cores with respective lengths of 336 cm and 166 cm were obtained. Both core samples contained mottled red sandstones with brick red inclusions, similar in appearance to some of the rocks in the type section of the Pictou Formation. The cores, examined by M. S. Barss (personal communication) for microfossils, did not contain suitable material for age determinations. It would appear that the sections sampled were slightly above the Point Aconi unit, or there is a facies change at the Point Aconi unit from coal measure strata at the west side of Sydney Basin to red sandstone at the east side. Further sampling is required to establish whether coal measures occur off the south coast of Newfoundland.

Chart 812H; Chart 5, Profile 19; and Chart 10, Profiles 22–25 indicate that the coal measures are gently folded. Although the survey control is not sufficiently detailed to resolve the structural pattern, the data do provide an estimate of the mining depths that will be necessary in the exploitation of future reserves. It is important to note that mining depths anticipated from the present slopes in the submarine mines will change and at times become much shallower.

SUMMARY

The sub-Pleistocene geology of the Scotian Shelf and adjacent areas can be divided into four main categories on the basis of the geology: (1) the Acadian Basin, an area of Triassic rocks in the Bay of Fundy and northern Gulf of Maine, (2) the acoustical basement, an area of acoustical basement that underlies the eastern and central part of the Gulf of Maine and the inner zone of the Scotian Shelf; (3) the east coast geosyncline, an area of Jurassic, Cretaceous, and Tertiary strata that underlie the outer part of the Gulf of Maine and the central and outer zones of the Scotian Shelf and Laurentian Channel; and (4) the Sydney Basin, an area of Carboniferous rocks between Cape Breton Island and Newfoundland.

The Acadian Basin contains most of the Triassic sediments of the map-area except for small outliers bordering Chedabucto Bay and possible local occurrences in structural basins concealed beneath the east coast deposits of the Scotian Shelf. Triassic deposits are continental in origin. In the Bay of Fundy and the northern Gulf of Maine these deposits also comprise interbedded basalt. The Acadian Basin is dominantly a syncline, downfaulted near the New Brunswick side by the Fundian Fault, part of the Glooscap fault system. This fault system is a major structure that cuts across the entire map-area. It may extend westward into New England, and probably extends eastward to the mouth of the Laurentian Channel where it is thought to join the Newfoundland fracture zone. In the northern Gulf of Maine the Triassic sediments are separated into three troughs by basement highs.

The eastern and central parts of the Gulf of Maine are underlain by rocks that for the most part constitute acoustical basement. Along the western coast of Nova Scotia a seaward continuation of the Cambro-Ordovician suite (Meguma Group) with Devonian intrusives, the Meguma platform, occurs. Farther west the acoustical basement is not as well differentiated and is mapped as a pre-Pennsylvanian unit which may include Precambrian and early Paleozoic rocks, part of the Cobequid and Caledonia Highland trend from the north. The western limit of the Meguma platform probably extends to approximately the central axis of the Gulf of Maine.

Undivided rocks of the Cambro-Ordovician Meguma Group and Devonian granite form the bedrock beneath the inner part of the Scotian Shelf south of mainland Nova Scotia. Adjacent to Cape Breton Island and Newfoundland coasts, rocks of Mississippian or older age have been mapped as pre-Pennsylvanian acoustical basement.

The outer part of the Gulf of Maine, the central and outer parts of the Scotian Shelf, and the western Grand Banks are underlain by a thick wedge of Mesozoic and Cenozoic strata which represents an extension of the sedimentary sequence underlying the Atlantic Coastal Plain and continental shelf of the eastern United States. This sequence comprises the rocks of the east coast geosyncline. South of mainland Nova Scotia these sediments overlie basement rocks about 45 km seaward from the present coast. South of Cape Breton Island and in the Laurentian Channel they overlie undivided pre-Pennsylvanian and Pennsylvanian rocks respectively. The east coast sediments have an estimated thickness of approximately 10 km. The strata dip gently seaward except where locally disturbed by tectonic or halokinetic movements, e.g. the Orpheus basin south of Cape Breton Island.

Pennsylvanian strata occur over much of the area between Cape Breton Island and Newfoundland and represent an offshore continuation of strata in the Sydney Basin. In the southern part of the area these strata flank the north side of the Scatarie basement ridge and extend for an unknown distance southward along the Laurentian Channel and into the Orpheus basin. The limits of Pennsylvanian strata on the Grand Banks to the southeast are also undetermined. Pennsylvanian strata adjacent to southern Newfoundland and northern Cape Breton Island are bounded by Mississippian or older rocks (pre-Pennsylvanian unit) close to the present shoreline.

The Sydney Basin is essentially saucer shaped with the beds generally dipping toward the central part of the basin. Steeper dips of 10–25° occur in a marginal fold belt adjacent to the Scatarie basement ridge, in the Sydney area of Cape Breton Island, and west of St. Georges Bay, Newfoundland, in the Magdalen Basin. The remainder of the section is locally disturbed by faulting and gentle folding. Pennsylvanian strata are continuous but faulted between the Sydney and Magdalen basins. The total section of Carboniferous sediments in the Sydney Basin is above 5000 m and may exceed 7000 m.

Strata of possible Tertiary or early Pleistocene age overlie Pennsylvanian strata across a large area of the Laurentian Channel in the vicinity of St. Paul Island and west of Burgeo Bank.

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