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Late Quaternary glaciation and sea-level change along the Atlantic coast of
Nova Scotia: correlation of land and sea events

by

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ABSTRACT

The inner continental shelf off Nova Scotia can be subdivided into 5 coast-parallel terrain zones which record glaciation, and sea level rise and fall during the Late-glacial period. At the last glacial maximum an ice mass centred in the Gulf of St. Lawrence extended to the shelf edge (Ice Flow Phase 2). During an initial deglaciation phase (ca. 17-15 ka) ice was drawn out of the Gulf of Maine, isolating an ice mass over Nova Scotia which later became an active centre of outflow (Scotian Ice Divide-Ice Flow Phase 3). The Scotian Shelf End Moraine Complex (SSEMC) lies at the seaward margin of the inner shelf. The surface SSEMC till is correlated with an autochthonous, stony till on land formed under the Scotian Ice Divide. The SSEMC formed at the ramp margin of a buoyant ice sheet. The Phase 3 ice margin was stabilized by isostatic recovery from Phase 2 ice loads.

Landward of the end moraines is a series of linear depositional basins termed the Basin Zone which contain a complete sedimentary record of events after the deposition of the SSEMC. The lowest depositional sequences (Sequences 1+2; Emerald Silt facies A) in these basins are interpreted to be ice proximal sediment, deposited by overflow and interflow meltwater plumes emanating from a retreating ice margin. Periodic stillstands of this ice mass are marked by small, incipient moraines within the Basin Zone. DeGeer moraines are found over a wide area (Morainal Zone) landward of the Basin Zone. Two morphological varieties were defined; symmetrical and asymmetrical moraines. These formed underneath and at the edge of a rapidly advancing local ice cap centred in northern Nova Scotia (Ice Flow Phase 4; ca 13 ka). From 13-12 ka sea-level dropped rapidly, due to general isostatic recovery. Ice receded out of marine areas depositing ice distal glacial marine Sequences 3 and 4 (Emerald Silt facies B), in the Basin Zone. A lowstand

shoreline (ca 11 6 ka) at -65 m is marked by the landward transition from morainal topography to a shoreface ramp, terrace and wave-cut platform. Increased storminess, sea ice and icebergs during the Younger Dryas climatic cooling (ca 11-10.0 ka), produced Sequence 5 in the Basin Zone.

LIST OF ABBREVIATIONS

IKU: Continental Shelf Institute (Norway) grab sampler

SSEMC: Scotian Shelf End Moraine Complex

SMB: South Mountain Batholith

LGM: Last glacial maximum

RSL: Relative sea level

BSL: Below present mean sea level

TESS: Truncated Emerald Silt subzone

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This Ph.D thesis was oorn out of the frustration I felt when losing the trail of glaciers at the last striated outcrop above high tide. During my 2 years at Dalhousie and with the support of the Geological Survey of Canada, I have learned to be a marine geologist, and to develop a larger view of glaciers, both on land and at sea.

My family had to put up with a truant husband and father for many sunny summer days while I toiled on this thesis. They deserve my first heartfelt thanks.

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CHAPTER 1: INTRODUCTION

"The subtlety of nature is greater many times over than the subtlety of argument"
Sir Francis Bacon

The Atlantic Coast of Nova Scotia is a boundary between two vastly different environments; land and sea. During the Quaternary, ocean, land and ice battled for territory. The present coastline is a transient feature, recording the continuing advance of the ocean onto the land before the next major glacial cycle.

Scientists who study the Quaternary in the marine and terrestrial environments have differing goals and methods. The purpose of this thesis is to establish a correlation between Quaternary landforms and sedimentary units on the Atlantic Coast of Nova Scotia and "bridge the gap" between the land and sea disciplines. The ultimate goal is to develop a glaciation/sea-level model for Nova Scotia and the inner continental shelf that is consistent with both the marine and terrestrial records.

Paleoclimatic research over the last two decades has been focussed on atmosphere, ocean and cryosphere interactions (Crowley and North, 1991). Linking the deep ocean Quaternary records with land glacial records is not an easy task. The land stratigraphic record consists of deposit. rom relatively recent glacial advances and retreats. In Atlantic Canada, pre-Illinoian strata have not been identified, except for the problematic "Bridgewater Conglomerate" (Grant, 1989). In fact, Tertiary sediments are not known on land and the youngest pre-Quaternary unconsolidated strata are Cretaceous in age (Fowler and Stea, 1979).

Erosion, sporadic deposition and exposure, and lack of suitable dating methods make the history of pre-Wisconsinan glaciations less resoluble (Clark *et al.*, 1993).

Deep ocean sediment faunal and isotopic records provide a continuous Quaternary climatic evolution but only give indirect clues to ice sheet activity, and the precision is limited by bioturbation, slow sedimentation rates and oceanic mixing (Kennett, 1982). The resolution of any glaciation/sea-level model is also limited by the "inertia" of the ice masses themselves. Small mountain glaciers are extremely sensitive and respond to changes in global climate in time spans of 10^2 years. Larger ice masses such as the Greenland Ice Sheet are sluggish, with response times in the order of 10^4 to 10^5 years (Sugden and John, 1976). Late Quaternary ice caps in the Maritime provinces were intermediate in size between these two extremes (Prest and Grant, 1969).

Cooke (1972) attempted a global correlation of onshore and offshore glacial events for the last 2 million years by matching major glacial and interglacial periods in diverse land and sea paleoclimatic records. More recently, Clarke *et al.* (1993) attempted to match the terrestrial record of glacial advances in North America with the oceanic record for the last 100,000 years. Such correlations are flawed because they rely on age assumptions rather than direct lithostratigraphic correlation. Radiocarbon dating provides an accurate chronology for deposits younger than 30,000 years BP. A lack of suitable methods beyond that range hinders temporal correlation (Clark *et al.*, 1993). The chronology of oceanic records has been refined based on the assumed causal relationship between Milankovitch cycles and climatic proxies in deep ocean cores (Hays *et al.*, 1976). This orbitally "tuned" chronology is currently in widespread use (SPECMAP; Imbrie *et al.*, 1984). Recent dating of the Devils Hole speleothems has provided an accurate terrestrial chronology that

is in conflict with the SPECMAP chronology (Winograd, 1992; Broecker, 1992). The application of a direct correlation of land and sea glacial deposits will help to explain discrepancies in land and sea glacial chronologies and refine the role of internal feedback mechanisms forcing glacial-interglacial climatic cycles.

The continental shelf of Nova Scotia is an interface between the deep ocean and the land. Glaciers eroded land areas and transported the sediment to the edge of the continental shelf (King and Fader, 1986; Piper et al., 1990). If erosional and depositional events on land and on the shelf can oe linked, then the first step in the linkage of the glaciers with offshore abyssal plain sediments will be established. Ice rafted debris (Conolly and Ewing, 1965; "Heinrich" layers; Heinrich, 1988; Bond et al., 1992; Grousset et al., 1993), recognized within the deep ocean basins, complete the sedimentary cycle from land to deep ocean.

This stuoy will focus on Wisconsinan events on the inner shelf of southern and eastern Nova Scotia. This was a time of worldwide glacial advances and retreats, and fluctuating climates.

The detailed objectives of the project include:

(1)   Development of lithic and seismic criteria for the correlation of offshore
        and onshore Quaternary landforms and formations.

(2)   Determination of the flow patterns, offshore extent and recessional history
        of glaciers.

(3)   Dating of the Quaternary formations to estaolish a temporal framework for

glacial events in the region.

(4)   Evaluation of the extent of the sea-level variations on inner shelf, including

low sea-level stands, residual beaches and erosional unconformities.

(5)   Elucidation of the glacial, proglacial and marine processes responsible for

the sedimentary units.

Glacial history on the continental shelf of Nova Scotia is inextricably linked to local sea-
level variations (Scott *et al ,* 1987a). The goal of this research is to develop
comprehensive, empirical model of glaciations and sea-level change in Maritime Canada.

1.1 STUDY AREA

The oceanic area selected for this study is a portion of the coastline and inner Scotian Shelf
from Halifax to Country Harbour, extending 80 km seaward of the present shoreline and
including a major morainal system termed the Scotian Shelf End Moraine Complex (King
et al., 1972, Fig. 1). The terrestrial area includes a strip of land approximately 40 km
wide along the Eastern Shore of Nova Scotia from Halifax to Country Harbour (Fig. 1).

Figure 1. Location of the study area, seismic tracklines and terrestrial reference sections. In this thesis study only the Halifax, Sheet Harbour and Country Harbour transects were mapped.

Terrestrial reference sections:

1. West Lawrencetown Section
2. Mushaboom Section
3. Smith Cove Section
4. Wine Harbour Section.

Figure 1.

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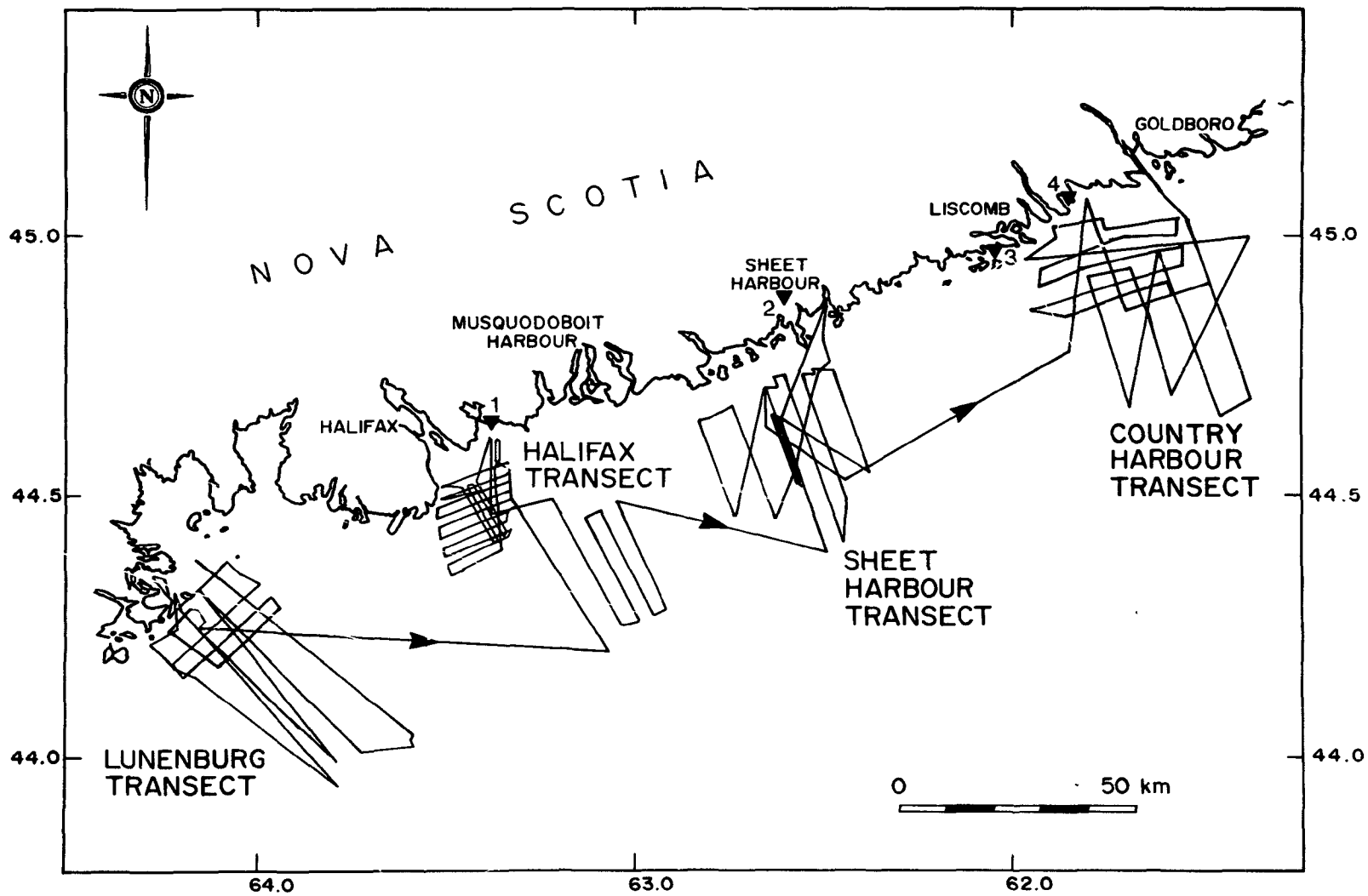
1.2 GEOLOGICAL SETTING AND PHYSIOGRAPHY

Nova Scotia is an amalgamation of disparate bedrock terranes brought together by the dynamics of plate tectonics (Fig. 2). On mainland Nova Scotia, the Cobequid-Chedabucto Fault system separates the Avalon Zone to the north from the Meguma Zone to the south (Williams, 1978). The Avalon Zone consists of highland massifs of Precambrian to Carboniferous volcanic, metasedimentary and igneous rocks flanked by basinal sedimentary rocks of Carboniferous and Triassic age. The Meguma Zone consists largely of Cambro-Ordovician metasedimentary rocks (Meguma Group) intruded by Devono-Carboniferous granitoid rocks.

1.2.1 Meguma Zone

The Meguma Group has been interpreted as the remnants of a North African continental slope sedimentary prism that was amalgamated onto the North American continent during the Devonian (Schenk, 1971). The age of these rocks ranges from Cambrian to Ordovician (O'Reilly *et al.,* 1992). These sedimentary rocks were regionally metamorphosed and deformed into upright, northeast-trending folds during the Lower Devonian Acadian Orogeny (Keppie, 1977). Regional metamorphism associated with the Acadian Orogeny has been dated radiometrically at 390-410 Ma (Muecke *et al.,* 1988). The regional metamorphic grade ranges from chlorite and biotite grade in the central region to andalusite; staurolite-cordierite and sillimanite grade toward the east and southwest (Keppie and Muecke, 1979).

Figure 2. Simplified regional bedrock geology (after Sanford *et al.*, 1991).

Figure 2.

Intrusive into the metasediments of the Meguma Group is a cogenetic suite of peraluminous granitic rocks which range in composition from tonalite to granodiorite to monzogranite (MacKenzie and Clarke, 1975; Albuquerque, 1977, MacDonald et al., 1992). All the granitic units contain the major minerals quartz, plagioclase, alkali feldspar, biotite and muscovite in varying degrees (O'Reilly et al., 1992). A large composite granitic pluton (South Mountain Batholith) underlies much of the area west of Halifax, while a number of smaller plutons occur along the Eastern Shore. The age of the granitic rocks has been established radiometrically and by intrusive relations with fossiliferous Lower Devonian sediments. Radiometric age dates indicate a range of ages from 374 Ma for the older biotite granodiorite and biotite monzogranite to 360 Ma for leucogranite dykes and two-mica monzogranite plutons (Clarke and Halliday, 1980).

The rock units of the Meguma Zone are part of an upland surface called the Southern Upland (Goldthwait, 1924; Roland, 1982; Map 1). The Southern Upland is an undulating, southeastward-dipping surface ranging in elevation from 300 m at the northern boundary with the Carboniferous Lowlands to sea level at the Atlantic coast. The upland surface is irregular with numerous strike-ridges and mounds formed of resistant rocks and constructional glacial features. The terrain is dominated by bedrock with thin drift cover. In the higher elevations, eastward-trending strike ridges are common following the regional Appalachian structural trend (Keppie, 1982). Glacially-modified, southeastward-trending fault valley systems (Cameron, 1956) create a rugged, irregular coastline. Major harbours such as Halifax, Sheet Harbour and Country Harbour (Fig. 1) and inland lakes such as Porters Lake east of Halifax, have fjord-like longitudinal profiles with overdeepened basins and sills (Hopkins, 1985). These silled basins attain 100 m in water depth (McKay, 1981).

A series of Carboniferous and Triassic basins are found within the Meguma Zone. These occur as fault-block basins with intervening upfaulted horst blocks (Boehner *et al.*, 1986). The Carboniferous basins consist of continental sedimentary rocks (Horton Group) overlain by a largely marine sequence of evaporites, limestone, dolomite and clastic sedimentary rocks (Windsor Group). In the Triassic basins red bed conglomerates, sandstones and mudstones of the Fundy Group are overlain by several basalt flows collectively termed the North Mountain Basalt. The Carboniferous and Triassic basins form prominent lowlands including the Annapolis Valley, and the Hants-Colchester lowland (Map 1).

The North Mountain is a cuesta ridge that forms the edge of the Bay of Fundy for 200 km. The ridge attains heights of 230 m and slopes towards the Bay of Fundy.

1.2.2 Avalon Zone

The Avalon Zone found north of the Cobequid-Chedabucto fault system, is defined by an overstep sequence of Cambrian to Ordovician shallow marine rocks that contain a unique Acado-Baltic fauna (Murphy *et al.*, 1991; Fig. 2). The terrane was formed by closure of the Iapetus Ocean during the Silurian to Early Devonian (Keppie, 1977). The Cobequid Highland is a prominent upland feature within the Avalon Zone attaining heights of 300 m (Fig. 2). It is composed of Pre-Late Carboniferous strata bounded by the Cobequid fault on the southern edge and unconformities and faults on the northern edge (Donohoe and Wallace, 1985). These rocks include Hadrynian basement gneisses, quartzites and metavolcanics surrounded by Silurian to Devonian metasediments (Donohoe and Wallace, 1985). Granitic plutons from Hadrynian to Devono-Carboniferous intrude sedimentary strata in this region. These plutons form a bimodal suite of diorite and syenogranite and

tend to be normative corundum free or corundum poor (Clarke, *et al.,* 1980; Pe-Piper *et al.,* 1989). In some areas they exhibit a foliation (Donohoe and Wallace, 1982). The top of the Cobequid Highlands is a plateau which is cut by youthful, V-shaped streams on the southern side and larger, U-shaped valleys on the northern side (Donohoe *et al.,* 1992).

The Antigonish Highlands is another distinctive upland block on the western end of the northern mainland (Fig. 2; Map 1). It consists largely of Precambrian mafic and felsic volcanic rocks and turbidites, unconformably overlain by lower Paleozoic red conglomerates, arkoses, felsic and lithic tuffs, and red slates (Murphy, *et al.,* 1991). Intrusive rocks are rare, compared to the Cobequid Highlands, and consist of appinites, gabbros, alaskite and granites. Appinites are found in isolated plutons in the Cobequid (H. V. Donohoe, pers. comm, 1993) and Antigonish Highlands (Murphy *et al.,* 1991). They are ideal as indicator erratics (Stea *et al.,* 1989). The upland surface of the Antigonish Highlands is more irregular than the Cobequid Highlands and dips gradually from 315 m at the steeper, northeastern fault-bounded edge to 180 m along the contact with the Devono-Carboniferous St. Mary's graben to the south.

1.2.3 Offshore Bedrock Geology

In the study area, the Scotian Shelf is divisible into three physiographic zones. The inner zone extends from the present shoreline out to the contact with the Scotian Basin (Fig. 2). The Scotian Basin is part of an accreted wedge of Mesozoic and Cenozoic sediments that were deposited on the eastern flank of the Appalachian Orogen, after the breakup of Pangea (Wade and MacLean, 1990). The inner zone is a zone of irregular topography with thin glacial drift and transgressive sediments underlain by metagreywacke of the

Goldenville Formation (King and MacLean, 1974). The middle zor.c consists of a series of broad basins filled with Quaternary sediments and underlain by Cretaceous and Tertiary marlstones, mudstones, sandstones and conglomerates (Wyandot and Banquereau Formations (King and MacLean, 1974). The outer zone is characterized by a series of broad, flat-topped banks composed of thick, sandy Quaternary sediments underlain by Mesozoic and Cenozoic rocks of the Scotian Basin.

1.3 CONCEPTS OF GLACIATION IN NOVA SCOTIA

As early as the late 1800s when the glacial theory was born, the nature of glaciation in Nova Scotia was being debated. Did former glaciers arise from local areas, originating in uplands and confined to the province, or was the ice part of a great continental mass which crossed the Bay of Fundy? The Reverend D. Honeyman, curator of the Provincial museum in the late 1800's, noted the long distance transport of amygdaloidal basalt boulders found along the Atlantic coast near Halifax and used the observation to support the concept of a continental-based ice movement that crossed the Bay of Fundy.

Robert Chalmers (1895) carefully mapped glacial grooves and striations in Nova Scotia and proposed that northern Nova Scotia had been glaciated largely by local glaciers with floating ice a secondary agent in low-lying areas. In contrast to Honeyman, he did not believe that a continental glacier had crossed the Bay of Fundy. Chalmers (1895, p. 95m) stated:

> The depression of the Bay of Fundy was not crossed by land ice from
> southern New Brunswick . . . Neither has Nova Scotia been glaciated by
> extra-peninsular ice from the north or northeast.

L. W. Bailey (1898) and W. H. Prest (1896), working in mainland Nova Scotia, observed erratics that supported both previous views. Bailey stated the compromise position (1898, p. 26m):

> As in other parts of southwestern Nova Scotia the facts connected with the glaciation of Digby Neck are, in the opinion of the writer, best explained upon the supposition of submergence beneath a continental glacier moving southward and bringing debris even from the other side of the Bay of Fundy, followed by a period of more local and restricted distribution, when the higher portions of the peninsula became themselves the centre of the movement, the latter now occurring in all directions.

J. W. Goldthwait (1924), in his treatise "The Physiography of Nova Scotia" dismissed all evidence regarding local glaciers in Nova Scotia. He envisioned a major ice mass moving southeastward, stemming from a Labrador-Laurentide source, and a subsequent southward-directed ice movement stemming from ice in the Gulf of St. Lawrence called the "Acadian Bay Lobe"

Pleistocene mapping in the Annapolis Valley initiated at Acadia University, Wolfville (MacNeill, 1951; Purdy, 1951; Swayne, 1952) revived the concepts of local glaciers (MacNeill and Purdy, 1951). Synchronously, Flint (1951) advanced the idea of local highland centres of outflow based largely on the previous work of Chalmers (1895). Hickox (1962) confirmed that granitic erratics on the North Mountain were derived from the South Mountain Batholith in Nova Scotia and not from New Brunswick as Goldthwait (1924) had previously suggested.

Regional analyses of air photographs prompted V. K. Prest and Grant (1969) to further develop the local glaciation model of eastern Canada. They defined several local centres of ice flow, termed the Appalachian Ice Complex that were sufficiently large to hold off the encroaching Laurentide ice sheet.

King (1969) concluded that the Scotian Shelf End Moraine Complex was the terminus of a Late Wisconsinan continental ice advance. Grant (1975) proposed a southward flood of ice prior to 39,000 years B.P. followed by a retreat about 38,000 years ago and re-expansion of Nova Scotia glaciers during the Late Wisconsinan. Grant (1977) and Grant and King (1984) further developed the hypothesis that Late Wisconsinan ice of Labradorean (Laurentide) origin never crossed the Bay of Fundy. This became known as the "minimum model" (Fig. 3). Grant (1977, p. 247) stated:

> "Evidence from scattered stratigraphic sections, from the relationship of a sequence of ice flow indicators to a raised interglacial marine platform, together with the limits of freshly glaciated terrain against weathered bedrock areas, indicates that late Wisconsinan glaciers spread weakly toward, and in many areas not beyond, the present coast. These were fed by a complex of small ice caps located on broad lowlands and uplands. The limiting factor was the deep submarine channels that transect the region".

Thus in Grant's view, Laurentide ice was limited to the northern Gulf of St. Lawrence. Today most continent-wide interpretations of the Late Wisconsinan glaciation show a relatively simple, monolithic ice sheet centred in Hudson's Bay and extending to the shelf

Figure 3. Summary of previous Late Wisconsinan glaciation models (after Stea *et al.*, 1987 and King *et al.*, 1972) and the location of major morainal systems on land and offshore.

Figure 3.

17
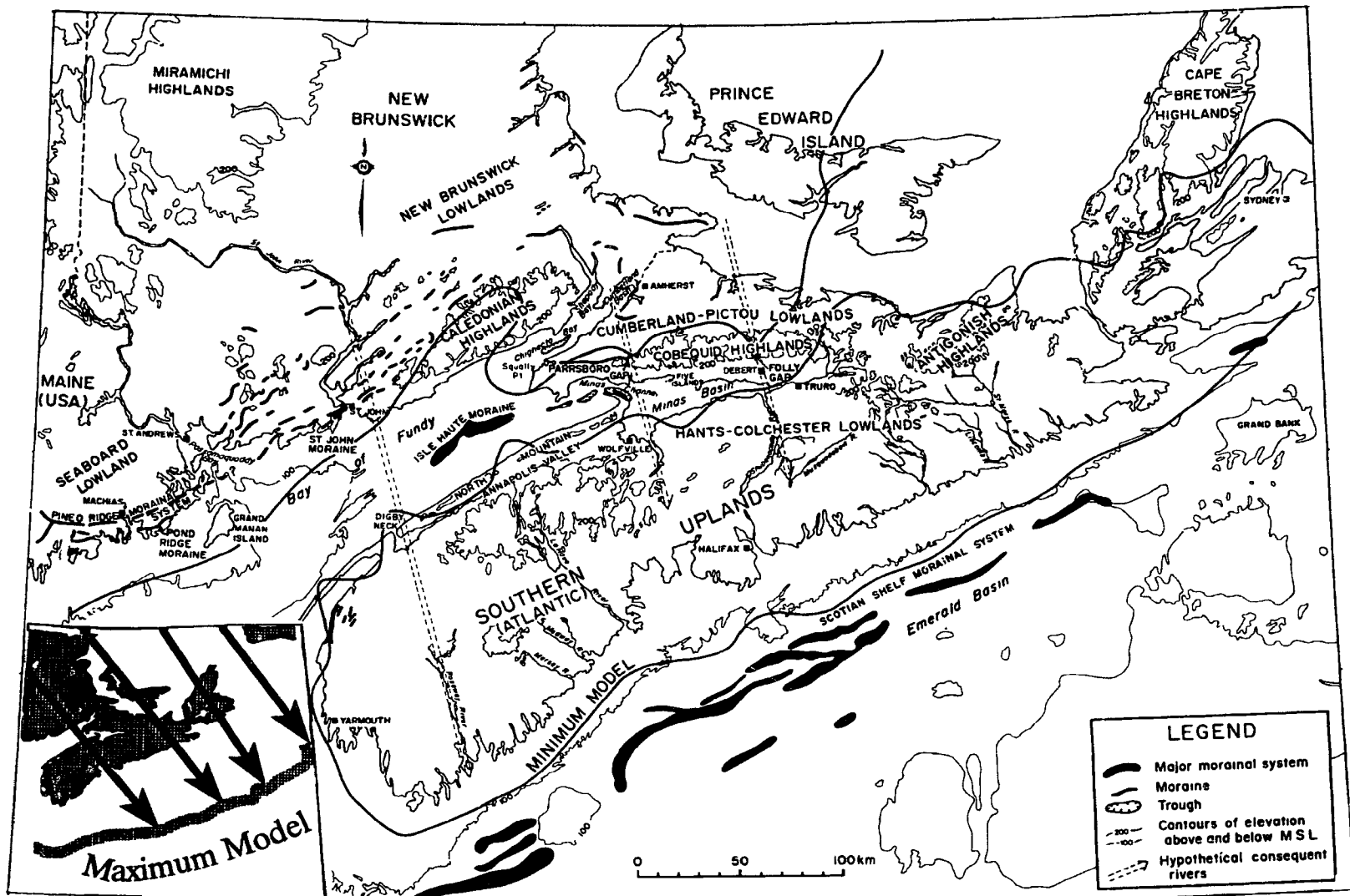
edge off Nova Scotia (Flint, 1971; Denton and Hughes, 1981; Budd and Smith, 1987). This is termed the "maximum" model and is believed to represent the equilibrium condition. The contrasting "minimum" model is one with local ice centres and thinner ice, extending only slightly off the coast of Nova Scotia and with some highland areas bare of ice (nunataks) (Dyke and Prest, 1987). These two extreme models are not in accord with recent mapping of glacier erosional and depositional landforms in New Brunswick and Nova Scotia (Wightman, 1980; Rampton *et al.*, 1984; Rappol, 1989; Foisy and Prichonnet, 1991; Stea and Finck, 1984; Stea *et al.*, 1986; 1989). These authors envision a time transgressive, ice flow phase evolution of ice caps in the region. Late Wisconsinan ice caps covered all highland areas and extended to the continental shelf edge (Mosher *et al.*, 1989; Gipp and Piper, 1990). The complex, but extensive, glaciation model is essentially a compromise between the earlier models and it represents the current state of the debate. Stea (1982; 1984), Stea and Finck (1984) and Stea *et al.* (1987; 1992) developed a 4 ice flow phase model of terrestrial glacier flow events in Nova Scotia (Fig. 4).

1.3.1 Ice Flow Phase Model

Complex glacier flow patterns have been imprinted on the landscape of Nova Scotia (Stea, 1984; Stea, 1994). Many outcrops reveal three or four crosscutting sets of striae and bevelled facets that can be traced regionally. Boulders are dispersed east, west, north and south of their bedrock sources in Nova Scotia. Sections can reveal four or more stacked till sheets of differing provenance. From these facts it is hard to conclude that one ice flow or glaciation (through topographic streaming) is responsible. Stea *et al.* (1984) developed an evolutionary model of flow events defined by discrete, regionally mappable

Figure 4. Ice flow patterns deduced from striae and drumlin directional data. Ice Flow Phases 1a and 1b from **Appalachian** or **Laurentide** source areas, flowed eastward and southeastward across the Bay of Fundy and onto the Continental Shelf. Ice Flow Phase 2 stems from the **Escuminac Ice Centre** or Divide. Ice Flow Phase 3 represents formation of an ice divide (Scotian Ice Divide) across the mainland of Nova Scotia. During Ice Flow Phase 4 remnant ice caps (Chedabucto Bay Glacier, Chignecto Glacier, South Mountain Ice Cap) flowed into marine basins adjacent to the province.
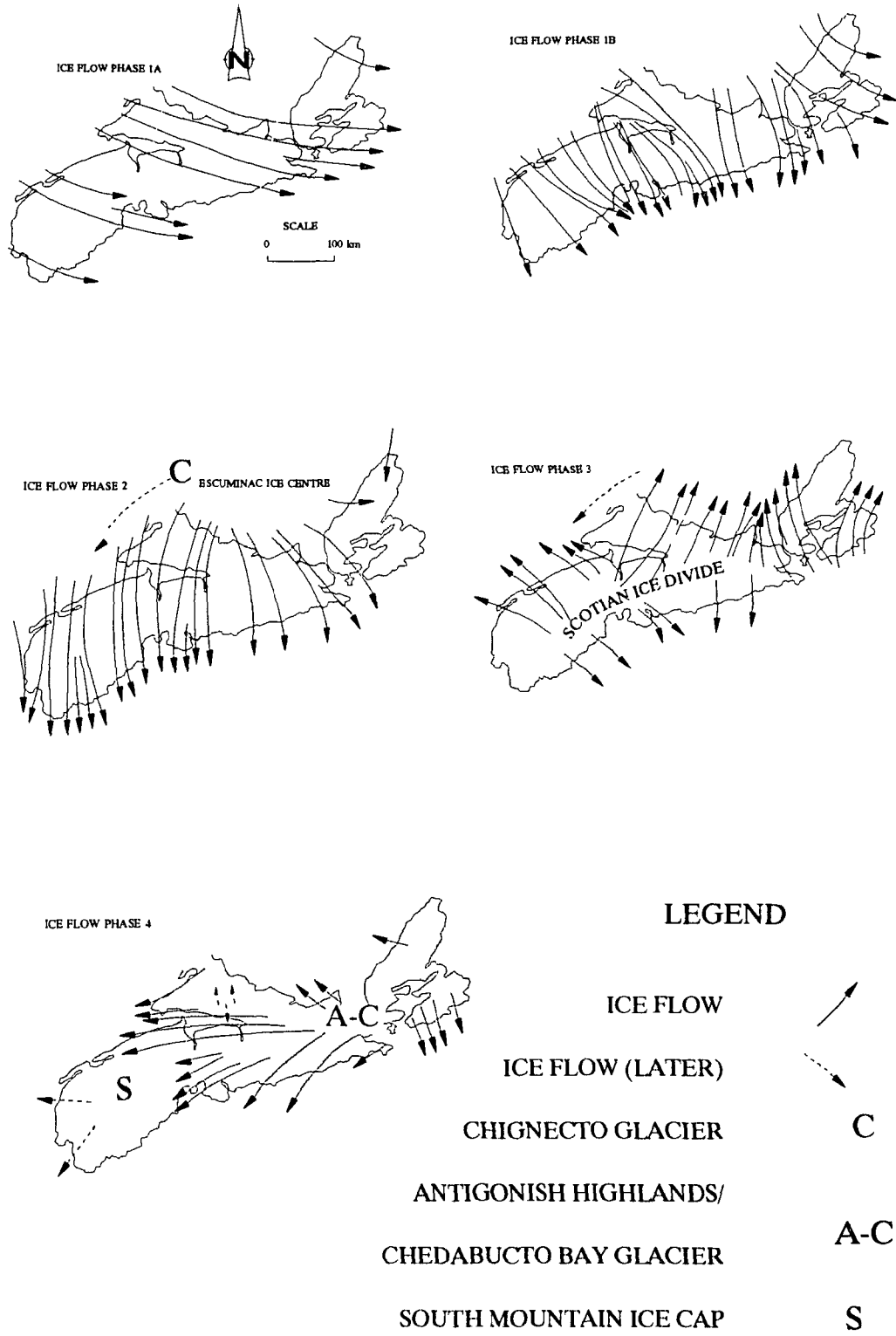
Figure 4.

ice-flow trends termed "erosional stratigraphy" (W.W. Shilts, personal communication, 1986). Each event is called an "Ice Flow Phase". Flow lines relating to each phase can be traced over broad regions of Nova Scotia using striae and drumlin orientations (Stea and Finck, 1984). Crosscutting relations and the preservation of older, weathered striations on lee-side surfaces are used in the development of an "erosional stratigraphy". The patterns of ice flow mapped by striae are verified by till fabric, dispersal studies and the orientation of glacial landforms such as eskers and drumlins (Stea, 1984; Stea et al., 1989). The sequence of ice-flow phases has been discerned from superimposed striae sites, and through correlation with stacked till sheets of known provenance (Stea, 1984). Each of the ice-flow phases produced at least one recognizable till sheet, sometimes with basal and englacial facies.

Striae patterns, distinctive erratics, till fabric, and striated boulder pavements suggest that the earliest and most extensive ice-flows in Nova Scotia were eastward and southeastward (Fig. 4). These have been designated Ice Flow Phases 1a and 1b. Several widely-spaced striae sites reveal evidence of a distinct eastward flow, later superseded by a southeastward flow. The eastward ice-flow may represent a separate, older phase of glaciation. Erratic trains of igneous rocks from the Cobequid Highlands and trains of basaltic rocks from the North Mountain are oriented southeastward and can be traced to the Atlantic Coast, up to 120 km down-ice (Nielsen, 1976). This phase may represent Laurentide ice-flow but more probably is related to a centre in New Brunswick (Rampton et al., 1984). Anorthosite erratics in western Prince Edward Island and the Gulf of St. Lawrence, derived from the Canadian Shield, suggest that Laurentide ice did cross the region at some time (Loring and Nota, 1969; Prest and Nielsen, 1987, Stea, 1991).

The second major ice-flow trend (Ice Flow Phase 2) was southward and southwestward from the Escuminac Ice Centre in the Prince Edward Island region (Prest, *et al.*, 1972; Rampton *et al.*, 1984; Fig. 4). This flow phase was called the "Acadian Bay Lobe" by Goldthwait (1924) and the "Fundian Glacier" by Shepard (1930). Goldthwait (1924) envisioned southward flow from a Laurentide source across the Gulf of St. Lawrence. Ice-flow trends in Prince Edward Island (Prest, 1973) and adjacent New Brunswick (Rampton *et al.* 1984) do not reflect a pervasive southward flow, but suggest radial flow from a local centre. This event is recorded by southward striae crossing earlier south- eastward-trending striae at many localities on the upland regions of Nova Scotia and New Brunswick. Carboniferous red beds from northern mainland Nova Scotia and Prince Edward Island region were eroded and transported southward onto the metamorphic and igneous Cobequid and Meguma Terranes of mainland Nova Scotia along with distinctive Cobequid Highland erratics (Grant. 1963; Stea *et al.*, 1989). Schnikter (1987) reported evidence of southward dispersal of red clastic material from the Bay of Fundy into the Gulf of Maine.

During the next event (Ice Flow Phase 3), ice flow was northward and southward from a divide (Scotian Ice Divide) across the axis of the Nova Scotia peninsula. Granitic debris from the South Mountain Batholith were transported northward onto the North Mountain basalt cuesta (Fig. 4; MacNeill, 1951; Hickox, 1962). Erratics from the Cobequid Highlands can be found dispersed throughout the Carboniferous lowlands to the north (Stea and Finck, 1984). Northward-trending striae can be traced across the northern mainland of Nova Scotia (Fig. 4). This well-documented northward ice-flow was a response to the development of an ice divide in southern Nova Scotia. This divide may have formed as a result of marine incursion into the Bay of Fundy (Prest and Grant, 1969) or increased

precipitation after recession of the Escuminac Ice Cap (MacNeill and Purdy, 1951; Hickox, 1962). Northward ice-flow from the Scotian Ice Divide was probably synchronous with the ice dome off Cape Breton Island proposed by Grant (1977). The divide can be traced from areas south of the Antigonish Highlands (Myers and Stea, 1986) offshore into Chedabucto Bay. Here, ice flow was funnelled through the submarine channels out of St. Georges Bay and the Cape Breton Channel towards the Gulf of St. Lawrence. Northward ice flow was less intense in the western Cobequid Highlands. As marine drawdown began to take effect, the ice may have been increasingly directed into the Bay of Fundy to merge with southwestward ice streams from New Brunswick.

During this final phase (Ice Flow Phase 4), remnant ice caps developed from the Scotian Ice Divide (Fig. 4). Eskers and striations cut across features formed by earlier ice flows. Ice caps or glaciers that formed over the Chignecto Peninsula and southern Nova Scotia had recessional margins on land, marked by hummocky moraine, glaciofluvial deposits, and the gradual pinch-out of till sheets. Ice flow during this last phase was funnelled into the Bay of Fundy and into the Atlantic Ocean. Erosional features and deposits relating to these late-glacial ice caps are restricted to low-lying areas.

1.3.2 Sea Level

Pronounced sea-level changes accompanied the last glacial cycle in Nova Scotia. Relict shorelines can be found above and below present sea level (Fig. 5). On land, a wave-cut platform 4-6 m above sea level was formed during the last interglacial interval (Grant, 1980, 1989; Stea et al., 1987; 1992d). This shoreline is a product of climatically-induced sea-level rise and isostatic equilibration from former ice loads. Raised marine strandlines,

Figure 5. Plot of elevation isolines of raised marine features and submerged shorelines in the maritime provinces and Maine (data from Welsted, 1971; Fader, 1977, 1989; Grant, 1980; Scott and Medioli, 1980; Kelley *et al.*, 1986; Rampton *et al.*, 1984; Stea, 1983; Stea *et al.*, 1994). Modified after Stea *et al.* (1987).
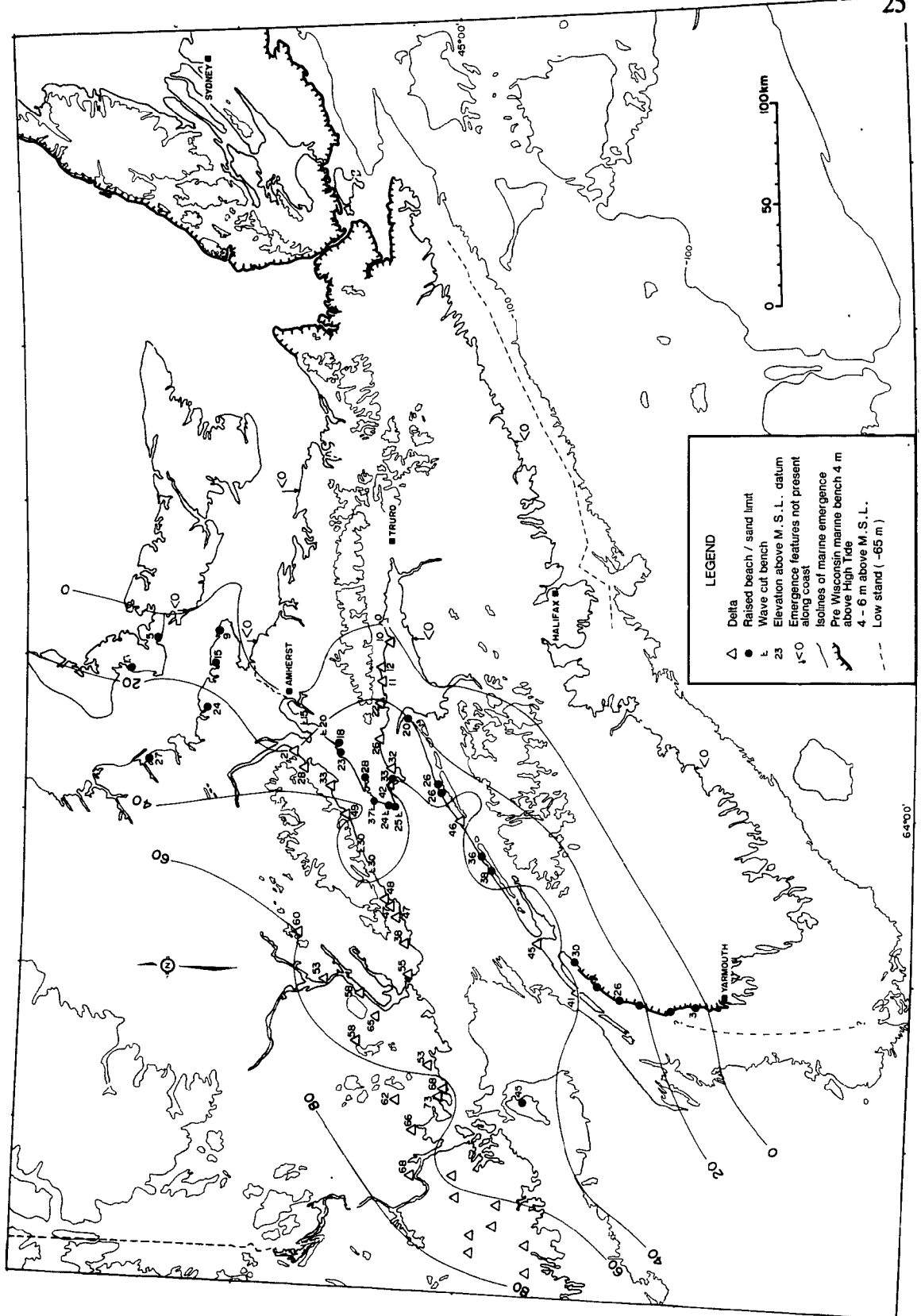
Figure 5.

formed by crustal rebound after the last glacial maximum, are found in the Bay of Fundy region of Nova Scotia. The complex variability of elevations, tilts and ages of these post-glacial strandlines has been interpreted as a response to the rate of ice retreat and the effects of local and regional ice caps (Wightman and Cooke,Quinlan and Beaumont, 1981; 1982; Scott et al., 1987b; Stea et al., 1987; Grant, 1989).

Evidence for sea-level rise has been found offshore of Nova Scotia. On the outer continental shelf, terraces and erosional features cut into bedrock and glacial deposits, 110-120 m below present mean sea level (BSL) have been interpreted as lowstand shorelines (Amos and Knoll, 1987; Amos and Miller, 1990; King, 1970; King and Fader, 1986; Fader, 1989a; Piper et al., 1990). McLaren (1988), however, reported maximum sea-level lowering of only 75 m (75 m BSL) in the Sable Island area, based on deltaic clinoforms and an associated unconformity. Scott et al. (1989) defined a continuous sea-level curve from 11 ka to the present based on dating of several salt and freshwater peat horizons. From this curve they extrapolated sea-level lowering to 78 m BSL at 15 ka. Summarizing much of the previous data, they emphasized the complexity of the sea-level history and stressed that sea-level histories and glaciation models are inextricably linked.

Contradictory evidence has been submitted regarding the sea-level history of the inner shelf, a portion of the continental shelf extending offshore from the present coastline to water depths of 150 m (Fig. 5). Fader (1989) proposed a shelf-wide low stand of sea-level at -110 to -120 m BSL based on terraces, unconformities and cross-shelf textural variations. King (1970) mapped the surficial geology of the Halifax to Sable Island map area using textural information from samples and morphological and acoustic characteristics from echograms. He defined the boundary between two surficial

formations - the Sambro Sand and the Sable Island Sand and Gravel, as representing a low sea-level stand. The Sambro Sand was described as a sublittoral muddy sand and the Sable Island Sand and Gravel as a clean well-sorted basal transgressive deposit formed through the reworking of glacial materials during the late Wisconsinan-Holocene marine transgression. Surrounding the offshore banks, this boundary consistently occurred at approximately 110-120 BSL. On the inner shelf, however, the depth of this transition varied, and in the area off Halifax, the boundary was mapped at 90 m BSL. Wang and Piper (1982), and Piper and Fehr (1991) proposed that a change from rolling to planar physiography at -50 to -60 m BSL indicates a lowstand and subsequent transgression. LaPierre (1985) mapped a sand body at -65 m which he interpreted as a relict beach. Forbes *et al.* (1991) found estuarine back-barrier deposits on the inner shelf dated at 10 ka, implying that sea-level fell to at least -50 m. They also defined coast-parallel depositional and erosional landform "zones". Stea *et al.* (1992b, c; 1994) reported evidence for a -65 to -70 m lowstand on the inner shelf off Nova Scotia, dated at 11.6 ka.

1.3.3 The Thesis Problem(s)

The main problems to be addressed in this dissertation are the glacial history of the inner shelf, the extent and direction of various ice flow phases on the inner shelf and sea levels associated with these glaciation events. Correlation of onshore-offshore glacial sediments and landforms is essential to accomplish this task.

CHAPTER 2: METHODS OF STUDY

To correlate onshore and offshore sedimentary units and landforms the author has employed three basic methods:

1.   Mapping of surficial sedimentary units and landforms

2.   Definition of the stratigraphy of surficial units.

3.   Determination of sediment properties: clast lithology, shape and surface features, grain size.

Two governing paradigms are used:

1.   Much of the land stratigraphy is mirrored in the inner shelf, especially in areas not affected by the transgression.

2.   The glacial depositional record increases in complexity towards the margin of ice sheets (Sugden and John, 1976).

2.1 MAPPING AND STRATIGRAPHIC CONCEPTS

The marine geologist relies primarily on geophysical techniques and point sampling for basic mapping whereas the land geologist relies on field investigation, aerial photography, and more recently, satellite imagery. It is easier to conduct seismic surveys at sea than on land because water is an excellent conductor of seismic signals. Transverse (shear) waves cannot be transmitted through water so they do not produce interference effects as they do on land (Savit, 1983). A continuous cross-section of the seafloor terrane under the ship is produced because the detector arrays are in continuous motion. Sampling Quaternary

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units in the marine realm, however, is difficult and costly. The advantage of land mapping is in the ease of sampling and identifying the Quaternary units in naturally exposed sections and by relatively inexpensive drilling. Another advantage of land surveys is the ability to get a "birds" eye (i.e. aerial photography) view of the terrain. This larger view is becoming available in the marine realm with the advent of digital multibeam sounding (Loncarevic *et al.*, 1992; Costello *et al.*, 1993). The Nova Scotia coast provides an unique opportunity to utilize the advantages of both the terrestrial and marine realms to solve the problems outlined earlier.

Geological maps portray orders of organization in the landscape derived from a remote aerial view (air photo-landsat imagery--multibeam-seismics) to a detailed one (stratigraphic and acoustic sections and samples). The terminology in the terrestrial realm is taken from the glacial-morphologic classification of Goldthwait (1989) utilized in the Surficial Map of the Province of Nova Scotia (Stea *et al.*, 1992a). Mapping essentially consists of identification, classification and interpretation of landform assemblages or terrain "zones". The seafloor topography and subbottom stratigraphy are a result of glacial, periglacial and marine processes acting over time. Distinct landscapes are produced by each erosional and depositional event. Land-sea correlation is accomplished by topographic and stratigraphic comparison of marine and terrestrial landforms. Forbes *et al.* (1991) and Stea *et al.* (1993; 1994) defined offshore terrain "zones" as distinct terrain types based on unique sea bottom morphology (landforms) and seismic sequences and facies (stratigraphy).

A major portion of this thesis concerns stratigraphic analysis of the offshore seismic reflection profiles and stratigraphic sections on land. Stratigraphy is obtained in the

offshore by the generation of seismic waves from towed or hull-mounted acoustic sources. These emit regular pulses which are transmitted through the water column, reflected by the seafloor and the underlying geology, then intercepted by hydrophones which convert the acoustic pressure waves to electrical signals. These signals are processed and displayed on an onboard recorder which burns a small mark on paper, then advances while keying another seismic signal. These marks vary in intensity depending on the strength of the returning signal. The reflection of an acoustic signal at the air-water, water-sediment or sediment-sediment interface is a result of the acoustic impedance differences between these mediums. Acoustic impedance is an intrinsic property of all substances and is defined as the product of the compressional wave velocity and the bulk density of the material (Sylwester, 1983). The amplitude or strength of the seismic signal depends on the ratio of acoustic impedances (reflection coefficient) of the media on either side of a reflecting interface. The air-water interface, for example, is nearly a perfect reflector, having a reflectivity coefficient equal to -1.

In essence, the seismic reflection record is an acoustic cross-section of the geology (Sylwester, 1983). The main sources of acoustic reflections in the geological section are stratal surfaces and unconformities. Stratal surfaces are defined as bedding contacts or relict depositional surfaces (Brown and Fischer, 1982). Unconformities are surfaces of erosion and nondeposition which represent gaps in the geological record. Stratigraphic analysis is based on the method of Vail *et al.* (1977), termed seismic sequence analysis. This analysis is based on the recognition of unconformity-bound packages of strata. Boundaries between seismic sequences are recognized on seismic profiles by terminations of reflections. The boundaries are either erosional, lapout (hiatal) or conformable. Within

each sequence, seismic "facies" can be defined (Mitchum *et al.*, 1977; Belknap and Shipp, 1991). The facies are based on the continuity, amplitude and frequency of the reflections. These acoustic properties are an indication of the lithic properties of the strata. Acoustic reflectivity, the degree of coherence of the incoming reflected pressure pulse, is also a useful tool in determining lithic properties of the seabed (Parrot *et al.*, 1980). Seismic sequence and facies analysis permit the interpretation of the depositional history of the region including sea-level changes and changes in depositional styles during ice advance and retreat. King and Fader (1986) used seismic and lithofacies analysis to differentiate acoustic units on the Scotian Shelf. Boyd *et al.* (1988o) were the first to utilize the sequence analysis approach on the Scotian Shelf in stratigraphic analyses of Sable Island Bank. Gipp (1989, 1994) defined seismic sequences within Emerald Basin.

King and Fader (1986) subdivided marine basin-fill sediments on the Scotian Shelf into three formations: the Scotian Shelf Drift, Emerald Silt and LaHave Clay. These terms are in wide use (cf. Piper *et al.*, 1990) and will serve as a basis for further stratigraphic subdivision in this study. A formation is defined as a mappable body of sedimentary strata which is distinguished and delimited on the basis of lithic characteristics and stratigraphic position (North American Stratigraphic Code, 1983). King and Fader (1986) and Fader (in Williams *et al.*, 1985) used a combination of lithic and acoustic attributes to define Formations and facies on the Scotian Shelf. The oldest formation is the Scotian Shelf Drift overlain by the Emerald Silt and LaHave Clay. These formations are described in Table 1. King and Fader (1986) never stipulated a single type acoustic section or cores for each of the surficial formations but described several piston-cored reference acoustic sections. The Emerald Silt is subdivided into three facies (A, B, and C) based on lithostratigraphy and

Formation	Facies	Lithic Properties	Seismic Character
Sable Island Sand and Gravel		Fine to coarse, well-sorted sand grading to subrounded to rounded gravels.	Highly reflective seabed, closely spaced, continuous reflections.
Sambro Sand		Silty-sand grading to gravelly-sand.	Similar to above.
LaHave Clay	LaHave Clay	Greyish-brown, soft, silty-clay grading to clayey-silt, confined mainly to basins and depressions in the shelf.	Generally transparent without reflections, some weak, continuous, coherent reflections at the base of the section[1]
Emerald Silt	Facies C	not well sampled	Discontinuous, coherent reflections, and incoherent zones.
Emerald Silt	Facies B	Dark greyish-brown, poorly sorted, clayey and sandy-silt, some gravel, poorly developed rhythmic banding.	Medium to low amplitude, continuous, coherent reflections; ponded depositional style.
Emerald Silt	Facies A	Greyish-brown, poorly sorted, clayey and sandy silt, some gravel, well developed rhythmic banding.	High amplitude, continuous, coherent reflections conformable to substrate irregularities.
Scotian Shelf Drift		Sandy-clay, matrix-supported, diamicton.	Incoherent reflections, sometimes with scattered, point source reflections.

Table 1. Quaternary formations and seismic facies defined by King and Fader (1986) and their properties. [1] These reflections are now considered to be part of a separate formation (Yankee Bank Formation) defined later in this dissertation.

seismic stratigraphy (Table 1). A facies is described as a body of rock characterized by a particular combination of lithology, physical and biological structures that bestow an aspect different from the bodies of rock above, below or laterally adjacent (Walker, 1992). In this study I will restrict the use of Emerald Silt facies terms defined by King and Fader (1986) to seismic facies (cf. Mitchum et al., 1977). This frees these facies terms from time constraints. Unfortunately, the LaHave Clay is both a formational and facies term. If referring to the formation the term "LaHave Clay Formation" will be used. When referring to the seismic facies, "LaHave Clay facies" will be used.

2.2 SEDIMENT PROPERTIES

Stratigraphic sections along the coast of Nova Scotia (Stea and Fowler, 1979) provide clues to the makeup of moraines in the offshore. Offshore glacial landforms can only be sampled on their uppermost surfaces while terrestrial counterparts, exposed in sea cliff sections, can be sampled in profile from top to bottom. Lithic data obtained from the cliff sections are used to:

1. Correlate with glacial deposits in the offshore.

2. Assess the genesis and provenance of the sedimentary units exposed in sea cliff sections of onshore glacial landforms.

?. Verify previous correlations with terrestrial regional ice flow patterns determined through landform analysis.

The Maritime provinces are characterized by the juxtaposition of tectonic terranes of unique geology. Changing centres of outflow in Maritime Canada during the Wisconsinan produced compositionally and texturally distinct till facies (Prest, 1896; Grant, 1963; Nielsen, 1976; Stea and Fowler, 1979; Graves and Finck, 1988; Stea *et al.*, 1989). These lithic variations are largely due to erosion of distinctive rock formations as ice centres shifted over the varied geological terranes of the region. The marked contrast between Nova Scotia till facies enhances the potential for correlation with the offshore sections. Piper *et al.* (1986) used lithology and stratigraphy to correlate tills on the inner shelf with terrestrial till units.

In the past small-volume, lightweight grab samplers (e.g.van Veen) have been used to sample inner shelf surficial sediments and as a basis for the interpretation of seabed and subbottom acoustic stratigraphy (cf. Fader *et al.*, 1977). These samples may not be representative of the underlying acoustic stratigraphy because of a widespread transgressive gravel-lag armor in areas above the lowstand (Fader, 1989a) and current winnowing and iceberg furrowing of the till surface on morainal landforms in deeper water (King and Fader, 1986, p. 31). In this study a heavyweight (1/2 ton) grab sampler (IKU-Appendix 2) was used to provide data on the makeup of seabed acoustic units. It penetrated the seabed to depths up to 1 metre, and obtained a relatively large, undisturbed sample in muddy sediments (Appendixes 3,4; Stea *et al.*, 1993).

Once the onshore-offshore sediment link is established, former glaciers can be modelled from terrestrial flow lines and offshore margins and put into a temporal context. Radiocarbon dating and correlation of glacial marine sediments with moraines in the

offshore basins (King and Fader, 1988a; Gipp and Piper, 1990) has made this possible. The interaction between sea-level change and glacial dynamics can be assessed by landform and stratigraphic analysis of the inner shelf.

2.3 MAPPING METHODS-MARINE GEOPHYSICAL DATA ACQUISITION

See Appendix 1

2.3.1 Marine Data Analysis

The ocean floor was mapped by systematically describing all record types along each seismic trackline. In addition to visual descriptions of landforms and seismic stratigraphy, the areal extent, seabed height and thickness of each stratigraphic unit and landform were measured. These units and landforms were later grouped into a hierarchical classification of terrain zones and subzones, formations and facies. The thickness of basinal stratigraphic units were measured every 5 minutes along tracklines.

2.4 TERRESTRIAL MAPPING METHODS

The surficial geological data used in this dissertation were compiled from the Surficial Map of the Province of Nova Scotia (Stea et al., 1992a). Field compass and altimeter traverses were conducted on specific landforms for more detailed information on surface profiles. Several reference Quaternary sections along the Eastern Shore have been selected for detailed stratigraphic and till-pebble lithological analysis. The sections were traversed

by compass and pace and measured by altimeter and tape. The altimeter surveys were run in loops with a high tide marker as datum. Photographic logs were obtained from small boats. Individual sedimentary units were visually described and logged according to the lithofacies classification scheme of Eyles *et ai.* (1983).

2.5 MARINE AND TERRESTRIAL SAMPLING METHODS AND SAMPLE PREPARATION

See Appendix 2.

2.6 SAMPLE ANALYSIS (MARINE AND TERRESTRIAL)

2.6.1 Pebble Lithology

Grant (1963) and Nielsen (1976) conducted regional studies of pebble lithology in Nova Scotia. Grant (1963) traced 50 rock species to seven source regions in Nova Scotia whereas Nielsen (1976) limited his study to basalt and granitic rocks. Both studies utilized the 5-22 mm fraction of the till sample. Many different size ranges have been used for the purpose of quantitative lithological evaluation of till (cf. Krumbein, 1933; Holmes, 1952; Dreimanis and Reavely, 1953; Marcussen, 1973; Fenton and Dreimanis, 1976; Teller and Fenton, 1980). In this study the entire pebble (4-64 mm) size range was utilized. Important questions about pebble analysis are:

1. Do the ratios of different lithologies change with grain size?

2. Are the number of clasts in the grade size sufficient for statistical analyses?

3. Can the worker identify the lithologies using that grade size, and are certain lithologies comminuted into constituent minerals: e.g., granite?

Dreimanis and Reavely (1953) found no significant change in lithology ratios from one grade to another using the 4.699-6.66 mm, 6.680-9.423 mm, 9.423-13.33 mm, and the 13.33-80 mm grade sizes. Bahnson (1972) concluded that the ratios of different rock groups remained relatively constant in fractions larger than 1.44 mm, but changed radically in the fractions smaller than 1.44 mm. In the latter fractions, igneous and metamorphic lithologies are under-represented, because identifiable rock species have been comminuted to mono-mineralic fragments. The accuracy of provenance determination depends on the identification of the pebbles, so utilization of the larger pebble sizes is necessary. In view of these considerations, the 4-64 mm fraction was chosen as a compromise to obtain a large number of clasts in an identifiable size range, utilizing a manageable 2-4 kg sample.

In this study more than 300 pebbles per sample were counted and divided into three main categories:

1. Metasediments (Meguma Group)
2. Granitoids (South Mountain Batholith (SMB)
3. Foreign (not Meguma Group or SMB granites)

In most samples the "foreign" or non-Meguma components comprise less than 10% of the total amount. The significance of statistical comparisons of point counts less than 10% from samples of 300 is questionable (Patterson and Fishbein, 1989). Because of this, various "foreign" components" were ranked in order of abundance, rather than individually counted. To enhance rock identification, selected exotic pebble species from marine and terrestrial samples were thin-sectioned and petrographically analyzed using standard techniques.

The lithologic assemblage of a till depends on the intrinsic factors of till formation, the nature of the substrate over which the glacier passes, and inheritance/overprinting processes inherent in a multi-glaciated region (Finck and Stea, 1990). Lodgement tills are deposited by plastering of glacial debris from the sliding base of a moving glacier by pressure melting or other mechanical processes (Dreimanis, 1989). This process tends to form tills dominated by local lithologies, whereas tills formed through a basal melting or ablation process can contain very high percentages of exotic clasts (Dreimanis, 1989). At the base of a glacier, mutual clast attrition is high and lithologies such as shales are rapidly comminuted (Boulton, 1975). Lodgement tills produced from this material generally show little down-ice dispersal. As material is shunted englacially, the amount of clast to clast attrition decreases and transport potential is increased. Boulton (1978) referred to this process as "mechanically passive transport". Debris can be moved up into an englacial position through these processes:

1. Plucking from rock protuberances high in the ice (Shilts, 1976).

2. Up-glacier shearing as ice passes over obstructions and regelation ice forms underneath (Boulton, 1975).

3. As the ice flow becomes compressive, shear planes are created, guiding the dirty ice above the substrate (Dreimanis, 1976).

In any section of tills deposited by a single ice sheet, material from the base, middle and upper parts of the ice sheet (basal, englacial, and superglacial) can be deposited as a sequence, as the temperature regime of the glacier changes. This ablation-lodgement couple is almost universally present in all sections (Shilts, 1976).

2.6.2 Till Provenance

Ice flow trajectories are determined by linking source regions to sample sites (cf. Meyer, 1983). Foreign lithologies at any site along the Eastern Shore study region can generally be traced to one or more of these source regions.

1. Antigonish Highlands
2. Cobequid Highlands
3. North Mountain

Table 2 summarizes the main lithologies and relative abundances of indicator erratics from these source areas. The sampling density and distribution in the marine and terrestrial environs are sufficient to intersect dispersal "trains" emanating from these large source areas (Fig. 6). In evaluation of provenance, the assemblage of erratic rock types are sometimes more valuable than identification of individual species. The possible glacier flow paths are reduced when more than one indicator rock species is considered. The

COBEQUID HIGHLAND LITHOLOGICAL SUITE (in order of total outcrop area.)
1. Granitoid rocks (≈40%) (a) red, orange, tan and grey hornblende-biotite monzogranite to alkali-feldspar granite. (b) dark grey hornblende-pyroxene diorite (c) red and grey to pale orange syenogranite (d) sheared (cataclastically-deformed) granitoids
2. Volcanic rocks (≈35%) (a) tan to orange rhyolites, andesites and dacites (tuffs, ignimbrites and agglomerates) (b) black to red-brown basalts
3. Sedimentary and metasedimentary rocks (≈25%) (a) siltstone, shale, mudstones, conglomerates, sandstones (b) quartzite, schist, gneisses, marble
ANTIGONISH HIGHLAND LITHOLOGICAL SUITE
1. Volcanic rocks (≈45%) (a) rhyolites, dacites, andesites (tufsf and ignimbrites) (b) basalt
2. Sedimentary and metasedimentary rocks (≈45%) (a) red arkosic sandstone, conglomerate (b) blue-grey shale, siltstone (c) red siltstone, shale (d) fossiliferous, sandstone; green and black, laminated siltstone
3. Granitoid rocks (≈10%) (a) grey granodiorite (b) red to pink monzorganites and syenogranites (some altered) (c) diorite, appinnite
NORTH MOUNTAIN LITHOLOGICAL SUITE 1. Massive and amygdaloidal (zeolitic) basalt (100%)

Table 2. Lithologies of the major highland source areas in northern mainland Nova Scotia.

Figure 6. Location of the terrestrial and marine samples in study region. Till type classifications are given for all land samples. Sediment classifications are shown for the offshore samples. Note the preponderance of gravel inside the 50 m contour, whereas diamicton and muds are largely found in deeper water (see Appendixes 3-7 for sample data).
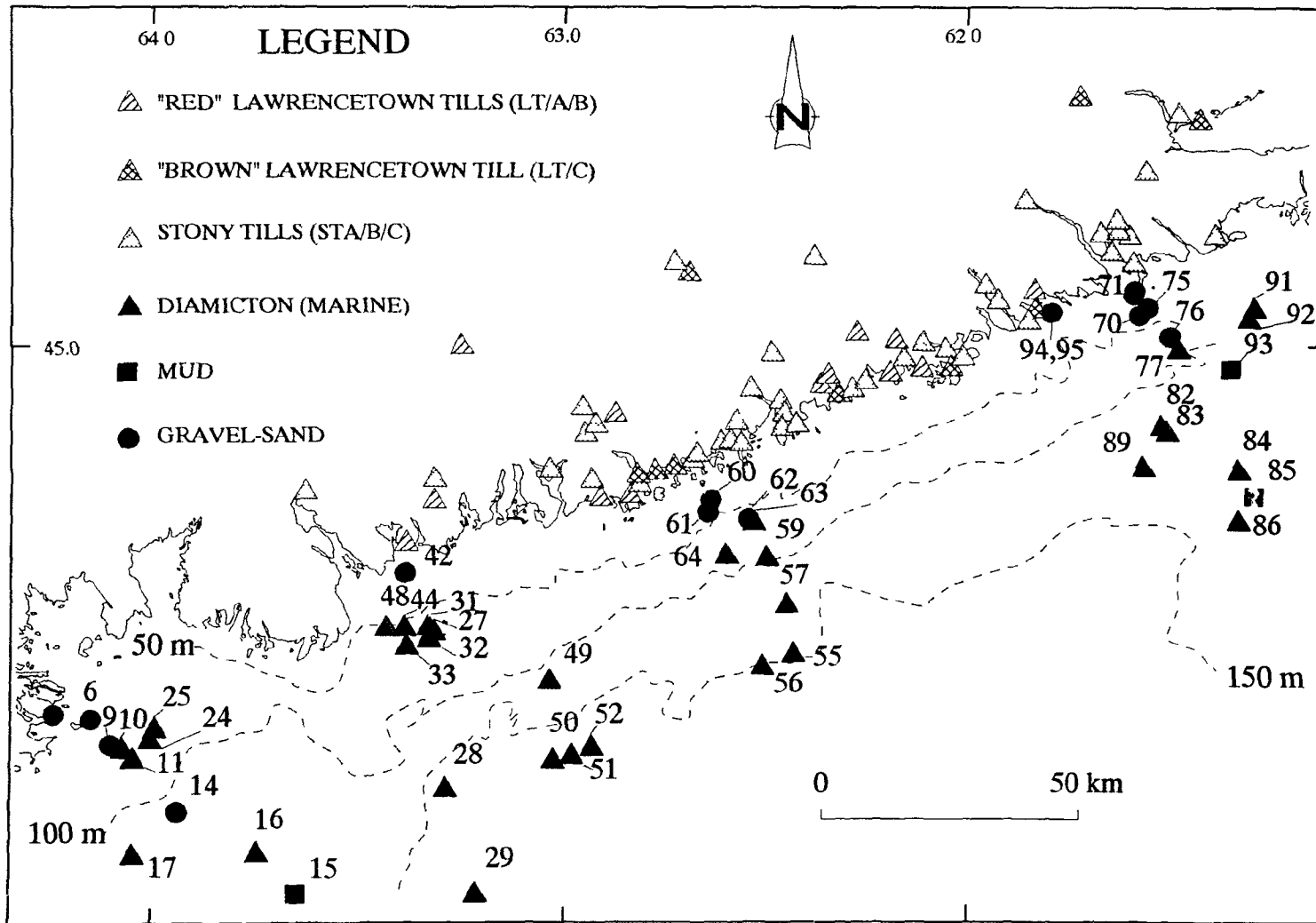
Figure 6.

presence of diagnostic minerals in the samples can assist in the delineation of provenance. For example, muscovite is not a common accessory in the granitic rocks of the Cobequid Highlands but is an important secondary mineral in the rocks of the South Mountain Batholith (Clarke *et al.*, 1980). Hornblende is not known to occur in the granitic rocks of the South Mountain batholith (MacKenzie and Clarke, 1975), but is common in Cobequid granites (Donohoe and Wallace, 1985).

2.6.3 Clast Morphology and Surface Features

Grain shape was qualitatively assessed using Powers (1953) visual scale augmented by identification of characteristic shape types (i.e. glacial flat-iron-"bullet" clasts; discoid beach pebbles) and surface markings, such as striations. The percentages of striated clasts were evaluated as an index to the degree of reworking by wave-erosion and the genesis of the deposit (Appendix 4).

Shape analysis is a powerful tool in discrimination of glacial facies and sedimentary environments (Mazzullo and Anderson, 1987). Glacial depositional environments can be inferred from pebble shapes (Boulton, 1978; Dreimanis, 1989).

2.6.4 Texture

Karrow (1976) maintained that fine detail in measurement is probably meaningless as local variations in till texture can be great. Till units in Nova Scotia can be distinguished based on their gravel/sand/mud ratios (Nielsen, 1976). Stea (1982; 1984) correlated till units

in central Nova Scotia based on their gravel/sand/mud ratios. Stea *et al.* (1989) divided these till units into older, matrix-dominated till units formed near the margin of extensive ice sheets and ice caps and clast-dominated, younger tills formed somewhere near a former ice divide.

For the terrestrial and marine samples (Appendix 7) the author uses a simple clast/matrix ratio, which is the weight ratio of the <64 mm->2 mm/<2 mm fractions. Grain size data from Nielsen (1976) are also utilized for the correlation of till units. Gravel/sand/mud weight percentages were calculated for samples from core 91018-53 (analyses courtesy of the Atlantic Geoscience Centre). A detailed grain size analysis, using 1/2 phi intervals, was done on selected till samples and marine sediments.

The texture of till depends not only on the energy of the glacier transporting agent, but on the provenance of the till itself (Shilts, 1978). As a glacier passes over unconsolidated sediments, these are incorporated into the till and impart a distinctive signature to the grain size distribution. Joint spacing, weathering and degree of induration, are all parameters which contribute to the susceptibility of rocks to erosion, and subsequently to the texture of the resultant till. The glacier base or "glacial mill" can produce fines by abrasion and crushing. Terminal grades in the silt sizes (Dreimanis and Vagners, 1971) are produced. In many regions, especially at the margins of the former great ice sheets, the fines are inherited from older till material. Meltwater may remove considerable volumes of the comminution debris (Drewry, 1986; Eyles and Eyles, 1992). Material in englacial transport is suspended above the traction zone and undergoes little comminution (Boulton, 1978).

2.6.4.1 Marine Tills

Sampling difficulties in the marine environment make genetic interpretation hazardous. Syvitski (1991) cautioned that on glaciated shelves, seismic facies characterized by incoherent reflections and high reflectivity, generally interpreted as till, may encompass a variety of sediment types, including well-sorted gravels. King (1993) compiled much of the pertinent data on marine till and states (p. 349) " The majority of studies ... interpret the diamictons as till a trend that possibly reflects Alley *et al.* (1989) (till-deformation) hypothesis that provided a plausible mechanism for subglacial deposition under a marine ice sheet". King (1993) states that it may be impossible to differentiate between primary and secondary till. Hart and Boulton (1991) have extended the concept of deformation till in the marine and terrestrial environment to include most till. They argue that deformed till is a common phenomenon. In the marine environment, clay-rich proglacial glacial marine sediments can be transformed into till by rapidly readvancing ice (Alley *et al.*, 1989; King, 1993), however, subglacial deformation may be less effective in coarser- grained sediments (Hughes in Denton and Hughes, 1981). Grain size analysis of large volume grab samples in this study will help to resolve the problems of till genesis in the marine environment.

2.6.5 Age Dating

Marine shell fragments and foraminifera were radiocarbon-dated using Accelerator Mass Spectrometry and regular beta disintegration methods (Table 3). Foraminifera were hand picked from seived (<64 μm) separates for age dating. All ages are calculated with

^{14}C Age date ^{13}C adjusted +/- 1 σ	Lab-Number	Sample No. and Type	Material	Water depth/ core depth (m)	Landform/ Formation
3970+/-60 AMS	Beta-61398	Pcore 91018-53	shell	168\./)24	Emerald Silt
5015+/-60 AMS	Beta-50594	IKU 91018-51	shell	165/.5	Scotian Shelf Dr.
5410+/-60 AMS	Beta-50593	IKU 91018-50	shell	165/.5	" "
5730+/-50	Beta-47892	VCore 91018-40	shell	80/.80	Channel Fill
?320+/-200	Beta-50595	IKU-91018-83	shell	82/.5	CH Moraine
8650+/-90 AMS	Beta-47889	Vcore 91018-22	shell	65/1.65	Valley Fill
8620+/-70 AMS	Beta-47890	Vcore 91018-36	shell	80/1.59	Valley Fill
9220+/-90 AMS	Beta-61624	Pcore 91018-53	foram	168/.99	Emerald Silt
10740 +/-90 AMS	Beta-57905	Pcore 91018-53	shell	168/3.45	" "
10870 +/-70 AMS	Beta-57907	Pcore 91018-53	shell	168/3.45	" "
11340 +/70 AMS	Beta-57906	Pcore 91018-53	shell	168/2.95	" "
11650 +/-110	Beta-47891	Vcore 91018-38	shell	73/.5	Sambro Delta
11770 +/-200	Beta-50596	IKU 91018-89	barnacle	106/.5	CH Moraine
12020 +/-90 AMS	Beta-57908	Pcore 91018-53	shell	168/5.90	Emerald Silt
12230 +/-70 AMS	Beta-57909	Pcore 91018-53	shell	168/6.16	" "
12420 +/-80 AMS	Beta-61626	Pcore 91018-53	foram	168/4.16	" "
13050+/-140 AMS	GX-17635	Pcore 91018-53	shell	168/6.95	" "

Table 3. Compilation of ^{14}C ages from this study.

respect to the Libby half-life of 5570 years and reported with the value of one standard deviation error resulting from the random nature of the disintegration process (Table 3). The reported dates are all adjusted for ^{13}C fractionation calculated relative to the PDB-1 international standard. They are not adjusted for oceanic reservoir effects, unless stipulated, because of the regional variability of the effect and poor mixing of oceanic water within the shallow, closed basins of the Scotian Shelf (Piper *et al.*, 1990).

CHAPTER 3: MARINE QUATERNARY GEOLOGY

3.1 THE STUDY AREA

The marine study area on the inner continental shelf off Nova Scotia, extends 40-60 km south from the present coastline to a prominent set of sea-bottom ridges termed the Scotian Shelf End Moraine Complex (King et al., 1972) (Fig 1) It is a region of irregular relief and highly variable sediment thicknesses (Forbes et al., 1991) The inner shelf trends NE-SW, parallel to the strike of Meguma bedrock basement and the continental shelf break (Piper et al., 1986)

3.2 OCEANOGRAPHY

The main oceanic circulation pattern over the inner shelf is a southwestward flow known as the Nova Scotian Current (Bigelow, 1927) Tides are semidiurnal with an average range of 1 4 m (Hopkins, 1985) Bottom drifter experiments have shown that fair weather tidal current velocities are not sufficient to transport sediment except when focussed into constricted inlets (Hopkins, 1985) The surface wave climate is seasonally variable, with larger waves during winter storms and rare hurricanes (Forbes et al., 1991) Northeastward-trending storm paths (cyclonic lows) across the mainland generate onshore winds Wave heights up to 8 m are generated with a median value of 1 m The offshore extent of sediment transport is best indicated in large embayments where shoreface sand wedges can be traced to -20 m (Hall, 1985, Boyd et al., 1988a) Pebble-sized gravel is mobilized during winter storms at 30 m water depth (Forbes and Drapeau, 1989) Combined wave-tidal current activity may entrain silts at depths of 100 m (Forbes et al., 1991)

48

3.3 ACOUSTIC TERRAIN "ZONES"

Cok (1970), King (1970) and Drapeau and King (1972) divided the Scotian Shelf into three physiographic zones an inner zone (Inner Shelf) characterized by rough topography, a middle zone (Central Shelf) consisting of broad shore-parallel depressions, and an outer zone (Outer Shelf) consisting of wide, flat banks Seismic methods have advanced considerably since the 70's enabling further detailed physiographic subdivisions Five major coast-parallel zones have been designated in the inner shelf (Fig 7) These are (seaward to landward)

(1) Scotian Shelf End-Moraine Complex (King *et al.*, 1972),

(2) Basin Zone (this study),

(3) Outcrop Zone (Forbes *et al.*, 1991),

(4) Morainal Zone (Stea *et al.*, 1993 a, b), and

(5) Truncation Zone (Forbes *et al.*, 1991, Stea *et al.*, 1993 a, b)

Kelley *et al.* (1989) mapped similar shore-parallel zones off the coast of Maine The inner shelves of both Nova Scotia and Maine exhibit a nearshore zone of sediment accumulation (sand-gravel) grading into a denuded zone with a thin veneer of residual material over rock and till The author has utilized these previous informal mapping concepts and fused them into a formalized zonal concept

"Terrain Zones" can be defined as areas of unique bottom morphology (landforms) and seismic sequences and facies (stratigraphy) The zones are a consequence of bedrock type and structure, glacial erosional and depositional processes and sea-level rise and fall They include assemblages of glacial landforms such as moraines and drumlin fields, areas of

Figure 7 Mapped terrain zones and subzones on the inner shelf These zones can be defined as areas of unique bottom morphology (landforms) and seismic sequences and facies (stratigraphy) The zones are a consequence of bedrock type and structure, glacial erosional and depositional processes and sea-level rise and fall Tracklines and the location of the grid model of the Sheet Harbour area (Fig. 8) are also indicated on this figure.

Figure 7.

Platform subzone } TRUNCATION ZONE
Valley subzone

Moraines } MORAINAL ZONE
Emerald Silt

OUTCROP ZONE

BASIN ZONE

SCOTIAN SHELF
END MORAINES

45.0

HALIFAX

ESTUARINE SUBZONE

BASIN ZONE

Country Harbour Moraine

Eastern Shore Moraine

Halifax Moraine

63.0

62.0

0   50 km

51
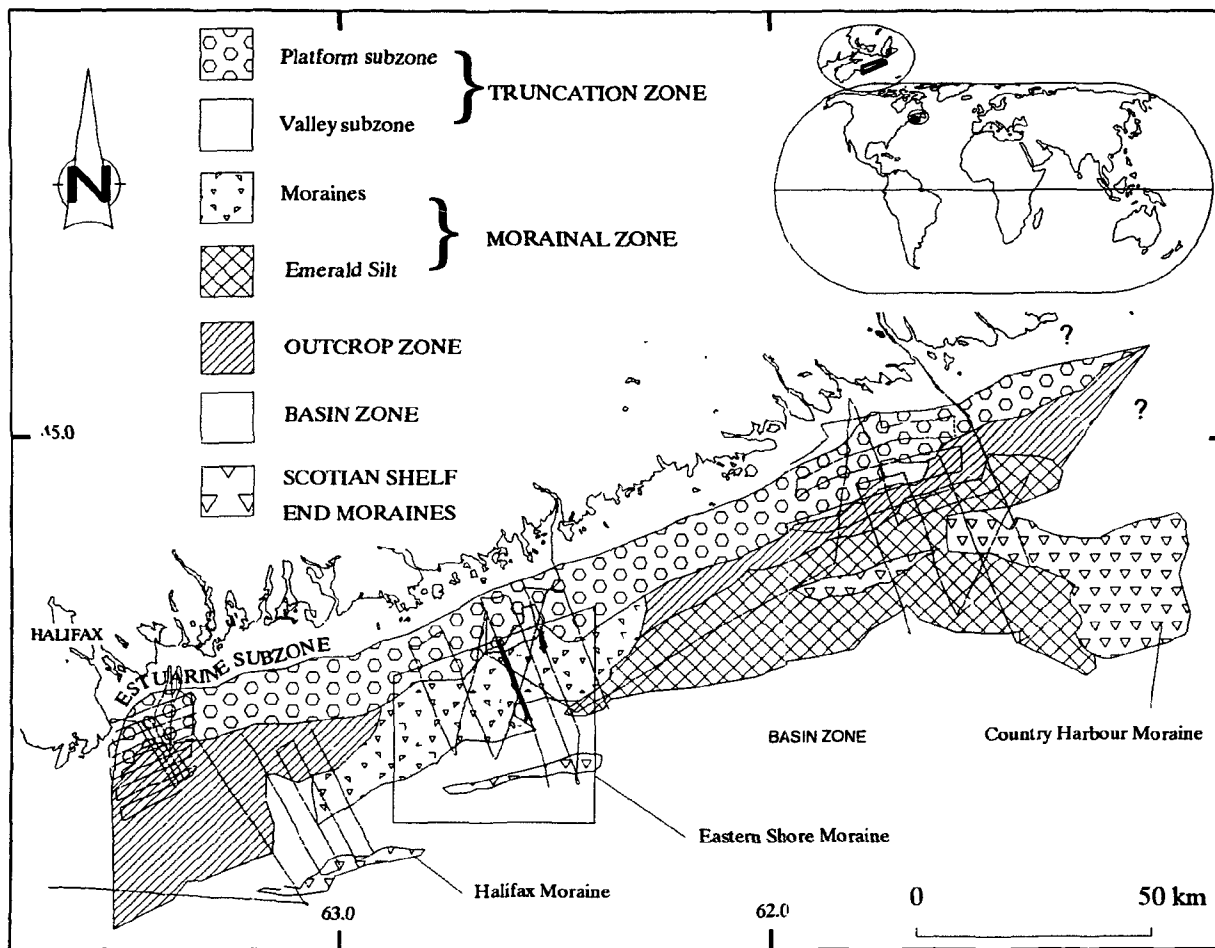
bedrock outcrop, and deep, sediment-filled basins and channels   Subzones are based on landform and stratigraphic commonalities at a smaller scale than zones The lowest level in the mapping hierarchy is individual stratigraphic units (sequences and facies) definable in basins and valleys within zones and subzones These seismic stratigraphic units are based on the amplitude, frequency and pattern of internal reflections and their relationship to bounding surfaces (e g , King and Fader, 1986, Vail *et al.*, 1977)

The Scotian Shelf End-Moraine Complex (SSEMC) is a series of large ridges that occur 30-40 km offshore, parallel to the present-day Nova Scotian coastline (King *et al.*, 1972, Fig 9) The Basin Zone is a series of closed, sediment-infilled basins in water depths greater than 145 m The "Outcrop Zone" was defined by Forbes *et al.* (1991) as a broad area of bedrock outcrop largely devoid of surficial sediment The "Morainal Zone" was defined as a region of sub-parallel ridges and intervening areas filled by conformably-bedded and ponded seismic units (Stea *et al.*, 1993 a, b) The Truncation Zone was defined as a region of the inner shelf with muted topography and planar erosional surfaces truncating bedrock and surficial cover (Stea *et al.*, 1993 a, b) A grid model of the bathymetry off Sheet Harbour (Appendix 1), displays four of these zones (Fig 8) A SSEMC morainal ridge (Eastern Shore Moraine) can be clearly seen, with a linear form and asymmetric profile   The Basin Zone is a flat topographic area north of the moraines characterized by conformably-bedded acoustic units with high amplitude, coherent reflections (Table 1, Emerald Silt) and transparent, ponded facies (Table 1, LaHave Clay) Landward of the Basin Zone are ridges and mounds composed of acoustically incoherent material (Morainal Zone) The Truncation Zone is marked by the change to muted topography around 80-90 m These topographic zones are described in detail in the next sub-chapters starting with the Scotian Shelf End-Moraine Complex

Figure 8   Digital grid model of the bathymetry of the inner shelf in the Sheet Harbour transect area (Fig 1)   It was digitized from 12 kHz seismic records of the Canadian Hydrographic Service   The tracklines were 93 km apart and depth measurements were taken every 5 minutes along lines   Note the continuity of the Scotian Shelf End Moraine   Complex (SSEMC)   The view is towards the southwest from the northeastern end cf the Eastern Shore Moraine (see Fig 9)   The arrow marks the location of a major channel also mapped in Huntec records

Figure 8.

LEGEND

Sable Island
Sand and Gravel

LaHave Clay

Emerald Silt

Scotian Shelf
Drift

Bedrock

TRUNCATION
ZONE

-66m

-224m

BASIN ZONE | SSEMC | BASIN ZONE | MORAINAL ZONE | TRUNCATION ZONE

54
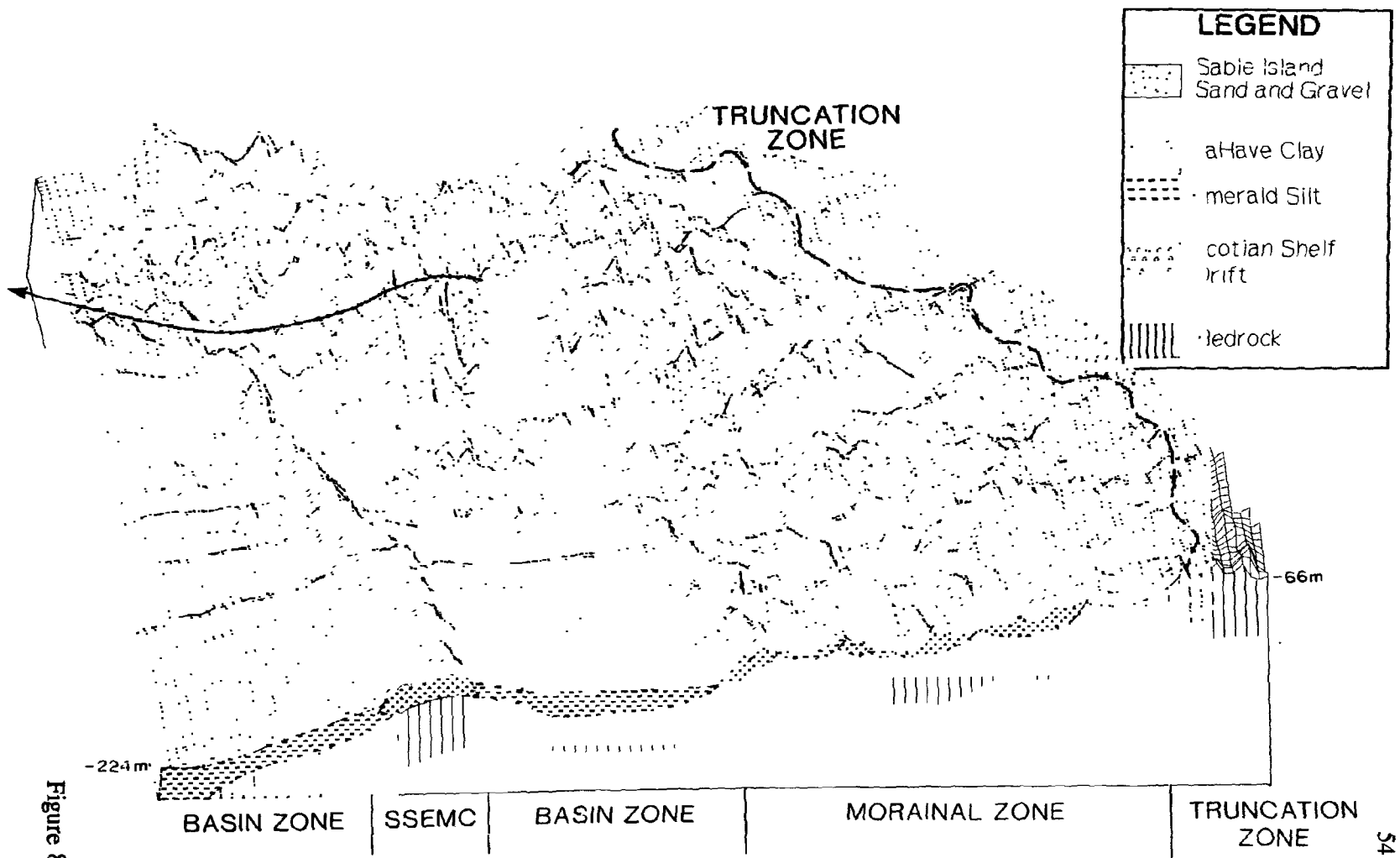
Figure 9   The Scotian Shelf End Moraine system (after King *et al* ,1972)

COUNTRY HARBOUR MORAINE

HALIFAX MORAINE

EASTERN SHORE
MORAINE

SAMBRO MORAINE

PENNANT POINT MORAINE

SOUTH SHORE MORAINE

| 0 | 20 | 40 mi |
| 0 | | 60 km |

Figure 9.

56
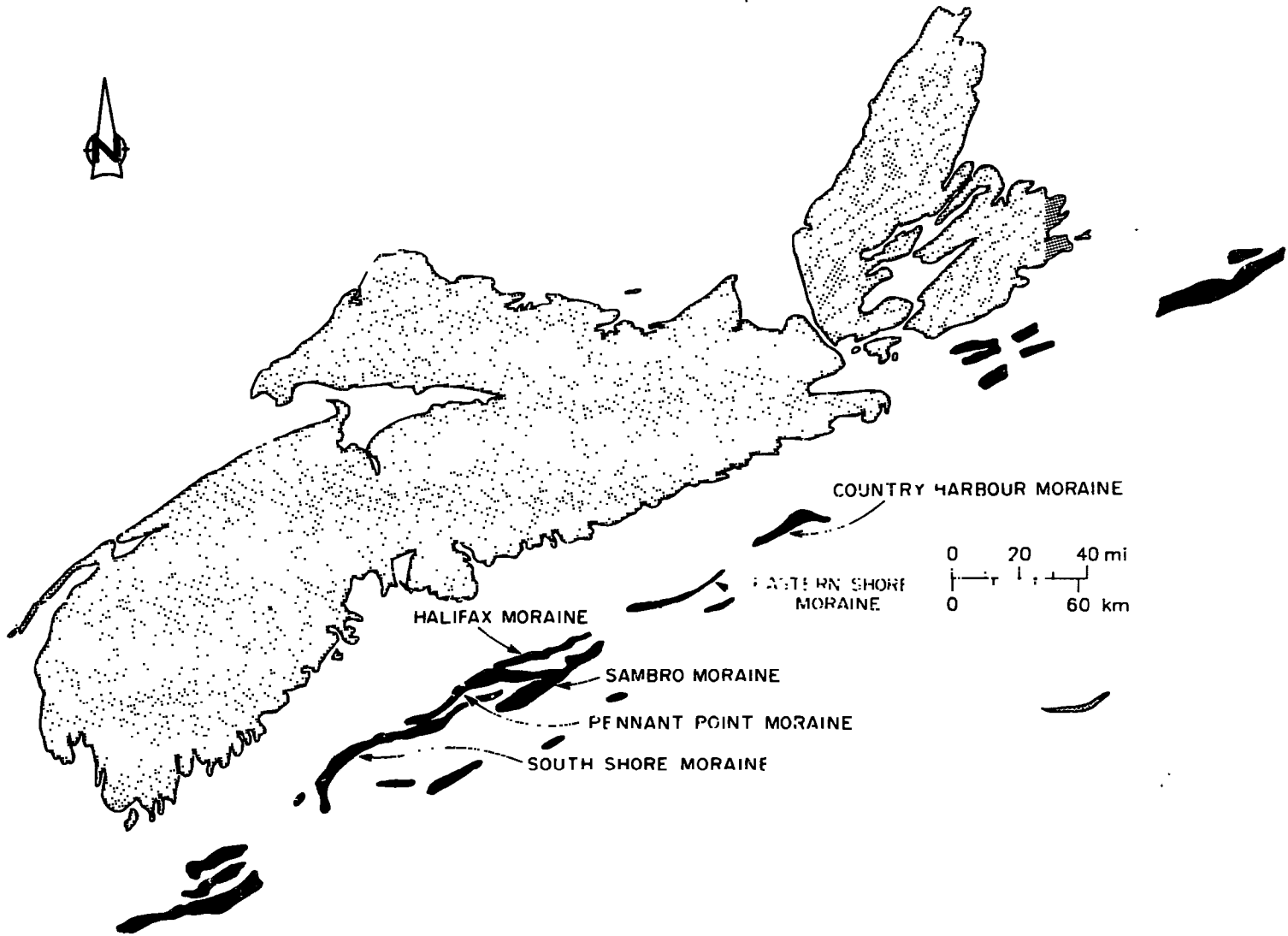
3.4 SCOTIAN SHELF END-MORAINE COMPLEX

3.4.1 Introduction

The Scotian Shelf End-Moraine Complex (SSEMC) is a series of large sea bottom ridges that occur 30-40 km offshore and parallel the present day Nova Scotian coastline (Fig 9) The ridges occupy the landward margin of a trough (Basin Zone) that extends more or less continuously along the entire Scotian Shelf with depths of 140-200 m and a width of 40-50 km (King *et al.*, 1972) They are composed of the Scotian Shelf Drift, defined as an incoherent acoustic unit with occasional diffractive point sources interpreted as boulders (King and Fader, 1986) (Table 1) On the southward-facing, deep water side these ridges interfinger with the Emerald Silt in a series of wedge-shaped projections called till-tongues Till-tongues are defined as wedge-shaped deposits lacking in internal reflections, interbedded with stratified glacial marine sediment and rooted in large constructional moraines (King and Fader 1986, King *et al.*, 1991, King, 1993) On the proximal (landward) side of the SSEMC moraines Emerald Silt laps onto the moraines

3.4.2 Halifax Moraine

3.4.2.1 Location and Stratigraphy

The Halifax Moraine is located 50 km southeast of Halifax Harbour (Figs 10, 11 and 12) and consists of a series of 2-4 km wide, discontinuous ridge segments which protrud above the seabed The main segment is oriented NE-SW and is 12 km long Several shorter segments to the northeast of the main ridge are oriented NW-SE The total length is 30 km The ridges

Figure 10 Legend foi the seismic geology-seismic landform maps of the inner shelf transect areas (Fig 1)   These maps depict the distribution of acoustic units and their associated landform assemblages In most cases, stratigraphic formations and facies (King and Fader, 1986, Table 1) or units (cf Forbes *et al.*, 1991) are mapped, but where the unit distribution is too complex, or erosion is dominant, then subzones are depicted on the maps Schematic diagrams illustrate the geometry and lithostratigraphy of the seismic bodies Stratigraphic classifications are from King and Fader (1986) and Forbes *et al*, 1991 (Table 1)

ZONES	SUBZONES	SCHEMATIC SEISMIC STRATIGRAPHY	LITHOSTRATIGRAPHY
	Estuarine Subzone		Sable Island Sand and Gravel
TRUNCATION ZONE	Platform subzone		Unit C
	Transition Subzone	shoreface and deltas	
	Valley Subzone		LaHave Clay
MORAINAL ZONE	Eroded Emerald Silt		Emerald Silt
	Moraines		
OUTCROP ZONE	Outcrop and channels		Scotian Shelf Drift/Unit B
BASIN ZONE			Scotian Shelf Drift
SCOTIAN SHELF END MORAINE COMPLEX			Unit A (Bedrock)

Figure 10

Figure 11 Surficial geology-landform map of the seismic tracklines in the southern Halifax transect region of the inner shelf of Nova Scotia (Fig 1) See Figure 10 for the legend to this map Core locations are marked by an X, IKU samples are marked by a box symbol Reference sections, depicted in later figures, are shown with solid black lines and large letters beside the interpreted tracklines Major southwest-trending channels can be interpolated between tracklines

Figure 11

62
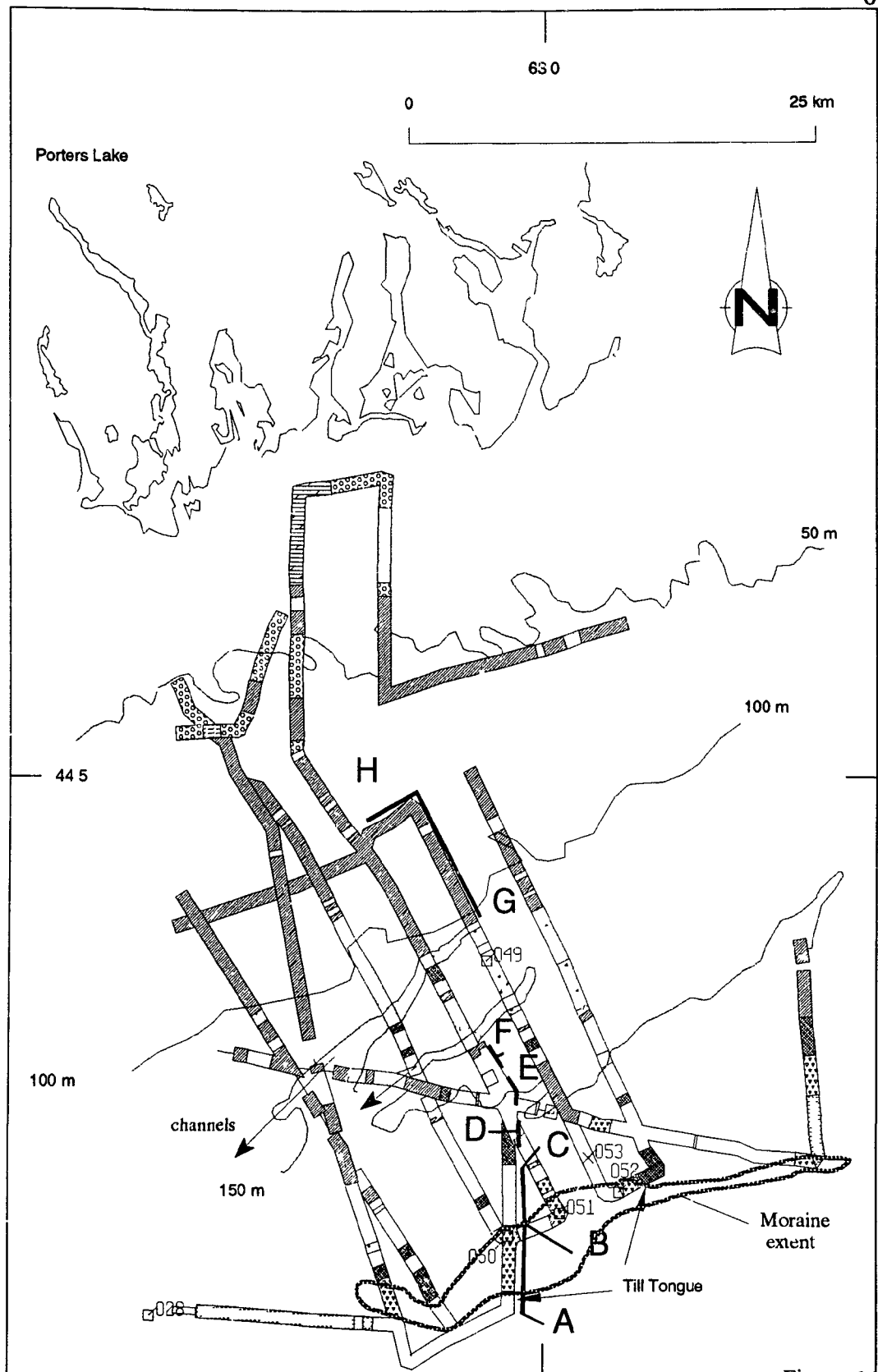
Figure 12   Sparker acoustic profile and interpretation of a segment of the Halifax Moraine (Sections B-A, Fig 11)   Three till tongues can be delineated in the southern or distal portion of the moraine   Close up of the distal portion of Till Tongue 3 showing the "feather edge"   The water depth is shown in metres on the side of the section   These depths are calculated from two-way travel times using 1500 m/sec as the velocity in water and the uppermost sediments

B

A

Feather
Edge

Land ⟶

0   700 m

150 m

LAHAVE CLAY

3

FACIES B

HALIFAX MORAINE

2

Emerald Silt Facies A

190 m

1
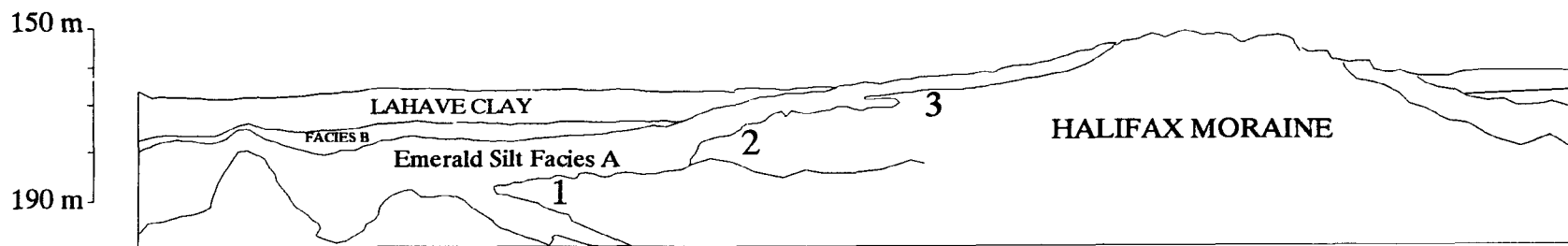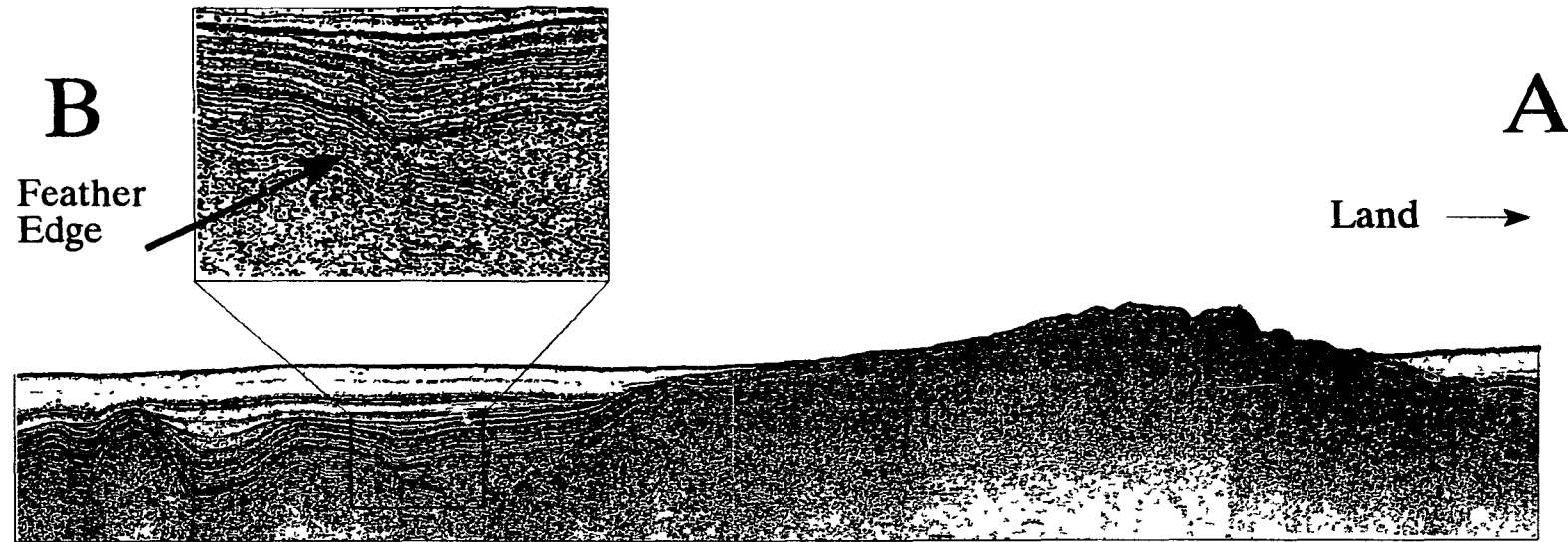
Figure 12

have an asymmetric profile, steeper on the landward (north) side   The moraine segment

reference section (Section A-B, Fig 12) is a 4 km wide, broad rise in the seabed   Sediment

thicknesses vary from 15 m on the landward (north side) to greater than 40 m on the seaward

side, whereas the ridge itself has 30 m of seabed relief   The upper moraine surface ranges

between 150 m and 170 m water depth   The reference section ridge is composed entirely of

acoustically incoherent material, coherent reflections are not visible even on the low frequency

sleevegun record (Appendix 2)   Three till-tongues can be resolved on the seaward side of the

type section (Fig 12), facing southeastward   These tongues are irregular in shape when

compared with the reference tongue from the Gulf of Maine (King and Fader, 1986, p 14)

The lowest wedge-shaped protrusion (400 m long by 10 m thick) is isolated from the morainal

fragment by irregularly-shaped, high amplitude reflections that extend well into the morainal

segment   It has a convex-upward shape and terminate sharply against the Emerald Silt   In

section A-B (Fig 12), a package of Emerald Silt reflections appear to be closer together at

the edge of the till-tongue, than either underneath or beyond the tongue (Fig 12)   The

second tongue is thicker with little apparent thinning at its extremity (Fig 12)   The highest

tongue is only a few ten's of metres long and few metres thick   On the seaward (southern)

side of the moraine the uppermost Emerald Silt reflections appear to grade into, rather than

lap onto, the incoherent material that makes up the ridge   The surface of the Halifax Moraine

is irregular, probably furrowed   Numerous point hyperbolic reflectors within the moraine may

indicate boulder-sized clasts   On the landward side, Emerald Silt reflections appear to lap

onto the moraine

3.4.1.2 Lithology

IKU grab samples (28, 50, 51 and 52, Figs 11, 13, Appendixes 3, 4) were taken from the

Halifax Moraine   IKUs 28, 50 and 52 consist of a homogenous, olive-grey, sandy, matrix-supported diamicton (Fig 13)   IKU 50 contains grey sand and reddish-brown clay inclusions   The basal samples of IKUs 28, 50, 51 and 52 vary between 23 8 and 38 2 wt % gravel (Appendix 7)   IKU 52 contains 51% sand and 23% mud (Fig 14)

The clast shapes of these samples generally fall into three populations, angular to subrounded, unstriated (70-95%), subangular to subrounded, striated (1-30%), and rounded (<5%)   Significantly, some rounded, unstriated pebbles in the bottom sample of IKU 52 (91018-52-5, Appendix 4) have angular faces indicating recycling (Fig 15)   There does not appear to be any significant variations in clast shape and striation percentages between the top, middle and bottom subsamples of all the IKU samples from the moraines (Appendix 4)

The pebbles consist primarily of Meguma Group metagreywacke (84-90%)   SMB granite fragments make up 1-5% of the pebble fraction and foreign lithologies comprise 5-11%   The foreign lithologies are dominated by mafic intrusive rocks (diorite), pink, K-feldspar and hornblende-bearing granitoid intrusive rocks, porphyries, felsic volcanic rocks and red clastic sedimentary rocks   Again, there is no apparent systematic variation between the top and bottom subsamples of each IKU grab (Appendix 4)

3.4.2.3 Age

The Halifax Moraine may be somewhat younger than the Sambro Moraine which is located

Figure 13. Photographs of the IKU grab samples. A: IKU 52 (M) Halifax Moraine, B: IKU 55 Sheet Harbour Moraine, C: IKU 49 Morainal Zone. Note that the diamictons are matrix-supported, and some clasts exhibit stoss and lee form.

A

B

C

91-018
49
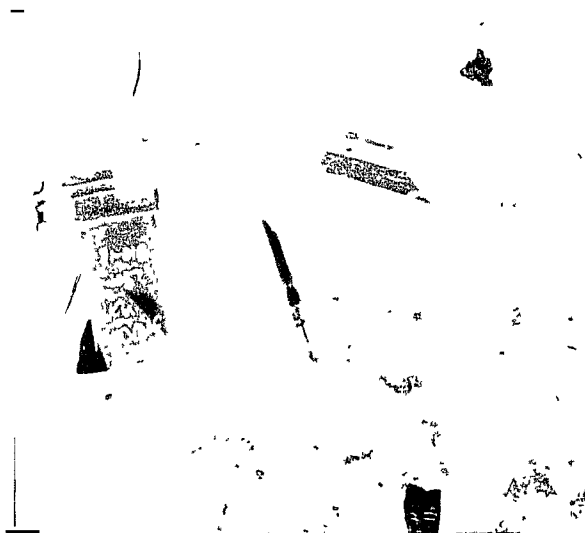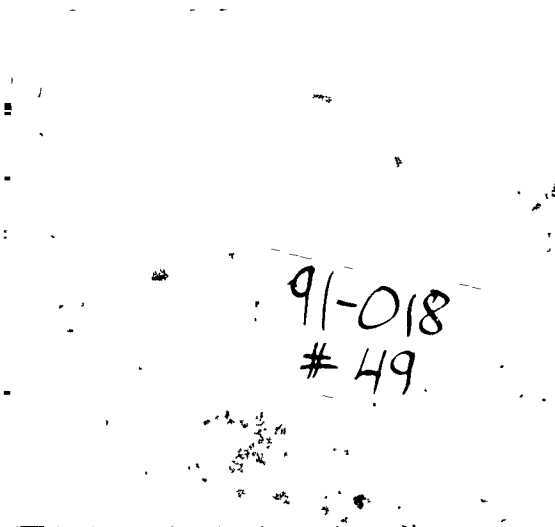
Figure 13.

Figure 14. Detailed grain size analysis of selected samples from the marine and terrestrial portions of the study region. LT-Lawrencetown Till; ST-Beaver River Till (Stony Till Plain); HT-Hartlen Till; TT-Till-Tongue (Emerald Silt?); RM-Morainal Zone (Scotian Shelf Drift); IKUs 52, 55 from Scotian Shelf Morainal Complex (Scotian Shelf Drift).
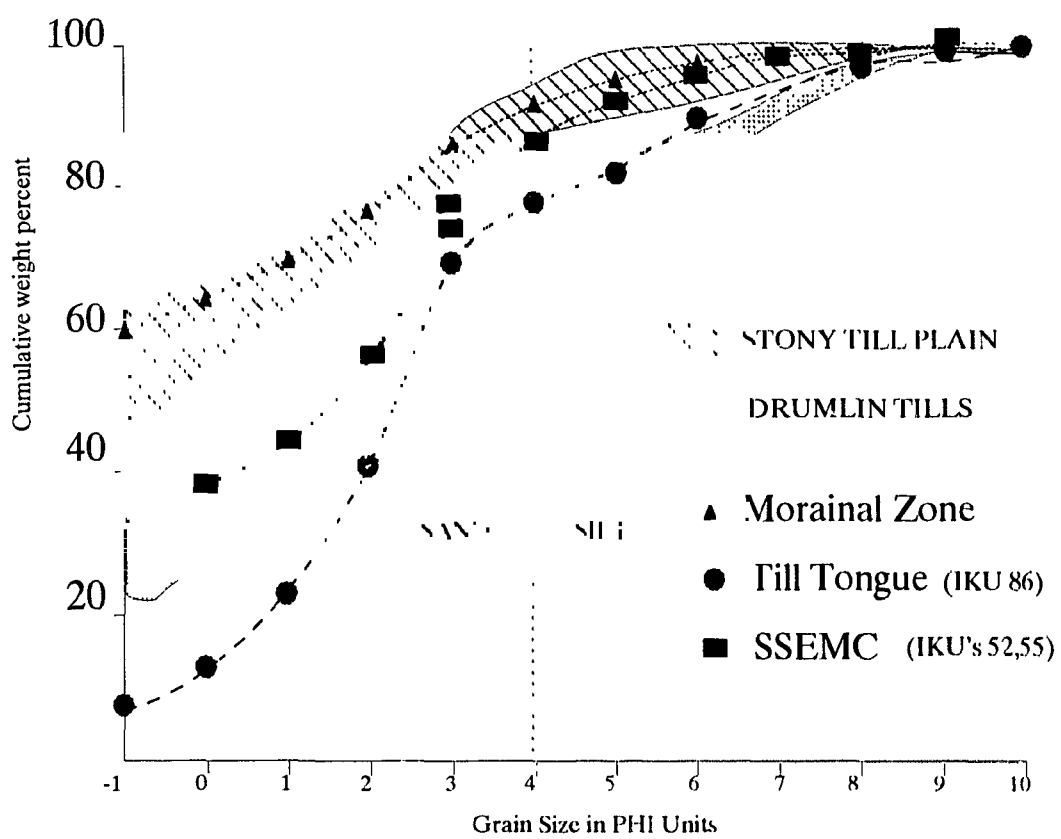
Figure 14.

Figure 15   Photographs of pebbles in IKU grab samples from the Scotian Shelf End Moraine

Complex   Three pebble shape populations can be distinguished in most samples from the

moraines (A-right) IKU 52, glacial, flat-iron with striations, (A-middle) well-rounded with

fracture indicating recycling, (A-left) angular, unstriated, (B-left) IKU 55 striated glacial

clasts, (B-right) IKU 85 (Till Tongue) - well-rounded clasts

A
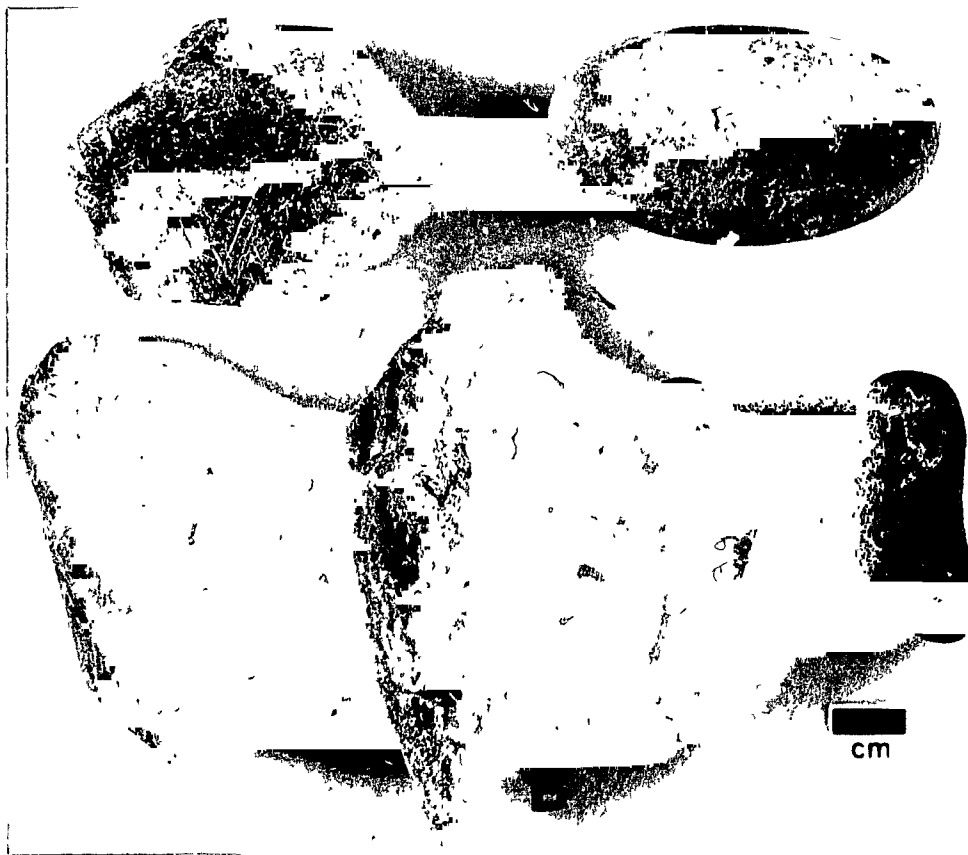
Figure 15.

15 km seaward (Fig. 9), assuming that the landforms were deposited sequentially during landward-retreat. The age of the distal till-tongue on the Sambro Moraine (Fig 9) has been estimated at 15 ka by Gipp and Piper (1990, age not corrected for reservoir-age effect) During the 1991 survey, core 91018-53 was obtained in a basin just north of the Halifax Moraine (Fig 11) The core penetrated into glacial marine sediments which onlap onto the proximal part of the Halifax Moraine The apparent age near the base of the core is 13,050 ± 140 ^{14}C years on a fragment of *Nucula* sp (^{13}C corrected) (Table 3) The age can be as much as 440 years older with reservoir age uncertainty (Mangerud, 1972) Gipp (1989) calculated sedimentation rates of 10-30 m/kyr for basal glacial marine sediments in the Emerald Basin Using 20 m/kyr as a sedimentation rate for the lower part of the core and an age of 14 1 ka for the core base (corrected for reservoir age-effect), the interpolated age for the top of the moraine surface at the core site is 14 5 ka This is considered to be a minimum age only

3.4.3 Eastern Shore Moraine

3.4.3.1 Location and Stratigraphy

The Eastern Shore Moraine is located 45 km south of Sheet Harbour (Fig 9) It is a continuous, NE-SW-trending ridge (Figs 8, 9, 16), 1-3 km wide and 23 km long This morainal segment has a marked asymmetry, thicker and steeper on the north (landward) side and thinner on the south (Fig 17) It has 20 m of seabed relief in water depths of 128 to 148 m and ranges in thickness from 45 to 70 m. The moraine consists of Scotian Shelf Drift divisible into three massive acoustic units on the sleevegun record (Fig 17), with a

Figure 16. Surficial geology-landforms of the Sheet Harbour Transect area (Fig. 1). See

Figure 10 for the legend to this map. Core locations are marked by an X; IKU samples are

marked by a box symbol. Reference sections, depicted in later figures, are shown with solid

black lines and large letters beside the interpreted tracklines. The geology is interpolated

between tracklines by matching morainal landforms on the Huntec records with topographic

highs on a contoured bathymetric map derived from echograms (Map 2). Boxed region is a

region of closely-spaced tracklines over the Morainal Zone. Note also a major channel

emanating from the Morainal Zone.
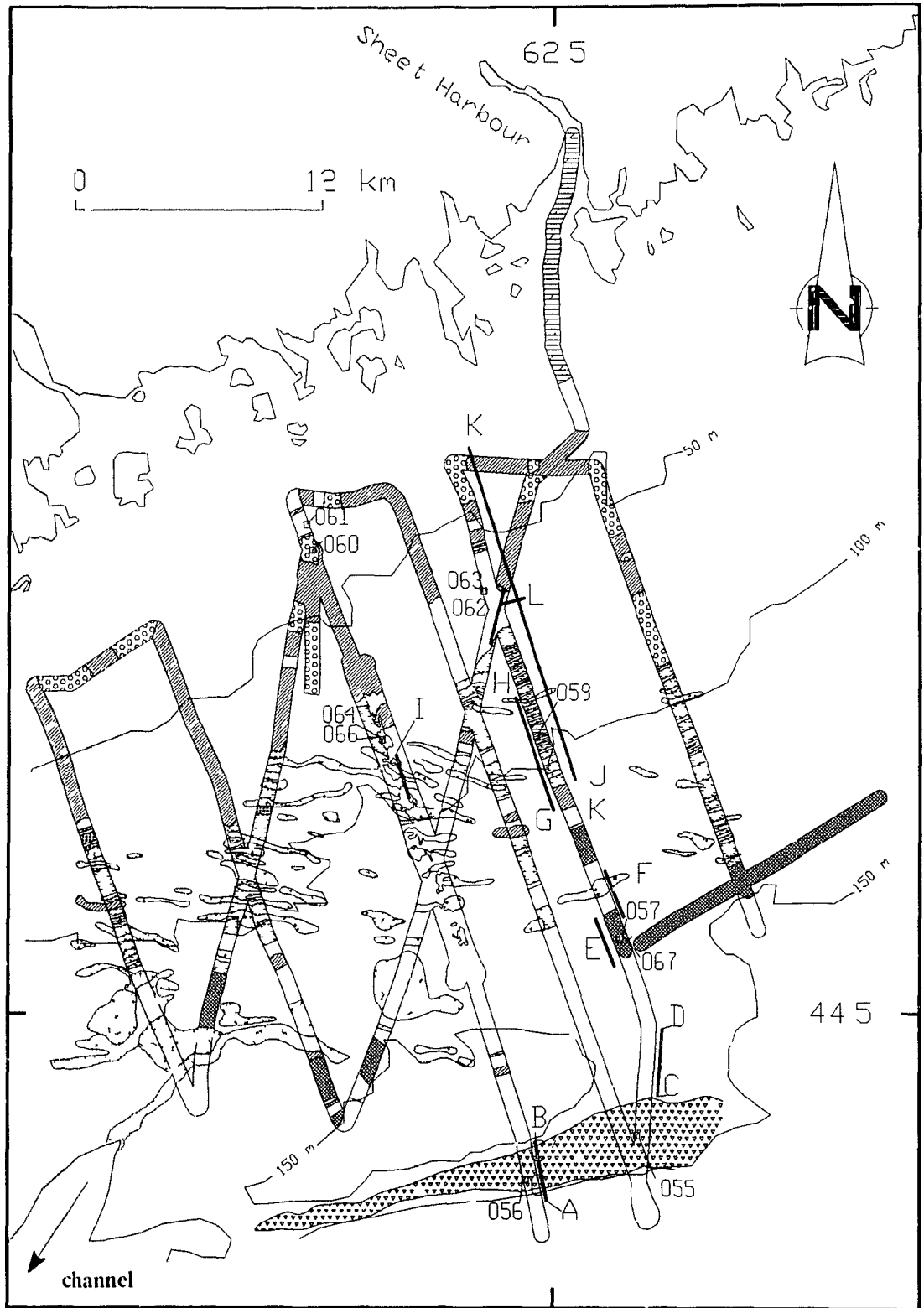
Figure 16

Figure 17   Sleevegun record and interpretation across main segment of the Eastern Shore

Moraine (Fig 16, A-B)   The moraine is comprised of three massive acoustic units (Units 1-

3)   The units taper in a seaward direction   Unit 3 appears to truncate Units 1 and 2 on the

landward side of the moraine

B

A
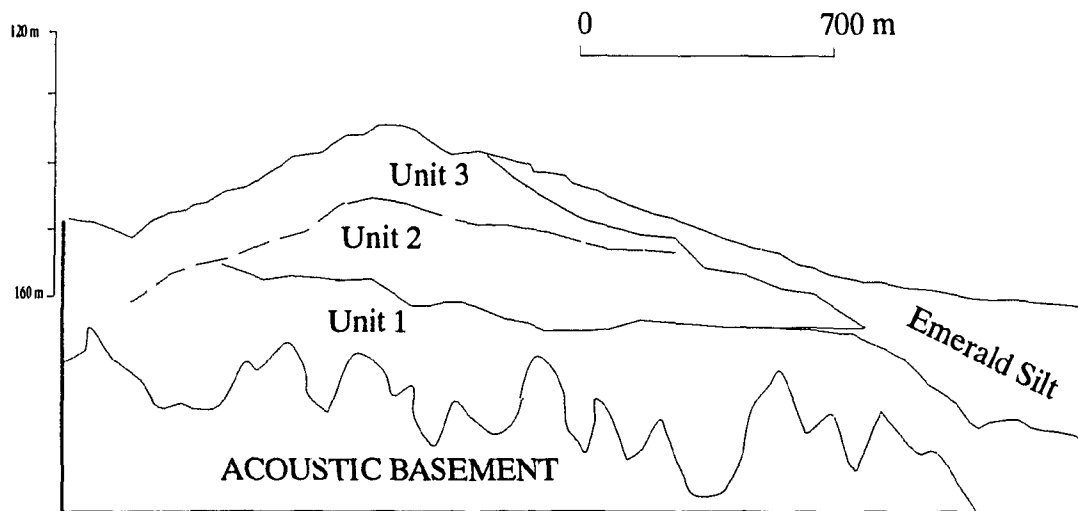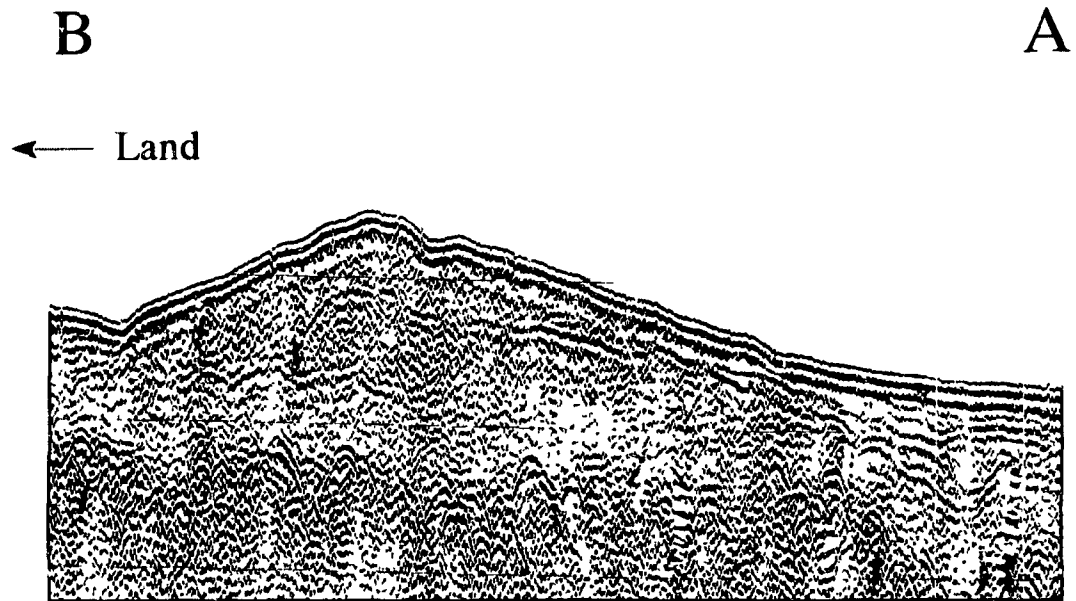
← Land

Figure 17

prominent reflection between each of them Unit 3 appears to truncate Units 1 and 2 on the

landward and seaward sides of the moraine On the seaward side of the moraine is a unit

with higher frequency reflections, interpreted as Emerald Silt (Fig 17) and the acoustically

incoherent units taper towards the Emerald Silt, but the resolution is inadequate to determine

the precise contact relationships Huntec records show that Emerald Silt reflections are

draped on the landward side and interfinger with Unit 3 on the seaward side The distal

surface of the moraine is rough with ridge-swale amplitudes of 2-6 m, while the proximal

slope is relatively smooth The sidescan record of the distal slope reveals a series of subdued,

straight grooves 30 to 50 m wide with elevated edges or "berms" The roughness of the

moraine surface apparent on the reflection records, is attributed to these linear furrows rather

than isolated mounds and hollows These furrows resemble those described by Fader (1989b)

and Josenhans and Barrie (1989) attributed to iceberg scour These appear to be best

developed in water depths above 145 m On the Sambro Moraine, iceberg furrows are found

above 180 m water depth

3.4.3.2 Lithology

IKU grab samples (55 and 56 Fig 16, Map 2) were taken from the top of the moraine They

consist of olive-grey, sandy, matrix-supported diamicton, with angular to subrounded clasts.

Both IKU samples have higher clast/matrix ratios in their top or surface samples IKU 56

contains clayey inclusions The basal samples of IKUs 55 and 56 vary between 18.8% and

20 4% gravel whereas the top sample of IKU 56 contains 34 8% gravel IKU 55 (basal

subsample) contains 37% gravel, 49% sand and 14% mud (Fig 14)

As in the Halifax Moraine samples, three distinct populations of clast shapes can be discerned. In IKU 55, most of the larger clasts are unstriated and subangular, whereas in IKU 56 they are largely subrounded In both samples a minor proportion of the clasts are striated (16 to 27%) and facetted with flat-iron shapes indicative of glacial erosion (3-7%) A few clasts are rounded to well-rounded with no surface features. There are no significant variations in pebble shapes and percentages of striated pebbles between the surface and bottom IKU subsamples. On sidescan sonograms the surface of the moraine is variegated with white and dark areas. The strong reflections (dark regions) and acoustic shadows (white areas) suggest randomly spread objects 1-4 m in diameter (boulders)

Metagreywacke of the Cambro-Ordovician Meguma Group (85-90%) is the dominant rock type in the pebble fraction of the IKU samples Meguma Zone granites and foreign lithologies are only minor components (Appendix B). Foreign lithologies include pink, K-feldspar and hornblende-bearing, intrusive rocks, felsic volcanic rocks and red and grey sandstones. Metagreywacke percentages do not vary significantly between the top and bottom IKU subsamples.

The age of the Eastern Shore Moraine could not be determined either directly or indirectly.

3.4.4. Country Harbour Moraine

3.4.4.1 Location and Stratigraphy

The Country Harbour Moraine, located 30 km south of Country Harbour, is the most complex landform in the thesis area (Figs. 9, 18). It has an arcuate shape, the western

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Figure 18 Surficial geology-landforms of the Country Harbour Transect area (Fig 1). See Figure 10 for the legend to this map Core locations are marked by an X; IKU samples are marked by a box symbol Reference sections, depicted in later figures, are shown with solid black lines and large letters beside the interpreted tracklines
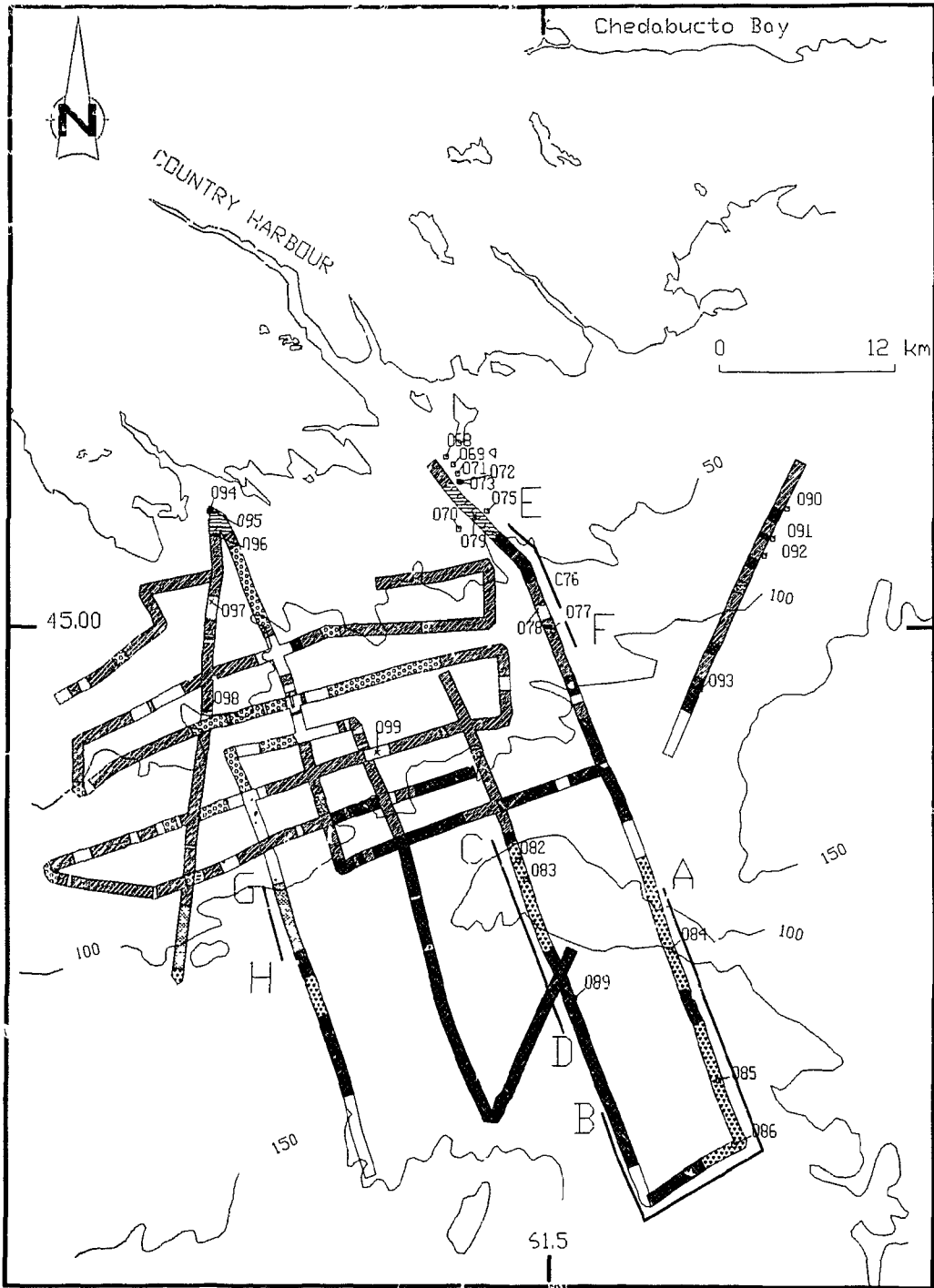
Figure 18.

segment trends NE-SW parallel to the other SSEMC moraines, whereas the eastern portion trends NW-SE, nearly perpendicular to the main moraine complex (Fig 9) The western segment is 3 to 8 km wide, similar to the other SSEMC moraines The eastern section widens to 23 km (King and Maclean, 1974) Like the two previously described moraines, profiles through the western section of the Country Harbour Moraine reveal a marked landward asymmetry and are composed of 3 sub-units of acoustically incoherent material (Fig 19) The Huntec profiles across the Country Harbour Moraine reveal an irregular surface above 125 m water depth resembling the iceberg furrows of the other SSEMC moraines but of lesser amplitude These were not visible on the sidescan sonograms from the 91018 cruise, but previous surveys G Fader (pers comm, 1994) has noted small-scale iceberg furrows on the truncation surface south of the moraine South of the Country Harbour Moraine are numerous wedge-shaped, acoustically massive units intercalated with Emerald Silt, Fig 20) These units are rooted in the moraine ridges and are therefore defined as till-tongues These tongues are several hundred metres to 10 or more kilometres long (Fig 20), but till-tongue lengths can be exaggerated in oblique and transverse sections

The Country Harbour Moraine differs from other SSEMC moraines in four respects

1 Shallower water depths (the moraine segment with the greatest seabed relief ranges from 84 to 115 m water depth)

2 Multiple till-tongues within an exceptionally thick glacial marine section (King and Fader, 1986, p 22)

3 An extensive, planar erosional surface seaward of the moraine which truncates till-tongues and Emerald Silt

4 Lack of an extensive basin or trough on the north side of the moraine

Figure 19   Sleevegun record and interpretation of transect C-D   Section is NW-SE across the Country Harbour Moraine (see Fig 18)   Three massive acoustic units can be differentiated in this moraine segment   The asterisk refers to the truncated root of the till-tongue (cf King *et al*, 1991)

83

COUNTRY HARBOUR MORAINE
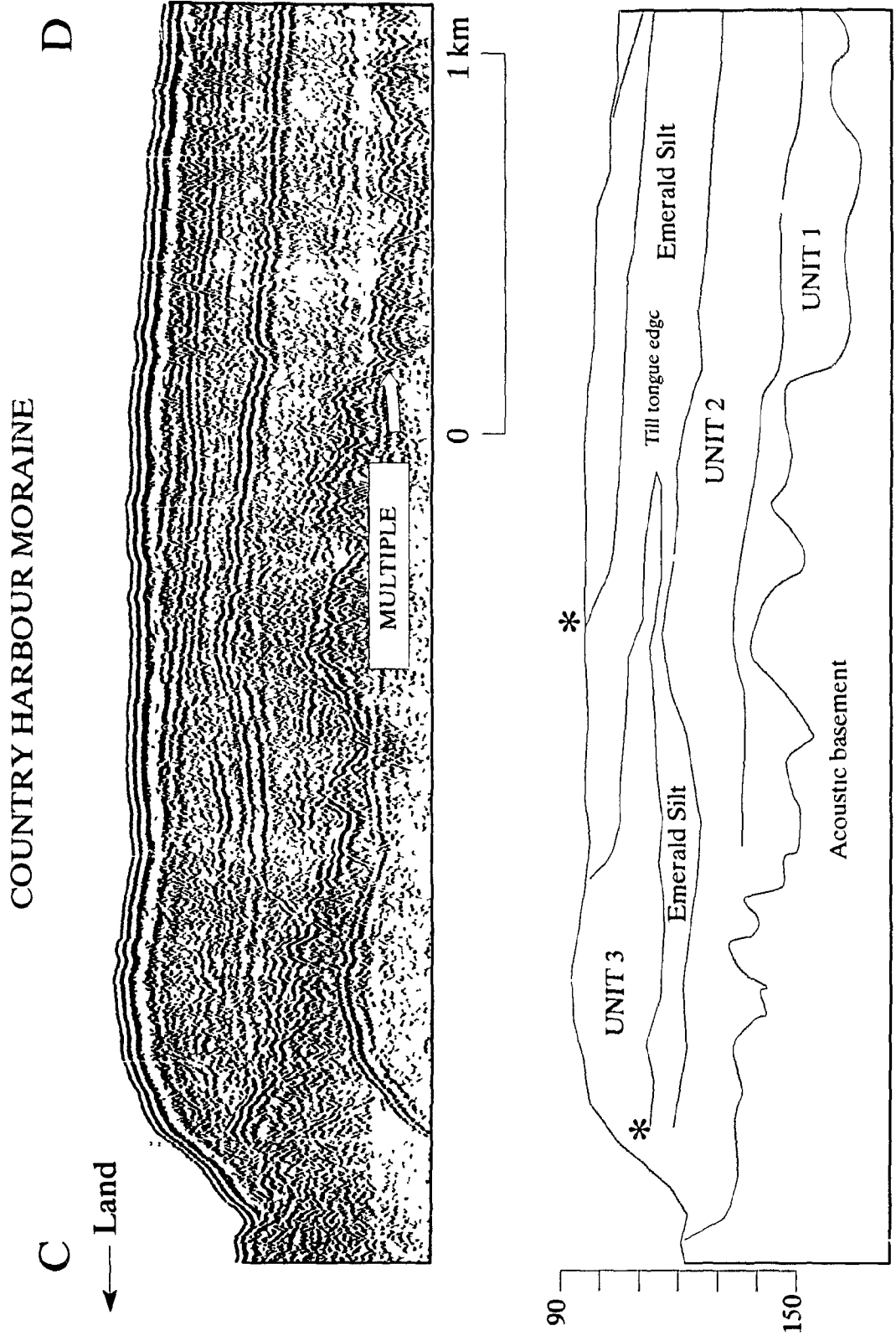
Figure 19

Figure 20 Sleevegun and Huntec acoustic records and interpretations of transect A-B (see

Fig 18 for locations) Till-tongues are numbered 1 through 6 (at their distal ends) These

tongues are separated by Emerald Silt of variable thickness The scale on the left is water

depth in metres Note the truncation of acoustically incoherent till tongues and Emerald Silt

reflections by the seabed surface The proximal end of Till Tongue 3 has an arcuate,

asymmetric profile with a steep and gentle slope and may represent a former morainal

position

HUNTEC PROFILE

SLEEVEGUN PROFILE

Depth below sea surface (m)

Acoustic Basement

Figure 20

85
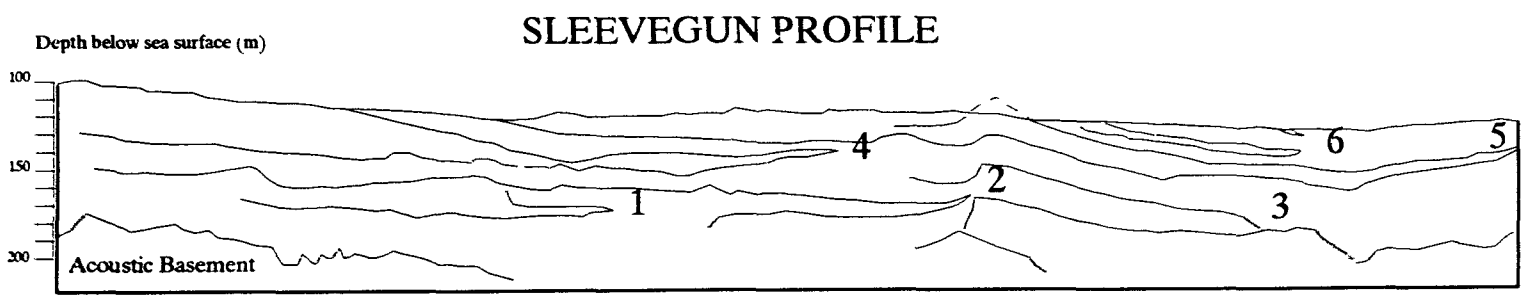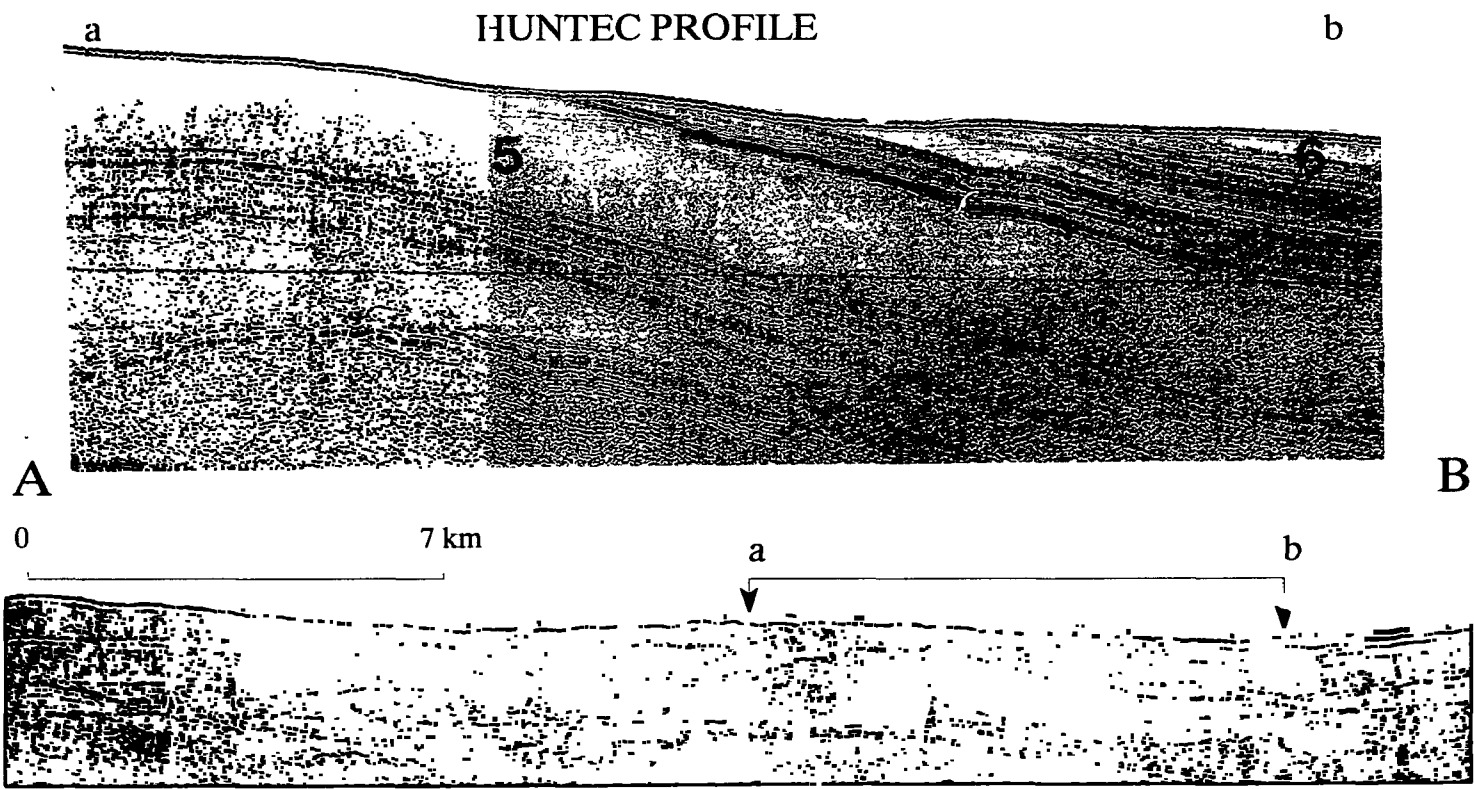
The moraine is a complex, interdigitating succession of till-tongues and intercalated Emerald Silt facies A King and Fader (1986) counted 9 till-tongues in a vertical section across the NE-trending section of the moraine 6 till-tongues were identified along with their truncated "roots" (King *et al.*, 1991) in Section A-B (Fig 20) They are 10 to 50 m thick, less than 1 km to 20 km long, and are horizontal, or nearly so, at their distal end The orientation of these tongues with respect to the main morainal segments is not certain, so these distances can be misleading A planar erosional surface truncates the roots of distal tongues 5 and 6 (Fig 20) Interpolating the tongues and intercalated Emerald Silt above the truncation surface a former morainal fragment can be reconstructed (Fig 20) The erosional surface can be traced to the distal part of an distinctly asymmetrical morainal ridge (Fig 19) The morainal ridge itself does not appear to be extensively eroded, as it exhibits some variable local relief. It has 18 to 25 m of seabed relief The sleevegun record shows a series of acoustically incoherent units each linked to a till-tongue and truncated by the proximal slope of the morainal ridge (Figs 19, 20)

3.4.4.2 Lithology

IKU grab samples 82, 83 and 84 were taken from the upper surface of the Country Harbour Moraine IKUs 85 and 86 were obtained from a till-tongue exposed on the erosional surface (Fig 18) IKUs 82, 84 and 86 consisted of olive-grey sandy-mud, matrix-supported diamicton IKU 83 grades from an olive-grey sandy-mud diamicton at the surface to a grey clay with few stones at the base The top sample of IKU 83 contains 41 7% gravel whereas the basal sample of IKU 84 contains 32 2% gravel comparable to other SSEMC samples (Appendix 9) IKUs 85 and 86 are from a till-tongue exposed on the erosional surface IKU 85 grades from an olive-grey sandy-mud, matrix-supported diamicton at the surface to a grey

clayey mud with few stones at the base (gravel content 3 5%) IKU 86 is a homogenous, olive-grey, sandy-mud diamicton It contains only 8% gravel, 68% sand and 24% mud (Fig 14) Core samples through a till-tongue from the Country Harbour moraine by King and Fader (1986, p 38) revealed a structureless silty-clay with an average composition of 1% gravel, 7% sand, 43% silt and 49% clay

IKUs 82 and 83 both display subangular to well-rounded clasts with 7-9% striated clasts in the basal samples, respectively In IKU 83 the percentages decrease from 7 at the base to 0 at the top IKU 84 has a higher percentage of rounded stones, some of which appear to be recycled, and has 3% striated pebbles There is a significantly greater degree of rounding in these IKUs than previous SSEMC diamictons (Fig 15) Striated pebbles were not found in IKUs 85 and 86 but most of the clasts were angular, soft marlstones, not amenable to retaining striae

IKUs 82, 83, and 84 contain 82-88% Meguma metagreywacke, 1-6% SMB granitoids and 2-6% foreign and 5% Tertiary or Cretaceous brown marlstones The foreign lithologies are dominated by volcanic rocks and some pink, probably K-feldspar-bearing intrusive rocks Also noted were andalusite? and cordierite?-bearing schists derived from high grade metamorphic terranes north of the section IKUs 85 and 86 on the till-tongues contain 6-17% Meguma metasedimentary rocks, 70-90% buff-brown soft Mesozoic marlstones, 1-3 % SMB granites, and 3-17% foreign lithologies

3.4.4.3 Age

Radiocarbon dates were obtained from two sites in the morainal complex, the morainal crest

(IKU 83) and the erosional surface south of the moraine (IKU 89) The base of IKU 83 contained a shell hash of pelecypods and barnacles including *Chalmys islandicus* and *Placopecten magellanicus* giving an age of 8320±200 yrs B P IKU 89 was taken from truncated Emerald Silt B (Table 1) facies above a till-tongue on the erosional surface Shell fragments include *Placopecten magellanicus* and *Palliolum subimbrifer* Barnacles (*Balanus crenatus*) were most abundant and were radiocarbon dated at 11,770 ± 200 yrs B P

The erosional surface, found distal to the morainal ridge, formed sometime during or after deposition of Emerald Silt glacial marine strata overlying the youngest till-tongue The surface appears to truncate reflections from part or all of Emerald Silt-Facies B and older till-tongues intercalated with Emerald Silt facies A In a basin west of the Country Harbour Moraine, King and Fader (1988a) dated the top of the Emerald Silt Formation at 10,580 ±110 yrs B P The erosional surface must therefore must be 10 5 ka or older if the correlation with the adjacent basin is valid The exceptional thickness of Emerald Silt south of the moraine makes correlation with the adjacent northeast Emerald Basin difficult Facies may be repeated in successive advance-retreat depositional seismic sequences The age of the erosional surface can only be estimated at somewhere between 10 5 ka and 14.2 ka (base of Emerald Silt Facies B at a reference section in the northeast Emerald Basin, King and Fader, 1988) The 11 7 ka date obtained from the surface of the moraine may represent a "maximum" age for this erosional event if one assumes that the barnacles lived during sediment deposition and younger material above the dated horizon was removed Alternatively, the barnacles may have grown on the erosional surface during a lowstand at 11 7 ka (Stea *et al.*, 1994 - see discussions of the Country Harbour Moraine in Truncation Zone subchapter)

The early Holocene age for the shell hash on the moraine crest (IKU 83) may be explained by accretion of marine muds, epifaunal growth and subsequent (later) Holocene erosion by submarine currents.

3.5 DEPOSITIONAL MODEL FOR THE SCOTIAN SHELF END MORAINES (SSEMC)

3.5.1 History of Ideas

The origin of these ridges has been debated since their discovery (King, 1969). They were originally interpreted as grounding-line moraines at the terminus of a Late Wisconsinan glacier either in advance or retreat (King, 1969; King *et al.*, 1972). This interpretation was based on the location of the .noraines; poised on the edge of a deep trough, at a presumed critical buoyancy depth.

MacDonald (1982) developed a conceptual model of four consecutive northward-retreating ice margins represented by the thickest part of the ridges, and readvance positions marked by till-tongues. King and Fader (1986) reinterpreted the mode of formation of the SSEMC as a subglacial ice-shelf moraine, based on the discovery of till-tongues on the northern edge of some moraines, notably the Country Harbour Moraine

King *et al.* (1991) synthesized work done on shelf ice margins off Norway and Nova Scotia and reassessed the sub ice-shelf origin of the SSEMC. They devised a classification of moraines relating to floating ice fronts based on the presence of till-tongues rooted in morainal ridges. The SSEMC was classified as a "linear grounding-zone moraine" deposited

at the grounding line of a floating ice front Powell (1984) and Syvitski (1991) pointed out

that ridge formation is unlikely under the constraints of an ice ceiling King *et al.* (1991) met

this objection by proposing that the ridges built up synchronously with rising sea level

To recapitulate, the SSEMC moraines have these salient characteristics

1 Asymmetric ridge morphology, steep landward side and gentler seaward
slope

2 Stacked, incoherent acoustic facies that, at least on the surface, are
composed of an olive-brown, gravelly-sandy-mud (27% gravel, 73% matrix,
Table 4), matrix-supported diamicton with striated (16%, Table 4) and
facetted clasts of predominately local origin (88% Meguma Group, 7%
foreign, 3% Meguma Zone granite, Table 4)

3 South-(seaward) facing, stacked till-tongues with morainal roots cut off by
the steep, north-facing slope Tongues composed of muddy diamictons and
mud (see also King and Fader, 1986, p 15)

4 Ice-berg furrowing above 180 m (Fader, 1991)

5 Absence of closely-spaced reflections and sorted sediments on the surface
of the moraine such as would characterize subaqueous outwash-grounding
line fan-lobes (Powell, 1990)

6 Anastomosing character in plan view (Fig 9)

The incoherent internal configuration and absence of high frequency reflections within the

morainal segments and till-tongues suggests that massive diamicton-till or unlaminated ice-

loaded glacial marine sediments are present and (Belknap and Shipp, 1991, Syvitski, 1991)

MARINE SEDIMENTS						
UNITS	SM	MZ	UB	UC	SSSG	ES
No.->	10	12	3	3	2	5
Gravel%	27	45	51	88	60	13
Matrix%	73	55	49	12	40	87
Ratio	0.4	0.9	2.1	9.2	1.5	0.1
No.->	25	12	11	11	12	14
Meguma%	88	86	84	88	87	74
Granite%	3	3	4	2	7	5
Foreign%	7	8	11	8	5	5
No->	22	12	10	5	12	14
Striae%	16	15	10	4	2	8

Table 4   Average values of lithic parameters for marine sediments in the study region   (SM)

Scotian Shelf End Moraine Complex   (MZ) Morainal Zone   (UB) Unit B   (UC) Unit C

(SSSG) Sable Island Sand and Gravel   (ES) Emerald Silt

Piper (1988) and Syvitski (1991) suggested that coarse waterlain deposits may also be present, but undistinguishable from till Surface sampling of the SSEMC, however, produced only massive diamictons and muds Matrix-supported diamictons were most common on the moraine ridges, with striated and facetted clasts indicative of subglacial erosional processes (Dreimanic, 1989) Sorted, waterlain deposits were not found, although well-rounded clasts were found in poorly-sorted muds and diamictons of the Country Harbour Moraine (Fig 15) Grab samples of the Scotian Shelf Drift (largely from the Gulf of Maine) taken by King and Fader (1986, p 31) have sorting (sigma) values >3 (very poorly sorted) and average textural analysis of 38% gravel, 41% sand, 11% silt and 10% clay Similarity in composition and texture between the SSEMC samples and samples of the Morainal Zone (see p) and the textural and lithologic homogeneity between top and bottom IKUs suggest that ice-berg turbation (ice-keel turbate, Vorren *et al.*, 1983, Josenhans and Fader, 1989) is not a major factor is the formation of these diamictons

Grounding line fan lobes, common at the mouth of channel conduits at tidewater margins (Powell, 1984, 1990, Ashley *et al.*, 1991) are not apparent either from the digital model of echogram profiles from the Eastern Shore Moraine (Fig 9) or from surficial mapping across the region (King and MacLean, 1970)

The absence of high frequency bedding or laminations within the moraine as evidenced in the high resolution Huntec and NSRF sparker records (eg. Fig 12) strongly suggests homogeneity of composition Grounding line fans, on the other hand, exhibit stacked, complex stratified sequences with variable bed thicknesses, often less than 2 m (Ashley *et al.*, 1991)

Isostatically-elevated, tidewater moraines in Maine and New Brunswick (Fig 3) are characterized by complex sedimentology dominated by coarse glaciofluvial and fine-grained glacial marine facies (Smith, 1982; Nicks, 1988). Bedded units within these moraines with large grain-size contrasts i.e. (clay-sand rhythmites; sand-gravel beds) have strong impedance contrasts and would produce reflections on seismic records. The morphology of some of these moraines (Fig. 21) also differs substantially from the SSEMC moraines.

3.5.2 Modern and Pleistocene Analogues

The SSEMC moraines appear to have elements in common with both the modern polar ice shelf and temperate valley glacier settings. Table 5 is a comparison of the characteristics of landforms and deposits produced at ice marginal grounding lines in Alaskan temperate tidewater glaciers and polar glacier ice shelves. Ice shelves inhibit the formation of morainal banks (Powell, 1984) but wedge-shaped, ice-marginal diamicton bodies (till-tongues) have been postulated and observed (Alley et al., 1989; Anderson and Bartek, 1992; Drewry and Cooper, 1981; Hambrey et al., 1992; Powell, 1991). Diamicton facies are dominant in ice shelf environments (Anderson et al., 1991; Hambrey et al., 1991) while tidewater termini are characterized by complex sedimentology and structure (Powell and Molnia, 1989). The tidewater environments described in Alaska are dominated by diamictons and proximal glaciofluvial sediment fans (subaqueous outwash, Rust and Romanelli, 1975, Powell, 1984; Powell and Molnia, 1989). The implied absence or rarity of bedded fluvial facies in the SSEMC suggests an incompatibility with the tidewater-morainal bank model.

The moraine created by the surging Bråsvellbreen glacier in Spitsbergen is a possible analogue to the SSEMC (Elverhφi et al., 1989). The scale and morphology of the morainal

Margin type/ Property	Tidewater/ Temp rate	Ice Shelf/ Polar
Topography	Linear, asymmetric ridges, (morainal banks) elongate, slump scars on the distal side, mud flow fans at the base of the ridges, subaqueous outwash fans also prevalent.	Flat or low relief, lobate fan-shaped areas tens of kilometres long.
Sediments	Muddy diamictons, poorly-sorted regions of sandy-gravel and sand with boulders common. Rhythmically-laminated muds and sand.	Muddy diamictons predominately, often texturally homogenous.
Stratigraphy	Glaciotectonic deformation; interdigitating diamictons, laminated muds and outwash, distal muds.	Deltaic clinoforms, made up of diamicton strata (till deltas).

Table 5. A sediment and landform comparison of temperate tidewater and polar ice shelf glacial margins.

ridge is similar to the SSEMC moraines (Fig. 21) but a surge hypothesis cannot explain the volume of glacial marine sediment interfingering with the SSEMC moraines. After a surge, the glacier profile is markedly lowered and large areas become stagnant as a new active front is initiated upstream (Paterson, 1981). Meltwater production at the surge front is reduced or curtailed as the hydrostatic head is reduced. In the case of the SSEMC moraines, the onlap and interfingering relationships between the moraine and laminated, coarse and fine-grained glacial marine sediment (Emerald Silt facies A) imply a quasi-stable, active ice margin and a substantive meltwater flux.

Holtedahl (1989) described a 60 km long submarine morainal feature (Ra Moraine-Fig. 21) off Norway that can be traced onto land. It has an asymmetric shape (steeper side facing landward) and is composed of diamicton with ice-push structures. Holtedahl (1989) interpreted it as a feature formed at the margin of an advancing ice-front. Barnett and Holdsworth (1974) studied lacustrine moraines from the Barnes Ice Cap, Baffin Island. They postulated that moraine formation occurs in a wedge-shaped space beneath a tapered section of ice (ramp) by meltout.

3.5.3 Till-tongues

Till-tongues are wedge-shaped deposits lacking in coherent internal reflections, interbedded with stratified glacial marine sediment and rooted in large constructional moraines (King and Fader 1986; King et al., 1991; King, 1993). They were originally interpreted by King and Fader (1986) as the result of buoyancy-line fluctuations of a grounded ice shelf. King (1993) later envisioned formation by combined processes of sediment-gravity flowage from the grounding zone of a floating-front glacier and upstream deformation during advance and

Figure 21   Profiles of moraines in the study are compared with other worldwide examples

Note in all cases a marked asymmetry, steeper on the landward side, and gentler slope on the

seaward-down glacier side   Data from Elverhφi (1989), Holtedahl (1989), Nicks (1988)

MORAINE PROFILES

Legend:
— · · — · · — Bråsvellbreen Moraine, Spitsbergen
· · · · · · · · · · St John Moraine, New Brunswick
— — — Ra Moraine Norway
— · — · · Wilkes Land Moraine, Antarctica
———— Scotian Shelf End Moraines

1 Eastern Shore Moraine
2 Halifax Moraine
3 Country Harbour Moraine

Figure 21.

retreat of the grounding zone The deformation till-tongue model is analogous to the till-delta hypothesis (Alley *et al.*, 1989) In this model, deforming till under an ice stream, responsible for the motion of the glacier, forms horizontal till-topset beds over inclined, foreset gravity-flow deposits at the grounding line The overlying ice shelf does not accommodate morainal ridge formation Banks or ridges imply a cessation of motion or stability and sediment accumulation (Powell, 1984) Bank or ridge formation in King's (1993) model postdates till-tongue formation and occurs during ice retreat Deposition occurs when sea-level rises and the glacier separates from the bed In the case of the Scotian Shelf, however, isostatic recovery during deglaciation would cause initial sea-level fall and grounding of the glacier

Alternative origins for till-tongues have been presented which include

1 Slumping at a tidewater margin (cf Syvitski, 1991, King, 1993)

2 Glacial marine deposition (Vorren *et al.*, 1991)

The details of the mass movement processes in hypothesis 1 have not been elucidated A slump is a type of slide whereby the movement is essentially rotational, and the mass of sediment is not deformed or fluidized Debris flow is a moving fluidized mass that when deposited, can exhibit lateral grain-size variations (Lee *et al.*, 1993) Grain-size variations between till-tongues and their morainal roots (Fig 14) suggest a mass-flow process rather than slumping The morphology of tongues from this study area (Figs 12, 19, 20) and the type sections in the Gulf of Maine (King and Fader, 1986, p 14) differ from classic debris or mud flows (Edwards *et al.*, 1993, Fig 22) Head scarps are not apparent in the sections although it could be argued that these were eroded by subsequent ice movements Instead

Figure 22   Contrasting the morphology of till tongues and mudflows   Mudflow morphology

(Edwards *et al.*, 1983)   1   A main scarp at the head of the slope failure that marks the point

of detachment of the flow (Head Scarp)   2   An arcuate amphitheatre-shaped region of

erosion (Evacuation Zone) whereby sediment is removed and constitutes the main body of

the mudflow downslope   3   The edge of the flow is generally marked by a thickening bulge

of sediment (Toe Bulge)   Till tongue morphology   1   Abrupt contact with distal sediments,

undulating under surfaces and flat upper surface near the thin or "feather edge" (King and

Fader, 1986, p 48)   2   Horizontal distal margin   3   Moraine-ward thickening

MUDFLOW MORPHOLOGY
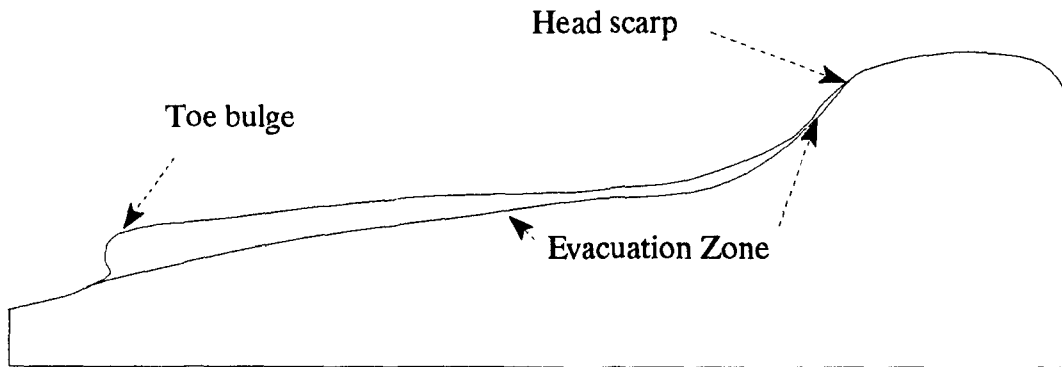
TILL TONGUE MORPHOLOGY
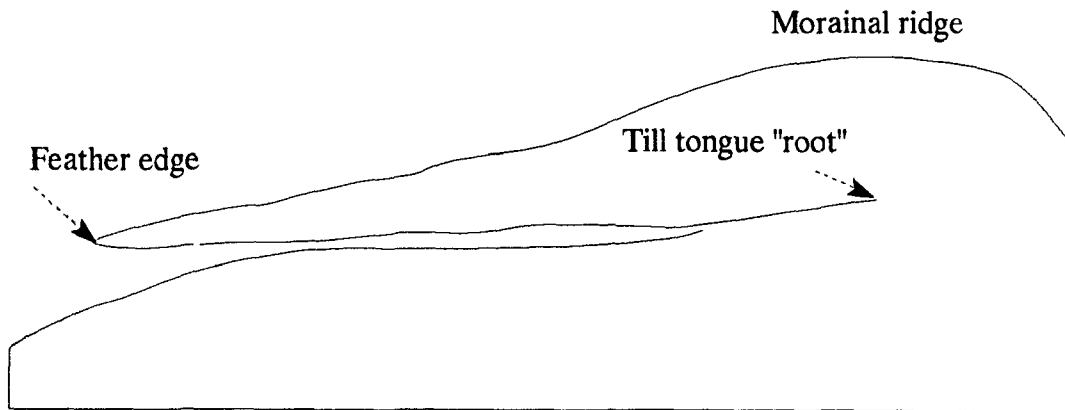
Figure 22.

of marginal thickening (toe bulge), till-tongues generally thicken towards the moraine source, sometimes quite markedly (Figs 12, 19, 20, King and Fader, 1986, p 14, 48) An evacuation zone is not apparent in any of the moraine profiles although some of the tongues have steep surface slopes at the margins The volume of sediment required for the tongues and the low repose angles also mitigate against a simple mass-wasting origin Tongues with a more complex shape than the idealized forms, may have been modified by minor syn-or post-depositional slumping, but in general these features do not display the characteristics of either slumps or debris flows (King *et al.* 1991)

Vorren *et al.* (1991) argue for a suspension-fallout marine origin for transparent, wedge-shaped facies in the Barents Sea based on preservation of relict iceberg furrows underneath the features and a proximal to distal decrease in backscatter along the "tongues" Core samples from these wedges produced overconsolidated and fissile, muddy diamictons which Vorren *et al.* (1991) attributed to post-depositional glacial modification

Wedge-shaped, incoherent-chaotic, seismic facies have been observed on the continental slope (Mosher *et al.*, 1989) but are not rooted in morainal ridges Some of these may be true mudflows or slides The term till-tongues should be restricted to those forms that are clearly rooted in morainal ridges and exhibit marginal thinning ("feather edge", King and Fader, 1986)

King and Fader (1986 p 38) cored a till-tongue (till-tongue 7) south of the Country Harbour Moraine They found that the tongue was texturally identical to Emerald Silt facies A Samples from the eroded surface of a distal to proximal till-tongue from Country Harbour (IKU 85-86, Fig 19) consist of a muddy diamicton and mud Minor deformation of Emerald

Silt strata is evident on underside of some till-tongues on an erosional surface that truncates till-tongues off Country Harbour (Fig. 23). Selective "homogenization" of Emerald Silt was also observed on this truncation surface. (Fig. 23). Fader (pers comm, 1994) cored till-tongues off Newfoundland and found that they were largely composed of mud, and less consolidated than morainal banks, but with higher shear strength than Emerald Silt.

3.5.4 Genesis of the Scotian Shelf End Moraine Complex

The author found King *et al.* (1972) and MacDonald's (1982) original interpretations of the SSEMC compelling and in accord with most of the evidence. The asymmetric profiles of the SSEMC moraines have not been stressed in the previous literature (cf. King and Fader, 1986; Piper *et al.*, 1990), but indicate that the ice front was closer to the proximal side than the distal. The Alaskan tidewater and polar ice shelf models do not satisfy many of the SSEMC characteristics, for reasons discussed earlier. Barnett and Holdsworth's model appears to be a compromise between ice-shelf and vertical tidewater fronts. Ridge formation occurs under an ice ramp rather than proximal to a vertical ice front (Fig. 24). Diamicton is deposited directly on the ice ramp-till bed by conveyor-belt recycling and lodgement (Powell, 1984) or push-squeeze processes (Boulton, 1986). Rock outcrop, thin drift and basins behind the SSEMC, and the steep morainal slope suggests erosion behind the grounding line. Erosion of previous till was accomplished through freeze-on (Powell, 1984). Changes in mass balance, sea level drop or buildup of the morainal bank (Powell, 1984) dictated further forward movement. Till-tongues were formed by grounding-line advance and smearing-out of the moraine in the proximal part, then deformation of Emerald Silt in the distal regions (cf. Boulton, 1990; Hart and Boulton, 1991). Increased buoyancy in deeper water caused the ice sheet to decouple from the substrate forming the "feather edge" till-tongue margin.

Figure 23   Huntec seismic profile and interpretation of a till-tongue cut by an erosional

surface south of the Country Harbour Moraine (see diamicton zone in section A-B, Fig 18)

Note apparent transformation of Emerald Silt reflections into a "massive zone" and

deformation of some Emerald Silt reflections

NW SEISMIC RECORD SE

INTERPRETATION

0   700 m   ☐   TILL TONGUE

110

130

160
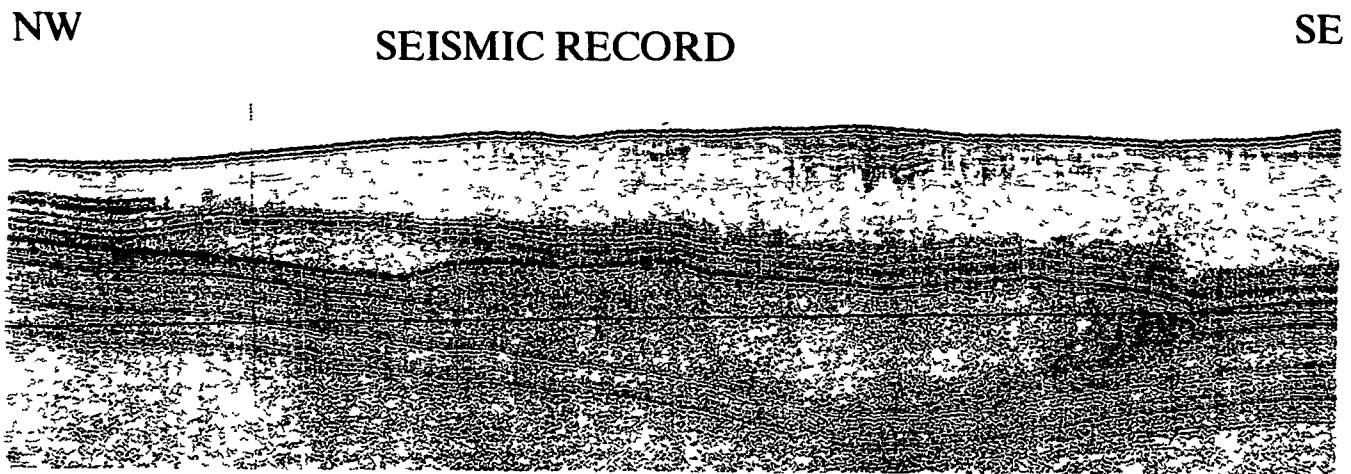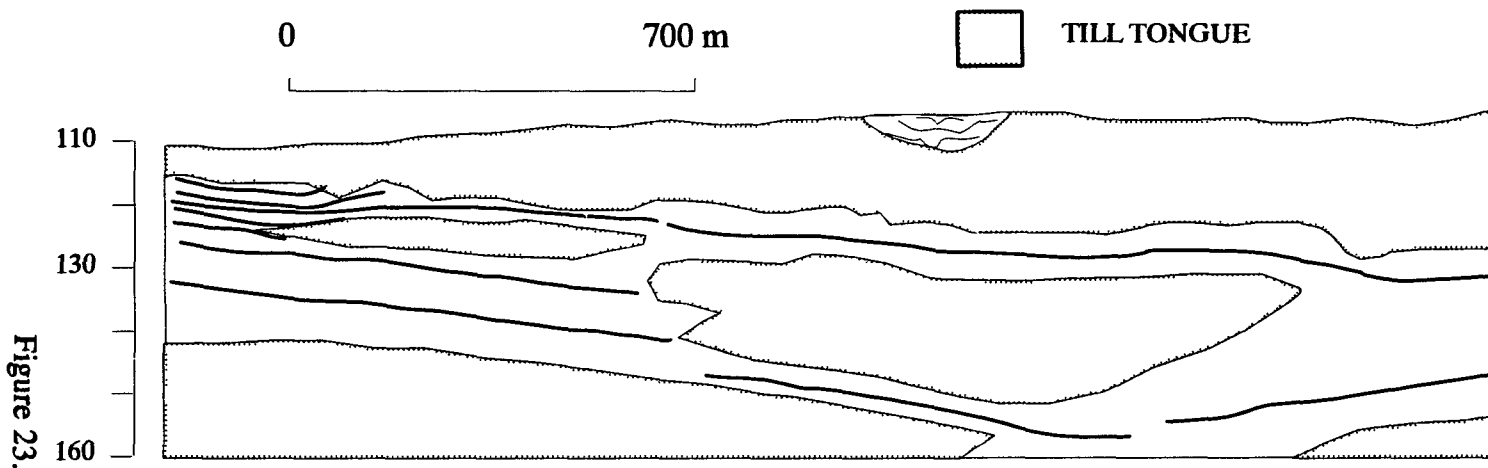
Figure 23.

Figure 24   Moraine and till-tongue formation a schematic model 1 Quasi-static ice front

at approximately 300 m water depth (critical buoyancy thickness)   Ice erodes the proximal

side of the moraine and builds-up the distal side by "conveyor-belt" transportation and melt-

out   2 A change in mass balance or sea level drop? causes ice to advance into deeper water

and truncate the former moraine surface, smearing-out moraine diamicton (A) in the proximal

part and forming a deformation till in the distal part (B) of the tongue with no debris in transit

3 Ice retreat and secondary bank formation, with deposition of Emerald Silt

1

2

3
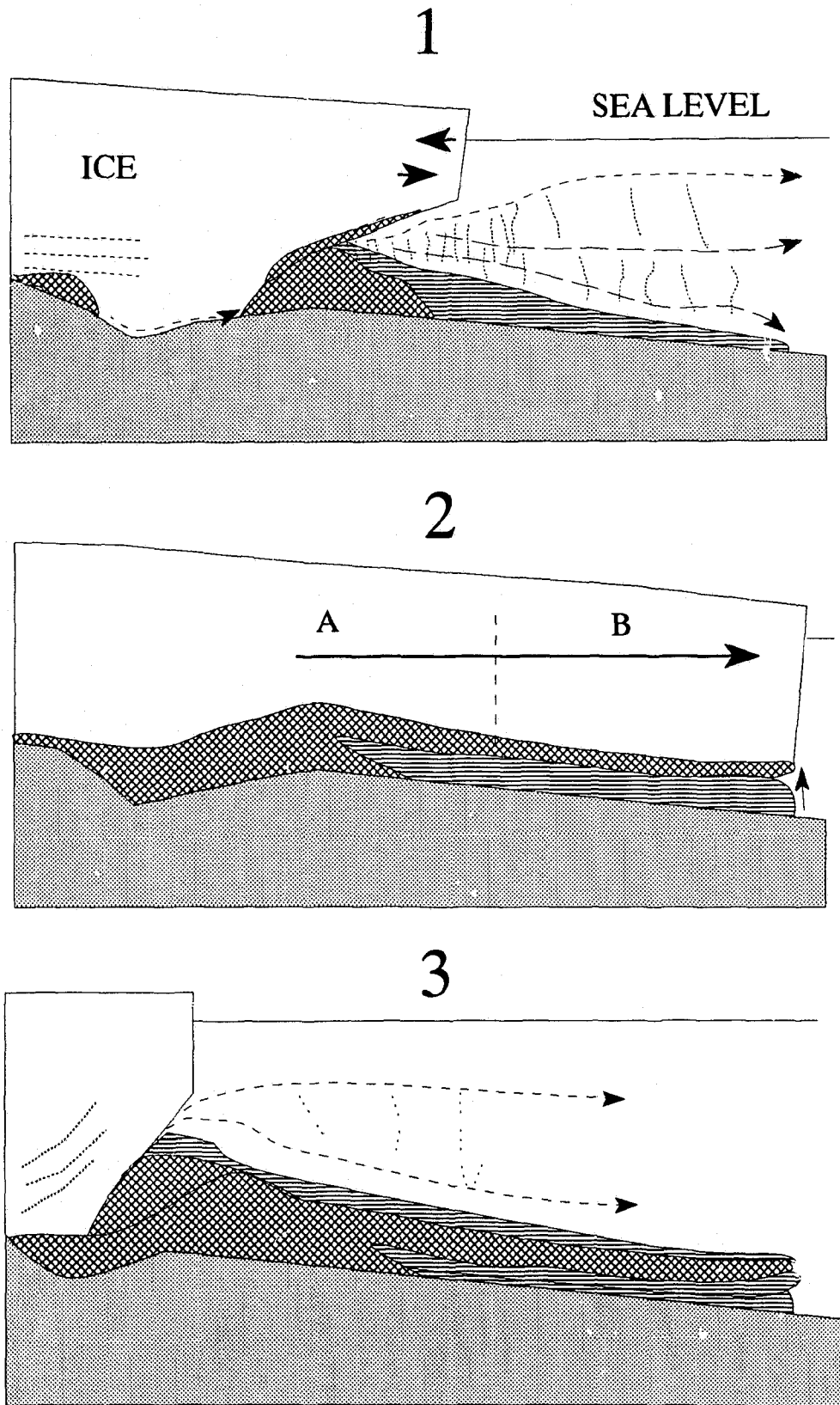
Figure 24.

Following this decoupling phase the ice either spread out as an ephemeral ice shelf or rapidly retreated through calving A new margin was established in shallower water near the region of thicker morainal deposits left behind at the former margin (Fig 24) Implicit in an ice-advance model for till-tongues is synchroneity of tongues across the shelf Age dating of the tongue margins will provide a test of this hypothesis

There is an apparent lack of sorted gravel and sand within and distal to the SSEMC moraines Grounding-line fans have not been identified (Fig 9) This is not compatible with a temperate-tidewater margin as described earlier (Table 5) A limited meltwater flux is indicated by glacial marine mud intercalated with the moraines High porewater pressures can result when glaciers override till and impermeable bedrock substrates like those of the inner Scotian Shelf (cf Boulton, 1990) Weertman (1966) suggested that meltwater in these environments is relegated to a thin film which emanates from the ice base as sheet flow The rapid transition from till to laminated muds which characterizes the Scotian Shelf End Moraine Complex can be explained by the interaction of low-velocity sheet flow and subglacial processes This relationship may also indicate that the glacier is in positive mass-balance; with frontal advance balanced by ice-berg calving In this case, meltwater generated at the surface of the ice sheet under high hydrostatic pressure would be minimal The tidewater moraines in New Brunswick and Maine (Fig 3) formed around 14 ka, during a period of enhanced worldwide glacial melting (Fairbanks, 1989)

3.6 BASIN ZONE

3.6.1 Introduction

North of the Scotian Shelf End-Moraine Complex is a series of narrow depositional troughs filled with glacial marine and marine sediments (Figs. 7, 8, 11, 16, 18). This region is termed the Basin Zone. Within the Basin Zone are two primary depositional areas termed the Sheet Harbour and Halifax sub-basins.

3.6.2 Sheet Harbour Sub-Basin

The Sheet Harbour sub-basin is a 7 km x 30 km trough located landward of the Eastern Shore Moraine in water depths greater than 145 m (Fig. 16; Map 2). At the type section (C-D; Fig. 16), six seismic sequences (SH1-SH6) with a total thickness from 12 to 30 m overlie acoustic basement (Fig. 25). Over most of the Sheet Harbour sub-basin, acoustic basement (internal reflections cannot be detected within this unit) occurs beneath a strong reflection with irregular relief marked by numerous side-echoes which extend 20 to 50 ms down-record. It is interpreted as Meguma Group bedrock (King and Fader, 1986). Bedrock is sporadically overlain by a unit with incoherent backscatter interpreted as the Scotian Shelf Drift (Table 1).

At the type section, the lowest sequence (SH1; Fig. 25) consists of hummocky, coherent reflections of low continuity and low to moderate amplitude. Emerald Silt facies A and C are represented in this sequence (Table 1). These reflections are draped over the underlying bedrock and drift topography. Isopach data show that SH1 is thickest (12 m) on the north

Figure 25. Huntec seismic profile and interpretation of the type section (C-D; Fig. 16) of the Sheet Harbour sub-basin. Seismic sequences (SH1-SH6) and erosional sequence boundaries (SHA-SHC) are shown. Water depths are in metres below sea surface.
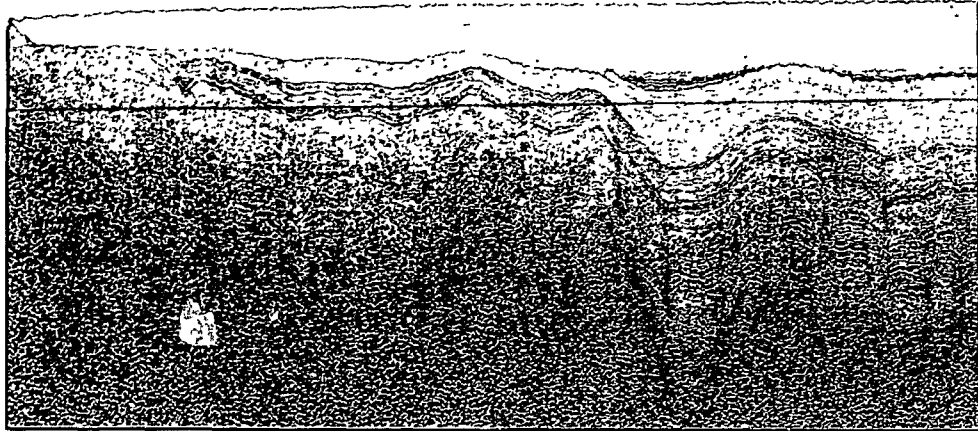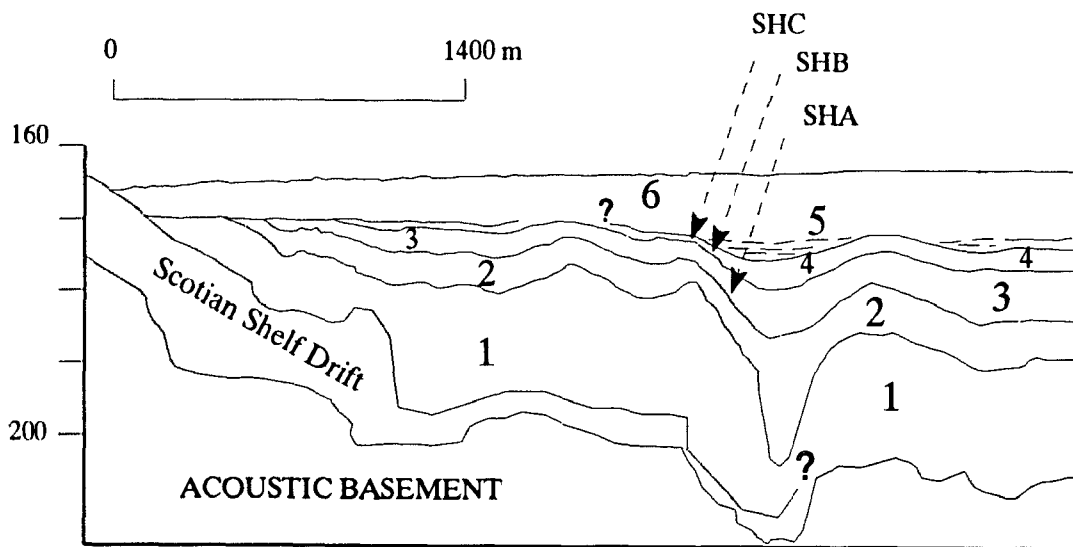
Figure 25

side of the Eastern Shore Moraine, and thins markedly in a northward direction to the till-tongue moraine on the northern boundary of the sub-basin (Fig. 16; 26).

Reflections within the overlying sequence (SH2) exhibit moderate to high continuity and amplitude. SH1 and SH2 appear conformable at the type section, but SH2 laps onto SH1 at the basin margin. Small and large scale undulations on the bounding surface between SH1 and SH2 are largely concomitant with the dips and rises in underlying bedrock. In the Emerald Basin, Gipp (1989, p. 116) reported steep, erosional features on the Emerald Silt surface marked by hyperbola and depressions and interpreted these as buried pockmarks and iceberg furrows. These features are rare or absent in the inner shelf Basin Zone. Isopach data shows that SH2 has variable thicknesses, thickening on the northern and southern boundaries of the basin (Fig. 26). The reflection configurations of SH1 and SH2 are compatible with the Emerald Silt facies "A" as defined by King and Fader (1986) (Table 1).

An erosional sequence boundary (SHA) separates SH2 and SH3. This sequence boundary is best developed where it merges with an erosional surface that truncates sequences SH1 and SH2 on the northern side of the Eastern Shore Moraine (Fig. 25). This boundary in the rest of the basin is formed by downlap of Sequence SH3. It can be traced across the Sheet Harbour sub-basin and the entire Basin Zone.

Sequence SH3 is characterized by moderate reflection amplitude and continuity and high frequency. It is ponded in broad hollows within the underlying sequence (SH2). SH3 and SH4 are separated by an erosional sequence boundary (SHB). SH4 is characterized by low amplitude, discontinuous reflections which lap onto Sequence SH3 at the basin margins. SH1 through SH4 drape over underlying topography to a lesser degree for each successively

Figure 26. Isopach data from Sequences 1 through 6 in the Sheet Harbour sub-basin. The contour interval is 2 m. Sample locations along tracklines are indicated as small boxes. See Fig. 16 for trackline locations.

6

5

3

4

2

1

SCOTIAN END MORAINE

SCOTIAN END MORAINE
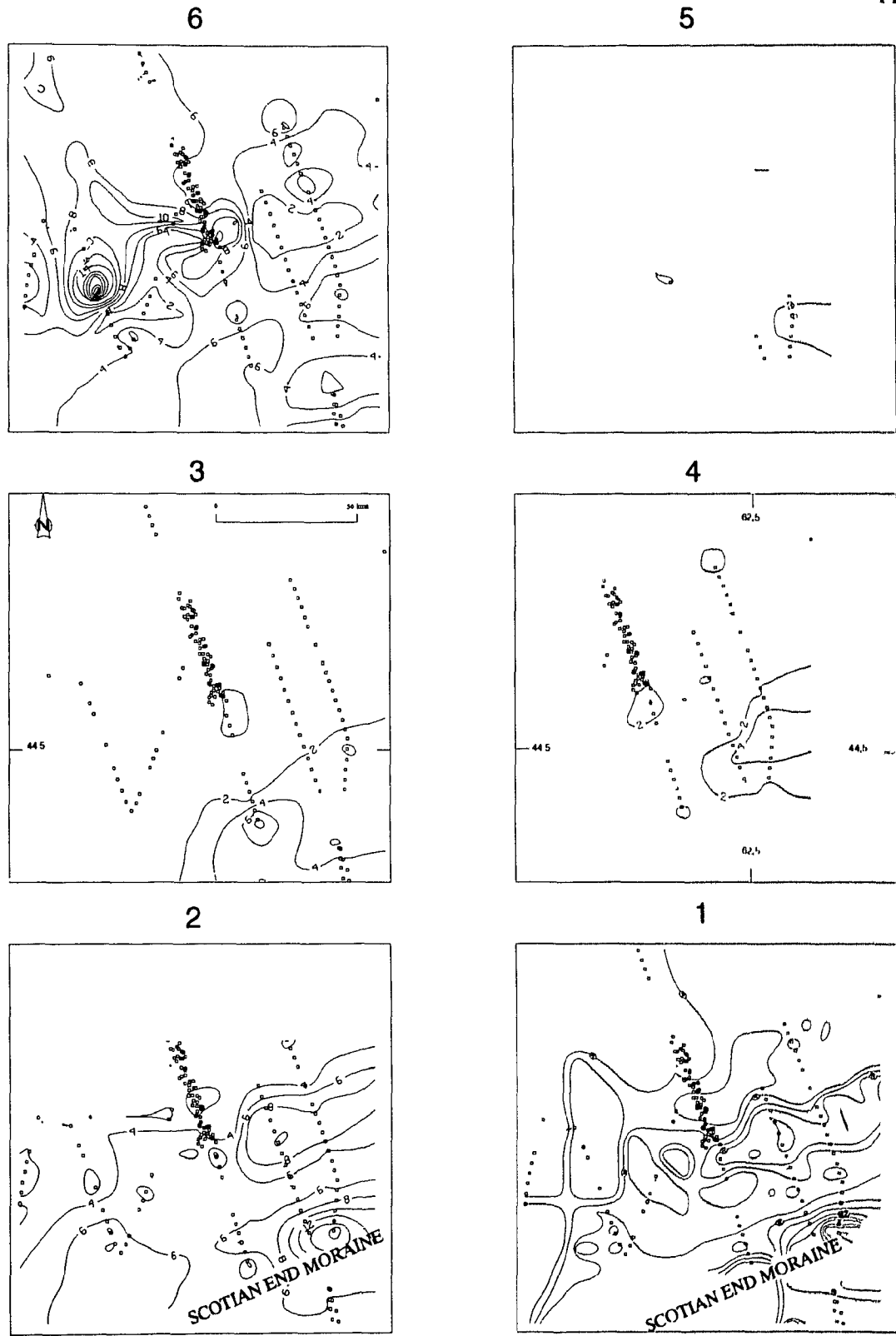
Figure 26.

younger unit SH3 and SH4 are composed of Emerald Silt facies "B" (Table 1) Isopach data shows a broad area of SH3 that exceeds 4 m in thickness just north of the Eastern Shore Moraine, while SH4 is thickest in the middle of the basin (Fig 26)

The SH4/SH5 sequence boundary (SHC-Fig 25) is marked by erosional truncation of the underlying units Sequence 5 (SH5) is characterized by a return to high amplitude, coherent and continuous reflections (Emerald Silt facies A) which lap on broad hollows in the SH4/5 boundary surface Above SH5 is a thick, transparent unit with some barely discernable, low amplitude reflections (SH6) This unit appears conformable with SH5 but the contact relationships are not well resolved SH5 and SH6 are thickest in the middle of the Sheet Harbour sub-basin (Fig 26) SH6 is also very thick (>20 m) in channels located in the southwest part of the Sheet Harbour map area (Fig 16, 26, Map 2)

SH1 and SH2 (Emerald Silt facies A) pinch out on the landward side of the Sheet Harbour sub-basin (Fig 16, Map 2) Where bedrock lies close to the seabed, SH1 and SH2 are truncated by an unconformity at the sea floor SH6 (LaHave Clay Formation) overlies Emerald Silt in basins between topographic highs in water depths from 137 to 124 m At the landward boundary SH6 (LaHave Clay) pinches out abruptly against a rise in acoustic basement

3.6.2.1 Lithology

This basin was not cored or otherwise sampled

3.6.3 Halifax Sub-Basin

The Halifax sub-basin is an irregular trough landward of the Halifax Moraine in water depths greater than 150 m (Fig. 11) The type section comprises a series of sparker records (Fig 27) located several km north of a segment of the Halifax Moraine (D-E-F, Fig 11) Six seismic sequences can be recognized in the NSRF sparker and Huntec seismic profiles at the type section These units are separated by sequence boundaries of erosional and lapout nature The lowest unit (Scotian Shelf Drift) is characterized by incoherent backscatter, high reflectivity, high surface relief and occasional point source diffractions It has some internal structure and less surface relief than the acoustic basement of the Sheet Harbour sub-basin A coherent reflection found underneath the Scotian Shelf Drift may be bedrock

The Scotian Shelf Drift is overlain by Sequence H1 which has a draped geometry, and is characterized by moderately continuous to discontinuous reflections of low to medium amplitude. Point-source diffractions (boulders) are visible within H1 The contact relations between acoustic basement, the Scotian Shelf Drift and H1 are obscure H1 is composed of both Emerald Silt facies "A" and "C" Isopach data show that H1 is thickest in proximity to morainal segments (Halifax Moraine) (Fig 28) In topographic hollows in the basin, H1 is overlain by a unit with reflections of higher amplitude and continuity (Sequence H2) Reflections within H2 lap onto H1 at basin edges Sequence H2 also appears to be thickest adjacent to morainal fragments especially in the eastern part of the Halifax sub-basin (Fig 28)

Sequences H2 and H3 are separated by a high intensity reflection which represents a major sequence boundary (HA) The boundary is predominately lap out in nature, although

Figure 27. Three segments representing the type section for the Halifax sub-basin. Sequences are indicated by boxed numbers shown on the figure. The locations of segments D, E, and F are on Figure 11. Sequences H1-H7 and boundary erosional unconformities (HA-HC) are described in the text. The arrow marks a prominent unconformity near top of Sequence 4 (HC) probably formed during the deposition of Sequence 5.

F

Unconformity C

5   6   7

140

4

3

160

ACOUSTIC BASEMENT

E

0   1400 m

150

7

6

5

4

170

3

1

ACOUSTIC BASEMENT

D

HB HC DIFFRACTION

HA

150

5

4

6

3

7

2

170

1

ACOUSTIC BASEMENT
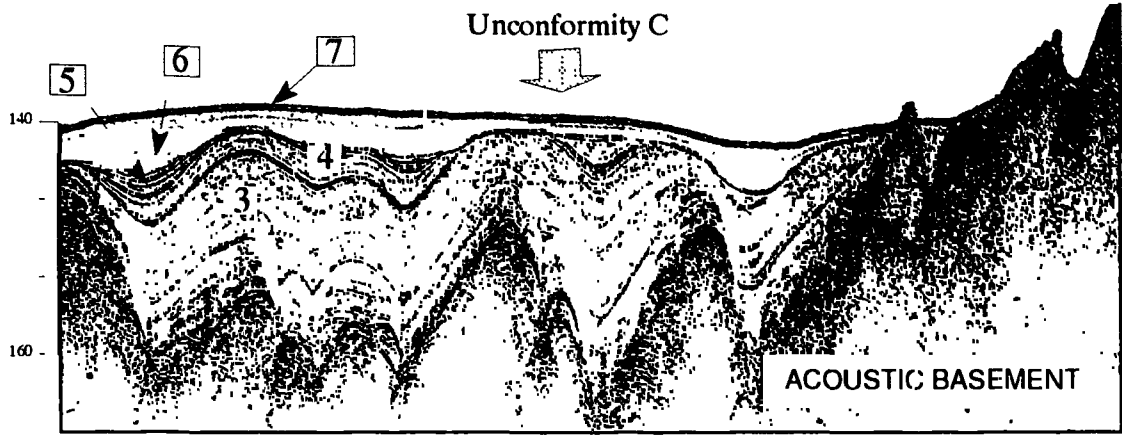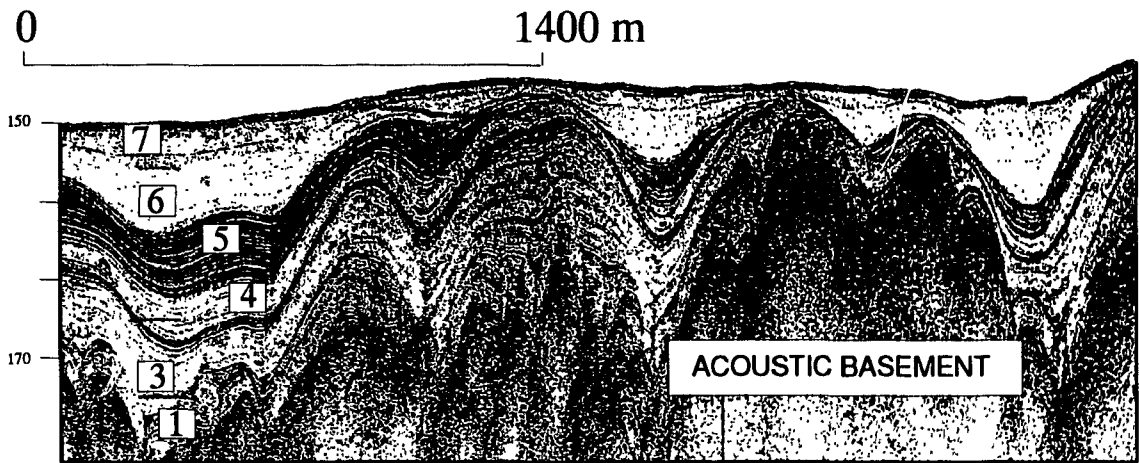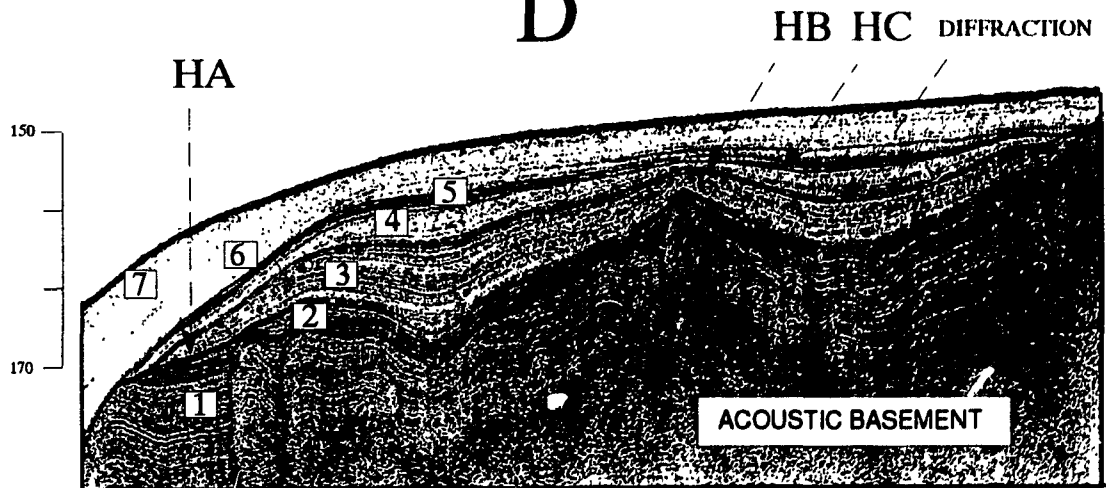
Figure 27.

Figure 28. Isopach data for Sequences H1 to H6 from the Halifax sub-basin. Contour intervals are 2 m. Tracklines from the Basin Zone area are included for clarity (see Fig. 11 for trackline geology).
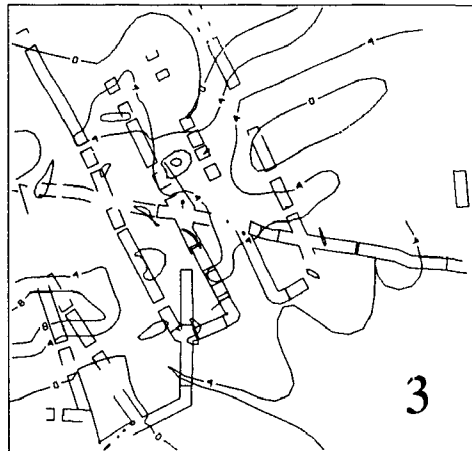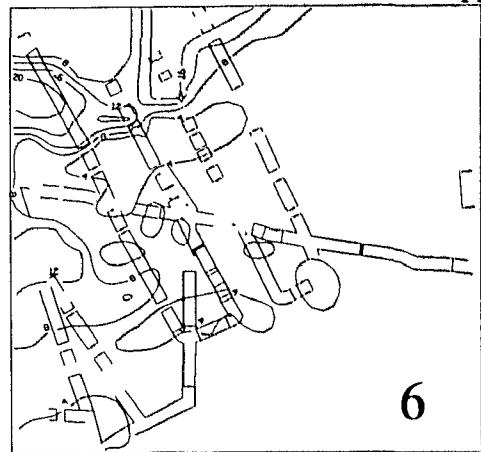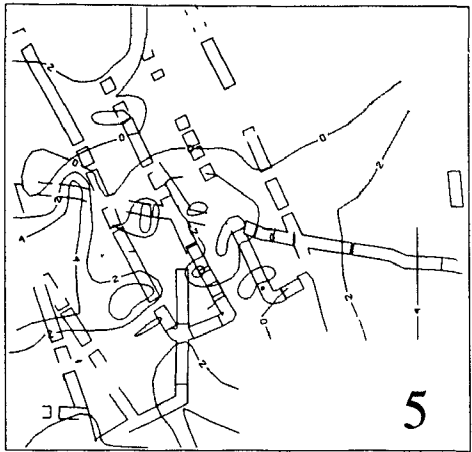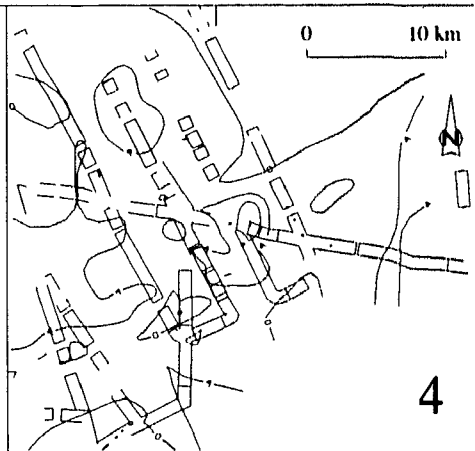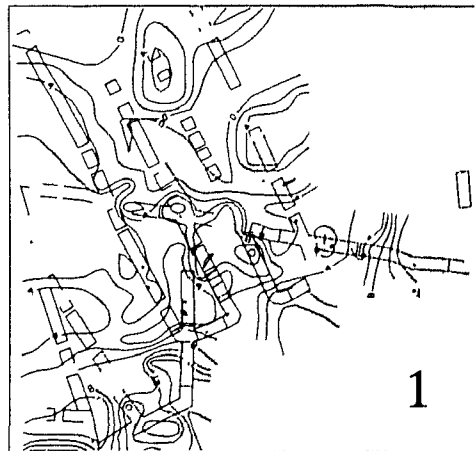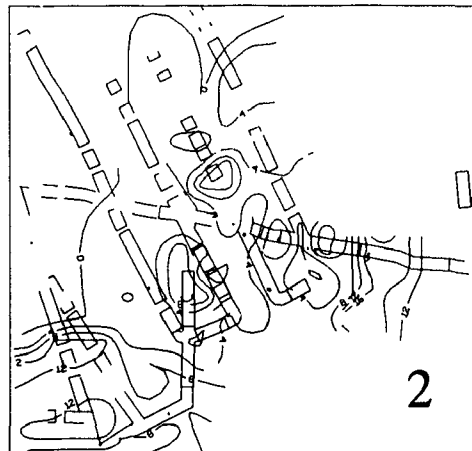
Figure 28.

evidence of erosional truncation can be found at basin margins   The magnitude of the acoustic impedance boundary represented by the unconformity is indicated by a "double" reflection which may indicate an abrupt grain size change or the presence of gas (Belknap *et al.*, 1991, Bacchus, 1993)

Sequences H3 and H4 are differentiated from H2 by lower amplitude reflections with less continuity   H3 contains a higher percentage of point-source diffractions (boulders) and slightly higher amplitude reflections than H4   These sequences also display a ponded, onlap-fill style of deposition   The base of H4 is characterized by a thin zone of high amplitude, continuous reflections   The rhythmic reflections evident in sequences H2, H3 and H4 may result from acoustic impedance contrasts between sand and silt layers and massive muds.   The sequence boundary that separates H3 and H4 (HB) is another high amplitude "double" reflection   H3 is truncated at the sequence boundary (HB) (Fig 27)   Isopach data shows that H3 and H4 are thickest in the middle of the basins north of the Halifax Moraine (Fig 28)

An erosional and hiatal (lapout) boundary (HC-Fig 27) separates sequences H4 and H5   This hiatal boundary can be traced to a planar erosional surface developed on the basin margins, where H3 and H4 are clearly truncated (arrow-Fig 27)

Sequence H5 consists of extremely high amplitude reflections (Emerald Silt Facies A) in marked contrast to H4, with a conformable depositional style   The correlative unit in the Sheet Harbour sub-basin (SH5) has a contrasting onlap-fill morphology   H5 is 4 m thick in the east and west end of the Halifax subzone north of the Halifax Moraine (Fig 28)   South of the moraine the unit appears to thin out

H6 has reflections of low amplitude and continuity which lap onto H5 and boundary HC. It is the seismostratigraphic equivalent to the LaHave Clay Formation of King and Fader (1986). It is thickest in the northern end of the Halifax sub-basin concomitant with the thinnest regions of Emerald Silt (H1-H4, Fig 28) A sequence boundary H6/H7, recognizable on the sparker records in the Halifax sub-basin is not seen in the Huntec records of the Sheet Harbour sub-basin H7 is marked by reflections of slightly higher amplitude than H6

3.6.3.1 Lithofacies

The Halifax sub-basin was piston cored at a location 2 5 km north of the Halifax Moraine (Fig 13) The core is located 46 km south of the present coastline in 168 m water depth (Fig 13, 29) A distinctive, high amplitude seismic horizon just below the LaHave Clay and above the Emerald Silt was targeted because of suspicions that it could relate to the Younger Dryas climatic event (G Fader, pers comm , 1992) The core penetrated 9 36 m of sediment and 8 20 m of core was recovered The core lithostratigraphy is described in Figure 30

3.6.3.2 Biofacies and Ages

A total of 72 samples from this core were qualitatively analyzed by D Scott (pers comm., 1992) and Costello (1994) for foraminiferal content and their results are summarized below with some modifications to defined biofacies and with additional data on marine pelecypod fauna. Seven major biofacies were defined (Fig 31) Radiocarbon dates were obtained from intact shell valves, or valve fragments, and samples of total foraminifers

Figure 29 Huntec seismic profile at core 91018-53 location (Fig 13) Core placement within the seismic section is based on matching high amplitude refections with coarse sediment beds in core 91018-53 and age dating core sediments Numbered boxes refer to seismic sequences described in the text The core lithostratigraphy is shown on Figure 30

S   N

CORE 91018-53   0   700 m

170

Depth BSL (metres)

180

7   ?

7
6

4

3

2

7

6   LaHave Clay

5

4

3

2

1

Younger Dryas "marker"

Emerald Silt

ACOUSTIC BASEMENT

Figure 29.

123
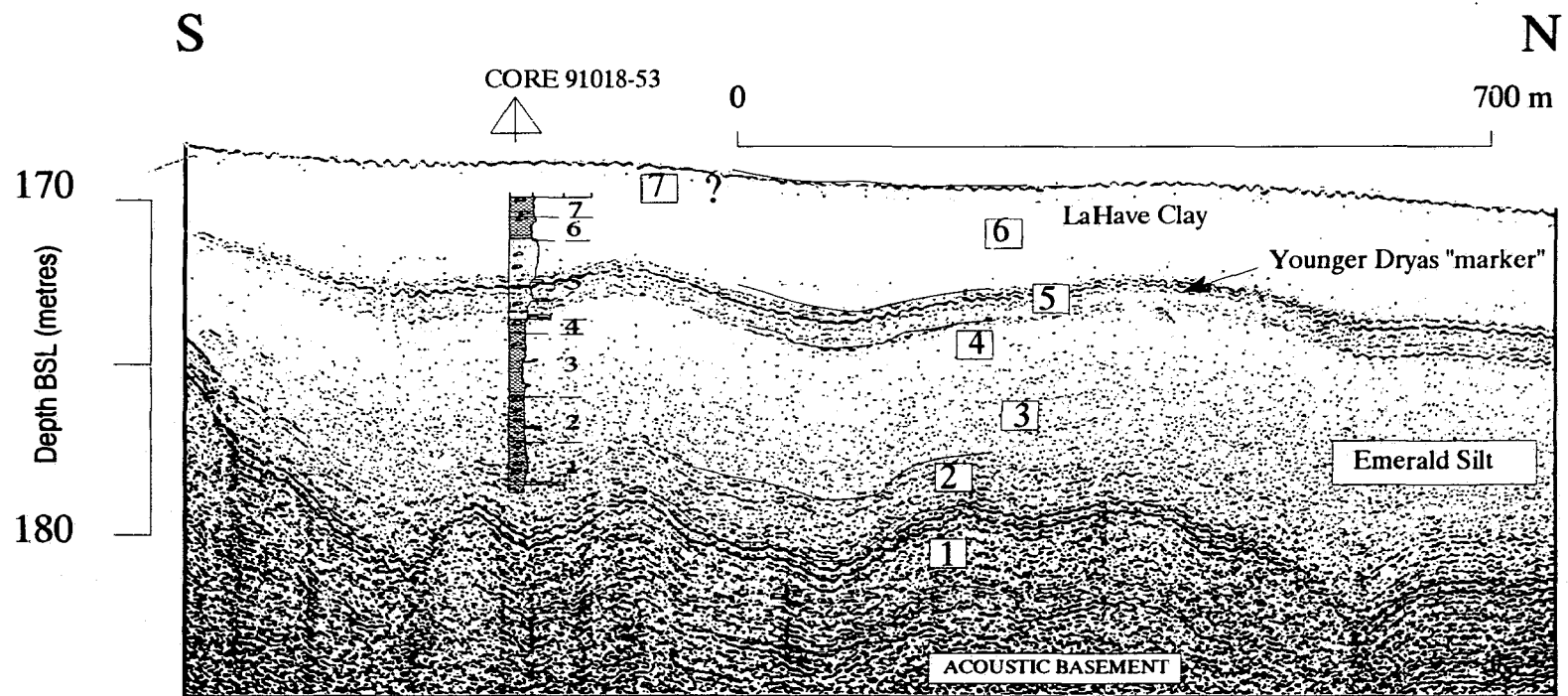
Figure 30. Lithology-lithofacies and sand percentages of core 91018-53 Dashed pattern refers to predominately clay-silt strata Dotted pattern refers to sandy-mud horizon (Lithofacies 5) Gravel percentages in the core are uniformly less than 1 percent Silt and clay (mud) make up 95 to 100% of the sample weight

GRAVEL/SAND/MUD PERCENTAGES STRATIGRAPHY LITHOFACIES LITHOLOGY

0   5   10...   100%

Gravel

Sand

Mud

Cl   Sl   SA   GR

1.0

2.0

3.0

4.0

5.0

6.0

7.0

8.0

7

6

5

4

3

2

1

Lithofacies 7. Olive-grey (5Y 3/2) massive mud.

Lithofacies 6..Dark greyish-brown (2.5Y 4/2) mud. Bioturbation at 100 cm.

Lithofacies 5. Olive grey (5y 3/2) massive stiff mud. Bioturbated from 100-240 cm. White silty layer at 230 cm.

Lithofacies 4.Dark greyish-brown (2.5Y 4/2). Oxidized to reddish hue. Mottling.

Lithofacies 3.Olive grey (5y 3/2) slightly mottled, bioturbated mud.

Lithofacies 2.Dark greyish brown (2.5 Y 3/2), heavy black mottling, oxidation to reddish hue.

Lithofacies 1. Dark greyish brown (2.5 y 4/2) compacted mud. red silt and sand in matrix.

Figure 30.

Figure 31   Graph showing percent foraminifera versus depth in core 91018-53 (after

Costello, 1994)   A-I are biofacies represented by foraminiferal assemblages (modified after

Costello, 1994)   See text for assemblage description

Figure 31.

127
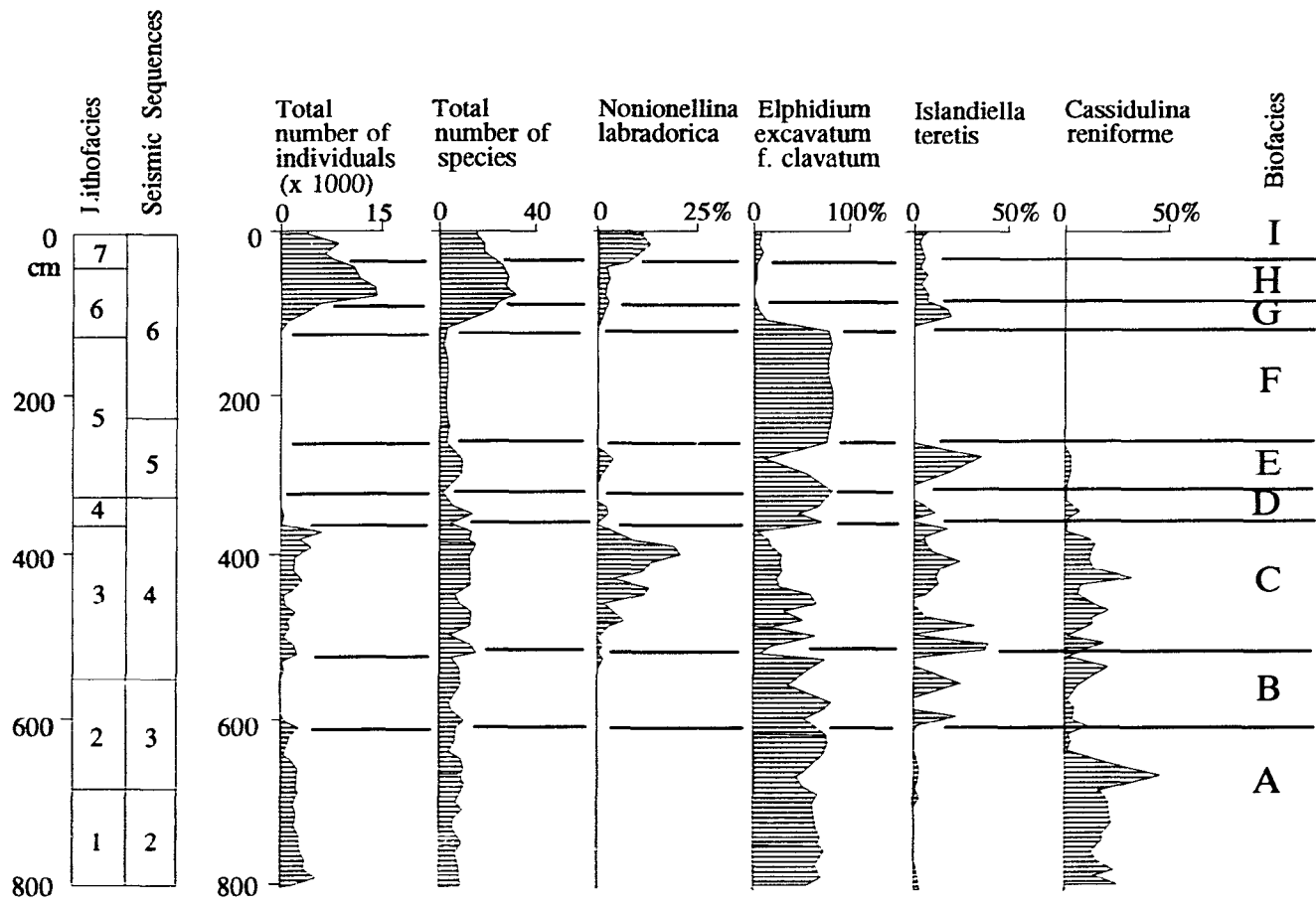
Figure 32   Summary diagram of core 91018-53 showing 'ates of sedimentation and the

correlation among foraminiferal assemblages (biofacies), lithofacies and seismic sequences

Included are the interpolated ages of the boundaries between lithofacies-biofacies

(foraminiferal assemblages) and seismic sequences (modified after Costello, 1994)

Figure 32.

129
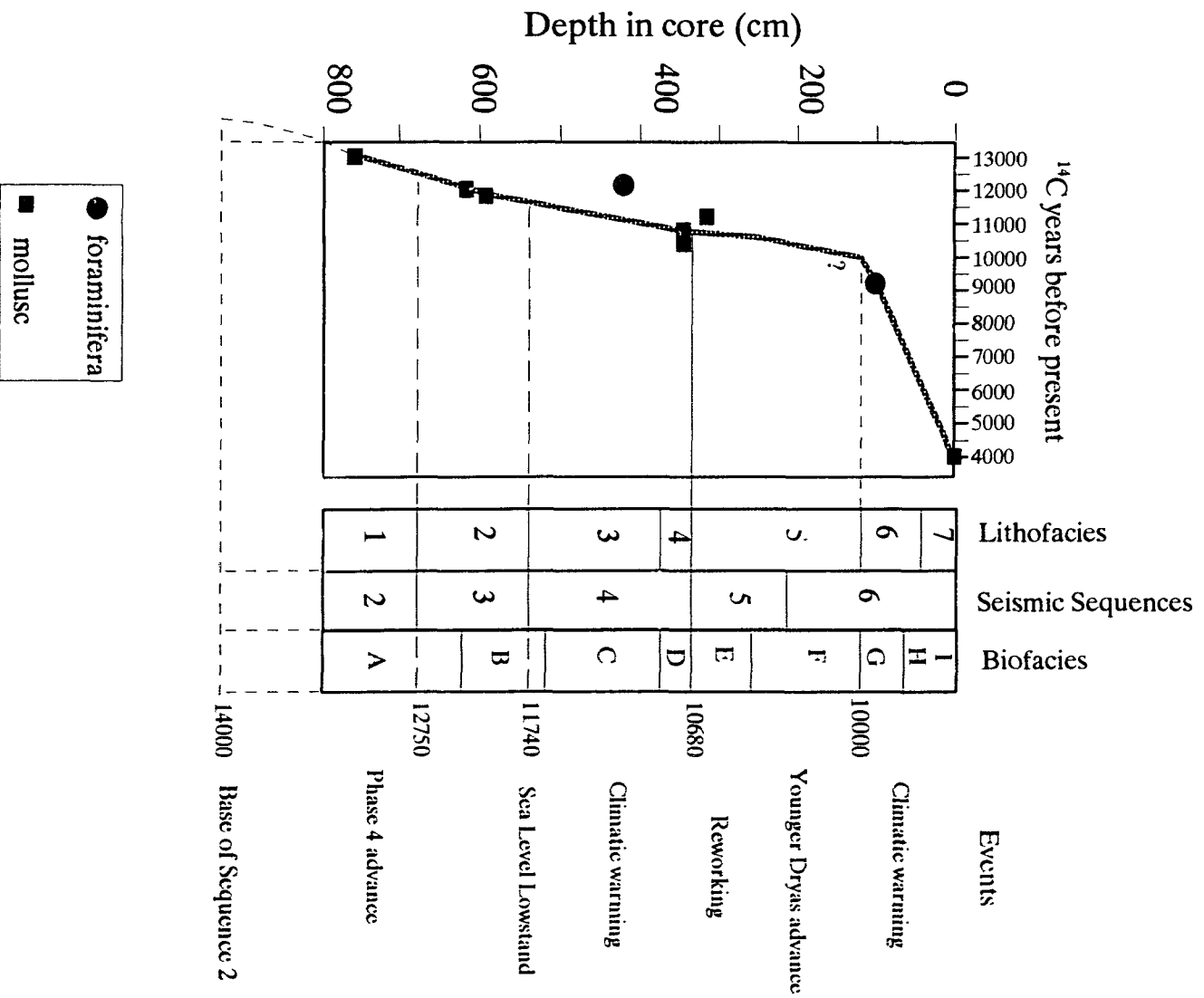
3.6.3.2.1 Biofacies G, H and I

The upper metre of the core revealed a high diversity assemblage of calcareous foraminifera (planktic and benthic), with 4-14,000 individuals per 10cc (Biofacies G-I, Fig 31) The dominant species are *Bulimina marginata*, *Nonionellina labradorica*, *Cassidulina laevigata* and *Bolivina subaenariensis* These biofacies represent Holocene warm water basin faunas similar to the present day Emerald Basin (Scott *et al.*, 1984) A radiocarbon date of 9220 ± 90 ^{14}C yrs BP was obtained from total foraminifera at 98-100 cm (Fig 30) A shell fragment (*Clinocardium* sp) from 24 cm depth was dated at 3970 ± 60 ^{14}C yr B P The interpolated age at the base of biofacies G based on an age-depth curve is 9840 ^{14}C yrs BP (Fig 32)

3.6.3.2.2 Biofacies E-F

Abruptly, at 130 cm to 260 cm the fauna changes to one dominated by *Elphidium excavatum f. clavatum* and little else The total foraminiferal count drops to 66-207/10cc concomitant with the influx of sandy sediment (Figs 30, 31) Diatoms are common with this faunal assemblage, occurring in pulses of abundance Diatoms have been reported in association with sea or pack ice (Kennett, 1982) In this core interval there is an increase in reddish-brown organic fragments (algae? twigs? and one spruce needle?) and pyritized organic fragments From 260 to 340 cm (Biofacies E) total foraminiferal amounts remain low (17-132/10cc) but several other species can be identified including *Nonionellina labradorica*, *Islandiella teretis*, and *Cassidulina reniforme* The base of Biofacies E corresponds to the base of sandy lithofacies 5 (Figs 30, 31) A single shell valve (*Yoldia thraciaeformis*) at 287 cm produced an age date of 11,340 ± 70 ^{14}C yr B P This shell fragment was probably reworked from older deposits, as erosion of previous deposits is clearly evident in seismic profiles at this stratigraphic level (Fig 27) The interpolated age for the base of Biofacies E-

Lithofacies 5 is 10680 ^{14}C yrs BP (Fig 32)

3.6.3.2.3 Biofacies D

Between 340 cm and 370 cm the total foraminiferal count increases to 600/10 cc and then decreases to 300/10 cc   *Elphidium excavatum f. clavatum*   is still the dominant species. Biofacies D was duplicate-dated to assess sampling variability   Ages of 10,740 ± 90 and 10,870 ± 70 ^{14}C yrs BP were obtained from separate shell fragments (*Yoldia thraciaeformis*) at 345 cm   The age at the base of this interval is interpolated as 10,900 ^{14}C yrs BP (Fig. 32).

3.6.3.2.4 Biofacies C

From 370 to 520 cm the total foraminifera increase to average about 2000/10cc   The fauna changes back into a cold water, normal-salinity fauna with the return of abundant *Nonionellina labradorica, Islandiella teretis* and other species of outer Labrador current affinities (cf Scott *et al.*, 1984) (Biofacies C)   *Elphidium excavatum f. clavatum* is the dominant species   The faunal assemblage of Biofacies C persists to about 390 cm where *Cassidulina reniforme* begins to increase   *Nonionellina labradorica* peaks and then decreases markedly towards the base of Biofacies C and total foraminiferal counts also decrease   A age of 12,420 ± 80 ^{14}C yr B P was obtained from this zone from bulk foraminifera   This date is slightly older than the shell dates and is offset on the age-depth curve (Fig. 32)   "Old carbon" contamination may account for this discrepancy because these samples cannot be etched and pretreated   Nielsen *et al.* (in press) describes a systematic offset of as much as 5000 years, between total foraminiferal dates and mollusc ages in the same core   They interpret the offset as a result of reworking   The interpolated age for the

base of Biofacies C is 11,650 ^{14}C yr B P

3.6.3.2.5 Biofacies B

Biofacies B from 520 to 620 cm depth is characterized by a marked drop in total foraminiferal abundances to 103-500/10 cc, similar to the values in Biofacies E-F   *Elphidium excavatum f. clavatum* remains the dominant species but *Islandiella teretis* begins to decline and *Nonionellina labradorica* disappears   Between 530 and 570 cm the counts drop to less than 300/10cc   There is an influx of detrital material including reworked organics and reddish clastic grains between 500 and 600 cm   Shell (*Yoldia thraciaeformis*) ages of 12,020 ± 90 (590 m) and 12,230±70 ^{14}C yrs BP were obtained from this foraminiferal unit   The interpolated age for the base of this interval is 12,203 ^{14}C yr B P

3.5.3.2.6 Biofacies A

Below 620 cm the dominant foraminiferal species are *Elphidium excavatum f. clavatum* and *Cassidulina reniforme*.   The total counts increase to average about 2000 individuals/10 cc   A single pelecypoda valve (*Nucula* sp) from the base of the core (750 cm) was dated at 13,050 ± 140 ^{14}C yr B P   Sandy sediment residues in this unit were reddish-brown in colour The age at the base of the core is interpolated at 13,500 ^{14}C yr B P

3.6.4 Core-Seismic Correlations

The discrepancy between the apparent penetration (clay on the outer core barrel) and actual core recovery is 1 16 m   This discrepancy may be due to

1   Sediment being forced away form the core barrel by the force of core penetration and core acceleration (bypassing, Buckley *et al*, 1994)

2   Sediment compaction

3   Incorrect scope length   The piston did not start moving at the correct time (D J W Piper, pers comm , 1994)

Assuming hypotheses 1 or 3 to be correct the core can be plotted on the seismic column displaced under the sea surface by 1 16 m   The position of the core on the seismic line is shown on Figure 29 although there may be up to 100 m of horizontal uncertainty (Fehr, 1991)   The trigger weight core did not deploy with Core 91018-53, hence valuable information about the surface metre of sediment was lost

The core and seismic stratigraphy can also be matched by correlating a unique event horizon in the core with a recognizable event in the seismic record   The uppermost sandy horizon within lithofacies 5 at 2 3 m can be matched neatly with the top of Sequence H5 (Emerald Silt facies A) consisting of high amplitude reflecting horizons   If this match is made, then the core is displaced under the sea surface by 1 2 to 1 8 m   This is close to agreement with the penetration-recovery discrepancy

Fehr (1991) tested the sediment-bypassing hypothesis (1) by extrapolating the age-depth curve from a dated core to the zero age of the core assuming a constant sedimentation rate, Extrapolation of the age-depth curve to the zero axis in Core 91018-53 (Fig 32) indicates that the seafloor is 1 m higher than the core surface   This is also consistent with the 1 16 m penetration-recovery discrepancy and indicates that sediment bypassing did indeed occur in the coring process

Using the previously-defined core placement within the acoustic section, the core seismic sequences, facies, lithofacies and biofacies can be correlated. This correlation is shown on Figure 32. Sequence H6 (LaHave Clay) can be correlated with lithofacies 5, 6 and 7 and Biofacies G-H-I and parts of F (Fig 31). H5 (ES facies A) matches well with the lower part of lithofacies 5 characterized by silt horizons. Biofacies E-F comprise most of Sequence H5. H4 (LaHave Clay seismic facies) is correlated with Lithofacies 3 and 4 and Biofacies C and D. H3 is correlative with Lithofacies 2 and Biofacies B and A. The boundary between Sequences H3 and H4 is marked by a drop in total foraminifera (Biofacies B-probably a response to sediment influx). The lowest part of the core, Lithofacies 1, matches with H2 (ES facies A) and Biofacies A.

3.6.5 "Proto" Moraines

At several locations in the Basin Zone north of the Halifax Moraine, mounds or ridges of Emerald Silt facies C (Table 1) rest on bedrock topographic highs and are draped and surrounded by acoustically laminated sedimentary infill of the Halifax sub-basin. These features are asymmetric in form, steeper on the north (landward) side, 50 to 70 m high and 200-400 m wide (Fig. 33). H1 interfingers with the mound on the south side, and overlies it on the north side (Fig. 33). H1 is approximately 30% thinner north of the feature than south. Sequence H2 drapes over the feature. These forms are called "Proto" Moraines. Emerald Silt facies C is interpreted as an ice-proximal, massive, glacial marine diamicton formed by coarse clast deposition from icebergs in association with fines from meltwater plumes at the glacier tidewater terminus (Powell, 1984; Powell and Molnia, 1989; Syvitski, 1991). The position of the former terminus is placed just north of the moraine (Fig. 33). These features differ from lift-off moraines described by (King and Fader, 1986, p. 15) in

Figure 33 Sparker acoustic profiles and interpretation through the Halifax sub-basin (B-C,

Fig 13) and close-up of "proto" moraines The Halifax Moraine is located on the south side

of a small basin The "proto" moraine close-up reveals a zone of acoustically incoherent

material till? or deformed glacial marine sediment that separates two sub-basins with varying

thicknesses of Emerald Silt Emerald Silt reflections appear to curve over the feature on the

north side and interfinger with it on the south side This feature is interpreted as a short-lived

ice marginal stand where till was formed or deposited through melt-out or deformation.

SEA LEVEL

ICE

Proto Moraine

Emerald Silt facies A

B

C

150 m

190 m

0

4 km
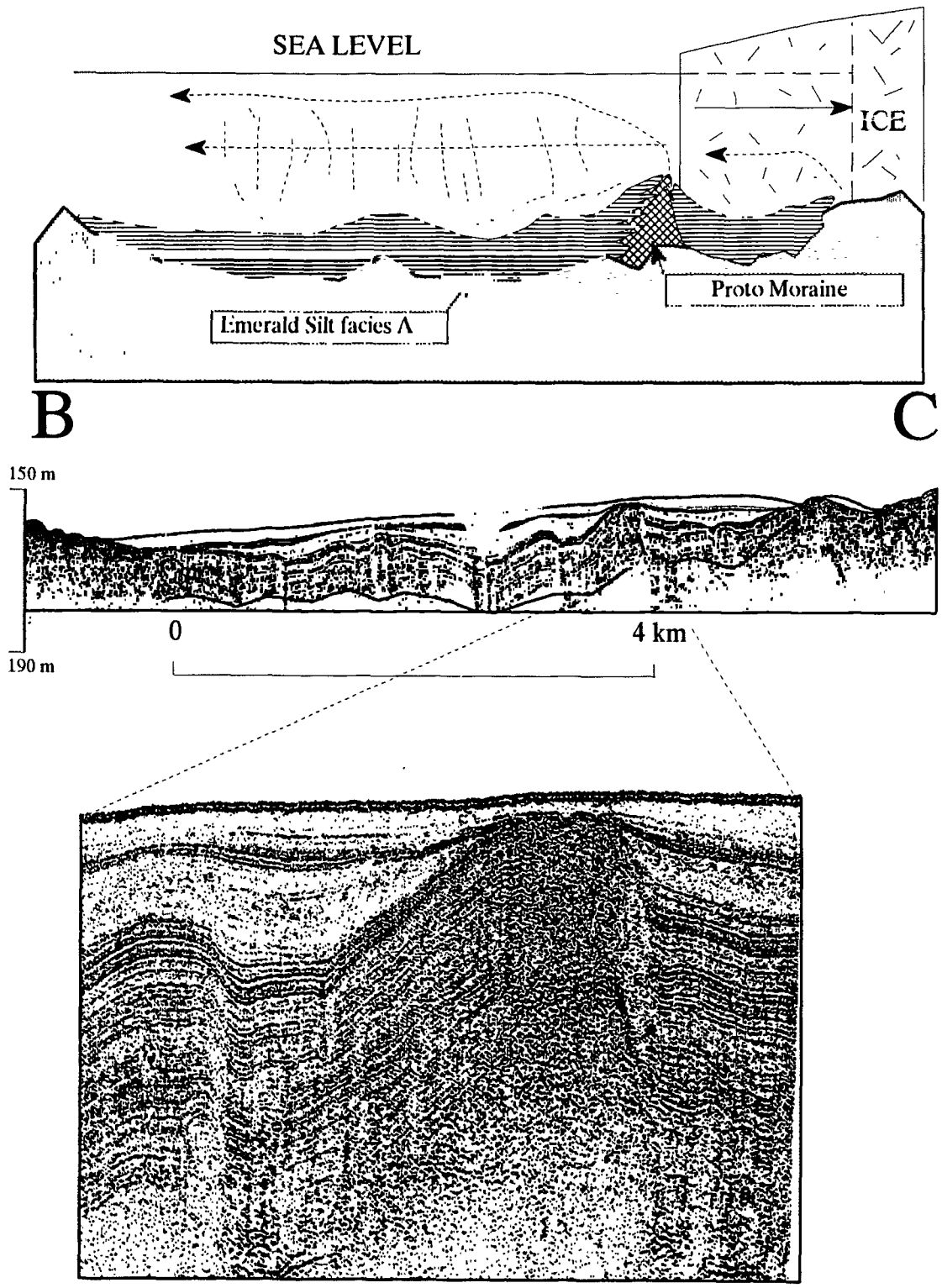
Figure 33.

two respects lack of symmetry and unequal thicknesses of Emerald Silt on either side of the feature

3.6.6 Local and Regional Correlations

The consistency of stratigraphy between the Halifax and Sheet Harbour sub-basins suggests that the six sequences found in each basin can be correlated one to one. Sequence H7 is an exception but was only resolved in the higher contrast sparker records in the Halifax sub-basin. The uppermost sequences representing Holocene marine deposition (SH6, H6) in both basins are correlative with the LaHave Clay Formation as defined by King and Fader (1986, 1988a; Table 1) The interpolated basal date of 9 2 ka (Fig. 32) agrees well with the basal date of the LaHave Clay (9 4 ka) obtained in the northern Emerald Basin by King and Fader (1988a) In the southwest Emerald Basin, Gipp (1989), Fehr (1991) and Piper and Fehr (1991) defined five sequences designated in this report as SW1-SW5 (Fig 34). Piper and Fehr (1991) correlated SW4 and SW5 with the LaHave Clay Formation. The age of the base of SW4 is estimated to be 14 ka (Gipp, 1989) The 4000 year age discrepancy between the LaHave Clay in the inner and outer Scotian Shelf has been attributed to the time-transgressive nature of the boundary (Piper and Fehr, 1991) Deglaciation generally proceeded from the southeast to the northwest on the Scotian Shelf, therefore all glacial marine sequence boundaries will be diachronous to some extent. A 4000 year age difference between the stadial/interstadial boundary in two adjacent basins, however, seems excessive. This paradox can be resolved with a reassessment of the correlations The difficulty in correlation is due to the acoustic similarity between Sequences SW4 and SW5 in the Emerald basin and between Sequences 4 and 6 on the inner shelf Some of the acoustic similarities between Sequence 4 and 6 may be gain effects, but the lithic and biotic attributes are

Figure 34. Correlation of seismic sequences, facies and formations in the Gulf of Maine and Scotian Shelf. Seismic sequences are numbered 1 through 7. Sequence boundaries are shown as bold lines. Marine inner shelf stratigraphy [1] is from Belknap and Shipp (1991). Maine outer shelf stratigraphy [2] is from Bacchus (1993). Generalized Scotian Shelf stratigraphy [3] is from King and Fader (1986). Emerald Basin seismic stratigraphy [4] is from Gipp (1989) and Piper and Fehr (1991).

MAINE NOVA SCOTIA FACIES LEGEND
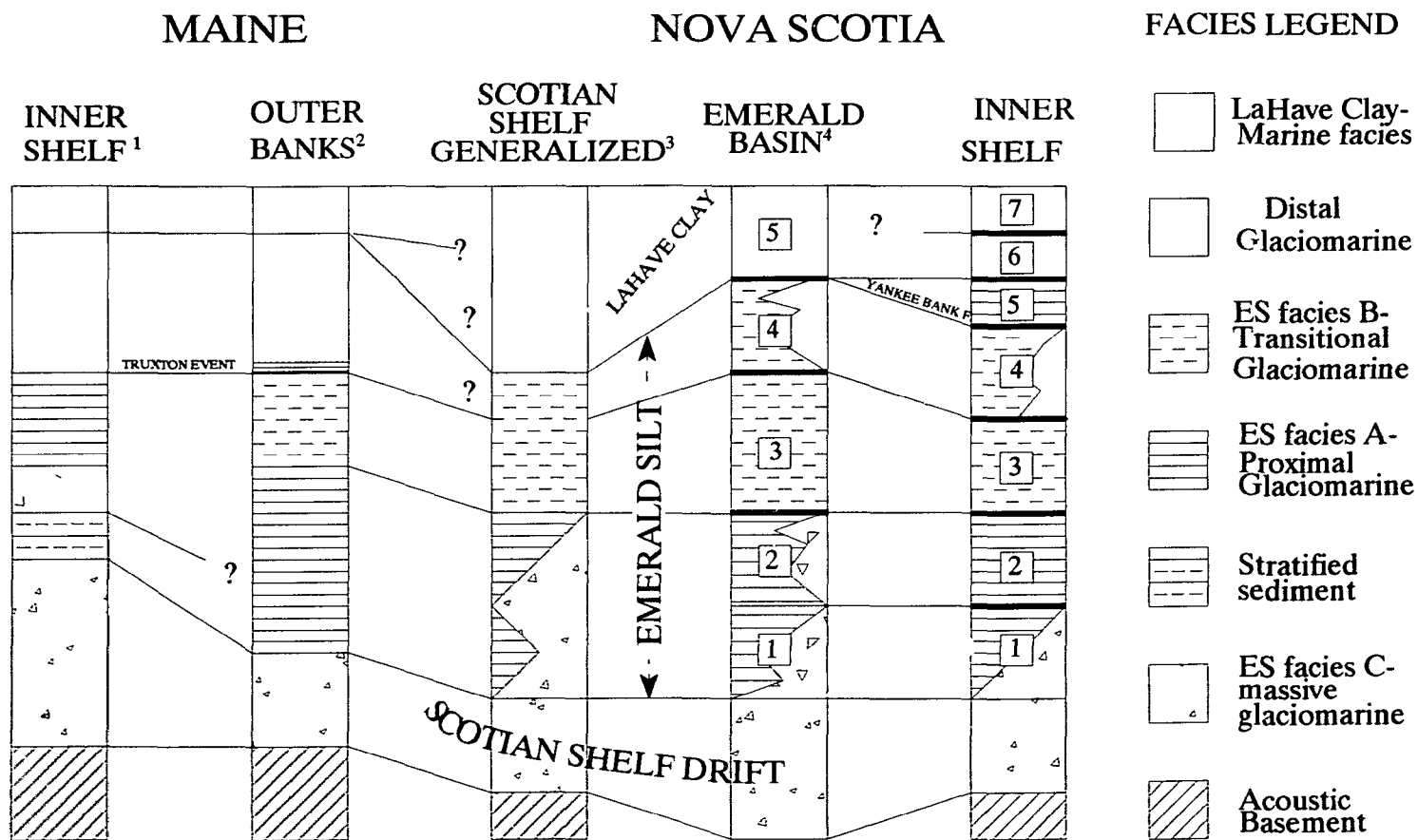
Figure 34.

analogous The abrupt and distinctive break in the acoustic record marked by Sequence 5

dated between 10 7 ka and 9 4 ka is correlative with an unconformity at the top of the

Emerald Silt Formation, in the northeastern Emerald Basin, dated between 10 0 and 10 5 ka

The boundary between SW4 and SW5 in the southwest Emerald Basin dated at 10 2 ka is a

single strong reflection that Piper and Fehr (1991) attributed to the Younger Dryas climatic

event Sequence 5 (inner shelf) characterized by Emerald Silt facies "A" with high amplitude

reflections, has not been described in the southwest Emerald Basin, but is a marker horizon

on the inner shelf The author proposes that the lower boundary of the LaHave Clay

Formation be designated as the top of Sequence 5 in the inner shelf and its correlative

unconformity (SW4/SW5 boundary) in the outer shelf basins The Emerald Silt Formation

should be redefined as Sequences 1 through 4 in both areas comprising seismic facies A, B

and C   Sequence 5 is regionally mappable, has unique seismic, lithic and biologic

characteristics and should be conferred with formational status I propose the name Yankee

Bank Formation (the nearest geographical name to the type section) to apply to Sequence 5 -

Lithofacies 5 - Biofacies E-F, bounded on the bottom by the Emerald Silt Formation and on

the top by the LaHave Clay Formation (Table 6)

The Yankee Bank Formation can be correlated with event horizons in other cores along the

inner shelf Marsters (1988) described a core (77-15) off Mahone Bay (see also Piper *et al.*,

1986) with an oscillation in foraminiferal assemblages from an ice-marginal fauna (*Elphidium-*

Cassidulina) (5 4-3 7 m) to a zone with low foraminiferal counts (2 5-3 m) and then to a

Post-Glacial assemblage (0-2 m) characterized by increasing numbers of *Islandiella teretis*

Marsters (1988) interpreted the "barren zone" as a period of rapid deposition The similarity

in biostratigraphy and depth suggests that the "barren zone" is correlative with the Yankee

Bank Formation   The   seismic   record of this core site does not resolve any distinct

SEQUENCE	FORMATION	INTERPRETATION
6	LaHave Clay	Holocene marine clay
5	Yankee Bank Formation	"paraglacial" deposit
4	Emerald Silt Formation	Glacial marine deposition-distal
3	Emerald Silt Formation	Glacial marine deposition-distal
2	Emerald Silt Formation	Glacial marine deposit-proximal
1	Emerald Silt Formation	Glacial marine deposit-proximal
	Scotian Shelf Drift	Till
	Acoustic Basement	Bedrock-Meguma Group metasediments

Table 6. Seismic sequences, Quaternary Formations, their correlation and interpretation for the study region.

horizon, but is of poor quality (Piper *et al.*, 1986). Souchen (1986) described a core in St. Ann's Basin north of Banquereau with a turbidite horizon between muddy sediment facies with a Late-Glacial faunal assemblage and a Post-Glacial normal-salinity assemblage. In this case an excellent seismic record revealed a distinct acoustic horizon characterized by high amplitude reflections on top of Emerald Silt facies "B" and below the LaHave Clay. On Banquereau, Amos and Miller (1990) interpreted a conformably-bedded sand unit dated at 11 ka as a proglacial unit based on the presence of an ice marginal foraminiferal fauna.

Belknap and Shipp (1991) divided the inner shelf glacial marine sediments in the Gulf of Maine into ponded and draped units. Bacchus (1993), working in deeper water, used unit subdivisions based on seismic reflection configurations equivalent to seismic "facies" (Table 7). Figure 34 is summary correlation diagram of formations, seismic sequences and seismic facies within the inner and outer Scotian Shelf and Gulf of Maine basins. Each region displays a general progression from Drift (massive-glacial marine) to Emerald Silt facies A and facies B (proximal to distal glacial marine) (cf. Syvitski, 1991). The distal glacial marine unit of Bacchus (1993) is a weakly stratified, ponded unit, similar to the uppermost seismic sequence (4) of the Emerald Silt which varies from acoustically transparent to weakly stratified. It may be correlative with the lower portion of the LaHave Clay or the uppermost Emerald Silt Formation (Fig. 34). Separating the transitional and distal glacial marine facies in the Gulf of Maine is a strong double reflection which has been termed the Truxton Event (G. Fader pers. comm., 1992). In some areas in the Gulf of Maine this horizon is series of high amplitude reflections. Cores through this unit revealed a distinctive, laminated, red-brown, gravelly-sandy mud (Bacchus, 1993, p. 172). The "Truxton Event" in the Gulf of Maine was estimated to be between 14.4 and 12.5 ka based on amino acid racemization dating but the method has a 2000 year uncertainty (Bacchus, 1993). Possible

Unit	Description	Interpretation	Designation
6	Acoustically transparent	Postglacial	M
5	Weakly stratified, conformable to unconformable reflectors	Ice-distal	DGM
4	Less densely stratified, conformable internal reflectors	Transitional	TGM
3	Densely stratified, conformable internal reflectors	Ice-proximal	PGM
2	Dense chaotic returns	Till	T
1	High intensity surface returns	Bedrock	B

Table 7. Seismic facies and interpretation from the Gulf of Maine (after Bacchus, 1993).

correlative horizons in the inner shelf study area are the Sequence 3/4 boundary and the Yankee Bank Formation (Fig 34) Syvitski (1991) compiled the stratigraphic sequences from twenty glaciated shelves around the world and found a common theme linking many of the sections His "composite section" consists of the following units summarized into genetic categories

1 Till, drift or ice contact sediments

2 Glacial marine sediment-proximal

3 Glacial marine sediment-distal

4 Paraglacial prodelta muds

5 Post-glacial basin fill

The first three genetic units are comparable to the sequence and facies progressions in the Nova Scotia inner shelf and the Gulf of Maine The "paraglacial" unit consists of deltaic wedges and may be more prominent in shelf areas close to the lowstand shoreline (see Truncation Zone)

3.6.7 Depositional Processes

Sequence boundaries as defined have no genetic connotations but are purely descriptive (Mitchum *et al.*, 1977) In models developed by Vail *et al.* (1977) sequence boundaries are considered to result from varying eustasy, tectonics and sediment supply producing changes in relative sea-level (RSL) The basins in the inner shelf were always below sea-level, hence the sequence boundaries must have formed from marine or glacial erosion and submarine onlap Sea-level fall may have indirectly played a role in regions of the inner shelf basins As

sea level falls, storm wave reworking may become an increasingly important erosional agent RSL fall may have been sporadic rather than continuous, responding to advances of ice, and meltwater loading (Belknap *et al.*, 1987, Stea *et al.*, 1994) Resuspension by turbidity, tidal and storm wave-generated currents are probably the main mechanisms generating lapout boundaries and ponded geometries (Barrie and Piper, 1982) Erosional truncation surfaces can be produced by currents, density flows and by direct glacial erosion Wedge-shaped sediment geometries are indicative of tidal currents (Piper *et al.*, 1983)

3.6.7.1 Sequence 1

Sequences 1 and 2 consist of Emerald Silt facies A and C and are thickest at the southern end of the basins nearest the moraines (Figs. 26, 28) It is assumed that they have common lithic characteristics with Emerald Silt facies A and C in the deeper basins south of the Scotian Shelf Morainal Complex (Table 1) In this study, Emerald Silt facies A was only sampled on erosional surfaces that were stripped of overlying seismic facies These samples were clay-rich but contained a significant amount of gravel (23 8% in IKU 51-Fig 4, Appendix 7). Much of this gravel, however, may have been winnowed from overlying sediments by the erosional processes responsible for the unconformity

Seismic facies A and C are characterized by draped geometries Reflections traceable for tens of kilometres are unique to facies A Two conflicting interpretations have been proposed to explain the properties of these acoustic units

1 Rapid deposition beneath an ice shelf by suspension settling (King and Fader, 1986, Belknap and Shipp, 1991, Bacchus, 1993)

2   Suspension settling from overflow and interflow plumes away from a

stationary ice front   (Oldale *et al.*, 1990)

It is generally agreed that a draped geometry results from rapid suspension fallout and high

sedimentation rates (Barrie and Piper, 1982, Belknap and Shipp, 1991, Syvitski, 1991)

Models 1 and 2 both produce draped geometries if the sedimentation rate is rapid enough

Facies "C" without bedding, has rarely been sampled and is interpreted either as a grounding

line proximal deposit or a till (King and Fader, 1986) Rhythmic bedding can be produced

by episodic deposition enhanced by low water temperatures which delay settling of fines but

not coarse sediments (Cowan and Powell, 1991) Episodic deposition can also be explained

in both models by periodic changes in sediment delivery, by tidal action, and seasonal (varve-

like) variation in sediment supply (Phillips *et al.*, 1991)   The continuity of glacial marine

sediments can be explained by both models

Powell (1984), Oldale *et al.* (1990), Anderson *et al.* (1991) and Syvitski (1991) argued that

ice shelves cannot form in temperate zones They presented these cogent arguments against

ice shelf formation

1   There are no modern examples

2   Warm water under ice shelves would rapidly cause their demise by

undermelt and enhanced calving

3   Cold ice is required because ice at the pressure melting point has lower

tensile strength and experiences easier fracture propagation

4   Ice shelves could not withstand the onslaught of open-sea storms with

breaking waves

These arguments have limited validity because they are based on modern, not ice age environments An ice shelf was postulated in the Gulf of Maine based on the lack of planktonic foraminifera (Schnitker, 1975) and diatoms (Schnitker and Jorgensen, 1986) in glacial marine sediments Diatoms are common in ice marginal environments today and absence implies light suppression Scott *et al.*, (1984) proposed that a ice shelf existed in the Notre Dame Channel off Newfoundland based on the presence of the deep water estuarine foraminifer *Fursenkoina fusiformis* Belknap and Shipp (1991) countered the anti-shelf arguments 2, 3 and 4 by suggesting that Gulf of Maine ice shelf was fed by fast moving ice streams and buttressed by numerous pinning points Wide, shallow banks in the Scotian Shelf may have attenuated storm waves (Argument 4). Gipp (1989) argues for a short-lived ice shelf in the Emerald Basin based on these properties of the lowest seismic sequence (O):

1 Sparse benthic foraminifera (8 tests/g)

2 Lack of evidence of current or storm wave resuspension

3 The absence of in-situ molluscs (cf Powell, 1984)

4 The absence of buried ice-berg scours

The most likely pinning points of a hypothetical ice shelf on the Scotian Shelf would be the outer banks King and Fader (1986, p. 55) proposed that the Scotian Shelf End Moraine Complex (SSEMC) was formed underneath the ice shelf, at a sub-shelf pinning point, while till-tongues and interfingering glacial marine sediment formed simultaneously on the north and south sides of the moraines In this study, till-tongues were found only on the deep water sides of the SSEMC If the ice shelf was pinned on the outer banks and Emerald Silt formed simultaneously with the SSEMC, then sediment thicknesses should be approximately equal in basins north and south of the SSEMC, or perhaps thicker on the northern (glacier-

proximal) inner shelf basins Sequence 1, however, markedly thins towards the north in the inner shelf basins (Figs 26, 28) Seismic records show a diachronous, onlap relationship between the moraines and the inner shelf basin sediments The "proto" moraines which separate sub-basins with varying thicknesses of Emerald Silt are interpreted as ice marginal stands Ice-rafted boulders within Sequences 1 and 2 also lend support to a proximal-ice marginal setting rather than sub ice-shelf origin The lack of iceberg scours in the basin sediments of the inner shelf can be related to water depths Iceberg furrowing seems to be restricted to the top surface of the SSEMC in the study area in water depths less than 170 m (Fader, 1991) Sequence 1 strata were deposited during sequential retreat and slight readvances of the ice margin from various pinning points represented by the "proto" moraines

3.6.7.2 Sequence 2

Sequence 2 can be distinguished from Sequence 1 in the Halifax and Sheet Harbour sub-basins by reflections of higher amplitude and continuity It can be traced northward as far as the Morainal and Outcrop zones (Fig 7) The synchronous, basin-wide extent and onlapping nature of this unit suggests deposition from overflow-interflow meltwater plumes by suspension fall-out followed by wave resuspension when ice was somewhat removed from the region The strong reflections imply impedance contrasts between mud and sand and/or gravelly-sand strata The unit may represent an enhanced period of melting This sedimentological interpretation is corroborated by biological data from core 91018-53 Sequence 2 records an ice marginal *Elphidium-Cassidulina* fauna (Fig 32)

3.6.7.3 Sequences 3-4

Sequences 3 and 4 are made up of Emerald Silt facies B and LaHave Clay seismic facies and are correlative with Biofacies B-D (Figs 32, 34, Table 1) Dominance of *Elphidium* within Biofacies B-D suggest an ice marginal environment (Scott *et al.*, 1984), but Biofacies B-D also exhibits an increasing up-section trend to a cold water, normal salinity fauna similar to the lower part of the LaHave Clay (Fig 32) In the Newfoundland shelf foraminiferal assemblages associated with the upper part of Emerald Silt facies B could not be easily differentiated from the lowest parts of the LaHave Clay (Scott *et al.*, 1984) Correlative transitional glacial marine units in the Maine inner shelf (Fig 34) have a similar lithology to the Presumpscot Formation on land (Belknap and Shipp, 1991) The onlap depositional style is due to resedimentation by currents and wave action (Barrie and Piper, 1982, Piper *et al*, 1983, Gipp, 1989, Belknap and Shipp, 1991) or from reduced rates of deposition (Vorren *et al.*, 1990) Asymmetric thickness distributions in the Basin Zone suggest wedging by tidal currents (Gipp, 1989) Higher percentages of point-source diffractions (boulder or boulder-dumps), higher-amplitude reflections and increased sediment thicknesses in a seaward (ice-distal) or southward direction (Fig 28) suggest that Sequence 3 was deposited closer to a glacial terminus than Sequence 4 The frequency of point-source diffractions implies that iceberg rafting played an important role in the deposition of this unit (Belknap and Shipp, 1991, Bacchus, 1993) In the Halifax sub-basin, Sequence 4 has a uniform thickness, and a low frequency of point source diffractions suggesting that the ice source had retreated north of the area, possibly onto the land areas (Fig 28) The boundary between Sequences 3 and 4 in the Halifax sub-basin is marked by erosional truncation, several high amplitude reflections, a drop in total foraminiferal count and species composition (Biofacies B; Fig 31). The increased sedimentation rate and erosion at the sequence boundary may be due to:

1 Falling sea levels and increased influence of storm waves with suspension
and transport of material from shallower areas to the Basin Zone

2 Glacier readvance, sea-level rise and increased sedimentation and current
erosional activity due to the proximity of a grounding line   A sequence
boundary may be formed by subglacial erosion, in the case of truncation, or
by proglacial erosion and by slump-driven turbidity currents adjacent to the
grounding line   Renewed crustal depression by advancing ice forms basin-
wide sequence boundaries by changing the accommodation space available for
sediment fill

Hypothesis 1 is favoured because sea level had dropped to its lowest point (-70 m) at about
11 6 ka (see Stea *et al.*, 1994)   Sequence 3/4 boundary occurs in water depths from 140 to
170 m, 70 to 100 m below the inferred lowstand   As stated in the introduction to this
chapter, Forbes (*et al.*, 1991) observed that combined wave-current activity can entrain silts
to depths of 100 m   Erosion and deposition during the lowstand may have also been
enhanced by the proximity of the paleo-shoreline to the Basin Zone

Hypothesis 2 is less likely, because at the time of formation of the Sequence 3/4 (11 7 ka)
boundary, ice had retreated from the land areas of Nova Scotia (Stea and Mott, 1990,
Map 1)

3.6.7.4 Sequence 5

Sequence 5 is composed of conformably-bedded, Emerald Silt facies "A", marked by an influx
of coarse material and a drop in total foraminiferal counts   Two hypotheses put forward to

explain the sequence 3/4 boundary are also applicable to Sequence 5. Hypothesis 1 (sea-level change) is unlikely because at the time of Sequence 5 deposition (10.8 ka) sea-levels had already dropped to their lowest levels (11.5 ka) and were rising (Stea *et al.*, 1994). A glacial marine environment (Hypothesis 2) may be indicated by the *Elphidium*-dominated foraminiferal assemblage (Fig. 31) but the absence of *Cassidulina* is enigmatic as the two forms are normally found together in these Pleistocene glacial marine environments (Scott and Medioli, 1980a; Vilks, 1981; Seidenkrantz, 1993). Lowered salinities may have excluded *Cassidulina* (D. B. Scott, pers. comm., 1995). Diatom fluxes within Biofacies E-F may point to increased winter sea ice cover (Kennett, 1982). The ice source probably was not a calving margin because point source diffractions (boulders) are lacking. Sequence 5 thickens towards the south, away from the extensive Younger Dryas marine ice margin proposed by King (1994) and the less extensive terrestrial margins postulated by Stea and Mott (1989; Map 1). Erosional surfaces synchronous with Sequence 5 (Fig. 27) did not form by ice advances because lake sediment records indicate adjacent land areas were cleared of ice by 12 ka and Younger Dryas ice was restricted to northern Nova Scotia (Stea and Mott, 1989; 1990; Map 1).

I interpret this event horizon as a response to a combination of increased storminess (cf. Gipp, 1989), debris-laden sea ice and increased sediment supply from the devegetated coastline. The coastline was about 20 km seaward of present about that time (Stea *et al.*, 1994). Permanent and semi-permanent snowpacks and small glaciers, terminating in shallow water provided plumes of low-salinity, sediment-laden water which may have spread over much of the inner shelf (cf. Map 1). Terrestrially-derived organic debris may have been borne by sea ice.

If correlations with the outer bank turbidite unit of Souchen (1986), the conformably-bedded sand of Amos and Miller (1990) and Gulf of St. Lawrence "paraglacial" units of Syvitski (1991) are correct then a widespread climatic event is implicated Ice advances have been documented in the land areas adjacent to the Gulf of St Lawrence (Stea and Mott, 1989, Grant, 1989, LaSalle and Shilts, 1993).

3.6.7.5 Sequences 6 and 7

A major sequence boundary can be resolved in the LaHave Clay Formation at the Halifax sub-basin type section (Fig 27) This boundary may be a response to changing climates and sea-levels during the mid-Holocene hypsithermal interval.

3.7 MORAINAL ZONE

3.7.1 Introduction

King et al. (1972) first described morainal ridges on the inner shelf north of the Scotian Shelf End-Moraine Complex LaPierre (1985) also identified transgressed till-cored ridges on the inner shelf off Petpeswick, Nova Scotia using sparker seismic profiles, sidescan sonograms and grab samples Fader et al. (1991) and Stea et al. (1992b, 1993) described a zone off Sheet Harbour characterized by morainal mounds and ridges The Morainal Zone is located 40 km northeast of Halifax along the Eastern Shore (Fig 7, 8) Huntec seismic profiles reveal a unique acoustic morphology characterized by steep, irregular mounds and ridges 2-30 m in height and 100 to 300 m wide They are scattered throughout a shore-parallel zone in water depths of 65 to 145 m. Continuous, coherent reflection traces cannot be resolved within the

landforms, they are acoustically homogeneous Sidescan sonograms of the mounds reveal high intensity backscatter (gravelly-bouldery) areas of irregular pattern and ridge shapes (Fig 35) Large boulders (1-4 m diameter) can be seen scattered randomly across the seabed These boulder patches occur in ribbons on the sonograms and appear to be uniquely associated with the moraines These landforms were originally interpreted to be glacial in origin, either drumlins or moraines (Fader *et al*, 1991)

The ridge morphology of the landforms in the Morainal Zone was defined by sidescan sonograms (Fig 35), mapping of closely-spaced tracklines (Fig 36) and a digital terrain model developed from echograms of the Canadian Hydrographic Service (Fig 8) Interpolation between widely-spaced tracklines was based on sea-bed depth contours obtained from the digital grid model (Fig 16, Map 2) Many of the Morainal Zone ridges are oriented northeast-southwest, parallel to the northeast-southwest orientation of the Scotian Shelf End-Moraine Complex In the northern part of the Morainal Zone ridge orientations change from NE-SW to NW-SE (Figs 16, 36)

Five main morphologic and stratigraphic categories of ridge-landforms were discerned from the seismic and sidescan sonar records

    1 Till-Tongue Moraine

    2 Symmetrical Moraine

    3 Hummocky and "Doughnut" Moraines

    4 Bedrock-Controlled (Ground) Moraine

    5 Asymmetrical Moraine

Figure 35   Sidescan sonograms of "doughnut" (A) and ridge-like (B) landforms in the Morainal Zone The scan width of the sonogram is approximately 400 m   The morainal segments in the sonogram are 20-40 m wide and 300-400 m long   Some of the moraine segments are buried under LaHave Clay, so are longer than they appear

A
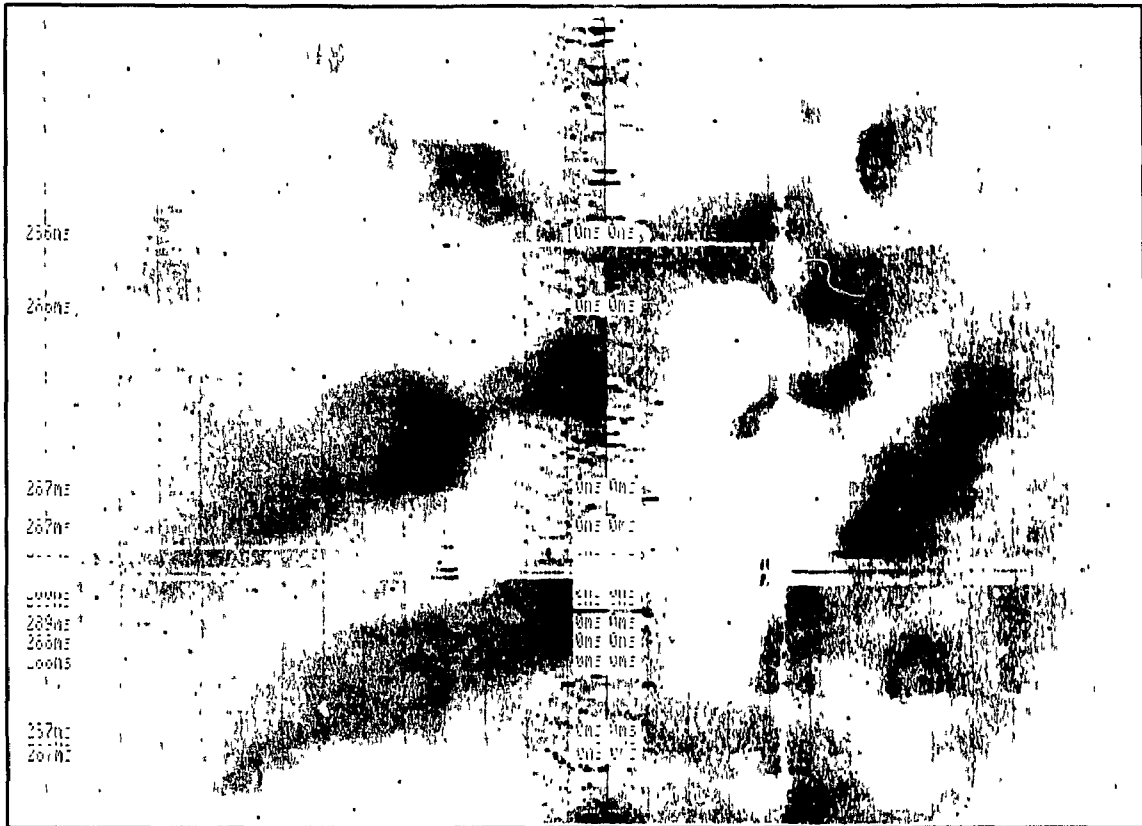
B
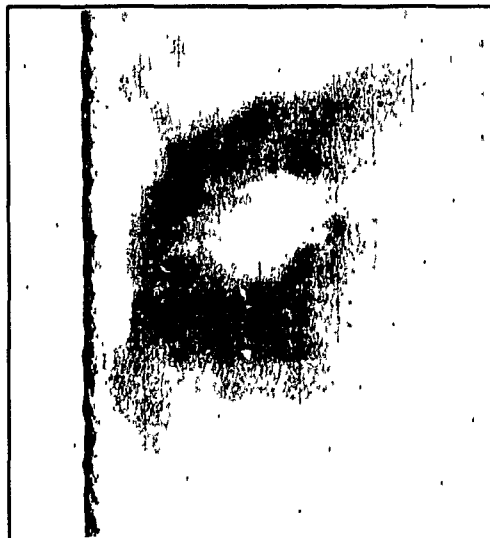
Figure 35.

Figure 36   An expanded view of a region of the Sheet Harbour Transect area (see Figure 16 for location) showing mapping details of closely-spaced tracklines Patterned areas are morainal ridge segments mapped using Huntec profiles and sidescan records The intervening white areas are underlain by LaHave Clay Note the change in orientation of the ridges in the northern part of the transects from E-W to NE-SW
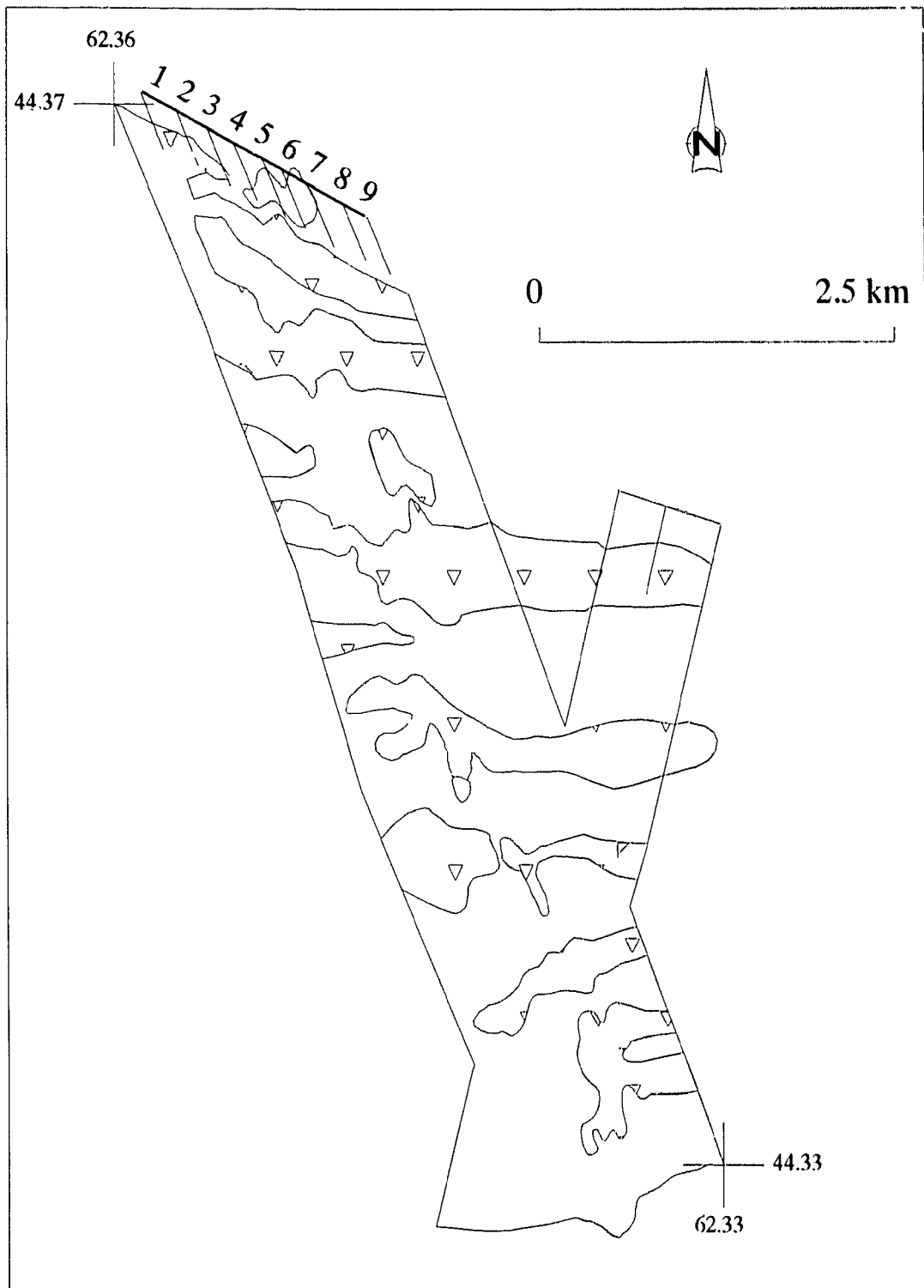
Figure 36.

3.7.2 Till-Tongue Moraine

Immediately north of the Sheet Harbour sub-basin (Fig 16, Map 2) are several mounds of acoustically-incoherent material equivalent to the Scotian Shelf Drift (Table 1) The largest feature, found in 124-135 m water depth, is a steep, asymmetrical ridge with 30 m of sea-bed relief connected to a lower, muted ridge (Fig 37) The ridges are composed of material lacking in coherent internal acoustic reflections A reflection representing acoustic basement can be recognized underneath the landform A till-tongue is rooted in the muted ridge and projects into Sequence SH1 where it terminates in a feather edge Sequence SH2 appears to drape over the tongue and is not found on the landward side of the moraine Sequence SH1 decreases in thickness from 11 m on the seaward side of the feature to 6 m on the landward side Sidescan records show a linear, high-intensity backscatter zone suggesting a gravel-boulder cover and ridge morphology These moraines are essentially smaller versions of the larger Scotian Shelf End Moraines and are transitional to the Morainal Zone in shallower water The main morainal fragment is likewise interpreted as formed by accretion of basal debris at a tidewater margin and the tongues by forward movement in the ice front which was halted by buoyancy forces

3.7.3 Symmetrical Moraine

The most common type of mound-ridge identifiable in the Huntec profiles has been termed "Symmetrical Moraine" These are defined as mounds or ridges with symmetrical sides consisting of acoustically-incoherent material (Fig 38) These are commonly found in water depths of 85-135 m (Fig 39) The symmetry of some of these landforms is quite remarkable (Fig 38) The shapes vary, however, from sharp-crested forms to those with

Figure 37. Huntec acoustic profile and interpretation of the "Till-Tongue" Moraine in the

Sheet Harbour transect area (see location F on Fig. 16). Water depth in m on the left.

SE

SEISMIC RECORD

NW

0   700 m

INTERPRETATION

130 m

SCOTIAN SHELF DRIFT

TILL TONGUE

150 m

LaHave Clay

Emerald Silt (Facies B)

Emerald Silt (Facies A)

Scotian Shelf Drift

Bedrock
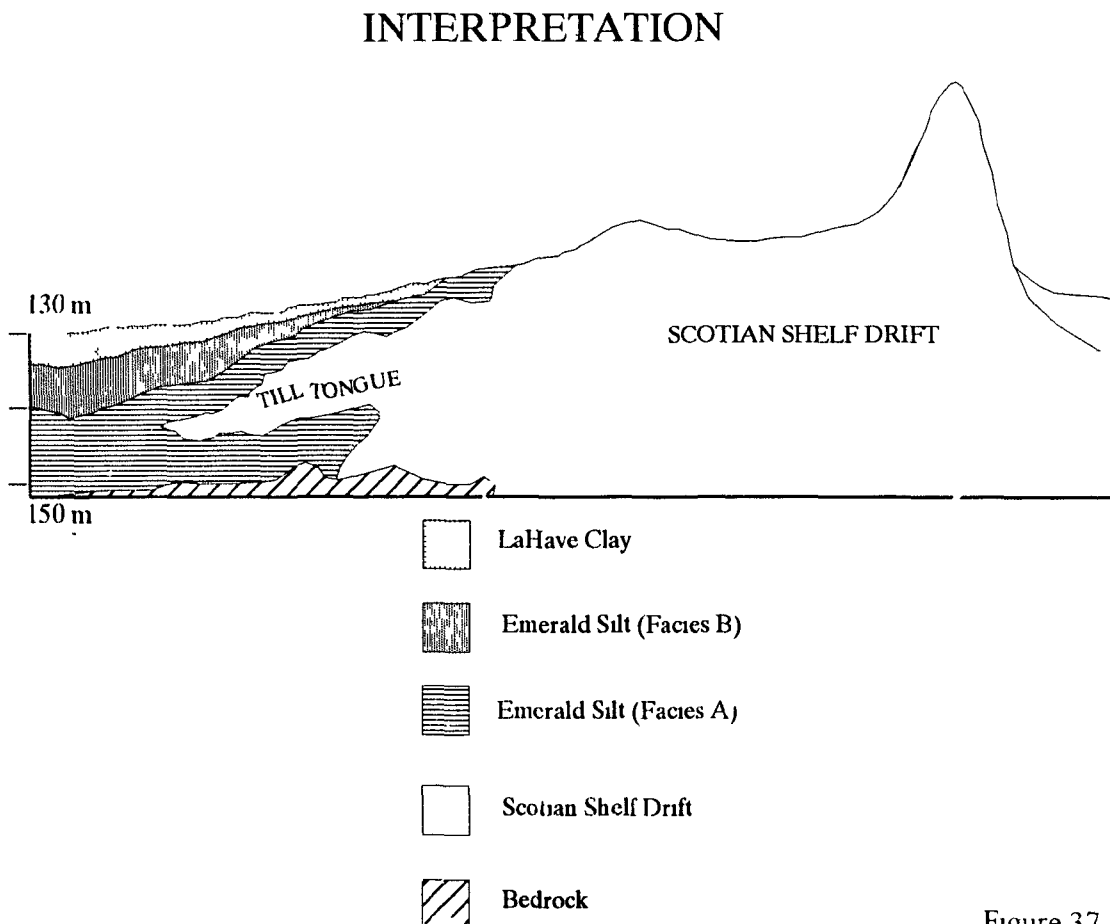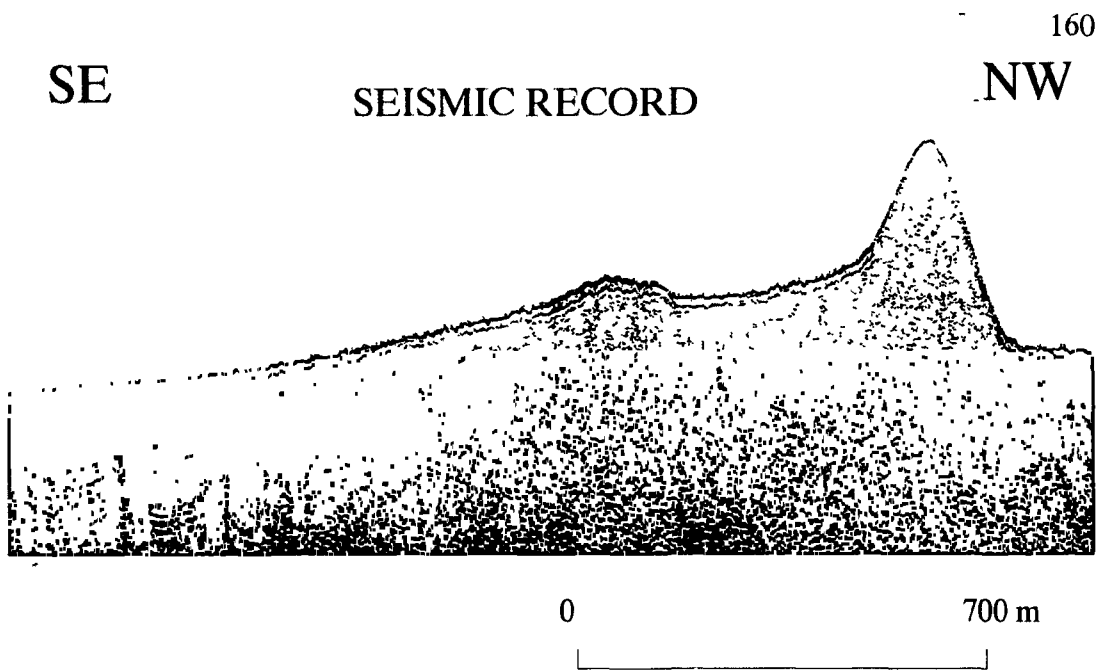
Figure 37

Figure 38. Huntec acrustic profile (external) and interpretation of symmetrical moraines in the Sheet Harbour transect area. Section G-H is located on Figure 16. Inter-moraine seismic sequences M1 and M2 are described in the text. Acoustically incoherent material within the Morainal Zone has been designated as Scotian Shelf Drift after King and Fader (1986; Table 1).

G

H

SEISMIC PROFILE

80

90

100

0   1400 m

Depth below water surface (m)

INTERPRETATION

Scotian Shelf Drift (Unit 3?)

M2

M1

ACOUSTIC BASEMENT
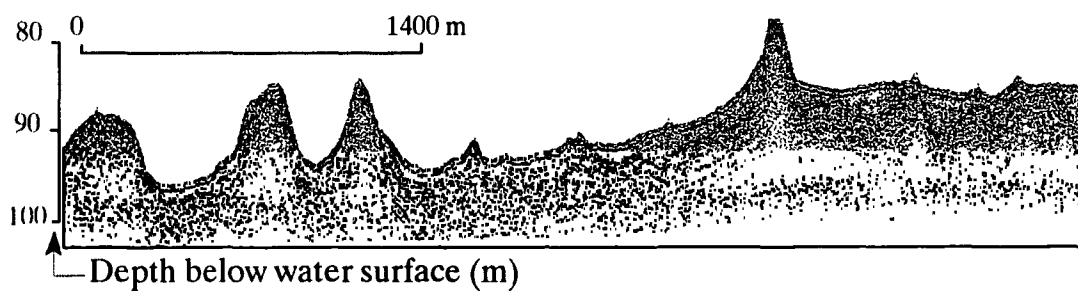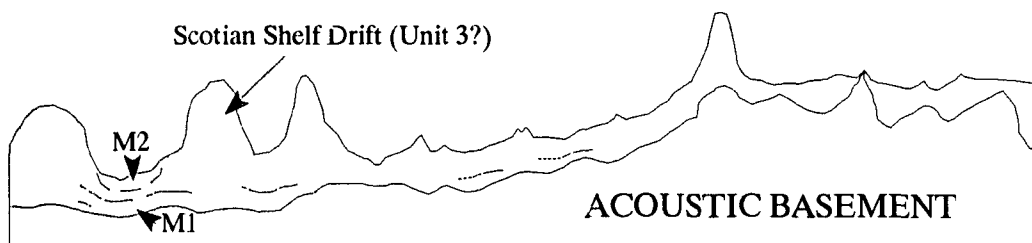
Figure 38.

Figure 39   Notched box and whisker plots of the water depth relationships of the various morphological types of moraines   The box and whisker plot is an effective way to demonstrate summary statistics graphically   The notched plot (McGill et al 1978) corresponds to the confidence interval for the median, whereas the width of the box is proportional to the square root of the number of observations in the data set   If the two notches on the boxes do not overlap (hatching) the median values of the data distributions do not significantly overlap at a 95% confidence level

Depth Relationships of Moraine Types, Eastern Shore Region.
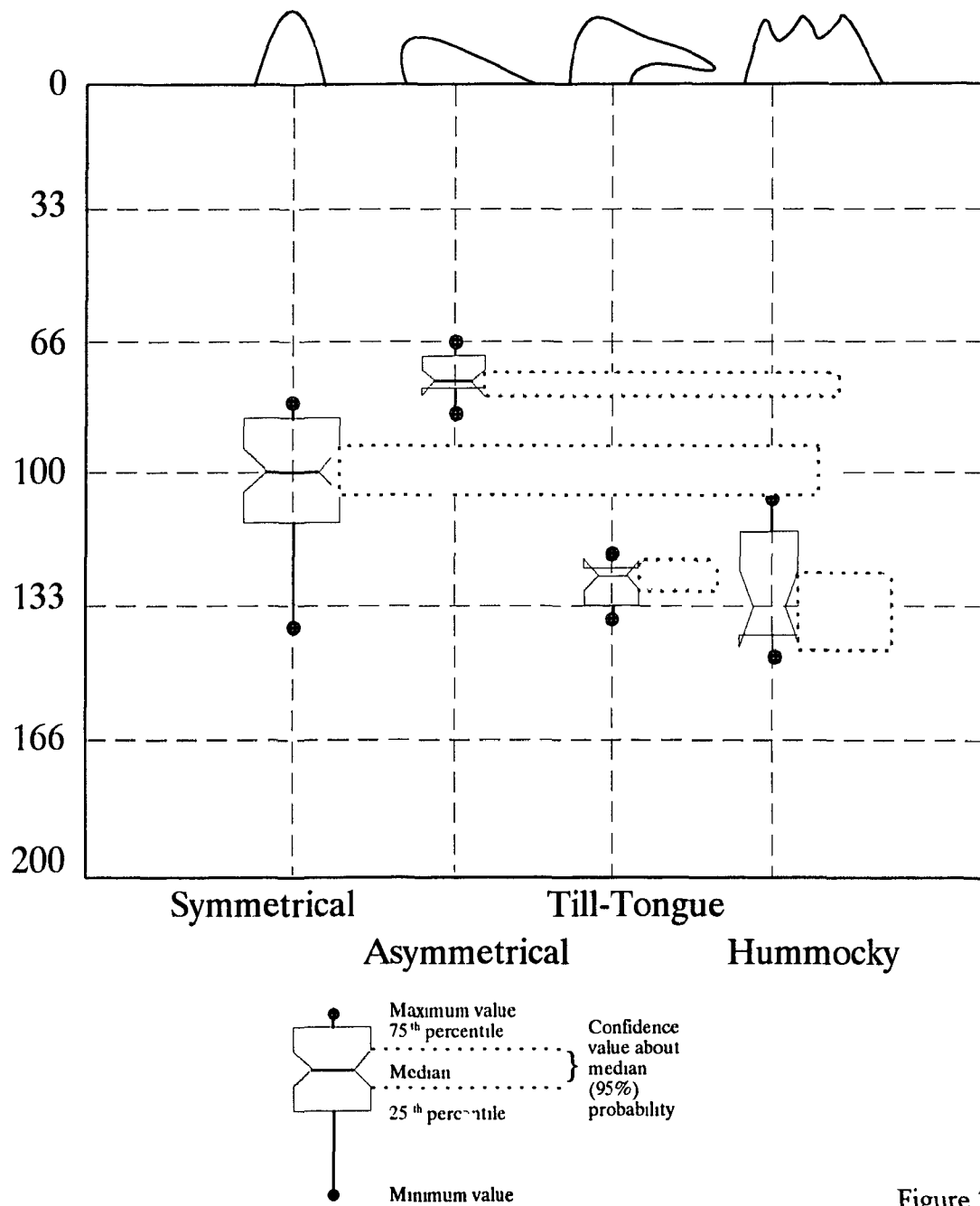
Figure 39

plateaus on top The seabed surfaces of these features exhibit moderate to high reflectivity

A horizontal reflection representing acoustic basement can be traced through many of the

landforms although some appear to have a "shadow zone" that is propagated downwards

from the sea surface and virtually eliminates all information below This zone often appears

to be best developed in the most symmetric forms (Fig 38) This "shadow zone" may be the

due to the dissipation of acoustic energy by a concentration of boulders on the moraine crests

and/or energy scattering on the steep sides The intervening regions between ridges

and mounds contain two acoustic sequences (Sequences M1, M2, Fig 38) Sequence M1

consists of low amplitude, draped reflections truncated by an onlap fill sequence (M2) of

moderate to high amplitude reflections In deeper water areas a sequence consisting of

LaHave Clay seismic facies (M3) infills inter-moraine depressions The lateral relationships

between Sequence M1 strata and the moraines are uncertain In some cases reflections

appear to lap onto the moraines while in other areas a gradational contact is observed.

Late in this thesis study, multibeam bathymetric imagery became available (Costello *et al*,

1993) A region of the inner shelf within the sampling area east of Lunenburg was surveyed

(Stea and Fader, 1993, Loncarevic *et al.*, 1994, Figs 1, 40) The image reveals three main

topographic zones, the eastern area characterized by irregular topography, the middle region

by closely-spaced, linear ridges and the western region dominated by crenulated, curvilinear

ridges with intervening flat, basin regions These ridges generally trend northeast-southwest

and are regularly spaced Huntec profiles across the ridges (Fig 40) show symmetrical

moraines 4-18 m high Many of these moraines are found on bedrock highs The linear

ridges in the central region were found to be bedrock-controlled forms A later survey by the

NSC Frederick G Creed (John Hughes-Clarke, pers comm 1993) over the moraines

included camera reconnaissance and grab samples The moraines were composed of a

Figure 40. Multibeam sonograph image of a region southeast of Lunenburg, Nova Scotia

(Fig. 1) and interpretation. The sonograph area shows two types of ridges; anastomosing,

curvilinear, ribbed moraines and straight bedrock ridges. The Huntec profile in the upper

left corner is an acoustic cross section of a typical ribbed moraine in the sonograph area

(from D. J. W. Piper, pers. comm, 1993). Huntec records across these features show that

they are identical to symmetrical moraines (Fig. 38) and relate to topographic highs

composed of acoustically incoherent material, underlain by a reflection representing

acoustic basement.

HUNTEC PROFILE OF TYPICAL RIBBED MORAINE
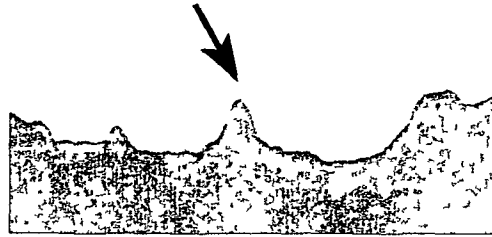
LEGEND

Ribbed moraines

Bedrock strike ridges

Glacial fluting?

MULTIBEAM IMAGE   63° 34'

44° 19'

INTERPRETATION

0   0 5 km

Figure 40

167
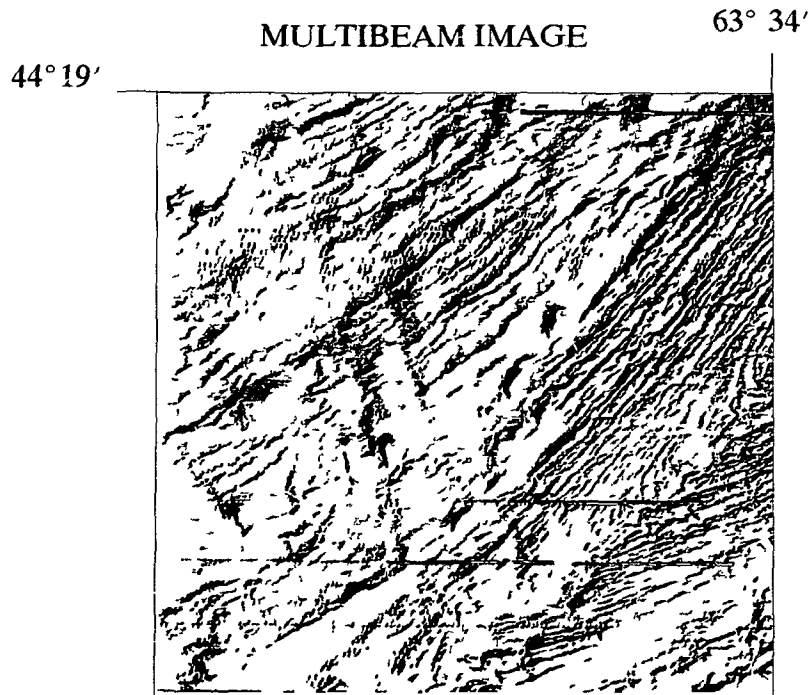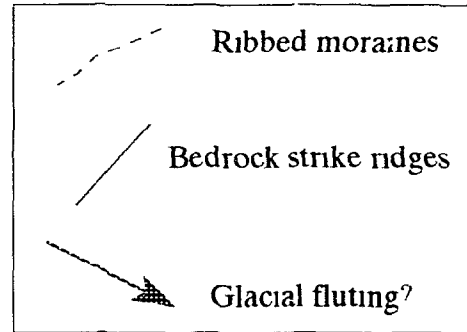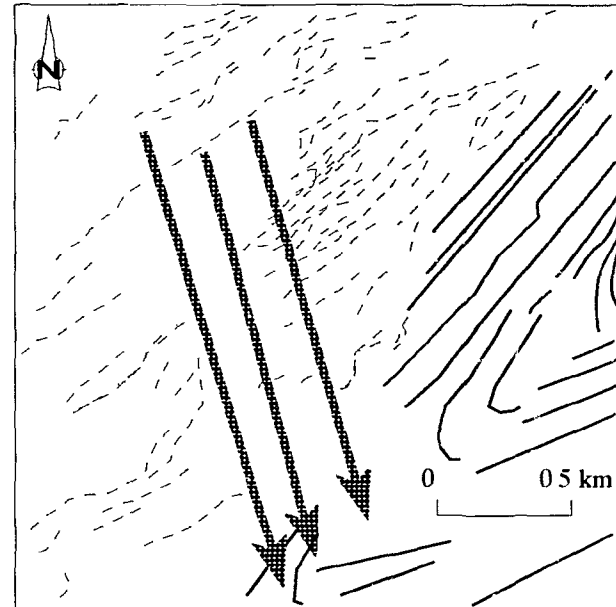
matrix-supported, sandy-mud diamicron, compared with silty-mud in the intervening flat regions

3.7.4 Hummocky and "Doughnut" Moraines

Another moraine type consists of ridge forms or mounds of acoustically incoherent material with two or more minor mounds superimposed on the upper su face These are termed hummocky moraines On sidescan sonograms some of these hummocky forms appear as closed loops of high backscatter regions with boulder shadowing ("doughnuts", Fig. 35 A).

3.7.5 Bedrock-Controlled Moraine

Some bathymetric highs consisting of acoustically incoherent material appear to be conformable with the undulating trace of acoustic basement interpreted to be the bedrock surface These features are called bedrock-controlled moraine

3.7.6 Asymmetrical Moraine

Moraines in the Sheet Harbour transect area in water depths less than 82 m, and not less than 65 m (Fig 39) have a distinctly asymmetric shap, with a steeper, landward side (Figs. 16, 39, 41) The external Huntec profile resolves indistinct clinoform beds on the seaward side of some of the asymmetrical moraines that are truncated by the landward slope The intervening areas between ridges consist of more transparent, incoherent acoustic material (M2-Fig 41) These moraines are similar in scale and morphology to terrestrial moraines in Nova Scotia (Fig 41)

Figure 41. Huntec seismic profile and interpretation of asymmetrical moraine ridges in the Sheet Harbour transect area (Location I- Fig. 16). The bottom figure is a profile of terrestrial ribbed moraines in the vicinity of Cobrielle Lake, southern Nova Scotia (Stea et al., 1992a), plotted using the same vertical exaggeration as the Huntec records.

SE   SEISMIC PROFILE   NW

INTERPRETATION

0   700 m

Metres below sea level

60

70

80

90

M2

Scotian Shelf Drift (Unit 3?)

ACOUSTIC BASEMENT
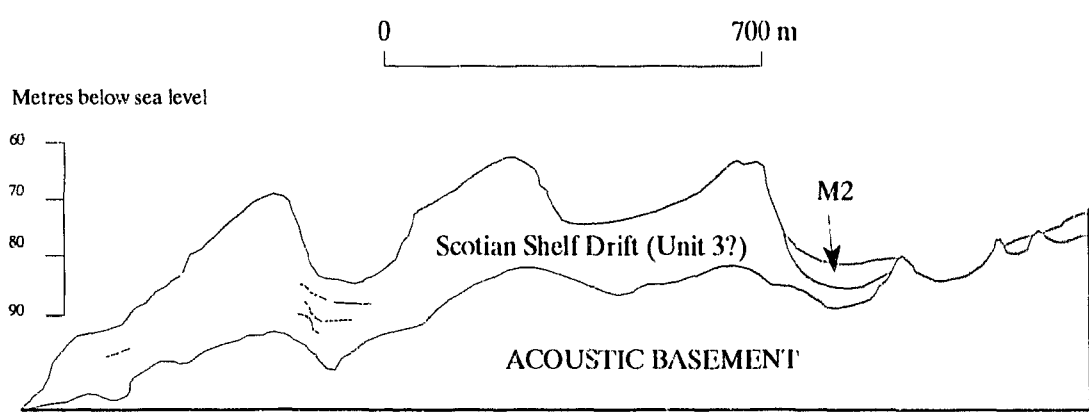
TERRESTRIAL MORAINES, SOUTHERN NS

Metres above datum

12

Beaver River Till

0   200 m
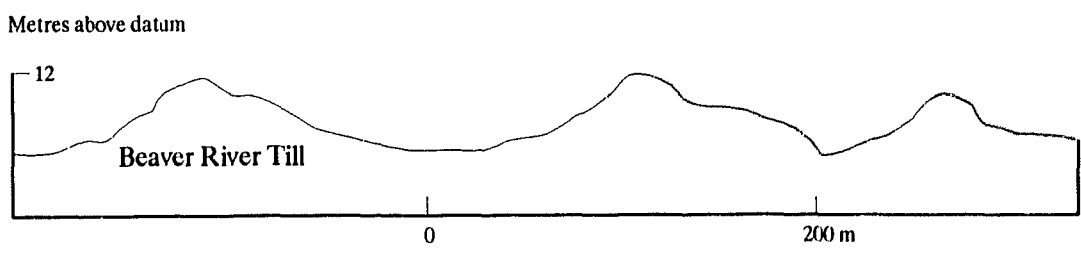
Figure 41.

3.7.7 Lithology

Six samples were obtained from ridges or mounds north of the Scotian Shelf End-Moraine Complex (IKUs 24, 25, 29, 49, 59, 64 - Appendixes 3, 4) Only one sample site produced complete recovery (IKU 29), the rest contained lag gravel (cobbles-pebbles) and lumps of olive-grey, matrix-supported, sandy-mud diamicton It is assumed that the lumps are bits of the "true" moraine material from underneath a lag armour of cobbles and boulders

The Morainal Zone grab samples contain subangular to subrounded clasts, with 8-47% striated, averaging 15% (Table 4) IKU 29 shows a significant increase in percentages of striated pebbles from the top to bottom subsamples (17%-Top, 47%-Bottom, Appendix 4) Sample 64, from 64 m water depth, contains subrounded to rounded clasts, none of which are striated Morainal Zone samples vary from 82 to 92% Meguma Group metasediments and average 86% (Table 4) They consist of an average of 45% gravel and 55% matrix weight percentages (Table 4)

3.7.8 Truncated Emerald Silt Subzone (TESS)

Another feature of the Morainal Zone is a large (approx 900 sq km) area of Emerald Silt outcropping at the seabed, truncated by planar erosional surfaces (Fig 8) This extensive area of erosion is found in water depths shallower than 140 m, at the contact between the Morainal and Basin Zones off Sheet Harbour, and widens to the northeast towards the Country Harbour Moraine (Figs 8, 42) Southeast of Country Harbour the surface is remarkably flat and featureless (Fig 19) Off Sheet Harbour, Sequences 1 and 2 (Emerald Silt facies A and C) are found at the seabed at water depths of 130-150 m (Fig 42)

Figure 42   Huntec acoustic profile of a region of eroded Emerald Silt 30 km south of Sheet

Harbour   Vibra-core 91018-67 was obtained from this area, and revealed an olive-brown,

sandy diamicton overlying a clayey-silt and silty-clay   Seismic sequences, shown on the left

of the acoustic profile, are extrapolated from the type section (Fig 25).
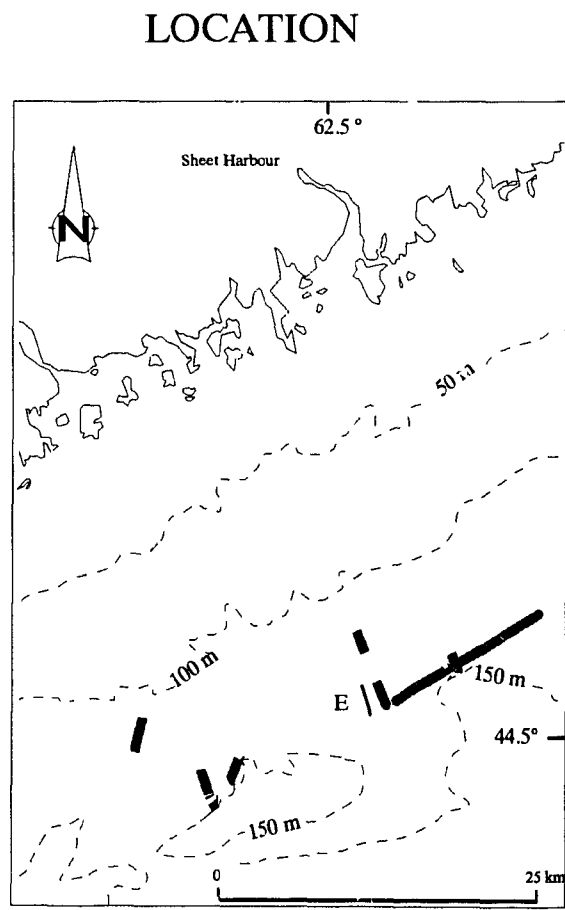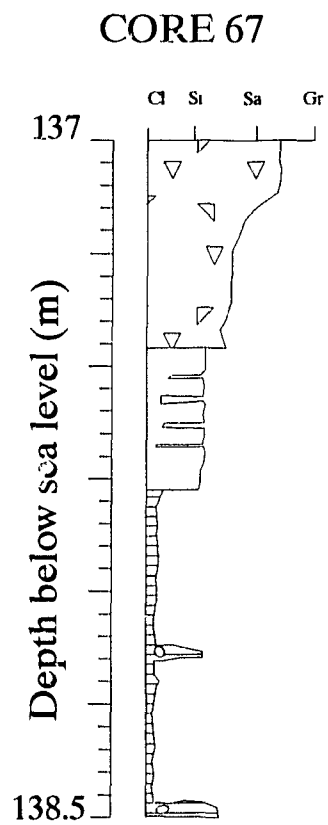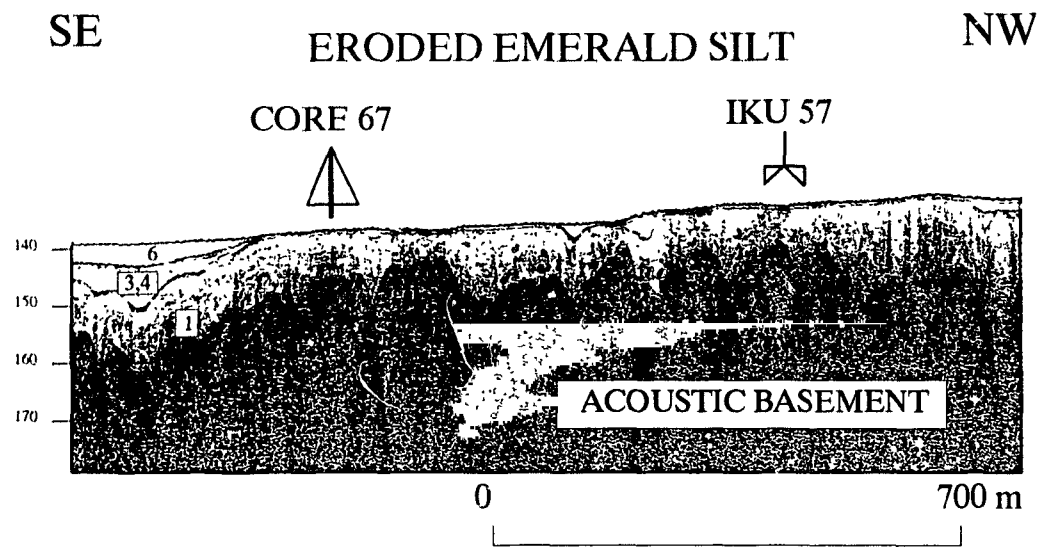
Figure 42

Sequences 3 and 4 (Emerald Silt facies B) lap out on the earlier units before the TESS surface Several channels were cut into the Emerald Silt and later infilled with LaHave Clay. At several locations an onlap unit (Emerald Silt facies B) is truncated by the erosional surface. King and Fader (1983a) correlated the erosional surface south of the Country Harbour Moraine to an unconformity at the top of the Emerald Silt Formation dated at 10.8 ka.

3.7.8.1 Lithology

An IKU sample from this subzone in the Sheet Harbour transect region (IKU 57) recovered an olive-grey, muddy, matrix-supported diamicton with subangular to subrounded clasts Eighteen percent of the clasts are striated and several have distinct, bullet-like shapes with distal facets indicative of erosion in the basal traction zone of a glacier (Krüger, 1984; Clark and Hansel, 1989). Eighty-seven percent of the clasts are derived from Meguma Group metasediments, 5% from Meguma Zone granitoids, and 8% are foreign to the Meguma Zone. Core 91018-67 (Fig. 42) taken on the TESS south of Sheet Harbour revealed an olive-brown, sandy diamicton over a grey cohesive clay with few pebbles. IKUs 85, 89 and 93 were obtained from the Emerald Silt on the erosional surface in the Country Harbour Transect region (Appendixes 3, 4, Fig. 18) IKUs 89 and 93 consisted largely of a grey, massive, silty clay. IKU 85 revealed a more complex stratigraphy, with a cobble lag overlying an olive-grey, sandy diamicton and a greyish mud with a few stones. Samples 89 and 93 contained a only a small percentage of striated stones (2-5%)

3.7.9 Age of the Morainal Zone

In the deeper parts of the Morainal Zone, Sequence M1 (Emerald Silt facies B) onlaps the symmetrical moraines. Sequence M1 correlates with either Sequence 3 or 4 in the Basin Zone which were dated between 12 75 and 10 7 ka (Fig 32) The Till-Tongue Moraine interfingers with Sequence 1 Therefore, the Morainal Zone formed between 14 0 ka (interpolated base of Sequence 1) and 10.7 ka (top of Sequence 4) (Fig 32) Sequence 2 can be traced as far landward as the distal side of the Till-Tongue Moraine and formed sometime after the moraine. In the Halifax sub-basin the top of Sequence 2 is dated at 12.75 ka (Fig. 32)

The TESS seabed surface (Fig. 42) appears to have formed during or after deposition of Sequences 3 and 4 (Emerald Silt facies B) Sequences 3 and 4 lapout onto the TESS surface (Fig. 42) in the Sheet Harbour transect area However, off Country Harbour, erosional truncation of Emerald Silt facies B has clearly occurred (Fig 19) King and Fader (1988 a, b) and King (1994) proposed that the TESS surface was formed by a Younger Dryas ice advance In the northeast Emerald Basin they correlated the erosional surface with the Sequences 4/6 boundary dated at 10.8 ka

Sea-levels reached their lowest point along the inner shelf (-65 to -70 m) around 11.6 ka after ice had retreated landward of the present coastline (Stea et al., 1994). Moraines or any other unmodified glacial landforms do not appear above the -65 m level, so it is assumed that they were destroyed by the post-glacial transgression The last glaciation therefore pre-dated 11.6 ka across much of the inner shelf By this reasoning the Morainal Zone formed sometime between 14.0 ka (deposition of Sequence 1 in the Basin Zone by the retreating glacier) and

11 6 ka, the time of the lowstand Sequence 2 is interpreted as the depositional response to the glacial advance that formed the Morainal Zone; so the time of formation of the Morainal Zone may be further bracketed between 13 5 ka and 12.75, the duration of Sequence 2 (Fig 32) These delicate morainal features probably represent the last glacial advance to have affected the inner shelf

3.7.10 Genesis of the Morainal Zone

Surface samples from the Morainal Zone ridges are composed of an olive-grey, matrix-supported diamicton In the Morainal Zone diamicton samples, Meguma pebbles average 86% whereas foreign pebbles average only 8% (Table 4). The gravel fraction averages 45% and the matrix 55% These diamicton samples average 15% striated clasts. This diamicton is similar in lithology and seismic character to the uppermost unit (3) of the Scotian Shelf Drift of the main morainal complex (Fig 41, Tables 1, 4). Morainal Zone ridges are similar in scale and morphology to land ribbed moraines (Fig 41) I therefore interpret these constructional landforms as ice-formed The term "moraine" in the marine environment is defined as "positive morphological features in a glacially-dominated region" (Von Haugwitz and Wong, 1993) DeGeer Moraines are defined as low-straight to arcuate ridges of loose, sandy diamicton or sand/clay formed parallel to the former ice cliff edge (Goldthwait, 1989), Theories about the formation of DeGeer Moraines fall into two main groups:

Group 1   The moraines represent successive, annual glacier-marginal stillstand or advance features with chronological significance (Smith, 1982; Larsen *et al.,* 1991)

Group 2 They are formed simultaneously by till-squeeze or meltwater inflow into basal crevasses some distance behind the ice front, and have no chronological significance (Elson, 1957, Hoppe, 1959, Zilliacus, 1989, Lundqvist 1989, Beaudry and Prichonnet, 1991)

The definition of DeGeer Moraine may be too broad to be useful for genetic classification For example, Elverhøi et al (1989) document two types of DeGeer Moraine resulting from a surge of the Bråsvalbreen glacier in 1936, "squeeze up" ridges (Group 1) and annual "push" moraines (Group 2) Group 1 moraine formation is indicated by these features

1 Parallel and linear ridges

2 Perpendicular to the regional ice flow direction

3 An asymmetric cross-sectional profile

4 A complex sedimentology, glaciotectonic deformation, and inter-fingering relationships with adjacent sediments

Group 2 moraines are more likely to display a simpler stratigraphy (i e till), and symmetric external form, but may be more variable in plan view as are the crevasse patterns in surging, marine glaciers The surging Bråsvalbreen glacier produced a rhombohedral pattern of crevasse-fill moraines (Elverhøi et al, 1989)

Parallel ridges ("Lift-off" Moraines) have been described in the basins south of the Scotian Shelf End Moraine Complex (King and Fader, 1986, p 15, Gipp, 1989) Lift-off Moraines vary in height from a few metres to 20 m and are composed of acoustically incoherent material overlain and interfingering with Emerald Silt facies A King and Fader (1986)

proposed that Lift-off Moraines form simultaneously when buoyant ice lifts off the seabed and till is injected into subglacial fractures. Lift-off Moraines fall into the Group 2 genetic category

The Morainal Zone moraine types fall within both of the two broad genetic categories. The till-tongue moraine of the Basin Zone is similar to the Scotian Shelf End Moraines which fall within Group 1 The "asymmetrical" moraines may also fall into this genetic category. The most abundant type, "symmetrical" moraines belong in Group 2. They appear to be identical in form to "Lift-Off" moraines without the cover of overlying Emerald Silt. The lack of Emerald Silt (facies A) between symmetrical moraine ridges in the Morainal Zone favours a simultaneous, subglacial origin, rather than as marginal features (Fig. 43).

The Truncated Emerald Silt Subzone (TESS) is found in similar water depths to the Morainal Zone (Figs 8, 16, 18). Emerald Silt facies A, C and B have been eroded. Formation of the TESS by surf-zone erosion is ruled out because of the depth of the erosion (130-150 m; see Truncation Zone subchapter) Direct subglacial erosion is unlikely especially in the case of the erosional surface south of Country Harbour because sediment was removed without widespread disturbance of the underlying beds (Fig. 20). The planar nature of the unconformity also mitigates against direct subglacial erosion. Subglacial deformation of the Emerald Silt has been proposed as a mechanism of the formation of till-tongues exposed on the surface, but these are clearly truncated by the TESS surface. The age of the erosional surface associated with the Country Harbour Moraine was discussed earlier. If it is synchronous with the -65 m lowstand (11.7 ka) then a sub-wave-base erosional origin may be plausible. Storm-generated bottom traction currents associated with the lowstand shoreline may have eroded soft, muddy sediments while leaving the till-cored landforms

Figure 43   Formation of the Morainal Zone   1   Formation of "symmeti 'cal moraines" by surges or readvances and stagnation   Till is squeezed into subglacial crevasses as the ice settled back on the substrate after the rapid movement (cf Zilliacus, 1989)   These features seem to located on acoustic basement highs, where a compressive flow regime favours vertical fracturing   2   Formation of "asymmetrical moraines" during shoaling of the ice mass Moraines are formed proglacially by seasonal readvances, similar to "push" moraines of Boulton (1986)

Symmetrical Moraines
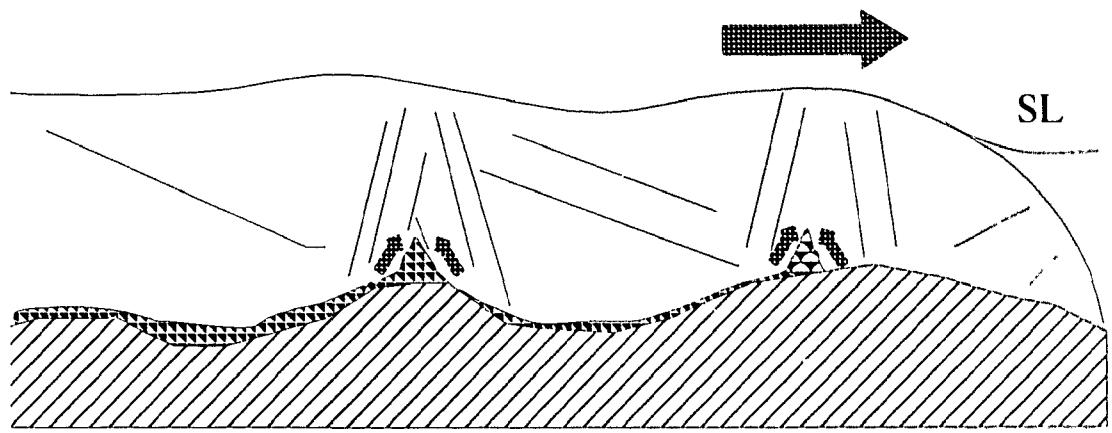
Asymmetrical Moraines
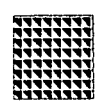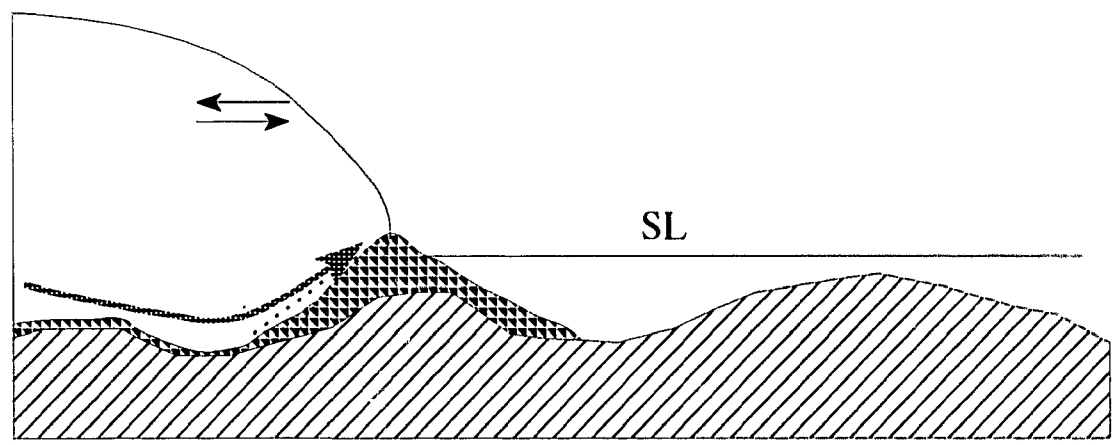
Debris in transit

Till
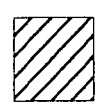
Bedrock
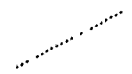
Crevasses

Figure 43.

such as in the Morainal Zone and SSEMC intact   Erosion seem to be prevalent above 140 m

or 60 m below the lowstand   It is also possible that in areas where only Emerald Silt A and

C outcrop on the seabed (Fig 42), erosion was accomplished either proglacially or

subglacially, during the readvance of ice that produced the Morainal Zone   After retreat of

this ice, and isostatic uplift, deposition was inhibited by stronger bottom currents   The

absence of significant thicknesses of Holocene mud from these surfaces implies erosion or

perhaps non deposition, resulting from strong bottom currents active at present, that may be

sufficient to erode earlier glacial marine sediments   More data has to be collected from these

surfaces in order to assess the validity of erosional models

3.8 OUTCROP ZONE

The Outcrop Zone was first reported by King and Fader (1986) and described in detail by

Piper *et al.* (1986), Forbes *et al.* (1991) and Stea *et al.* (1994)   It is a broad area of high-

relief acoustic basement, largely devoid of surficial sediments, extending from 80 to 120 m

water depth south and southeast of Halifax (Figs 13, 44)   The Outcrop Zone merges with

the Morainal Zone southeast of Halifax as the two zones occupy similar water depths (Figs

8, 45)   The contact between the two zones was not surveyed

3.8.1 Unit B

Within the Outcrop Zone, acoustic basement is sporadically overlain by a thin (1-10 m),

incoherent, transparent seismic unit termed Unit B by Forbes *et al.* (1991)   It can be found

at the base of channels and isolated valleys, or as muted, ridge-like features visible in the

multibeam image of the sea floor near the contact with the Truncation Zone (Fig 46)   IKU

Figure 44 Huntec profile and location of the type section of the Outcrop Zone (see Figs 10,

11 for legend and figure locations) Note the high relief and lack of sedimentary infill in the

southeast part of the transect, located within the Outcrop Zone In the Truncation Zone, the

amplitude of surface relief of the seabed surface lessens markedly
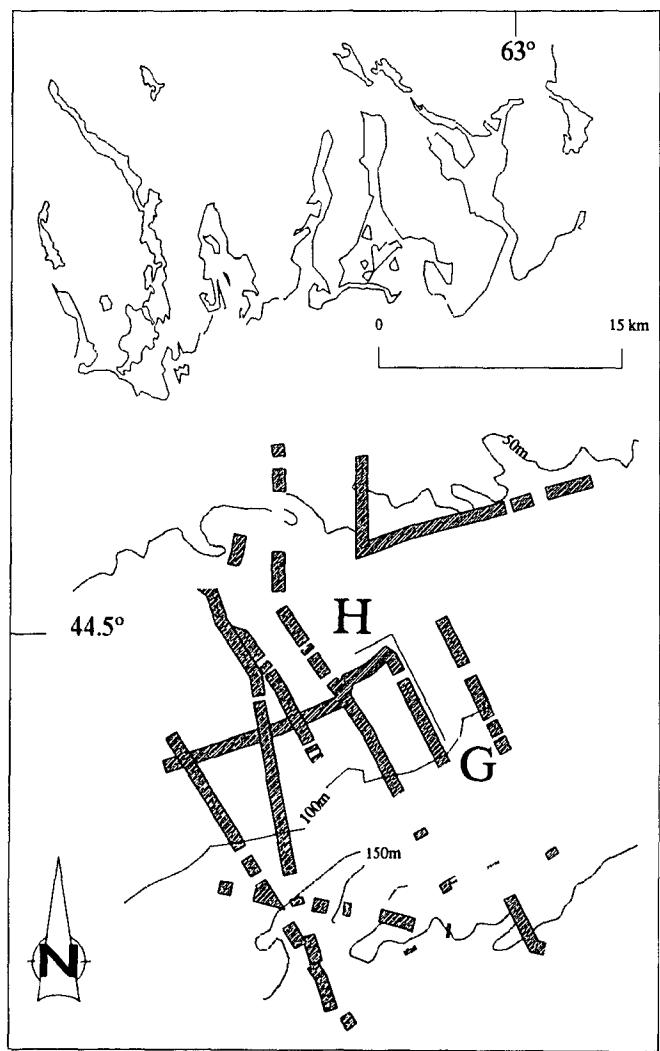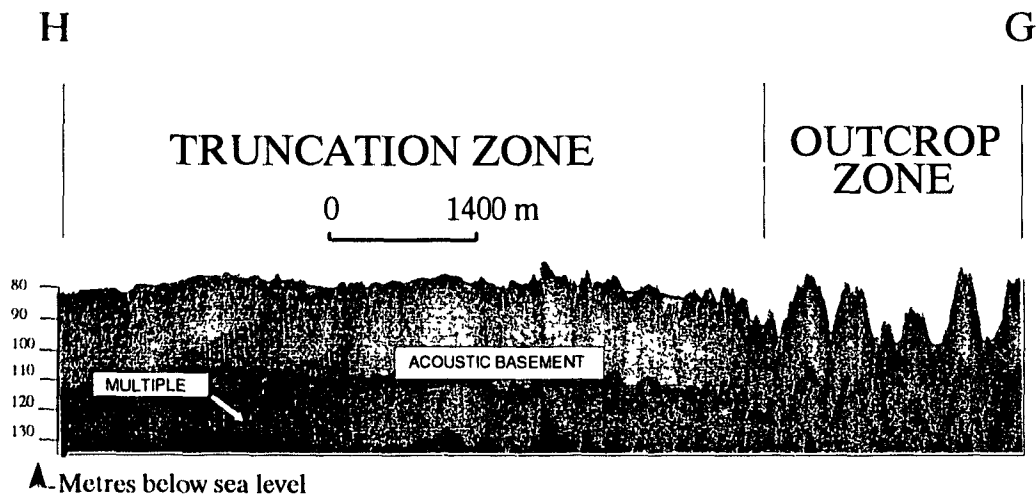
Figure 44

Figure 45. Surficial geology-landforms of the Halifax north transect area (Fig. 1). See Figure 10 for legend. Locations of IKU (boxes with numbered leaders) and core samples (crosses with numbered leaders). Note the southwest-trending channel delineated by the 100 m bathymetric contour. Dashed box indicates multibeam survey area (Fig. 48). Core 91018-38 is located over the Sambro Delta.
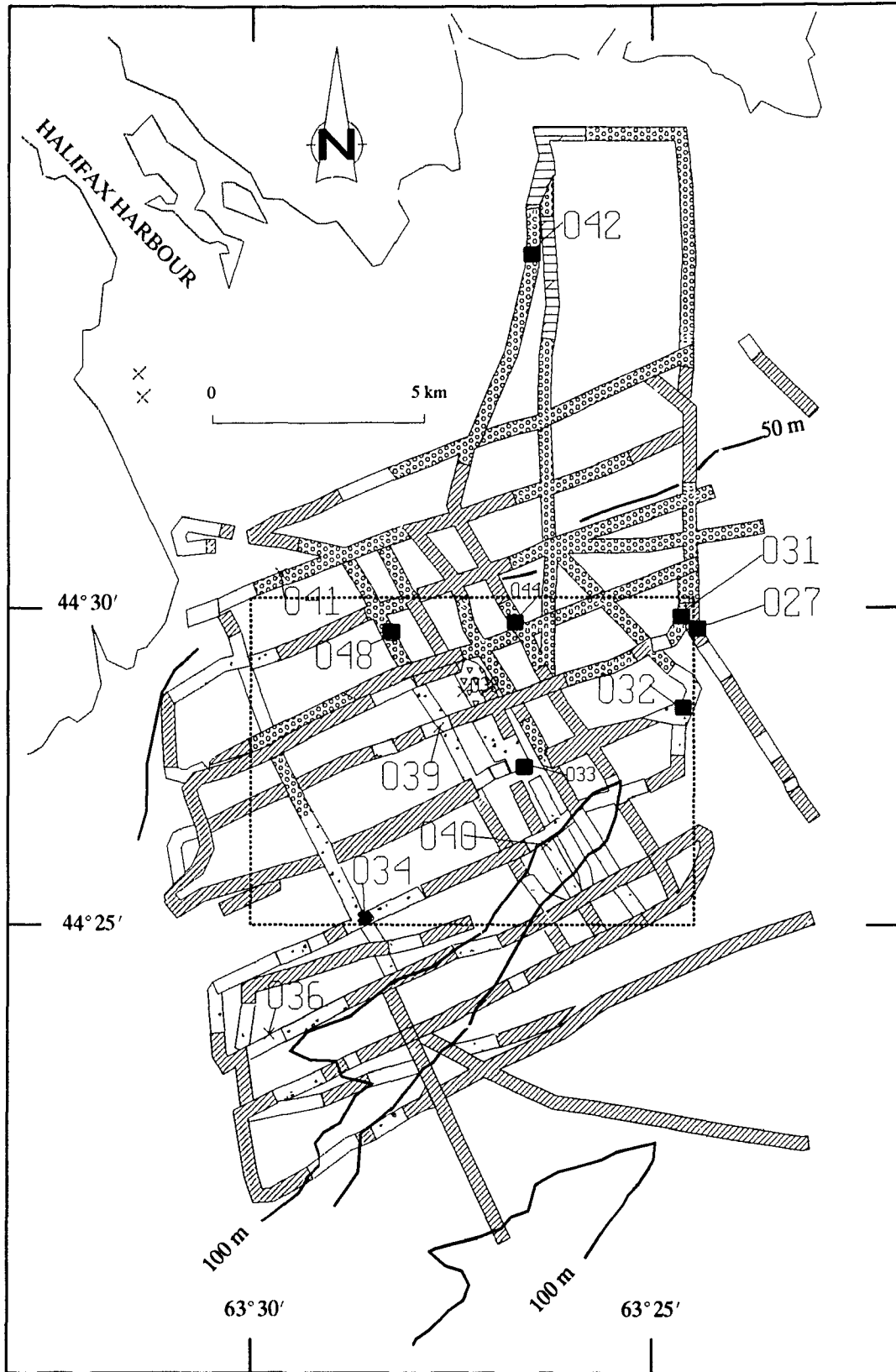
Figure 45.

samples taken from Unit B include nos 14, 17, 32, 33, 63 and 91 (Figs 7, 16, 18, 45;

Appendices 3, 4) in water depths ranging from 65 to 106 m The samples often consisted

of gravel (pebble-cobble) and "lumps" of diamicton The lumps consisted of an olive-grey,

sandy diamicton with subangular to subrounded clasts, with an average value of 10% striated

clasts (Table 4, Figs 46, 47) It is assumed that these lumps represent remnants of an

unmodified unit underneath a pebble-cobble armour on the sea bottom In IKUs 32 and 91,

the "lag" samples were devoid of striated pebbles while percentages in the diamicton "lumps"

varied from 3-40% Meguma pebble percentages vary from 74 to 98% with an average of

84% (Table 4) and foreign lithologies vary from 2-24%, averaging 11% (Table 4). IKUs 32

and 33 have a higher percentage of Meguma lithologies in the diamicton lumps (Appendix 4)

than the lag samples (74%/82%, 74%/83%) If the lag samples have been reworked through

transgression one would expect a greater percentage of metagreywacke clasts in the lag

gravels because of the durability of Meguma metagreywacke (Piper *et al.*, 1986). The

decrease in metagreywacke pebbles in the surface subsamples of the IKUs may be due to

primary glacial depositional processes including englacial transport and melt-out deposition

of far-travelled "foreign" components Unit B is interpreted as a till because of ridge

morphology, diamicton sedimentology and striated pebbles

3.8.2 Origin of the Outcrop Zone

Three erosional mechanisms have been advanced to explain the widespread outcrop zone on

the inner shelf (Fader, 1989a, Forbes *et al.*, 1991)

    1 Coastal transgression and wave-erosion under lower relative sea-level

    2 Locally-intensified glacial erosion

    3 Subglacial meltwater erosion

Figure 46. Type Huntec profiles of "Unit B" in the northern Halifax transect area (Figs. 1, 45). Middle Panel-Huntec profile of IKU 32. Note the undulating sea-bed topography. Left-bottom and left panels-Huntec profile and stratigraphy of vibra-core 91018-36 Right bottom-right panels- Huntec profile and stratigraphy of vibra-core 91018-40. Unit B at this locality underlies the LaHave Clay.

CORE 36

Cl Si Sa Gr

90

Depth below sea level (m)

8620 ^{14}C YRS

92

Figure 46

UNIT B TYPE SECTIONS

IKU 32

UNIT B

80

ACOUSTIC BASEMENT

100 m

0   350 m

UNIT B

ACOUSTIC BASEMENT

CORE 40

Cl Si Sa Gr

80

5670

^{14}C YRS

81.2

0   700 m

UNIT B

LAHAVE CLAY   GAS

ACOUSTIC BASEMENT

188
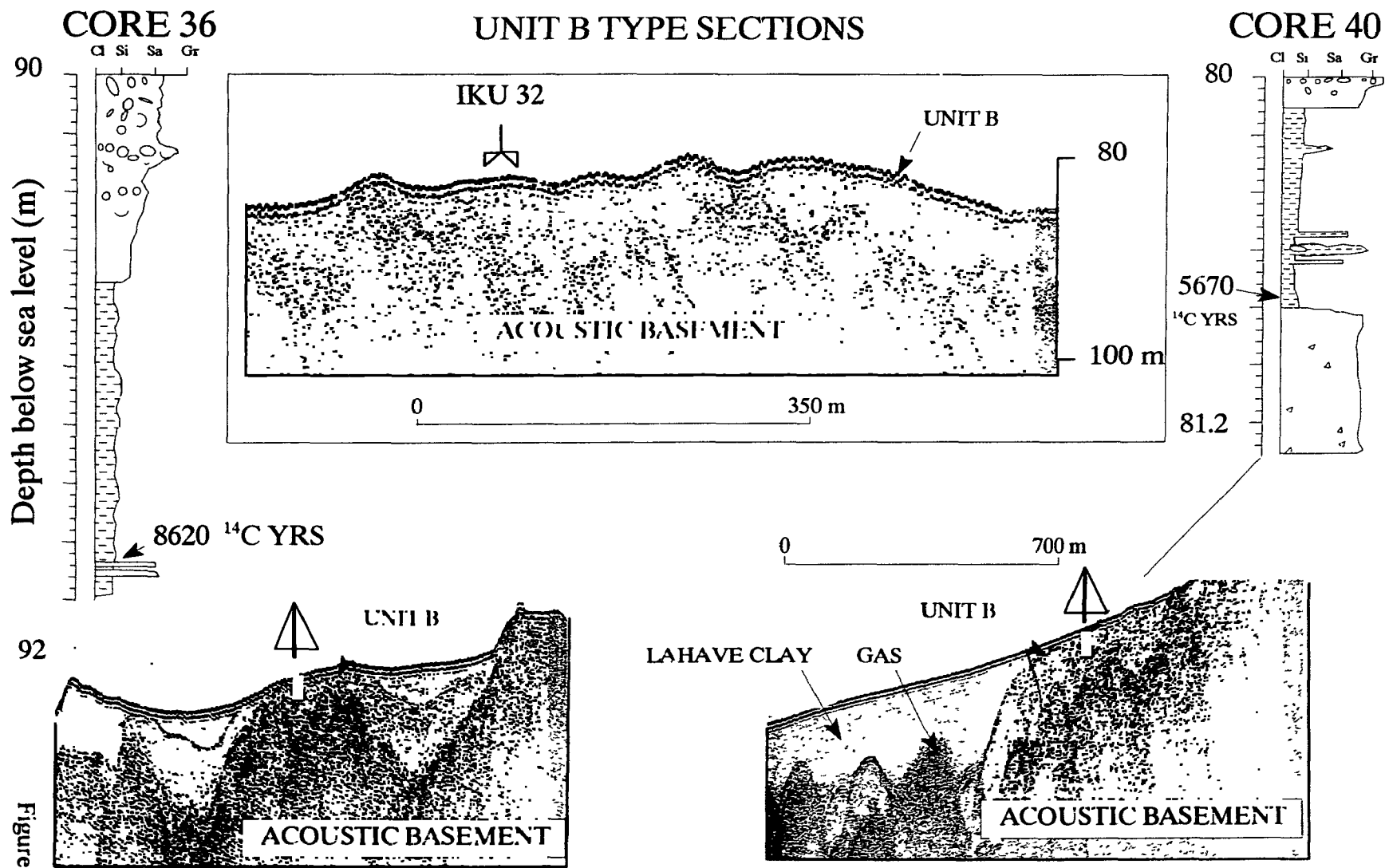
Figure 47. Sea bed photographs of Unit B in the vicinity of core 91018-99 (Figure 18-location). Scale is 10 cm long. Note the surface armor of subangular to subrounded clasts.

A
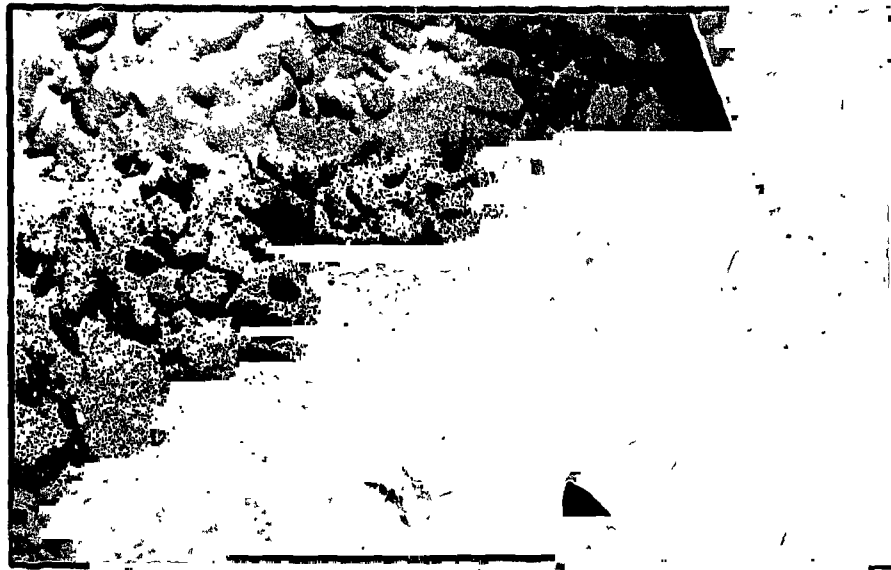
B
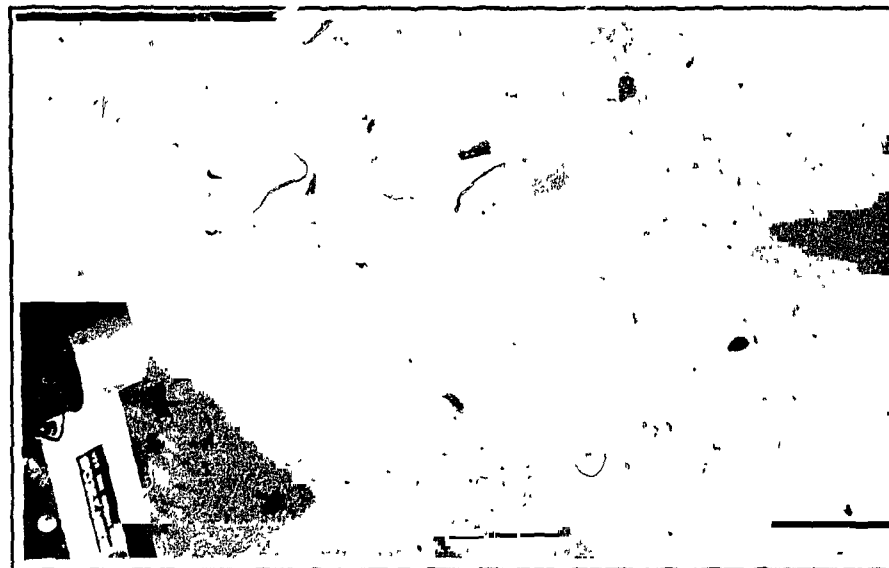
Figure 47.

Hypothesis 3 was discussed at some length by Forbes *et al.* (1991) They suggested that the smaller Nova Scotian ice caps and glaciers were not thick enough to produce or store the vast quantities of water required to produce catastrophic subglacial outbursts Wave-base erosion in the intertidal zone can be discounted as a primary erosional mechanism because of the water depth in which the outcropping bedrock occurs (120 m) and the interpreted low-stand position of -65 m (Stea *et al.*, 1994, Loncarevic *et al.*, 1994) The high relief and dearth of sediment within some valleys in the outcrop zone suggests that this region was not planed off by surf-zone erosion and then transgressed

Glacial erosion is most effective in a wet-based ice zone and erosion is closely linked to deposition (Sugden and John, 1976, Boulton, 1979, Hughes, 1981) Linear fluting evident on the outcrop zone (Fig 48) implies erosion by a wet-based glacier (Boulton, 1979) but the reason for the lack of deposits over this broad region is unclear Large areas of bedrock exposed in land areas along the Eastern Shore of Nova Scotia (Stea *et al.*, 1992a) are surrounded by till-covered terrain These barren areas are generally constrained to local topographic highs On land, strike-ridges developed from Goldenville Formation rocks have similar amplitudes to the ridges in the outcrop zone and are free of intervening sediment in some areas Many of the bedrock areas are located near a Wisconsinan ice divide that straddled the axis of the Nova Scotia peninsula (Stea *et al.*, 1989) Freezing and frozen bed conditions inhibit both erosion and deposition (Hughes, 1981) Glacier flow, deflected upwards by slight variations in the elevation between bedrock facies of differing competency, can create freezing or frozen bed conditions (Nobles and Weertman, 1971) It is suggested, therefore, that the outcrop zone is a result of non-deposition rather than erosion This region of non-deposition can be explained by subglacial freezing zones at the margin of the former Scotian Ice Divide (Stea *et al.*, 1989, 1992a) localized over the Nova Scotia

Figure 48. Multibeam image and interpretation in the north Halifax Transect area (see Figs. 7 and 45 for location). Note the muted, topography in the Truncation Zone compared with the starker, strike-ridge topography of the Outcrop Zone. Morainal ridges formed of Unit B are found south of the Truncation Zone. A major southwest-trending channel cuts across the map area. Southeast-trending lineations that cross-cut structures are interpreted as large scale glacial grooves or fluting.

MULTIBEAM IMAGE
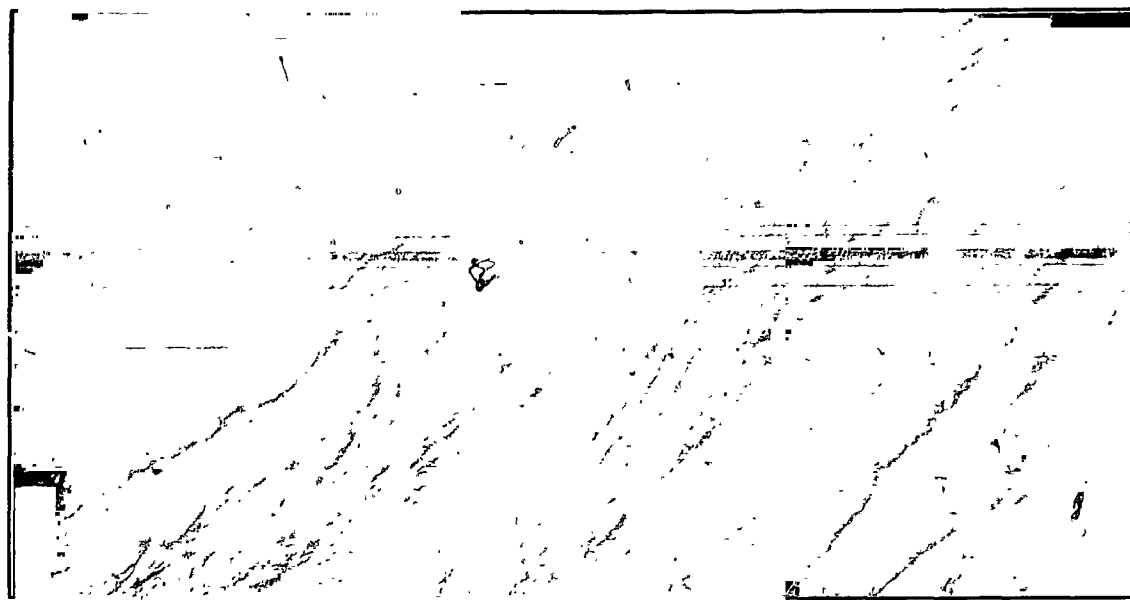
63° 30'W   63° 20'W

INTERPRETATION

44° 30'N

TRUNCATION ZONE

Unit B

P.S.

Platform Subzone

Valley Subzone

OUTCROP ZONE

Channel

0   1400m

Legend

Transition Subzone
(Shoreface-deltas)

Moraines

Glacial fluting

Location of Sambro Delta

Strike ridges

Terrace scarp

Contact between
terrain zones
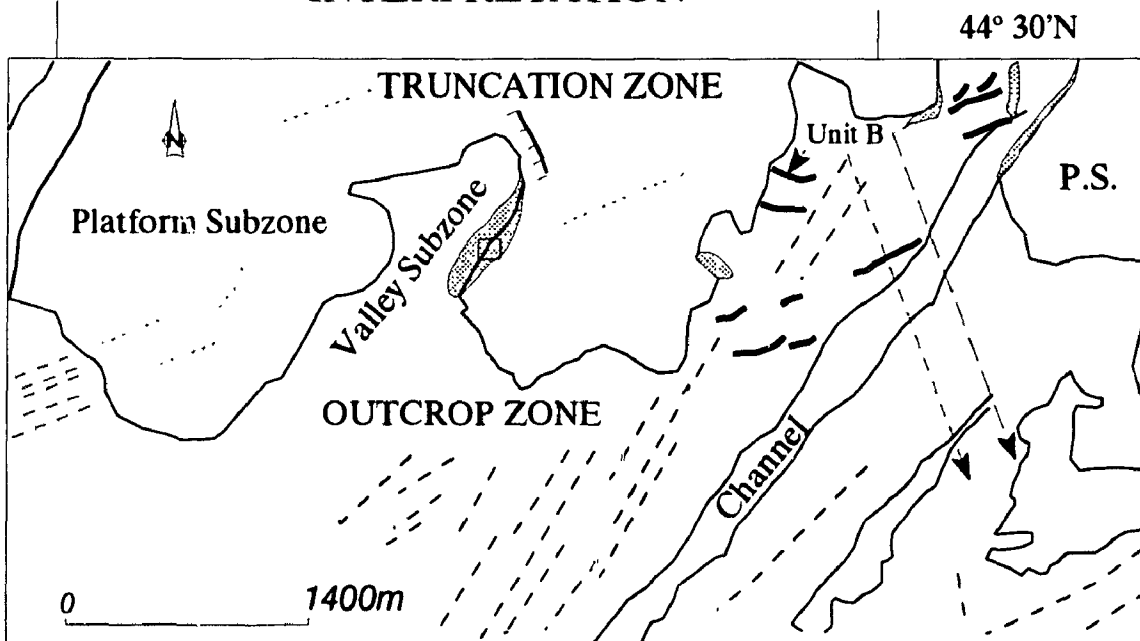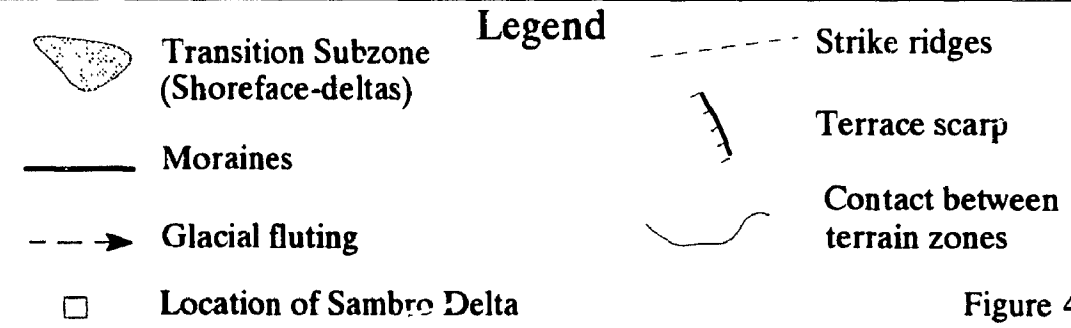
Figure 48.

peninsula during the last glacial maximum, or the relative competency of the metagreywacke strike ridges.

3.9 TRUNCATION ZONE

3.9.1 Introduction

The Truncation Zone is defined as a region of the inner shelf from 90 m water depth to the present shoreline, characterized by muted acoustic topography, terraces and sub-bottom erosional surfaces truncating bedrock and surficial cover. The type sections for the Truncation Zone are acoustic profiles K-J and E-F (Fig. 49). These profiles, the trackline maps (Figs. 16, 18, 45) and the Halifax multibeam map area (Fig. 48) show a similar landward progression of depositional and erosional landform subzones. These are (seaward to landward):

(1) Valley Subzone

(2) Transition Subzone (shoreline)

(3) Platform Subzone

(4) Estuarine Subzone

3.9.2 Valley Subzone

Sediment-infilled valleys are commonly found in water depths of 65-90 m. These valleys trend southwestward and southeastward parallel to drainage systems on land (Figs. 16, 18, 45, 48). They display a distinctive seismic architecture consisting of several seismic

Figure 49 Huntec profiles K-J (Fig 16) and E-F (Fig 18) northwest-southeast off Sheet Harbour and Country Harbour These are the type transects of the Truncation Zone The transect shows a parallel progression of landforms from sediment-infilled valleys (Valley subzone) to a ramp and terrace (Transition subzone) and finally a platform surface with truncation of both bedrock and surficial deposits (Platform subzone) (modified after Stea *et al.*, 1994)

J   K

TRUNCATION ZONE

MORAINAL ZONE | *VALLEY SUBZONE* | *TRANSITION* | *PLATFORM SUBZONE*

SUBZONE

62

63

90

115

140

ACOUSTIC BASEMENT

MUI TIPLI

0   14⁻0 m

E   F

TRUNCATION ZONE

CORE

VALLEY   TS   *PLATFORM SUBZONE*
SUBZONE

77

GRAB

78 76

85

ACOUSTIC BASEMENT

MULTIPLE

125

Depth below water surface (m)

Figure 49

196
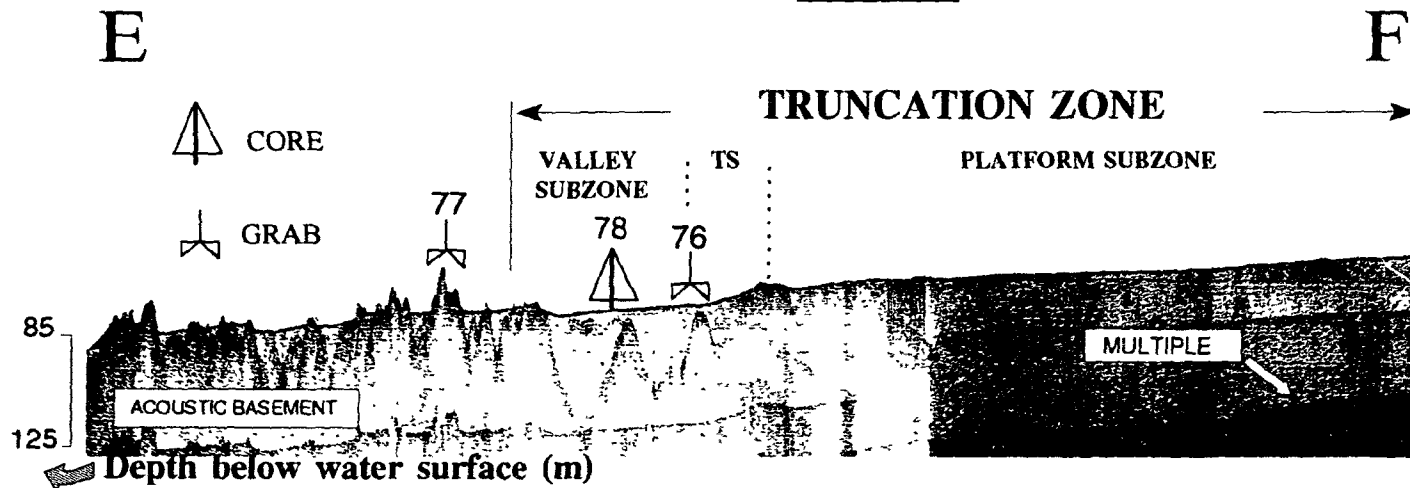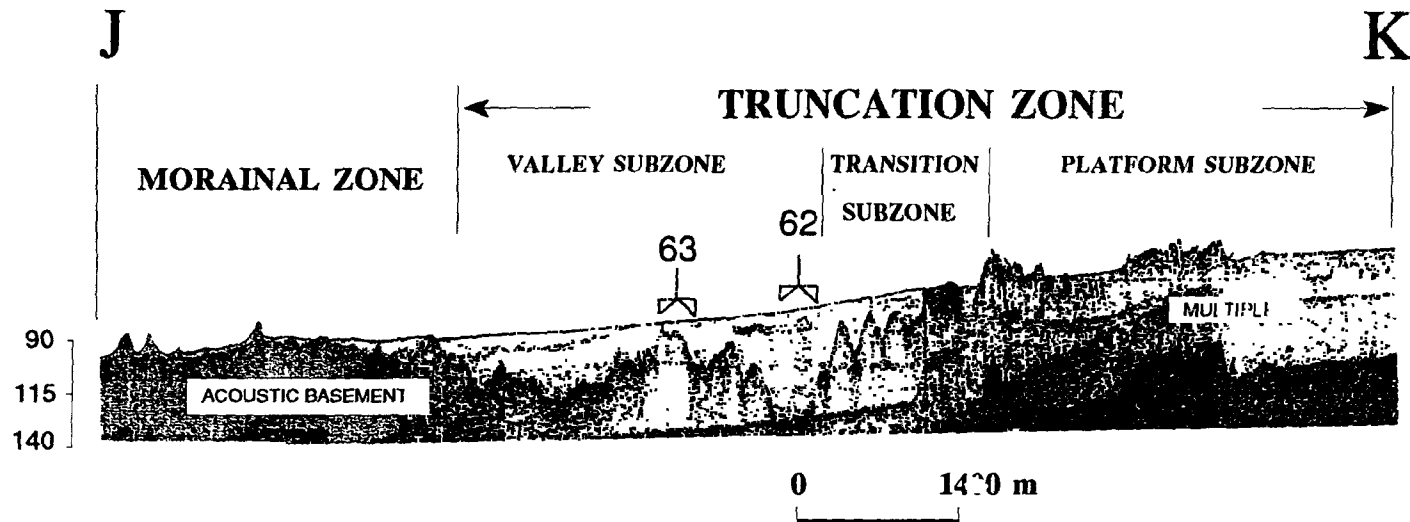
sequences with a ponded style of deposition, truncated by erosional unconformities in the subbottom and at the sea floor (Figs 49, 50) In the valleys, a basal, acoustically incoherent unit (Unit B), is overlain by a succession of ponded, onlap-fill acoustic units with moderate to high amplitude reflections In the Sheet Harbour map region several southeastward-trending valleys or basins have been mapped (Fig 16, Map 2) The valleys are 700 to 1000 m wide and 40 to 70 m deep and incised into acoustic basement (Meguma Group bedrock)

At the type section off Sheet Harbour (L- Fig 16, Fig 50), seven sequences are found within the Valley Subzone A conformable massive acoustic unit with occasional indistinctly stratified zones (Unit B) overlies acoustic basement Overlying and infilling channels within Unit B are a sequence with horizontal reflections of moderate to high amplitude (V1) V1 is overlain by a sequence with reflections of higher amplitude and frequency (V2) V2 is overlain by two ponded, inclined seismic units, with low amplitude reflections varying in reflection amplitude and continuity (V3 and V4) These units are truncated by a major horizontal unconformity (VA) which is overlain by an acoustically transparent unit (V5) V5 is incised by channels infilled with V6

3.9.2.1 Lithology

Grab samples and cores were obtained within the Valley Subzone at various locations Samples taken within the Valley Subzone in Sequences V5 and V6 produced cobble lags with subrounded to well-rounded, discoid clasts (IKU 62, 76 Figs 16, 18) and no striated pebbles

Figure 50. Type section (L; Fig. 16) of the Valley Subzone. The ponded units (V1-V4) within this valley are truncated by an unconformity. Units V5 and V6 rest on this major subbottom unconformity and appear to be themselves truncated by an erosional unconformity represented by the sea bottom reflection.

199

SEISMIC PROFILE

Depth below sea surface (m)

0   700 m
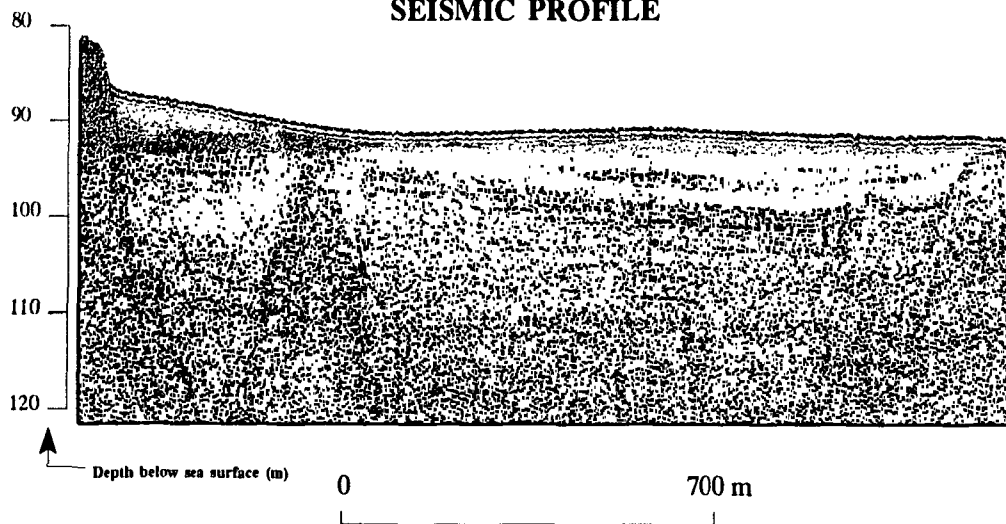
INTERPRETATION
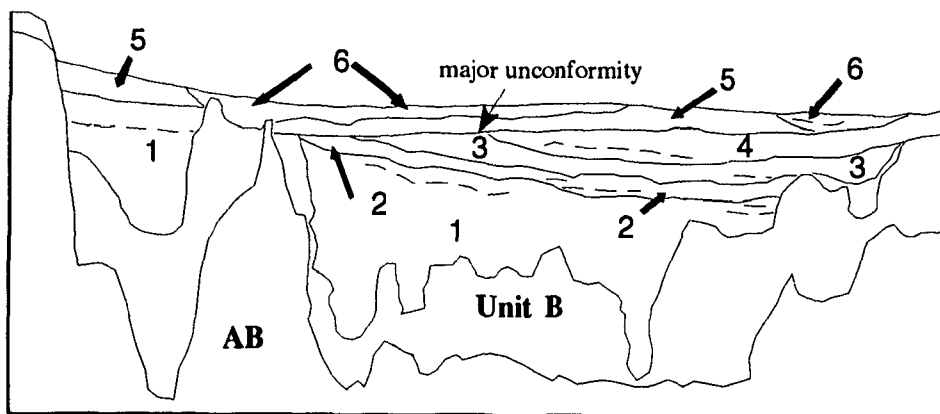
Figure 50.

Two vibracores were taken in the Valley Subzone at the type sections (Cores 91018-78; 91018-66, Fig 16, 18) The recovery was poor, but both revealed a cobble-lag of subrounded to rounded metagreywacke pebbles overlying coarse to medium sand and grey clay Samples of the bottom clay in both cores revealed a foraminiferal assemblage dominated by *Elphidium excavatum* and *Cassidulina reniforme* (E Collins, pers comm , 1992) This benthic foraminiferal assemblage is similar to that described for the Emerald Silt, formed near a temperate ice margin (Scott *et al.*, 1984)

3.9.3 Transition Subzone

Landward of the Valley Subzone the sea floor topography abruptly changes from an undulating, irregular surface to a planar one (Platform Subzone) This transition between these two subzones is marked by a relatively steep ramp leading to a terrace and sometimes a terrace scarp (Fig 51) The surface of the Transition Subzone ramp can be an erosional unconformity, cut into Unit B, as in transect K-J off Sheet Harbour (Fig 49), or a depositional surface formed by clinoform beds of Sable Island Sand and Gravel (Table 1). A enlarged multibeam bathymetric image of the Transition subzone reveals a relatively narrow zone with a gentle dip, resembling the modern shoreface (Fig 51) The ramp at the type section of the Transition Subzone (Sambro-Delta Fig 51) extends from 75 to 60 m water depth Topographic profiles through the type region show the distinctive ramp-terrace morphology (Fig 52) Profiles C and D and the multibeam image reveal a terrace scarp at 63 to 65 m water depth Similar terraces have been found on the Maine inner shelf at 55 to 60 m water depth (Kelley *et al.*, 1989, Shipp *et al.*, 1989, 1991) and are interpreted as lowstand shorelines

3.9.3.1 "Sambro Delta"

A progradational feature, the "Sambro Delta" is located in the Transition Subzone in the Halifax trackline map region, a region also covered by multibeam bathymetry (Figs 45, 48, 51) It is interpreted as a delta primarily because of oblique terminations of clinoform reflections against the upper sea bed, wedge-like geometry, and its location in an embayment of the Truncation Zone (Figs 51, 53) The Sambro Delta surface can be seen as a flat depositional surface, roughly triangular in shape, on the enlarged multibeam image (Fig 51) Along the axis of a channel in deeper water the delta merges into a valley

A strong, coherent and serrated reflection with point and cross hyperbolic diffractions, interpreted to be bedrock, occurs at the base of the progradational section (Fig 53) Above this reflection is an incoherent seismic unit (Unit B), 1-10 m thick Unit B is incised and infilled with another unit (Sequence 1) with moderate amplitude reflections and a ponded style of deposition Downlapping on unit 1 on the flank of a low hill are clinoform reflections that are obliquely terminated at the sea floor (Sequence 2) On the upper terraced surface another sequence (3) with chaotic, steeply-dipping reflections becomes prevalent Sequences 1, 2 and 3 are interpreted as the topset, foreset and bottomset parts of a delta The clinoform reflections of sequence 2 could be interpreted as shoreface progradational beds or deltaic foresets, but oblique terminations are more characteristic of deltaic systems (Mitchum *et al.*, 1977) From a submersible, Forbes (1990) noted a pebbly sand on the foreset slope. Sequence 3 overlies or grades into an acoustically incoherent Unit (C) (Forbes *et al.*, 1991) that outcrops at the sea floor over much of the Halifax transect area (Figs 10, 45) Forbes *et al.* (1991) interpret Unit "C" as glacial outwash, subaqueous in origin, based on the complex internal structures and gravelly-sand lithology They noted that the unit is truncated

Figure 51 (A) A digitally-enhanced color SWATH image, enlargement of Figure 48, looking

northeastward up an embayment in the Truncation Zone, revealing morphology and

subdivisions The Valley Subzone is in the topographic low The Transition Subzone is a

ramp leading to a planar surface (Platform Subzone) A is at the approximate location of the

Sambro Delta B depicts the interpreted extent of the topset part of the paleo-delta (after

Stea et al. 1994) (B) A terrain model of an offshore drumlin field described in Loncarevic

et al. (1994) located SE of Lunenburg Nova Scotia (44° 19'N, 63° 49'W) compared with the

digital terrain model of a similar-sized drumlin field from the Lunenburg drumlin field (Map

1) Note the truncated surface on the drumlin (arrow) at -65 m Ribbed moraines are

superimposed on the drumlins The colours in the diagram B are in 10 m increments The

offshore drumlin diagram keys are deep red - 70-60 m BSL, orange 70-80 m BSL, yellow 80-

90 m BSL

A
SHOREFACE-DELTA COMPLEX
HALIFAX NORTH TRANSECT AREA

44°27'

63°25'
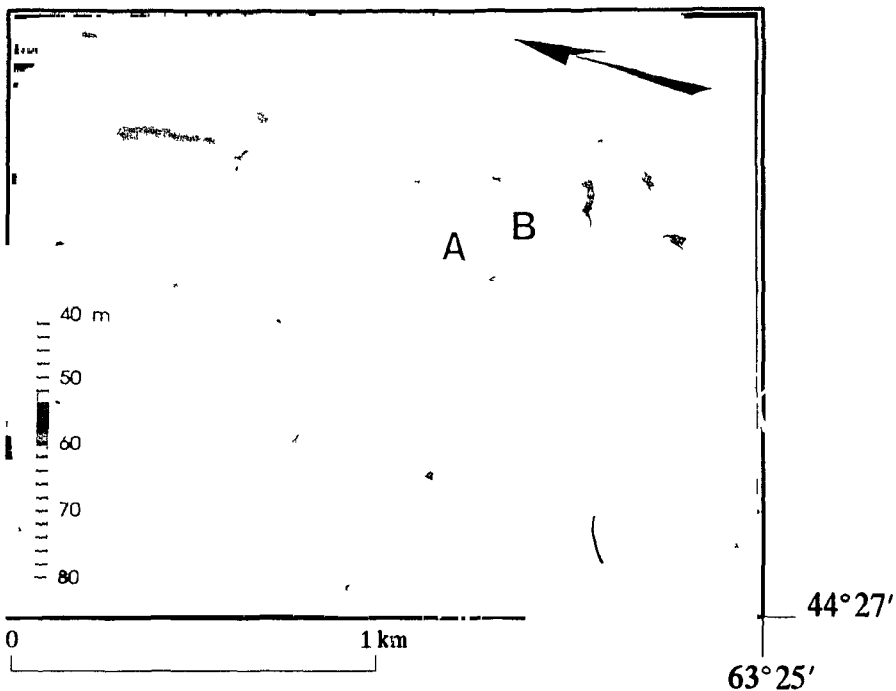
B
TRUNCATED DRUMLINS OFFSHORE
COMPARED WITH LUNENBURG
DRUMLIN FIELD

44°28'   **64°20'**

44°19

63°49'
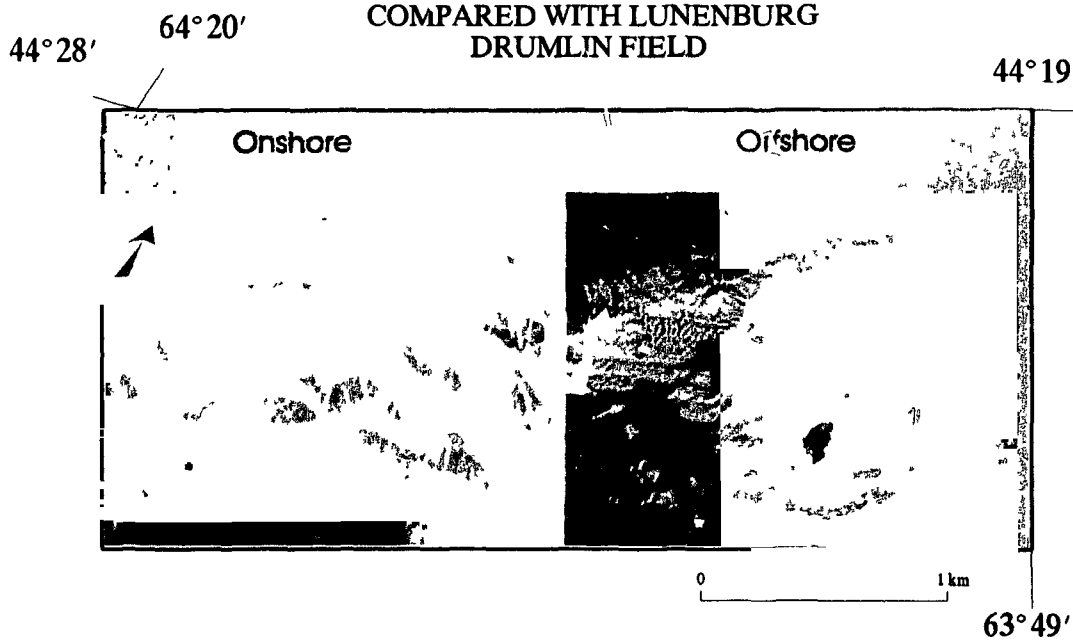
Figure 51.

Figure 52. Topographic profiles across the embayment in the Truncation Zone (Figs. 46, 51).

Note the distinctive ramp/terrace morphology and the terrace scarp at the landward end of

the embayment. Four topographic profiles across the embayment show the ramp/terrace

morphology of the Transition Subzone. The break from the ramp to the upper terrace is

inferred to be the former lowstand. This occurs at -65 m (modified after Stea *et al.*, 1994).
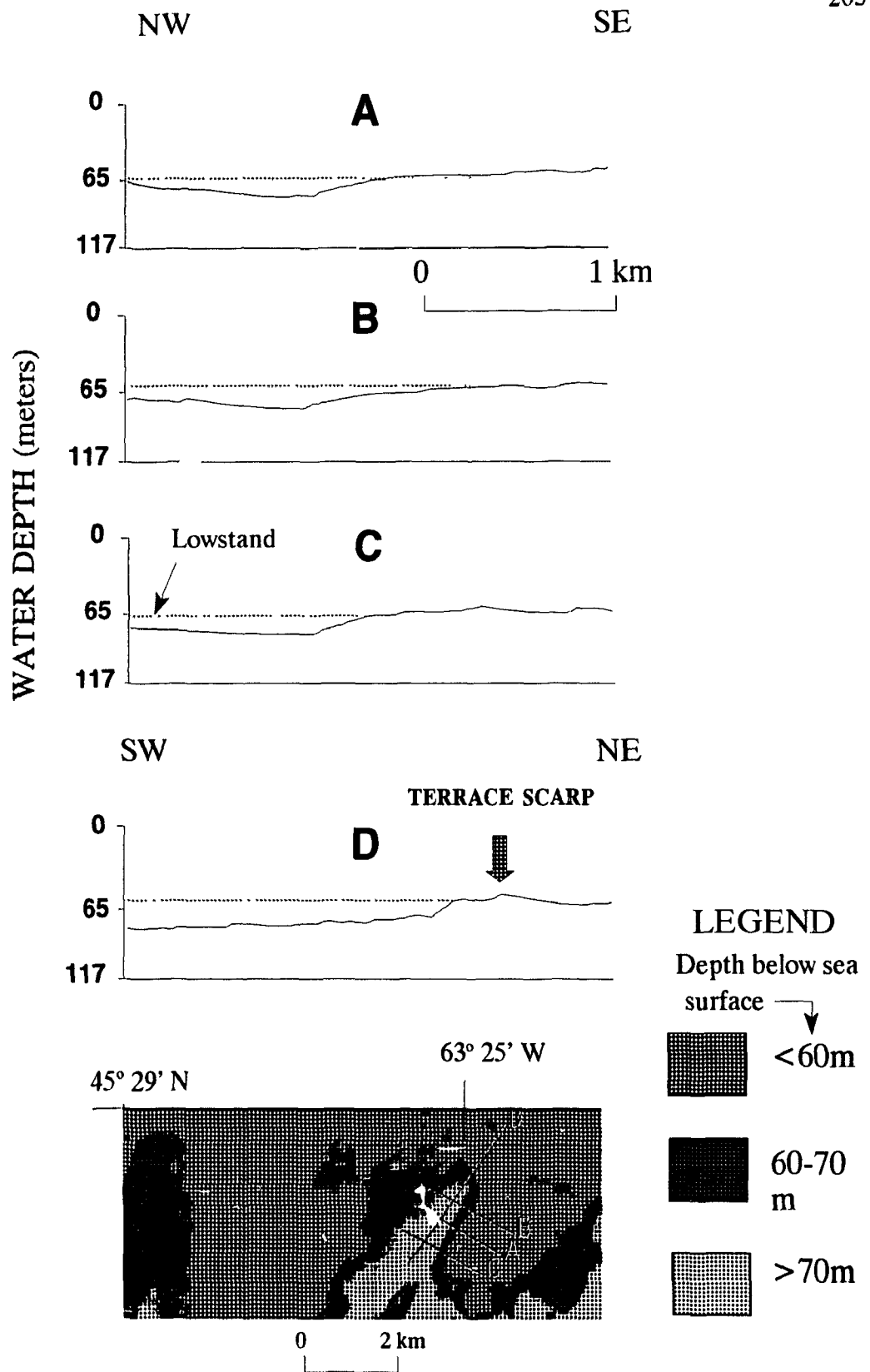
Figure 52.

Figure 53. Nova Scotia Research Foundation sparker profile and interpretation of the Truncation Zone in the Halifax area (Figs. 1, 4; Forbes, 1987). Description of core 91018-38 on the right. Note the coarse surface layers underlain by fine sand (dotted pattern). A shell hash was found consisting entirely of mussel valve fragments (*Mytilus edulis*). One of these fragments was radiocarbon dated and an age of 11,650 +/-110 ^{14}C years BP. Unit stratigraphy from Forbes *et al.*, (1991). Core depths in centimetres (modified after Stea *et al.*, 1994).

SEISMIC PROFILE

0   500m

60

70

80

Core

Depth below sea surface (m)

INTERPRETATION

Topset\foreset contact?

Unit C   3

Unit B

1

1

2

ACOUSTIC BASEMENT (Unit A)

Depth
(cm)

Core 91018-38

Cl   Si   Sa   Gr

0

40

80

11,650 ¹⁴C yr BP

120

160

Figure 53

207
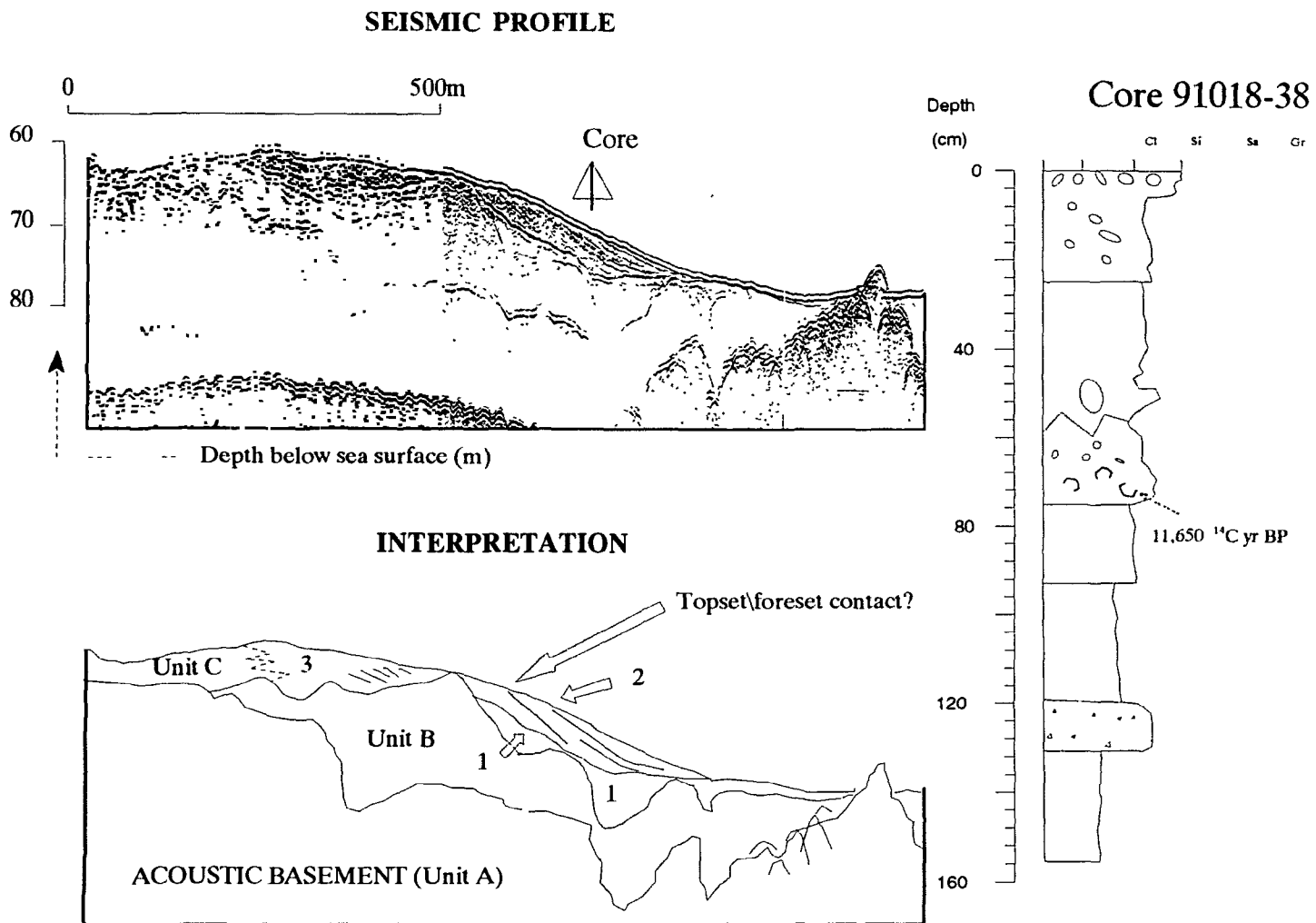
by the sea floor at depths less than 70 m Forbes (1990) also noted large boulders on the surface of Unit "C" on the upper slope of the "Sambro Delta"

3.9.3.1.1 Lithology and Age

Core 91018-38 was obtained from Sequence 2 (Fig 53) at 73 m water depth The top 70 cm of the core consists of grey, medium to coarse sand capped by a lag surface of well-rounded cobbles At 70 cm depth a shell hash was found consisting entirely of mussel valve fragments (*Mytilus edulis*) One of these fragments was radiocarbon dated and an age of 11,650 ± 110 ^{14}C yr B P was obtained, adjusted for isotopic fractionation The reservoir effect correction has not been assessed in this region, but a correction of 400 years can be applied representing a world-wide mixed layer oceanic average (Mangerud, 1972) The corrected age is the same as the pre-^{13}C adjusted age of 11,250 ^{14}C yr B P

The upper 40 cm of core 38 revealed abundant (>1000/10 cm^3) nearshore-type benthic foraminifera dominated by *Islandiella islandica*, *Cibicides lobatulus*, and *Islandiella teretis*. The bottom 50 cm, however, is barren of foraminifera, probably implying higher sedimentation rates or lowered salinity typical of a glacial front deltaic system (Swift and Borns, 1967, Stea and Wightman, 1987)

3.9.3.2 Country Harbour "Delta"

Huntec records revealed progradational clinoforms at the contact between the Platform Subzone and Outcrop Zone in water depths of 68 to 75 m in the Country Harbour transect region (Fig 18) The Transition Subzone shoreline can be traced NE of Country Harbour in

water depths of approximately -70 m where Huntec and 3 5 kHz seismic profiles indicate a marked topographic transition from Platform Subzone to Outcrop Zone In water depths greater than 70 m, the seabed is marked by moderate to high relief bedrock ridges and intervening basins filled with Emerald Silt At -70 m a terrace\scarp is developed Above -70 m the bedrock-dominated terrain becomes muted

3.9.4 Platform Subzone

The Platform Subzone of the Truncation Zone is defined as a low relief erosional surface with a seaward gradient of approximately 1°, cut into bedrock and surficial deposits, in water depths of -65 to -70 m The multibeam bathymetric images reveal a region of muted topography broken by occasional bedrock highs that rarely exceed 5 m of seabed relief (Figs 45, 51) The type section for the Platform Subzone is transect E-F which extends southeastward off Country Harbour (Fig 49) This remarkably flat erosional surface cuts bedrock and unconsolidated deposits

3.9.4.1 Unit C

A widespread, incoherent seismic facies (Unit C, Fig 45) overlies acoustic basement (Unit A) and Unit B in the Platform Subzone It varies from a metre to 10 m in thickness and has a blanket-like morphology It is best developed on the inner shelf near Halifax (Forbes *et al.*, 1991) The surface of Unit C is flat and featureless (Fig 54), in sharp contrast to Unit B (Fig 47) which can have undulating, or ridge and basin topography Two subunits can be resolved within Unit C, one distinguished by chaotic incoherent reflections, and the other with arcuate coherent reflections (Fig 54) These reflections are truncated by the sea bed in

Figure 54   Huntec seismic profiles of Unit C (locations on Fig 45)   Contrast these records with Unit B (Fig 47)   Surficial Unit C   reflects more of the incoming acoustic energy than Unit B, hence the unit is darker, and sometimes obscures the trace of acoustic basement in the subbottom   The lower section of Unit C (from Forbes *et al.*, 1991) reveals some coherent, arcuate reflections

UNIT C TYPE SECTIONS

Figure 54.

211
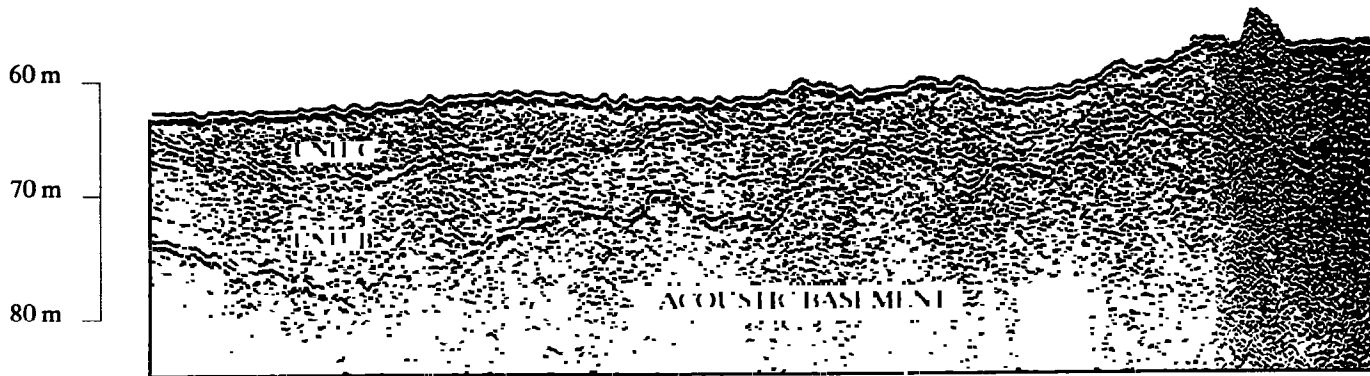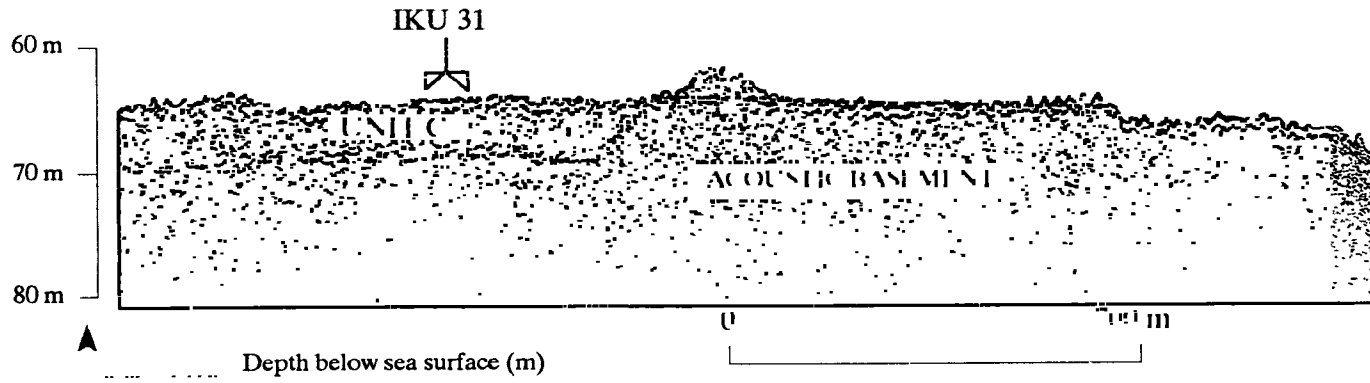
water depths between 50 and 70 m (Forbes *et al.*, 1991)   Sidescan sonograms show a variably reflective, light and dark (salt and pepper) surface interpreted as a cobble veneer. Bottom photographs of this surface from the Halifax region show that it is armored with a cobble lag of well-rounded boulders (Sable Island Sand and Gravel, Fig 55). Eight IKUs taken from Unit C ranged in texture from diamictons to gravelly-sand, with relatively little matrix (12%, Table 4) and abundant gravel (88%, Table 4) Pebbles are subrounded to well-rounded with an average of 4% striated pebbles compared to an average of 10% for Unit B (Table 4, Fig 56) The lag armour on Unit C can be considered to be equivalent to the Sable Island Sand and Gravel Formation of King and Fader (1986-Table 1) The boundary between Units B and C in the Halifax map area (Fig 45) occurs between 70 and 80 m water depth Unit C may be a composite of outwash, ice-contact stratified drift, or melt-out till overlying basal till, these deposits may not always be resolvable on seismic profiles The surface lag-armour probably reflected much of the incoming acoustic energy, so low- impedance contrast, subbottom reflections were not resolved

3.9.4.2 Valley Fill

Isolated valleys or basins are found in the Platform Subzone incised into the acoustic basement (Meguma Group bedrock) These valleys are several hundred metres to 2 km wide and 4-20 m deep and contain a sedimentary infill with a similar facies geometry to the Valley Subzone At the base of the valley sequence is a draped, acoustically incoherent unit (Unit B) Incised into Unit B are channels filled with ponded sediments consisting of several sequences of moderate to high amplitude reflections These high amplitude sequences are truncated by a horizontal erosional unconformity often near the sea bed Overlying the unconformity are two incoherent or indistinctly-bedded seismic facies

Figure 55. (A) Rounded gravels obtained from the Sable Island Sand and Gravel above Unit C in the vicinity of IKU 44 (Location Fig. 45). (B) Sable Island Sand and Gravel from IKU 79 (Location Fig. 18). (C) Bottom photograph of Unit C at IKU 31 (Water depth 64 m; Fig. 45). Contrast the pebble shapes evident from these photographs with those from Unit B (Fig. 47) in water depths greater than 80 m.

A

B

C
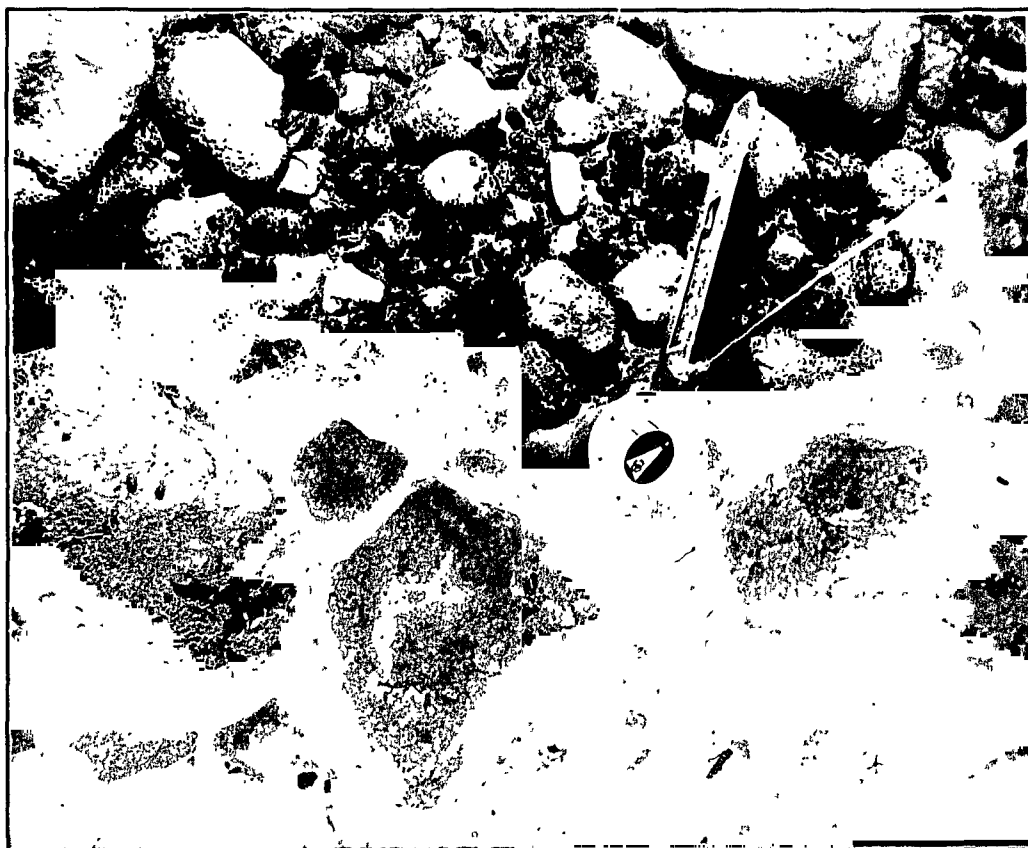
Figure 55.

Figure 56 Plot of striated pebble percentages and sample sedimentology vs water depth for all IKU samples The sedimentology of the samples is clearly related to water depth, with diamictons and mud found generally below 65 m, whereas sand and gravel is restricted to water depths above this level Note also the marked reduction of striated pebbles above 65 m, the inferred sea level lowstand position The landform-unit designations are indicated for each sample (see Fig 10).

Inferred lowstand depth
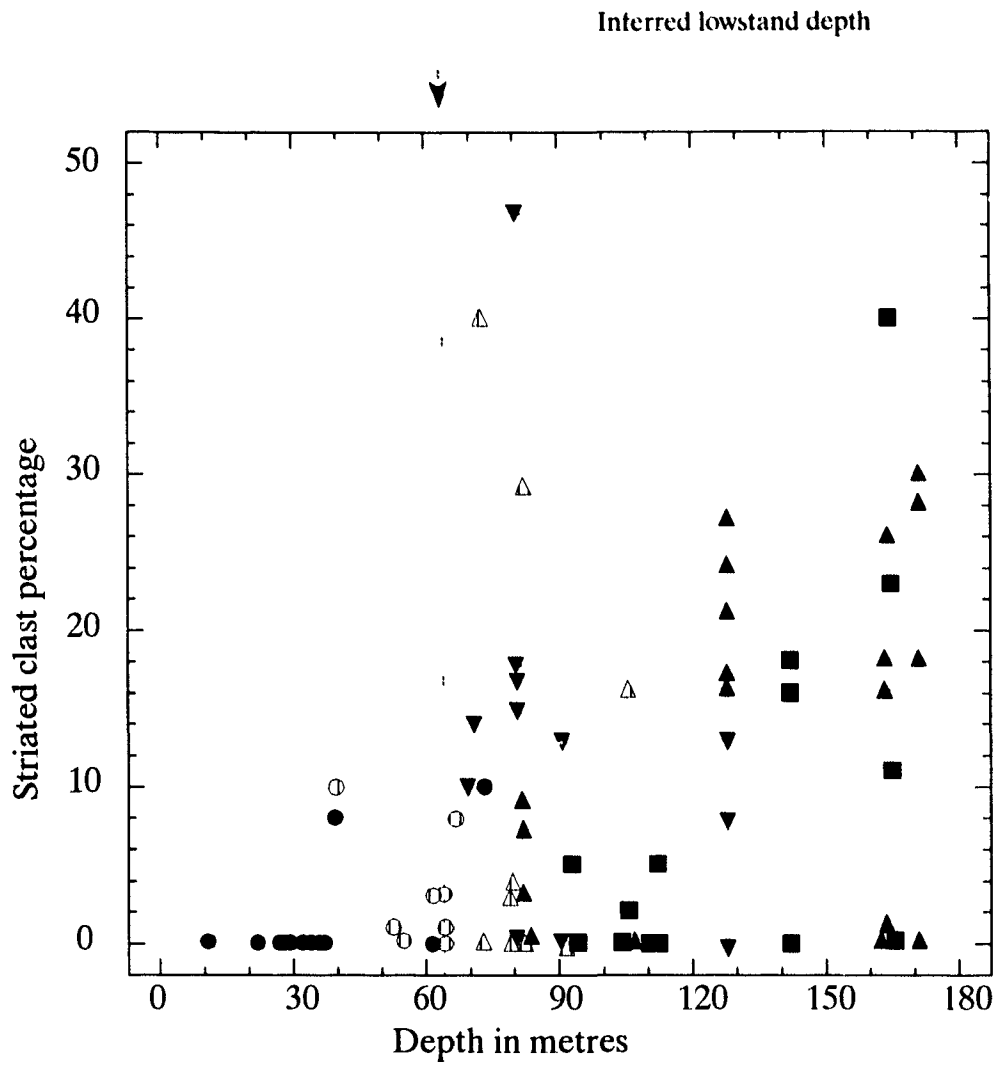
LEGEND

▲ Scotian Shelf End Moraine Complex

■ Emerald Silt Formation

▼ Morainal Zone (moraines)

⚠ Unit B

o Unit C

● Sable Island Sand and Gravel

Figure 56

Samples from the sea bed (Sable Island Sand and Gravel) in these valleys typically contain variable amounts of sand and gravel, the gravel fraction is overrepresented (60%, Table 4) due to sand wash-out upon IKU retrieval Pebbles in the gravel lag are typically subrounded to well rounded, and lacking or devoid of striations (2%, Table 4) Twelve gravel samples from valleys and basins within the Truncation Zone averaged 2% striated clasts (Fig 56, Table 4, Appendix 4) The uppermost incoherent and transparent seismic facies in these valleys encompass the Sable Island Sand and Gravel (Table 1)

3.9.4.3 The Estuarine Subzone

Forbes *et al.* (1991) and Boyd *et al* (1992) identified and mapped estuarine deposits in valleys confined to water depths less than 50 m Above 50 m water depth, north of the type section (E-F) of the Platform Subzone off Country Harbour (Fig 49), are a series of wedge-shaped acoustic units composed of gravel and sand interpreted as a transgressed barrier system (Stea *et al.*, 1993) Boyd *et al.* (1992) also identified transgressed barrier-lagoonal systems The Platform Subzone appears to have largely formed through erosion, whereas depositional processes were dominant within the Estuarine Subzone

3.9.5 Origin of the Truncation Zone

Erosional processes related to the regression and the post-glacial rise in sea level are largely responsible for the formation of the Truncation Zone and its constituent subzones The paleo-shoreline or lowstand is interpreted to be the top of the Transition Subzone The Platform Subzone represents the transgression surface (Fig 46)

3.9.5.1 Valley Subzone

The Valley Subzone is essentially a series of valleys and embayments that merge landward and are attenuated at the lowstand shoreline (Figs 8, 49, 51) Some of these incisions merge with larger valleys that trend southwestward and cut the SSEMC ridges (Figs, 8, 11, 16). The origin of these incisions is unclear Some may be meltwater conduits of the ice cap that formed the Morainal Zone, as they appear to start at the Zone (Fig 16) Others formed before the last glacial advance because they are lined with Scotian Shelf Drift or Unit B, acoustic units believed to be tills The predominant south-westward trend of these incisions is also problematic, as it is at odds with the primary southeastward, fault-related trend of most river valleys on the Nova Scotia mainland

Unconformities in the valley fill at the surface and sub-bottom may have formed by erosion at or below wave-base, or even by earlier glacial advances Erosional unconformities in glacial marine clays contained within these valleys, may indicate direct glacial erosion or current erosion that predated sea-level rise This is evident along the South Shore of Nova Scotia, where shell dates of 14 and 28 ka have been obtained from truncated glacial marine valley fill at -60 m (Piper and Fehr, 1991) An unconformity at the top of the Emerald Silt in valley fill at 71 m water depth was dated between at 14 ka and 9 ka (Piper and Fehr, 1991, D J W , Piper, pers comm , 1993) This unconformity is similar in age to the TESS surface and may be related to the lowstand at 11 6 ka

The sand and gravel bodies on the surface of valleys in water depths from -65 to -90 m are a result of wave-current redistribution of shoreface deposits related to the lowstand (Lapierre, 1982; Stea et al., 1994) The seaward margin of the Truncation Zone is essentially the limit

of sublittoral deposition and wave reworking during the lowstand The sublittoral Sambro

Sand (Table 1) mapped by King (1970) represents the seaward limit of wave-base reworking

King (1970) interpreted the contact between the Sable Island Sand and Gravel (Table 1) and

the Sambro Sand as the lowstand Off Halifax this contact was mapped at -90 m

3.9.5.2 Transition Subzone (shoreline) and Platform Subzone

Three major lines of evidence suggest that the maximum sea-level lowering was only -65 m

1   Till-moraines do not appear to have been modified or removed by a regression-transgression cycle as they have retained a distinctive constructional morphology They are found in water depths of 145 to 65 m, similar to the depth range of the Outcrop Zone

2   The seabed surface changes markedly from one of low or subdued relief (Platform Subzone) above -65 m water depth to high or undulating relief seaward below -65 m Unit C and Sable Island Sand and Gravel are only found above -65 m

3   Sediments below -65 m are largely mud and diamicton whereas above -65 m gravel and gravelly-sand predominate (Fig 6) Pebble roundness changes from predominately subangular to subrounded below -65 m, to subrounded to well-rounded above -65 m and the percentage of striated pebbles decrease markedly above -65 m (Fig 56)

At -65 m to -70 m the Transition Subzone ramp and terrace separates the Platform Subzone from the Valley Subzone (Fig 51) It is interpreted as a product of shoreface erosion during regression and transgression (Belknap and Kraft, 1981), in essence a ravinement surface

(Nummedal and Swift, 1987) or, in part, a deltaic surface The terrace surface is interpreted to be the paleo-shoreline, although the transgression may have been initiated at a slightly lower elevation The average ramp height of 10 m found in this study is similar to values of wave-base erosion cited by Suter *et al* (1987) At the type profiles (Fig 49) the base of the ramp represents the lower limit of wave-base erosion in late-glacial time

From the Sambro Delta type locality, sea level is interpreted to be near the topset/foreset contact (Fig 52) which is approximately -65 m The presence of *Mytilus edulis* in the core indicates deposition of the foresets close to the intertidal zone Mussel shell hashes have been described in foreset beds of raised glacial marine deltas and moraines in the Saint John, New Brunswick, area (Nicks, 1988) The known deglaciation chronology does not negate a glacio-deltaic hypothesis Stea and Mott (1989) and Gipp (1994) estimated that the ice margin was close to the present coastline at about 12 ka Recent AMS radiocarbon dating of the base of Porters Lake, near Halifax, suggests deglaciation by 11 7 ka (D B Scott pers comm, 1994) The age of the Sambro Delta is close enough to the lake date to infer a glacial sediment source, but the evidence for meltwater drainage has been removed by the regression/transgression Thus, the deltaic hypothesis must remain speculative An alternative explanation for this zone may be a shoreface-coastal terrace Boulders noted by Forbes (1990) on the surface of the Sambro delta may be relict from till-cliff erosion

The Country Harbour and Sheet Harbour type transects (Fig 49), in water depths of less than -65 m show low gradient erosional surfaces cut into acoustic basement and unconsolidated deposits These planar surfaces are interpreted as shore platforms, defined as surfaces of low gradient (1-5°) formed by mechanical wave erosion at or near sea level (Trenhaile, 1987) The Country Harbour transect (Fig 49) is a particularly striking example of a low gradient

shore platform These surfaces were cut during the regressive and transgressive phases of the Late-glacial period.

Forbes *et al.* (1991) and Boyd *et al.* (1992) describe estuarine facies within a depositional zone (Estuarine Subzone) restricted to water depths of less than 50 m The reason for the lack of estuaries and relict barriers within the Platform Subzone below depths of 50 m is unclear One reason could be that they are there but were not found Another reason may be related to rapid initial transgression rates Belknap and Kraft (1981), however, suggested that preservation of estuarine sequences is more likely with higher rates of relative sea-level rise Climate may have also played a role in the production of estuarine sediments

3.9.6 Revised Sea-level Curve for the Eastern Shore

The recognition of ravinement surfaces, shore platforms and deltas graded to depths of 65 m BSL on the inner shelf, extends the sea-level curve for the region (Fig 57) Shell dates obtained from this study, and Piper and Fehr (1991) have been added to a sea-level curve of the inner shelf compiled by Forbes *et al.* (1991) from Scott (1977), Scott and Medioli (1982), Miller *et al.*, (1982), and Honig (1987) (Fig 57) The curve before 9000 ^{14}C yr B P is based on shell dates The accuracy and precision of the data are controlled by the uncertainty of reservoir corrections and depth assignments The data after 7000 ^{14}C yr B P are better constrained because they are based on salt marsh peat cores whose RSL assignments are determined by foraminiferal assemblages accurate to ± 10 cm of RSL (Scott and Medioli, 1978) Upon initial deglaciation, sea levels were higher than -60 m (Piper and Fehr, 1991, Forbes *et al.*, 1991) The maximum RSL at this time is not known although Emerald Silt has been identified in 40 m water depth (Stea *et al.*, 1993) RSL then fell to a lowstand of

Figure 57. Relative sea level curve for study region compiled from this study, Scott

(1977), Scott and Medioli, (1982), Miller *et al.*, (1982), Honig, (1987) and Forbes *et al.*,

(1991). Curve A represents the calculated RSL curve based on a maximum ice model from

Quinlan and Beaumont, (1981). Curve B represents a curve of the minimum model of

Quinlan and Beaumont, (1982). Also shown for comparison is Fairbanks (1989) Barbados

sea level curve. (modified after Stea *et al.*, 1994).
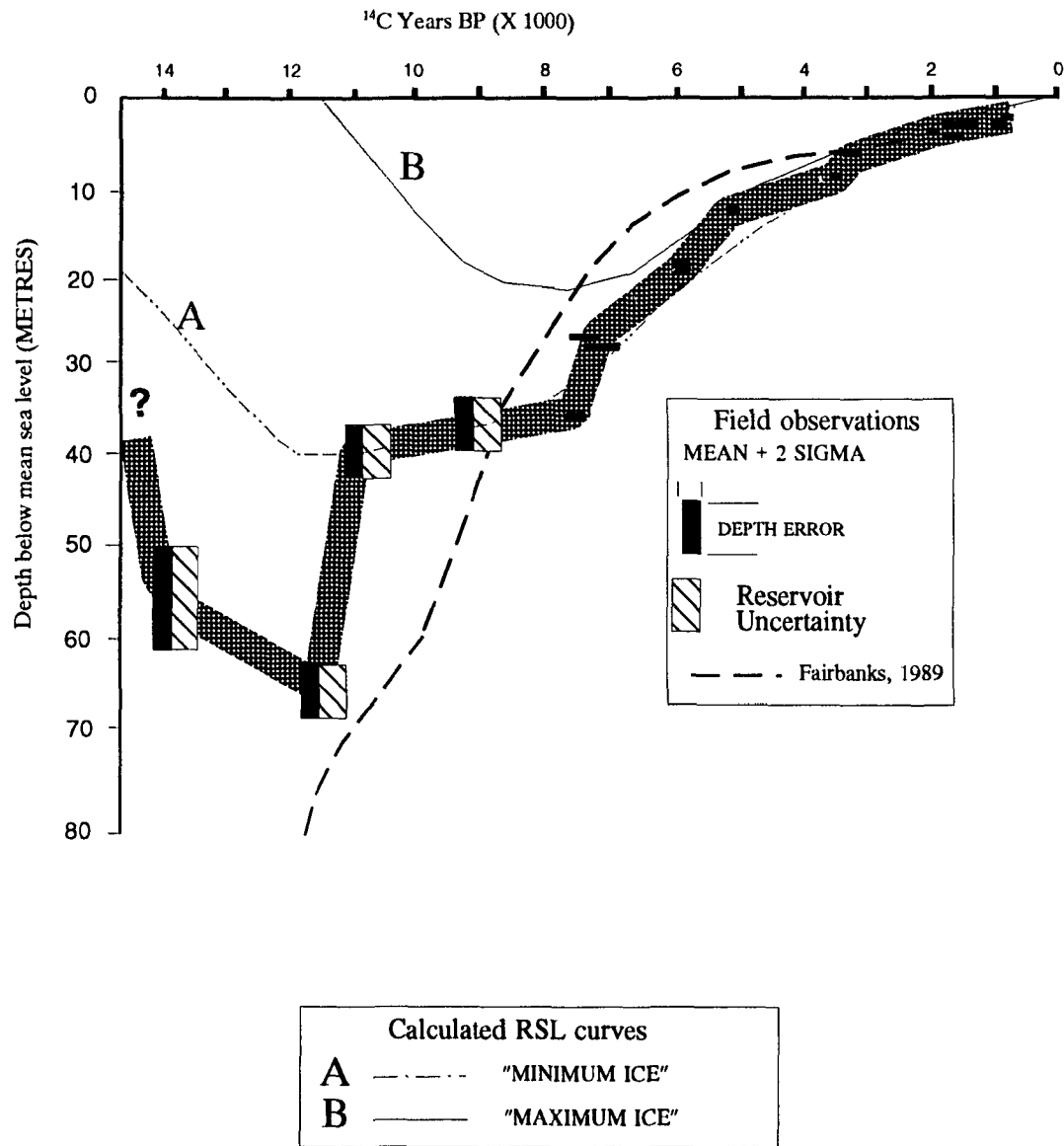
Figure 57.

-65 m, followed by a rapid rise of 1 5 to 2 m per century until ca 11 ka Rates of sea-level rise decrease markedly at 11 ka and then increase starting at about 8 ka From 9 ka to present, rates of sea-level rise follow a step-like pattern with inflection points (Scott and Medioli, 1982, D B Scott, pers comm 1995) This curve is characterized by an initial high amplitude, short wavelength isostatic response, followed by step-like sea-level changes It is remarkably similar to the new curve obtained for the inner shelf off Maine, USA which has a lowstand position of -50-60 m followed by a RSL plateau between 11 and 9 (Barnhardt *et al.*, 1992) All data points are within a 50 km radius, so the complexity of the curve cannot be explained by rebound variations relating to ice thickness or crustal variations New sea level data presented after this thesis was in preparation by Edgecombe (1994) suggests a more complex sea level curve after 9 ka than presented in Figure 57

3.9.7 Glaciological and Geophysical Implications

Clark *et al.* (1978) developed a mathematical model which derived a relative sea level history from the earths rheological properties, ice sheet thickness and deglaciation history Quinlan and Beaumont (1981, 1982) utilized this approach to deduce the sea-level response of two contrasting ice models for the Maritime Provinces of Canada They divided the Maritime Provinces into four zones based on their model-derived RSL history Zone A (continuous emergence) to Zone D (continuous submergence) According to their model, these zones shift seaward with more ice and landward with less ice A primary factor governing the shape of the resulting sea-level curves is the peripheral forebulge, which migrates towards the former ice centres after deglaciation The maximum model represents a uniform ice cover over eastern Canada (1-2 km), thinning to the southeast, and a margin at the outer shelf (cf Flint, 1971) The minimum model (Grant, 1977, Grant and King, 1984) has much thinner ice

(<1 km), segregated over Nova Scotia, with margins near the present coastline and no grounded ice in the Gulf of St Lawrence Quinlan and Beaumont (1981) calculated theoretical relative sea-level curves for the inner shelf based on the maximum and minimum ice models At that time they found that the observed RSL field data were bracketed by the theoretical curves derived from the extreme ice models In a later paper (Quinlan and Beaumont, 1982) constructed a "compromise" ice model based on existing field RSL observations characterized by

1 No grounded ice in the Gulf of St Lawrence

2 Margins not substantially seaward of the minimum reconstruction

3 Ice retreat from Nova Scotia by 14 'ca

The "compromise" RSL ice model closely resembles the minimum model of Grant (1977) because both models feature an ice-free Gulf of St Lawrence Tushingham and Peltier's (1991) recent ice sheet reconstruction (ICE-3G) also based on existing field RSL data, produced a similar ice distribution and retreat pattern to the Quinlan and Beaumont (1982) RSL-derived model

The new empirical RSL curve of the inner shelf (Fig 57) differs from the theoretical minimum curves of Quinlan and Beaumont (1981, 1982) and Tushingham and Peltier (1991) primarily in the high amplitude and short wavelength response of RSL change after deglaciation The maximum sea-level lowering is about 20 m below that predicted for the "compromise" minimum model and 40 m or more lower than predicted in the maximum model The transition from initial RSL fall to RSL rise occurs over a much shorter time span than predicted

The most recent theoretical RSL curve obtained from Peltier (pers. comm., 1993) also fails to predict the magnitude of sea-level lowering evident in the empirical RSL curve by 20 m but it does predict the response in the later Holocene rather well. The low-tand can be reproduced by either shifting the ice margin 2° westward or thinning the ice substantially to ice volumes comparable with the minimum model (Peltier, pers. comm., 1993). Muting of the pre-lowstand emergence pattern characterized by RSL fall, however, is concomitant with removal of the ice.

If ice margins existed out on the outer shelf, as recent field observations suggest (McLaren, 1988; Mosher et al., 1989; Gipp, 1994), then observed sea-level curves should be skewed toward the calculated curves for maximum ice (Fig. 57) which also predict raised strandlines along the Eastern Shore of Nova Scotia. Low-profile ice masses (cf. Boulton and Jones, 1979) cannot be invoked to explain the discrepancies between extensive ice and minimal rebound because of the presence of local ice divides (Stea et al., 1992a, b) and the vast areas of Meguma Group metagreywacke outcrop on land and the inner shelf, which would tend to increase basal shear stresses and produce more parabolic ice masses (Forbes et al., 1991). Ice thicknesses in the Maritime provinces of Canada were more comparable to southern Maine, a region on the outer edge of the Laurentide Ice Sheet (Mayewski et al., 1981)

The timing and mode of ice retreat are crucial factors affecting RSL history. A brief summary of the deglaciation history of the Atlantic shore of Nova Scotia is necessary to place the RSL curves in context with the position and timing of retreating ice. Till-tongues along the northern margin of Emerald Basin have radiocarbon ages of 15,000 to 17,000 ^{14}C yr B.P. (King and Fader, 1988; Gipp and Piper, 1990; King pers comm, 1994). Based on lake sediment chronologies, Stea and Mott (1989, 1990) and Gipp (1994) estimated that the ice

retreated to the present coastline by 12,000 ^{14}C yr B P (Map 1)   Southern Nova Scotia land areas, deglaciated by ablation and downwasting (Grant, 1989, Stea and Mott, 1989), are characterized by vast areas of melt-out tills, and hummocky topography without ice marginal moraines   In contrast, the deglaciation of southern Maine proceeded by rapid calving and active-zone retreat marked by extensive morainal systems and was largely complete by 12 8 ka (Smith and Hunter, 1989, Belknap and Shipp, 1991)   The glacial marine Presumpscot Formation clay (Bloom, 1963) forms a widespread blanket over southern Maine below the marine limit   The Atlantic coast of Nova Scotia has no raised marine features, although these are predicted to occur if ice extended as far as the outer banks (Quinlan and Beaumont, 1981)   The paradox is best explained by sub-ice emergence under a carapace of late-melting ice (Fig 58)   Rapid deglaciation of the Nova Scotia inner shelf was probably hindered by the outer banks which acted as bastions to help buttress the ice sheets against sea-level rise (Gipp, 1989)   Ice sheet deflation occurred from the top down and large areas of the ice sheet stagnated   Raised features did not form along the Atlantic coast because by the time the ice melted, RSL fell below the ice margin surface (Fig 58)

The drop in RSL between 14,000 and 12,000 ^{14}C yr B P (Fig 57) on the inner shelf may be attributed to initial, rapid crustal response (rebound) as the ice retreated from the inner shelf The rate of RSL drop during this period, however, is largely unknown   Differential uplift of various moraines across Eastern Shore indicates initial RSL drop assuming that the moraines were formed by grounded ice at similar water depths (-250 m) 70 m of differential uplift occurred between the Country Harbour Moraine (-84 m) and the Sambro Moraine (-160 m)

Figure 58 Schematic comparison of ice sheet-sea level interactions between Maine and Nova

Scotia during the period between 14 and 12 Ka Rapid ice retreat of an ice stream in the Gulf

of Maine allowed the formation of the Presumpscot Formation on the isostatically-depressed

landscape Delayed retreat, ablation by downwasting and sub-ice isostatic equilibration of the

Scotian Ice Divide prevented the formation of raised features along the Atlantic coast Arrows

indicate uplift and ice retreat and downwasting

MAINE

SEA LEVEL 15-14 KA

13-12 KA   ICE

COASTLINE

NOVA SCOTIA

15-14 KA

13-12 KA

Presumpscot Formation
Emerald Silt

BEDROCK

Ablation

Retreat

Isostatic uplift
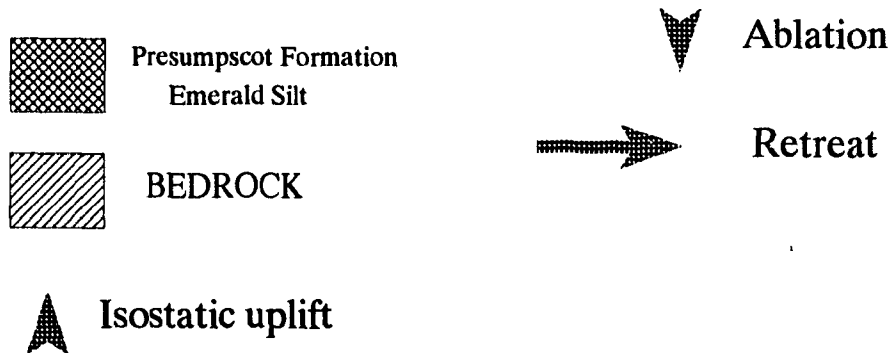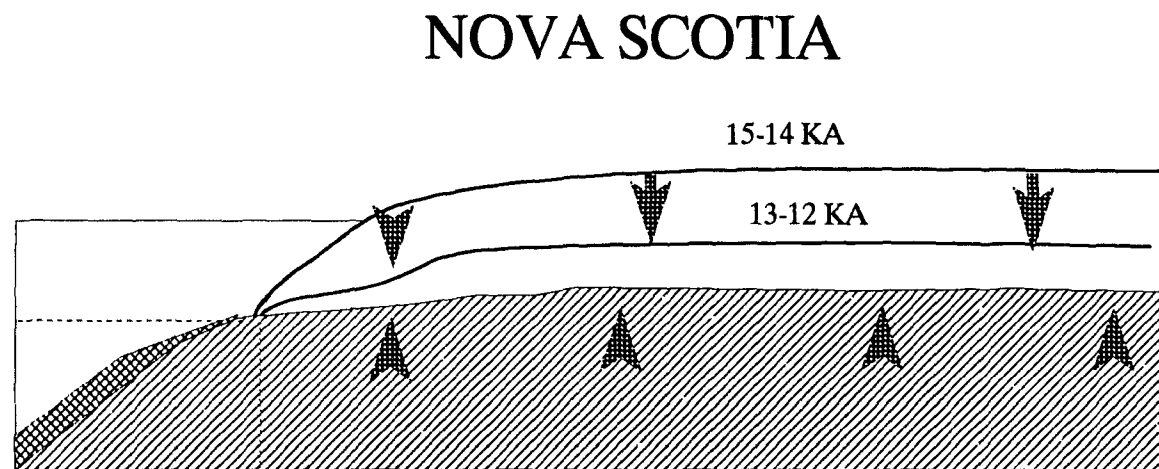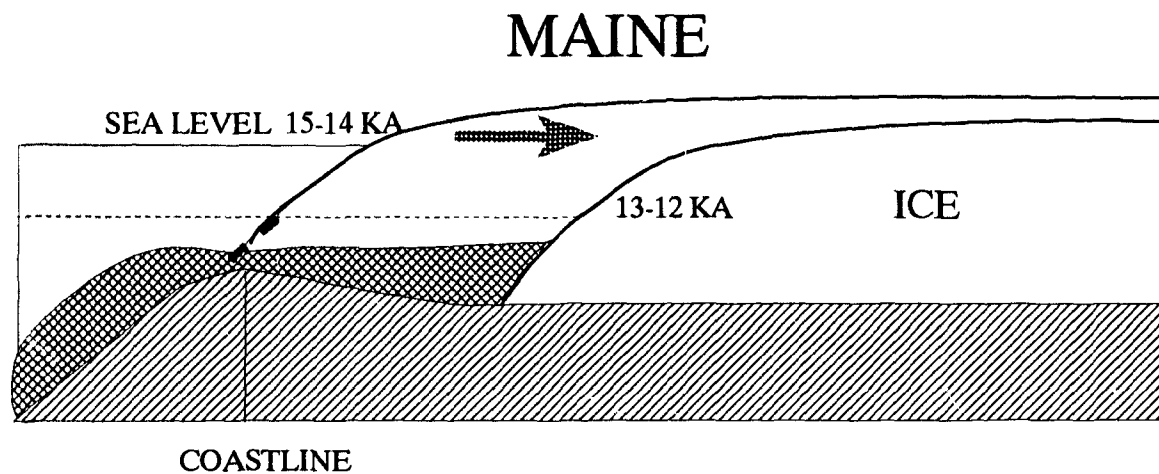
Figure 58.

The amplitude and wavelength of RSL change is the late glacial period is not predicted by the geophysical models Barnhardt *et al.* (1992) and Shipp *et al.* (1991) made the same observation for the Maine continental shelf Josenhans *et al.* (1992) also noted substantial sea-level lowering adjacent to the Cordilleran Ice Sheet at 10 6 ka for the Pacific coast RSL lowering predicted in the maximum ice model (Fig 57) is only 20 m between 9 and 7 ka. Some of this discrepancy can be explained by underestimation of worldwide ice volumes, but the proximity of the age and depth of the lowstand to the RSL curve of Fairbanks (1989) suggests that crustal depression was not as protracted as predicted by visco-elastic earth models Variations in the strength and thickness of the lithosphere may be responsible for the disparity between models and data, but this effect was discounted by Tushingham and Peltier (1991)

The rapidity of RSL rise after the lowstand from 11,500 to 11,000 ^{14}C yr B P may be due entirely to melting, as rates of rise are comparable to the Fairbanks (1989) curve for this interval (Fig 57) The RSL plateau between 11,000 and 8000 ^{14}C yr B P can be explained by crustal uplift due to passage of a peripheral forebulge across the region This forebulge-related plateau is evident on both the maximum and "compromise" minimum ice theoretical curves (Fig 57) In the Maritime Provinces, glaciers advanced during the Younger Dryas Chronozone (11-10 ka, Stea and Mott, 1989, Grant, 1989, King, 1994) Local ice advances, and by analogy local ice centres, are considered to have negligible effects on the RSL record because of the lithosphere's ability to support loads of small areal extent (Quinlan and Beaumont, 1981)

The -65 m shoreline appears to be a level surface over most of the Eastern Shore of Nova Scotia J Shaw (pers comm , 1993) has documented a lowstand (as yet undated) in

Chedabucto Bay of only -35 m   The amplitude of the RSL inflection is not known in these cases so the significance of these RSL fluctuations is unknown   The discrepancy in Chedabucto Bay may also be explained by late ice   Northern Nova Scotia was the breeding ground for the Younger Dryas glaciers postulated by King and Fader (1988) and Stea and Mott (1988, 1989)   Although this area was deglaciated ca 12 4 ka (Stea and Mott, 1989), evidence of early marine incursion may have been removed by the late re-advance   Local crustal depression caused by the Younger Dryas glacier would decrease the magnitude of lowering after removal of the load

3.10 SUMMARY OF MARINE GLACIATION AND SEA-LEVEL EVENTS FOR THE EASTERN SHORE

The author presented a preliminary interpretation of marine events on the inner shelf after initial seismo-stratigraphic interpretation (Stea et al., 1992b)   Although details have changed, the basic six-phase evolutionary model is still valid (Fig 59)

The composition and symmetry of the Scotian Shelf End Moraine Complex suggests that it was formed underneath the ramp-margin of a grounded glacier   Diamicton was deposited directly on the ice ramp-till bed by conveyor-belt recycling and lodgement or push-squeeze processes   Meltwater was restricted to basal sheet flow rather than being channelized   The steep landward slope of the moraine probably reflects the former ice contact slope   Till-tongues rooted in the morainal complex represent short-lived readvances of the semi-buoyant ice front, smearing-out till on the morainal front and overriding and deforming previously-

Figure 59   Six phase model of proposed deglaciation and sea level events on the Eastern

Shore of Nova Scotia (modified after Stea *et al.*, 1992 b)

1   Scotian End Moraines form at a ramp-margin of a grounded glacier.

2   Retreat to "proto" moraine Proglacial deposition of Sequence 1

3   Retreat, then a readvance-surge ca 13 ka forming the symmetrical

moraines and Sequence 2 in the Basin Zone

4   Retreat and shoaling of the glacier, increased wave-activity-turbulence and

dropping sea levels entrain sediments Sequence 3 deposited in the Basin

Zone

5   Lowstand nadir Erosion at the lowstand nadir produces a shoreline

(Truncation Zone-Transition Subzone) and Sequence Boundary 3/4 in the

Basin Zone Subsequent sea level rise and climatic warming Sequence 4

deposited in the Basin Zone

6   Climatic cooling, increases storminess, sea ice and ice bergs increase

sedimentation rates during the Younger Dryas Sequence 5 is deposited in the

Basin Zone

1. 16-15 KA

2. 15-14 KA

SEQUENCE 1

3. 14-12.8 KA

SEQUENCE 2

4. 12.8-12 KA

SEQUENCE 3

5. 12-11 KA

SEQUENCE 3/4

6. 11-10 KA

SEQUENCE 5 YANKEE BANK FORMATION

LEGEND

GLACIER

ICEBERG

SEA ICE

Meltwater Plume

Current Erosion

Breaking Waves
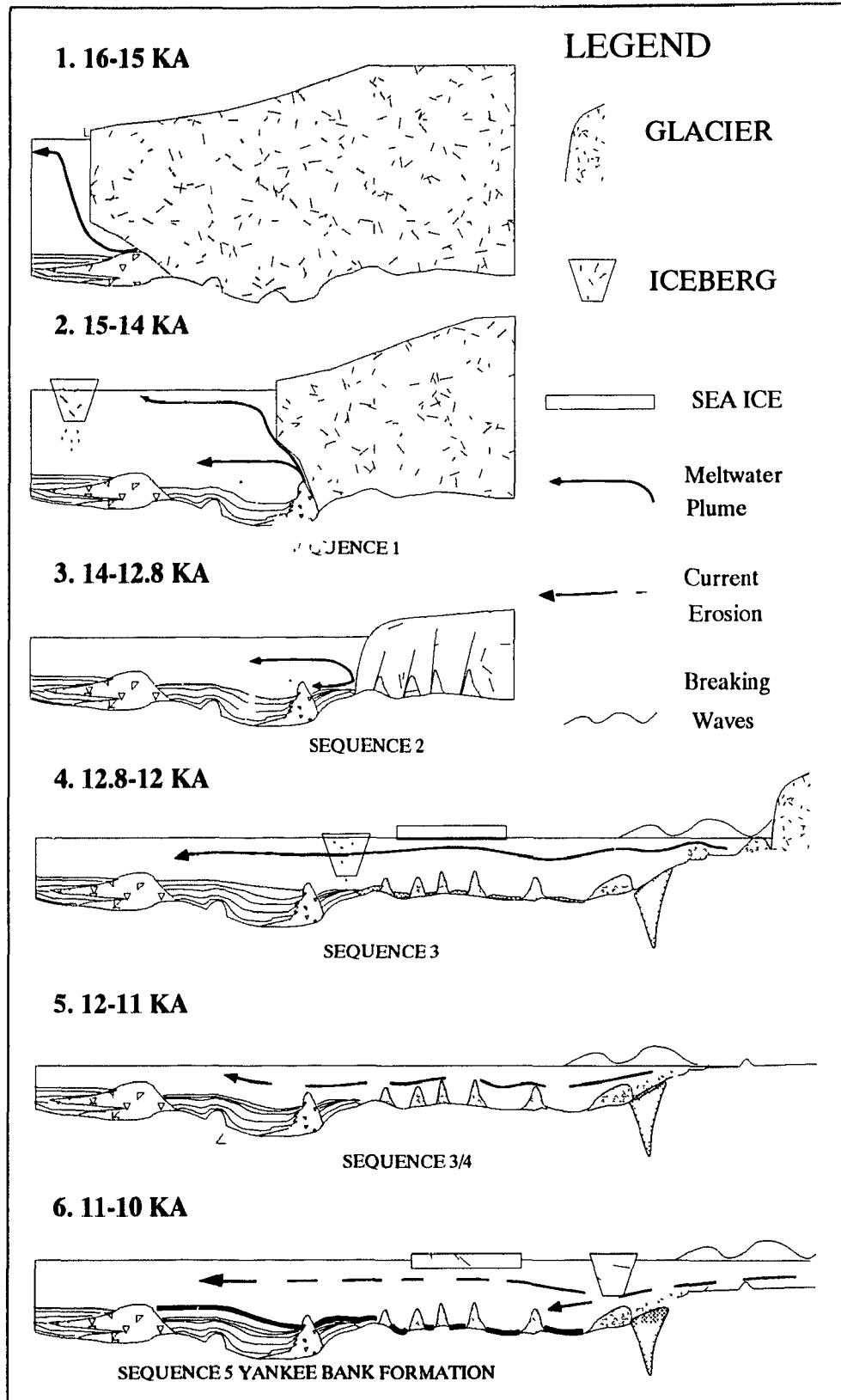
Figure 59

deposited Emerald Silt

Sequence 1 in the Basin Zone (Emerald Silt) is interpreted to be ice proximal, glacial marine sediment deposited by overflow and interflow meltwater plumes, emanating from an ice margin Landward thinning of the Emerald Silt and the landward decrease in identifiable seismic sequences imply diachronous deposition from retreating ice margin rather than synchronous deposition under an ice shelf "Proto" moraines represent these short-lived ice marginal stands Sequence 1 in the Basin Zone was deposited from 14 5 to 13 5 ka

The Morainal Zone formed after retreat of the glacier out of the Basin Zone and during the deposition of Sequence 2 in the Basin Zone (ca 13 5-12 7 ka) Symmetrical Moraines probably formed synchronously, as a result of a readvance (surge?) Asymmetrical Moraines formed at the margin of a shallow-water tidewater glacier After this readvance (13 5 to 12 7 ka), sea levels dropped rapidly, due to general isostatic recovery Wave turbulence and debris from the melting glacier suspended very large amounts of sediment Iceberg rafting was also an important mechanism for sediment delivery into the nearshore basins

Sea levels dropped to their lowest point at -65 to -70 m around 11 6 ka A shoreline formed during a short period of crustal stability (Transition Subzone) Sea-level rose rapidly after 11 6 ka and a large area of the inner shelf was transformed by erosion into a low-relief surface, barren of depositional features (Platform Subzone) At the lowstand nadir erosion

was prevalent below the lowstand to depths as great as 140 m above which substantial

quantities of Emerald Silt were removed   Synchronously in the Basin Zone an erosional

sequence boundary was formed (Sequence 3/4)   The rate of relative sea-level rise slowed

markedly between 11 and 9 ka, a result of forebulge passage, and depositional features were

again established (Estuarine Subzone)

A distinctive seismic and lithic unit (Yankee Bank Formation) was deposited during the

period from 10 7 to 10 0 ka   This event horizon was a response to several possible factors

increased storminess, debris-laden sea ice and increased sediment supply from the devegetated

coastline   The coastline was about 20 km seaward of present about that time   Permanent and

semi-permanent snowpacks and small glaciers in northern Nova Scotia extending slightly

offshore provided pulses of low-salinity, debris-laden meltwater plumes and small bergs which

may have spread debris over much of the inner shelf

CHAPTER 4: TERRESTRIAL QUATERNARY GEOLOGY

4.1 INTRODUCTION

A fundamental understanding of the morphology, stratigraphy and lithology of terrestrial Quaternary deposits is essential for correlation with seismic records of the offshore. The scope of the terrestrial study of this thesis is limited   The author will draw heavily on previously published material, especially the Surficial Geological Map of the Province of Nova Scotia (Map 1, Stea *et al.*, 1992c)   Several reference sections are examined in detail to provide a basis for land-sea correlation of till sheets

Stea *et al.* (1992a) derived regional ice flow lines and the ice flow phase concept from their compilation of all striae, drumlin and esker orientations in Nova Scotia, verified with pebble and boulder trajectories from known source areas (Grant, 1963, Nielsen, 1976, Stea, 1984, Stea and Finck, 1984, Graves and Finck, 1988, Stea *et al.*, 1989) These ice flow phases were correlated with till sheets in stratigraphic section based on detailed structural and pebble-provenance studies (e g Stea, 1984, Graves and Finck, 1988, McClenaghan and Dilabio, 1993)   The relative chronology of ice flow phases developed through analysis of superimposed striae ("erosional stratigraphy" - Stea *et al.* 1992a) was verified by correlation with depositional stratigraphy

About 20% of the Eastern Shore study region can be characterized as bedrock-controlled topography or bedrock (Map 1)   This can be subdivided into greywacke and granite types of country (Goldthwait, 1924, Roland, 1982)   Areas underlain by Devono-Carboniferous

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granites consist of low, rounded hills with relief amplitudes less than 20 m   The topography

is random and irregular   Large, rounded perched boulders are common ranging from less

than a meter in diameter to a maximum of 50 m   Valleys between bedrock highs are

commonly filled with sediment which may typically be a stony diamicton at the base, overlain

by waterlain sediments and peat in low-lying regions

The dominant bedrock type is metagreywacke of the Meguma Group (Schenk, 1971)   The

greywacke topography consists of long, low ridges running east to west   Like the granitic

areas, the intervening hollows are swampy and filled with a stony diamicton, sand and peat

Trellis drainage is developed in many areas   Small and large scale glacial erosional features

are well developed on the bedrock surfaces

Most of Nova Scotia is covered with glacial drift molded into a variety of landforms   Two

common glacial landforms in Nova Scotia are till plains and streamlined drift or drumlins

Boulton (1990, p 15) suggested that "there is no fundamental reason why subglacial

sedimentary processes should be different in kind between glaciers terminating in water and

those terminating on land"   The sedimentology and stratigraphy of onshore tills provide a

model for the offshore   In the following subchapters the stratigraphy, sedimentology and

lithology of till sheets on land are examined in detail to determine the local and regional

variability of till properties and hence the applicability of longer-ranged, onshore-offshore

correlations

4.2 STONY TILL PLAIN

4.2.1 Morphology

A till plain is defined (Goldthwait, 1989, p 274) as a nearly flat, or slightly rolling, and gently inclined plain with mostly thick cover, often with multiple till layers (varying compositions) and nonglacial beds, completely masking bedrock undulations The "Stony Till Plain" is defined by irregular, hummocky topography or topography characterized by linear, en-echelon ridges (ribbed moraine) with large boulders (from <1 m up to 20 m in diameter) strewn on the surface Ribbed moraine is best developed in southern Nova Scotia near Kejimikujik Lake (Map 1) and in the Chignecto Peninsula (Map 1, Stea *et al.*, 1986) In land areas these ribbed moraine are occasionally found draped over drumhnoid landforms Ribbed moraine have also been identified in the offshore regions using multibeam imaging (Figs 40, 51) In the offshore areas ribbed moraine are also draped over drumlins (Fig 51) Drift thicknesses in the stony till plain vary widely, generally increasing from 1-5 m in upland areas (>200 m elevation) to >7 m along the coast (Fig 60)

4.2.2 Stratigraphy and Lithology

Along the Eastern Shore study region the stony till plain consists of a clast-supported, sandy diamicton derived almost exclusively from local bedrock sources and characterized by a high percentage of angular, cobbles and boulders (Figs 14, 61) It has been termed the Beaver River Till from the type section near Yarmouth, Nova Scotia (Map 1, Grant, 1980b, Williams *et al.*, 1985) For this study three textural and lithological "facies" of the Beaver River Till have been differentiated: ST/A, ST/B and ST/C Facies "ST/A" is a olive-bluish grey, clast-supported, sandy diamicton associated with ground or ribbed moraine regions It has a

Figure 60. Generalized cross-section through the "stony" till plain and drumlins along the Eastern Shore of Nova Scotia

LEGEND

- Glacio fluvial deposits
- Hummocky Ground Moraine
- Stony Till Plain granite, greywacke, slate derived facies
- Silty Till Drumlins Lawrencetown till
- Hartlen till
- Residuum
- Bedrock

NW

ATLANTIC UPLANDS
PHYSIOGRAPHIC PROVINCE

Granitic rocks Meta greywacke Slate

SE ATLANTIC OCEAN
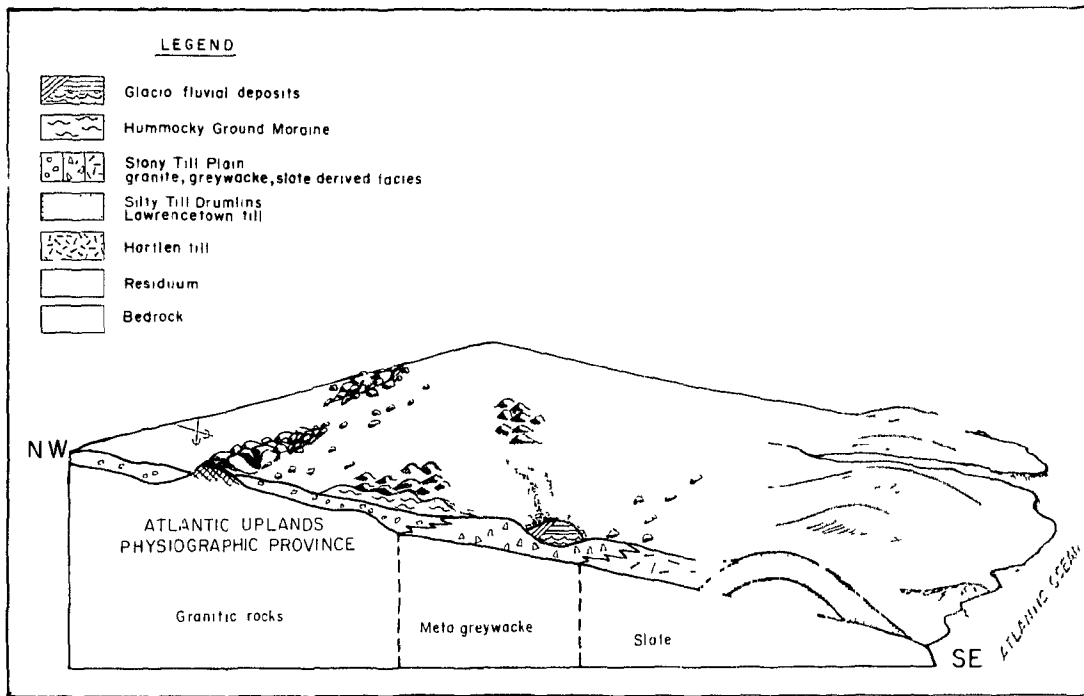
Figure 60.

Figure 61. Gravel/sand/mud ratios of tills along the Eastern Shore of Nova Scotia. Field A: Beaver River Till Field B: "Drumlin" tills- Lawrencetown and Hartlen Tills. (after Nielsen, 1976).
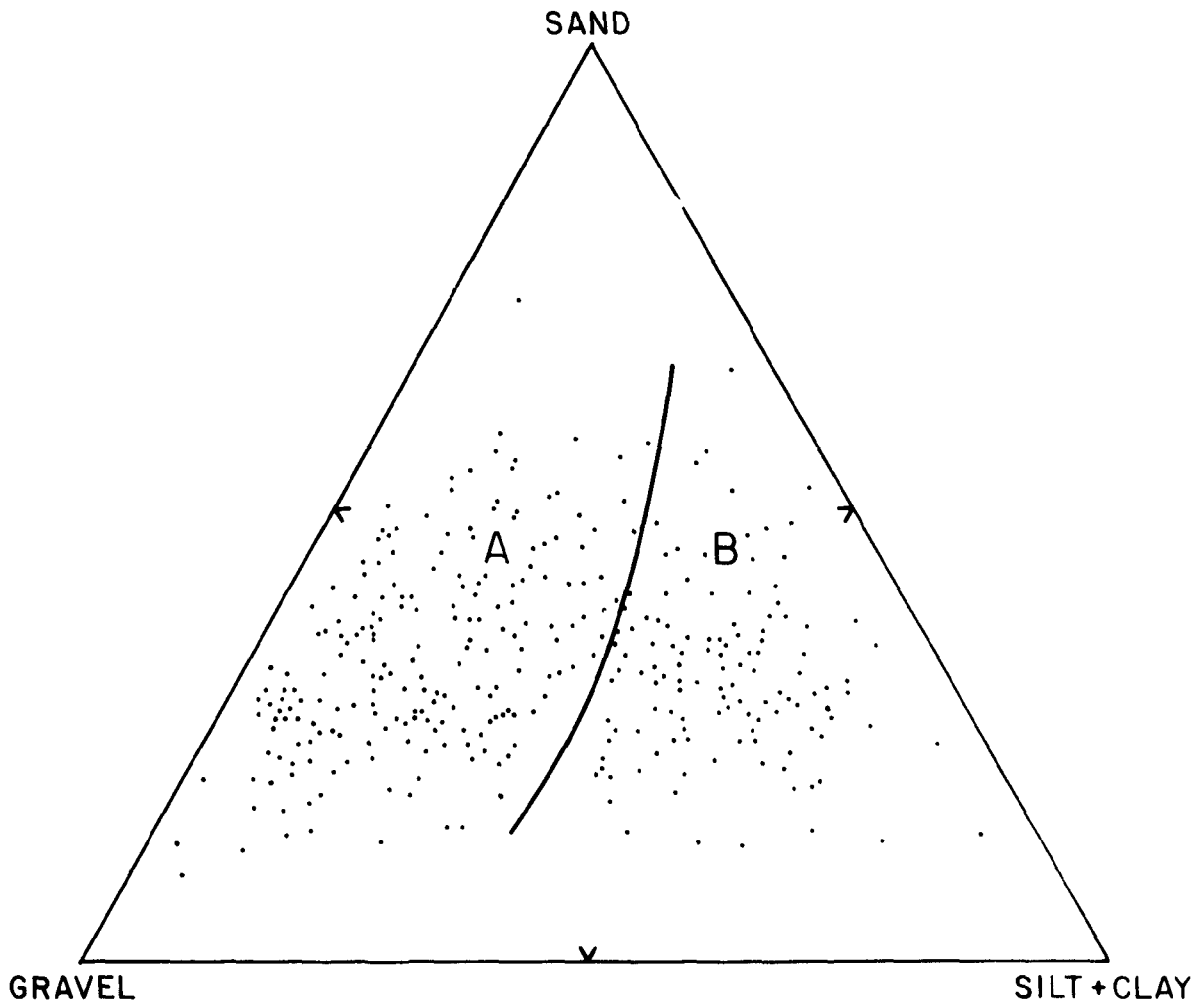
Figure 61.

homogenous, autochthonous composition with pebble percentage of the underlying or adjacent rock unit (in the sampling area mainly Meguma Group metasediments) averaging 86% and generally greater than 90%, whereas foreign or non-Meguma Group pebbles average 6% (Table 8, Fig 62) ST/A averages 64% gravel or clast weight percent with a matrix weight percent average of only 37% and a clast/matrix ratio of nearly 2 (Table 8, Fig 61) Only an average of 2% of the clasts are striated (Table 8) Facies ST/A covers most of the Eastern Shore study region (Map 1) Facies "ST/B" is similar in colour and texture to ST/A, but is found near drumlin fields and on top of drumlins It has inherited components of older tills, either directly as till inclusions or indirectly with higher erratic percentages Meguma metasedimentary (local) pebbles average 79% while foreign percentages average 19% Facies "ST/C" differs from the previous two facies with a coarser matrix texture and gravelly-sand and sand inclusions

4.2.3 Mushaboom Reference Section

A reference section for the stony till plain is a borrow pit described previously by Stea and Fowler (1979), located approximately 100 km east of Halifax, south of a contact between a large granitic pluton (Musquodoboit Batholith) and Meguma group metasediments (Keppie and Muecke, 1979, Fig 1, Section 61, Map 1) Several southward-trending Lawrencetown Till drumlins occur north of the section Bedrock outcrops nearby revealed parallel striae sets trending 175° (oldest) and 155° (youngest) (Map 1)

TERRESTRIAL TILLS						
Beaver River Till			Lawrencetown Till			Hartlen Till
Facies	ST/A	ST/B	ST/C	LT/A	LT/B	LT/C	
No.->	10	2	----	10	7	7	5
Gravel %	64	50		19.7	28.5	27.0	24.1
Matrix %	37	52		81.2	72.7	74.5	76.9
Ratio	1.9	1.1		0.3	0.4	0.4	0.3
No.->	33	8	9	16	16	29	21
Meg%	86	79	77	47	59	70	68
Grnt%	8	3	6	4	2	4	14
For%	6	19	17	49	39	26	18
No->	31	6	9	15	14	20	15
Striae %	2	6	8	12	18	10	9

Table 8. Average values of lithic parameters for terrestrial tills in the study region.

Figure 62. Triangular plots of the ratio of percentages of Meguma metasedimentary pebbles, granitic (Meguma Zone granitic plutons) and "foreign" or erratic pebbles (from terranes outside the Meguma Zone). Sample locations given in Fig. 7 and data in Appendix 8 Beaver River Till facies ST/A and ST/B are lumped together as they show no significant differences in pebble percentages The same is true for Lawrencetown Till facies A and B.

STONY TILL PLAIN

MEGUMA

☐ STONY TILL FACIES A+B

▦ STONY TILL FACIES C

GRANITE

FOREIGN

DRUMLINS

▨ LAWRENCETOWN TILL FACIES A+B

▨ LT HYBRID FACIES C

▨ HARTLEN TILL

Figure 62

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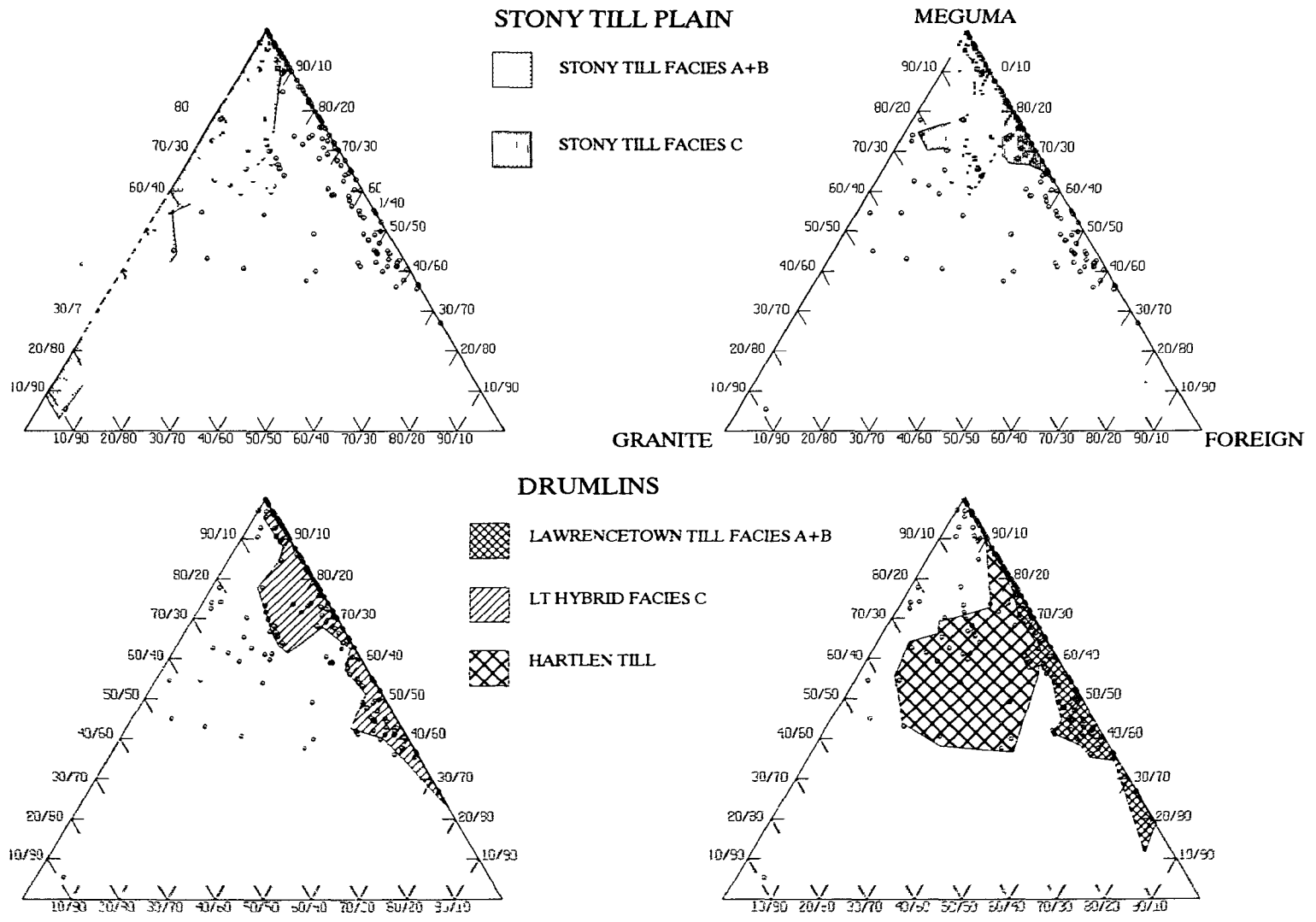
4.2.3.1 Stratigraphy and Lithology

At this site 14 m of bouldery, clast-matrix supported, sandy diamicton (Beaver River Till) overlies metagreywacke bedrock (Fig 63) The stony diamicton contains 55-75% metagreywacke clasts of the underlying Meguma Group Goldenville Formation and 21-45% clasts derived from the Musquodoboit Batholith, 100 m to the NW (Fig 63) The abundance of granitic clasts within the section implies southeastward clast dispersal from the Musquodoboit Batholith, rather than southward, parallel to the drumlin-forming flow phase which would not have crossed granitic rocks (Fig 63) The precise azimuth of flow is uncertain, because of variable and indistinct till fabrics (Graves and Finck, 1988) Clast/matrix weight ratios in this section vary from 0 9 to 2 0, compared with regional average values of less than 0 4 for the Hartlen and Lawrencetown Tills (Table 8, Fig 63) This stony diamicton is capped by a surface boulder layer dominated by granites Large, bluish, metagreywacke and smaller, white, megacrystic, granitoid boulders are found embedded within the section (Fig 63) The clasts are generally angular to subangular with no evidence of surface erosional markings such as striations Pebbles do not display the distinctive, glacier flat-iron shapes like the metagreywacke-dominated Hartlen Till at West Lawrencetown and Wine Harbour

4.3 STREAMLINED DRIFT-DRUMLINS

4.3.1 Morphology

The most prominent glacial landforms in the Eastern Shore terrestrial study area are drumlins They have a characteristic shape defined by a steep, up-glacier facing (stoss) side

Figure 63   Location, stratigraphy, lithology and clast/matrix weight percent ratios of till

samples of the Mushaboom section (Fig 1, Section 61-Map 1)   The dashed ᴡᴇ:.ern refers to

Meguma metasediments whereas the dotted pattern to Meguma Zone (Musquodoboit

Batholith) granitic lithologies   On the lithology profile plot the non-shaded portion (2%) is

the non-Meguma Zone component of the clast fraction

Granite

Butler Lake

Drumlins

Meguma Group metasediments

MUSHABOOM HARBOUR

0   1 km

Clast/matrix ratio

0   50   100   1   2

3

metagreywacke boulder

Sample site 2

granite boulder

5m

1   Beaver River Till (ST/A)

Meguma outcrop

0
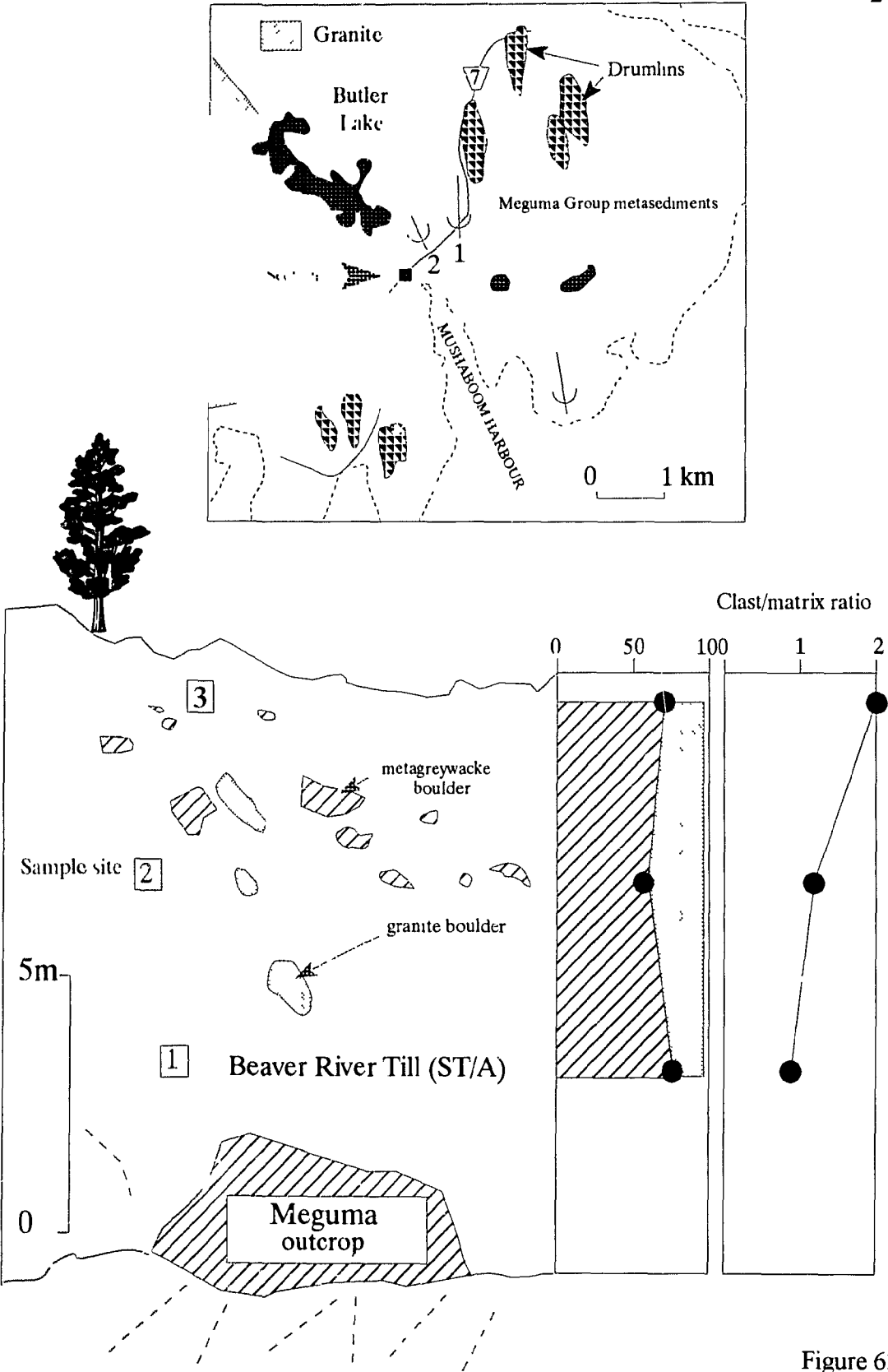
Figure 63

and a gentler lee slope (Fig. 51). Nova Scotia has 4 major drumlin fields with thousands of individual drumlins (Map 1). The long axes of drumlins are parallel to the ice flow that formed them (Flint, 1971). V-shaped, "palimpsest" drumlins are present in Nova Scotia drumlin fields with axes parallel to both earlier and later ice flow phases (Stea and Brown, 1989; Stea, 1994). Drumlins are generally drift-cored and can exceed 30 m in total thickness at the stoss summit.

4.3.2 Stratigraphy and Lithology

Drumlin sections along the Eastern Shore reveal thick, predictable drift sequences which can be correlated regionally (Stea and Fowler, 1979). At the core of many drumlins is a grey, overconsolidated, matrix-supported, silty diamicton (Hartlen Till) overlain by a reddish, erratic-rich, matrix-supported, silty diamicton termed the Lawrencetown Till. The contact is sharp, often associated with striated, bullet-shaped boulder horizons or pavements (Grant, 1963; Nielsen, 1976). The red matrix colour of the Lawrencetown Till is very distinctive, entirely foreign to the Meguma Zone, which is comprised largely of grey and black slates, metawackes and white granites. In some sections the Beaver River Till (ST/B) overlies the Lawrencetown Till with an erosive contact (Fig. 64).

The Lawrencetown Till is divided into three textural facies (LT/A, LT/B and LT/C). Facies "LT/A" is a reddish, muddy diamicton with a high percentage of foreign (non-Meguma Zone) lithologies. It averages 20% gravel and 80% matrix regionally with a clast/matrix ratio of 0.3 (Table 8). The percentages of Meguma Group and foreign lithologies are nearly equal (47 and 49% respectively; Table 8). Facies "LT/C" is a brownish, sandy diamicton containing an average of 27% gravel and 73% matrix (sand+mud). It has generally higher percentages

Figure 64. (A) Three tills exposed in a drumlin section near Smith Point, Nova Scotia. The lowest unit is the Hartlen Till, the middle unit is the Lawrencetown Till and the upper unit the Beaver River Till (ST/B) (B) Beaver River Till (ST/B) overlying oxidized Hartlen Till at the Wine Harbour Section. Note the abundant boulders in the younger Beaver River Till.

A

B
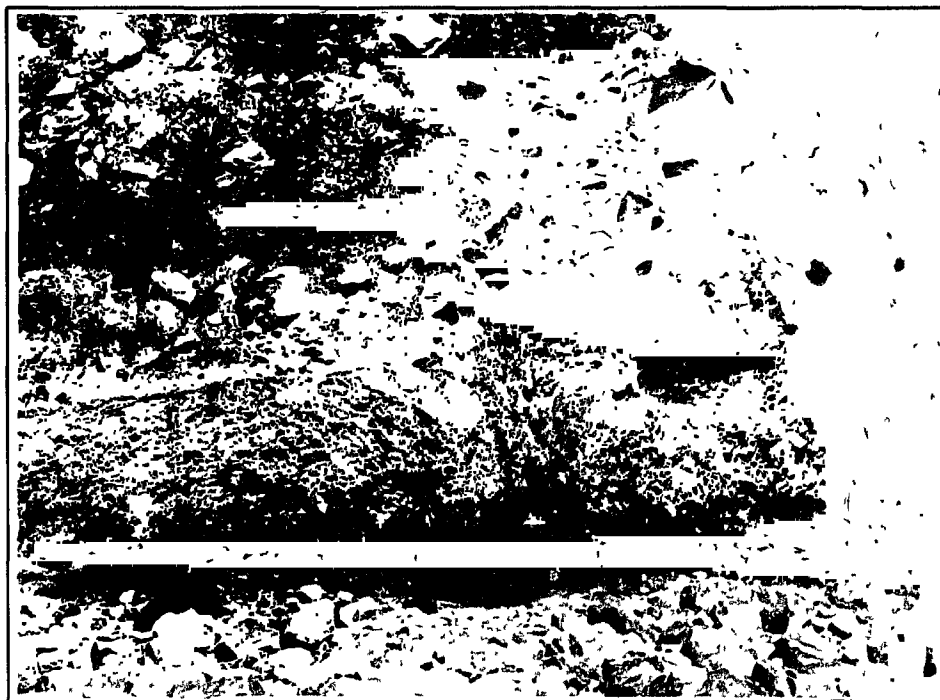
Figure 64.

of Meguma pebbles (70%, Table) and less foreign or erratic lithologies (26%, Table 8)

Facies "LT/B" is intermediate in lithic properties between these two "end-members" (Table

8) In many drumlin sections a tripartite diamicton sequence is recognized, with the Beaver

River Till (ST/B) overlying the Lawrencetown and Hartlen Tills (Fig 64) Grant (1963)

originally interpreted these diamicton units as tills formed by separate glaciations, with

contacts (including boulder pavements and thin waterlain units) representing interstadial

intervals Nielsen (1976) described this widespread three-till sequence as a single depositional

package from one ice flow encompassing lodgement, and englacial and supraglacial melt-out

tills (Nielsen, 1976) The author's present view is a compromise of these positions, with each

till unit assigned to separate phases of ice flow from evolving ice centres and divides without

intervening nonglacial intervals (Stea *et al.*, 1992 a, c)

4.3.3 West Lawrencetown Reference Section

The West Lawrencetown section is in a wave-eroded drumlin located 3 km east of Cole

Harbour near Halifax (Fig 1, Section 56-Map 1), first described by Grant (1963) and later

by Nielsen (1976) The drumlin has a v-shaped, lobate form with a main axis trending 150°

and another axis trending 185° (Fig 65) Between the two lobes is a circular depression,

partially eroded by the sea with a base resting on a lower diamicton unit. The depression was

originally interpreted as a kettle (Grant, 1963, p 107) Bedrock outcrop on the western flank

of the drumlin complex reveals wide, parallel grooves 10-40 cm in width and striae that trend

155° The sense of flow is determined by nailhead striae (Prest, 1983) Another distinct set

of slightly divergent, finer striae trending 180-190° cut across the older grooves inscribing

only the north-facing slopes (cf Lowell *et al.*, 1990) Three sections were profile-sampled

in order to assess local-scale lithic variations in the till sheets

Figure 65   Stratigraphy, till fabric, and locations of detailed profiles (1, 2 and 3) at the West

Lawrencetown reference sec.ion (Fig 1, Section 56, Map 1)   Arrows on the map delineate

distinct lobes of the drumlin   Bedrock striae are shown on the upper map. Fabric 1 is located

beside profile 1 (black square)   Fabric 2 is located near profile 2   Till fabrics are represented

by contoured lower-hemispheric, equal-area projections of the trend and plunge of the a-axes

of 50 elongate stones (3 1) (modified after Stea, 1994)   Black dots represent locations of

stoss/lee (bullet) boulders with directional data presented in Stea (1994)

FABRIC (1)

LEGEND
- 0-2%
- 2-6%
- 5-10%
- 10-14%

TREND	PLUNGE	ICE FLOW
3340	25	1540

EIGENVALUE
698
246
056

Conrods Head

Atlantic Ocean

0   500m

FABRIC (2)

LEGEND
- 0-2%
- 2-6%
- 6-10%
- 10-14%
- 14-18%

TREND	PLUNGE	ICE FLOW
1001	2	1001

EIGENVALUE
756
191
053

1   **2**   **3**

Lawrencetown Till facies C

Lawrencetown Till facies A

Hartlen Till

HARTLEN TILL 4

LEGEND
- 1-5%
- 5-10%
- 10-15%
- 15-20%
- 20-25%
- 25-30%

TREND	PLUNGE	ICE FLOW
3346	92	1546
2405	235	
845	645	

EIGENVALUE
8102
1547
0351

LAWRENCETOWN TILL 3

LEGEND
- 1-5%
- 5-10%
- 10-15%
- 15-20%

TREND	PLUNGE	ICE FLOW
3568	84	1768
927	349	
2552	538	

EIGENVALUE
6915
2489
0596

Figure 65.

255

4.3.3.1 Stratigraphy and Lithology

The southern, tapered end of the drumlin has been truncated by the sea. Two exposures separated by the inter-lobe depression reveal two compositionally-distinct diamicton units termed the Hartlen and Lawrencetown Tills (Fig. 65). The Hartlen Till was originally designated by Stea and Fowler (1979) for the indurated "core" diamicton of drumlins along the Atlantic Coast whose type section is at Hartlen Point a few km east of Cow Bay (Section 55-Map 1). The Lawrencetown Till defined by Grant (1975) represents the reddish drumlin "mantle" till. The Lawrencetown Till type section is designated as Sandwich Point, south of Halifax (Section 53-Map 1, Grant in Williams *et al.*, 1985).

The Hartlen Till is a grey, matrix-supported, silty diamicton. It is compacted or overconsolidated, forming steeper slopes (60 degrees) than the overlying Lawrencetown Till. Bullet-shaped, stoss-lee boulders embedded within the Hartlen Till and at the Hartlen-Lawrencetown Till contact (Fig. 65) trend parallel to the major drumlin axis (Stea, 1994). Fabrics in the Hartlen Till trend parallel to the main drumlin axis and local bedrock striae (Fig. 65). Pebble counts in the Hartlen Till average 59% metagreywacke, (derived from of the underlying Cambro-Ordovician Meguma Group), 23% whitish, megacrystic Meguma Zone (MZ) granitic pebbles and 17% erratic (non Meguma Group) pebbles (Fig. 66). Erratic lithologies include red and grey siliciclastic rocks, pink, alkali-feldspar granitoids, diorites and felsic and mafic volcanic rocks This pebble assemblage is derived from the Cobequid Highlands (Stea and Mott, 1990; Stea, 1994, Table 2). The percentage of MZ granite and erratic pebbles increase to 40 and 20% respectively towards the top of the Hartlen Till in profile 3 (Fig. 66). Gravel percentages in the Hartlen Till vary from 19.4 to 32.5% (Figs 66, 67). Clast/matrix ratios in the Hartlen Till at this section vary from 0.2 to 0.4 (Appendix 9). Striae percentages vary from 4-13%.

Figure 66   (Top) Simplified geological map of central Nova Scotia showing the upland

igneous and metamorphic complexes of the Avalon and Meguma Zones and the pebble

assemblage source areas for the Hartlen and Lawrencetown Tills (Facies A) from Stea,

(1994)   (Bottom) Stratigraphy and vertical variation in pebble lithology and texture

(clast/matrix ratio) for profile 1 (see Fig 65 for location)   Flow directions for till units are

indicated by erratic boulder assemblages in the Lawrencetown Till (after Stea, 1994)   The

patterned region between sample points on the pebble graph represents the variability between

duplicates counts on the same sample
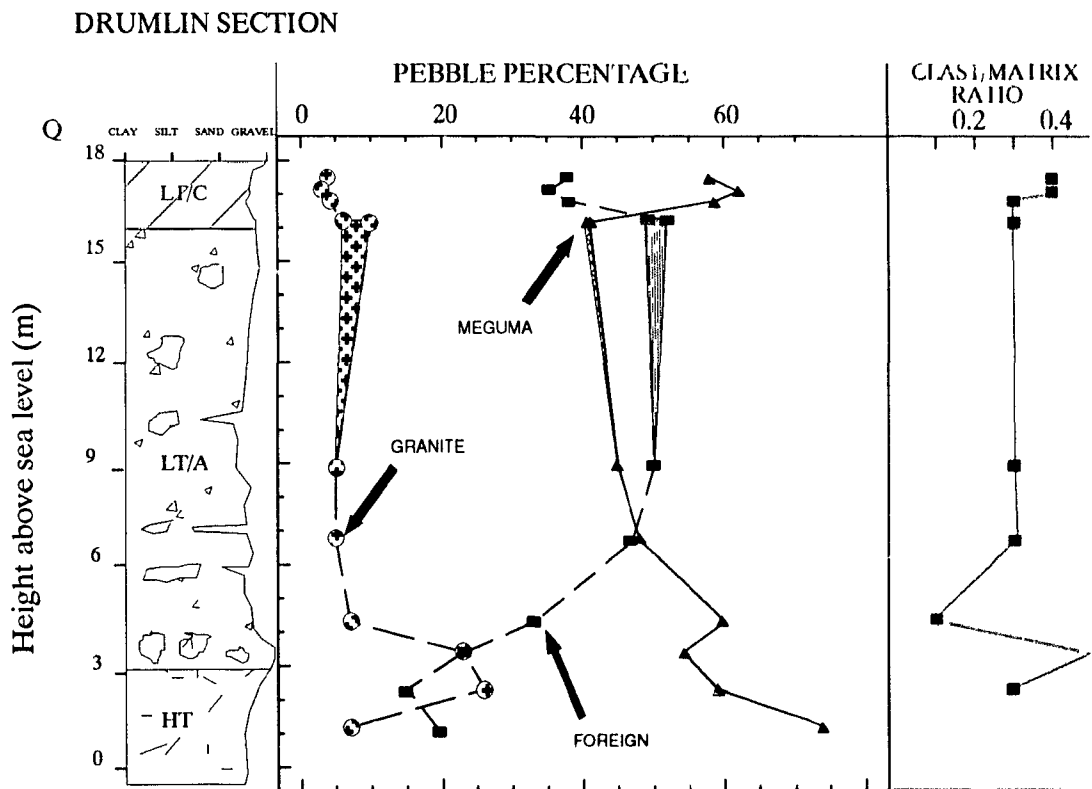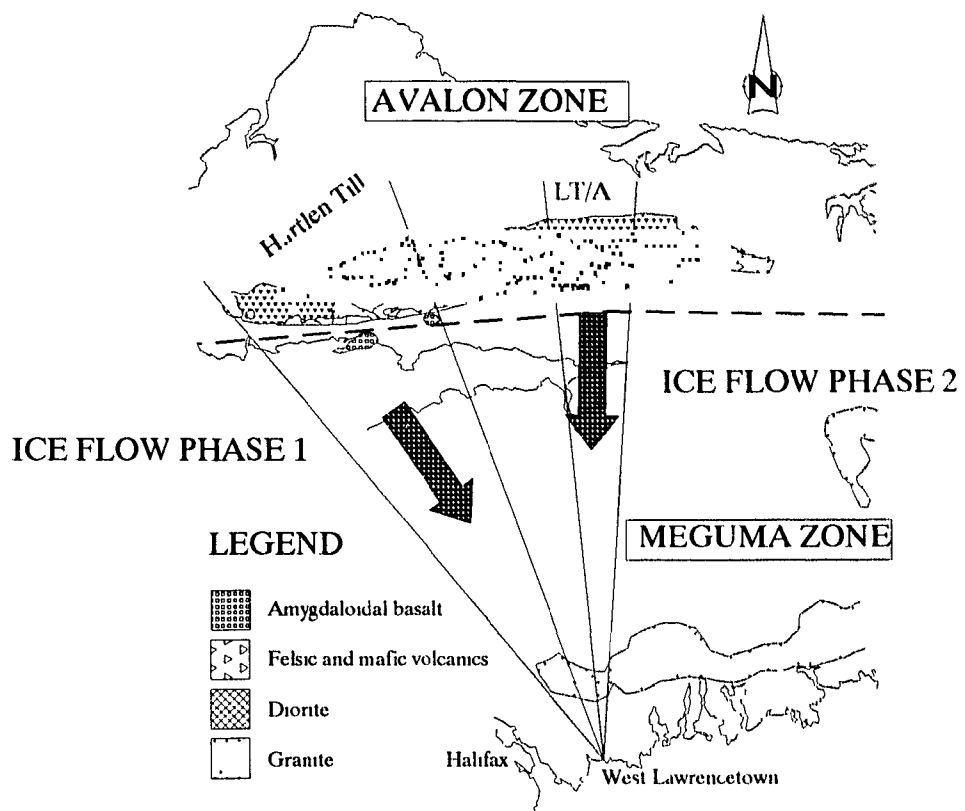
Figure 66.

A reddish, muddy, matrix-supported diamicton (Lawrencetown Till Facies A) overlies the

Hartlen Till with a knife-sharp contact It is distinguished from the Hartlen Till by its red

colour and high erratic content (Figs 66, 67) The Lawrencetown Till can be divided into an

upper, sandy (LT/C) and a lower clay-rich facies (LT/A) with sand inclusions It is thickest

in the southern lobe section of the drumlin, whereas the Hartlen Till is thickest in the

southeastern lobe of the drumlin (Fig 65) LT/A exhibits a southward-trending till fabric,

parallel to the youngest striae set on the adjacent bedrock outcrop and lobate drumlin axis

In all profiles sampled, erratic pebble percentages increase dramatically in the Lawrencetown

Till concomitant with the decline in MZ granite and Meguma Group metasediment

percentages (Figs 66, 67) The erratic fraction is dominated by distinctive hornblende-

bearing, equigranular, salmon-pink granites with varying textures, followed by granodiorite-

diorites, and mafic and felsic volcanics in order of abundance Table 9 is a list of erratic

lithologies visually identified by Dr H V Donohoe (pers comm , 1991) from a large sample

(30) of sectioned boulders The source of the plutonic and volcanic erratics in the Hartlen and

Lawrencetown tills is likely to be the eastern Cobequid Highlands, 80 km north of the section

(H V Donohoe, pers comm , 1991, Fig 66) The dominance of granites and diorites would

preclude the Antigonish Highlands as a possible source (Table 2) Gravel weight percentages

in LT/A vary from as low as 8% to 35% (Figs 66, 67) The clast/matrix ratio varies from 0 1

to 0 5 (Appendix 9) Clast striae percentages average 12% LT/C exhibits a marked increase

in the percentages of local Meguma Group pebbles (av 57%, Figs 66, 67) and a sympathetic

increase in clast/matrix ratio (0 3 -0 4, Fig. 66). Striae percentages vary from 7-11% in this

facies (Figs 66, 67)

West Lawrencetown Section Erratic Boulder Assemblages
A. white, megacrystic, biotite granodiorite; monzogranite
B. metapelites; grey, red sandstones; limestone
C. foliated, hornblende-bearing granodiorite
D. Foliated pink alkali-feldspar granite
E. felsic and mafic volcanics; subvolcanics
F. metasomatized diorite; diabase; fine grained dark diorite
G. rapakivi-textured granite; fractured granite; microporphyritic granite; hornblende monzogranite; hornblende granite; altered pink alkali-feldspar granite; micrographic syenite
H. Amygdaloidal (zeolitic) and vesicular basalt

Table 9. Lithologies from visual identification of sectioned boulders from the West Lawrencetown Section.

Figure 67 Stratigraphy and vertical pebble lithology variations in profiles 2 and 3 (see Fig 65 for location)
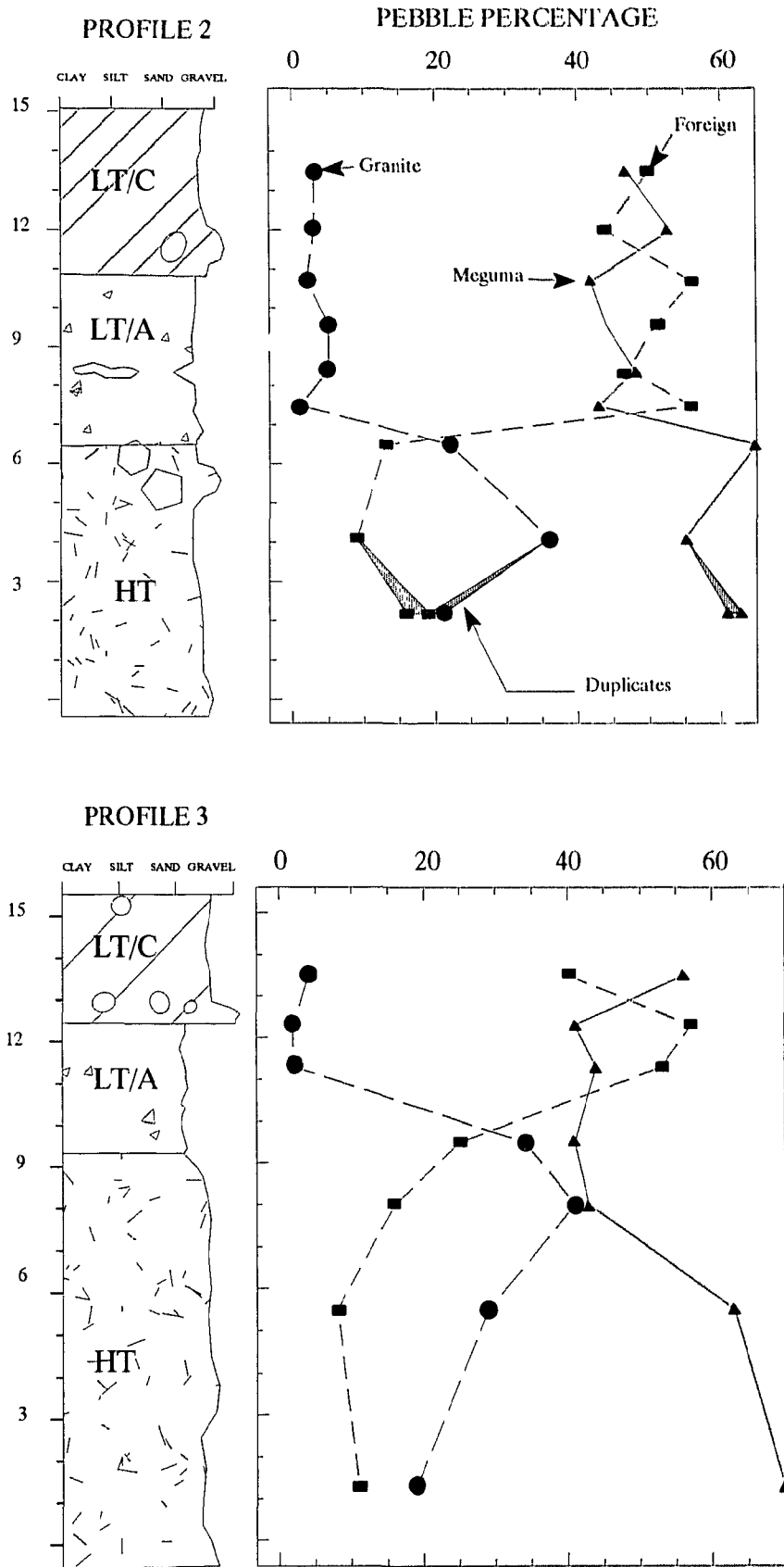
Figure 67.
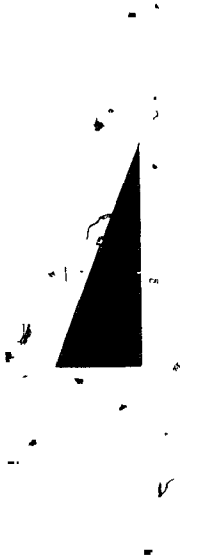
PM-1 3½"×4" PHOTOGRAPHIC MICROCOPY TARGET
NBS 1010a ANSI/ISO #2 EQUIVALENT

1.0	2.8	2.5
1.1	3.2	2.2
	3.6	2.0
	4.0	1.8
1.25	1.4	1.6
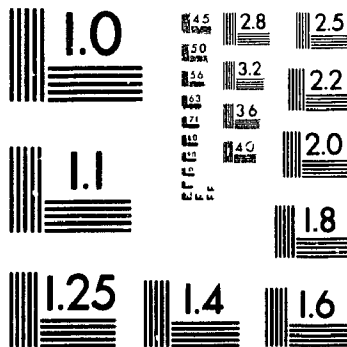
PRECISIONˢᴹ **RESOLUTION TARGETS**

4.3.4 Wine Harbour Reference Section

The Wine Harbour reference section is located 180 km northeast of Halifax along the Eastern Shore at Wine Harbour Bay (Fig 1, Section 64-Map 1) Two drumlins are cut transverse to 160°-trending long axes The section is located on the easternmost of two drumlins Drumlin long axes trends vary from 150° to 175° within the region of the sections and in the Country Harbour drumlin field (Map 1) Bedrock striations mapped locally also show three main trends, the oldest sets trending 150° to 160°, followed by minor sets of parallel striations with mean trends of 133° and 179°

4.3.4.1 Stratigraphy and Lithology

The Wine Harbour Section has been previously described by Stea and Fowler (1979) and Stea and Brown (1989) They recognized four main drumlin diamicton unit from base to top

1 A greyish-red to olive-grey, matrix-supported, silty diamicton with few stones (Unit 1)

2 Recumbently-folded laminated silt, sand and clay strata (Unit 2, Fig 68) which may underlie Unit 1, but the contact relationships are unclear

3 A brown, stony, silty diamicton (Unit 3) which comprises most of the drumlin

4 A reddish, sandy diamicton (Unit 4)

The section was revisited by the author in 1991 and 1992 Unit 3 was further subdivided into two units, a brown, matrix-supported, sandy-silt diamicton (Unit 3) which comprises much

of the drumlin and a sandy diamicton (Unit 4) with a higher clast/matrix ratio, which c..n be found on both flanks of the drumlin in gradational contact with Unit 3 (Fig 68) Separating Units 1 and 3 east of the drumlin core are lenticular pods or inclusions of silty-sand with deformed strata The reddish diamicton is now termed Unit 5

Unit 1 has the lowest percentage of local Meguma metagreywacke pebbles (57%) Local pebble percentages increase in Unit 3 to 66-72% (Fig 69) Unit 4 has the highest percentage of local Meguma Group pebbles (82%) Meguma Zone granites are only found in Unit 3 from a sample in the centre of the drumlin attaining 3% of the entire pebble fraction (Fig 69)

Erratic pebbles present in the Wine Harbour section fall into 6 main lithological groups (Fig 70)

1   Hard, maroon to red mudstone

2   Greenish and grey, coarse, feldspathic arenite

3   Red-orange-purple-grey porphyritic felsic and intermediate volcanic rocks

4   Reddish, altered, porphyritic granitoid rocks

5   Hard, green and black, finely laminated mudstone

Unit 1 has the highest erratic percentages in the section (43%), dominated by volcanic rocks and hard, red mudstones, typical rocks of the Antigonish Highlands (Fig 70, Table 2) The Fraser Brook member of the Keppoch Formation in the Antigonish Highlands is the probable source of red mudstones and volcanics (Murphy et al., 1991) Green, hard, finely-laminated

Figure 68   Stratigraphy of the Wine Harbour section (Fig 1, Section 64-Map 1). (A) Photo

log of the eastern half of the drumlin at Wine Harbour Bay. (B) Close up of folded and

boudinaged sand beds and silt and clay laminae (after Stea and Brown, 1989).

(C) Photograph of the eastern part of the drumlin exposure showing Units 1 (Hartlen Till) and

4 (Beaver River Till, see Fig. 64 B) (D) Interpretation of the drumlin section.

SW　　　　　　　　　　　　　　　　　　　　　　　NE

A

B

UNIT 2

LEGEND

UNIT 5

UNIT 4

UNIT 3

UNIT 1

SAND INCLUSION

C

D

0　　　　　　　　　　100m
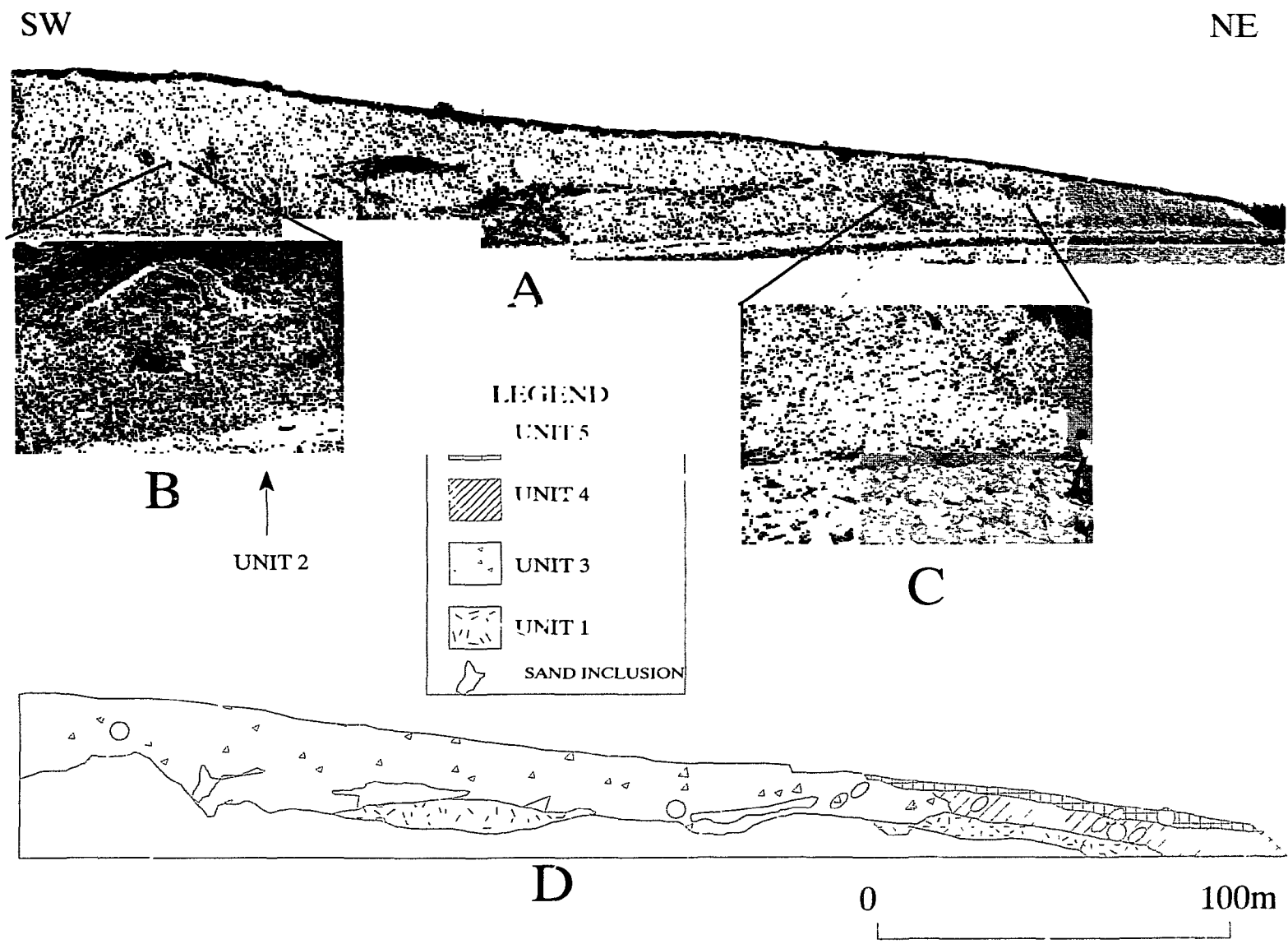
Figure 68.

Figure 69. Pebble lithology of selected samples throughout the Wine Harbour Section. Pie diagrams show the percentages of local Meguma Group pebbles (metagreywacke), an' the percentages of "foreign" and Meguma Zone granites (SMB-South Mountain batholith-type granites).

1   2   3   4 56

1   3   4

4   5   6

Meguma

Banded silt

Other granites

SMB granite

Volcanic

Green sandstone

Maroon siltstone

Figure 69

268
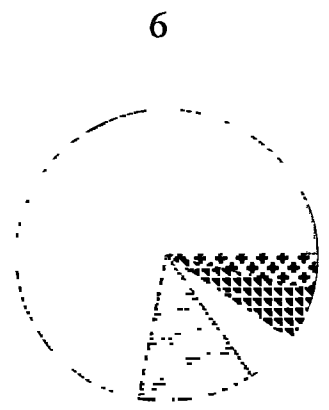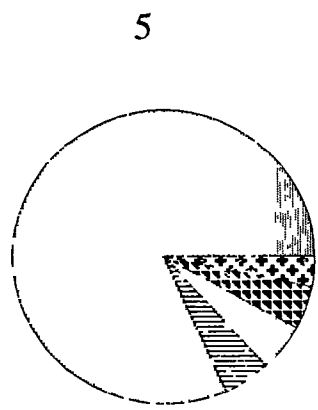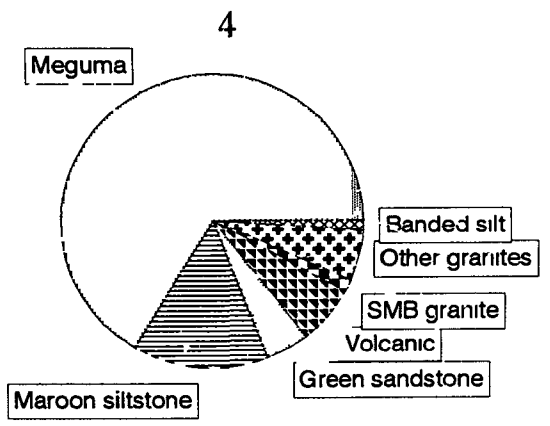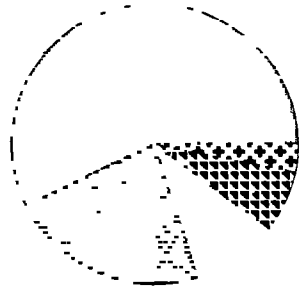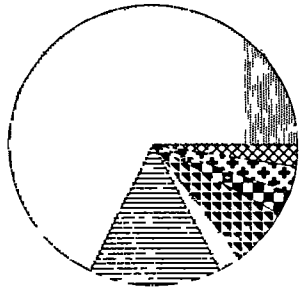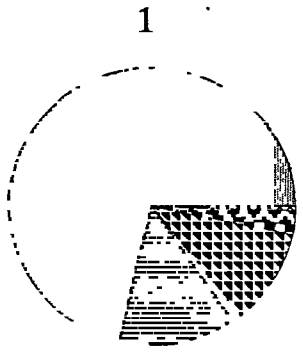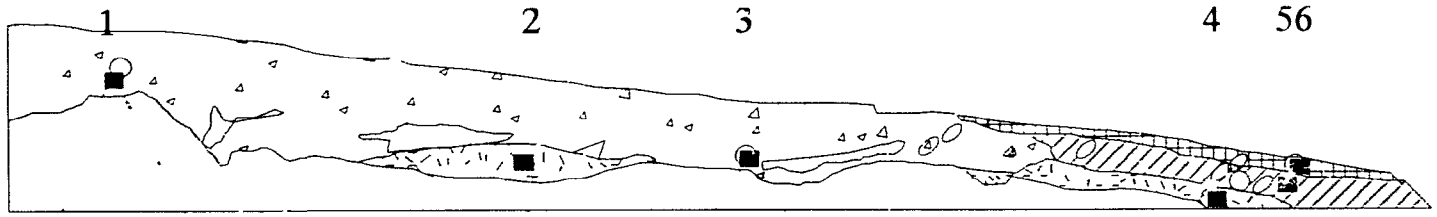
Figure 70   (Top) Dispersal of pebble and boulder assemblages to sample points along the Eastern Shore study area (Legend on Fig. 66) (after Stea and Murphy, 1994). Areas of geology in black are appinite-diorite complexes. Source areas are defined by pebble-boulder assemblages, distinctive erratics (ie hornblendite, appinite) and boulder whole-rock geochemistry (Stea and Murphy 1994) (Bottom) Structural data from the Wine Harbour Section. Till fabric is represented by lower-hemispheric equal area projections of the trend and plunge of the a-axes of elongate stones (3:1) and simple rose diagrams depicting the long axis orientations of pebble-sided stones in till. Some structural data from the folded clay unit at the core of the drumlin (after Stea and Brown, 1989). Boulder long axis and upper surface striae orientation are depicted by striae symbols above boulders.
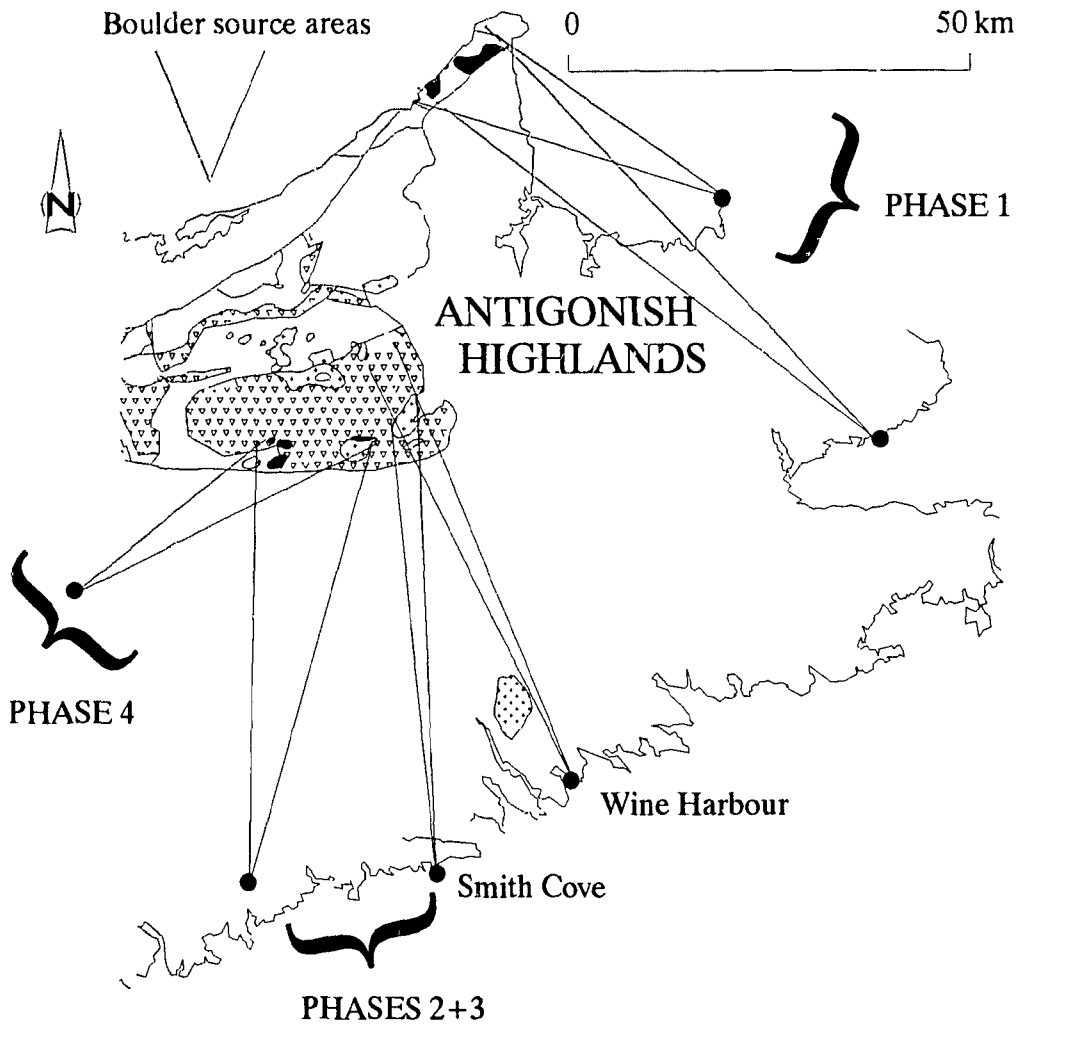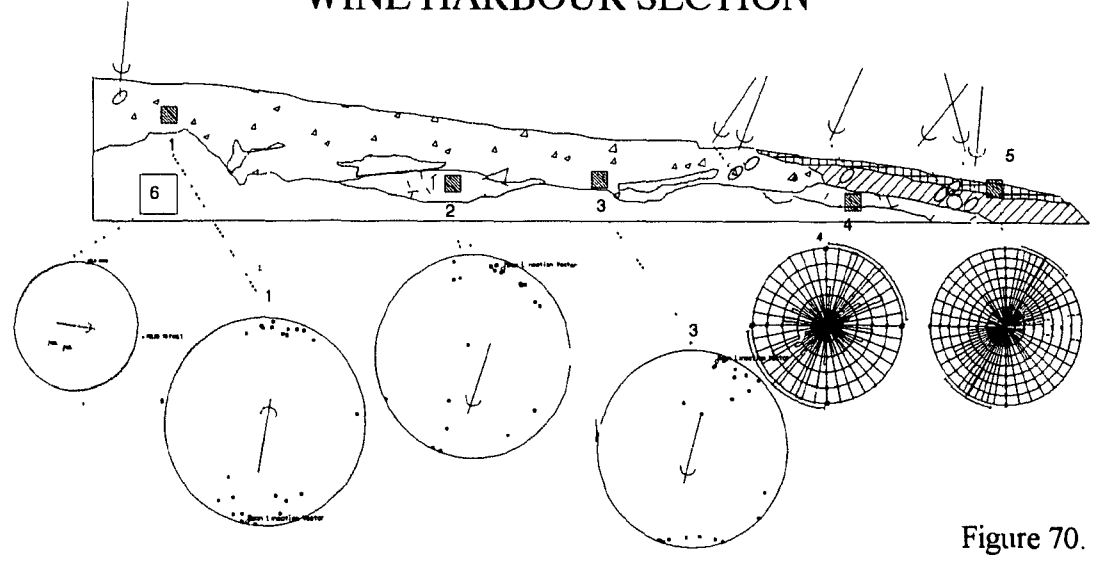
Figure 70.

siltstones occur in the Moose River Member of the Keppoch Formation. White, megacrystic monzogranite or granodioritic lithologies are probably derived from the Sherbrooke Pluton, 20 km to the northwest (Fig. 70). The flow direction of Unit 1 interpolated from this pebble assemblage, is between 150° and 160°. This is parallel with the drumlin axis, and the oldest striation set on adjacent rock outcrops. Pebble fabric in the unit, however, shows a southwest orientation, nearly perpendicular to the presumed ice flow based on provenance (Fig. 70). Stea and Brown (1989) interpreted this paradox as contour deflection of the formative ice around the incipient drumlin form. This anomalous fabric orientation persists into the drumlin core itself. A more likely explanation for the discrepancy of provenance and boulder and pebble fabrics is fabric overprinting or reorientation by a late southwestward (Phase 4) ice flow (Fig. 4), defined regionally by striae, erratic transport and esker orientations (Stea et al., 1992a, Map 1).

Unit 3 has lower erratic percentages than Unit 1 (28-37%) but the same pebble types are represented. The flow direction of Unit 3, interpolated from this pebble assemblage, is also between 150° and 160'. Glaciotectonic deformation in laminated, fine-grained sediments at the base of the drumlin section indicate a southeastward flow (Stea and Brown, 1989), but pebble fabric and boulder orientations are largely southward-trending.

Units 4 and 5, the uppermost till units, have the lowest percentage of erratic lithologies (18-28%) probably reworked from the older units. Till fabric, boulder striae and orientation indicate a southwestward ice flow (Fig. 70). Unit 4 can be correlated to adjacent ground moraine regions overlain by Beaver River Till (ST/A). Bedrock striations underneath sections of ST/A and till-embedded boulders are oriented 170° to 180°. The red coloration of Unit 5 may be derived from flow across red-beds within Carboniferous basins to the north and northeast.

Units 4 and 5 formed during late southward and southwestward flow events mapped regionally (Ice Flow Phases 3 and 4, Fig, Map 1) The decline in foreign pebble percentages is consistent with reworking of the underlying erratic-rich till units (1 and 3)

4.5 CORRELATION OF EASTERN SHORE TILL UNITS

A correlation diagram of Eastern Shore sections described here and on the Surficial Map of Nova Scotia (Map 1) is presented (Fig 71) Compacted, drumlin-base and core diamicton units with low clast/matrix ratios and moderate to high erratic contents are all correlated with the Hartlen Till at the type and reference sections at Hartlen Point (Map 1) and West Lawrencetown At several sections, waterlain units and boulder horizons (pavements) separate the Hartlen Till from later till units The Lawrencetown Till comprises all the reddish to brown, erratic-rich diamicton facies (LT/A/B/C) which overly the Hartlen Till They are distinguished from the Hartlen Till by stratigraphic position, less consolidation, higher erratic content, sand-silt interbeds and inclusions (Table 8) Drumlins throughout the Eastern Shore region display varying proportions of the Lawrencetown Till facies (Stea and Fowler, 1979) but all three facies are generally present within individual drumlins and drumlin fields The stony, locally-derived surface till (Beaver River Till) at Mushaboom, Smith Point (4 km east of Section 63, Map 1) and Holland Harbour (Section 65, Map 1) is the next youngest till unit It is lithologically and texturally distinct from the drumlin Lawrencetown and Hartlen Tills (Table 8) In areas remote from drumlin fields the Beaver River Till is compositionally uniform, consisting of 90% or greater local or underlying bedrock It is also distinguished from the drumlin tills by angular to subangular clast-shapes and few striated or bullet-shaped clasts (Table 8)

Figure 71   Correlation of major sections along the Er .tern Shore of Nova Scotia: l. West

Lawrencetown 2 Smith Point east (1) 3 Smith Point west (Fig 64) 4 Wine Harbour 5

Holland Harbour (Section 65-Map 1) 6 Mushaboom

1 HT = Hartlen Till

2 LT/A/C = Lawrencetown Till facies A and C

3 ST/A/B = Beaver River Till facies A and B

Figure 71.

ST/A ⎫ Beaver River Till (end member (A) and inherited (B) facies)
ST/B ⎭ *loose, stony, locally-derived, clast-matrix-supported, sandy diamicton*

LT/C ⎫ Lawrencetown Till (end member (A) and hybrid facies (C))
LT/A ⎭ *moderately compacted, polymictic, matrix-supported, reddish-brown to brown, sandy-silty diamictons*

HT Hartlen Till
compact, polymictic, grey-brown, silty diamicton
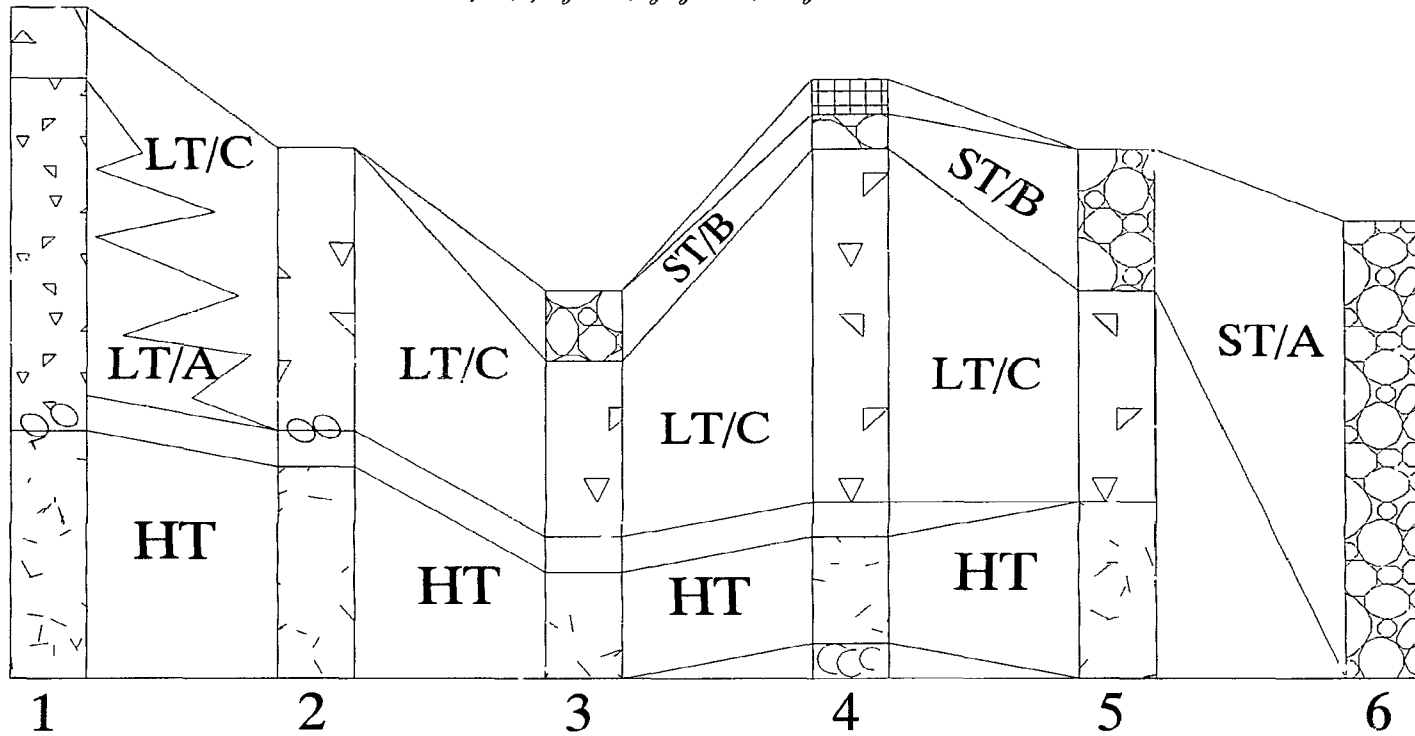
4.6 AGE

The till sequences along the Eastern Shore are interpreted to span the entire Wisconsinan (70-11 ka) A correlative of the Hartlen Till in central Nova Scotia overlies forest beds believed to encompass the Sangamon Interglacial interval (Mott and Grant, 1985; Sections 117, 120-Map 1) On the mainland of Nova Scotia, organic horizons have not been found within or between till layers, indicating continuous ice cover throughout the last glacial period (Stea et al., 1992c) Mid-Wisconsinan interstadial inter-till fossiliferous and organic sediments have only been found in northern Cape Breton Island (Grant, 1989)

4.7 INTERPRETATION

Fabric, striation and provenance data strongly imply that the drumlin diamictons (Hartlen and Lawrencetown Tills) were formed by successive, divergent ice flows from differing ice centres These drumlin diamictons are interpreted as subglacial, primary till based on over-consolidation, abundant striated bullet-boulders, and strong, unidirectional till fabrics (Dreimanis, 1989) Drumlins are largely relict from an early southeastward ice flow (Ice Flow Phase 1, Fig 4) During Ice Flow Phases 1a and 1b, southeastward ice flows from an Appalachian source glacier produced a fine grained, matrix-dominated till (Hartlen Till) as ground moraine and drumlins (Fig 4) Some of the fine-grained matrix material may have been derived from interglacial residuum, and perhaps pre-existing glacio-lacustrine deposits (Fig 72)

Some drumlins are palimpsest forms, moulded from proto-drumlins composed of the Hartlen Till during a southward flow that formed the Lawrencetown Till (Ice Flow Phase 2; Stea,

1994). The southward ice flow brought the "flood" of red, fine-grained material from the red beds in the Maritimes Basin north of the Cobequid Highlands (Boehner *et al.*, 1986) to the Atlantic Coast As the ice sheet crossed the Cobequid Highlands, red, fine-grained material, and highland clasts were shunted to an englacial position by upward vectors of flow and regelation (Boulton, 1975) or shearing (Sugden and John, 1976, Fig 72)

The autochthonous, Beaver River Till (ST/A/B/C) represents the last stages of ice formation during the Late Wisconsinan Late, southeastward ice flow events (Ice Flow Phase 3) formed the Beaver River Till and associated stony till plain Striae associated with Phase 3 are hard to differentiate from relict, Phase 1b southeastward patterns (Fig. 4) Coker *et al.* (1988) and MacEachern and Stea (1986) defined southeastward (140° to 160°) dispersal trains from known ore bodies of gold and related elements within the Beaver River Till Phase 3 flow appears to have shifted to the south in the vicinity of the Wine Harbour section

Ice Flow Phase 4 produced southwestward-trending striae, eskers and pebble-dispersal trains (Turner and Stea, 1987, Stea *et al.*, 1989) in northeastern Nova Scotia (Map 1) This flow produced thin, discontinuous, stony tills (Unit 5-Wine Harbour) and a few constructional till-landforms.

Diamictons termed the Beaver River Till are interpreted to be subglacial till based on these characteristics

1. Local derivation and ubiquitous areal extent (MacEachern and Stea, 1986)

2. Rapid transition from one dominant lithology to another across bedrock

contacts (Peltoniemi, 1985; Dreimanis, 1989). "Renewal" distances are generally less than 1 km (Graves and Finck, 1988).

3. Erosive lower contacts and till-inclusions of older tills (Nielsen, 1976).

A subglacial hypothesis is not supported by the lack of striated clasts and clast angularity. Stea *et al.* (1989) suggested that the contradictory properties of the Beaver River Till are an indicative of proximity to an ice divide, well documented over Nova Scotia (MacNeill, 1951; Hickox, 1962; Stea, 1984; Grant, 1989; Graves and Finck, 1988; Stea *et al.*, 1992c;). It may have formed underneath a thermally-variable glacier, with cold-based and warm-based zones (Hughes, in Denton and Hughes, 1981). This divide was short-lived, so the lack of significant transportation and abrasion may be a function of time within the traction zone or "maturity" or in the sense of Dreimanis and Vagners (1971). Basal velocities in the ice divide environment are low, hence transport in the tractional zone is limited. The Beaver River Till can be termed an "ice divide till" (Fig. 72).

Drumlins are rarely overlain by the lithologically homogenous, Beaver River Till, but rather "swim" within the stony till plain (Grant, 1963). A possible explanation for this phenomenon may be increased basal ice velocities due to sole lubrication (meltwater trapped in a low permeability clay till) and substrate deformation (Boulton and Jones, 1979; Clark, 1992; Hart and Boulton, 1992). Relatively high ice velocities will decrease mixing rates and maintain debris in transport (Clark, 1987). Lawrencetown Till facies C, is a result of "overprinting" by the ice from Scotian Ice Divide (Ice Flow Phase 3-Fig. 4). It is produced as fast-moving ice as it deforms the earlier drumlin tills (Fig. 72).

Figure 72 Schematic cross sections showing the genesis and source glaciers for the Eastern Shore till units

1 During Phase 1a and 1b, southward flow from Appalachian source glaciers (Fig 4) produced a fine grained, matrix-dominated till (Hartlen Till) as ground moraine and molded into drumlins Some of the fine-grained matrix material may have been derived from interglacial residuum, and perhaps pre-existing glacio-lacustrine deposits

2 Ice Flow Phase 2 stemming from the Escuminac ice Centre (Fig 4), produced a reddish, fine-grained, matrix-dominated till (Lawrencetown Till) that mantles drumlins This till is largely derived from englacial debris, produced when the glacier crossed the Cobequid Highlands to the north The Lawrencetown Till also contains inherited components of the Hartlen Till, derived from local erosion

3 During Ice Flow Phase 3 an ice divide developed over Nova Scotia itself, and a distinctive, sandy, clast-dominated till was produced This "ice divide till" is characterized by local transport, and lack of abrasion Drumlin tills were "overprinted" with local rocks creating Lawrencetown Till facies C Ice Flow Phase 4 was produced from reactivated glaciers remnant from the Scotian Ice Divide and produced thin, discontinuous, tills similar in texture to the Beaver River Till

Phase 1a and 1b

Escuminac Ice Centre

Phase 2

Scotian Ice Divide

Phase 3

	Beaver River Till
	Lawrencetown Till
	Hartlen Till
	Residuum

Glacier flow line whose length is proportional to velocity

Erosion and entrainment
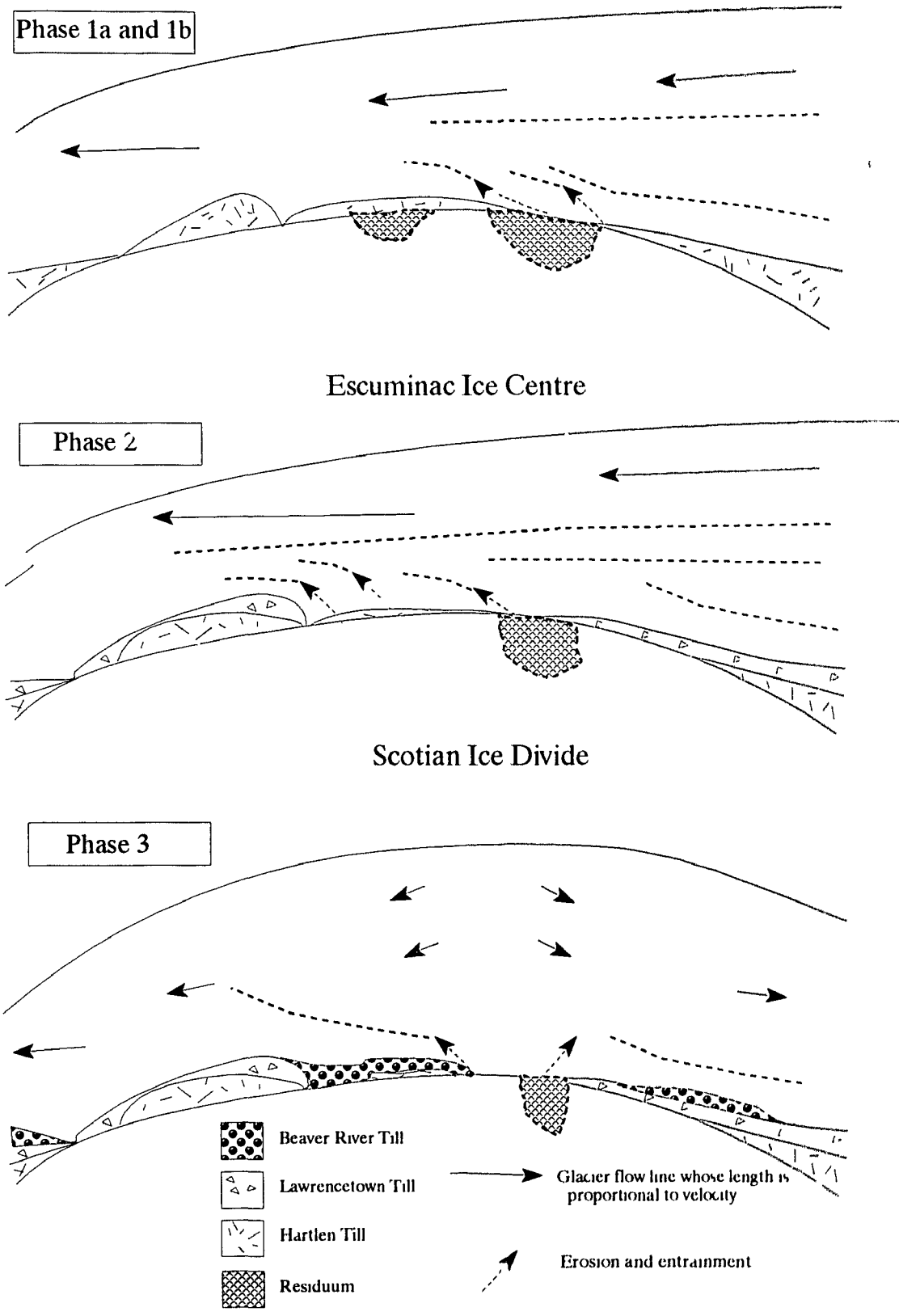
Figure 72

CHAPTER 5: CORRELATION OF MARINE AND TERRESTRIAL GLACIAL EVENTS ALONG THE EASTERN SHORE

5.1 INTRODUCTION

In the last chapter till-sheets were correlated and then linked to regional ice flow phases. All these ice flow events extended past the present day shoreline of Nova Scotia (Fig 4; Map 1). In this next chapter the author will attempt to correlate the terrestrial till sheets with offshore tills and morainal landforms. In this manner these former ice sheets can be reconstructed with both flowlines and margins. A complicating factor in this correlation is the modification of seabed landforms and deposits between the modern shoreline and 70 m BSL by the post-glacial transgression.

5.2 LAND-SEA CORRELATION BASED ON ICE FLOW PATTERNS

Four ice flow phases can be traced to the present shoreline (Fig. 4). What evidence exists for ice movement beyond the present coastline, considering that the marine transgression may have removed former morainal margins? Erratics are present in almost all of the offshore diamicton samples (Figs. 6; 73). Dioritic, granitic and volcanic erratics are distributed in two distinct dispersal fans; southeastward (Phase 1b) and southward (Phase 2) (Figs. 4; 73). The glaciers that formed these fans must have traversed the inner shelf, as most erratics have been transported at least that far.

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Figure 73. Erratic pebble percentages in marine and terrestrial samples (Fig. 6). Triangles represent the relative abundances of each pebble class. The source area geology is simplified after Keppie and Muecke (1979). The maximum extent of distinctive erratic assemblages is shown by arrows from lines connected to the upland source regions. Southeastward transport is indicated by the extent of North Mountain basalt pebbles (Ice Flow Phase 1). Dioritic, volcanic and granitic pebble assemblages down-ice from the Antigonish and Cobequid Highland source areas indicate southward ice flow (Ice Flow Phase 2).

Figure 73

282
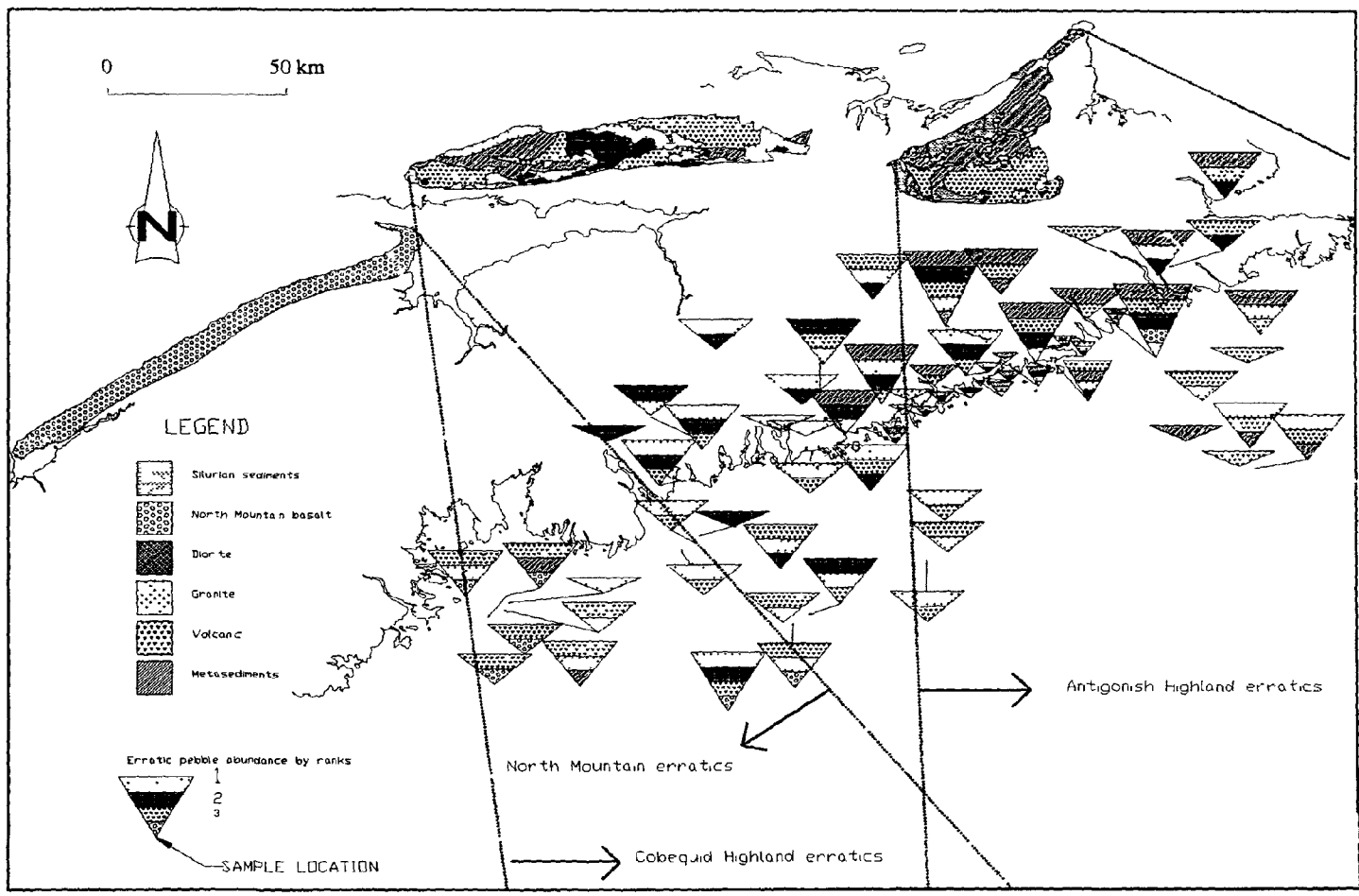
It is generally true that end moraines are oriented normal to the direction of ice flow except at lobate margins (Flint, 1971). The prominent northeastward trend of the Scotian Shelf End Moraine Complex (Fig. 3) is compatible with two flow events, Ice Flow Phase 1b, and Ice Flow Phase 3 (Fig. 4). Ice Flow Phase 1b is a regional glaciation that crossed the Bay of Fundy and probably extended to the shelf edge based on erratic transport (Grant and King, 1984). Ice Flow Phase 3 is the most likely candidate, but if buoyancy is a major factor in moraine formation then the flow orientation may not solely define the trends of moraines. Southward ice flow during Phase 2 may have been restricted to fast-moving ice streams (cf. Grant, 1963) that disintegrated rapidly, leaving no depositional record. Long-distance transport and the restricted areal extent of the Lawrencetown Till is compatible with fast ice flow and ice streams (Denton and Hughes, 1981).

The symmetrical and asymmetrical moraines of the Morainal Zone are oriented NW-SE, indicating a change in ice flow directions from the prominent NE-SW trend of the Scotian Shelf End Moraine Complex (Fig. 16; Map 2). Southwestward-trending channels are found at the distal end of the Morainal Zone. Ice Flow Phase 4, a southwestward flow which postdates Phase 3, is normal to this morainal complex (Map 1; Figs. 3, 4) and can be traced offshore. The Morainal Zone is interpreted as a marginal depositional zone of this ice flow, centred in northeast Nova Scotia. The NW-SE portion of the Country Harbour Moraine may have also formed during Ice Flow Phase 4.

Patterns of ice flow have been interpreted from the orientation of deeply-incised, "tunnel" valleys on the outer Scotian Shelf near Sable Island Bank (Boyd et al., 1989; Loncarevic et al., 1992; Fig. 74). The origin of these valleys is controversial. Previous authors have suggested glacial erosion of pre-existing river valleys (King et al., 1974) and subglacial

Figure 74. Digital bathymetry shadowgram of the Scotian Shelf southeast of Cape Breton Island (after Loncarevic et al., 1992). Some tunnel valleys are indicated by white lines. (A) Sable Island Bank and morainal complex. (B) Banquereau (C) Note the lack of tunnel valley incisions in the presumed offshore continuation of the Scotian Ice Divide (Map 1; Fig. 4).
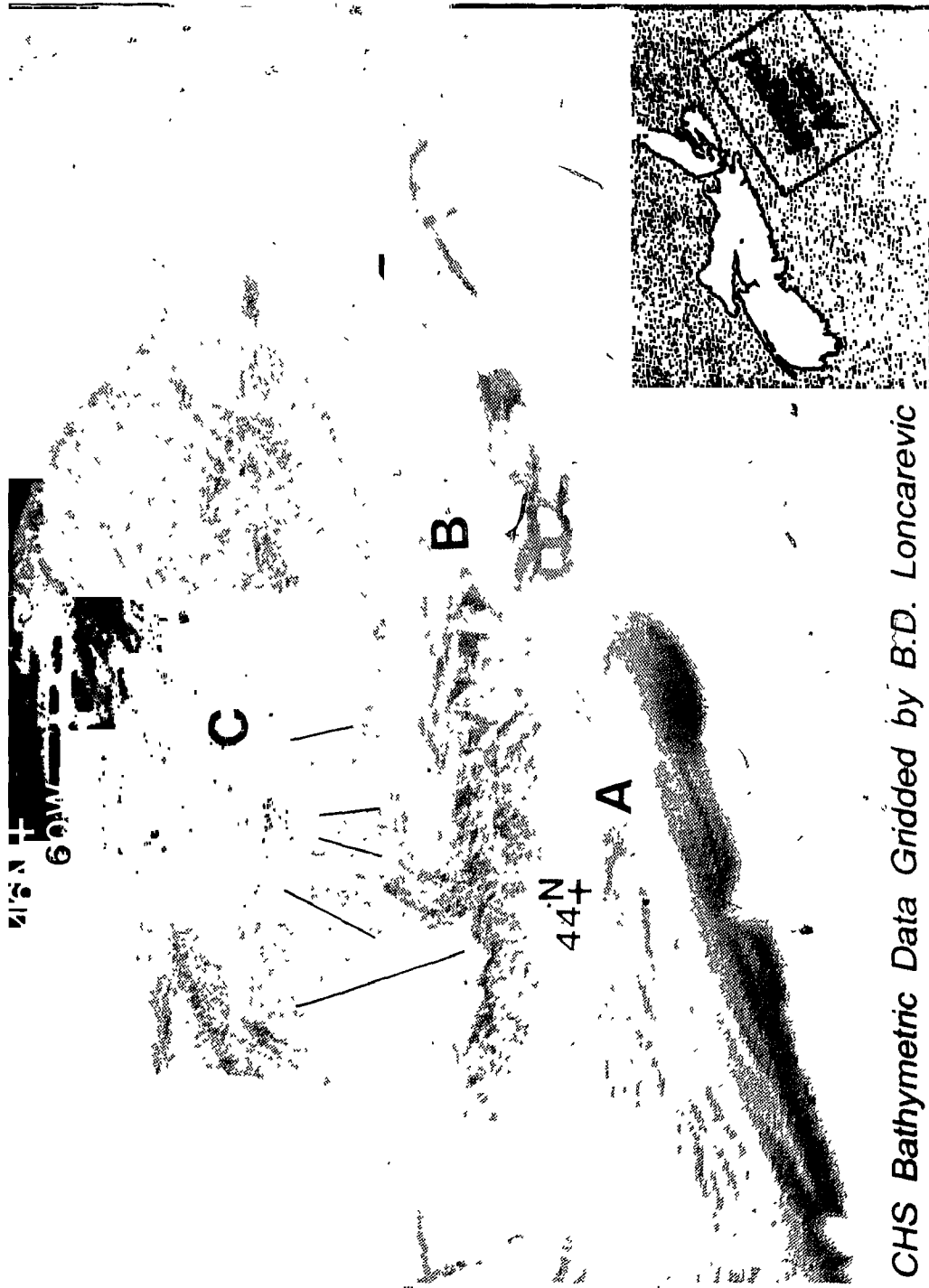
CHS Bathymetric Data Gridded by B.D. Loncarevic

Figure 74.

meltwater erosion (Boyd *et al.*, 1983, Loncarevic *et al.*, 1992) Cross-cutting tunnel valleys suggest several glacial configurations (Loncarevic *et al.*, 1992, Fig 74)

The E-W orientation of Sable Island Bank and southward-trending tunnel valleys imply a southward-flowing ice sheet (McLaren, 1988) These flow patterns are consistent with Ice Flow Phase and an offshore continuation of the Scotian Ice Divide (Fig 4) Northwest-trending tunnel valleys on the shelf west of Cape Breton Island are parallel to northwestward ice flow patterns on Cape Breton (Grant, 1989) The undissected part of the shelf (C-Fig 74) between the incised zones may be the location of the Scotian ice Divide The northern edge of Sable Island bank may correspond with recessional margins of the Late Wisconsinan Escuminac Ice Centre and Scotian Ice Divide

5.3 STRATIGRAPHIC CORRELATION

Three seismic units can be discerned within the Scotian Shelf End Moraine Complex (Fig 17) Three incoherent acoustic units have also been noted within the nearshore basins of the inner shelf by Hall (1985), who correlated these units with three major till units on land near Halifax Piper *et al.* (1986) defined and sampled two massive acoustic facies on the inner shelf off Mahone Bay termed the "Late and "Early" tills They correlated the shore-proximal "Late" till with the Beaver River Till and the distal "Early" till with the drumlin tills The tripartite acoustic divisions within the Eastern Shore Moraine (Fig 17) may be correlated with the three-till land sequences, the uppermost till in the moraine sequences being equivalent to the Beaver River Till "facies B" (ST/B) (Figs. 64, 71) The significant percentages of erratics within the Scotian Shelf End Moraine Complex samples (Tables 4, 8) suggests erosion of underlying Lawrencetown and Hartlen Tills.

These moraines may be palimpsest, sites of readvances or stillstands during several phases of ice flow Earlier accumulations of till would serve as pinning points for later readvances (Powell, 1984)

Grant and King (1984) correlated both the Hartlen and Lawrencetown Tills with the Scotian Shelf Drift (Table 1) and proposed a shelf-wide, extensive southeastward glaciation in the Early Wisconsinan described as the "great red flood" They did not recognize the independent, southward flow (Phase 2) first elucidated by Chalmers (1895) then by Goldthwait (1924) and later by Prest *et al.* (1972) According to their model, after the major Early Wisconsinan glaciation, Late Wisconsinan ice extended slightly past the present coastline, not as far as the Scotian Shelf End Moraines I interpret the Scotian Shelf Drift as a composite of three glacial diamictons, formed from different ice centres spanning the Wisconsinan age

5.4 MORPHOLOGIC CORRELATION

The offshore Morainal Zone and the Stony Till Plain are correlative based on the presence of ribbed moraine (Fig. 41) and coarse, bouldery, surface deposits (Fig 36). The Stony Till Plain, which occupies most of the Eastern Shore study region, is expected to have an offshore counterpart Ribbed moraines on land have not been widely recognized, but may be more common than realized Ridges with amplitudes of less than 5 m, readily visible on the Huntec and the multibeam bathymetric records offshore (Figs 40, 41) may not be apparent on land due to tree cover. After deglaciation, land moraines were deflated by wind and water, Offshore moraines were spared subareal erosion below the transgression,

Drumlins are evident in the multibeam bathymetric image in the region south of Peggy's Cove (Loncarevic *et al.*, 1994, Fig 51) Below -65 m, they are similar in size and shape to land drumlins of the Lunenburg Drumlin Field (Fig 51, Map 1) Ribbed moraines are draped on the drumlins, indicating that they formed later These offshore drumlins and ribbed moraines indicate that drumlin and till-plain-forming Ice Flow Phases (1-3) extended well offshore

5.5 LITHIC CORRELATION

The lithic composition of the inner shelf diamictons is uniform (Fig 75) Offshore diamictons are generally olive-grey with some samples exhibiting a brownish hue (Appendix 3) The coloration reflects derivation from greenschist facies Meguma Group metasediments (Stea and Fowler, 1979) Other than isolated inclusions, no reddish matrix samples comparable in colour to the Lawrencetown Till were obtained (Appendix 3) The colour of offshore diamictons implies a correlation with the Beaver River Till

The pebble lithology of offshore diamictons is also compatible with the Beaver River Till Offshore sediments consist of 75-98% autochthonous (local bedrock) components with a mean value of 86% (Tables 4, 8) Local rocks consist mainly of Meguma Group metawacke, except for samples from the Country Harbour Moraine and adjacent till-tongues, which are underlain by a wedge of gently-dipping Mesozoic or Cenozoic rocks (visible in the sleevegun records) and contain mostly brown marlstones (King and MacLean, 1974) Mean Meguma pebble percentages in the Beaver River Till facies vary from 77-86% (Table 7) The ground moraine facies of the Beaver River Till (ST/A) contains an average Meguma pebble percentage of 86% A box and whisker plot of foreign/local clast percentage ratios
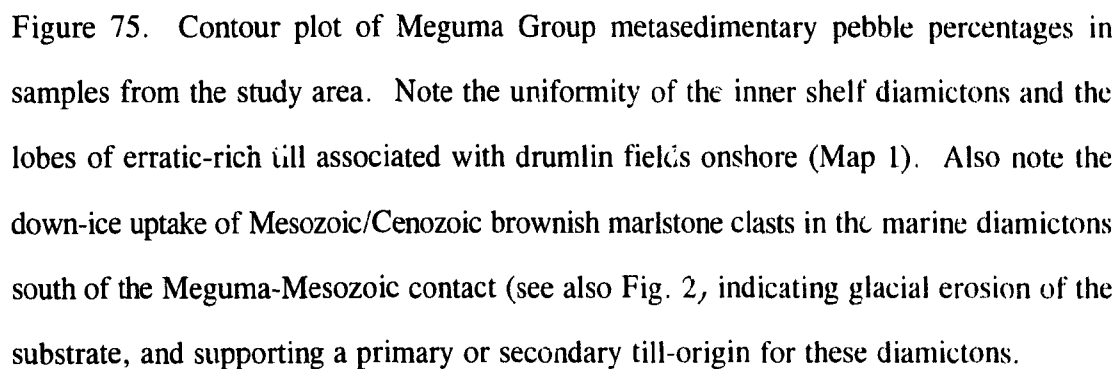
Figure 75. Contour plot of Meguma Group metasedimentary pebble percentages in samples from the study area. Note the uniformity of the inner shelf diamictons and the lobes of erratic-rich till associated with drumlin fields onshore (Map 1). Also note the down-ice uptake of Mesozoic/Cenozoic brownish marlstone clasts in the marine diamictons south of the Meguma-Mesozoic contact (see also Fig. 2, indicating glacial erosion of the substrate, and supporting a primary or secondary till-origin for these diamictons.
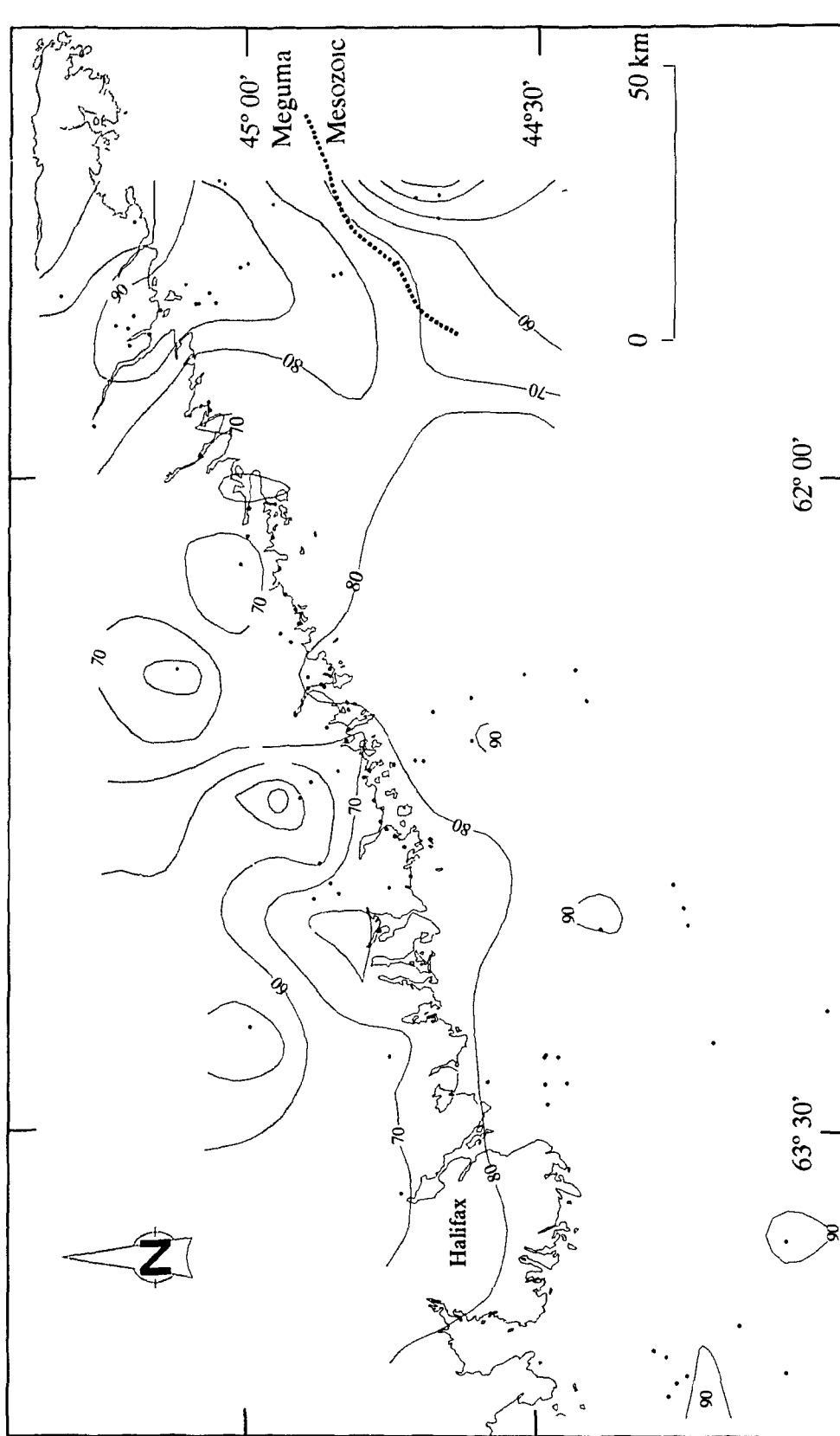
Figure 75

graphically and statistically demonstrates the similarities between the Beaver River Till (ST/A/B/C) and the marine diamictons (Fig 76) Offshore sediments in all mapped terrain zones of the inner shelf have significantly different lithological ratios than the drumlin Lawrencetown and Hartlen Tills and are statistically indistinguishable from the Beaver River Till (Tables 4, 8, Fig 76)

The lack of a reddish, muddy component and low foreign content precludes correlation of the offshore diamictons with the drumlin Lawrencetown and Hartlen Tills Down-ice dilution of foreign components cannot explain lithological differences for these reasons.

1 Lawrencetown Till samples on land show a negligible down-ice uptake of underlying bedrock (P Finck, pers comm , 1994) Regional mapping of clast lithology over the South Mountain batholith revealed a considerable "skip zone" with little uptake of local rocks in the Lawrencetown Till (Finck and Stea, 1990, Finck *et al.*, 1994 a,b,c,d,e) "Renewal distances" can exceed 30 km A regression curve of Lawrencetown Till samples over the South Mountain batholith in southern Nova Scotia (Fig 2) show negligible uptake of local rocks (Fig 77) The predicted foreign clast percentage in the Lawrencetown Till at the Scotian End Moraine complex is between 33 and ₁2% (Fig 77) This is a conservative estimate because only surface Lawrencetown Tills were used in this analysis and these are largely the overprinted LT/C type

2 Lack of red matrix components in the offshore diamictons The red colour persists in land sections 50 to 100 km south of the Carboniferous source regions and out to the edge of the shelf where anomalous red mud has been

Figure 7G. Notched Box and whisker plots of foreign/local clast percentage ratios plotted for terrestrial till facies and offshore diamictons. The box and whisker plot is an effective way to demonstrate summary statistics graphically. The notched plot (McGill *et al.*, 1978) corresponds to the confidence interval of the median, whereas the width of the box is proportional to the square root of the number of observations in the data set. If the two notches on the boxes do not overlap the median values of the data distributions do not significantly overlap at a 95% confidence level. The dashed lines show the overlap boundaries of the drumlin tills.

Sedimentary Units: Onshore Tills

1. Hartlen Till

2. Lawrencetown Till facies A

3. Lawrencetown Till facies B

4. Lawrencetown Till facies C

5. Beaver River Till facies A

6. Beaver River Till facies B

7. Beaver River Till facies C

Offshore diamictons and gravels

8. Emerald Silt

9. Morainal Zone (Scotian Shelf Drift)

10. Scotian Shelf End Morainal Complex (Scotian Shelf Drift)

11. Sable Island Sand and Gravel

12. Unit B

13. Unit C
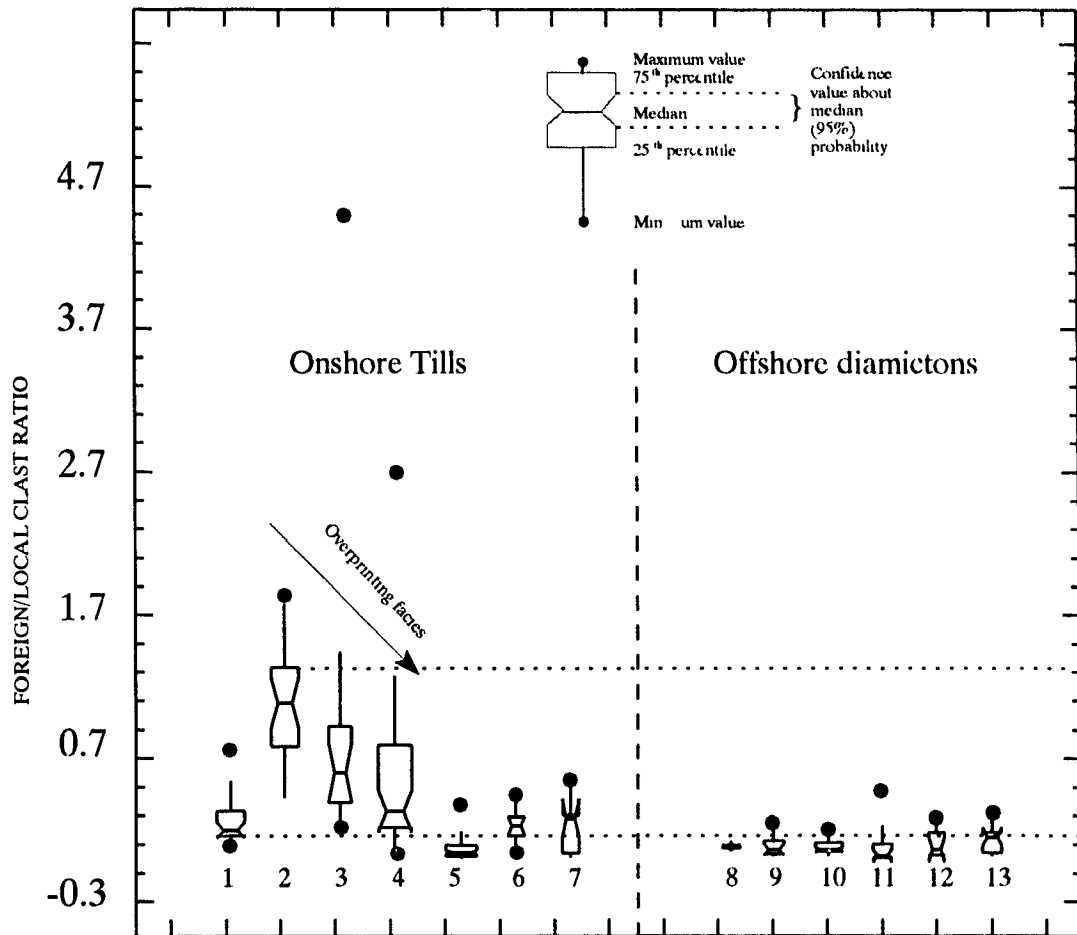
Figure 76

Figure 77. Regression plot of erratic percentages in Lawrencetown Till vs. distance down-ice from the Carboniferous basin/Meguma Group bedrock contact in southern Nova Scotia. Data from a regional till survey over the South Mountain Batholith (Graves and Finck, 1987a, b; Finck *et al.*, 1993, 1994 a,b,c,d,e). The regression curve of Lawrencetown Till samples over the South Mountain batholith in southern Nova Scotia (Fig. 2) shows slow uptake of local rocks, an indication of englacial transport. The predicted foreign clast percentage in the Lawrencetown Till at the Scotian End Moraine complex is between 33 and 12% with a median of 20% This is a conservative estimate because only "overprinted" surface Lawrencetown Tills were used in this analysis.
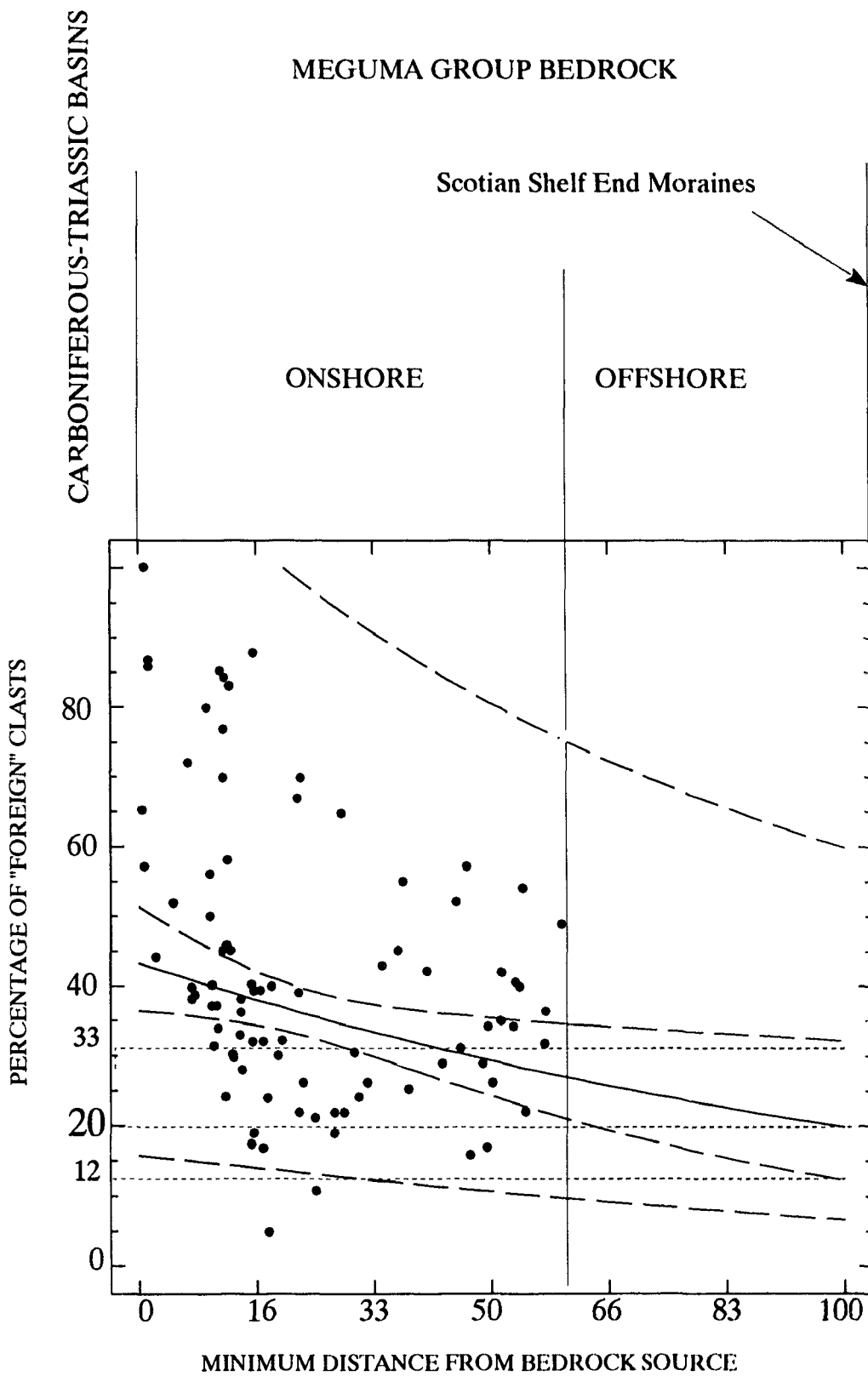
Figure 77.

attributed to glacial transport (Hill, 1981, Mosher *et al.*, 1989)

3   Homogeneity of composition throughout the inner shelf Erratic dilution cannot be discerned from proximal to distal areas of the inner shelf In the Truncation Zone less competent pebbles may have been preferentially destroyed by the transgression, but a significant proportion of exotic clasts are competent lithologies   Piper *et al.* (1986) found that the petrology of nearshore gravels were indistinguishable from parent tills onshore

The stratigraphic position of the Hartlen Till would preclude correlation with seabed-outcropping marine diamictons because it is invariably overlain by the Lawrencetown Till and sometimes the Beaver River Till in land sections   The small (<10%) but significant percentages of non-Meguma lithologies in most morainal diamicton samples of the inner shelf, indicate that an underlying or nearby source of Lawrencetown or Hartlen Till has been eroded   "End member" ground moraine facies of the Beaver River Tills (ST/A), removed from drumlin fields, contain virtually no foreign lithologies, but hybrid facies (ST/B), contain erratic percentages of greater than 10% (Table 8, Fig 62)   Erratics within the "hybrid" Beaver River Till can be attributed to the proximity of Lawrencetown Till drumlins or subcropping Lawrencetown Till   It is probable that the Lawrencetown Till extends out at least as far as the Scotian Shelf End Moraine Complex   Significant grain size and density differences between the Beaver River Till and the Lawrencetown and Hartlen Tills would account for acoustic impedance boundaries as observed in the sleevegun profiles of the Eastern Shore Moraine (Fig 17)

Two factors which make the correlation between marine and terrestrial tills using grain size parameters difficult are

1   Incorporation of marine muds (especially at grounding-line) by glacial erosion

2   Sampling difficulties and loss of fines upon IKU retrieval This does not apply to matrix-rich moraine samples (Appendix 3) which were retrieved without loss of fines, however gravel percentages in Sable Island Sand and Gravel samples are anomalously high

A box and whisker plot of the clast/matrix weight percentage ratios for the entire data set is shown on Figure 78 The Beaver River Till is clearly distinct from other onshore tills The Sable Island Sand and Gravel (Truncation Zone) and Morainal Zone samples are statistically distinct from the other marine sediments The Truncation Zone lag gravels are clast-rich because fines have been removed by wave action and sample retrieval The Morainal Zone "lump" or "matrix" samples (Appendixes, 3, 4) should be representative of the texture of the true morainal material Textural overlap with the Beaver River Till is apparent

Detailed grain size analysis verifies the textural similarity between the Beaver River Till and the Morainal Zone samples and suggests similarity between the Beaver River Till and the Scotian End Moraine surface diamicton samples The Beaver River Till and offshore morainal samples overlap in the fine sand and silt size grades (3-5 phi, Fig 14) but are deficient in clay (>8 phi, Fig 14) unlike the clay-rich drumlin tills

Figure 78 Notched box and whisker plots of clast/matrix weight ratios plotted for terrestrial till facies and offshore diamictons See Figure 76 for box legend

Sedimentary Units Onshore Tills

1   Hartlen Till

2   Lawrencetown Till facies A

3   Lawrencetown Till facies B

4   Lawrencetown Till facies C

5   Beaver River Till facies A (ST/A)

6   Beaver River Till facies B (ST/B)

Offshore diamictons and gravels

7   Emerald Silt

8   Morainal Zone (Scotian Shelf Drift)

9   Scotian Shelf End Morainal Complex (Scotian Shelf Drift)

10   Sable Island Sand and Gravel

11   Unit B

12   Unit C
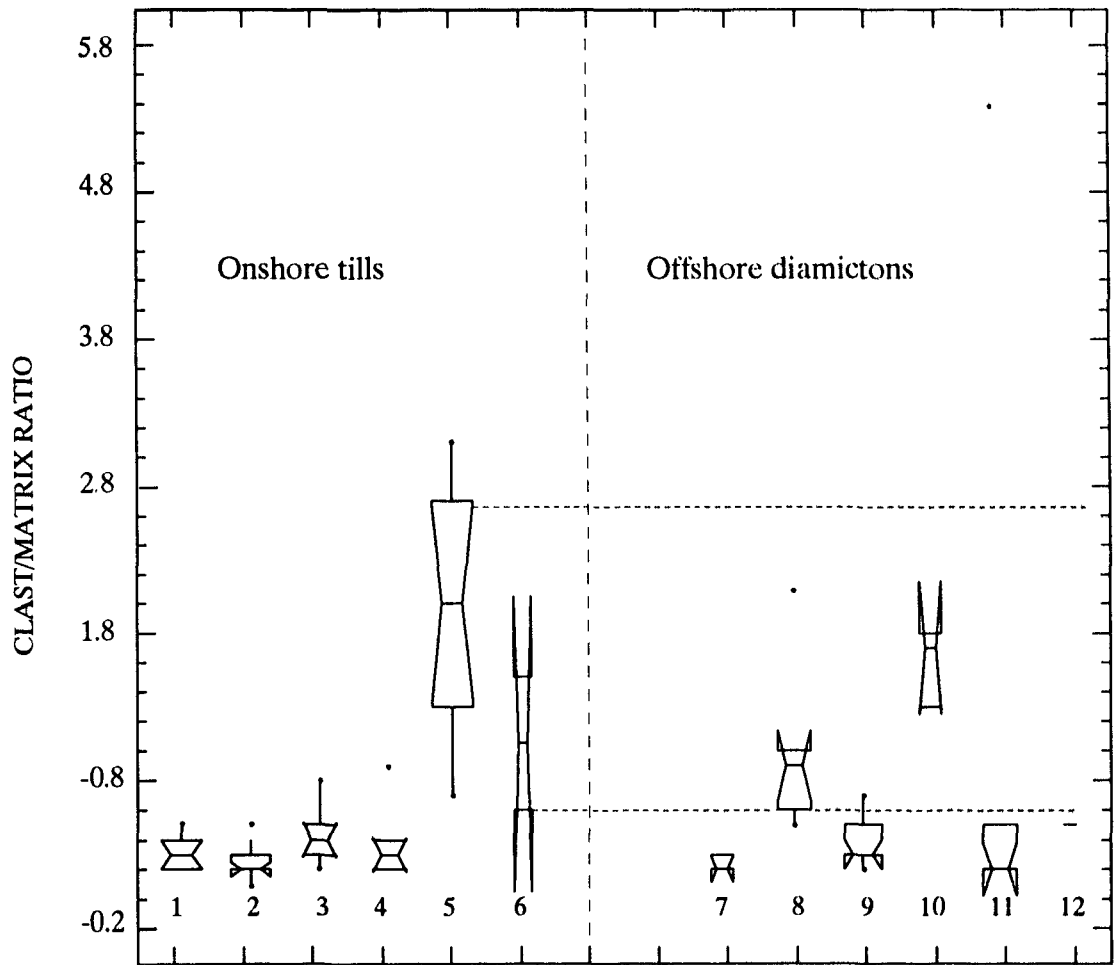
Figure 78.

The Scotian Shelf End Moraine samples have lower clast contents than the Beaver River Till and are comparable with the drumlin tills, probably as a result of incorporation of Emerald Silt at or behind the grounding line (Figs 14, 78)

The highest percentages of striated clasts occur in the Scotian Shelf Drift and the lowest in the Beaver River Till (Tables 4, 8, Fig 79)   Assuming correlation of these two units, this discrepancy can be explained by differing basal processes of till formation between the Scotian Ice Divide and its margin (Fig 4)   Outward from the Scotian Ice Divide (Fig 4) basal sliding velocities increased   Clast abrasion, comminution and matrix formation are enhanced with higher ice velocities, hence the decrease in clast modes and increases in clast-surface striae (Figs 72, 78)   The change in till properties from divide to margin could be summarized as follows

Striated clast percentages increase->

Clast weight percentages decrease->

Ice divide-> Stony Till Plain -> Morainal Zone ->SSEMC

5.6 ICE DYNAMICS AND THICKNESSES

Glacier ice physics can be used to elucidate the processes of formation of the Scotian   Shelf End Moraines and their relationship to the Scotian Ice Divide   Ice Flow Phase 3 overtopped the 300 m high Cobequid and Antigonish Highlands in northern Nova Scotia (Stea and Finck, 1984, Map 1, Fig 4)   Ice thickness over the highlands was sufficient to allow for basal-melting and basal slip over the substrate and the production of erosional and depositional landforms (Denton and Hughes, 1981)   An initial ice thickness value of 300 m may be assumed based on the temperature distribution of modern glaciers (Paterson, 1981)   The

Figure 79. Scattergram of clast weight percentages vs striated clast percentages for terrestrial till units and offshore diamictons.

Offshore diamictons

1. Scotian Shelf End Morainal Complex (Scotian Shelf Drift)

2. Emerald Silt

3. Unit B

4. Morainal Zone (Scotian Shelf Drift)

Onshore tills

5. Lawrencetown Till (LT/C)

6. Lawrencetown Till (LT/A/B)

7. Hartlen Till

8. Beaver River Till (ST/A/B/C)
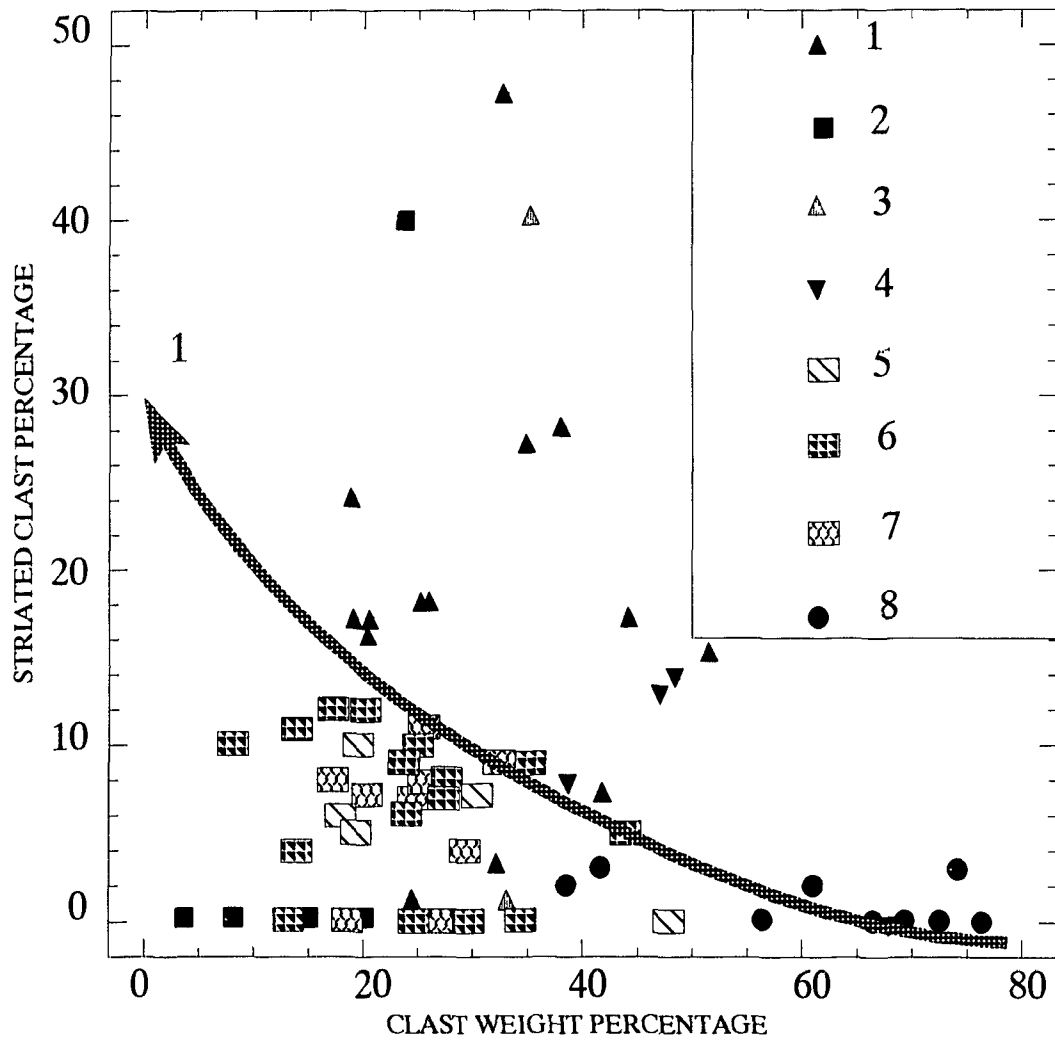
1. Hypothetical trend line of increasing abrasion away from the Scotian Ice Divide to the offshore.

Figure 79.

height of the Scotian Ice Divide can then be calculated from this initial starting point, using

a simple ice model based on equations of ice motion for a perfectly plastic ice sheet (Paterson,

1981)

$$H = (2\tau_0 L/\rho g)^{1/2} \quad (1)$$

Here ρ is ice density (0 91 g/cm^3, assumed constant), and g is acceleration due to gravity

(981cm/sec^2) τ_0 is the yield or shear stress, L is the distance to the ice margin, H is the ice

thickness The author modified an iterative scheme by Schilling and Hollin (1981) to model

Nova Scotia ice caps with variable bedrock topography based on equation (1) to include

variable basal shear stresses (Appendix 8) The ice thickness equation for this iterative

scheme is

H (i+1) = Hi + $\tau\Delta$X/ ρgti (2) (Appendix 8)

where Hi = initial ice elevation (including bedrock elevation)

ΔX = iterative step length

ti = initial ice thickness

In this model steady-state equilibrium is assumed and isostatic adjustments are ignored,

because for this discussion ice thickness is the primary concern

The ice profile was constructed in a north to south transect across the former Scotian Ice

Divide (Ice Flow Phase 3, Fig 80) The model starts with an initial (minimum) ice thickness

of 300 m where Ice Flow Phase 3 overtopped the Cobequid Highlands at 300 m elevation

The Cobequid Highlands have a rough, bedrock-dominated surface topography. Basal shear

Figure 80. Calculated profiles of the Ice Flow Phase 3-Scotian Ice Divide and an estimate

of the thickness of the earlier Phase 2 ice cap (Escuminac Ice Centre). The solid line in

the Phase 3 glacier reconstruction represents iterated ice sheet profile calculations from a

program modified from Schilling and Hollin (1981). Dotted glacier profiles are

interpolated using the previous ice slope calculations. (B) Bedrock areas with basal shear

stress set at 0.8 bar. (D) Deformable beds with basal shear stresses set at 0.2 bar. Ice Flow

Phase 2 ice thickness estimated from isostatic rebound at Scotian End Moraines (maximum

thickness).
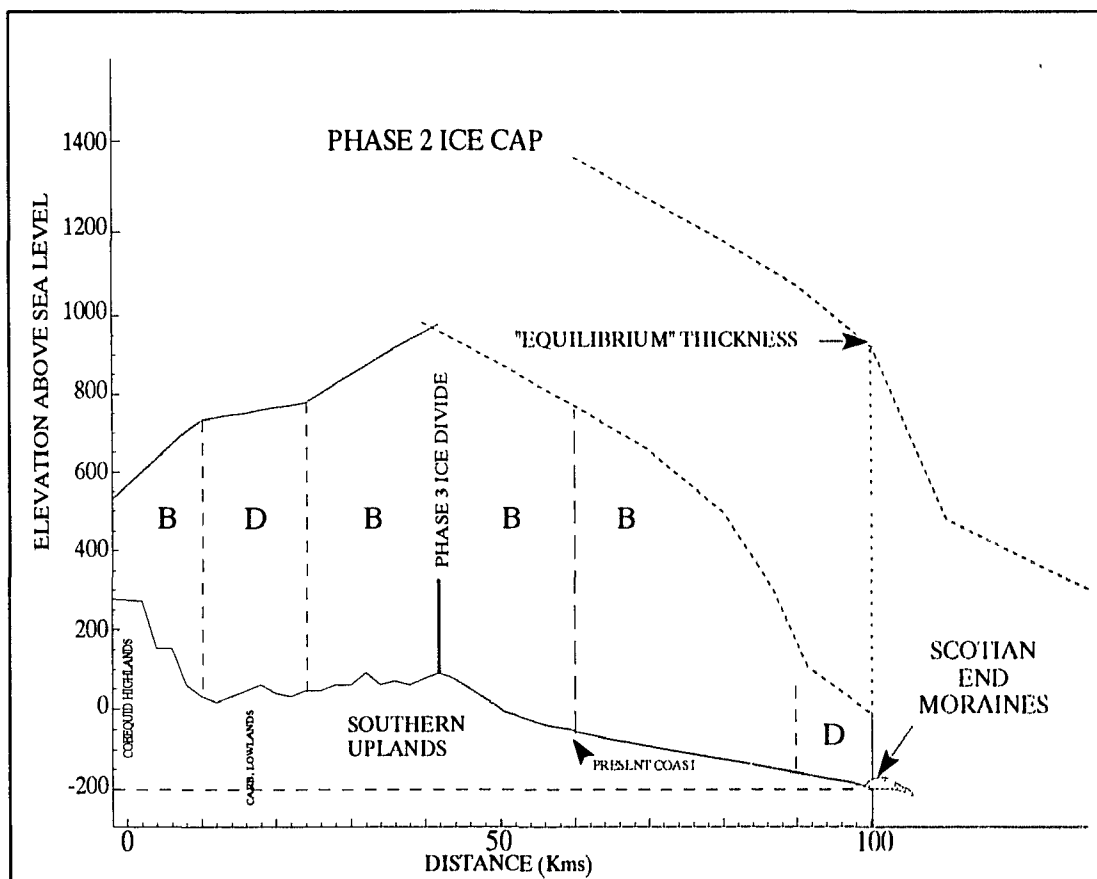
Figure 80.

stresses in this environment would be relatively high A minimum value of 80 kPa (0 8 bar) is assumed (Schilling and Hollin, 1981) The Minas Basin region south of the Cobequid Highlands is a till plain Boulton and Jones (1979) calculated shear stresses of 20 kPa (0 2 bar) for till substrates The South Mountain region (like the Cobequid Highlands) is a bedrock-dominated environment with a thin veneer of bouldery till A basal shear stress value of 80 kPa was also used in this region With these model constraints, the height at the centre of the Scotian Ice Divide is calculated to be 978 m (Fig 80)

Another estimate of ice thickness can be derived from the depth relationships of the Scotian Shelf End Moraines With the exception of the Country Harbour Moraine, the morainal ridges of the Scotian Shelf End-Moraine Complex are found in water depths of 140-160 m King *et al.* (1972) originally suggested that the consistent depth of most of the morainal ridges implies that ice buoyancy may be a formational factor The depth of water required for flotation is governed by this relationship from Reeh (1968)

$$h(w) = (\rho w / \rho i) hi \quad (3)$$

(h(w)=water depth, hi=ice thickness, ρi=density ice, ρw=density water)

If ice advances into water approximately 1 1 times its height, then the ice mass will become buoyant As it does, basal shear stresses tend towards zero and the ice mass spreads out and thins This thinning will result in retreat of the grounding line until an equilibrium is attained between ice production through surface accumulation and lateral advection and ice wastage by bottom melting and calving (Thomas, 1979) Powell (1991, p 78) suggested that a maximum or critical water depth exists for calving glaciers, independent of ice thickness, beyond which the front becomes unstable At this water depth calving rates greatly exceed

ice flux to the terminus (Powell, 1991) The grounding line of unconfined glaciers along the polar East Antarctic glaciated shelf are commonly found at 200-300 m water depth (Schilling and Hollin, 1981) Similarly, the maximum depth of the grounding line in temperate Alaskan tidewater glaciers was found to be around 300 m (Brown *et al.*, 1982) The modal maximum height of modern icebergs in the Labrador Shelf of eastern Canada is 300 m (Hotzel and Miller, 1983, Josenhans and Fader, 1989).

During moraine formation at about 16 ka (Gipp and Piper, 1989), RSL lowering in Barbados was 115 m (Fairbanks, 1989) Assuming gravitational and hydro-isostatic effects to be minimal, much of the present day continental shelf would have shoaled to water depths that would not support ice with an assumed "critical" lift-off thickness of 300 m The formation of grounding-line moraines on the Scotian Shelf implies that isostatic depression compensated for the eustatic decrease in sea-level. It is assumed that isostatic depression of the crust under the moraines resulted from a major ice flow to the shelf edge (Phase 2, Fig 4) The amount of crustal depression can be calculated from the difference between the present day moraine depths and the depth of moraine formation during eustatic minima with a simple equation similar to that used by Morner (1971) and Belknap *et al.* (1987) using present day sea-level as datum (Fig 81)

$$I = B+S \quad (4)$$
$$B = E+300 \text{ m} \quad (5)$$

where   I = isostatic uplift at the outermost moraines

      E = eustatic sea-level depression (115 m)

      S = present day average Scotian Shelf Moraine depths

      (-150)

Figure 81   Schematic diagram illustrating the concepts of isostatic recovery at the Scotian

Shelf End Moraine Complex

I   = isostatic uplift at the outermost moraines

E   = eustatic sea-level depression (115 m)

S   = present day average Scotian Shelf Moraine depths

          (-150)

B   = critical buoyancy depth at eustatic minima (below

          present sea level) = 415 m

S (-150 m)

E (-115 m)

S (-85 m)

Country Harbour
Moraine

Halifax Moraine

I

B (300 m)
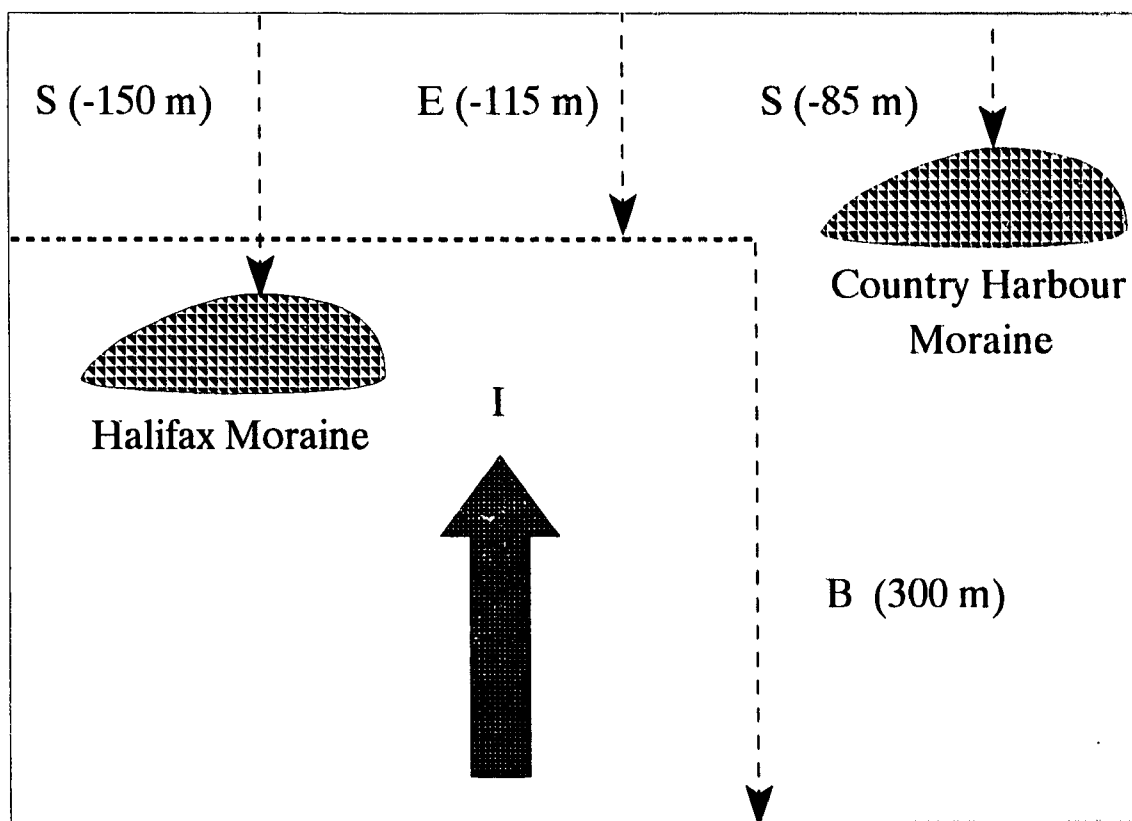
Figure 81.

B = critical buoyancy depth at eustatic minima (below

present sea level) = 415 m

Therefore I = 265 m

If isostatic equilibrium is established then a thickness h of ice will depress bedrock by

(Weertman, 1961)

$$h (\rho i/\rho r) = I \quad (6)$$

using I = 265 m,

h = 795

Using an approximate 1/3 ratio of ice density to rock density (Hughes, 1981) an ice thickness

of 795 m is produced for the Scotian Moraines   This is a crude estimate, but a reasonable

one, because factors affecting the model such as greater ice volumes, ice-water attraction,

disequilibrium etc would tend to both increase and decrease the estimate of I   The Scotian

Shelf End Moraines are generally found in water depths of 140-160 m   The Country Harbour

Moraine crest is a notable exception in only 85 m water depth   This may reflect thicker ice

over the site

It is important to remember that these values represent ice thicknesses **overlying** the Scotian

Shelf End Moraines from the previous larger ice mass (Escuminac Ice Centre; Ice Flow Phase

?, Figs 4, 80) that extended out to the shelf edge   I am proposing that rebound-induced

stabilization of the ice front during rapid recession of phase 2 ice may have been responsible

for the formation of the moraines

5.7 CORRELATION OF MARINE AND TERRESTRIAL DEGLACIATION RECORDS

Seismic sequences within the sedimentary infill of the Basin Zone and valleys of the Truncation Zone record deglaciation and sea-level change The sedimentary record of Core 91018-53 within the Halifax subzone spans the time from 13 ka to 2 ka On land, lake core records span the same length of time (Mott et al., 1986, Ogden, 1987) and can be used for correlation

Most lake cores in Nova Scotia show successions of pollen zones and lithostratigraphy that indicate climatic fluctuations (Livingstone and Livingstone, 1958, Mott et al., 1986, Ogden, 1987) At the base of most lake cores is inorganic sand or mud, sometimes rhythmically-laminated In southern Nova Scotia, this is succeeded by black or brown organic mud accumulation (gyttja) which has been radiocarbon-dated between 13 and 12 ka (Jetté and Mott, 1989, Stea and Mott, 1990) The pollen successions in lake gyttja during this time invariably record a change from tundra to spruce forests indicating climatic amelioration (Railton, 1972, Ogden, 1987, Jetté and Mott, 1989) Around 10 8 ka an abrupt and pronounced climatic deterioration occurred that strongly affected the landscape and its vegetation cover Lake cores reveal a sedimentological "oscillation" that marks the Younger Dryas Chronozone (11,000-10,000 ka, Mangerud et al., 1974) This oscillation is defined by a distinct inorganic clay layer that separates gyttja near the base of the cores (Mott et al., 1986) from gyttja that constitute the rest of the cores Changes in pollen assemblages in these lakes, imply a warmer-colder-warmer climatic cycle In southern Nova Scotia, the clay layer may have formed by solifluction of the adjacent devegetated slopes during the reversion to cold climatic conditions (Mott and Stea, 1990, 1994) or runoff from ephemeral or permanent

snowpacks (Stea and Mott, 1992) The remaining record in the lake cores indicates an initial rapid warming and climate fluctuations during the Holocene (Ogden, 1987) In northern mainland Nova Scotia, stratigraphic sections reveal diamictons, clay and sand overlying peats that predate the distinctive inorganic and clay layer in the lake sediment records Radiocarbon ages from wood and peat increments at the top of the peat layer cluster around 10 8 ka (Mott and Stea, 1994) Stea and Mott (1989) interpret the overlying sediments as largely glacigenic, implying a renewed glaciation in this region

The offshore seismic sequences and events can be correlated to the onshore lake stratigraphy The Yankee Bank Formation is correlative with the Younger Dryas clay layer in the lakes and the glacigenic sediments that overly peat in land sections On land and sea a zone of increased inorganic sedimentation is bracketed by organic strata with biota indicating a warming trend The inorganic sedimentation events were initiated at around 10 8 ka and represent climatic cooling and snowfield/glacier buildup on land and increased sea-ice/icebergs in the marine realm The land and ocean events appear synchronous, in spite of the postulated 400 year lag time of oceanic ^{14}C equilibration (Mangerud, 1972) Isolation from the ocean may have decreased the mixing time within these nearshore basins

5.8 SUMMARY

In this chapter, a direct land to sea correlation of glacial deposits and landforms was made These are the salient conclusions

1   Ice Flow Phases 1 and 2 extended to at least as far as

the Scotian Shelf End Moraine Complex because erratic

dispersal trains, associated with each flow phase, can be traced to the SSEMC moraines (Fig 82)

2 The Scotian Shelf End Moraines represent a margin of Ice Flow Phase 3 based on direct correlation between Beaver River Till formed under the Scotian Ice Divide and the morainal diamictons (Fig 82) The SSEMC was probably a recessional margin that originally formed when Ice Flow Phase 2 retreated from the outer shelf Rebound-induced stabilization of the ice front at the moraines may have been partly responsible for the buildup of the Scotian Ice Divide Flow from the Scotian Ice Divide may also have briefly extended past the morainal complex as an ephemeral ice shelf during readvances or surges that formed till-tongues

3 The Morainal Zone represents the margin of Ice Flow Phase 4, the last, till-forming, widespread glacier advance in northeastern Nova Scotia (Fig 4) Sequence 2 (ca 12 9) in the Basin Zone, probably formed during this event

4 A climatic event ca 10 8 ka to 10 ka that is recorded in land sections and lake cores is also recorded in the offshore basins by the Yankee Bank Formation (Sequence 5)

Figure 82   Schematic cross section through the Scotian Ice Divide to the outer shelf showing correlation of till units and major depositional zones (A) Scotian Shelf End Moraine Complex (B) Drumlin fields (C) Stony Till Plain (D) Bedrock and residuum

Scotian Ice Divide

Phase 3

offshore | onshore

A

B

C

D

Beaver River Till

Lawrencetown Till

Hartlen Till

Residuum

Sea Level

Glacier flow line

Erosion and entrainment

Figure 82.

315
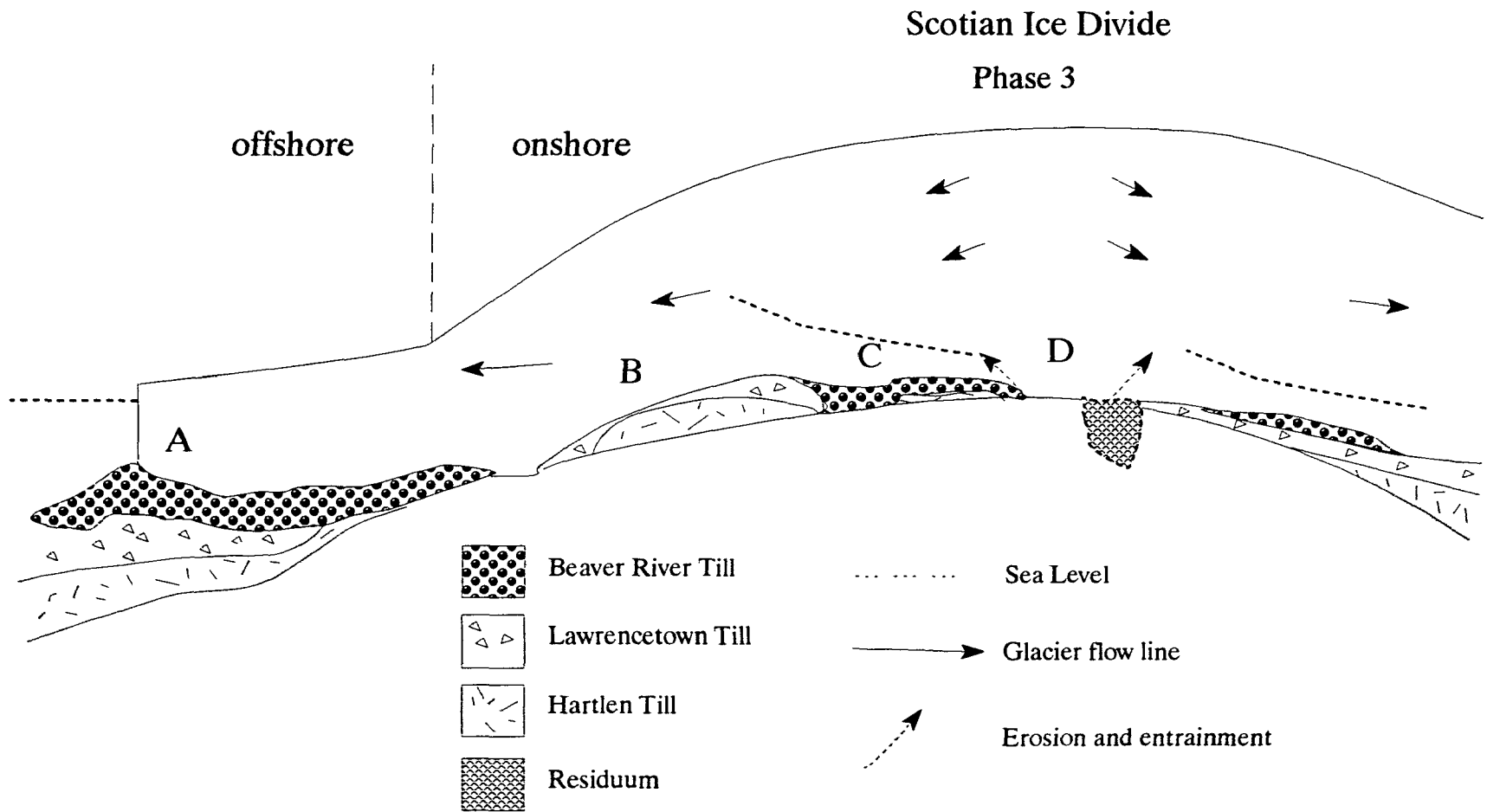
CHAPTER 6: DISCUSSION AND CONCLUSIONS: WISCONSINAN GLACIAL AND SEA LEVEL HISTORY OF EASTERN CANADA AND THE CONTINENTAL SHELF

6.1 INTRODUCTION

The processes, correlations and sea-level history established for the inner Nova Scotian shelf are crucial in the interpretation of glacial events for the entire Eastern Canadian-Appalachian region. Previous Wisconsinan glaciation models discussed in the introduction, are simplistic, and not in accord with the land and sea evidence. The author will present a new empirical model of ice advances and retreats and relative sea-level changes for Eastern Canada incorporating the inner shelf study area concepts. Some of these ideas are speculative, but should serve as a basis for further study and a development of ideas on the glaciation of the onshore-offshore region. The new compilation of Wisconsinan flow paths for Eastern Canada (Fig. 83) which includes offshore margins is a major step forward from the previous ice flow phase concept (Fig. 4). L.H. King (pers. comm., 1994) has also proposed a similar marine-land ice flow model based on the author's ice flow phase concept.

6.2 ICE FLOW PHASES 1A AND 1B

The oldest observed ice flow patterns in Maritime Canada are eastward and southeastward (Ice Flow Phases 1a, 1b). Eastward flow patterns (Phase 1a) prevalent along the Northumberland Strait region (Map 1; Fig. 83), were originally interpreted by Chalmers (1895) to be the Appalachian-derived Northumberland Glacier. This flow phase

Figure 83. Evolution (advance and retreat) of ice divides and domes over Maritime Canada during the Wisconsinan (70-10 ka). (A) Ice Flow Phase 1a in Atlantic Canada and margin. (B) Phase 1b (C) Ice Flow Phase 2 from the Escuminac Ice Centre and Divide on the Magdalen Plateau. A retreat margin over Sable Island, Western, Emerald Banks (after Boyd in McLaren, 1988). (D) Advance and retreat of Phase 3 ice (Scotian Ice Divide) (E) Ice Flow Phase 4. Ice flow data from Chalmers, 1895; MacNeill, 1951; Prest and Grant, 1969; Rampton et al., 1984; Pronk et al., 1989; Rappol et al., 1989; Stea et al., 1992a).

LEGEND FOR ICE FLOW MAPS

Ice flow line .... – – –▶

Ice flow line (later)......... • • • • ▶

Ice margin....................... ▬▬▬▬▬

Ice shelf.......................

Ice rise........................

End moraines...............

G Gaspereau Ice Centre/Divide

E Escuminac Ice Centre/Divide

C Chignecto Glacier
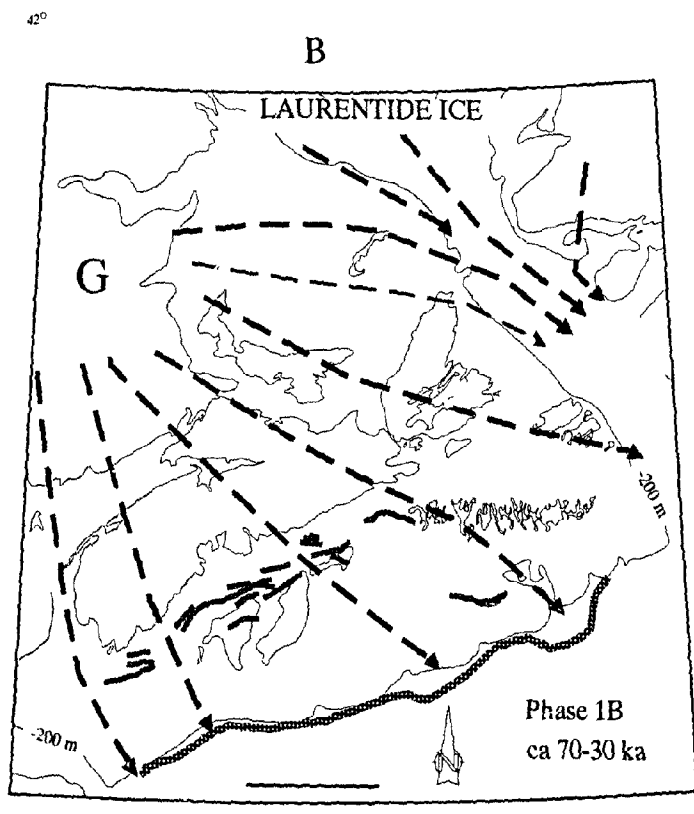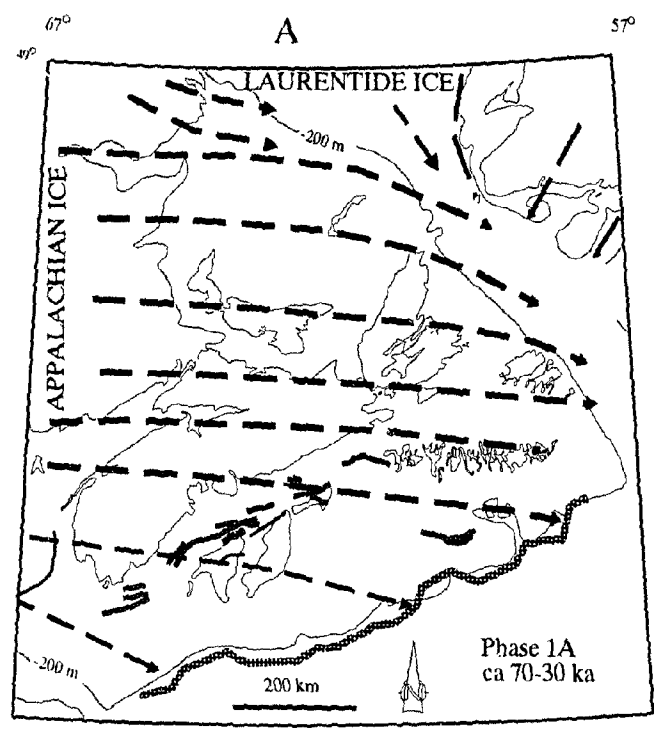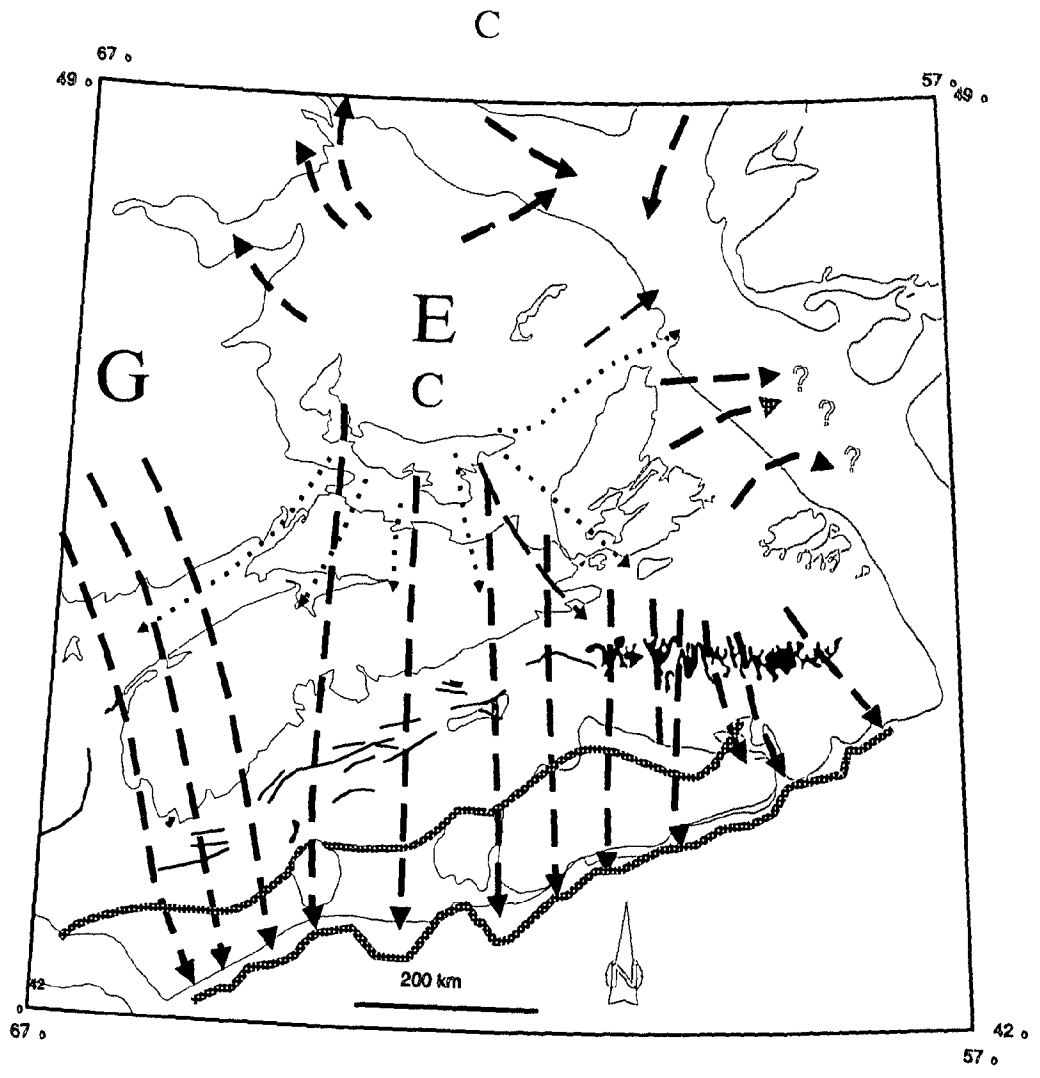
Figure 83.

Figure 83.

Figure 83.

E
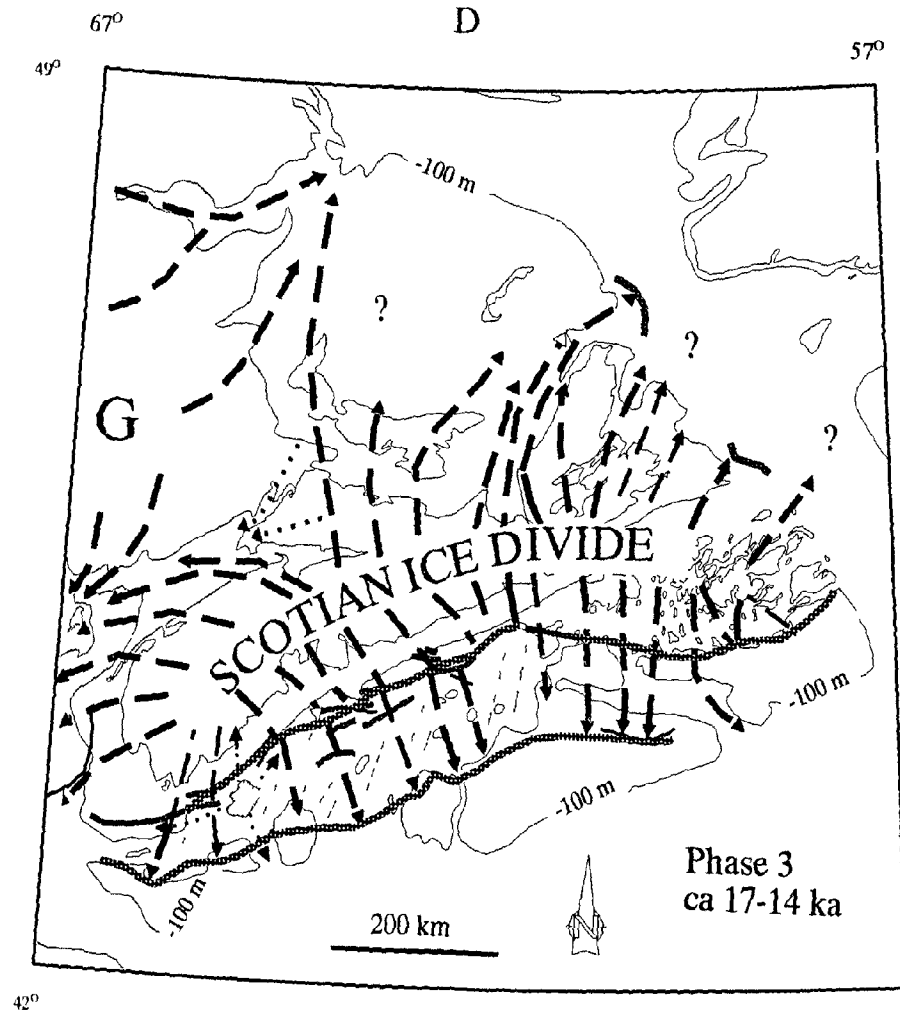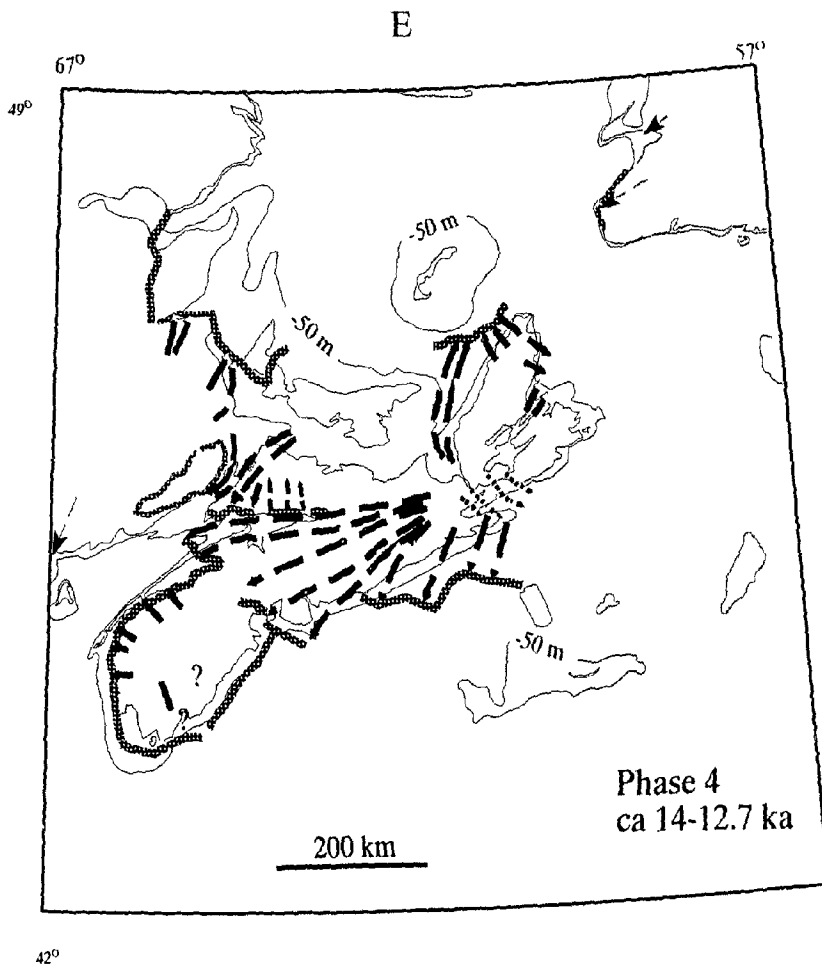
Figure 83.

may represent a separate, older phase of glaciation. The ice configuration later changed to a centre in New Brunswick (Gaspéreau Ice Centre; Rampton *et al.*, 1984) which produced southeastward striae flow patterns on the southern New Brunswick highlands (Caledonia Phase; Rampton *et al.*, 1984) and distinctive till units in Nova Scotia (Hartlen Till-East Milford Till; Stea *et al.*, 1992a, c). The East Milford Till has been assigned an Early Wisconsinan age because it postdates the last interglacial interval and is overlain by recessional sediments and Late Wisconsinan tills. Land and offshore deep sea oceanic records show a major glaciation at this time (Clark *et al.*, 1993). The Hartlen Till is correlated with the middle of three major reflections seen in the Scotian Shelf end moraines and the lowest wedge-shaped, massive reflections on the Scotian Slope interpolated to be Early Wisconsinan by Mosher *et al.* (1989). Evidence of the passage of Laurentide ice across New Brunswick is equivocal (Rampton *et al.*, 1984; Pronk *et al.*, 1989; Rappol, 1989). Shield anorthosite boulders in western Prince Edward Island (Prest and Nielsen, 1987) and in the Gulf of St. Lawrence (Loring and Nota, 1973; Stea, 1991) indicate that Laurentide ice may have been confluent with ice from the Gaspereau Ice Centre (Fig. 83).

Ice Flow Phases 1a and 1b left a strong imprint on the Nova Scotia landscape. These flow patterns can be traced throughout the Maritimes region (Fig. 83) and across the inner shelf. They represent the most "vigourous" ice flow events characterized by extensive erosion and deposition of thick, overconsolidated, matrix-rich tills (cf. Grant, 1977, 1989). The margin of these events are placed at the shelf\slope break at water depths of approximately 300-600 m, the maximum depth of relict iceberg furrowing (Mosher *et al.*, 1989; Dodds and Fader, 1986).

6.3 ICE FLOW PHASE 2

Late Wisconsinan ice flow trends across much of northern Nova Scotia are southward and southwestward. Along the Nova Scotia - New Brunswick border region, ice flow recorded by striae is largely southwestward (Prest, 1973), (Stea and Finck, 1984, Rampton *et al.*, 1984; Foisy and Prichonnet, 1991). Northward ice flow has been reported in the Magdalen Islands (Parent *et al.*, 1990). These flow trends have been attributed to an ice dome or divide near Prince Edward Island, termed the Escuminac Ice Centre (Rampton *et al.*, 1984; Fig. 84). Northward flow features in the Baie des Chaleurs region of New Brunswick have been attributed to the development of the Escuminac Ice Centre (Pronk *et al.*, 1989). H. Josenhans (pers. comm., 1990) interprets an incoherent seismic unit that pinches out in the Laurentian Channel as a till formed by ice from the Magdalen plateau region. Flow from a centre in the region of Prince Edward Island was likely responsible for the "flood" of red mud (cf. Grant and King, 1984) from the vast areas of Carboniferous red-beds in northern Nova Scotia onto igneous and metamorphic terrains to the south. Anomalous red muddy diamictons have been described in some offshore cores adjacent to the Lunenburg (Piper *et al.*, 1986) and Chezzetcook drumlin fields (Forbes *et al.*, 1988) but were not encountered in grab samples in this study. The Sable Island and Western Bank regions are characterized by high percentages of red-stained (hematite) detrital quartz grains with a possible Carboniferous red bed source (Cok, 1970). Cok (1970) also describes a sizeable "skip zone" with little or no red-stained quartz across the inner shelf, which corresponds to the extent of Ice Flow Phase 3 (Fig. 83). Amos and Miller (1990) reported abundant red siltstone lithic fragments in the cores of southwest Sable Island Bank. Piston cores in continental slope regions to the south and west of the Sable Island and Western banks have a characteristic, consistent stratigraphy consisting of

an olive-grey mud, overlying a red-brown mud (Hill, 1981; Mosher *et al.*, 1989). Conolly *et al.* (1967) also described a similar stratigraphy in cores on the slope off the Laurentian Channel. Hill (1981) determined a Carboniferous source region for the red mud based on reworked Carboniferous palynomorphs. According to Hill (1981) the red unit was deposited from suspension fallout from the ice sheet that formed the Lawrencetown Till. The olive-grey unit is Holocene in age and derived from adjacent banks.

The "red flood" of Ice Flow Phase 2 crossed the inner shelf to the outer banks and slope, in 300 m water depths (Dodds and Fader, 1986; Mosher *et al.*, 1989). The timing of this flow event is between 18 and 21 ka (Mosher *et al.*, 1989; Baltzer *et al.*, 1994). The inferred maximum extent of Phase 2 is shown in Fig 83. This is comparable to the "maximum model" and consistent with the ice thickness estimates on the inner shelf (1 km) obtained earlier (Fig. 80). Ice outflow from the Escuminac Ice Divide and Centre during Phase 2 may have been in the form of ice streams or ice "currents" (Grant, 1963). These rapidly flowing ice streams would have converged into inter-bank channels, drawn by rapid calving of the ice margin in deeper water.

Late Ice Flow Phase 2 ice flow indicators along the northern part of the study region appear to veer to the southeast parallel to the earlier Phase 1b ice flow (Fig. 83). The east-west orientation of Sable Island and Banquereau and north-south trending tunnel valleys imply a major southward-flowing ice sheet (Fig. 74; Boyd *et al.*, 1988b). The southeastward flow trajectory in the Wine Harbour area may be due to a localized ice stream that merged with southward-trending streams from an extensive, former ice divide across the Magdalen Plateau and possibly, Cape Breton Island. This divide (Escuminac

Ice Divide) may have formed during the Middle to Late Wisconsinan (Stea *et al.*, 1992a) when Laurentide Ice was removed from the Laurentian Channel, cutting off Magdalen Plateau ice from a Laurentide source (Occhietti, 1989). Alternatively, (Phase 2) southeastward ice flows may represent later, radial flow from a remnant centre (Fig. 83).

6.3.1 Retreat of Phase 2 Ice

Retreat of the Phase 2 ice margin was hastened by calving at the marine shelf/slope break margin. Calving was a primary feedback mechanism for initiation of the retreat of the northern hemisphere glaciers (Denton and Hughes, 1981). Mosher *et al.* (1989) reported Late Wisconsinan iceberg furrowing at 300 m adjacent to the margin. Rapid retreat of Ice Flow Phase 2 ice from the shelf edge margin and from the Laurentian Channel may have contributed to the formation of Heinrich events in the deep ocean dated 18.9-21.4 ka (Heinrich, 1988; Broecker *et al.*, 1992; Bond *et al.*, 1992; Grousset *et al.*, 1993). Ice streams in the Laurentian Channel emanating from a Newfoundland Ice Cap (Grant, 1989) and the Escuminac Ice Divide (Fig. 83) eroded large quantities of limestone from the Anticosti and Magdalen Basins and also carried a substantial quantity of Appalachian terrane debris. Based on the sand mineralogy of continental rise sediments off southeast Canada, Piper *et al.* (1994) suggested the development of Appalachian ice caps during marine oxygen isotope stages 4 and 2. A Baffin Bay source has been postulated for Heinrich layers, based on petrography and geochemistry (Grousset *et al.*, 1993), but the technique cannot rule out iceberg debris derived from the complex bedrock terranes of the eastern Canadian margin. Individual Heinrich layers (Hl1 and Hl2) appear to thicken towards the Appalachian margin (Grousset *et al.*, 1993). The ice margin may have initially retreated as far as the inner shelf. Boyd (in McLaren, 1988) and King (1994)

proposed that Sable Island Bank was the site of a significant ice. marginal stand. According to these authors, a glacier grounded near sea level produced an outwash-delta-dominated moraine. Boyd (in McLaren, 1988) correlated this margin across Western and Emerald Bank as far as Georges Bank.

6.4 ICE FLOW PHASE 3

Flow from the Scotian Ice Divide was northwestward into the Bay of Fundy and southeastward over the Eastern Shore, veering southward east of Country Harbour (Fig. 83). It was also funnelled northward into Georges Bay and the Cape Breton Channel from Cape Breton and the mainland. At an early stage of development, the Scotian Ice divide merged with glaciers in the Baie des Chaleurs in New Brunswick to flow northward through the Shediac Channel into the Laurentian Channel (Fig. 83). An ice dome off Cape Breton Island proposed by Grant (1977) was probably part of this divide which can be traced eastward through Chedabucto Bay onto the continental shelf. Offshore tunnel valleys, oriented northeastward towards the Laurentian Channel and southward towards Sable Island (Boyd *et al.,* 1988b), converge in an undissected zone, probably the offshore location of the Scotian Ice Divide (Figs. 74, 83).

Three hypotheses can be invoked to explain the formation of the Scotian Ice Divide; two based on autocyclic, self-regulating mechanisms, and one based on external factors. They are:

1. Ice retreated rapidly, through calving, into the marine channels bordering Nova Scotia including the Gulf of Maine-Bay of Fundy (Prest

and Grant, 1969), and Cape Breton Channels. In this manner Nova Scotia ice was cut off from the Escuminac and Gaspereau ice sources (Fig. 83).

2. Stabilization of the retreating Phase 2 ice margin at the Scotian Shelf End Moraine complex due to crustal rebound and marginal sediment accumulations. At Sable Island, crustal depression was minimal, and outwash deltas formerly graded to a sea level of 75-80 m bsl (McLaren, 1988).

3. Change in climatic factors, favouring snow accretion on the Nova Scotia mainland (MacNeill and Purdy, 1951).

Simple drawdown (Hypothesis 1) may not completely explain an ice sheet whose flow-lines can be traced across the northern mainland highland areas exceeding 400 m. A combination of all 3 formative mechanisms is likely. Snow accretion may be favoured if jet stream position and seasonal storm tracks were shifted southward around the larger Laurentide ice sheet (Shinn and Barron, 1989).

The Scotian Ice Divide may have extended as far as Sable Island Bank and the series of banks which line the outer shelf. The southern margin of the Scotian Ice Divide may have been a short-lived ice shelf, with ice rises briefly acting as centres of outflow during recession (Gipp, 1989; 1994). Ice later settled at the Scotian End Moraine Complex, the site of former ice retreat margins from earlier advances (Phases 1a, 1b) and Banquereau Bank (Fig. 83). These margins are nearly equidistant from the inferred divide (Fig. 83). The Scotian Shelf End Moraine Complex formed at approximately 15.5 ka in the northeast

(Gipp, 1989; Gipp and Piper, 1990), but ages in the southern portion are not well constrained.

6.4.1 Retreat of Phase 3 Ice

Calving retreat of the Scotian Shelf and Banquereau ice margin was initiated when sea levels rose again following the outer shelf lowstand at 17-15 ka (Amos and Miller, 1990; King, 1994). By 14 ka the ice margin was close to the present day coastline over much of Nova Scotia (Piper et al., 1986; Stea and Wightman, 1987; Stea and Mott, 1989; 1990; Piper, 1991; Gipp, 1994), but it stubbornly remained there for at least 1500 years (Stea and Mott, 1989; Gipp, 1994). The lack of raised features along the Atlantic Coast of Nova Scotia indicates that an ice carapace prevented shoreline formation during isostatic recovery. This was not the case on the Gulf of Maine and Bay of Fundy, where vigourous ice stream drawdown cleared ice from these regions (Mayewski et al., 1981; Belknap et al., 1991). Raised beaches, deltas and marine deposits dated from 16 to 12.6 ka are found along the Bay of Fundy (Grant, 1980a, b, 1989; Scott and Medioli, 1980a; Stea et al., 1986; 1987; Honig and Scott, 1987; Stea and Wightman, 1987). In northern Nova Scotia deglaciation was delayed by as much as 2000 years until the region around Georges Bay was cleared of ice by landward propagation of a calving bay in the Cape Breton Channel.

The rapid calving-style retreat of the Phase 3 ice margin can be correlated with the youngest of the Heinrich events (13.4-15.0 ka) in the deep North Atlantic ocean (Grousset et al., 1993). Sequence 2 of the inner shelf Basin Zone records much of the iceberg activity in the form of point-source diffractions (boulders and boulder dumps). Bacchus (1993) and Gipp (1994) also report extensive iceberg activity in the Scotian Shelf and Gulf

of Maine at this time. From 15 to 13 ka much of the ice was removed from the Gulf of Maine-Bay of Fundy system and the Laurentian Channel (Piper, 1991).

6.5 ICE FLOW PHASE 4

During this phase ice caps remnant from the Scotian Ice Divide briefly reactivated (Fig. 83). These small ice caps or glaciers formed over Southern Nova Scotia, (South Mountain Ice Cap-MacNeill, 1951), the Chignecto Peninsula (Chignecto Glacier-Chalmers, 1895) and Antigonish Highlands in northern Nova Scotia (Chedabucto Bay Glacier Complex-Stea *et al.*, 1989; Figs. 4, 83). During Phase 4, ice was strongly funnelled westward into the Bay of Fundy and southwestward to the Atlantic coast and beyond. Rapid advance of Phase 4 ice offshore formed the Morainal Zone. Southwestward-trending channels which cut the Phase 3 ice margins and are initiated at the Morainal Zone (Fig. 16; Map 2) may have served as meltwater conduits from this glacier. Truncation of Emerald Silt in water depths between 140 and 160 m may have been synchronous with the Phase 4 margin.

The Country Harbour End Moraine is a complex, palimpsest feature. The southwest-trending ridge may have initially formed during Ice Flow Phase 3. Phase 4 ice eroded and reshaped the NW-SE segment, probably at the same time as the formation of the Morainal Zone. The complex-interdigitating succession of till-tongues and thick Emerald Silt section are a result of ice advance and retreat from the successive Phase 3 and 4 ice margins.

Ice Flow Phase 4 on land can be traced to re-advance margins in the Annapolis Valley

(Hickox, 1962) and in southern Nova Scotia near Chester (Graves and Finck, 1988; Map 1; Figs. 4, 83). In the Annapolis Valley this margin is marked by outwash deltas. Marine limit beyond the margin is +40 m whereas inside the margin it is <25 m (Stea *et al.*, 1987; Fig. 5). The time of formation is bracketed between dates on the oldest marine limit indicator south of the margin (ca. 14 ka, Grant, 1989) and the youngest, north of the margin (ca. 12.4 ka; Stea *et al.*, 1987). This event may correspond with the erosional event that formed the Sequence 2 boundary in the Basin Zone dated at approximately 13.5 to 12.7 ka. Ice Flow Phase 4 is correlative with the Robinson's Head advance in Newfoundland dated at 12.6 (Grant, 1989).

6.5.1 Retreat of Phase 4 Ice and the Sea Level Lowstand

After 12.6 ka, the climate warmed considerably (Mott and Stea, 1994) resulting in ice retreat to small, remnant terrestrial centres (Map 1). Trees migrated into southern Nova Scotia after 12 ka (Mott and Stea, 1994). Sea-level fall stranded Phase 4 glaciers into isolated pockets. Ablation by downwasting ensued, leaving tracts of hummocky ground moraine (Map 1) throughout the marginal regions. Phase 4 ice may have disappeared by 11 ka (Stea and Mott, 1989; Gipp, 1994). Sea levels dropped to their lowest point at -65-70 m around 11.6 ka. A shoreline formed during a short period of crustal stability (Transition Subzone). Sea-level rose rapidly after 11.6 ka and a large area of the inner shelf was transformed by erosion into a low-relief surface, barren of depositional features (Platform Subzone). The rate of relative sea-level rise slowed markedly between 11 and 9 ka, a result of forebulge passage, and depositional features were again established (Estuarine Subzone).

6.6 THE YOUNGER DRYAS EVENT

Around 11,000 yr B.P. an abrupt and pronounced climatic deterioration occurred that strongly affected the terrestrial landscape, its vegetation cover and the nature of sedimentation and fauna of adjacent oceanic basins. A wide variety of sediments covered organic sediments at many sites in the Maritime Provinces. Lake cores on land and the inner shelf basins reveal a sedimentological "oscillation" that marks the Younger Dryas (11,000-10,000 ka; Mott et al., 1986). Changes in pollen and foraminiferal assemblages in these depositional areas imply a warm-cool-warm cycle. Stea and Mott (1989) proposed that small glaciers developed from pre-existing ice or reformed during this time on land. King (1994) proposed a major glacial advance terminating at Sable Island.

Using a general circulation model, Rind et al. (1986) predicted accentuated cooling in northern Europe and northeastern North America during the Younger Dryas with increased onshore wind flow, storm activity and precipitation. Shinn and Barron's (1989) climate model of the last glacial maximum also evokes a northward shift of storm tracks along the margin of the Laurentide ice mass and net increase in precipitation along the margin. According to their theory, storms over the region reached a maximum frequency when the retreating Laurentide and Appalachian ice masses were somewhat removed from the region. The increase in storminess, coupled with a North Atlantic meltwater-induced cooling (Broecker, et al., 1985) would explain a local buildup of ice during the Younger Dryas.

APPENDIX 1: Mapping methods-marine geophysical data acquisition.

Seismic data for the study were collected during Cruise 91018 (CSS Dawson; Fader *et al.*

1993) on the eastern inner Scotian Shelf (Fig. 1). The Huntec Deep Tow boomer system

was used to generate analogue seismic data with vertical resolution of less than 1 metre

(c.f. Hutchins *et al.* 1976). Operating frequencies ranged from 500 Hz to 2 KHz with a

power output of 4-6 kV. Two recorders were employed, an internal transducer mounted

underneath the towed sound source and an external array. The deep tow system is towed

at 10-75m water to minimize the effects of surface swell and wave noise. Seismic

reflection data with less resolution but more penetration were obtained using a 40 cubic

inch Haliburton sleevegun system operating at 5-500 Hz. Bathymetric information was

obtained using data produced by a hull-mounted 3.5 KHz acoustic profiler, from Canadian

Hydrographic Service charts, and from the depth of the first multiple below the seabed in

the Huntec records (Sylwester, 1983). Seafloor topography/reflectivity were obtained

using the Bedford Institute of Oceanography-designed sidescan operating at 70 KHz with

a range of 1 kilometer and Klein dual frequency sidescan sonar systems at 100 and 500

KHz with a range of 100 to 400 m.

Additional data were obtained from seismic records of a previous CSS Dawson cruise in

1987 (Forbes *et al.* 1991). The Nova Scotia Research Foundation Corporation (NSRFC)

deep-tow seismic system was deployed on this cruise and included a nine element streamer

and a 30-tip sparker source operating at 200j.

14.25 kHz echograms collected by the Canadian Hydrographic service in the 1960's for

charting purposes were also used in the mapping of the offshore. A region from Sheet

Harbour to Halifax was surveyed at a track spacing of 0.93 km (King *et al.* 1972).

Late in this thesis study, high resolution swath bathymetry was made available to the author. A region of the inner shelf off Halifax was surveyed using the Simrad EM-100 multibeam sounder. It provides a digital image of the sea floor. The coverage is 1.7 X water depth across track (80° angle) with 32 narrow beams, each about 2.5°. It operates at 95 Khz and has a depth range of 10 to 600m. Spatial resolution of a single beam is 5 metres (Costello *et al.* 1993).

Offshore digital terrain data obtained from this system was gridded using GRASS GIS software (R. Courtney pers comm, 1992). The digitized bathymetric 14 kHz data was gridded and a terrain model produced using AUTOMINER software. Digital elevation data was also obtained from the Lunenburg drumlin field through the Land Survey and Registration Service (Prince Edward Island). This was also gridded and plotted using GRASS GIS software.

APPENDIX 2: Marine and terrestrial sampling methods and sample preparation.

Most samples of the seafloor were obtained with a large (0.3 ton capacity IKU) wire-line grab (Fig). These grab samples were described carefully and subsampled on deck using a shovel and five gallon pails. If the IKU was full sampling proceeded from the top down. Five gallon pail samples were collected from the surface lag, from the zone in the middle of the sediment block, and from the bottom. The preservation of stratigraphy within the filled grabs suggest minimal modification of the sediment package by the sampler. At other sites, however, the grab did not "bite" into the substrate. These grabs brought back a surface lag of cobble and boulders and occasionally some matrix. Other, coarser-grained samples were thoroughly mixed when the sampler was discharged on the deck.

Shallow cores in coarser, hard sediments were taken with a Brooke Ocean vibrocorer capable of 3m penetration. In softer sediments (muds) a modified benthos piston corer was employed v·ith a penetration capability of 20m. Cores were split, photographed, described and subsampled for grain size and biostratigraphic analysis using foraminifera (Costello, 1994).

2-5 kg till samples were obtained from road cuts, sea cliffs and borrow pits. Sixty-five samples of till pebble separates from a previous survey in 1977 (Stea and Fowler, 1979) were utilized to augment the pebble count databas·. The reference section at West Lawrencetown was systematically profile-sampled at regular intervals. One sample per metre of depth was obtained.

A 1-2 kilogram aliquot of sample was removed from the sample bags of terrestrial and marine samples. This portion was dried overnight and then weighed with the container (aluminum pan). If the sample flowed freely then it was dry seived through 63mm, 4mm and 2mm pans. The clast fractions (>2mm) were weighed and the matrix fraction discarded. The >4mm <30 mm fraction was retained for pebble lithological analysis. Lumpy samples (clay-rich) were wet seived through 2mm screens after disggregation and dispersal in a calgon solution. The clast fraction was dried overnight and then processed like the previous dry samples.

APPENDIX 3: Marine samples locations and field notes.

Vibro-Core data

SAMP #	SAMPLE TYPE	DAY/TIME (GMT)	LATITUDE LONGITUDE	DEPTH (MTRS)	GEOGRAPHIC LOCATION	NOTES
001	VIBRO	1551913	44 38 65N 63 33 36W	21 9	HALIFAX HARBOUR	CATCHER SAMPLE IN A BUCKET (125 ML) ANN MILLER HAS TAKEN THIS SAMPLE TO WASH FOR FORAMS NO CUTTER SAMPLE SEISMIC TIME FROM NAVICULA 89009 DATA
003	VIBRO	1561615	44 33 62N 63 32 17W	31 0	HALIFAX HARBOUR	1 BUCKET WITH CUTTER SAMPLE ANN MILLER HAS THE SAMPLE THIS IS THE BOT VIBROCORE NOT THE AGC VIBROCORE
004	VIBRO	1561722	44 33 25N 63 32 07W	24 0	HALIFAX HARBOUR	STOPPED VIBROCORING WITH 30CM TO GO BECAUSE OF THE LACK OF PENETRATION THROUGH SEDIMENTS OVER A FEW MINUTES FINE SAND VERY DRY GREEN-BLACK WELL SORTED FEW SHELL FRAGMENTS
018	VIBRO	1591637	44 15 60N 64 10 43W	56 0	SOUTH CROSS ISLAND	LATE TILL PIPERS YOUNG MORAINE SOUTH OF CROSS ISLAND TILL MOUND LINER JAMMED IN THE BARREL BUT THERE ONLY WAS A CATCHER SAMPLE FINE GRAVEL AND A COBBLE IN THE CATCHER
022	VIBRO	1601438	44 15 74N 64 09 69W	65 0		GOUGES IN THE CORE BARRELL, BOULDERS ? SILTY SAND GRAY SULPHIDE- H2S SMELL IN CORE BOTTOM GRAVELLY SAND (COARSE) WITH FEW PEBBLES IN CORE CATCHER CORE CATCHER SAMPLE STORED IN A 1 GAL BUCKET SAMPLE CUT INTO 2 SECTIONS A-B = 152CM, B-C = 66CM SECTION A B SLUMPED(COMPRESSED) 20CM WHEN HELD UPRIGHT MAIN SECTION COARSE SAND, GRANULE, GREY (SLATE FRAGMENTS) NOT WELL SORTED ANGULAR ROCKS CORE ON DISTAL (LATE TILL) MOUND TOTAL RECOVERY 2 2M INCLUDING CATCHER
034	VIBRO	1621710	44 25 09N 63 27 01W	82 3	EAST SAMBRO LEDGES	OLIVE GREY STONY DIAMICTON ANGULAR SLATE FRAGMENTS SILTY CLAYEY MATRIX WITH GREY MOTTLING SEISMIC UNIT (C) SURFACE TOP CRUDELY LAMINATED MASSIVE ACOUSTIC UNIT TILL- GLACIAL MARINE PROXIMAL ?? CORE CATCHER IMPLODED CUTTER DAMAGED BY BOULDER CORE CUTTER SAMPLE BAGGED IN A BUCKET
036	VIBRO	1621920	44 23 36N 63 29 13W	80 5	OLD SACKVILLE RIVER VALLEY	OLIVE GREY SILTY CLAY DIAMICTON FEW STONES COBBLING ON SURFACE SHELL FRAGMENTS MUCH MORE CLAY THEN 034 SOME SAND HORIZONS-INCLUSIONS, SHELL FRAGMENTS ON SURFACE SEISMIC UNIT (C) OUTCROPS ON SURFACE APPARENT LAMINATION CORE CUTTER SAMPLE BAGGED IN BUCKET

Appendix 3

038	VIBRO	1631200	44 28 65N 63 24 86W	73 0	DELTA ON FLANK OLD SACKVILLE RIVER	KEPT CORE AS 1 PIECE BECAUSE OF COARSE NATURE OF THE SAMPLE. SAMPLE WOULD BE DAMAGED BY CUTTING. NO CATCHER OR CUTTER SAMPLES. POSSIBLE DELTA ? MOUND WITH REFLECTORS DIPPING DOWN SLOPE TERMINATING ON FLAT HORIZONTAL REFLECTORS AT BASE, TOP 92CM OLIVE GREY COARSE SAND, GRANULES COBBLES ON TOP. SHELL FRAGMENT THROUGHOUT. SHARP CONTACT WITH LOWER 80CM OF OLIVE GREY SILTY FINE SAND WITH A FEW PEBBLES-MASSIVE NO SHELLS.
039	VIBRO	1631330	44 47 95N 63 25 17W	64 0	NORTH EAST OF SAMPLE 038	CATCHER SAMPLE + 15CM SAMPLE BAGGED IN A BUCKET UNDER UNIT (C) OR (B) OUTCROPS ON BEDROCK CHANNEL FLANK UNIT (C)INCISED IN CHANNEL AND FILLED BY YOUNGER SEDIMENTS (HOLOCENE)? TOP 15CM SANDY, GREY GREEN. COBBLES, SHELL FRAGMENTS CORE CATCHER GREY DIAMICTON WITH REDDISH TINGE. SILTY, METAGRAYWACKE CLASTS (ANGULAR-SUBROUNDED), ABUNDANT SHELL FRAGMENTS CORE DID NOT SAMPLE UPPER UNIT BUT SAMPLED LOWER UNIT (C),PENETRATED 2 METRES WITHOUT SAMPLING UNIT.
040	VIBRO	1631429	44 26 24N 63 22 96W	80 0	SACKVILLE RIVER SOUTHERN TRIBUTARY	OLIVE GREY SILTY SAND (SOME CLAY). DIAMICTON COBBLEY SURFACE, NO VISIBLE SHELLS-TILL OR GLACIAL MARINE. METAGREYWACKE CLASTS (SUBANGULAR-SUBROUNDED). 1 GRANITE CLAST
041	VIBRO	1631620	44 30 48N 63 28 95W	60 0	DUNCANS COVE	NO RECOVERY.
053	BENTHOS PISTON	1641630	44 17 72N 62 58 12W	168 0	HALIFAX MORAINE	LAHAVE CLAY APPROX 6M THICK. TOP 22 FT.,OLIVE-GREY SILTY CLAY BOTTOM 5 FT GREY-BLACK, REDUCED MUD, H2S ODOUR.CUTTER SLIGHTLY DAMAGED ATTEMPT TO CORE COARSE UNIT AT BASE OF LAHAVE CLAY. STRATIGRAPHY-LAHAVE CLAY OVER FACIES A, THIS COULD BE THE YOUNGER DRYAS EVENT (FACIES A) BENEATH LAHAVE CLAY. NO TRIGGER WEIGHT-BARREL TOO LONG TO CLEAR THE RAIL.
066	VIBRO	1671630	44 37 28N 62 36 48W	64 0	SOUTH OF MUSHABOOM	OLIVE GREY GREEN SILTY SAND WITH COBBLE LAG. BRITTLE STAR ON SURFACE. GREY SILT AND CLAY, NO STONES AT 20CM. DEPTH 3 (1 GAL) PAILS 1= TOP 10CM 2= BOTTOM20CM, 1= CORE CUTTER.
067	VIBRO	1671900	44 31 88N 62 27 13W	137 0	SOUTH OF SHEET HARBOUR	STRATIGRAPHY OF CORE UNIT-2 OLIVE-GREY SANDY MATRIX, UNIT-1 GREEN AND BROWN SILTY MUD FEW GRANULES (METAWACKE)
078	VIBRO	1681654	45 00 28N 61 30 38W	80 0	SOUTH OF COUNTRY HARBOUR	SEISMIC OUTCROP OR OLDER UNIT (C)? OLIVE-GREY SAND (20CM OVERLYING BLACK ORGANIC CLAY (4CM). CORE EXTRUDED INTO 2 (1 GAL)

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						BUCKETS 1 IS LABELLED 78TOP 20CM AND THE OTHER IS LABELLED 78 BOTTOM 4CM CORE MOTOR HOUSING FRAME BROKEN WHILE HITTING THE SIDE OF THESHIP ONLY A FEW WELDS LEFT. ONLY BOLTS HOLDING THE FRAME ON THE VIBROCORE
079	VIBRO	1681755	45 03 78N 61 33 66W	45 0	SOUTH OF DOME, COUNTRY HARBOUR	CUTTER CONTAINED OLDER UNIT (C). VENEERED BY SABLE ISLAND SAND UNIT 3=COBBLE-PEBBLE LAG METAGRAYWACKE QUARTZ VEIN GRANITE. UNIT 2= OLIVE-GREY COARSE TO MEDIUM SAND UNIT 1= GREY-BLACK ORGANIC CLAY SLOWED DOWN THE DESCENT OF THE VIBROCORE TO THE BOTTOM AND GOT BETTER RECOVERY/APP. PENETRATION RATIO AS A RESULT.
080	VIBRO	1681836	45 04 50N 61 34 73W	36 0	SOUTH OF DOME, COUNTRY HARBOUR	ONLAP OF THICK SABLE 'ILAND SAND? WEDGE ONTO DOME STRUCTURE. OLIVE-GREY SAND WITH BLACK SANDY BANDS APP. PENETRATION O F 2 1 METRES (RECORDER) BUT ONLY 78CM RECOVERY MUCH OF THE SAMPLE MAY HAVE WASHED THROUGH THE CATCHER
081	VIBRO	1681925	45 06 36N 61 36 36W	27 4	NORTH OF DOME, COUNTRY HARBOUR	SEISMIC WEDGE OF SAND NORTH OF DOME OLIVE-GREY SAND. CORE SOCK DID NOT HOLD SAMPLE. EXTRUDED FROM THE BOTTOM ONLY 40CM RETAINED. BAGGED IN A BUCKET.
096	VIBRO	1701726	45 03 25N 61 47.79W	25 00	SOUTH OF INDIAN HARBOUR	OLIVE-GREY SAND LITHOTHAMNION ENCRUSTED COBBLE ON TOP. BOTTOM IN COBBLY SAND. SEISMIC- BEDROCK CHANNEL FILLED WITH LAMINATE ON TOP FILL. SOCK IN CORE CATCHER PREVENTED SOME LOSS 1 GAL BUCKET WITH CORE CATCHER MATERIAL.
097	VIBRO	1701820	45 00 76N 61 48.03W	25.60	SOUTH OF INDIAN HARBOUR	SEISMIC-CHANNELS IN BEDROCK FILLED WITH TRANSGRESSIVE ON TOP FACIES WITH UNIT (E). MYSTERY IN BASE OF CHANNELS OLIVE-GREY SILTY SAND, COBBLE PINK COVERED CLASTS ON SURFACE (LITHOTHAMNION). LAG, WELL SORTED, BLACK REDUC'-D ZONES MOTTLING (SULPHIDE) FEW GRANULES 2 SUBSAMPLES (CUTTER-CATCHER).
098	VIBRO	1701908	44 56 73N 61 48 46W	47 00	SOUTH OF INDIAN HARBOUR	CORING BASIN CHANNEL FILL UNITS (30CM),MAY GET INTO UNIT 2? UNIT 3 IS SABLE ISLAND SAND. UNIT 2- ESTUARINE UNIT 1- TILL-UNIT (C). UNIT 2- OLIVE-GREY SILTY SAND WELL SORTED, COBBLE-PEBBLE LAG. UNIT 1- GREY-BLACK SILTY CLAY REDUCED- ORGANIC- SULPHIDE MOTTLING. FRAME AROUND THE MOTOR WAS DESTROYED
099	VIBRO	1711840	44 55.12N 61 39 13W	89 00	SOUTH OF LISCOMB TILL	CORE HIT STONE IN UPPER UNIT(3) AND CONTINUED TO PENETRATE WITHOUT FURTHER RETENTION. THE RESULTANT CORE WAS AN OLIVE-GREY SAND (UNIT 3), THE TOP AN APPARENT TRANSGRESSIVE SAND. THE OUTSIDE OF THE BARREL WAS COVERED WITH A

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SAMPLE NUMBER	TYPE OF IKU	JULIAN DAY/TIME	LATITUDE LONGITUDE	DEPTH (MTRS)	GEOGRAPHIC LOCATION	NOTES
002	IKU	1561448	44 33 62N 63 32 17W	31 0	HALIFAX HARBOUR	GREENISH GREY COMPACTED MUDDY SEDIMENT WITH QUOHOG SHELLS IN SEDIMENT HIGHLY DISTURBED SO NO PUSH CORE TAKEN SAMPLE STORED IN 1 (5 GAL) BUCKET SMALL SAMPLE
005	IKU	1581231	44 19 50N 64 09 17W	20 00	LUNENBURG HARBOUR	POCKED BEDROCK SURFACE ON SIDE SCAN HALIFAX SLATE COBBLES
006	IKU	1581247	44 19 46N 64 09 14W	22 00	LUNENBURG HARBOUR, NORTH CROSS ISLAND	BEDROCK SURFACE POSSIBLY HALIFAX SLATE 3 (5 GAL) BUCKETS TAKEN IN AREA OF BEDROCK ON THE SIDESCAN WITH UNUSUAL PITS AT SEABED POSSIBLY OLD MINING PITS BY SEAGOLD
007	IKU	1581326	44 17 08N 64 06 09W	62 0	LUNENBURG	1ST ATTEMPT JAWS OPEN BROUGHT BACK ROCKS IN THE JAWS
008	IKU	1581334	44 17 08N 64 06 21W	62 0	LUNENBURG	NO RECOVERY
009	IKU	1581345	44 16 95N 64 06 34W	62 0	LUNENBURG	MUDDY SANDY GRAVEL MOSTLY SLATE SAMPLE STORED IN 5 (5 GAL) BUCKETS PANNED SAMPLE HEAVIES MAGNETITE GARNET, ILMENITE NO GOLD SUBSAMPLES - GRAVEL FINES
010	IKU	1581409	44 16 12N 64 04 46W	65 0	LUNENBURG	SAMPLE STORED IN 4 (5 GAL) BUCKETS 2 PHOTOS TAKEN
011	IKU	1581441	44 15 23N 64 03 41W	67 0	LUNENBURG	SAMPLE ROCKS/MACROFAUNA SAMPLE STORED IN 1 (5 GAL) BUCKET
012	IKU	1581608	44 09 89N 63 56 40W	106 0	LUNENBURG	NO RECOVERY
013	IKU	1581618	44 09 89N 63 56 40W	106 0	LUNENBURG	NO RECOVERY
014	IKU	1581624	44 09 90N 63 56 43W	106 0	LUNENBURG	SAMPLER JAMMED OPEN WITH LARGE BOULDER 1/3 FULL PANNED SUBSAMPLE, NO GOLD BOULDERS COBBLES SAND SILT AND MUD STARFISH (BRITTLE) GREENISH BROWN COLOR AREA OF EXPOSED BEDROCK WITH SAND AND GRAVEL IN RIPPLES BETWEEN RIDGES
015	IKU	1581825	44 01 22N 63 39 23W	165 0	PENNANT PT	3 PUSH CORES (AREA E) 40CM EACH GREY MUD NO STONES (LAHAVE CLAY) FEW SHELLS MORAINE TOP SAMPLE (PENNANT PT) MAY HAVE MISSED TOPOGRAPHIC HIGH MISSED TILL GOT LAHAVE CLAY ALL MUD NO STONES SAMPLE STORED IN 3 (5 GAL BUCKETS) LABELLED - SURFACE LAG JUST BENEATH SURFACE, BOTTOM
016	IKU	1591236	43 55 27N 63 45 41W		LUNENBURG	ICEBERG FURROWS ON SEABED GOOD TILL-SOUTH SHORE MORAINE SLATE FACETTED-STRIATED SOME GRANITE CLASTS GREY BROWN MUDDY MATRIX TOP

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SAMPLE PANNED- 2 SUBSAMPLES 1=
PEBBLE 2=GRANULE SAMPLE STORED IN 5
(5 GAL BUCKETS) 1 TOP, 2 MIDDLE, 2
BOTTOM PUSH CORE WAS STARTED IN THE
MIDDLE OF GRAB AVOIDED SURFACE LAG
PUSH CORE LABELLED AS 91-18-015
SUBSAMPLES LABELLED AS IKU-16 PEBBLE,
IKU-16 GRANULE

017	IKU 1591424	44 05 16N 64 02 71W	82 3	LUNENBURG	(SEISMIC) SABLE ISL SAND ON REWORKED TILL,CLASTS ANGULAR AND ROUNDED SLATE GRANITE 5-10 %, SANDY MATRIX, COARSE GRANULES GREY QTZ VEIN IN FLOAT 2 SUBSAMPLES IKU-17 GRAVEL GRANULE, IKU-17 GRANULE SAMPLE STORED IN 2 (5 GAL) BUCKETS 1 BUCKET RETAINED FOR PANNING
019	IKU 1591746	44 15 60N 64 10 43W	56 0	SOUTH CROSS ISLAND	JUST RECOVERED ROUNDED BOULDERS OF METAGRAYWACKE 1-2 FT IN DIAMETER 10-12 BOULDERS IN 4 TRIES
020	IKU 1591838	44 14 85N 64 09 40W	53 0	SOUTH CROSS ISLAND	(SEISMIC) BOULDERY SURFACE INTERMIXED WITH GRAVEL TILL OR BEDROCK COVER MAYBE LATE TILL? 1 BOULDER RETAINED BOULDER IN FIRST 2 ATTEMPTS, WATER IN THIRD
021	IKU 1591928	44 12 96N 64 16 75W	40 0	LUNENBURG	GRAVEL RIPPLES IN BEDROCK FIRST ATTEMPT WAS WATER SECOND ATTEMPT BOULDERS AND SOME GRAVEL SAMPLE STORED IN 1 (5 GAL) BUCKET
023	IKU 1601650	44 19 33N 64 15 01W	20 0	DIRECTLY OFF OVENS PARK	8 ATTEMPTS- ONLY ONE HAS SMALL SAMPLE MUDDY GRAVEL- OTHERS HAVE BOULDERS IN JAWS UNUSUAL BOULDERS OF BRIDGEWATER CONGLOMERATE IN ONE ATTEMPT MUDDY GRAVEL WASHED DOWN 3 BAGED SUBSAMPLES FROM PANNING 1= GRAVEL SAMPLE, 2=GRANULE SAMPLE 3= HEAVIES SAMPLE 1 BUCKET SAMPLE OF BRIDGEWATER CONGLOMERATE
024	IKU 1601850	44 18 19N 64 00 06W	70 0	LUNENBURG	MATRIX-SILTY-SAND, SOME CLAY GRAVEL- PEBBLES GREY BROWN LARGE CLASTS SOME STRIATED HALIFAX SLATE TOP OF INTERPRETED DRUMLIN (SEE SIDESCAN) DRUMLIN EXPOSURE 3 (5 GAL) BUCKETS OF LARGE CLASTS 1 BAG OF MATRIX
025	IKU 1601915	44 17 33N 64 00 96W	71 0	LUNENBURG	DRUMLIN EXPOSURE- TOP OF DRUMLIN 1 (5 GAL) BUCKET SAMPLE GOOD TILL, LOTS OF MATRIX GREY-BROWN, SILTY-SAND MATRIX
026	IKU 1611148	44 35 95N 63 21 36W	18 0	SOUTH OF LAWRENCETOWN	SAMPLING BOULDER ARMOR SOUTH OF LAWRENCETOWN BEACH 2 (5 GAL) BUCKETS OF GRAVEL ROCKS
027	IKU 1611240	44 29 68N 63 19 65W	62 0	SOUTH OF THREE FATHOM HARBOUR	HUMMOCKY TILL SURFACE BOULDERY ROUNDED AND ANGULAR CLASTS S A N D Y MATRIX 3 (5 GAL) BUCKETS + 1 BAG OF MATRIX STORED IN A (1 GAL) BUCKET
028	IKU 1611432	44 12 75N 63 17 83W	164 0	HALIFAX MORAINE	BROWN-GREY SILTY TILL, STRIATED CLASTS SURFACE LAG BOULDERY, SOME EDGE ROUNDING INCLUSIONS OF UNOXIDIZED GREY-BLACK SILTY TILL(DRY) WITHIN BASE OF GRAB THIS WAS SAVED AS

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A BAG SAMPLE, HALIFAX MORAINE CONTINUATION. MOUND OF TILL (SEISMIC). 1 PUSH CORE LABELLED 91-18-028 AND 4 (5 GAL) BUCKETS PUSH CORE WAS BENEATH SURFACE LAG BUCKETS LABELLED AS 1= TOP, 1= MIDDLE AND 2=BOTTOM.

029	IKU 1611640	44 01 13N 63 13 50W	81 0	HALIFAX HARBOUR	NORTH SAMBRO BANK- TILL MOUND OR MORAINE SAMPLE GREY-BROWN STONY TILL SILTY-CLAY-SAND MATRIX CLASTS: METAWACKE, PINK GRANITE. INCLUSIONS OF RED SEDIMENT FEW SHELLS EDGE ROUNDING SAMPLE STORED IN 5 (5 GAL) BUCKETS, 1 TOP, 2 MIDDLE AND 2 BOTTOM 1 PUSH CORE LABELLED 91-18-029 REFER TO 3 5KHZ RECORD AT 161/1640.
031	IKU 1621415	44 29 85N 63 19 98W	64 0	OLD SACKVILLE RIVER VALLEY	SURFACE TILL? SHEET TRANSGRESSED-SANDY MATRIX SLATE-METAWACKE CLASTS, EDGE ROUNDED, LOOKS LIKE BEAVER RIVER TILL LOCAL LITHOLOGY LARGE BOULDERS COBBLES. 2 (5 GAL) BUCKETS LARGEBOULDERS PEBBLES SOME MATRIX RECOVERED PUT IN BUCKET.
032	IKU 1621440	44 28 41N 63 19 97W	82 0	EAST OF OLD SACKVILLE RIVER VALLEY	SURFACE TILL SHEET OR OUTWASH MOUNDS ? GRAVEL SURFACE (SIDESCAN) GREY-BROWN SANDY MATRIX METAWACKE CLASTS ROUNDED TO SUBANGULAR BEAVERRIVER TILL ? LARGE BOULDERS SAME AS PREVIOUS TILL! 3 (5 GAL) BUCKETS 2 BOULDERS- PEBBLE LAGS 1 BUCKET OF MATRIX-TILL.
033	IKU 1621650	44 27 52N 63 23 49W	64 0	SOUTH OF DARTMOUTH	TILL-SHEET HUMMOCKY SURFACE, (SIDESCAN) GRAVEL-BOULDERS GREY SANDY MATRIX (SILT < 20%) UNWASHED. CLASTS SUBROUNDED TO SUBANGULAR METAGRAYWACKE > 90% GRANITE < 5% SHELL FRAGMENTS-PELECYPOD BEAVER RIVER TILL 3 (5 GAL) BUCKETS 2 FOR TOP LAG AND 1 FOR BOTTOM TILL 1 SUBSAMPLE OF MATRIX TILL FOR GRAIN SIZE LABELLED AS 91-18-33
042	IKU 1631709	44 35 59N 63 23 39W	27 4	SOUTH CONRODS HEAD	SAMPLE STORED IN 5 (5 GAL) BUCKETS. TILL SURFACE-BOULDERY-HUMMOCKY-REWORKED SURFACE, WELL ROUNDED AND DISCOIDAL COBBLES PEBBLES GRAVEL AND SAND, GREY BROWN, BLACK ORGANIC ZONE, INNER MIXED (ESTUARINE?) LITHOLOGIES METAGRAYWACKE GRANITE, RED SANDSTONE (WIDE VARIETY)
044	IKU 1631825	44 29 73N 63 23 73W	55 0	TILL SHEET, SOUTH CONRODS HEAD	COBBLES- FEW BOULDERS SEISMIC-SIDESCAN COBBLE LAG-SUBROUNDED TO SUBANGULAR METAGRAYWACKE CLASTS, < 2% GRANITOID (SOUTH MTN). MATRIX-COARSE SAND, OLIVEGREY SOME MATRIX RETAINED IN GRAB, (BEAVER RIVER TILL ?) SAMPLE STORED IN 2 (5 GAL) BUCKETS
047	IKU 1631904	44 29 30N 63 24 31W	54 0	INNER SHELF, SOUTH OF HALIFAX	SAMPLE STORED IN 2 (5 GAL) BUCKETS LABELLED MATRIX AND LAG BLACK SIDESCAN COBBLE SURFACE, A FEW BOULDERS DIAMICTON-TILL, COBBLE-BOULDER LAG OLIVE GREY SILTY

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SAND TILL UNDERNEATH LAG SURFACE PROTECTS AN UNDERLYING TILL MATRIX WHICH IS NOT WASHED > 90% METAGRAYWACKE CLASTS, SANDY MATRIX

048	IKU 1631940	44 29 53N 63 26 46W	53 0	INNER SHELF, SOUTH OF HALIFAX	SAMPLE STORED IN 2 (5 GAL) BUCKETS LABELLED MATRIX AND LAG TILL-SECTION (SEISMIC INTERP) OLIVE- GREY SANDY MATRIX, UNWASHED- SUBROUNDED- SUBANGULAR CLASTS, LAG SURFACE OF METAGRAYWACKE 1 LARGE METASOMATIZED ? GRANITE BOULDER
049	IKU 1641211	44 24 18N 63 02 50W	128 0	EASTERN SHORE MORAINE	SAMPLE STORED IN 4 (5 GAL) BUCKETS LABELLED AS 1=TOP, 1=MIDDLE, 1=BOTTOM AND 1 LABELLED RED LAYER TILL MOUND ADJACENT TO POSSIBLE LIFTOFF? MORAINE OLIVE GREY SAND / SILTY DIAMICTON-TILL STRIATED FACETTED METAGRAY-WACKE CLASTS AND GRANITE CLASTS ANOMALOUS RED GREY LAYER IN TILL (SAMPLE)
050	IKU 1611320	44 15 35N 63 01 88W	164 0	NORTH OF EASTERN SHORE	TILL MOUND SURROUNDED BY GLACIO MARINE EMERALD SILT OLIVE GREY SILTY TILL MORAINE GREY SAND AND RED CLAY INCLUSIONS SHELL FRAGMENTS METAGRAYWACKE CLASTS, SUBROUNDED TO SUBANGULAR, SURFACE COBBLE LAG-TILL DOMINATED BY PEBBLE-SIZED CLASTS 1 PUSH CORE FROM AREA (E) SAMPLE STORED IN 4 (5 GAL) BUCKETS LABELLED 1=TOP, 3=BOTTOM
051	IKU 1641415	44 15 79N 62 59 54W	165 0		SURFACE LAG SILTY-SANDY DIAMICTON-TILL? WITH SUBROUNDED TO SUBANGULAR CLASTS-METAGRAY-WACKE (>90 %) RED SILTSTONE, VOLCANIC, METAMORPHIS CLASTS <5%, GRADES INTO MASSIVE GREYISH CLAY-SILTY-CLAY FEW STONES 1 PUSH CORE OF BOTTOM SILTY-CLAY SEDIMENTS POSSIBLE EMERALD SILT (A) (SEE SEISMIC) GRAB WELL STRATIFIED, NOT MIXED INSITU 1SUBSAMPLE OF LITHOLOGY SAMPLE STORED IN 5 (5 GAL) BUCKETS 1 FROM TOP, 2 FROM MIDDLE AND 2 FROM THE BOTTOM
052	IKU 1641500	44 16 85N 62 56 41W	171 0	HALIFAX MORAINE	OLIVE GREY SANDY-SILTY DIAMICTON (TILL)SAND INCLUSIONS, COBBLE-BOULDER LAG SURFACE METAGRAYWACKE CLASTS >90 % SUBROUNDED TO SUBANGULAR, 1 PINK GRANITOID CLAST ON SURFACE (SYENITE) SAMPLE STORED IN 4 (5 GAL) BUCKETS LABELLED 1=TOP, 1=MIDDLE AND 2 FROM BOTTOM 1 SUBSAMPLE OF ERRATIC GRANITE IN A BAG
055	IKU 1651428	44 28 90N 63 19 88W	128 0	EASTERN SHORE MORAINE	TOP OF MORAINE-ICEBERG FURROWS? OLIVE-GREY SILTY SANDY MATRIX (DIAMICTON) METAGRAY-WACKE >90 % GRANITE, MUD CLASTS (CARB ?) (<5 %)- SANDY INCLUSIONS BURROWS INSIDE SAND 2 BUCKETS FROM THE TOP AND 2 FROM THE BOTTOM BASE OF CLASTS-METAGRAYWACKE GRANITE, MUD CLASTS 1 GREY GREEN MUDSTONE
056	IKU 1651630	44 25 61N 62 31 08W	128 0	EASTERN SHORE MORAINE	TOP OF EASTERN SHORE MORAINE SURFACE LAG-BOULDER-COBBLE LAYER

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					METAGRAYWACKE ANGULAR TO SUBROUNDED, CLASTS (> 90%) S O M E FACETTED AND STRIATED BECOMING CLAYISH AND LESS STONY BENEATH THE SURFACE MATRIX OLIVE-GREY SILTY-CLAY SAND RED-BROWN CLAYEY LAYERS- INCLUSIONS 1 GRANITE CLAST SOME CLASTS VERY ANGULAR AND SOME WITH EDGE ROUNDING SAMPLE STORED IN 5 (5 GAL) BUCKETS 2 FROM TOP, 2 FROM BOTTOM AND 1 OF CLASTS
057	IKU 1651749	44 31 93N 62 27 43W	142 0	NORTH OF EASTERN SHORE MORAINE	EMERALD SILT (ERODED) COBBLE- BOULDER SURFACE LAG METAGRAY- WACKE >90% SILTY-CLAY SAND MATRIX BELOW OLIVE GREY SILTY DIAMICTON COBBLE-PEBBLE SIZED CLASTS BOULDERS ENCRUSTED WITH POLYPS- LARGE WORM RECOVERED 1 BAG OF PURPLE SLIME OF UNKNOWN ORIGIN SAMPLE STORED IN 3 (5 GAL) BUCKETS 1 FROM THE TOP AND 2 FROM THE BOTTOM
059	IKU 1651930	44 37 37N 62 30 59W	91 0	DRUMLIN FIELDS	HUMMOCKY MOUNDS OF TILL BOULDERY LAG IN IKU. METAGRAYWACKE GRANITE SOME MATRIX (OLIVE GREY SAND), VERY BOULDERY SAMPLE STORED IN 2 (5 GAL) BUCKETS 1 OF LAG BOULDERS AND 1 OF MATRIX
060	IKU 1671150	44 42 25N 62 39 28W	37 0	SOUTH OF TANGIER ISLAND	SAND BEDFORMS OVERLYING ARMOUR UNCONFORMING ESTUARINE/GLACIOMARINE SEDIMENTS (SEISMIC) ARMOUR OF COBBLES BOULDERS, DISCOIDAL CLASTS (SHINGLE) OVERLYING OLIVE GREY BLACK SILTY SAND MATRIX, TILL? (DIAMICTON) SAMPLE STORED IN 3 (5 GAL) BUCKETS 1 LABELLED LAG 1 LABELLED MIXED AND 1 LABELLED MATRIX
061	IKU 1671215	44 43 11N 62 39 17W	38 0	SOUTH OF TANGIER ISLAND	SAND BODY (WHITE ON SIDESCAN) COBBLE LAG-DISCOID CLASTS (SHINGLE SHAPE) METAGRAYWACKE, GRANITE LITHOTHAMNION ENCRUSTATION ON CLASTS, MATRIX, SAND 2 (5 GAL) BUCKETS
062	IKU 1671320	44 41 40N 62 32 56W	79 0	SOUTH OF MUSHABOOM	BEACH GRAVEL (SEISMIC) DISCOID CLASTS METAWACKE-GRANITE SAND MATRIX WAS WELL SORTED GREY-GREEN IN COLOR (BEACH) MISSED ON 1ST ATTEMPT, OVERSHOT, 2(5 GAL) BUCKETS
063	IKU 1671337	44 41 23N 62 32 59W	80 0	SOUTH OF MUSHABOOM	UNIT-C OUTCROPS ON SURFACE BETWEEN 2 DEEP VALLEYS FILLED WITH BEACH (UNIT-B) AND ESTUARINE SEDIMENT (UNIT-G) (SEISMIC) OLIVE-GREY STONEY SANDY DIAMICTON (TILL) METAGRAYWACKE CLASTS 1 GRANITE CLAST 3 (5 GAL) BUCKETS OF MIXED SAMPLE (LAG + SUBSURFACE) (SMALL VOLUMN IN GRAB)
064	IKU 1671428	44 37 28N 62 36 48W	64 0	SOUTH OF MUSHABOOM	TILL MOUNDS (SEISMIC) OLIVE-GREY STONEY DIAMICTON (TILL) SUBANGULAR TO SUBROUNDED CLASTS, MOSTLY SUBROUNDED SANDY MATRIX METAGRAYWACKE CLASTS >90% SAMPLE WELL WASHED DURING RECOVERY 4 (5 GAL) BUCKETS 1= TOP, 3= MATRIX

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068	IKU 1681127	45 05 78N 61 35 92W	27 0	MOUTH OF COUNTRY HARBOUR	OLIVE-GREY MEDIUM GRAINED SAND WITH ABUNDANT SAND SIZED SHELL FRAGMENTS SAMPLE ALSO CONTAINS ABUNDANT SAND DOLLARS 4 (5 GAL) BUCKETS
069	IKU 1681147	45 05 46N 61 35 54W	31 0	MOUTH OF COUNTRY HARBOUR	DESCRIPTION- OLIVE-GREY MEDIUM SAND WITH SAND SIZED SHELL FRAGMENTS NICE SMELL TO THE SAMPLE!!!!! PROBABLY A HIGH CONCENTRATION OF HEAVIES IN SAMPLE SAND DOLLARS AND QUOHOG SHELL 4 (5 GAL) BUCKETS
070	IKU 1681202	45 05 11N 61 35 22W	27 0	MOUTH OF COUNTRY HARBOUR	ON THE DOME GRAVEL LAG OVER MATRIX MUDDY SAND LITHOTHAMNION ON ALL ROCKS 2 (5 GAL) BUCKETS OF MATRIX ONLY 4 (5 GAL) BUCKETS OF FULL SAMPLE THIS IS A SPECIAL SAMPLE FOR ASSAY SAMPLE ACCUMULATED IN 4 GRABS AT THIS SITE
071	IKU 1681226	45 05 12N 61 35 29W	29 0	MOUTH OF COUNTRY	MUDDY GRAVEL CLASTS ARE COVERED WITH LITHOTHAMNION SLATE-METAGRAYWACKE >90% 1 (5 GAL) BUCKET PANNED SAMPLE, NO VISIBLE GOLD LOTS OF HEAVIES (GARNET)
072	IKU 1681236	45 04 81N 61 35 16W	33 0	MOUTH OF COUNTRY HARBOUR	OLIVE-GREY MEDIUM SAND WITH GRAVEL CLASTS SLATE METAGRAYWACKE >90%- GRANITE-QUARTZ VEIN (NO VG) 1 (5 GAL) BUCKET PANNED SAMPLE NO VISIBLE GOLD BUT LOTS OF HEAVIES
073	IKU 1681242	45 04 80N 61 35 13W	31 0	MOUTH OF COUNTRY HARBOUR	OLIVE-GREY MEDIUM SAND (NO GRAVEL) SAND DOLLARS 2 (5 GAL) BUCKETS
074	IKU 1681329	45 04 52N 61 34 98W	35 0	MOUTH OF COUNTRY HARBOUR	OLIVE-GREY MEDIUM SAND FEW COBBLES SAND DOLLARS (SAND WEDGE SEISMIC) PANNED SAMPLE - ABUNDANT GARNET, A FEW COBBLES SILT-SIZED 3 (5 GAL) BUCKETS SAMPLER WAS 1/4 FULL
075	IKU 1681349	45 03 70N 61 33 74W	35 0	SOUTH OF COUNTRY HARBOUR	GRAVEL AND COBBLES SANDY MATRIX OLIVE GREY DISCOID CLASTS, SLATE- (DOME) METAGRAYWACKE > 90% SOME GRANITE, REWORKED TILL (SEISMIC) SABLE ISLAND SAND-GRAVEL 2 (5 GAL) BUCKETS SAMPLER WAS 1/8 FULL
076	IKU 1681437	45 00 43N 61 30 46W	73 0	SOUTH OF COUNTRY HARBOUR	(SEISMIC) SABLE ISLAND SAND-GRAVEL BROAD CHANNEL COBBLE LAG METAGRAYWACKE (DOME) SUBANGULAR TO SUBROUNDED MOSTLY SUBROUNDED, MATRIX OLIVE-GREY (<5%) SAND MEDIUM, NOT AS MUCH ROUNDING AS PREVIOUS SAMPLE SAMPLE THOROUGHLY WASHED ON RETRIEVAL 1 (5 GAL) BUCKET SAMPLER WAS 1/4 FULL
077	IKU 1681630	44 59 61N 61 29 85W	40 0	SOUTH OF COUNTRY HARBOUR	SEISMIC RIPPLE ZONE BETWEEN 2 ROCK KNOBS OLIVE-GREY STONY DIAMICTON-METAGRAYWACKE (DOME) CLASTS > 90% SUBANGULAR TO SUBROUNDED (WIDE RANGE) SILTY-CLAY SAND MATRIX SOME BLACK ORGANIC CLAY IN MATRIX 3 (5 GAL) BUCKETS OF MATRIX SAMPLE LAG LEFT

Appendix 3

082	IKU	1691250	44 50 95N 61 31 71W	82 0	SOUTH OF COUNTRY HARBOUR	ON TOP OF BRASS NUT MOUND, TRANSGRESSED COUNTRY HBR MORAINE, LAG GRAVEL OVER TILL LAG-COBBLE BOULDER SUBROUNDED, TILL; OLIVE-GREY SANDY DIAMICTON, SUBROUNDED TO ANGULAR CLASTS. METAGRAYWACKE > 95% 2 (5 GAL) BUCKETS SAMPLER WAS 1/4 FULL
083	IKU	1691320	44 50 18N 61 31 55W	82 0	SOUTH OF COUNTRY HARBOUR	ONSIDE OF MOUND (BRASS NUT) COB LE-BOULDER LAG SUBANGULAR TO UNIT-3, SUBROUNDED, METAGRAYWACKE AND QUARTZ VEIN OVERLYING GREY-BROWN SANDY DIAMICTON, 20CM. UNIT-2 OVERLYING GREY CLAY WITH SHELLS, FEW STONES UNIT-1 (EMERALD SILT) 3 (5 GAL) BUCKETS, 1=TOP, 1=MIDDI E AND 1= BOTTOM SAMPLER WAS 3/4 FULL
084	IKU	1691409	44 40 25N 61 24 11W	82 0	SOUTH OF COUNTRY HARBOUR	MORAINE MOUND (TRANSGRESSED) COBBLE-BOULDER LAG QUARTZ VEIN IN BOULDER (MORAINE) METAGRAYWACKE >95% TILL UNDERNEATH OLIVE-GREY SANDY DIAMICTON METAGRAYWACKE SUBROUNDED TO SUBANGULAR, METAGRAYWACKE >95% 1 (5 GAL) BUCKET OF LAG DEPOSIT AND 1 (5 GAL) BUCKET OF TILL BENEATH (BOTTOM) SAMPLER WAS 1/2 FULL
085	IKU	1691615	44 42 46N 61 21 71W	109 0	SOUTH OF COUNTRY HARBOUR	SEISMIC MOUND MORAINE OVERLAIN BY VENEER OF EMERALD SILT SAMPLE 3 UNITS TOP (MORAINE) TOP UNIT- COBBLE-BOULDER LAG METAGRAYWACKE, MIDDLE UNIT- (10 40CM)OLIVE GREY-SANDY DIAMICTON UNIT 3-(+ 40CM) GREY-BROWN (REDDISH TINGE) CLAY WITH FEW STONES. 3 (5 GAL) BUCKETS 1= TOP LAG, 1= MIDDLE SAMPLE, 1= BOTTOM SAMPLER WAS 3/4 FULL
086	IKU	1691650	44 40 08N 61 20 95W	107 0	COUNTRY HARBOUR	SURFACE OUTCROPPING TILL TONGUE OVERLAIN BY EMERALD SILT, THEN TRUNCATED BY MARINE EROSION ? COBBLE-BOULDER LAG METAGRAYWACKE SUBROUNDED TO SUBANGULAR OVERLYING OLIVE-GREEN-GREY SANDY DIAMICTON. > 95% METAGRAYWACKE CLASTS A THIN CLAY LAYER NOTED AT BASE PROBABLY OVERLIES EMERALD SILT PANNED SAMPI E CLASTS MOSTLY SUBANGULAR QUARTZ VEIN NO VG (VISIBLE GOLD) ILMANITE GARNET 2 (5 GAL) BUCKETS, 1= LAG (SURFACE), 1= BOTTOM, SAMPLER WAS 1/2 FULL
089	IKU	1691920	44 44 62N 61 45 35W	106 0	COUNTRY HARBOUR MORAINE	BOTTOM- UNIT-1 GREY-SANDY CLAY-SILT / CLAY MASSIVE, SHELL BEARING, HEAVY > 6CM MIDDLE- UNIT 2 OLIVE GREY SILTY SANDY DIAMICTON 2-6CM TOP- UNIT 3 BOULDER COBBLE LAG, SUBANGULAR TO SUBROUNDED METAGRAYWACKE > 95%. PUSH CORE WAS TAKEN UNDERNEATH THE SURFACE LAG SAMPLE STORED IN 3 BUCKETS. 1 (2 1/2 GAL) BUCKET LABELLED TOP 1 (2 1/2 GAL) BUCKET LABELLED MIDDLE 1 (5 GAL) BUCKET LABELLED

Appendix 3

BOTTOM APPROX 70CM FROM TOP TO BOTTOM SAMPLER WAS FULL TO BRIMMING

091	IKU 1701248	45 02 53N 61 18 24W	73 0	SOUTH OF TOR BAY	BEDROCK RIDGE LAG DEPOSITS (SEISMIC) COBBLE-BOULDER LAG- WELL ROUNDED COBBLES -BOULDERS MIXED WITH SUBANGULAR COBBLES- PEBBLES, OVERLYING GREY DIAMICTON, METAGRAYWACKE >95% SOME RED INCLUSIONS IN MATRIX DERIVED LAWRENCETOWN TILL 1 (2 5 GAL) BUCKET LABELLED BOTTOM CONTAINS UNDERLYING TILL MATRIX AND 2 (1 GAL) BUCKETS LABELLED TOP CONTAINING TRANSGRESSIVE LAG + 1 BAG OF MATRIX FOR GRAIN SIZE SAMPLER WAS 1/2 FULL
092	IKU 1701340	45 01 77N 61 18 71W	93 0	SOUTH OF TOR BAY	ERODED UNIT (C)? TILL ? IN BEDROCK CHANNEL (SEISMIC) COBBLE BOULDER LAG SLATE-ANGULAR (>80%) ROUNDED GRANITE (CANSO PLUTON?) UNDERLYING GREY MD BROWN SILTY CLAY DIAMICTON FEW STONES NOTE REDDISH TINGE TRIP ARM WAS BENT NEEDED 2 ATTEMPTS 2 (1 GAL) BUCKETS LABELLED TOP LAG AND 1 (2 1/2 GAL) BUCKET OF UNDERLYING TILL LABELLED BOTTOM + 1 BAG OF GRANITE (CLAST LITHOLOGY)
093	IKU 1701414	44 57 07N 61 21 64W	112 0	SOUTH OF NEW HARBOUR RIVER	ERODED EMERALD SILT (A) AT LOW SEA LEVEL POSITION (SEE HUNTEC, SIDESCAN) PEBBLE-LAG (5CM) BROWNISH-GREY DIAMICTON METAGRAYWACKE >90% (UNIT-3) OVERLYING GREYISH-GREEN SANDY SILT DIAMICTON (UNIT-2) OVERLYING (15-40CM) CLAY WITH REDDISH INCLUSIONS (SHELL FRAGMENTS) (UNIT 1) 4 (1 GAL) BUCKETS 2= TOP 1=MIDDLE AND 1= BOTTOM PUSH CORES (BLOW BY) 4-10CM OF SEDIMENT (COMPRESS) SAMPLER WAS FULL
094	IKU 1701633	45 03 86N 61 48 87W	11 00	WINE HEAD	WINE HEAD SAND SAMPLE FIRST ATTEMPT HAD KELP AND MUSSELS WASHED AND REWORKED GRAVEL AND COBBLES WITH ORGANIC SILTY SAND (SECOND KELP) 1 (5 GAL)BUCKET + 3 BAGS SAMPLER WAS 1/2 FULL
095	IKU 1701648	45 03 85N 61 48 60W	18 00	WINE HEAD	BROWN COBBLY-SAND OXIDIZED OVER BLACK ORGANIC SILTY-SAND WITH PEBBLES (ESTUARINE) 3 BAGS LABELLED TOP BOTTOM AND SURFACE GRAVEL SAMPLER WAS 1/2 FULL

Appendix 4

MARINE SEDIMENT DATA

91018-DAWSON CRUISE

SAMPLE TYPES, ASSOCIATED LANDFORMS AND LITHOLOGIC AND SHAPE

OBSERVATIONS

1 = Sample number

2 = Sample type (0=full. 1=surface lag, 2=matrix, 3=top, 4=middle, 5=bottom.)

3 = Sediment Class (G-Gravel, GS-Gravelly sand, D-Diamicton, S-Sand, M-Mud)

4 = Landform (TD-Transgressive deposit, UC- Unit C, UB- Unit B, RM-Moraines (Morainal Zone), SM-Scotian Shelf End Moraines.

5 = Duplicate status (D-Duplicate if true .T)

1	2	3	4	5	Comments
006	0	G	TD	F	Rounded to well rounded, Foreigns include North Mountain basal, volcanics, pink, k-spar granitoids.
009	1	GS	TD	F	Subangular to subrounded.
009	2	GS	TD	F	
010	0	D	UC	F	Subangular to subrounded. Foreign include North Mountain basalt, volcanic fragments and pink k-spar granitoids.
011	0	D	UC	F	Angular to subrounded. 27 Fragments of an indurated diamict. Foreign include coarse, feldpathic sandstone, pink granitoid.
014	0	G	UB	F	Subangular to subrounded. Foreigns include amygdaloidal basalt, red and grey clastic sedimentary rocks, volcanics?
015	3	M	ES	F	No granule or pebble-sized clasts in sample.
015	5	M	ES	F	
016	3	D	SM	F	Subangular to subrounded. Foreigns include foliated granitoids (gneiss), volcanic, red and grey clastics, pink k-spar granitoid.
016	4	D	SM	F	Subangular to subrounded mostly subangular. Metapelitic lithologies with abundance of siliceous, greenish (Epidote?)alteration and disseminated sulphides. Foreign include mafic granitoids, porphyritic felsic volcanics, and red metasiltstone. Presence of an indurated grey diamict, possible older tills?
016	5	D	SM	F	Subangular to subrounded.Foreigns include mafic and felsic volcanics, grey and red clastic sedimentary rocks, pink, k-spar granitoids.
016	5	D	SM	T	Angular to subrounded. Forein include mafic and felsic volcanics, red and grey felsic volcanics, pink K-spar granitoids.
017	0	D	UB	F	Subangular to subrounded. North Mountain Basalt Volcanic, red and grey sedimentary
021	0	D	TD	F	Subangular to subrounded. Foreign include pink k-spar granitoids.
024	2	D	RM	F	Subangular to subrounded. Foreigns include foliated granitoids, gneiss?, grey sandstone.
025	0	D	RM	F	Subangular to subrounded. Foreigns include granitoid,Mwolcanics, mostly unrecognizeable.
027	2	D	UB	F	Subangular to subrounded. Foreign lithologies include foliated mafic igneous rocks, granitoids.

1	2	3	4	5	Comments
028	3	D	UB	F	Subangular to subrounded mostly subangular. Meguma metapelitic clasts mineralized-chalcopyrite?.
028	5	D	SM	F	Subrounded to subangular.
029	3	D	RM	F	Mostly subrounded to subangular, no rounded clasts; two or more directions indicated on some clasts; One mineralized Meguma clast (sulphides -grey metallic-arsenopyrite-galena?)
029	4	D	RM	T	Subangular to subrounded. Foreigns include grey and red clastic sedimentary rocks, pink, k-spar granitoids, diorite, and felsic volcanics.
029	4	D	RM	F	Subangular to subrounded most of the larger clasts (>8.00) m are striated. Quartz vein fragments mineralized with pyrite. Foreign include 1 amygdaloidal basalt fragment, 3 k-spar granitoids and aphanitic granitoids.
029	5	D	RM	T	Subrounded to subangular. Foreign include volcanic, pink k-spar granitoids, limestone (micrite) with brachiopod shells-Windsor Group?),red mudstone, grey sedimentary.
029	5	D	RM	F	Subangular to subrounded.Foreigns include pink kspar granitoids, diorite, red and grey clastic sedimentary rocks.
031	0	D	UC	F	Rounded to subrounded mostly rounded. No surface markings. Many stained with iron oxide. Foreign include volcanics.
032	1	D	UB	F	Rounded to subrounded. No striated clasts. Foreigns include sandstones, volcanic, granitoids.
032	2	D	UB	F	Subrounded; bullet-nose clasts modified by abrasion, edge rounding, foreigns include foliated granitoids with pink k-spars.
033	3	D	UB	F	Subangular to subrounded, mostly subrounded. Foreign clasts include red and grey clastic sedimentary, pink, granitoids and felsic volcanic.
042	0	G	UC	F	Rounded to well rounded clasts some discoid. No striations. Foreign components consist of greyish diotitic granitoids with porhyritic textures, volcanics and sandstones.
044	0	D	UC	F	Subrounded to rounded. No striations. Some bullet clasts, apparently reworked. Several greenish (silicified) metapelites. Surface foreigns include sandstones and granitoids.

1	2	3	4	5	Comments
048	1	D	UC	F	Subangular to subrounded,mostly subrounded. A mineralized,subangular and striated clast has flecks of chalcopyrite. Also appears silicified.
048	2	D	UC	F	Subangular to rounded, mostly subrounded, surface feature obliterated by algal growth; a mineralized clast seen, may be chalcopyrite.
049	3	D	RM	F	Angular to rounded; felsic volcanics, pink granitoids, red-grey ss, diorite-gabbro.
049	4	D	RM	F	Meguma clasts largely greenish metapelite few slate, Foreigns include porphyrytic felsic volcanics, grey sandstone, pink kspar granitoids.
049	5	D	RM	F	Pebbles more rounded than 50 Bottom; subrounded mainly, a few subangular; Foreigns include porphyritic aphanitic microgranitoid, mafic igneous rocks, red ss, pink, k-spar granitoid-Meguma mostly grey metapelite
050	3	D	SM	F	Roundness sorting value high angular to rounded two distinct populations apparent, well rounded and glacial clasts; felsic prophyritic volcanic, ss, granitoids
050	4	D	SM	F	
050	5	D	SM	F	Sample contains subangular to subrounded clasts one rounded Mineralized clast disseminated shiny in greenish metapelite note*5=bottom 4=middle 3=top 2=matrix 1=lag 0=full codes for ikutype.
051	3	D	ES	F	Angular to rounded; wide range of grain shapes in sample 51. Foreign include volcanic with phenocrysts, grey and red clastic sedimentary rocks, pink k-spar granitoids.
051	4	D	ES	F	Subangular to subrounded. Meguma mostly black metapsammite-pelite with a few schistose fragments. Foreign include pink, k-spar granitoids, red and grey clastic sedimentary rocks.
051	5	M	ES	F	Subangular to rounded. Only a few rounded. Foreign include an amygdaloidal basalt fragment, red sandstone and conglomerate and phenocrystic volcanics.
052	3	D	SM	F	Angular to rounded; wide range of particle shapes. Meguma mostly grey metapelite and metapsammite. Foreigns include mafic igneous (diorite); pink K-spar granitoids and volcanics.

Appendix 4

1	2	3	4	5	Comments
052	4	D	SM	F	Angular to subrounded. Foreigns include diorites, porphyry, k-spar pink granitoids, red mudstone, sandstone, rhyolites.
052	5	D	SM	F	Angular to rounded. Meguma lithologies consist mainly of greenish metapelites and metapsammites. Foreigns consist of sandstone, volcanic porphyry, pink k-spar granitoids.
055	3	D	SM	F	Angular to subrounded. Meguma clasts have disseminated sulphides, veinlets of quartz. Foreign include grey and red mudstones and felsic volcanics.
055	5	D	SM	F	Angular to rounded. Meguma lithologies consist primarily of grey metapelite. Foreigns include porphyritic volcanics, grey and red clastic sedimentary rocks, pink, k-spar, phaneritic and aphanitic granitoids.
055	5	D	SM	T	Angular to subrounded, mostly subrounded. Foreign include red and grey clastic sedimentary rocks, greenish volcanics and pink granitoids.
056	3	D	SM	F	Subangular to rounded, mostly subrounded. Meguma consists of grey and greenish metapelite and metapsammite. Foreigns include grey and red clastic sedimentary rocks, volcanic porphyry, and pink k-spar granitoids.
056	5	D	SM	F	Angular to rounded. Foreigns include gneiss and pink k-spar granitoids, volcanics and red sandstone.
057	3	D	ES	F	Subangular to subrounded. Some well rounded, discoid clasts. Foreign include red mudstone, granitoids, volcanics.
057	4	M	ES	F	Subangular to subrounded. Foreigns include granitoid clasts and grey clastic sedimentary rocks.
059	2	D	RM	F	Subangular to subrounded. Meguma lithologies consist of grey and green metapelite speckled with sulphides. Foreigns may be volcanic, origin doubtful.
060	1	G	UC	F	Subrounded to well rounded. No striated clasts.
061	0	G	TD	F	Subrounded to rounded. Foreign include volcanic?, grey sandstone.
063	0	D	UB	F	Subangular to well rounded. South Mountain type large granitoids.
064	2	D	RM	F	Subrounded to rounded. Foreign include phenocrystic volcanic and red clastic sedimentary rocks.

Appendix 4

1	2	3	4	5	Comments
065	6	D	ST	F	Angular to subangular. Till sample taken on land while in port at Sheet Harbour. One clast appears to be a transitional bullet-nose form. Foreign includes red sandstone.
070	0	G	TD	F	Subangular to rounded.
070	2	G	TD	F	Subrounded to well rounded. Meguma lithologies with sulphides. Foreign include granitoids, sandstone.
071	0	G	TD	F	Subrounded to well rounded. Greenish metapelites and spotted slates.
072	0	S	TD	F	Subangular to rounded. Meguma lithologies include schistose rocks, mostly metapelites, some hornfels.
075	0	S	TD	F	Subrounded to well rounded. Meguma lithologies mostly metapelite, a few schistose, muscovite-biotite bearing rocks (higher meta grade?)
076	0	S	TD	F	Subangular to subrounded. Meguma metapelites.
077	2	D	UC	F	Subangular to rounded.
082	0	D	SM	F	Subangular to subrounded. One clast appeared to be a glacially-reworked beach? pebble; well rounded with a basal facet and striations. Foreigns include banded volcanic rocks, and porphyritic granitoid.
083	3	D	SM	F	Subrounded to rounded. Foreigns include volcanic, granitoids, sandstone.
083	4	D	SM	F	Subangular to rounded with many rounded clasts. Wide variety of Meguma lithologies including grey, greenish metapelites, metapsammites and buff metawackes. Foreigns include granitoids and volcanics.
083	5	D	SM	F	Subangular to well rounded. Meguma lithologies also include staurolite-andalusite? schistose fragments. Foregins include pink, K-spar granitoid, red sandstone.
084	1	D	SM	F	Subangular to rounded, mostly rounded. Evidence of reworking of glacial clasts. Foreign clasts include a buff marlstone of unknown age (Tertiary?) as well as sedimentary and volcanic species.

1	2	3	4	5	Comments
084	2	D	SM	F	Subangular to rounded with many rounded clasts. Wide variety of Meguma lithologies including grey, greenish metapelites, metapsammites, and buff metawackes. Foreigns include granitoids and volcanics.
085	3	D	ES	F	Rounded to subrounded. Abundance of soft, buff-coloured marlstones Tertiary?.
085	5	M	ES	F	Subangular to rounded. Many fragments of brownish marlstone. One fossiliferous limestone.
086	3	D	SM	F	Subangular to subrounded, but no striated. This in unusual because many diamictons with this angularity have striated clasts. Foreigns include small granitoids.
086	5	D	SM	F	Subangular to subrounded. Foreigns include two fossiliferous limestones (corals?, crinoid stems, brachiopods). Others include granitoids, volcanics, red and grey sedimentary rocks.
089	3	D	ES	F	Subangular to subrounded. Granitoid and volcanic clasts in foreign component.
089	5	M	ES	F	Angular to well rounded, an extreme mix of grain shapes. Foreigns include red mudstone.
091	3	D	UB	F	Angular to subrounded mostly subangular.
091	5	D	UB	F	Angular to subrounded mostly subangular. Meguma lithologies consist of coarse metapelite. Foreign include volcanic, pink k-spar granitoid.
092	3	D	ES	F	Subangular to rounded. Foreign include conglomerate, sandstone, pink, k-spar granitoid, volcanics?
092	5	D	ES	F	Subangular to subrounded. No striations in spite of the angular nature of the Sediments. Foreigns include red mudstone, grey sandstone and pink granitoids.
093	5	M	ES	F	Subangular to rounded. One porphyritic felsic volcanic clast.
094	0	G	TD	F	Subrounded to rounded. None striated. Metapelites with greenschist to biotite grade metamorphism. Foreigns include red and grey clastic sedimentary rocks, felsic, porphyritic volcanics, mafic igneous rocks.

APPENDIX 5: Terrestrial till data: locations and till types.

Year	Sample	Subsample	Till type	Longitude	Latitude
77	64	A	HT	61.73014	45.44721
77	69	A	ST/C	61.56564	45.31369
77	74	A	ST/C	61.39558	45.18779
77	75	B	ST/A	61.48980	45.18929
77	77	A	ST/A	61.60095	45.14439
77	90	A	ST/A	61.64258	45.19892
77	92	A	ST/C	61.93847	45.08022
77	94	A	LT/B	61.83418	45.06245
77	95	A	LT/B	61.84689	45.09790
77	107	A	ST/A	61.86919	45.26071
77	109	A	ST/A	61.68249	45.19708
77	110	A	ST/A	61.65649	45.16264
77	158	A	ST/A	61.63575	45.21909
77	159	A	ST/A	61.61308	45.18955
77	160	A	LT/C	62.05431	44.95482
77	160	B	LT/B		
77	162	A	ST/B	62.06434	44.99698
77	163	A	LT/A		
77	164	A	LT/C	62.13225	44.95856
77	164	B	ST/B		
77	66	A	LT/A	62.19589	45.01237
77	176	A	ST/A	62.12851	44.99997
77	183	A	ST/B	62.20861	44.94857
77	183	C	LT/A		
77	193	A	ST/A	61.48954	45.40858
77	194	A	LT/C	61.43427	45.40133
77	231	A	ST/B	62.26777	44.93763
77	232	A	ST/A	62.30107	44.92199
77	233	A	LT/C	62.33472	44.91516
77	234	A	ST/A	62.35785	44.94648
77	236	A	LT/B	62.29171	45.02237
77	238	A	ST/A	62.48550	44.89981
77	239	A	HT	62.47671	44.87709
77	241	A	ST/A	62.44132	44.86236
77	243	A	LT/A	62.37730	44.92864
77	262	A	ST/A	62.43856	45.12236
77	323	A	ST/A	62.54700	44.92115
77	325	A	ST/A	62.57714	44.86847

Year	Sample	Subsample	Till type	Longitude	Latitude
77	327	A	ST/A	62.58152	44.83184
77	329	A	ST/A	62.60700	44.83455
77	334	A	LT/C	62.70129	44.89455
77	335	A	ST/A	62.73842	44.91497
77	362	A	ST/C	62.97166	44.88868
77	364	A	ST/C	62.95979	44.84658
77	366	A	ST/C	62.93624	44.86105
77	367	A	LT/B	62.89075	44.88071
77	372	A	LT/C	62.81097	44.76729
77	373	A	QT/C	62.82658	44.75207
77	375	A	LT/C	62.79351	44.77658
77	376	A	LT/C		
77	376	A	LT/C	62.74448	44.78923
77	377	A	ST/C	62.69157	44.80472
77	378	A	ST/C	62.67401	44.79732
77	381	A	ST/A	63.04565	44.77752
77	393	A	LT/B	62.92059	44.72674
77	404	A	LT/C	62.32274	44.63863
77	428	A	LT/C		
77	443	A	ST/C	63.64666	44.74387
77	446	A	LT/B	62.85139	44.73656
77	451	A	LT/A	63.26731	44.99708
91	1	1	LT/A	63.31821	44.72676
91	2	1	ST/B	62.62114	44.82839
91	3	1	ST/A	62.58103	44.86441
91	3	2	ST/A		
91	3	3	ST/A		
91	4	1	ST/A	62.53726	44.92404
91	4	2	ST/A		
91	5	1	ST/A	62.47232	44.84832
91	6	1	LT/A	62.37694	44.92679
91	7	1	ST/A	62.17400	44.97889
91	8	1	LT/B	62.11889	44.95561
91	9	1	HT	62.01560	44.97583
91	9	2	LT/C		
91	10	1	ST/A	62.02256	44.97706
91	10	3	LT/C		
91	12	1	ST/A	61.96125	45.10642
91	13	1	ST/A	61.95941	45.10235
91	14	1	LT/B	61.82242	45.07032

Year	Sample	Subsample	Till type	Longitude	Latitude
91	14	2	LT/B		
91	14	5	LT/B		
91	15	1	LT/C		
91	15	2	ST/B		
91	22	1	LT/C		
91	22	2	HT		
91	22	3	LT/B		
91	22	4	LT/B		
91	22	5	LT/A		
91	22	6	LT/A		
91	22	7	LT/A		
91	22	8	LT/A		
91	22	9	HT		
91	22	10	HT		
91	22	11	HT		
91	22	12	LT/C		
91	22	13	LT/C		
91	22	14	LT/B		
91	22	15	LT/A		
91	22	16	LT/A		
91	22	17	LT/A		
91	22	18	HT		
91	22	19	HT		
91	22	20	HT		
91	22	21	HT		
91	22	22	LT/C		
91	22	23	LT/A		
91	22	24	LT/A		
91	22	25	HT		
91	22	26	HT		
91	22	27	HT		
91	22	28	HT		
92	6	1	LT/B	62.33714	45.04977
92	8	1	LT/C	62.05431	44.95782
92	8	2	LT/C		
92	8	3	LT/B		
92	8	4	LT/C		
92	8	5	HT		
92	8	6	HT		
92	8	7	HT		

Year	Sample	Subsample	Till type	Longitude	Latitude
92	8	8	HT		
92	8	9	LT/C		
92	8	10	LT/C		
92	8	11	LT/C		
92	8	12	LT/C		
92	8	13	LT/C		
92	8	14	LT/C		
92	10	1	HT	61.83418	45.06245
92	10	2	ST/B		
92	10	3	LT/C		
92	10	4	LT/C		
92	10	5	HT		
92	10	6	LT/C		
92	12	1	ST/B	61.84193	45.04784
92	13	1	ST/A	62.48818	44.98640

APPENDIX 6: Terrestrial till data 1977-1992

Lithology and Shape parameters
YEAR (YR)
SAMPLE NUMBER (SN)
SUBSAMPLE (SBB)
TOTAL COUNT (T)
MEGUMA PERCENTAGE (MG)
GRANITE (MEGUMA ZONE) PERCENTAGE (GR)
FOREIGN PERCENTAGE (FR)
STRIATED CLAST PERCENTAGE (STR)

YR	SN	SB	T	MG	GR	FR	STR	COMMENTS
77	64	A	337	90	10	0	4	subangular shapes. Meguma- pelites and psammites. Foreigns- red and brown sandstone, quartz and feldspar fragments, volcanics
77	69	A	279	77	0	23	0	subangular shapes. Meguma- pelites and psammites. Foreigns- grey sandstone, quartz and feldspar fragments.
77	74	A	238	67	16	18	5	subrounded- subangular. Meguma-psammites and pel:·es.Foreigns- till fragments, grey sandstones, quartz.
77	75	B	138	94	0	6	0	subangular shapes. Meguma mostly psammites.Foreigns- quartz, grey sandstones, 1 diorite.
77	77	A	198	100	0	0	0	subangular shapes. Meguma-psammites.
77	90	A	246	91	2	7	0	subangular shapes. Meguma- mostly psammites. Foreigns- quartz, grey sandstone, diorite, red sandstone.
77	92	A	557	76	12	3	0	subangular shapes. Foreigns- till fragments, red sandstones, grey sandstones, diorites, quartz fragments, syenite.
77	94	A	248	65	1	35	43	subangular to subrounded. Foreigns- greenish sandstone, hard red sandstone, pinkish granitoid, felsic volcanic
77	95	A	128	72	0	28	18	subangular to subrounded shapes.Coarse feldspathic-arkosic sandstone, purplish red sandstone, granitoids.
77	107	A	215	84	0	16	0	subrounded subangular shapes.Meguma- many unusually large schists 50 %. Foreigns- grey and brown sandstone, volcanics, micaceous sandstone, quartz and feldspar fragments.
77	109	A	303	93	5	3	1	more subangular than subrounded. Purple sandstones, syenites, quartz fragments, diorite.
77	110	A	320	96	0	4	0	subangular shapes. Meguma mostly psammites. foreigns- micaceous sandstone, diorites, syenites, feldspar fragments.
77	158	A	228	93	0	7	0	subrounded-subangular shapes. Meguma- mostly psammites, some schists. Foreigns- quartz, grey sandstones, volcanics, diorites
77	159	A	248	97	0	3	0	subangular shapes. meguma- mostly psammites. Foreigns- quartz sandstones.

YR	SN	SB	T	MG	GR	FR	STR	COMMENTS
77	160	A	305	79	0	21	15	subrounded shapes. Meguma- mostly psammites. Foreigns- grey and red sandstones, volcanics, diorites, granites (SMB)
77	160	B	392	82	0	18	24	subangular to subrounded shapes. Foreigns- hard red siltstones, grey sandstone, syenitic granite, volcanic-felsic,mafic ?, 2 Quartz.
77	162	A	301	93	2	6	3	subangular to subrounded shapes. Foreigns- pink purple felsic volcanic, granitoids.
77	163	A	251	65	0	35	24	subrounded to subangular shapes. Meguma-pelites Foreigns- red/purple sandstones, till fragments, dio·ites, volcanics, syenites.
77	164	A	357	54	0	46	37	subangular to subrounded shapes. foreigns- red, grey sandstones, volcanics, diorites, syenites
77	164	B	269	81	0	19	5	subangular shapes. foreigns- grey sandstone, volcanics, brown sandstone, coarse grained sandstone, quartz fragments, diorite.
77	166	A	372	36	0	64	22	subrounded shapes. foreigns- red sandstones, sandstones,syenites volcanics, quartz and feldspar fragments.
77	176	A	324	95	0	5	7	subrounded to subangular shapes. Meguma mostly psammites. Foreigns- grey sandstones, volcanics.
77	183	A	263	91	0	9	4	subangular shapes. Meguma- mostly psammites. foreigns- pink volcanics, grey sandstones,syenites.
77	183	C	74	70	0	30	0	subangular to subrounded. foreigns- pinkish granitoid, diorite, pink felsic volcanic.
77	193	A	281	92	0	8	0	subrounded-subangular shapes. Foreigns- red and grey sandstone, quartz.
77	194	A	305	27	0	73	0	subangular to subrounded shapes.Foreigns- red sandstones, grey sandstones, quartz volcanics
77	231	A	239	71	0	29	21	subangular to subrounded shapes. Foreigns- red sandstone, grey sandstone, grey micaceous sandstone, syenites, quartz, volcanics.
77	232	A	408	94	0	6	1	subangular shapes Foreigns- red sandstones, grey sandstones, diorite.
77	233	A	167	52	0	48	13	subangular to subrounded shapes. Foreigns- red sandstones, coarse grained sandstones, volcanics, quartz and feldspar,syenites, concretion.
77	234	A	284	71	3	26	10	subrounded- subangular shapes. Foreigns- red sandstone,grey sandstone, micaceous sandstone, quartz, diorite.

YR	SN	SB	T	MG	GR	FR	STR	COMMENTS
77	236	A	291	63	0	37	67	mostly subrounded shapes. Meguma- slates and metagreywackes. Foreigns- hard green siltstone (banded), diorites, syenitic granites, felsic volcanics
77	238	A	325	96	0	4	25	subangular to subrounded. meguma mostly metawackes and psammites. foreigns- grey sandstone, hard brown siltstone, volcanic silicic volcanic.
77	239	A	239	73	5	22	34	subrounded to subangular shapes. Meguma- pelites (striated) and psammites. Foreigns- grey micaceous sandstone, purple quartz fragments, diorite.
77	241	A	200	98	0	2	0	subangular shapes. Meguma- mostly psammites.
77	243	A	171	59	6	35	0	subrounded shapes. Foreigns- red sandstone, syenites, volcanics.
77	262	A	306	99	0	1	0	subangular shapes. Meguma- many schistose. Foreigns- sandstones.
77	323	A	179	89	2	8	0	subangular to subrounded shapes. foreigns- grey sandstones, mudstone, volcanics.
77	325	A	211	74	24	2	0	subangular shapes. Meguma- mostly psammites. foreigns- quartz and feldspar fragments.
77	327	A	241	61	27	12	0	subrounded-subangular shapes. Meguma- mostly psammites. Foreigns- quartz, syenites, grey sandstones, diorite.
77	329	A	325	70	14	16	0	subangular shapes. Foreigns- grey sandstone, syenite, quartz.
77	334	A	327	67	14	19	13	subrounded- subangular shapes. Foreigns- red and brown sandstone, volcanics, syenites, quartz and feldspar, diorite.
77	335	A	367	5	89	6	0	subangular shapes. foreigns- quartz and feldspar fragments.
77	362	A	343	99	0	1	0	subangular. Meguma- mostly psammites. Foreigns- quartz.
77	364	A	268	72	7	22	0	subangular shapes. mostly psammites. Foreigns-grey sandstones, syenites, red sandstones, diorites.
77	366	A	361	65	0	35	0	subangular shapes. Foreigns- till fragments, grey sandstone, diorite, quartz, syenite.
77	367	A	201	55	0	45	15	subrounded- subangular shapes. Meguma- mostly pelites. Foreigns- red sandstone, grey sandstone, diorites, volcanics, syenites, quartz.

YR	SN	SB	T	MG	GR	FR	STR	COMMENTS
77	372	A	428	78	12	11	0	subangular to subrounded shapes. Foreigns- hard red siltstone, dioritic granites, volcanic ?.
77	373	A	161	93	0	7	0	subrounded- subrounded shapes. Meguma- mostly psammmites. Foreigns- grey sandstones, quartz, volcanics.
77	375	A	308	38	14	18	0	subrounded to subangular. Foreigns- grey sandstones, red sandstones, volcanics, diorite, syenite.
77	376	A	389	73	13	13	19	subangular to subrounded shapes. Foreigns- hard red purplish siltstone, granitoid, diorite.
77	376	A	325	64	14	22	4	subangular to subrounded shapes. Meguma- pelites and psammites.Foreigns- red and grey sandstone, syenites, quartz, diorite
77	377	A	224	97	1	2	4	subangular shapes. Meguma- many pelites.Foreigns- quartz, sandstones
77	378	A	414	74	22	4	48	subrounded-subangular shapes. Meguma- many flat bullet nosed clasts. Foreigns- hard red siltstone,diorites, granitoids.
77	381	A	252	90	6	3	0	subangular shapes. Meguma- mostly psammites. Foreigns- grey sandstone, syenites.
77	393	A	202	59	7	34	0	subangular to subrounded shapes. Foreigns- red sandstones, grey sandstones, syenites, quartz,
77	404	A	371	95	2	2	3	more subangular than subrounded. foreigns- pink syenogranite, grey sandstone, volcanic.
77	428	A	96	66	15	20	0	subangular shapes. Meguma- psammites and pelites. Foreigns- sandstones, diorites, syenites.
77	443	A	257	68	5	27	5	subrounded- subangular shapes. Foreigns- reddish sandstone, diorites, grey sandstone.
77	446	A	207	73	2	25	21	subangular shapes foreig is- reddish sandstones, syenites, volcanics, quartz and feldspar fragments, diorites.
77	451	A	186	37	0	63	28	subrounded to subangular shapes. foreigns- red sandstones, grey sandstones, syenites, diorites, quartz fragments.
91	1	1	441	38	2	60	11	more subrounded than subangular shapes. Meguma-some schistose. Foreigns- red sandstones, grey sandstones, green-grey sandstones, syenites, diorites, volcanics, quartz and feldspar fragments, till fragment.

YR	SN	SB	T	MG	GR	FR	STR	COMMENTS
91	2	1	328	72	14	14	2	subrounded- subangular shapes. Foreigns- grey and red sandstone, micaceous sandstone, volcanics, quartz and feldspar fragments, pinkish sandstone with multiple quartz veins.
91	3	1	527	72	25	2	0	subangular shapes. foreigns- grey sandstone,diorites, syenites, micaceous sandstones.
91	3	2	509	55	43	3	0	subangular shapes. Meguma- mostly psammites. Foreigns- grey micaceous sandstone, syenites, red sandstone.
91	3	3	377	78	21	2	0	angular to subangular shapes. Meguma- mostly psammites. Foreigns- diorites, volcanics, sandstones.
91	4	1	429	97	0	3	0	Mostly subangular-subrounded shapes. foreigns- grey and brown sandstone, micaceous sandstone, quartz fragments.
91	4	2	385	93	0	7	0	subangular shapes. meguma- mostly psammites, some schists. Foreigns- grey and red sandstones, quartz fragments, micaceous sandstone.
91	5	1	329	90	2	9	3	subangular shapes. Meguma- mostly psammites. foreigns- diorites, grey sandstones, brown sandstones.
91	6	1	361	40	6	54	0	subrounded to subangular shapes. Meguma-psammites, pelites, schists. foreigns- red sandstone, grey sandstone, brown sandstone, syenites, diorites, volcanics, fe cemented conglomerate.
91	7	1	232	97	0	3	0	subangular shapes. meguma- mostly psammites. foreigns- grey and brown sandstone, micaceous sandstone, quartz fragments.
91	8	1	640	60	0	39	7	subangular to subrounded shapes Foreigns-red and grey sandstone, brown sandstone, micaceous sandstone, volcanics, syenites, diorites, quartz fragments.
91	9	1	373	83	0	17	7	subrounded shapes. foreigns- grey sandstones, diorites, volcanics, quartz fragments, red sandstones.
91	9	2	212	75	0	25	5	subrounded to subangular shapes. Foreigns- grey mudstone, grey micaceous sandstone, volcanics, syenites, quartz fragments.

YR	SN	SB	T	MG	GR	FR	STR	COMMENTS
91	10	1	448	83	0	17	3	subangular to subrounded shapes. Meguma- some schists, psammites. Foreigns- grey sandstones, diorites, syenites, volcanics, quartz fragments.
91	10	3	178	80	0	20	8	subrounded to subangular shapes. Foreigns- grey sandstones, volcanics, syenites, red sandstones.
91	12	1	210	99	0	1	0	subrounded to subangular shapes. foreigns- basalt, volcanic.
91	13	1	243	97	3	0	0	more subangular than subrounded shapes. Meguma- pelites, psammites, conglomerate, and biotite schists.
91	14	1	206	49	3	48	0	more subrounded than subangular shapes. Foreigns- red sandstone, grey sandstone, micaceous sandstone, syenites, volcanics, coarse grained red quartzite, concretion.
91	14	2	197	60	2	38	8	more subangular than subrounded. foreigns- red sandstone, grey sandstone, micaceous sandstone, brown mudstone, green siltstone, volcanics,quartz fragments.
91	14	5	161	35	82	5		more subangular than subrounded shapes. Meguma- psammites, pelites, and 1 schist. Foreigns- purplish mudstones, felsic volcanics, mafic basalt, micaceous sandstones.
91	15	1	200	54	44	21	0	more subrounded than subangular. Meguma- many schists foreigns- grey micaceous sandstone, red sandstone,quartz fragments.
91	15	2	416	74	42	3	2	subangular to subrounded shapes. Meguma- mostly psammites. Foreigns- red sandstone, grey sandstone, coarse grained sandstone-conglomerate,micaceous sandstone, quartz fragments, 1syenite.
91	22	1	302	58	43	8	7	subangular to subrounded shapes. Meguma- some schistose. Foreigns- red sandstone, brown sandstone, grey sandstone, syenites, diorites, volcanic, rhyolite/mylonite fragment.
91	22	10	194	59	26	15	7	subrounded to subangular shapes. Meguma- some schistose. Foreigns- red sandstone, grey sandstone brown sandstone, syenites and diorites.

YR	SN	SB	T	MG	GR	FR	STR	COMMENTS
91	22	11	254	74	7	19	0	more subrounded than subangular. Meguma-many pelites striated. Foreigns- grey micaceous sandstone, quartz fragments, 1 red sandstone, 1 syenite.
91	22	12	234	47	3	50	6	subrounded to subangular shapes. Meguma- some schistose. Foreigns-red sandstone, grey sandstone, grey-green sandstone, brown sandstone,syenites, diorites, concretion.
91	22	13	293	53	3	44	11	subangular to subrounded shapes. Meguma- some schistose. Foreigns- red sandstone, brown sandstone, grey-green sandstone, syenites, diorites, quartz fragments.
91	22	14	224	42	2	56	12	subangular to subrounded shapes Foreigns- red sandstone, grey sandstone, syenites diorites, quartz fragments, volcanics, conglomerate.
91	22	15	212	44	5	51	0	subangular to subrounded shapes. Meguma- some schistose. Foreigns- red sandstones, grey sandstones, brown sandstones, syenites, diorites, volcanics, quartz fragments, and rhyolitic/mylonitic fragment.
91	22	16	228	48	5	47	0	subangular to subrounded shapes. Meguma- some schistose foreigns- red sandstones, red-brown sandstones, grey-green sandstones, syenites, diorites, and quartz sandstones.
91	22	17	197	43	1	56	11	subangular to subrounded shapes. Meguma- some schists. Foreigns- red sandstones, grey sandstones, grey-green sandstones, syenites, diorites, volcanics, conglomerate.
91	22	18	446	65	22	13	0	subrounded to subangular shapes. Meguma- some schistose. Foreigns- red sandstone, grey sandstone, brown sandstone, syenites, and quartz fragments.
91	22	19	238	55	36	9	0	subrounded to subangular shapes. Meguma- some schistose. Foreigns- red sandstone, grey sandstone, syenites, conglomeritic sandstone.
91	22	2	280	62	33	5	4	subrounded to subangular shapes. Foreigns- red sandstone, brown sandstone, grey micaceous sandstone, syenites, diorites, volcanic, 1 rhyolite.
91	22	20	233	63	21	16	12	subangular to subrounded shapes. Meguma- some schistose. Foreigns- red sandstone, grey sandstone, syenites, quartz fragments.

YR	SN	SB	T	MG	GR	FR	STR	COMMENTS
91	22	21	226	61	19	19	0	subangular to subrounded shapes. meguma- some schists. Foreigns- red sandstones, grey sandstones, green-grey sandstones, syenites, and diorites.
91	22	22	192	56	4	40	0	subangular to subrounded shapes. Meguma- some schists, psammites. Foreigns- red sandstones, grey sandstones, syenites, volcanics, quartz fragments, diorites.
91	22	23	182	41	2	57	4	subangular to subrounded shapes. Meguma- some schistose. Foreigns- red sandstone, grey-green sandstone, brown sandstone, syenites, diorites, quartz fragments, till fragment, and concretion
91	22	24	174	44	2	53	12	mostly subangular to subrounded shapes. Foreigns- grey sandstone, red sandstone, syenites, diorites, micaceous sandstones, quartz fragments.
91	22	25	261	41	34	25	13	subangular to subrounded shapes. Foreigns- grey sandstones, red sandstones, grey-green sandstones, syenites, diorites, volcanics, quartz fragments, till fragments.
91	22	26	267	43	41	16	11	Subrounded to subangular shapes. Meguma- some schistose. Foreigns- red sandstone, grey sandstone, brown sandstone, syenites, diorites, and volcanics.
91	22	27	241	63	29	8	8	subangular to subrounded shapes. Meguma- some schistose. Foreigns- red sandstone, grey-green sandstone, one dioritic pebble.
91	22	28	245	70	19	11	8	more subangular than subrounded. Meguma-mostly psammites, some schists. Foreigns- grey sandstone,red sandstone, quartz fragments, syenites, diorites, till fragments.
91	22	3	281	59	4	38	0	subangular to subrounded shapes. Meguma- some schistose. Foreigns- red sandstone, grey sandstone, green sandstone, syenitic granite, dioritic granite and quartz fragments.
91	22	4	280	42	6	52	6	subangular to subrounded shapes. Meguma-mostly psammites.Foreigns- red and grey sandstone, diorite,syenite, volcanics,quartz fragments, micaceous sandstone, gneissic ?.

YR	SN	SB	T	MG	GR	FR	STR	COMMENTS
91	22	5	323	41	10	49	9	subrounded to subangular shapes, some well rounded. Foreigns- red sandstones, grey sandstones, syenites, diorites,volcanics, micaceous sandstones, quartz fragments.
91	22	6	239	45	5	50	9	subrounded to subangular shapes. Meguma- some schistose. Foreigns- red sandstone, grey sandstone, brown sandstone, grey-green sandstone, syenites, diorites, volcanics, qtz fragments
91	22	7	243	48	5	47	10	more subrounded than subangular. Meguma-psammites and pelites some schists. Foreigns- red and grey sandstone, micaceous sandstone, quartz fragments, volcanics,syenites, diorites.
91	22	8	129	60	7	33	10	subangular to subrounded, meguma lithologies -some schistose, foreign include red-brown ss, grey brown ss, syentic granite, grey green ss.
91	22	9	213	54	23	23	9	subangular to subrounded shapes. Meguma- some schistose. Foreigns- grey sandstone, brown sandstone, diorites, volcanics.
92	6	1	267	74	0	26	0	subangular shape. Meguma-mostly psammites. Foreigns- grey sandstone, red sandstone, quartz fragments, syenites, volcanics.
92	8	1	251	74	12	5	0	loosely compactedlight brown silty till meguma-green metapelites and psammites foreigns 1. coarse quartz-rich arenite 2. ignimbrites 3.granitoids 4. siltstone
92	8	10	252	78	0	22	0	subangular to subrounded shapes. Meguma- mostly psammites. Foreigns- red sandstone, grey sandstone, coarse grained sandstone-conglomerate, micaceous sandstone, quartz fragments, 1syenite.
92	8	11	298	86	0	14	0	subangular to subrounded shapes. Meguma- some schists, psammites. Foreigns- grey sandstones, diorites,syenites, volcanics.
92	8	12	243	88	0	12	0	subrounded to subangular shapes. Foreigns- grey sandstones, volcanics, syenites, red sandstones.

YR	SN	SB	T	MG	GR	FR	STR	COMMENTS
92	8	13	294	85	4	11	0	subrounded to subangular shapes. Meguma-pelites are striated. Foreigns- red/purple sandstones, till fragments, diorites, volcanics, syenites.
92	8	14	351	85	0	15	0	subrounded to subangular shapes. Foreigns- grey sandstones, volcanics syenites, red sandstones.
92	8	2	375	82	0	18	0	subangular shapes. Meguma- mostly psammites. Foreigns- quartz sandstones.
92	8	3	285	76	1	24	0	subangular to subrounded shapes. Meguma- some schists, psammites. Foreigns- grey sandstones, diorites, syenites, volcanics, quartz fragments.
92	8	4	288	85	0	15	0	subangular to subrounded shapes. Foreigns- hard red siltstones, grey sandstone, syenitic granite, volcanic-felsic, mafic ?, 2 Quartz.
91	8	5	414	86	0	14	0	subrounded-subangularshapes. Meguma- mostly psammites, some schists. Foreigns- quartz, grey sandstones, volcanics, diorites
92	8	6	370	85	0	15	0	more subangular than subrounded. Foreigns-purple sandstones, syenites, quartz fragments
92	8	7	288	85	0	15	0	subrounded shapes. Meguma- mostly psammites. Foreigns- grey and red sandstones, volcanics, diorites, granites (smb?).
92	8	8	234	90	0	10	0	subrounded, subangular shapes. Meguma- many unusually large schists ~ 50 %. Foreigns- grey and brown sandstone, volcanics, micaceous sandstone, quartz and feldspar fragments.
92	8	9	268	88	0	12	0	subangular shape. Meguma-mostly psammites. foreigns- grey sandstone, red sandstone, quartz fragments, syenites, volcanics.
92	10	1	183	57	0	43	0	subangular shapes. Meguma mostly psammites. Foreigns- micaceous sandstone, diorites, syenites, feldspar fragments.
92	10	2	213	82	0	18	0	subrounded to subangular shapes. Foreigns-basalt, volcanic.
92	10	3	247	72	0	28	0	more subangular than subrounded shapes. Meguma- pelites, psammites, conglomerate, and biotite schists.
92	10	4	185	72	12	6	0	more subrounded than subangular shapes. Foreigns- red sandstone, grey sandstone, micaceous sandstone, syenites, volcanics, coarse grained red quartzite, concretions.

YR	SN	SB	T	MG	GR	FR	STR	COMMENTS
92	10	5	274	66	1	32	0	more subangular than subrounded shapes. Meguma- psammites, pelites, and 1 schist. Foreigns- purplish mudstones, felsic volcanics, mafic basalt, micaceous sandstones.
92	10	6	278	69	3	28	0	more subangular than subrounded. Foreigns- red sandstone, grey sandstone, micaceous sandstone, brown mudstone, green siltstone, volcanics, quartz fragments.
92	12	1	306	68	2	31	0	more subrounded than subangular. Meguma- many schists foreigns- grey micaceous sandstone, red sandstone,quartz fragments.
92	13	1	300	100	0	0	0	

APPENDIX 7: Grain size data

SAMPLE: Sample numbers (see Appendixes 3-7)
TT: Till type
TOT: Total sample weight (dry)
PHI1: Weight of -1 PHI fraction (Gravel)
GR%: Gravel percentage
MA%: Matrix percentage
PWT: PAN WEIGHT
RAT: GRAVEL/MATRIX RATIO

Terrestrial samples

SAMPLE	TT	TOT	PHI1	GR%	MA%	FWT	RAT
91-1-1	LT/A	733.9	100.7	13.9	87.7	11.7	0.2
91-2-1	ST/B	840.0	504.2	60.9	40.5	11.5	1.5
91-3-1	ST/A	1212.6	833.1	69.3	31.6	10.0	2.2
91-3-2	ST/A	1137.0	640.6	56.3	43.7	0.0	1.3
91-3-3	ST/A	1372.9	664.0	48.8	52.1	11.7	0.9
91-4-1	ST/A	1442.3	967.7	67.6	33.2	11.0	2.0
91-4-1	ST/A	1317.4	880.3	67.4	33.5	11.9	2.0
91-5-1	ST/A	1071.8	440.0	41.5	59 6	11.4	0.7
91-6-1	LT/A	1296.0	382.5	29.8	71.1	11.6	0.4
91-7-1	ST/A	1509.0	1086.	72.5	28.2	11.0	2.6
91-8-1	LT/B	837.3	225.6	27.3	74.1	11.4	0.4
91-9-1	HT	811.0	197.4	24.7	76.8	11.9	0.3
91-9-2	LT/C	548 0	105.1	19.6	82.6	12.1	0.2
91-10-1	ST/A	840.9	615.5	74.1	27.1	10.6	2.7
91-10-3	LT/C	641.7	303.0	48.1	53.8	12.1	0.9
91-12-1	ST/A	897.6	677.0	76.4	24.9	11.7	3.1
91-13-1	ST/A	1292.0	852.8	66.6	34.3	11.4	1.9
91-14-1	LT/B	1063.3	358.4	34.1	67.0	11.3	0.5
91-14-1	LT/B	806.1	221.1	27.9	73.9	14.4	0.4
91-14-5	LT/B	974.3	423.6	44.0	57.2	11.3	0.8
91-15-1	LT/C	760.7	145.2	19.4	82.2	11.5	0.2
91-15-2	ST/B	877 3	333.2	38.5	62.8	11.4	0.6
91-22-1	LT/C	1179.1	358.4	30.7	70.2	10.8	0.4
91-22-2	HT	893.5	261.5	29.6	71.7	11.5	0.4
91-22-3	LT/B	1135.5	277.0	24.6	76.3	11.0	0.3
91-22-3	LT/B	1374.7	328.0	24.1	76.8	11.5	0.3
91-22-5	LT/A	1503.4	523.5	35.1	65.7	11.1	0.5
91-22-6	LT/A	1410.5	334.8	23.9	76.9	11.7	0.3
91-22-7	LT/A	1140.0	280.9	24.9	76.1	10.9	0.3
91-22-8	LT/A	1207.9	95.4	8.0	93.0	11.5	0.1
91-22-9	HT	1295.4	417.4	32.5	68.4	11.3	0.5
91-22-10	HT	1093.8	219.6	20.3	80.8	11.8	0.3
91-22-12	LT/C	1345.0	240.0	18.0	82.9	11.7	0.2
91-22-13	LT/C	1493.1	364.0	24.6	76.2	11.3	0.3
91-22-14	LT/B	1268.9	217.5	17.3	83.6	11.1	0.2
91-22-15	LT/A	1270.0	177.5	14.1	86.8	11.5	0.2
91-22-16	LT/A	1316.8	178.2	13.7	87.2	11.4	0.2

SAMPLE	TT	TOT	PHI1	GR%	MA%	PWT	RAT
91-22-18	HT	1327.6	369.1	28.0	72.8	10.4	0.4
91-22-19	HT	1129.9	212.4	19.0	82.1	11.7	0.2
91-22-21	HT	1114.8	213.6	19.4	81.7	11.8	0.2
91-22-22	LT/C	1325.1	374.8	28.5	72.3	11.6	0.4
91-22-23	LT/A	1349.1	187.8	14.0	86.8	10.7	0.2
91-22-24	LT/A	1270.0	251.8	20.0	80.9	11.4	0.2
91-22-26	HT	1356.0	337.5	25.1	75.7	11.0	0.3
91-22-27	HT	1179.3	201.3	17.2	83.7	11.3	0.2
91-22-28	HT	1167.0	296.5	25.7	75.4	11.8	0.3

Marine Samples

SAMPLE	TOT	PHI1	GR%	MA%	PWT	RAT
011 0	15004.0	14805.0	98.7	1.3	1.0	75.9
014 0	32414.0	27369.0	84.4	15.6	1.0	5.4
015 5	2181.0	1.0	0.0	100.0	1.0	0.0
016 5	1583.5	300.0	19.1	81.7	13.0	0.2
016 5	1288.0	263.0	20 6	80.4	12.9	0.3
025 0	1618.3	780.5	48.6	52.2	13.0	0.9
028 5	1765.0	429.7	24.5	76.2	11.9	0.3
029 3	1317.0	576.6	44.2	56.7	11.7	0.8
029 4	1423.4	727.0	51.5	49.3	11.4	1.0
029 5	1734.1	564.5	32.8	67.9	11.2	0.5
029 5	2021.2	512.9	25.5	75.1	11.7	0.3
031 0	19425.0	19319.0	99.5	0.5	1.0	199.0
033 5	1283.0	422.6	33.2	67.7	11.7	0.5
049 5	1682.1	647.4	38.7	61.9	11.3	0.6
050 5	1481.4	382.6	26.0	74.8	12.1	0.3
051 5	3988.0	2140.0	23.8	76.2	1.0	0.3
052 5	1553.4	589.6	38.2	62.5	11.3	0.6
055 5	1852.9	345.7	18.8	81.9	12.2	0.7
056 3	1327.0	457.4	34.8	66.1	11.2	0.5
056 5	1758.7	356.4	20.4	80.3	12.4	0.3
059 2	945.5	438.8	47.0	54.2	11.0	0.9
064 2	1489.3	1003.5	67.9	32.9	11.4	2.1
065 6	1794.8	1190.0	66.8	33.9	12.7	2.0
070 0	14529.0	8292.0	57.1	42.9	1.0	1.3
071 0	9743.0	6152.0	63.1	36.9	0.0	1.7

SAMPLE	TOT	PHI1	GR%	MA%	PWT	F.AT
077 2	13073.0	8435.0	64.5	35.5	0.0	1.8
083 5	8081.0	3370.0	41.7	58.3	0.0	0.7
084 1	1725.4	551.1	32.2	68.5	11.6	0.5
085 5	1212.2	42.0	3.5	97.4	11.2	0.0
089 5	4612.0	696.0	15.1	84.9	1.0	0.2
091 5	1450.1	508.6	35.3	65.4	10.1	0.5
092 5	764.0	152.2	20.2	81.3	11.5	0.2

Appendix 8

```
C  ABLAT.FOR: SCHILLING & HOLLIN: SURFACE PROFILES FOR VALLEY
GLACIERS
C
C  PROGRAM SOURCE: THE LAST GREAT ICE SHEETS, DENTON G.H. &
HUGHEST.J.EDS,
C              WILEY  1981 pp. 212-3
C
C  TAU IS THE BASAL SHEAR STRESS
C  RHO IS DENSITY OF THE ICE
C  GR IS THE GRAVITATIONAL CONSTANT
C  S IS THE "SHAPE: FACTOR"
C  G IS THE BEDROCK ELEVATION
C  H IS THE SURFACE ELEVATION  OF THE ICE
C  T IS THE ICE THICKNESS
C  NOTE:  LENGTHS CONVERTED TO METRES IN THE PROGRAM
C       ELEVATION AT SNOUT NOT ENTERED.
C
C  MODIFIED BY:  D.W.RIGBY, NSDME DEC 87  FOR MICROSOFT FORTRAN
V3.0
C
C  SUBROUTINES GETFIL/SAVFIL CALLED FROM ULIB.LIB AVAILABLE AT
NSDME
C  FTAU -FIRST SHEAR FACTOR TA(3) 3 SUBSEQUENT SHEAR FACTORS
C  ----------------------------------------------------------------
      PROGRAM ABLAT
C
      REAL G(15),H(15),T(15),POS(15),FT(15),HS(15),TS(15)
      REAL DELX,S,TAU,FTAU,TA(3)
      INTEGER ITA(3)
      LOGICAL CTAU,CERR,IERR
      CHARACTER INFIL*12,OUTFIL*12,OTIT*30,ORD(3)*6,INP*8,ANS*1
C
      DATA ORD/' First','Second',' Third'/
C
      WRITE (*,*) ' WELCOME TO SCHILLING`S GLACIER SURFACE PROGRAM'
C
      WRITE (*,'(/'' INSTRUCTIONS? Y/N  <Ret> =N  >> ''\)')
      READ (*,'(A1)') ANS
      IF (ANS.EQ.'Y'.OR. ANS.EQ.'y') THEN
```

```
C
      WRITE (*,3)
3     FORMAT (//' THE PROGRAM RECONSTRUCTS THE GLACIER SURFACE',/
     *          ' ',/
     *          ' INPUT FILE:'/,
     *          '   Max 99 ground elevations in feet col 1-10 (Real #s)'/,
     *          '   Entered one per record with last record as 999999'/,
     *          ' '/,
     *          ' PROMPTED FOR:'/,
     *          '   Output title - max 30 chars'/,
     *          '   Horizontal step distance from ice snout'/,
     *          '   Initial ice thickness in metres'/,
     *          '   Shaping factor'/,
     *          '   Initial basal shear stress'/,
     *          '   Additional 3 stress factors after defined steps'/,
     *          ' '/,
     *          ' OUTPUT FILE:'/,
     *          '   Prints/plots on printer ground and reconstructed'/,
     *          '   ice surface.'//)
      ENDIF
C
C     OPEN INPUT/OUTPUT FILES
      WRITE (*,'(/'' Enter data filename  > >  ''\)')
      CALL GETFIL (1,INFIL)
      WRITE (*,'(/'' Enter output filename  > >  ''\)')
      CALL SAVFIL (3,OUTFIL)
C
      WRITE (*, '(/'' Enter output title;  <Ret> =` ` > >  ''\)')
      READ (*,'(A20)') OTIT
4     WRITE (*,5)
5     FORMAT (/' Enter Horizonal step distance (metres):  <Ret> =5000.  > >
     *''\)
      READ (*,'(A8)') INP
      IF (INP.EQ.'  ') THEN
        DELX = 5000.
        WRITE (*,'(1X,F8.3)') DELX
      ELSE
        CALL CTOR (INP,DELX,CERR)
        IF (CERR) THEN
          WRITE (*,'('' Please enter a number'')')
          GOTO 4
        ELSE
```

```
      WRITE (*,'(1X,F8.3)') DELX
      ENDIF
      ENDIF
C
  6   WRITE (*,7)
  7   FORMAT (/' Enter Initial ice thickness (metres):  <Ret> =200. > > '\)
      READ (*,'(A8)') INP
      IF (INP.EQ.' ') THEN
         T(1)= 200.
         WRITE (*,'(1X,F8.3)') T(1)
      ELSE
        CALL CTOR (INP,T(1),CERR)
        IF (CERR) THEN
          WRITE (*,'('' Please enter a number'')')
          GOTO 6
        ELSE
          WRITE (*,'(F8.3)') T(1)
        ENDIF
      ENDIF
C
  8   WRITE (*,'(/'' Enter "Shape" Factor:  <Ret> =1.000> ''\)')
      READ (*,'(A8)') INP
      IF (INP.EQ.' ') THEN
         S = 1.000
         WRITE (*,'(F8.3)') S
      ELSE
        CALL CTOR (INP,S,CERR)
        IF (CERR) THEN
          WRITE (*,'('' Please enter a number'')')
          GOTO 8
        ELSE
          WRITE (*,'(1X.F8.3)') S
        ENDIF
      ENDIF
C
  9   WRITE (*,'(/'' Enter "Basal Shear Factor":  <Ret> =0.8> ''\)')
      READ (*,'(A8)') INP
      IF (INP.EQ.' ') THEN
         TAU = 0.800
         WRITE (*,'(F8.3)') TAU
      ELSE
        CALL CTOR (INP,TAU,CERR)
```

```
      IF (CERR) THEN
        WRITE (*,'('' Please enter a number'')')
        GOTO 9
      ELSE
        WRITE (*,'(F8.3)') TAU
      ENDIF
    ENDIF
    FTAU = TAU
C
    CTAU = .FALSE.
    WRITE (*,10)
 10 FORMAT (' Change shear factor at 3 user defined steps? Y/N  <Ret> =N
   *  > >' \)
    READ (*,'(A1)') ANS
    IF (ANS.EQ.'Y'.OR.ANS.EQ.'y') THEN
      CTAU = .TRUE.
      DO 20 I =1,3
 13     WRITE (*,'(/'' Enter step  > >  ''\)')
        READ (*,'(A8)') INP
        CALL CTOI (INP,ITA(I),IERR)
        IF (IERR) THEN
          WRITE (*,'('' Please enter an integer number'')/')
          GOTO 13
        ENDIF
C
 12     WRITE (*,'('' Enter shear factor at step '',I3,''  > >  ''\)')
   *ITA(I)
        READ (*,'(A8)') INP
        CALL CTOR (INP,TA(I),CERR)
        IF (CERR) THEN
          WRITE (*,'('' Please enter a number'')')
          GOTO 12
        ELSE
          WRITE (*,'(F8.3)') TA(I)
        ENDIF
 20   CONTINUE
      WRITE (*,'('' '')')
    ENDIF
C
    RHO = .91
    GR = 981.
    I = 1
```

```
     SUM = 0.
     TU = TAU*1.E06
     C = TU/(RHO*GR*100.*S)
     WRITE (3,'(1X,A30//)') OTIT
     WRITE (3,44)
  44 FORMAT (11X,'VERTICAL MEASUREMENTS IN FEET',/)
     WRITE (3,22)
  22 FORMAT (/,1X,'DISTANCE (KM.)',3X,'GROUND LEVEL',3X,'ICE SURFACE'
    *,3X,'THICKNESS',/)
C
     READ (1,11) FT(1)
C    NOTE CONVERSION TO METRES
     G(1) = FT(1)* .3048
     H(1) = G(1)+ T(1)
     TS(1) = T(1)* 3.2808
     HS(1) = H(1)* 3.2808
     POS(1) = DELX/1000.
     SUM = SUM+ T(1)
     WRITE (3,33) POS(1),FT(1),HS(1),TS(1)
     I = 2
C
  30 READ (1,11) FT(I)
  11 FORMAT (F10.2)
C    NOTE CONVERSION TO METRES
     IF (FT(I).GT.900000.) GOTO 99
C
C CHANGE BASAL STRESS FACTOR BY STEPS (CTAU .TRUE.)
     IF (CTAU) THEN
       IF (I.GT.ITA(1)) TAU = TA(1)
       IF (I.GT.ITA(2)) TAU = TA(2)
       IF (I.GT.ITA(3)) TAU = TA(3)
       TU = TAU*1.E06
     ENDIF
C
     C = TU/(RHO*GR*100.*S)
     G(I) =FT(I)*.3048
     H(I) =H(I-1) +(C/T(I-1))*DELX
     T(I) =H(I) -G(I)
C
C THE FOLLOWING CARDS STOP PROGRAM AT NUNATAKS
     IF (T(I).LE.25.) GOTO 89
     SUM = SUM +T(I)
```

```fortran
      HS(I) =H(I)*3.2808
      TS(I) =T(I)*3.2808
      POS(I) = (I)*DELX/1000.
      WRITE (3,33) POS(I),FT(I),HS(I),TS(I)
   33 FORMAT (1X,F9.2,6X,F9.2,6X,F9.2,6X,F9.2)
      I = I+1
      GOTO 30
C
   89 WRITE (3,41)
   41 FORMAT (/1X,'NUNATAK OR MAXIIMUM HEIGHT')
   99 XI = I-1
      AVE = SUM/XI
      AVEFT = AVE*3.2808
      WRITE (3,47) DELX,T(1),S,FTAU
   47 FORMAT (//' HORIZONTAL STEP DISTANCE = ',F6.0,/1X,'INITIAL ICE THI
     *CKNESS = ',F5.0,/1X,'SHAPE FACTOR = ',F5.3,/1X,'INITIAL BASAL SHEA
     *R STRESS = ',F5.3)
C
      DO 50 I = 1,3
      WRITE (3, 25) ITA(I),TA(I)
   25 FORMAT (1X,'SHEAR FACTOR AFTER STEP ',I3,' = ',F5.3)
   50 CONTINUE
C
      WRITE (3,55) AVE, AVEFT
   55 FORMAT (///,1X,'AVERAGE ICE THICKNESS IN METRES:
     ',F7.2,/1X,'AVERA
     *GE ICE THICKNESS IN FEET: ',F7.2,///)
C
      CALL PLOT(FT,HS)
C
      WRITE (*,'(/'' OUTPUT IN FILE: '',A12/)') OUTFIL
      CLOSE (1,STATUS='KEEP')
      CLOSE (3,STATUS='KEEP')
      STOP
      END
C
      SUBROUTINE PLOT(G,H)
C
C   WRITTEN BY RALPH STEA  1982 FOR FORTRAN IV ON CYBER 170
C
C   MODIFIED BY DOUG RIGBY DEC 87 FOR MICROSOFT FORTRAN V3.0
C     DIMENSION STATEMENTS CHANGED TO REAL
```

```
C    MULTIPLE INITIALIZATION OF IG,IH OMITTED
C    MATRIX C CHANGED FROM INTEGER HOLLORITH TO CHARACTER
C    DOUBLE CHARACTER QUOTES CHANGED TO SINGLE QUOTES
C    SPACING CHANGED TO 8 BY 11 PAPER FOR 70 RECORDS
C
C         CUMULATIVE HORIZONTAL DISTANCE (POS) REPLACED WITH J
COUNTER
C    TO PLOT STEPS ONE PER COLUMN.
C
     REAL G(15),H(15)
     CHARACTER C(35,15)
     INTEGER IG(15),IH(15)
C
     DO 10 J=1,15
     IG(J)=IFIX(G(J))*0.025
     IH(J)=IFIX(H(J))*0.025
  10 CONTINUE
     DO 987 J=1,15
     DO 987 I=1,35
 987 C(I,J)=' '
     DO 11 J=1,15
     IF(IH(J).EQ.0)GO TO 11
     IF(IG(J).EQ.0)IG(J)=1
     KX=IH(J)
     LX=IG(J)
     KX=36-KX
     LX=36-LX
     C(LX,J)='#'
     C(KX,J)='*'
  11 CONTINUE
     WRITE(3,33)((C(I,J),J=1,15),I=1,35)
  33 FORMAT(1X,'    ',2X,'I',15(A1,'    ')/,
    *34(7X,'I',15(A1,'    ')/),7X,72('_'))
     END
C
     SUBROUTINE CTOR (CVAR,RVAR,CERR)
C
C    INTEGER TO REAL CONVERSION AND ALPHA ERROR TRAP
C    GETS CVAR: CHARACTER*8
C    CONVERTS CVAR TO INTEGER AND/OR REAL
C    RETURNS REAL AS RVAR
C    IF ALPHA CHARACTER, RETURNS "CERR" AS .TRUE.
```

```
C
C    D.W RIGBY, NSDME  DEC 87

     INTEGER IVAR
     REAL RVAR
     CHARACTER CVAR*8
     LOGICAL CERR
C
     CERR = .FALSE.
C    IF INTEGER, CONVERT TO REAL; BUT FIRST FLUSH SCREEN BUFFER
     WRITE (*,'('' '')')
     READ (CVAR,*,ERR=50) IVAR
C    IF ERROR GOTO LABEL 50
     RVAR = FLOAT(IVAR)
     RETURN
  50 READ (CVAR,'(F8.3)',ERR=60) RVAR
     RETURN
  60 CERR =.TRUE.
     RETURN
     END
C
     SUBROUTINE CTOI (CVAR,IVAR,IERR)
C
C    Written by D.W. Rigby NSDME, Feb 5/88
C    Character to integer conversion and alpha error trap
C    Gets CVAR: Character*8
C    Converts CVAR to integer
C    Returns integer as IVAR
C    If real or alpha character, returns IERR as .true.
C
C    D.W Rigby, NSDME  Feb 87
C
     INTEGER IVAR
     CHARACTER CVAR*8
     LOGICAL IERR
C
     IERR = .FALSE.
C    Flush screen buffer
     WRITE (*,'('' '')')
     READ (CVAR,*,ERR=50) IVAR
     RETURN
C    If error go to label 50
```

```
50  IERR = .TRUE.
    RETURN
    END
```

REFERENCES CITED

Albuquerque, C A R De, 1977 Geochemistry of the tonalitic and granitic rocks of the Nova Scotia southern plutons, Geochimica et Cosmochemica Acta v 41, p 1-13

Alley, R B , Blankenship, D D , Rooney, S T , and Bentley, C R , 1989 Sedimentation beneath ice shelves-the view from ice stream B, Marine Geology, v 85, p 101-120

Amos, C L , and Knoll, R G , 1987 The Quaternary sediments of Banquereau, Scotian Shelf, Geological Society of America Bulletin, v 99 no 2, p 244-260

Amos, C L , and Miller, A A L , 1990 The Quaternary stratigraphy of southwest Sable Island Bank, eastern Canada, Geological Society of America Bulletin, v 102, p 915-934

Anderson, J B , Kennedy, D S , Smith, M J , and Domack, E W , 1991 Sedimentary facies associated with Antarctica's floating ice masses, in J B Anderson, and G M Ashley, eds , Glacial Marine Sedimentation, Paleoclimatic Significance Boulder Colorado, Geological Society of America, Special Paper 261, p 1-25

Anderson, J B , and Bartek L R , 1992 Cenozoic glacial history of the Ross Sea revealed by intermediate resolution seismic reflection data combined with drill site information, American Geophysical Union, Antarctic Research Series, v 56 , p 231-263

Ashley, G M , Boothroyd, J C , and Borns, H W , Jr , 1991 Sedimentology of Late Pleistocene (Laurentide) deglacial-phase deposits, eastern Maine, An example of a temperate marine grounded ice-sheet margin, in J B Anderson, and G M Ashley, eds , Glacial Marine Sedimentation, Paleoclimatic Significance Boulder Colorado, Geological Society of America, Special Paper 261, p 1-25

Bacchus, T S , 1993 Late Quaternary Stratigraphy and Evolution of the Eastern Gulf of Maine, Ph D Thesis, University of Maine, Orono, Maine, 346 p

Bahnson, H , 1972 Lithological investigations in some Danish boulder clay profiles, in Konigsson, L K , ed , The Uppsala Symposium on Till and Till Stratigraphy, Bulletin of the Geological Institution of the University of Uppsala, v 5 p 93-109

Bailey, L W , 1898 Report on the geology of southwestern Nova Scotia, Geological Survey of Canada, Annual Report, v 9, pt M, p 30-60

Baltzer, A , Cochonat, P , and Piper, D J W , 1994 In situ geotechnical characterization of sediments on the Nova Scotian slope, eastern Canadian continental margin, Marine Geology, v 120, p 291-308

Barnett, D M, and Holdsworth, G, 1974 Origin, morphology and chronology of sublacustrine moraines, Generator Lake, Northwest Territories, Canada, Canadian Journal of Earth Sciences, v 11, p 380-408

Barnhardt, W A, Kelley, Joseph, T, and Belknap, Daniel, F, 1992 Lowstand deltas of the western Gulf of Maine, in Abstracts Volume, Wolfville '92, Geological Association of Canada - Mineralogical Association of Canada Joint Annual Meeting, p A6

Barrie, Q C, and Piper, D J W, 1982 Late Quaternary marine geology of Makkovic Bay, Labrador, Geological Survey of Canada, Paper 81-17, 37 p

Beaudry, L M, and Prichonnet, G, 1991 Late-glacial De Geer moraines with glaciofluvial sediment in the Chapais area, Quebec (Canada), Boreas, v 20, p 378-394

Belknap, D F, Andersen, B G, Anderson, R S, Anderson, W A, Borns, H W, Jr, Jacobson, G L Kelley, J T, Shipp, R C, Smith, D C, Stuckenrath, R Jr, Thompson, W B, and Tyler, D A, 1987 Late Quaternary sea-level changes in Maine, in D Nummedal, O H, Pilkey, Jr, and J D Howard, eds, Sea-Level Fluctuations and Coastal Evolution, SEPM special publication 41, p 71-85

Belknap D F, and Kraft, J C, 1981 Preservation potential of transgressive coastal lithosomes on the U S Atlantic Shelf, in C A Nittrouer, ed, Sedimentary Dynamics of Continental Shelves, Elsevier, p 429-442

Belknap, D F, and Shipp, R C, 1991 Seismic stratigraphy of glacial marine units, Maine inner shelf, in J B Anderson, and G M Ashley, eds, Glacial Marine Sedimentation Paleoclimatic significance, Geological Society of America, Special Paper, 261, p 137-157

Belknap, D F, Schnikter, D, Bacchus, T S, Batchelor, B A, and Fader, G B J, 1991 New seismic and core data from the Gulf of Maine Glaciomarine and grounding line deposits, Geological Society of America, Abstracts with Programs, v 23

Bigelow, H B, 1927 Physical Oceanography of the Gulf of Maine, U S Department of Commerce, Bureau of Fisheries, Bulletin 40, p 511-1027

Bloom, A L, 1963 Late Pleistocene fluctuation of sea-level and post-glacial crustal rebound in coastal Maine, American Journal of Science, v 261, p 862-879

Boehner, R C, Calder, J H, Carter, D C, Donohoe, H V, Ferguson, L, Pickerill, R K, and Ryan, R J, 1986 Carboniferous-Jurassic sedimentation and tectonics, Minas, Cumberland and Moncton Basins, Nova Scotia and New Brunswick, Atlantic Geoscience Society Special Publication Number 4, 122 p

Bond, G H , Heinrich, S , Huon, W , Broecker, L , Labeyrie, J , Andrews, J , McManus, S , Clasen, K , Tedesco, R , Jantschik, C , Simet, and Klas, M , 1992 Evidence of massive discharges of icebergs into glacial North Atlantic, Nature, v 360, p 245-249

Boulton, G S , 1975 Processes and patterns of sub-glacial sedimentation a theoretical approach, *in* A Wright and F Mosely, eds , Ice Ages Ancient and Modern, Seel House Press, Liverpool, p 7-42

Boulton, G S , 1978 Boulder shapes and grain-size distributions as indicators of transport paths through a glacier and till genesis, Sedimentology, v 25, p 773-799

Boulton, G S , 1979 Processes of erosion on different substrata, Journal of Glaciology, v 23, no 89, p 15-38

Boulton, G S , 1986 Push Moraines and glacier contact fans in marine and terrestrial environments, Sedimentology v 33, p 677-698

Boulton, G S , 1990 Glaciomarine facies architecture, *in* Dowdeswell, J A , and Scourse, J D , eds , Glaciomarine Environments Processes and Sediments, Geological Society of London, Special Publication no 53, p 15-52

Boulton, G S , and Jones, A S , 1979 Stability of temperate ice caps and ice sheets resting on beds of deformable sediment, Journal of Glaciology, v 24, no 90, p 29-43

Boyd, R , Forbes, D L , and Heffler, D E , 1988a Time sequence observations of wave-formed sand ripples on an ocean shoreface, Sedimentology, v 35, p 449-464

Boyd, R , Scott, D B , and Douma, M , 1988b Glacial tunnel valleys and Quaternary history of the outer Scotian Shelf Nature, v 333, no 6168, p 61-64

Boyd, R , Forbes, D L , and Nichol, S L , 1992 Transgression of the Eastern Shore, Nova Scotia, *in* Abstracts Volume, Wolfville '92, Geological Association of Canada - Mineralogical Association of Canada, Joint Annual Meeting, p A11

Broecker, W S , Peteet, D M , and Rind, D , 1985 Does the ocean-atmosphere system have more than one stable mode of operation? Nature, v 315, P 21-26

Broecker, W S , 1992 Upset for Milankovitch theory, Nature, v 359, p 779-780

Broecker, W , Bond, G , Klas, M , Clark, E , and McManus, J , 1992 Origin of the northern Atlantic's Heinrich events, Climate Dynamics, v 6, p 265-273

Brown, L F, Jr, and Fischer, W L, 1982 Seismic stratigraphic interpretation and petroleum exploration, American Association of Petroleum Geologists, Continuing Education Course Note Series, no 16, 56 p

Brown, C S, Meier, M F, and Post, A, 1982 Calving speed of Alaskan tidewater glaciers, with applications to Columbia Glacier, United States Geological Survey, Professional Paper, 1258-C, 13 p

Buckley, D E, MacKinnon, W G, Cranston, R E, and Christian, H, 1994 Problems with piston core sampling mechanical and geochemical diagnosis, Marine Geology, v 117, p 95-106

Budd, W F, and Smith, I N, 1987 Conditions for growth and retreat of the Laurentide Ice Sheet, Géographie physique et Quaternaire, v 41, p 279-290

Cameron, H, 1956 Tectonics of the Maritime area Transactions of the Royal Society of Canada, v 50, Series 3, p 45-51

Chalmers, R, 1895 Report on the surface geology of eastern New Brunswick, northwestern Nova Scotia and a portion of Prince Edward Island, Geological Survey of Canada, Annual Report 1894, v 1, no 7, pt m, 144 p

Clark, P U, 1987 Subglacial sediment dispersal and till composition, Journal of Geology, v 95, p 527-541

Clark, P U, and Hansel, A K, 1989 Clast ploughing, lodgement and glacial sliding over a soft glacier bed, Boreas, v 1! 18, p 201-207

Clark, P U, 1992 Surface form of the southern Laurentide ice sheet and its implications to ice sheet dynamics, Geological Society of America Bulletin, v 104, p 595-605

Clark, P U, Clague, J J, Curry, B B, Dreimanis, A, Hicock, S, Miller, G H, Berger, G W, Eyles, N, Lamothe, M, Miller, B B, Mott, R J, Oldale, R N, Stea, R R, Szabo, J P, Thorleifsen, L H, ano Vincent, J S, 1993 Intitiation and development of the Laurentide and Cordilleran ice sheets following the last glaciation, Quaternary Science Reviews, v 12, p 79-114

Clark, J A, Farrell, W E, and Peltier, W R, 1978 Global changes in Postglacial sea-level A numerical calculation, Quaternary Research, v 9, p 265-287

Clarke, D G, Barr, S M, and Donohoe, H V, 1980 Granitoid and other plutonic rocks of Nova Scotia, in proceedings, The Caledonides in the U S A IGCP project 27 Caledonide

Orogen, Department of Geological Science, Virginia Polytechnic Institute and State University, Memoir no 2, p 107-116 .

Clarke, D B , and Halliday, A N , 1980 Strontium isotope geology of the South Mountain Batholith, Nova Scotia, Geochimica et Cosmochimica Acta, v 44, p 1045-1058

Cok, A E , 1970 Morphology and surficial sediments of the eastern half of the Nova Scotia shelf, unpublished Ph D dissertation, Dalhousie University, 261 p

Coker, W B , Sexton, A , Lawyer, I , and Duncan, D R , 1988 Bedrock, Till and Soil Geochemical Signatures at the Beaver Dam gold deposit, Nova Scotia, Canada, *in* D R MacDonald, ed , Prospecting in Areas of Glaciated Terrain, 1988, Canadian Institute of Mining and Metallurgy, p 242-255

Conolly, J R , and Ewing, M , 1965 Pleistocene glacial-marine zones in North Atlantic deep sea sediments, Nature, v 208, p 135-138

Cooke, H B S , 1973 Pleistocene chronology long or short?, Quaternary Research, v 3, p 206-220

Costello, G , Loncarevic, B D , and Mayer, L , 1993 New frontiers in ocean mapping, *in* Program with Abstracts, Atlantic Geoscience Society, Annual Colloqium and Symposia, Halifax, Nova Scotia, 1993, p 2-3

Costello, O P , 1994 Paleooceanographic reconstruction of the inner Scotian Shelf during the Younger Dryas A benthic foraminiferal study, B Sc Hons Thesis, Dalhousie University, Halifax, 85 p

Cowan, E , and Powell, R D , 1991 Ice-proximal sediment accumulation rates in a temperate glacial fjord, southeastern Alaska, *in* Anderson, J B , and Ashley, G M , eds , Glacial Marine Sedimentation Paleoclimatic significance, Boulder Colorado, Geological Society of America Special Paper, 261, p 61-74

Crowley, T J , and North G R , 1991 Paleoclimatology, Oxford University Press, New York, 339 p

Denton, G H , and Hughes, T J , 1981 The last great ice sheets, John Wiley and Sons, Inc , Toronto, Ontario, 484 p

Dodds, D J , and Fader, G B J , 1986 A combined seismic reflection profiler and sidescan sonar system for deep ocean geological surveys, *in* H Merklinger, ed , Proceedings of the Twelfth International Congress on Acoustics, Plenum press, New York, p 169-179

Donohoe, H V, Jr, and Wallace, P I, 1982 Geological maps of the Cobequid Highlands-Colchester, Cumberland and Pictou Counties, Nova Scotia, Nova Scotia Department of Mines and Energy, Maps 82-6 to 82-9

Donohoe, H V, Jr, and Wallace, P I, 1985 Repeated orogeny, faulting and stratigraphy in the Cobequid Highlands, Avalon Terrain of Northern Nova Scotia, Geological Association of Canada - Mineralogical Association of Canada, Field Trip Guidebook, Excursion 3, 77 p

Donohoe, H V, Jr, Piper, D J W, Pe-Piper, G, Murphy, B, and Nance, D, 1992 Cobequid Highlands, Nova Scotia The interplay of episodic magmatism, volcanism and ductile/brittle strain, Geological Association of Canada, Joint Annual Meeting, Wolfville '92, Field trip C-2, Guidebook, 25 p

Drapeau, G, and King, L H, 1972 Surficial geology of the Yarmouth-Browns Bank map area, Geological Survey of Canada, Marine Science Paper, 72-24, 6 p

Dreimanis, A, 1976. Tills Their origin and properties, in Leggett, R F, ed, Clacial Till, an Interdisciplinary Study, The Royal Society of Canada, Special Publication, no 12, p 11-49

Dreimanis, A, 1989 Genetic classification of tills, in Goldthwait R P and Matsch, C L, Genetic Classification of Glacigenic Deposits, p 17-84, Balkema, Rotterdam

Dreimanis, A, and Reavely, G H, 1953 Differentiation of the lower and upper till along the North Shore of Lake Erie, Journal of Sedimentary Petrology, v 23, no 4, p 238-259

Dreimanis, A, and Vagners, U, 1971. Bimodal distribution of rock and mineral fragments in basal tills, in Goldthwait R P, ed, Till a symposium, The Ohio State University press, p 237-250

Drewry, D J., 1986 Glacial geologic processes, Edward Arnold, London, 276 p

Drewry, D J, and Cooper, A P R., 1981 Processes and models of glaciomarine sedimentation, Annals of Glaciology, v 2, p 117-122

Dyke, A S, and Prest, V K, 1987 Late Wisconsinan and Holocene history of the Laurentide ice sheet, in Fulton, R J and Andrews, J T eds, The Laurentide Ice Sheet, Géographie physique et Quaternaire, v 41, p 237-264

Edgecombe, R B, 1994 Paleoenvironmental analysis of Halifax Harbour sedimentology, paleoclimatology ahd Holocene sea level, B Sc (Hons) Thesis, Dalhousie University, 63 p

Edwards, B D, Lee, H J, and Field, M E, 1993 Seismically induced mudflow in Santa Barbara Basin, California, in W C Schwab, H J Lee, and D C Twichell, U S, eds,

Submarine Landslides Selected Studies in the U S Exclusive Economic Zone, Geological Survey, Bulletin 2002, p 167-175

Elverhøi, A, Pfirman, S, Solheim, A, and Larssen, B B, 1989 Glaciomarine sedimentation in epicontinental seas exemplified by the northern Barents Sea, *in* R D Powell and A Elverhøi, eds, Modern Glacimarine Environments Glacial and Marine Controls of Modern Lithofacies and Biofacies, Marine Geology, v 85, p 225-250

Elson, J, 1957 Origin of washboard moraines, Geological Society of America Bulletin, v 68, p 1721

Eyles, N, Eyles, C H, and Miall, A D, 1983 Lithofacies types and vertical profile models an alternative approach to the description and environmental interpretation of glacial diamict and diamictite sequences, Sedimentology, v 30, p 393-410

Eyles N, and Eyles, C H, 1992 Glacial depositional systems, *in* Facies Models Response to Sea-level Change, eds R G Walker and N P James, Geological Association of Canada, Special Publication p 73-100

Fader, G B, King, L H, and MacLean, B, 1977 Surficial Geology of the Eastern Gulf of Maine and Bay of Fundy, Geological Survey of Canada, Paper 76-17, 23 p

Fader, G B J, 1989a A Late Pleistocene low sea-level stand of the southeast Canadian offshore, *in* D B Scott *et al.*, eds Late Quaternary sea-level correlations and applications, Kluwer Academic Publishers, p 71-103

Fader, G B J, 1989b Submersible observations of iceberg furrows and sand ridges, Grand Banks of Newfoundland, *in* D J W Piper, ed, Submersible Observations off the East Coast of Canada, Geological Survey of Canada, Paper 88-20, p 27-39

Fader, G B J, 1991 Surficial geology and physical properties 3 Subsurface Features, *in* East Coast Basin Atlas Series Scotian Shelf, Atlantic Geoscience Centre, Geological Survey of Canada, p 115

Fader, G B J, Miller, R, Stea, R R, and Pecore, S, 1991 Cruise Report 91018 CSS Dawson, operations on the inner Scotian Shelf, Geological Survey of Canada, Open File 2633, 30 p

Fairbanks, R G, 1989 A 17,000-year glacio-eustatic sea-level record influence of glacial melting rates on the Younger Dryas event and deep ocean circulation, Nature, v 342, p 637-642

Fehr, S D , 1991 A geoacoustic model for the upper sediments of Emerald Basin, M Sc Thesis, Dalhousie University, 241 p

Fenton, M M , and Dreimanis, A , 1976 Methods of stratigraphic correlations of till in central and western Ontario, *in* Glacial Till, ed R F Legget, Royal Society of Canada, Special Publication no 23, p 67-82

Finck, P W , and Stea, R R , 1990 Inheritance and overprinting controlling factors of till genesis in Nova Scotia, Canadian Quaternary Association-American Quaternary Association First Joint Meeting, Programme and Abstracts, p 18

Finck, P W , Graves, R M , and Boner, F J , 1993 Glacial and till clast geology map of New Germany (21A10), Nova Scotia Department of Natural Resources Map 93-02, 1 50 000

Finck, P W , Graves, R M , and Boner, F J , 1994a Glacial and till clast geology map of Lake Rossignol (21A03), Nova Scotia Department of Natural Resources Map 94-09; 1 50,000

Finck, P W , Graves, R. M , and Boner, F J , 1994b Glacial and till clast geology map of Wentworth Lake (20P14); Nova Scotia Department of Natural Resources Map 94-010, 1 50,000

Finck, P W , Graves, R M , and Boner, F J , 1994c Glacial and till clast geology map of Kejimikujik Lake (21A6+7), Nova Scotia Department of Natural Resources Map 94-012, 1 50,000

Finck, P W , Graves, R M , and Boner, F J , 1994d Glacial and till clast geology map of Milford, Nova Scotia (21A11), Nova Scotia Department of Natural Resources Map 94-013, 1 50,000

Finck, P W , Graves, R M , and Boner, F. J , 1994e Glacial and till clast geology map of Gasperaux Lake, Nova Scotia (21A15), Nova Scotia Department of Natural Resources Map 94-014, 1 50,000

Flint, R F., 1951 Highland centres of former glacial outflow in northeastern North America, Geological Society of America Bulletin, v 62, p 21-38

Flint, R F , 1971. Glacial and Quaternary Geology, John Wiley and Sons, 892 p

Foisy, M , and Prichonnet, G , 1991 Reconstruction of glacial events in southeastern New Brunswick, Canadian Journal of Earth Sciences, v 28, p 1594-1612

Forbes, D L, 1990 HMCS Cormorant and SDL-1 operations on the inner Scotian Shelf, Cruise Report 89302, Open File 2344, 36 p

Forbes, D L, and Drapeau, G, 1988 Near bottom currents and sediment transport on the inner Scotian Shelf Sea floor reponse to winter storms durin CASP, Atmosphere-Ocean v 27, p 258-278

Forbes D L, Boyd, R, Shaw, J, Johnston, L, Heffler, D E, and McLaren S, 1988 Cruise report 87042 CSS Dawson operations on inner Scotian Shelf and Sable Island Bank , Geological Survey of Canada, Open File Report 2063, 51 p

Forbes, D L, Boyd, R, and Shaw, J, 1991 Late Quaternary sedimentation and sea-level changes on the inner Scotian Shelf Quaternary Shelf Research, v 11, nos 8-10, p 1155-1179

Fowler, J H, and Stea, R R, 1979 Cretaceous deposits in Nova Scotia, *in* Mineral Resources Division, Report of Activities, 1978, Nova Scotia Department of Mines and Energy, Report 79-1, p 9-14

Gipp, M R, 1989 Late Wisconsinan deglaciation of Emerald Basin, M Sc Thesis, Memorial University, St Johns, Newfoundland, 219 p

Gipp, M R, 1994 Late Wisconsinan deglaciation of Emerald Basin, Scotian Shelf, Canadian Journal of Earth Sciences, v 31, p 554-566

Gipp, M R, and Piper, D J W, 1989 Chronology of Late Wisconsinan glaciation, Emerald Basin, Scotian Shelf, Canadian Journal of Earth Sciences, v 26, p 333-335

Goldthwait, J W, 1924 Physiography of Nova Scotia, Geological Survey of Canada, Memoir 140, Nova Scotia Department of Mines and Energy, Microfiche no 41, p 60-103

Goldthwait, R P, 1989 Classification of glacial morphologic features, *in* R P Goldthwait and C L Matsch, eds , Genetic Classification of Glacigenic Deposits, Balkema, Rotterdamp, p 267-278

Grant, D R, 1963 Pebble lithology of the tills of southeast Nova Scotia, M Sc thesis, Dalhousie University, Halifax, Nova Scotia, 235 p

Grant, D R, 1975 Glacial style and the Quaternary stratigraphic record in the Atlantic Provinces, Canada, *in* Report of Activities, Part B, Geological Survey of Canada, Paper 75-1B, p 109-110

Grant, D R , 1977 Glacial style and ice limits, the Quaternary stratigraphic record, and changes of land and ocean level in the Atlantic Provinces, Canada, Géographie physique et Quaternaire, v 31, no 3-4, p 247-260

Grant, D R , 1980a Quaternary sea-level change in Atlantic Canada as an indication of crustal delevelling, *in* Earth Rheology, Isostasy and Eustasy, ed N A Morner, John Wiley and Sons, London, p 201-214

Grant, D R , 1980b Quaternary stratigraphy of southwestern Nova Scotia glacial events and sea-level changes Geological association of Canada and Mineralogical Association of Canada Guidebook, 63 p

Grant, D R , and King, L H , 1984 A stratigraphic framework for the Quaternary history of the Atlantic Provinces, *in* Quaternary Stratigraphy of Canada - A Canadian Contribution to IGCP Project 24, ed R J Fulton, Geological Survey of Canada, Paper 84-10, p 173-191

Grant, D R , 1989 Quaternary Geology of the Atlantic Appalachian region of Canada, Chapter 5 *in* Quaternary Geology of Canada and Adjacent Greenland, R J Fulton, (ed), Geological Survey of Canada, Geology of Canada no 1 (also Geological Society of America, the Geology of North America, v K-1), p 393-440

Graves, R M , and Finck, P W , 1987a Till clast and simplified glacial geology map of Mount Uniacke (11D13W), Nova Scotia Department of Mines and Energy Map 87-03, 1 50,000

Graves, R M , and Finck, P W , 1987b Till clast and simplified glacial geology map of Halifax-Sambro (11D12 and 11D05), Nova Scotia Department of Mines and Energy Map 87-02, 1 50,000

Graves, R M , and Finck, P W , 1990 Till clast and simplified glacial geology map of Chester, Nova Scotia (21A9), Nova Scotia Department of Mines and Energy Map 87-02, 1 50,000

Graves, R M , and Finck, P W , 1988 The provenance of tills overlying the eastern part of the South Mountain Batholith, Nova Scotia, Maritime Sediments and Atlantic Geology, v 24, p 61-70

Grousset, F E , Labeyrie, L , Sinko, J A , Cremer, M , Bond, G , Duprat, J , Cortijo, E , and Huon, S , 1993 Patterns of ice-rafted detritus in the glacial North Atlantic (40-55°), Paleoceanography, v 8 , no 2, p 175-192

Hall, R K , 1985 Inner shelf acoustic facies and surficial sediment distribution of the Eastern Shore, Nova Scotia, Dalhousie University Centre for Marine Geology, Technical Report no 8, 197 p

Hambrey, M J, Ehrmann, W U, and Larsen, B, 1991 Cenozoic glacial record of the Prydz Bay continental shelf, East Antarctica, Proceeding of the Ocean Drilling Program, Scientific Results, v 119, p 77-103

Hambrey, M J, Barrett, P J, Ehrmann, W U, and Larsen, B, 1992 Cenozoic sedimentary processes on the Antarctic continental margin and the record from deep drilling, Zeitschrift für Geomorphologie Supplementband, v 86, p 77-103

Hart J K, and Boulton, G S, 1991 The interrelation of glaciotectonic and glaciodepositional processes within the glacial environment, Quaternary Science Reviews, v 10, p 335-350

Hays, J D, Imbrie, J, and Shackleton, N J, 1976 Variations in the earth's orbit, pacemaker of the ice ages, Science v 194, p 1121-1132

Heinrich, H, 1988 Origin and consequences of cyclic ice rafting in the northeast Atlantic Ocean during the past 130,000 years, Quaternary Research v 29, p 143-152

Hickox, C F, Jr, 1962 Pleistocene geology of the central Annapolis Valley, Nova Scotia, Nova Scotia Department of Mines, Memoir 5, 36 p

Hill, P R, 1981 Detailed moprhology and Late Quaternary sedimentation on the Nova Scotian Slope south of Halifax, Unpublished Ph D, thesis, Dalhousie Universit, Halifax, 331 p

Holmes, C D, 1952 Drift dispersion in West-Central New York, Geological Society of America Bulletin, v 63, p 993-1010

Holtedahl, H, 1989 Submarine end moraines and associated deposits of the south coast of Norway, Marine Geology, p 23-48

Honeyman, D, 1882 Glacial transportation in Nova Scotia and beyond, Proceedings of the Transactions of the Nova Scotia Institute of Science, v 6, p 34-42

Honig, C, 1987 Estuarine sedimentation on a glaciated coast Lawrencetown Lake, Eastern Shore, Nova Scotia, Centre of Marine Geology, Dalhousie University, Technical Report no 9 132 p

Honig, C A, and Scott, D B, 1987 Postglacial stratigraphy and sea level change in southwestern New Brunswick, Canadian Journal of Earth Sciences, v 24, p 354-364

Hopkins, R, 1985 Placer gold potential offshore of Country Harbour Nova Scotia, Canada Oil and Gas Lands Administration (COGLA) Special Report, 89 p

Hoppe, G, 1959 Glacial morphology and inland ice recession in northern Sweden, Geografiska Annaler, v 41, p 193-212

Hotzel, S I, and Miller, J D, 1983 Icebergs their physical dimensions and the presentation and application of measured data, Annaler Glaciologie, v 4, p 116-123

Hughes, 1981 Numerical recontruction of paleo-ice sheets, Chapter 5 in G H, Denton and T J Hughes, eds, The Last Great Ice Sheets, p 222-260, John Wiley and Sons, 1981

Hutchins, R W, McKeown, D, and King, L H, 1976 A deep tow high resolution seismic system for continental shelf mapping, Geoscience Canada,, v 3, p 95-100

Imbrie, J, Hays, J D, Martinson, D G, McIntyre, A, Mix, A C, Morley, J J, Pisias, N G, Prell, W L, and Shackleton, H J, 1984 The orbital theory of Pleistocene climate Support from a revised chronology of the marine δ ^{18}O record, in A L Berger et al., eds, Milankovitch and Climate, Part 1, p 269-305, D Riegel, Hingham, Mass, 1984

Jetté, H, and Mott, R J, 1989 Palynostratigraphie du tardiglaciaire et de l'Holocéne de la région du lac Chance Harbour, Nouvelle-Ecosse, Géographie physique et Quaternaire, v 43, p 27-38

Josenhans, H W, and Fader, G B J, 1989 A comparison of glacial sedimentation along the eastern Canadian margin, Marine Geology, v 85, p 273-300

Josenhans, H W, and Barrie, J V, 1989 Submersible observations on the Labrador Shelf, Hudson Strait and Baffin Shelf, in D J W Piper, ed, Submersible Observations off the East Coast of Canada, Geological Survey of Canada, Paper 88-20, p 41-56

Josenhans, H W, Barrie, J V, and Conway K W, 1992 The Younger Dryas on the Canadian pacific rim continental shelf Evidence for full glacial retreat and lowering of sea-level by 10 6 ka, in Abstracts Volume, Wolfville '92, Geological Association of Canada - Mineralogical Association of Canada Joint Annual Meeting, p A6

Karrow, P F, 1976 The texture, mineralogy and petrography of North American tills, in R F Legget, ed, Glacial Till, The Royal Society of Canada, Special Publication, no 12, p 83-98

Kelley, J T, Belknap, D F, and Shipp, R C, 1989 Sedimentary framework of the southern Maine inner continental shelf Influence of glaciation and sea-level change, Marine Geology, p. 139-147

Kennett, J P, 1982 Marine Geology, Prentice-Hall, 813 p

Keppie, J D , 1977 Tectonics of southern Nova Scotia, Nova Scotia Department of Mines, Paper 77-1, 34 p

Keppie, J D , 1982 Tectonic map of the Province of Nova Scotia, Nova Scotia Department of Mines and Energy, Map 82-1, scale 1 500 000

Keppie, J D , and Muecke, G K , 1979 Geology Map of Nova Scotia (metamorphic edition), Nova Scotia Department of Mines and Energy Map, scale 1,500 000

King, L H , 1969 Submarine end moraines and associated deposits on the Scotian Shelf, Geological Society of America Bulletin, v 80, no 1, p 83-96

King, L H , 1970 Surficial geology of the Halifax-Sable Island map area, Marine Science Branch, Geological Survey of Canada, Paper 1, 16 p

King, L H , 1993 Till in the Marine Environment, Journal of Quaternary Science, v 8, p 347-358

King, L H , 1994 Proposed Younger Dryas glaciation of the eastern Scotian Shelf, Canadian Journal of Earth Sciences, v 31, p 401-417

King, L H , and Fader, G B , 1986 Wisconsinan glaciation of the Continental Shelf of Southeast Atlantic Canada, Geological Survey of Canada, Bulletin 363, 72 p

King, L H , and Fader, G B J , 1988 A comparison between the Late Wisconsinan history of Southwest and Northeast Emerald Basins, Geological Survey of Canada, Open File Report, v 2060, 12 p

King, L H , and MacLean, B C , 1974 Geology of the Scotian Shelf, Geological Survey of Canada, Paper 74-31, 31 p

King, L H , MacLean, B , and Drapeau, G , 1972 The Scotian Shelf submarine end-moraine complex, in International Geological Congress, 24th session, Section 8, Marine Geology and Geophysics, p 237-249

King, L H , MacLean, B , and Fader, G B J , 1974 Unconformities on the Scotian Shelf, Canadian Journal of Earth Sciences, v 11, p 89-100

King, L H , Rokoengen, K , Fader, G B J , and Gunleiksrud, T , 1991 Till tongue stratigraphy, Geological Society of America Bulletin, v 103, p 637- 659

Kruger, J , 1984 Clasts with stoss-lee form in lodgement tills a discussion, Journal of Glaciology, v 30, p 241-243

Krumbein, W C, 1933 Textural and lithological variations in glacial till, Journal of Geology v 41, p 710-722

LaPierre, A, 1985 Modern sedimentary environments on the inner shelf, Eastern Shore, Nova Scotia, B Sc, Hons Thesis, Dalhousie University, 90 p

Larsen, E, Longva, O, and Follestad, B A, 1991 Formation of DeGeer moraines and implications for deglaciation dynamics, Journal of Quaternary Science, v 6, p 263-277

LaSalle, P, and Shilts, W W, 1993 Younger Dryas age readvance of Laurentide ice into the Champlain Sea, Boreas, v 22, p 25-27

Lee, H J, Schwab, W C, and Booth, J S, 1993 Submarine landslides An introduction, in W C Schwab, H J Lee, and D C Twichell, eds, Submarine Landslides Selected Studies in the U S Exclusive Economic Zone, U S Geological Survey, Bulletin 2002, p 1-13

Livingstone, D A, and Livingstone, B G R, 1958 Late-glacial and postglacial vegetation from Gills Lake in Richmond County, Cape Breton Island, Nova Scotia, American Journal of Science, v 256, p 341-359

Loncarevic, B D, Piper, D J W, and Fader, G B J, 1992 Application of high quality bathymetry to geological interpretation on the Scotian Shelf, Geoscience Canada, v 19 no 1, p 5-12

Loncarevic, B D, Courtney, R C, Fader, G B J, Giles, P S, Piper, G J W, Costello, G, Hughes-Clark, J E, and Stea, R R, 1994 Sonography of a glaciated continental shelf, Geology, v 22, p 747-750

Loring, D H, and Nota, D J G, 1973 Morphology and sediments of the Gulf of St Lawrence, Fisheries Research Board of Canada, Bulletin, 182, 147 p

Lowell, T V, Kite, J S, Calkin, P E, and Halter, E F, 1990 Analysis of small scale erosional data and a sequence of Late Pleistocene flow reversal, northern New England, Geological Society of America Bulletin, v 74-85

Lundqvist, J, 1989 Glacigenic processes, deposits and landforms, in Genetic Classification of Glacigenic Deposits, eds R P Goldthwait and C I Matsch, p 3-16, Balkema, Rotterdam

MacDonald, A, 1982 The depositional environments of Roseway Basin, Scotian Shelf, B Sc, Honours Thesis, St Marys University, 37p

MacDonald, M A, Horne, R J, Corey, M C, and Ham, L J, 1992 An overview of recent bedrock mapping and follow up petrological studies of the South Mountain Batholith,

southwestern Nova Scotia, Canada, Atlantic Geology, v 28, p 7-28

MacEachern, I J, and Stea, R R, 1986 The dispersal of gold and related elements in tills and soils at the Forest Hill Gold District Guysborough County, Nova Scotia, Geological Survey of Canada, Paper 85-18

MacKenzie, C B, and Clarke, D B, 1975 Petrology of the South Mountain Batholith, Nova Scotia, Canadian Journal of Earth Science, v 12, p 1209-1218

MacNeill R H, and Purdy, C A, 1951 A local glacier in the Annapolis-Cornwallis Valley, (abstract), Proceedings of the Nova Scotian Institute of Science, v 23, pt 1, p 111

MacNeill, R H, 1951 Pleistocene geology of the Wolfville area, Nova Scotia, M Sc thesis, Acadia University, Wolfville, Nova Scotia, 59 p

Mangerud, J, 1972 Radiocarbon dating of marine shells, including a discussion of apparent ages of Recent shells from Norway, Boreas, v 1, p 143-172

Mangerud, J, Andersen, S T, Berglund, B E, and Donner, J J, 1974 Quaternary stratigraphy of Norden, a proposal for terminology and classification, Boreas, v 3, p 109-128

Marcussen, I, 1973 Stones in Danish tills as a stratigraphic tool, A review, in L K Konigsson, ed, The Uppsala Symposium on Till and Till Stratigraphy, p 177-181

Marsters, S, 1988 Latest Pleistocene-Holocene paleoceanographic trends on the inner shelf of the south shore of Nova Scotia benthic foraminiferal evidence, B Sc hons thesis Dalhousie University, Halifax, 64 p

Mayewski, P A, Denton, G H, and Hughes, T J, 1981 Late Wisconsin Ice Sheets in North America, Chapter 2, in G H Denton, and T J, Hughes, eds, The Last Great Ice Sheets, John Wiley and Sons, New York, 484 p

Mazzullo, J, and Anderson, J B, 1987 Grain shape and surface texture analysis of till and glacial marine sand grains from the Weddell and Ross Seas, Antarctica, in J R Marshall, ed, Clastic Particles, Van Nostrand-Reinhold, p 314-327

McClenaghan, M B, and Dilabio, R N W, 1993 Till geochemistry and its implications for mineral exploration southeastern Cape Breton Island, Nova Scotia, Canada, Quaternary International, v 20, p 107-122

McLaren, S A, 1988 Quaternary stratigraphy of the Sable Island sand body, Dalhousie University Centre for Marine Geology, Technical Report no 11, 95 p

McGill, R , Tukey, J W , and Larsen, W A , 1978 Variation of box plots, American Statistician, v 32, p 12-16

Meyer, K-D , 1983 Indicator pebbles and stone count methods, *in* J Ehlers, ed , Glacial Deposits in North-West Europe, Balkema, Rotterdam, p 285-287

Miller, A A L , Mudie, P , and Scott, D B , 1982 Holocene history of Bedford Basin, Nova Scotia, foraminifera. dinoflagellate, and pollen records, Canadian Journal of Earth Sciences, v 19, no 12, p 2342-2367

Mitchum, R M , Jr , Vail, P R , and Thompson, S , 1977 Seismic stratigraphy and global changes of sea-level, Part 2, The depositional sequence as a basic unit for stratigraphic analysis, *in* Seismic Stratigraphy, Applications for Hydrocarbon Exploration, American Association of Petroleum Geologists, Memoir 26, p 53-62

Morner N-A, 1971 Eustatic changes during the last 20,000 years and a method of separating the isostatic and eustatic factors in an uplifted area, Paleogeography, Paleoclimatology, Paleoecology, v 9 p 163-181

Mosher, D C , Piper, D J W , Vilks, G V , Aksu, A E , and Fader, G B , 1989 Evidence for Wisconsinan glaciations in the Verrill Canyon area, Scotian Slope Quaternary Research, v 31, p 27-40

Mott, R J , and Grant, D R G , 1985 Pre-Late Wisconsinan paleoenvironments in Atlantic Canada, Géographie physique at Quaternaire, v 39, p 239-254

Mott, R J , Grant, D R G , Stea, R R , and Occhietti, S , 1986 Late-glacial climatic oscillation in Atlantic Canada equivalent to the Allerod-Younger Dryas event, Nature, v 323, no 6085, p 247-250

Mott, R J , and Stea R R , 1990 Rapid late-glacial climate fluctuations in Atlantic Canada, *in* Program and Abstracts Canadian Quaternary Association-American Quaternary Association Joint Meeting, Waterloo Ontario, p 27

Mott, R J , and Stea R R , 1994 Late-Glacial (Allerod/Younger Dryas) buried organic deposits, Nova Scotia, Canada, Quaternary Science Reviews, v 12, p 645-657

Muecke, G K , Elias, P , and Reynolds, P H , 1988 Hercynian/Alleghenian overprinting of an Aca ian Terrane $^{40}A/^{39}A$ studies in the Meguma Zone, Nova Scotia, Canada Chemical Geology, v 73, p 153-167

Murphy, J B , Keppie, J D , and Hynes, A J , 1991 The geology of the Antigonish Highlands, Geological Survey of Canada Paper, 89-10, 115 p

Myers, R. A., and Stea, R. R., 1986 Surficial mapping results Pictou, Guysborough, and Antigonish Counties, Nova Scotia, *in* J L Bates, ed, Mines and Minerals Branch Report of Activities, p 189-194

Nicks, L, 1988 A study of the glacial stratigraphy and sedimentation of the Sheldon Point Moraine, Saint John, New Brunswick, M Sc thesis, Dalhousie University, Halifax, Nova Scotia, 171 p

Nielsen, E, 1976 The composition and origin of Wisconsinan tills in mainland Nova Scotia, Ph D thesis, Dalhousie University, Halifax, Nova Scotia, Nova Scotia Department of Mines and Energy, Thesis 277, 256 p

Nielsen, S H, Conradsen, K, Heinemeier, J, Knudsen, K L, Nielsen, H L, Rud, N, and Sveinbjornsdóttir, Á E, in press Radiocarbon dating of shells and foraminifera from the Skagen core, Denmark Evidence of reworking, 15th International Radiocarbon Conference, 1994

Nobles, L H, and Weertman, J, 1971 Influence of irregularities of the bed of an ice sheet on deposition rate of till, *in* R P Goldthwait, ed, Till a Symposium, Ohio State University Press, p 117-126

North American Commission on Stratigraphic Nomenclature, 1983 North American Stratigraphic Code, The American Association of Petroleum Geologists Bulletin, v 67, no 5, p 841-875

Nummedal D, and Swift, D ' P, 1987 Transgressive stratigraphy at sequence-bounding unconformities some principles derived from Holocene and Cretaceous examples, *in* D Nummedal, O H Pilkey, and J D Howard, eds, Sea-level Fluctuation and Coastal Evolution, Society of Economic Paleontologists and Mineralogists Special Publication No 41, p 241-260

Occhietti, S, 1989 Quaternary geology of St Lawrence Valley and adjacent Appalachian subregion, *in* R J Fulton, ed, Chapter 4 of Quaternary Geology of Canada and Greenland, Geological Survey of Canada, Geology of Canada no 1, p 350-389

Ogden, J G, III, 1987 Vegetational and climatic history of Nova Scotia 1 Radiocarbon-dated pollen profiles from Halifax, Nova Scotia, Canadian Journal of Botany, v 65, no 7, p 1482-1490

Oldale, R N, Williams, R S, Jr, and Colman, S M, 1990 Evidence against a Late Wisconsinan ice shelf in the Gulf of Maine, Quaternary Science Reviews, v 9, p 1-13

O'Reilly, G A , MacDonald, M A , Kontak, D J , and Corey, M C , 1992 Granite- and metasediment-hosted mineral deposits of southwestern Nova Scotia, Field Excursion C-3 Guidebook, Geological Association of Canada-Mineralogical Association of Canada Joint Annual Meeting Wolfville, Nova Scotia 1992, 91 p

Parent, M , and Dubois, J M M , 1990 Les depots glaciares et marins des ils de la madelaine (Quebec), temoins d'une englaciation rapide dans les appalaches septentrionales au Pleistocene Superieur, In Canadian Quaternary Association-American Quaternary Association, First Joint Meeting, Programme and Abstracts, p 28

Parrott, D R , Dodds, D J , King, L H , and Simpkin, P G , 1980 Measurement and evaluation of the acoustic reflectivity of the sea floor, Canadian Journal of Earth Sciences, v 17, p 722-737

Paterson, W S B , 1981 The physics of glaciers, Oxford, Pergamon Press, 250 p

Pe-Piper, G , Murphy, J B and Turner, D S , 1989 Petrology, geochemistry, and tectonic setting of some Carboniferous plutons of the eastern Cobequid hills, Atlantic Geology, v 25 p 37 49

Peltoniemi, H , 1985 Till lithology and glacial transport in Kuhmo eastern Finland, Boreas, v 14, p 67-74

Phillips, A C , Smith N D , and Powell, R D , 1991 Laminated sediments in prodeltaic deposits, Glacier Bay, Alaska, in Anderson, J B , and Ashley, G M , eds , Glacial Marine Sedimentation Paleoclimatic significance, Boulder Colorado, Geological Society of America Special Paper, 261, p 51-60

Piper, D J W , 1988 Glaciomarine sedimentation on the continental shelf off eastern Canada, Geoscience Canada, v 15 p 23-28

Piper, D I W , 1991 Surficial geology and physical properties 7 paleo-oceanography and paleo-glaciology, in East Coast Atlas Series Scotian Shelf, Atlantic Geoscience Centre, Geological Survey of Canada p 123

Piper D J W , and Fehr, S D , 1991 Radiocarbon chronology of Late Quaternary sections on the inner and middle Scotian Shelf south of Nova Scotia, in Current Research, Part E, Geological Survey of Canada, Paper 91-1E, p 321-325

Piper, D J W , Letson, J R J , Delure, A M , and Barrie, C Q , 1983 Sediment accumulation in low sedimentation, wave dominated, glaciated inlets, Sedimentary Geology, v 36 , p 195-215

Piper, D J W, Mudie, P J, Aksu, A E, and Skene, K I, 1994 A 1 Ma record of sediment flux south of the Grand Banks used to infer the development of glaciatioi in Southeastern Canada, Quaternary Science Reviews, v 13, p 23-27

Piper, D J W, Mudie, P J, Fader, G B, Josenhans, H W, MacLean, B, and Vilks, G, 1990 Quaternary Geology, Chapter 10, *in* M J Keen and G L Williams, eds, Geology of the Continental Margin of Eastern Canada, Geological Survey of Canada, Geology of Canada, no 2, p 475-607

Piper, D J W, Mudie, P J, Letson, J R J, Barnes, N E, and Iuliucci, R J, 1986 The marine geology of the inner Scotian Shelf off the south shore, Nova Scotia, Geological Survey of Canada, Paper 85-19, 65 p

Powell, R D, 1984 Glacimarine processes and inductive lithofacies modelling of ice shelf and tidewater glacier sediments based on Quaternary examples, Marine Geology, v 57, p 1-52

Powell, R. D, and Molnia, B F, 1989 Glacimarine sedimentary processes, facies and morphology of the south-southeast Alaska shelf and fjords, Marine Geology, v 85, p 359-390

Powell, R D, 1990 Glacimarine processes at grounding-line fans and their growth to ice contact deltas, *in* Dowdeswell, J A, and Scourse, J D, eds, Glaciomarine Environments Processes and Sediments, Geological Society of London, Special Publication no 53, p 53-73

Powell, R D, 1991 Grounding line systems as second-order controls on fluctuations of tidewater termini of temperate glaciers, *in* J B Anderson, and G M Ashley, eds, Glacial Marine Sedimentation, Paleoclimatic Significance Geological Society of America, Special Paper 261, p 75-93

Powers, M C, 1953 A new roundness scale for sedimentary particles, Journal of Sedimentary Petrology, v 23, p 117-119

Prest, V K, and Grant, D R, 1969 Retreat of the last ice sheet from the Maritime Provinces - Gulf of St Lawrence region, Geological Survey of Canada, Paper 69-33, 15 p

Prest, V K, 1973 Surficial deposits of Prince Edward Island, Geological Survey of Canada, Map 1366A

Prest, V K, 1983 Canada's heritage of glacial features, Geological Survey of Canada, Miscellaneous Report 28, 89 p

Prest, V K , and Nielsen, E , 1987 The Laurentide ice sheet and long distance transport, *in* R Kujansuu and M , Saarnisto, eds , INQUA Till Symposium, Finland 1985, Geological Survey of Finland, Special Paper 3, p 91-102

Prest, V K , Grant, D R , MacNeill, R H , Brooks, I A , Borns, H W , Ogden, J G , III, Jones, J F , Lin, C L , Hennigar, T W , and Parsons, M L , 1972 Quaternary geology, geomorphology and hydrogeology of the Atlantic Provinces, 24th International Geological Congress, Excursion Guidebook, A61-C61, 79 p

Prest, W H , 1896 Glacial succession in central Lunenburg, Nova Scotia, Proceedings and Transactions of the Nova Scotian Institute of Science, Halifax, v 9, session 1895-96, p 158-170

Pronk, A G , Bobrowsky, P T , and Parkhill, M A , 1989 An interpretation of the late Quaternary glacial flow indicators in the Baie des Chaleurs region, northern New Brunswick, Geographie physique et Quaternaire, v 43, no 2, p 179-190

Purdy, C A , 1951 Pleistocene geology of the Kentville area, Nova Scotia, M Sc thesis, Acadia University, Wolfville, Nova Scotia, 51 p

Quinlan, G , and Beaumont, C , 1981 A comparison of observed and theoretical relative sea-levels in Atlantic Canada, Canadian Journal of Earth Sciences, v 18, p 1146-1163

Quinlan G and Beaumont, C , 1982 The deglaciation of Atlantic Canada as reconstructed from the postglacial relative sea-level record, Canadian Journal of Earth Sciences, v 19, no 12, p 2232-2246

Railton, J G , 1972 Vegetation and climatic history of southwestern Nova Scotia in relation to a South Mountain Ice Cap, unpublished Ph D dissertation, Dalhousie University, Halifax, Nova Scotia

Rampton, V N , Gauthier, R C Thibault, J , and Seaman, A A , 1984 Quaternary geology of New Brunswick, Geological Survey of Canada, Memoir 416 77 p

Rappol, M , 1989 Glacial history of northwestern New Brunswick, Geographie phys que et Quaternaire, v 43, no 2, p 191-206

Reeh, N , 1968 On the calving of ice from floating glaciers and ice shelves, Journal of Glaciology, v 24, p 177-212

Rind, D , Peteet, D , Broecker, W , McIntyre, A , and Ruddiman, W , 1986 The impact of cold North Atlantic sea surface temperatures on climate Implications for the Younger Dryas cooling (11-10k), Climate Dynamics, v 1, p 3-33

Rust, B R , and Romanelli, R , 1975 Late Quaternary subaqueous outwash deposits near Ottawa, Canada, *in* A V Jopling and B C MacDonald, eds , Glaciofluvial and Glaciolacustrine Sedimentation, Society of Economic Paleontologists and Mineralogists, Special Publication no 23, p 177-192

Roland, A E , 1982 Geological background and physiography of Nova Scotia, Ford Publishing Company, Halifax, Nova Scotia, 311 p

Sanford, B V , Fader, G B J , and Moir, P N (compilers), 1991 Regional geology and geophysics 8 Bedrock geology, *in* East Coast Basin Atlas Series, Scotian Shelf, Atlantic Geoscience Centre, Geological Survey of Canada, p 23

Savit, C H , 1983 Acquisition of seismic data at sea, *in* R A Geyer, ed , CRC Handbook of Geophysical Exploration at Sea, CRC Press, Boca Raton, p 69-76

Schenk, P E , 1971 Southeastern Atlantic Canada, northwestern Africa, and continental drift, Canadian Journal of Earth Sciences, v 8, p 1218-1251

Schilling, D H , and Hollin, J T , 1981 Numerical recontructions of valley glaciers and small ice caps, *in* G H Denton and T J Hughes, eds , The Last Great Ice Sheets, New York, John Wiley and Sons, p 207-221

Schnitker, D , 1974 Late Glacial to Recent paleoceanography of the Gulf of Maine, *in* 1st International Symposium on Continental Margin Benthonic Foraminifera, Part B Paleoecology and Biostratigraphy, Maritimes Sediments, Special Publication 1 , p 385-392

Schnikter, D , 1987 Late Glacial paleoceanography of the Gulf of Maine, abstract, International Union of Quaternary Research, 12 International Congress, Ottawa, Canada, Programme and Abstracts, p 260

Schnikter, D , and Jorgensen, J , 1986 Late Glacial and Holocene diatom successions in the Gulf of Maine Response to climatologic and oceanographic Change, *in* D Garbary and G South, eds , Evolutionary Biogeography of the Marine Algae of the North Atlantic, NATO ASI series Vol G-22

Scott, D , 1977 Distributions and population dynamics of marsh-estuarine foraminifera with implications to relocating Holocene sea-levels, unpublished Ph D Dissertation, Dalhousie University, Halifax, 252 p

Scott, D B , Boyd, R , and Medioli, F S , 1987a Relative sea-level changes in Atlantic Canada Observed level and sedimentological changes vs theoretical models, *in* Nummedal, O H , Pilkey, Jr , and J D Howard, eds , Sea-Level Fluctuations and Coastal Evolution, SEPM Special Publication 41, p 88-95

Scott, D B , Boyd, R , Douma, M , Medioli, F S , Yuill, Y , Leavitt, E , and Lewis, C F M , 1989 Holocene relative sea -level changes and Quaternary glacial events on a continental shelf edge Sable Island Bank, *in* D B Scott, P A Pirazzoli, and C A , Honig eds , Late Quaternary Sea-Level Correlations and Applications, p 105-120

Scott, D B , and Medioli, F S , 1978 Vertical zonations of marsh foraminifera as accurate indicators of former sea levels, Nature, v 272, p 528-531

Scott, D B , and Medioli, F S , 1980a Post-Glacial emergence curves in the Maritimes determined from marine sediment in raised basins, *in* Proceedings, Canadian Coastal Conference, 1980, p 428-446

Scott, D B , and Medioli, F S , 1980b Quantitative studies of marsh Foraminiferal distributions in Nova Scotia, implications for sea-level studies, Cushman Foundation of Foraminiferal Research, Special Publication, no 17, 58 p

Scott, D B , and Medioli, F S , 1982 Micropaleontological documentation for early Holocene fall of relative sea-level on the Atlantic coast of Nova Scotia, Geology, v 10, no 5, p 278-281

Scott, D B , and Medioli, F S , 1988 Tertiary-Cretaceous reworked microfossils in Pleistocene Glacial-Marine sediments An index to glacial activity, Marine Geology, v 84, p 31-41

Scott, D B , Medioli, F S , and Miller, A A L , 1987b Holocene sea-levels, paleooceanography and late glacial ice configuration near the Northumberland Strait, Maritime Provinces, Canadian Journal of Earth Sciences, v 24, p 668-675

Scott, D B , Mudie, P J , Vilks, G , and Younger, D C , 1984 Latest Pleistocene-Holocene paleoceanographic trends on the continental margin of Eastern Canada foraminiferal, dinoflagellate and pollen evidence, Marine Micropaleontology, v 9 , p 181-218

Seidenkrantz, M S , 1993 Benthic foraminiferal and stable isotope evidence for a "Younger Dryas-style" cold spell at the Saalian-Eemian transition, Denmark , Palaeogeography, Palaeoclimatology, Palaeoecology, v 102, p 103-120

Shepard, F P , 1930 Fundian faults or Fundian glaciers, Geological Society of America Bulletin, v 41, p 659-674

Shilts, W W , 1976 Glacial till and mineral exploration, *in* R F Legget, ed , Glacial Till, Royal Society of Canada, Special Publication no 12, p 205-224

Shilts, W W , 1978 Detailed sedimentological study of till sheets in a stratigraphic section, Samson River, Quebec, Geological Survey of Canada, Bulletin 285, 29 p

Shinn, R A , and Barron, E J , 1989 Climate sensitivity to continental ice sheet size and configuration, Journal of Climate, v 2, p 1517-1537

Shipp, R C , Belknap, D F , and Kelley, J T , 1989 A submerged shoreline on the inner continental shelf of the western Gulf of Maine, *in* R D Tucker, and R G Marvinney, eds , Studies in Maine Geology, Volume 5, Maine Geological Survey, p 11-28

Shipp, R C , Belknap, D F , and Kelley, J T , 1991 Seismic stratigraphic evidence and geomorphic evidence for a post-glacial sea-level lowstand in the northern Gulf of Maine, Journal of Coastal Research, v 7, no 2, p 341-364

Smith, G W , and Hunter, L E , 1989 Late Wisconsinan deglaciation of coastal Maine *in* R D Tucker and R G , Marvinney,eds , Studies in Maine Geology, Volume 6, Quaternary Geology, p 13-32

Smith, G W , 1982 End moraines and the pattern of the last ice retreat from central and south coastal Maine, *in* G J , Larsen, and B D Stone, eds , Late Wisconsinan Glaciation of New England, Kendall Hunt Publishers, Dubuque, Iowa, p 195-210

Souchen, D W , 1986 Late Pleistocene-Holocene benthonic foraminifera from the northern Scotian Shelf, B Sc hons thesis, Dalhousie University, Halifax, 57 p

Stea, R R , 1982 The properties, correlation and interpretation of Pleistocene sediments in central Nova Scotia, M Sc thesis, Dalhousie University, Halifax, Nova Scotia, 215 p

Stea, R R , 1983 Surficial geology of the western Part of Cumberland County, Nova Scotia, *in* Current Research, Part A, Geological Survey of Canada, Paper 83-1A, p 197-202

Stea, R R , 1984 The sequence of glacier movements in northern mainland Nova Scotia determined through mapping and till provenance studies, *in* W C Mahaney, ed , Correlation of Quaternary Chronologies, Geo Books, Norwich England, p 279-297

Stea, R R , 1991 Clasts dispersal in the Laurentian Channel off Cape Breton Island and mainland Nova Scotia Test of a glacial dispersal model, Dalhousie University, Centre of Marine Geology, technical report no 13, 28 p

Stea, R R , 1994, Relict and palimpsest glacial landforms in Nova Scotia, Canada, *in* W P Warren and D G Groot, eds , Formation and Deformation of Glacial Deposits, Balkema, Rotterdam, p 141-158

Stea, R R , Boyd, R , Fader, G B J , Courtney, R C , Scott, D B , and Pecore, S S , 1994 Morphology and seismic stratigraphy of the inner continental shelf off Nova Scotia, Canada Evidence for a -65 m lowstand between 11,650 and 11,250 ^{14}C yr B P , Marine Geology, v 117, p 135-154

Stea, R R , and Brown, Y , 1989 Variation in drumlin orientation, form and stratigraphy relating to successive ice flows in southern and central Nova Scotia, Sedimentary Geology, v 62, p 223-240

Stea R R , Conley, H , and Brown, Y , (compilers) 1992a Surficial geology of the Province of Nova Scotia, Nova Scotia Department of Natural Resources, Map 92-1, Scale 1 500 000

Stea, R R , and Fader, G B J , 1993 Morphology and depositional facies, inner Scotian Shelf near Halifax Harbour Implications for Late-Glacial sea-level, *in* Program with Abstracts, Atlantic Geoscience Society , Annual Colloqium and Symposia, Halifax, Nova Scotia, 1993, p 27-28

Stea, R R , Fader, G B J , and Boyd, R , 1992b Quaternary seismic stratigraphy of the inner shelf region, Eastern Shore, Nova Scotia, *in* Current Research, Part D, Geological Survey of Canada, Paper 92-1D, p 179-187

Stea, R R , and Finck, P W , 1984 Patterns of glacier movement in Cumberland, Colchester, Hants, and Pictou Counties, northern Nova Scotia, *in* Current Research, Part A, Geological Survey of Canada, Paper 84-1A, p 477-484

Stea, R R , Finck, P W , and Wightman, D M , 1986 Quaternary geology and till geochemistry of the western part of Cumberland County, Nova Scotia (sheet 9), Geological Survey of Canada, Paper 85-17, 58 p

Stea, R R , and Fowler, J H , 1979 Minor and trace-element variations in Wisconsinan tills, Eastern Shore Region, Nova Scotia, Nova Scotia Department of Mines and Energy, Paper 79-4, 30 p

Stea R R , and Mott, R J , 1989 Deglaciation environments and evidence for glaciers of Younger Dryas age in Nova Scotia, Canada, Boreas, v 18, p 169-187

Stea, R R , and Mott, R J , 1990 Quaternary Geology of Nova Scotia Guidebook for 53rd annual Friends of the Pleistocene Field Excursion Nova Scotia Department of Mines and Energy, Open File Report 90-008, 85 p

Stea, R R , and Mott, R J , 1992 Sedimentation response to climate change in Maritime Canada during the Younger Dryas Chronozone, *in* Abstracts volume, Wolfville '92, Geological Association of Canada-Mineralogical Association of Canada Joint Annual Meeting, p A66

Stea, R R , Mott, R J , Belknap, D F , and Radtke, U , 1992d The Pre-Late Wisconsinan Chronology of Nova Scotia, Canada, *in* P U Clark and P D Lea, eds , The Last Interglaciation/Glaciation Transition in North America, Geological Society of America, Special Paper 270, p 185-206

Stea, R R , and Murphy, B , 1994 The source of erratics in Lawrencetown Till along the Eastern Shore of Nova Scotia Petrology and Whole-rock geochemistry, *in* Mines and Minerals Branch, Report of Activities 1993, Nova Scotia Department of Natural Resources, Mines and Energy Branches Report 94-1, p 93-103

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

Stea, R R , and Wightman, D M , 1987 Age of the Five Islands Formation, Nova Scotia, and the deglaciation of the Bay of Fundy, Quaternary Research, v 27, p 211-219

Stea, R R , Scott, D B , Kelley, J T , Kelley, A R , Wightman, D M , Finck, P W , Seaman, A , Nicks, L , Bleakney, S , Boyd, R and Douma, M , 1987 Quaternary Glaciations, Geomorphology and Sea-level changes Bay of Fundy Region, NATO Advanced Course on Sea-level Correlations and Applications, Halifax, Nova Scotia, Field Trip Guidebook, 79 p

Stea, R R , Turner, R G , Finck, P W , and Graves, R M , 1989 Glacial dispersal in Nova Scotia a zonal concept, *in* R N W DiLabio and W B Coker, eds , Drift Prospecting, Geological Survey of Canada, Paper 89-20, p 155-169

Sugden, D E , and John, B S , 1976 Glaciers and landscape A geomorphological approach, Edward Arnold, London, 376 p

Suter, J R , Berryhill, H L , Jr , and Penland S , 1987 Late Quaternary sea-level fluctuations and depositional sequences, southwest Louisiana continental shelf, *in* D Nummedal, O H Pilkey, and J D Howard, eds , Sea-level Fluctuation and Coastal Evolution, Society of Economic Paleontologists and Mineralogists special publication, no 41, p 199-219

Swayne, L E , 1952 The Pleistocene geology of the Digby area, Nova Scotia, M Sc thesis, Acadia University, Wolfville, Nova Scotia, 56 p

Swift, D J P , and Borns, H W , Jr , 1967 A raised fluviomarine outwash terrace, north shore of the Minas Basin, Nova Scotia, Journal of Geology, v 75, no 6, p 693-710

Sylwester, R L , 1983 Single-channel, high resolution, seismic reflection profiling A review of the fundamentals and intrumentation, *in* R A Geyer, ed , CRC Handbook of Geophysical

Exploration at Sea, CRC Press, Boca Raton, p 77-124

Syvitski, J P M , 1991 Towards an understanding of sediment deposition on glaciated continental shelves, Continental Shelf Research, v 11, nos , 8-10, p 897-937

Teller, J T , and Fenton, M M , 1980 Late Wisconsinan glacial stratigraphy and history of Southeastern Manitoba, Canadian Journal of Earth Sciences, v 17, no 1, p 19-35

Thomas, R H , 1979 Ice shelves a review, Journal of Glaciology, v 24, no 90 , p 273-285

Trenhaile, A S , 1987 The development of shore platforms in high latitudes, *in* D E Smith and A G Dawson, eds , Shorelines and Isostasy, Institute of British Geographers Special Publication No 16, p 77-93

Tushingham, A M , and Peltier, W R , Ice 3G A new global model of Late Pleistocene deglaciation based upon geophysical predictions of Post-Glacial relative sea-level change, Journal of Geophysical Research, v 96, p 4497-4523

Turner, R R , and Stea, R R , 1987 The Garden of Eden dispersal train, *in* J L Bates and D R MacDonald, eds , Mines and Mineral Branch Report of Activities, p 165-169

Vail, P R , Mitchum, R M , Todd, R G , Widmier, J M S , Thompson III, Sangree, J B , Bubb, J N , and Hatelid, W G , 1977 Seismic stratigraphy and global changes in sea level, *in* C E Payton, ed , Seismic Stratigraphy-Applications to Hydrocarbon Exploration, Association of Petroleum Geologists, Memoir 26, 516 p

Vilks, G , 1981 Late glacial-postglacial foraminiferal boundary in sediments of Eastern Canada, Denmark and Norway, Geoscience Canada, v 8, no 2, p 48-55

Von Haugwitz W R , and Wong, H K , 1993 Multiple Pleistocene ice advances into the Skagerrak A detailed seismic stratigraphy from high resolution seismic profiles, Marine Geology, v 111, p 189-207

Vorren, T O , Hald, M , Edvardsen, M , and Handsen-Lind, O-W , 1983 Glacigenic sediments and sedimentary environments on continental shelves General principles with a case study from the Norwegian Shelf, *in* J Ehlers, ed , Glacial Deposits in North-West Europe, Balkema, Rotterdam, p 61-73

Vorren, T O , Lebesbye, E , and Larsen, K B , 1990 Geometry and genesis of the glacigenic sediments in the southern Barents Sea, *in* Dowdeswell, J A , and Scourse, J D , eds , Glaciomarine Environments Processes and Sediments, Geological Society of London, Special Publication no 53, p 269-288

Wade, J A , and MacLean, B C , 1990 The geology of the southeast margin of Canada, Chapter 5 *in* M J Keen and G L Williams, eds ,Geology of the Continental Margin of Eastern Canada, Geological Survey of Canada, Geology of Canada, no 2, p 167-238

Walker, R G , 1992 Facies, facies models and modern stratigraphic concepts, *in* R G Walker and N P James, eds , Facies Models Response to Sea-Level Change, Geological Association of Canada, Special Publication p 1- 14

Wang, Y , and Piper, D J W , 1982 Dynamic geomorphology of the drumlin coast of southeast Cape Breton Island, Maritime Sediments and Atlantic Geology, v 18, p 1-27

Weertman, J , 1961 Equilibrium profile of ice caps, Journal of Glaciology, v 3 p 33-38

Weertman, J , 1966 Effect of a basal water layer on the dimensions of ice sheets, Journal of Glaciology, v , 6, p 191-207

Wightman, D M , 1980 Late Pleistoce ie glaciofluvial and glaciomarine sediments on the north side of the Minas Basin, Nova Scotia, Ph D thesis, Dalhousie University, Halifax, Nova Scotia, Nova Scotia Department of Mines and Energy, Thesis 405, 426 p

Wightman, D M , and Cooke, H B S , 1978 Post-glacial emergence in Atlantic Canada, Geoscience Canada, v 5, p 61-65

Williams, G L , Fyffe, L R , Wardle, R J Colman-Sadd, S P , Boehner, R C , and Watt, J A , 1985 Lexicon of Canadian Stratigraphy, Volume VI, Atlantic Region, Canadian Society of Petroleum Geologists, 572 p

Williams, H , 1978 Tectonic lithofacies map of the Appalachian Orogen Memorial University of Newfoundland, Map 1, scale 1 1 000 000

Winograd, I J , Coplen, T B , Landwehr, J M , Riggs, A C , Lud·vig, K R , Szabo, B J , Kolesar P T , and Revesz, K M , 1992 Continuous 500,000-year climate record from vein calcite in Devils Hole, Nevada, Science, v 258 p 255-260

Zilliacus, H , 1989 Genesis of De Geer moraines in Finland, Sedimentary Geology, v 62, p 309-317

Bathymetry (m) — 70 —

SCALE (km)

0   2.5   5.0

1:80000

44-45N

Borgles Island

Baltee

Tangier I

Cable I

Wolfee Island

30

30

30

30

30

30

30

50

MAP 2

LEGEND

GEOLOGICAL UNITS

VALLEY FILL

SADDLE FILL

BASIN FILL (LAHAVE CLAY)

ERODED BASIN FILL
(OUTCROPPING EMERALD SILT)

ASYMMETRICAL MORAINES

SYMMETRICAL MORAINES

HUMMOCKY MORAINES

TILL-TONGUE MORAINES

BEDROCK
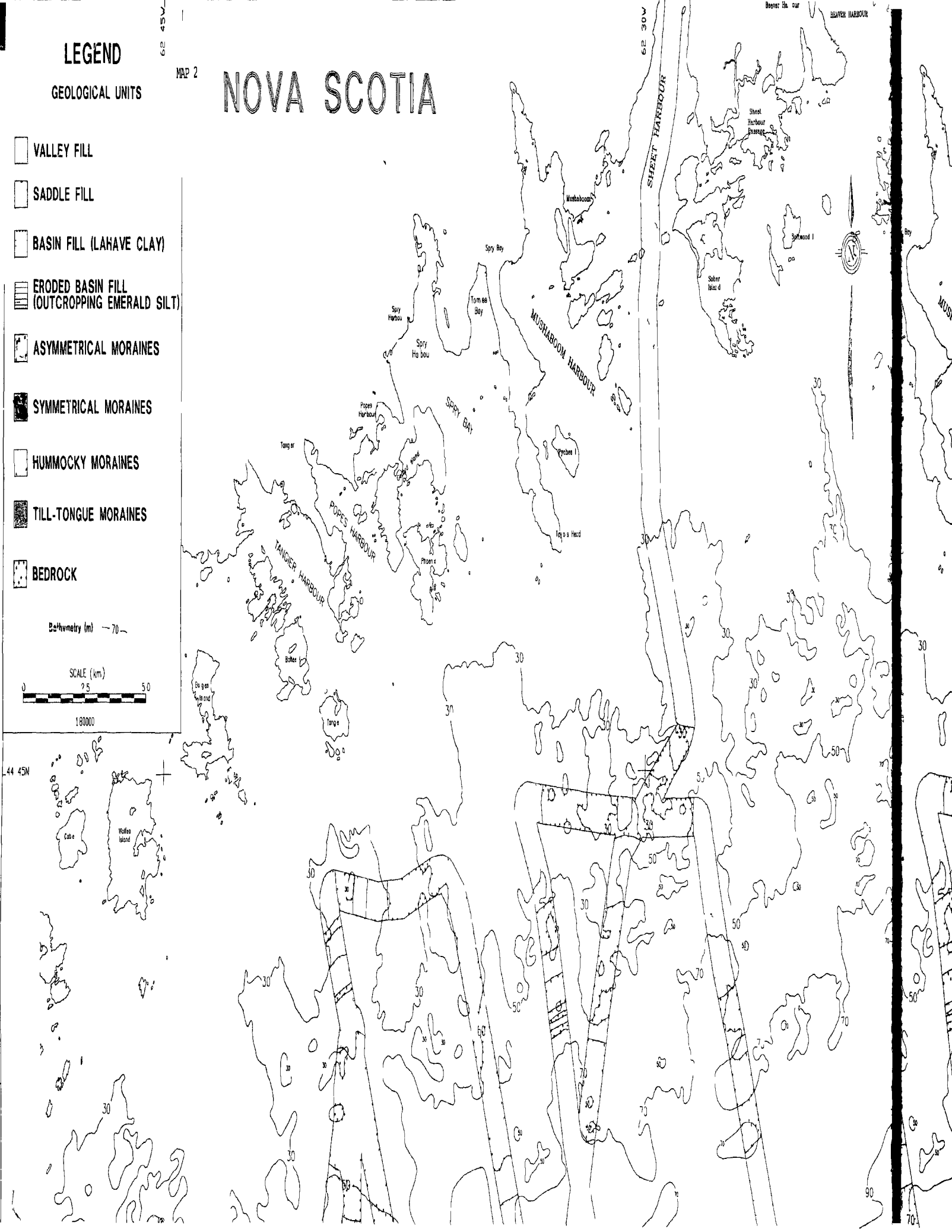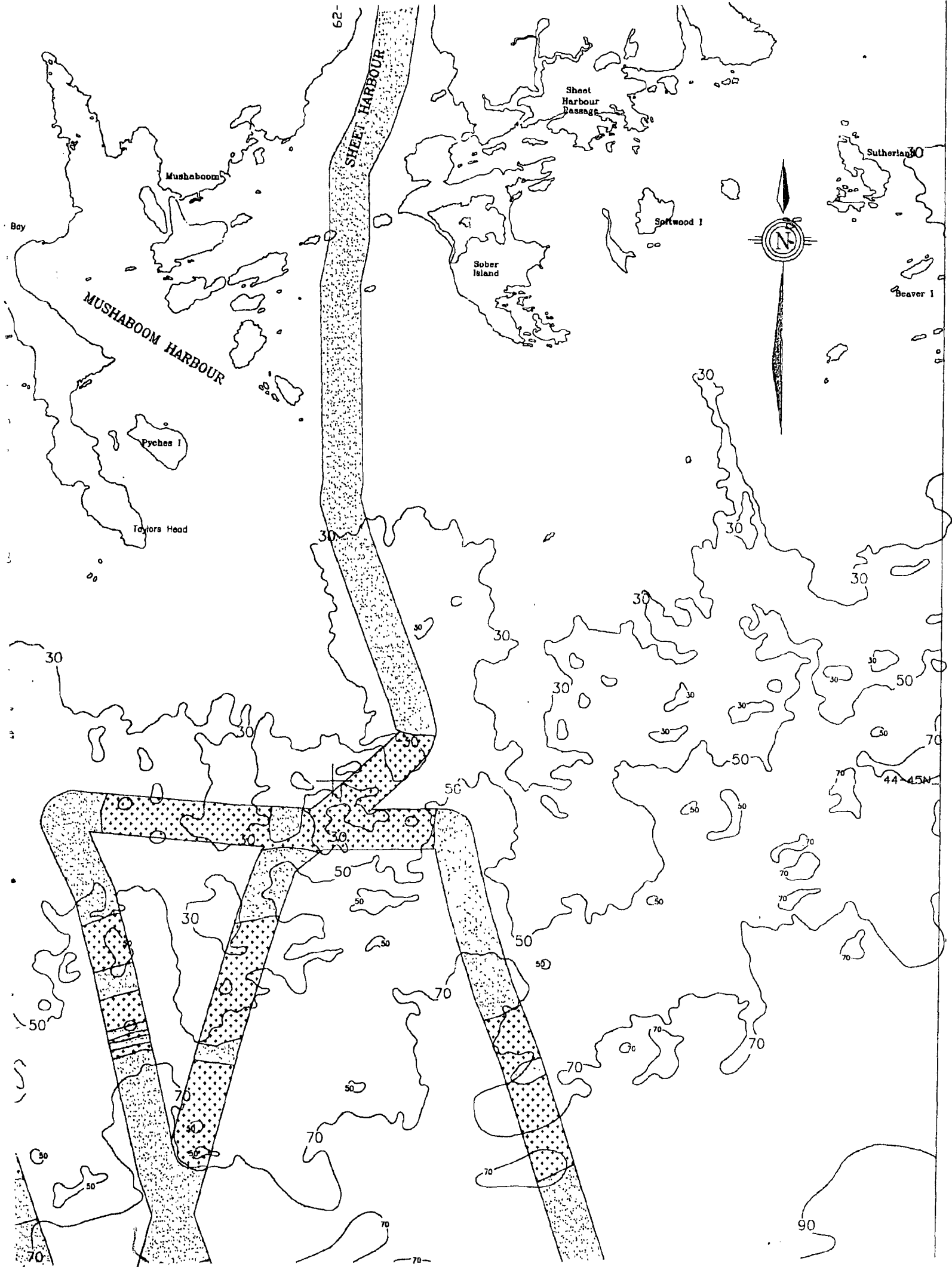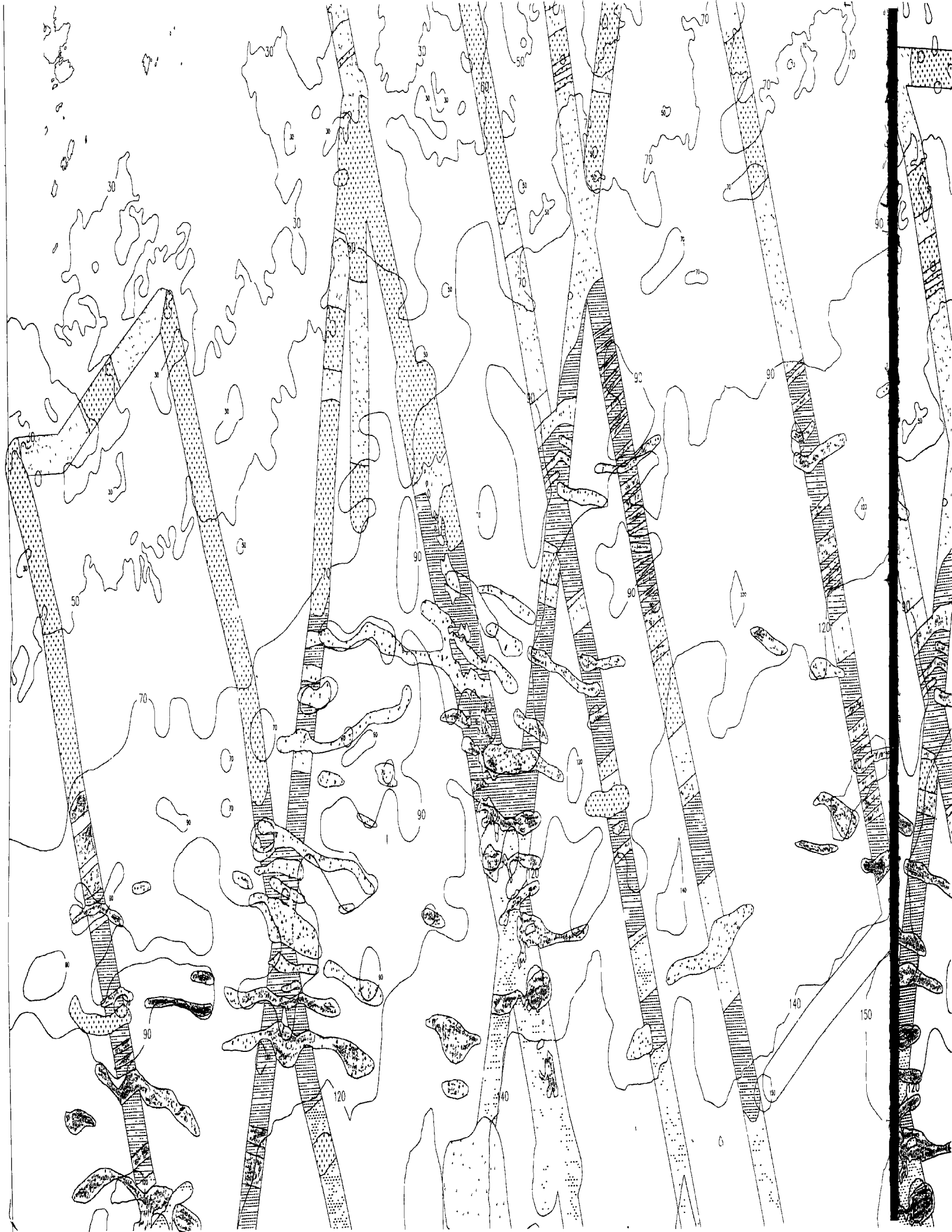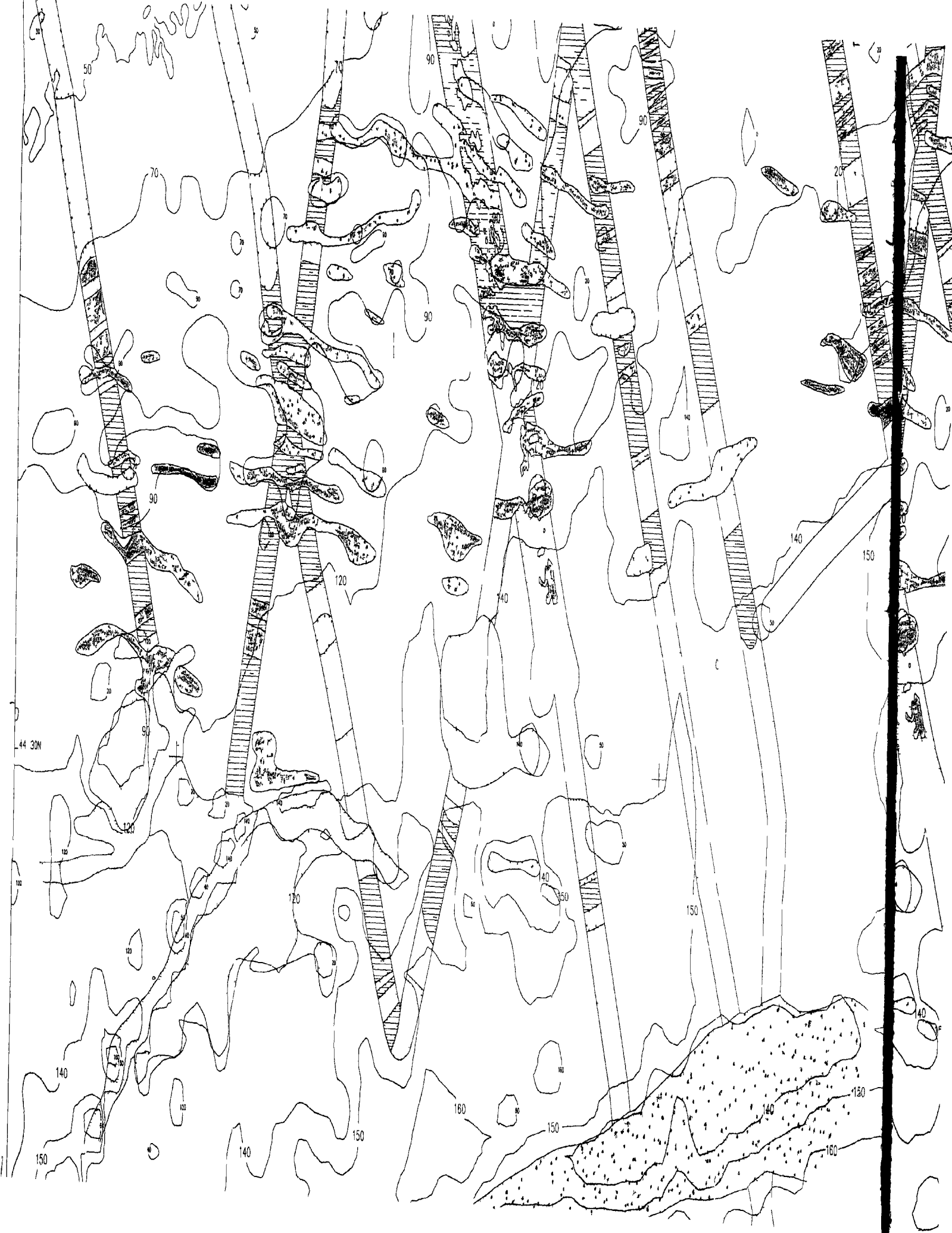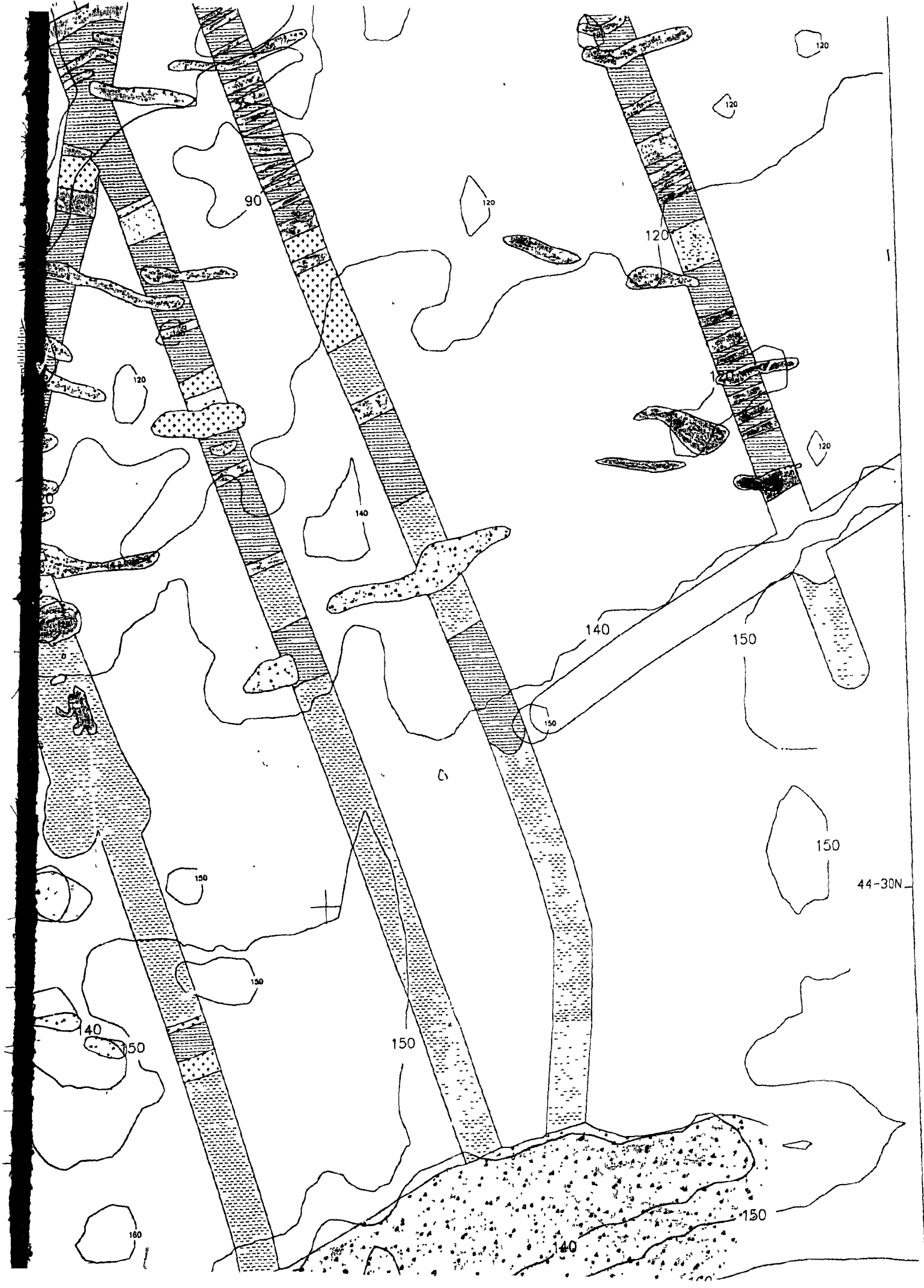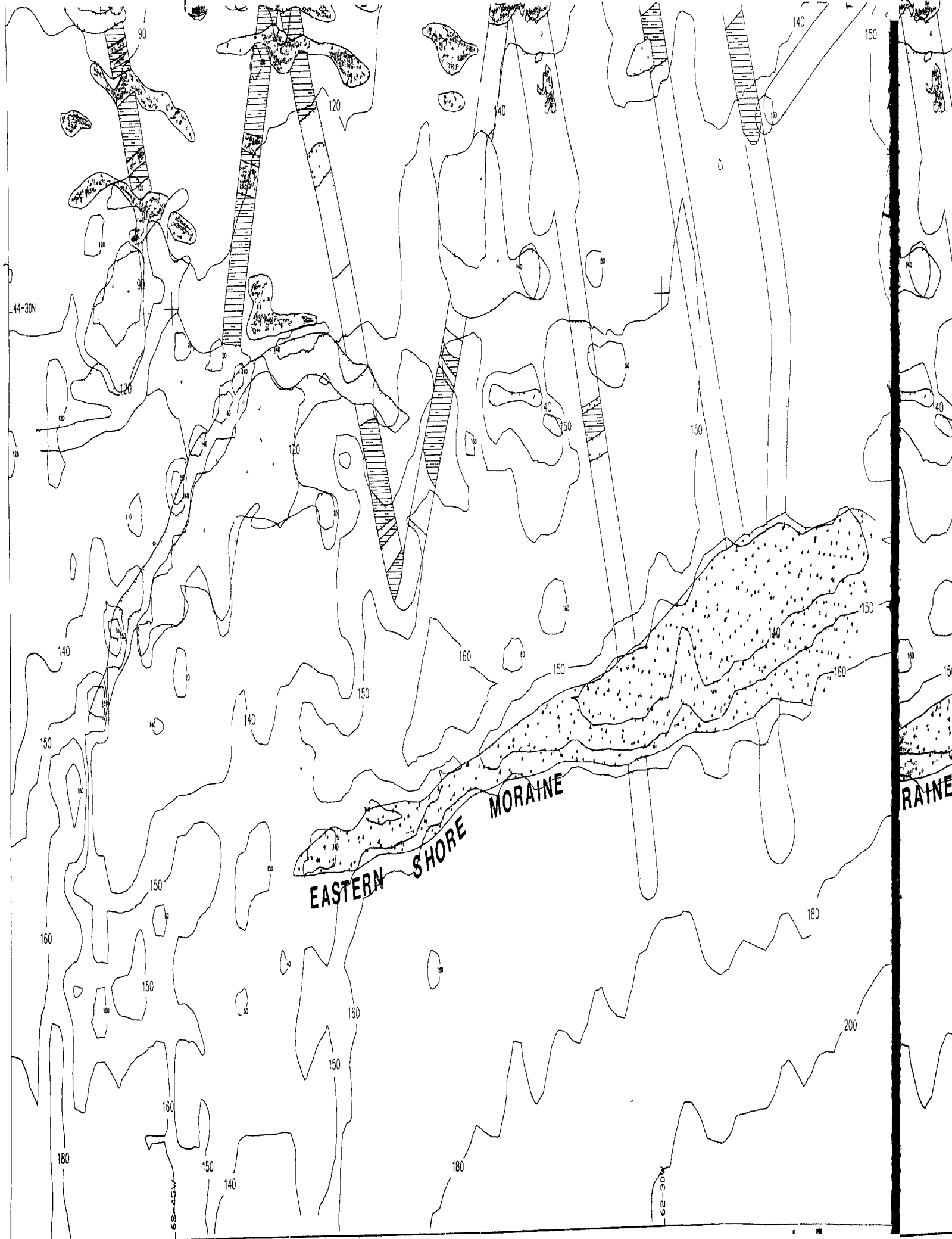
Bathymetry (m) — 70 —

SCALE (km)
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1 80000

NOVA SCOTIA

MUSHABOOM HARBOUR

SHEET HARBOUR

Mushaboom

Bay

Pyches I

Taylors Head

Sheet
Harbour
Passage

Softwood I

Sober
Island

Sutherland

Beaver I

N

62

30

30

30

30

30

30

30

30

30

30

30

50

50

50

50

70

44 45N

50

30

30

30

30

30

50

50

50

70

70

70

70

50

70

70

70

70

90

70

70

90

120

140

44-30N

EASTERN SHORE MORAINE

RAINE

150

160

180

200

62-45W

62-30W

140

150

150

44-30N

150

150

50

40

150

160

140

160

150

160

150

RAINE

180

200

62-30W
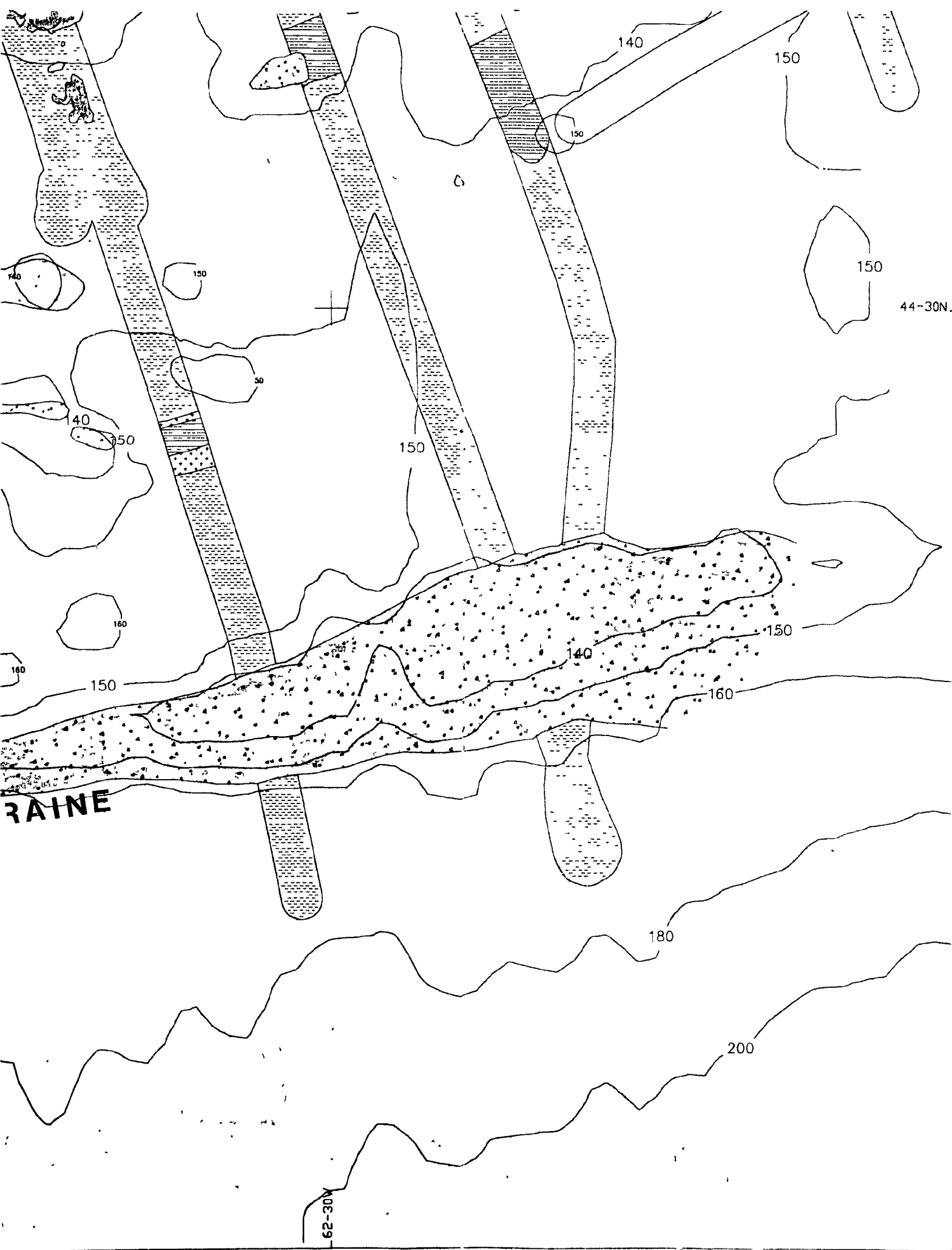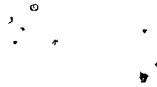
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NBS 1010a ANSI/ISO #2 EQUIVALENT
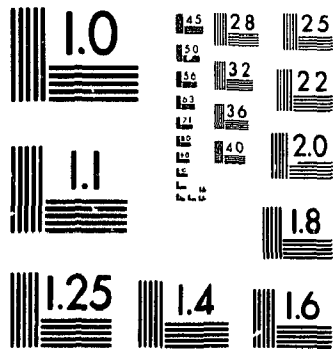
PRECISION^{SM} RESOLUTION TARGETS

ADDITIONAL SOURCES OF GEOLOGICAL INFORMATION

Alcock, P.W. 1984. A sedimentologic and stratigraphic study of Wisconsin tills in an area of the Cobequid Highlands north western Nova Scotia. unpublished M Sc thesis. University of Toronto 255 p.

Anderson, A.R. and Broughm, W.A. 1988. Evaluation of Nova Scotia's peatland resources. Nova Scotia Department of Mines and Energy Bulletin no. 6.

Blake, W. Jr. 1982. Geological Survey of Canada radiocarbon dates XII. Geological Survey of Canada Paper 82.7. 22 p.

Blake, W. Jr. 1984. Geological Survey of Canada radiocarbon dates XIV. Geological Survey of Canada Paper 84.7. 35 p.

Borns, H.W. 1966. The geography of paleo-Indian occupation in Nova Scotia. Quaternaria v. 6 p. 49 57.

Cameron, H.L. 1961. Glacial geology and the soils of Nova Scotia. in Soils in Canada ed. R.F. Leggett. Royal Society of Canada Special Publication no. 3. p. 109-114.

Cann, D.B. and Hilchey, J.D. 1954. Soil survey of Antigonish County Nova Scotia. Nova Scotia Soil Survey Report no. 6. 54 p.

Cann, D.B. and Hilchey, J.D. 1958. Soil Survey of Lunenburg County Nova Scotia. Nova Scotia Soil Survey Report no. 7. 48 p.

Cann, D.B. and Hilchey, J.D. 1959. Soil Survey of Queens County Nova Scotia. Nova Scotia Soil Survey Report no. 8. 48 p.

Cann, D.B. Hilchey, J.D. and Smith, G.R. 1954. Soil Survey of Hants County Nova Scotia. Nova Scotia Soil Survey Report no. 5. 65 p.

Cann, D.B. MacDougall, J.I. and Hilchey, J.D. 1963. Soil survey of Cape Breton Island. Nova Scotia Nova Scotia Soil Survey Report no. 12. 85 p.

Cann, D.B. and Wicklund, R.E. 1950. Soil survey of Pictou County Nova Scotia. Nova Scotia Soil Survey Report no. 4. 66 p.

Chalmers, R. 1895. Report on the surface geology of eastern New Brunswick northwestern Nova Scotia and a portion of Prince Edward Island. Geological Survey of Canada Annual Report 1894 v.7 no. 7 pt.m. 144 p.

Clark, A.H. Grant, D.R. and MacPherson, E. 1972. The relationship of Atractodon stonei (Pilsbry (Mollusca Buccinidae) to Pleistocene stratigraphy and paleoecology of southwestern Nova Scotia. Canadian Journal of Earth Sciences v. 9 p. 1030-1038.

Cornish, R.A. 1980. Report on geology and overburden drilling base metals Noel Lake Hants County Nova Scotia. Shell Canada Resources Limited. Nova Scotia Department of Mines and Energy Assessment Report 11E/05A 07-1-29(01).

de Vernal, A. 1983. Paleoenvironnements du Wisconsinien par la palynologie dans la region de la Baie Saint Laurent, Ile-du-Cap-Breton. Thèse de Maitrise. Universite de Montreal. Montreal Quebec 97 p.

de Vernal, A. Causse, C. Hillaire Marcel, C. Mott, R.J. and Occhietti, S. 1986. Paleostratigraphy and Th/U ages of upper Pleistocene interglacial and interstadial deposits on Cape Breton Island, eastern Canada. Geology v. 14. 554 557.

de Vernal, A. Richard, P.J.H. and Occhietti, S. 1983. Palynologie et paleoenvironnements du Wisconsinien de la region de la Baie Saint Laurent, Ile-du-Cap-Breton. Géographie physique et Quaternaire v. 37 p. 307 322.

Dickie, G.B. 1979. Report on geological soil and radon geochemical surveys EM magnetic airborne and ground radiometric surveys uranium Lambs Lake Annapolis County Nova Scotia. Shell Canada Resources Limited. Nova Scotia Department of Mines and Energy Assessment Report 21A/11C 54 A 74(02).

Ferguson, S.A. 1983. Geological map of the Hantsport area Nova Scotia. Nova Scotia Department of Mines and Energy Map 83.1. scale 1:50 000.

Finck, P.W. and Graves, R.M. 1984. Glacial Geology of Halifax and Sambro (NTS sheets 11D/12 and 11D/05). Nova Scotia. Nova Scotia Department of Mines and Energy Map 87.2. scale 1:50 000.

Finck, P.W. and Graves, R.M. 1987. Glacial Geology of Mount Uniacke (NTS sheet 11D/13 west half). Nova Scotia. Nova Scotia Department of Mines and Energy Map 87.1. scale 1:50 000.

Fowler, J.H. 1979. Sand and gravel occurrences in Nova Scotia. Nova Scotia Department of Mines and Energy Open File Report 378. 1:50 000 scale maps.

Fowler, J.H. and Dickie, G.B. 1978. Sand and gravel resources of Pictou County Nova Scotia. Nova

Prest, V.K. 1972. Quaternary geology of Canada. in Geology and Economic Minerals of Canada ed. R.J.W. Douglas. Geological Survey of Canada. Economic Geology Report no. 1 p. 676 764.

1977. General stratigraphic framework of the Quaternary in eastern Canada. Geographie physique et Quaternaire v. 31 p. 7-14.

Prest, V.K. and Grant, D.R.G. 1969. Retreat of the last ice sheet from the Maritime Provinces. Gulf of St. Lawrence region. Geological Survey of Canada Paper 69-33. 15 p.

Prest, V.K. Grant, D.R. MacNeil, R.H. Brookes, I.A. Borns, H.W. Ogden, J.G. III Jones, J.F. Lin, C.L. Hennigar, T.W. and Parsons, M.L. 1972. Quaternary geology geomorphology and hydrogeology of the Atlantic Provinces. 24th International Geological Congress, Excursions Guidebook A61 C61. 79 p.

Prest, W.H. 1896. Glacial succession in central Lunenburg Nova Scotia. Proceedings and Transactions of the Nova Scotian Institute of Science. Halifax v. 9 session 1895 96 p. 158 170.

Purdy, C.A. 1951. Pleistocene geology of the Kentville area Nova Scotia. M.S. thesis, Acadia University. Wolfville Nova Scotia 51 p.

Railton, J.B. 1972. Vegetation and climatic history of southwestern Nova Scotia in relation to a South Mountain ice cap. Ph.D. thesis. Dalhousie University Halifax Nova Scotia 146 p.

Rutherford, G.K. and Thacker, D.J. 1968. Characteristics of two mafic saprolites and their associated soil profiles in Canada. Canadian Journal of Soil Science v. 68 p. 223-238.

Rutter, N.A. (ed.) 1985. Dating methods of Pleistocene deposits and their problems. Geoscience Canada. Reprint Series 2. 87 p.

Sinclair, P.E. 1978. An application of Pleistocene geology to mineral exploration in southwestern Nova Scotia. B.Sc. thesis. Dalhousie University. Halifax Nova Scotia 109 p.

Sinclair, P.E. MacGillivray, G. and Needham, B. 1980. Report on geochemical till and rock geochemical surveys on Snider Pond Lunenburg County Nova Scotia. Shell Canada Resources Limited. Nova Scotia Department of Mines and Energy Assessment Report 21A/09C 51 L 42(01).

1980b. Report on geochemical till and rock geochemical surveys on Bezanson Lake, Lunenburg County Nova Scotia. Shell Canada Resources Limited. Nova Scotia Department of Mines and Energy Assessment Report 21A/09C 51 L 44(01).

1980c. Report on geological survey till and till geochemical survey on Spry Bay Halifax County Nova Scotia. Shell Canada Resources Limited. Nova Scotia Department of Mines and Energy Assessment Report 11D/15A 51 H 86(01).

Sonnichsen, G. 1984. The relationship of coastal drumlins to barrier beach formation along the eastern shore of Nova Scotia. B.Sc. thesis. Dalhousie University. Halifax Nova Scotia. 66 p.

Stea, R.R. 1978. Notes on the Bridgewater Conglomerate and related deposits along the Eastern Shore of Nova Scotia. in Mineral Resources Division. Report of Activities. 1977. Nova Scotia Department of Mines. Report 78.1 p. 15-17.

1980. A study of a section of till exposed in a waste cut drumlin. Meisners Reef, Lunenburg County, in Mineral Resources Division. Report of Activities 1978. Nova Scotia Department of Mines and Energy. Report 80.1 p. 9-20.

1987. The properties correlation and interpretation of Pleistocene sediments in central Nova Scotia. M.Sc. thesis. Dalhousie University. Halifax Nova Scotia. Nova Scotia Department of Mines and Energy Thesis 503. 163 p.

1983. Surficial geology of the western Part of Cumberland County Nova Scotia. in Current Research Part A. Geological Survey of Canada Paper 83-1A p. 197-202. also in Mines and Minerals Branch Report of Activities 1982. Nova Scotia Department of Mines and Energy. Report 83.1 p. 357-368.

1984. The sequence of glacier movements in northern mainland Nova Scotia determined through mapping and till provenance studies. in Correlation of Quaternary Chronologies. ed. W.C. Mahaney. Geo Books Norwich England p. 279-297.

Stea, R.R. and Brown, Y. 1989. Variations in drumlin orientation form and stratigraphy relating to successive ice flows in southern and central Nova Scotia. Sedimentary Geology v. 62 p. 223-240.

Stea, R.R. and Finck, P.W. 1984. Patterns of glacier movement in Cumberland Colchester Hants and Pictou Counties northern Nova Scotia. in Current Research Part A. Geological Survey of Canada Paper 84-1A p. 477-464.

Stea, R.R. Graves, R.M. and Rogers, P.J. 1988. Glacial geology and mineral deposits of mainland Nova Scotia. 5th International symposium on Prospecting in Areas of Glaciated Terrain. Halifax Nova Scotia Field Trip Guide. 76 p.

Stea, R.R. and Hemsworth, D. 1979. Pleistocene stratigraphy of the Miller Creek Section Hants County Nova Scotia. Nova Scotia Department of Mines and Energy Paper 79.5. 16 p.

Stea, R.R. and Mott, R.J. 1989. Deglaciation environment and evidence for glaciers of Younger Dryas age in Nova Scotia. Canada. Boreas v. 18 p. 169-187.

LIST OF REFERENCE SECTIONS

This list provides a brief description of the reference sections in Nova Scotia. These are sites usually coastal and river banks or road cuts and excavations that display surficial units underneath the mapped surface unit. Most of the surficial units on this map have been subdivided into informal lithostratigraphic units on smaller scale maps with names based largely on the location of the type and reference sections. A complete review of the nomenclature of the surficial units is given in Williams et al. 1985. These named units are presented in this list along with a brief sedimentological description. For Cape Breton Island only the sections with dating control are presented. Other important reference sections are described in forthcoming memoir by D.R. Grant to accompany the surficial map of Cape Breton Island (Grant 1988).

1 Refer to map for section locations. 2. See legend on reverse side for explanation of terms. 3. Abbreviations: ESR = Electron Spin Resonance Dating. AAR = Amino Acid Racemization Dating. LEU = Leucine ratio. ASP = Aspartic acid ratio. GSC = Geological Survey of Canada Radiocarbon Dating Laboratory. Y = Yale University. I = Isotopes Inc. UQ = Université de Quebec. BETA = Beta Analytical Inc. P = University of Pennsylvania. L = Lamont Doherty. MSL = Mean Sea Level.

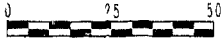| Number/Locality	Stratigraphy/Description	Dates (yr B.P.)	Principal references
1 Pembroke Cove	Base to top (10 m) calcareous silty diamicton (Red Head Till) with shell fragments brownish basaltic silty diamicton (Saulnierville Till) stony sandy diamicton (Beaver River Till) drumlin coastal exposure		Grant 1976, 1977, 1980. Nielsen 1976. Stea and Grant 1982.
2 Sanford			As above
3 Red Head			As above
4 Salmon River	Base to top (20 m) compact silty shell-bearing diamicton (Red Head Till) sand both reduced and oxidized with complete shells of the extinct gastropod Atractodon stonei (Salmon River Sand) reddish brown basaltic silty diamicton brown silty diamicton (Saulnierville Till) stony sandy diamicton (Beaver River Till) drumlin exposure	Radiocarbon series 38,600 + 1300 (GSC-1440) shell from Salmon River Sand. AAR series (Wehmiller et al. 1988) (D/L Leu 24 age estimate 170,000) Mercenaria shells from Salmon River Sand. AAR series (Grant 1980) age estimate 70,000-80,000 shells from Salmon River Sand. U-Th series 33,000-40,000 (L-1348a) shell	As above Clarke et al. 1972. Wehmiller et al. 1988
5 Cape St Mary	Base to top (5 m) compact reddish brown shelly diamicton Fe cemented oxidized sandy gravel grey stony diamicton (Beaver River Till) marine gravel c. to 13 m	>8,000 (GSC-695) shell in lower diamicton	As above Lowdon and Blake 1970
6 Devens Cove			As above
7 South Bear Cove			As above
8 Meteghan Corner			As above
9 Lr Saulnierville			As above
10 Saulnierville	Base to top (20 m grey silty shelly diamicton reddish brown silty shelly diamicton with New Brunswick erratics greyish locally-derived diamictons marine sediments. Section consists of 4 tabular drift sheets composing a ridge	AAR series (D/L Leu 24) age estimate 120,000 shell in lower diamicton	Grant 1980. Wehmiller et al. 1988.
11 Little Brook	Base to top coarsely fissile calcareous silty diamicton with shell fragments Little Brook Till) brown silty non-calcareous diamicton sand layer reddish-brown silty-sandy diamicton stony sandy diamicton (Beaver River Till) morainal exposure		Grant 1980. Stea and Grant 1982
12 Cape Forchu			Grant 1980
13 Sissiboo Dam			Grant 1980
14 Deta Road			Grant 1980
15 Kennes Shore			Grant 1980
16 Gilbert Cove	Base to top grey silt with shell fragment including oyster (Barton Silt) reddish brown sand and marine gravel	Radiocarbon series >39,000 (GSC-987) shell fragments Barton Silt. 14,000 ± 200 (GSC-1259) sea weed in marine gravel	Grant 1980. Wehmiller et al. 1988
17 Church Brook	Base to top (22 m) grey silt with	AAR series (D/L Leu 32) age esti	Grant 1980

LIST OF REFERENCE SECTIONS

rence sections in Nova Scotia. These are sites, usually coastal and river banks or road cuts and excava- mapped surface unit. Most of the surficial units on this map have been subdivided into informal with names based largely on the location of the type and reference sections. A complete review of in Wehmiller et al 1985. These named units are presented in this list along with a brief sedimentological sections with dating control are presented. Other important reference sections are described in a forth- the surficial map of Cape Breton Island (Grant 1988)

and/or reverse side for explanation of terms 3 Abbreviations ESR = Electron Spin Resonance Dating EU = Leucine ratio ASP = Aspartic acid ratio GSC = Geological Survey of Canada Radiocarbon Isotopes Inc UQ Le versité du Québec BETA Beta Analytical Inc P = University of Pennsyl Sea Level

iption	Dates (yr B.P)	Principal references
calcareous silty al Till with shell basaltic, silty d ile Till stony aver Till) ure		Grant 1976 197 / 1980 Nielsen 1976 Stea and Grant 198?
		As above
		As above
compact silty ton (Red Head col and crushed s of the contact ratons (Salmon brown basaltic pe silty diamic till stony sand ver Till) drum	Radiocarbon series 38,600 ± 1500 (GSC-4444) shell from Salmon River Sand / AAR series (Wehmiller et al 1988) (D'L Leu 24) age estimate 120,000 Mercenaria shells from Salmon River Sand / AAR series (Grant 1980) age esti mate, 700,000-80,000 shells from Salmon River Sand / U/Th series 33,000-40,000 (L 1348a shell	
c mpact reddish ton Fe cement y stom diamic l) marine grav	)38,000 (GSC-695) shell in lower diamiction	As above Lowdon and Blake 1970
;		
		As above
		As above
		As above
rev silty diam wn silty shelly w Brunswick ll-derived dia ments Section till sheets com	AAR series (D'L Leu 24) age esti mate 120,000 shells in lower d amiction	Grant 1980 Wehmiller et al 1988
fissile, calcar with shell frag l) brown silt tco and layer ly diamicton Beaver River re		Grant 1980 Stea and Grant 1982
th shell frag r (Barton Silt) marine gravel	Radiocarbon series 39 000 (GSC-887) shell fragments Barton Silt 34,000 ± 200 (GSC 1259) sea weed in marine gravel	Grant 1980 Wehmiller et al 1988
grey silt with gravel foreset	AAR series (D'L Leu 32) age esti mate, 700,000-300,000 shell frags	Grant 1980

Number/Locality	Stratigraphy/Description	Dates (yr B.P)	Principal reference
32 Blomidon	Base to top (3 m) clay peat mono- lith d-formed sandy-silt		
33 Grand Pre	Tree stumps rooted in till 8 m be- low MSL overlain by estuarine silt oysters in silt 13.5 m	3400 ± 140 (GSC-4054) tree stump / 3820 ± 130 (GSC 972) tree stump	Lowdon and Blake, 1970 Grant 1970 / Stea et al 1987
34 Wagner Lake	Base to top (10 m) grey compact silty diamicton gravelly and red dish silty diamicton (Lawrencetown Till) olive-grey stony sandy diamic ton (Beaver River Till) drumlin ex posure upper till patches out toward the top of the drumlin		Stea unpublished
35 Northfield	Similar to above		
36 Newcombville	Base to top (5 m) grey massive silty diamicton (Hartlen Till) reddish silty diamicton (Lawrencetown Till) brownish diamicton with slate debris		Stea unpubl shed
37 Blockhouse	Base to top greyish silty diamicton with basalt stones erosion al discontinuity brown oxidized stony diamicton with aurific ous quartz		Prest 1896
38 Messners Reef	Base to top grey compact silty di amicton with North Mountain basalt clasts jointed SE fabric (Hartlen Till) reddish brown sandy till with abundant granitic and basaltic boul ders (Lawrencetown Till) drumlin exposure		Stea 1980 Stea and Brown 1989
39 Pentz	Type exposure of the Bridgewater Conglomerate an iron-cemented di amicton of slate and granite fabric At this locality it overlies bedrock and its surface is striated by southeast flow ing ice It is believed to predate the last glaciation		MacNeill in Prest et al 1972
40 Broad Cove	Base to top grey compact massive, silty diamicton (Hartlen Till) bould ery iron-cemented diamicton brown sandy diamicton with sand partings and inclusions (Lawrencetown Till) drumlin exposure		Stea 1980
41 Shule Lake	Base to top (3 m) conglomerate resid uum reddish stony diamicton (Eastonville Till) stony sandy diamic ton (Shule Lake Till) The section is located along an ice margin related to a phase 4 glacier flowing southwest ward into Chignecto Bay North of the margin the Shule Lake Till ground moraine is relatively flat with many bogs and characterized by ribbed moraine development South of the contact the Eastonville Till terrace is deeply incised Terrain maturity and greater soil development on the Eastonville Till indicates several thou sand years of subaerial exposure be fore the Shule Lake Till terrain north of the ice margin became ice free		Stea et al 198? Wang et al 1986
42 Spencers Island	At the mouth of Mahoney Brook a delta exposure reveals a tripartite structure with rhythmically bedded sand and clay and diamicton at the base (bottomset beds) overlain by planar bedded sand and gravel beds (foreset beds) and horizontally strati fied gravelly sand (topset beds) The bottomset and foreset beds are the ma rine member (Advocate Harbour Member) of the Five Islands Forma tion The topset part of the delta represents the subaerial outwash mem ber (Saints Rest Member) These del tas formed when ice was cleared out of the Minas Basin but remained on the south slope of the Cobequid High lands and the valleys therein The ele vation of the contact between topset and bottomset beds is a measure of former sea levels The elevation of this	14 300 ± 320 (BETA 12858 13 400 ± 300 (BETA 13728) 12,600 ± 270 (BETA 12859) shell periostracum fragments of Portlandia arctica from the delta bottomset beds	Swift and Borns, 1967 Wightman 1980 Stea et al 1985 Stea and Wightman 1987

Number/Locality	Stratigraphy/Description	Dates (yr B.P)	Principal reference
43 Squally Point	Well developed terraces are found along the coast from Squally Point to Cape Chignecto. The highest terrace at Squally Point has an elevation of 37 m above MSL. The terraces consist of wave-cut rock platforms with vary ing thicknesses of beach gravel on top Terrace elevations appear to decrease along the coast towards Cape Chignecto		Stea 1983 Stea et al 1985
44 McCarron Brook	Base to top (30 m) reddish brown silty diamicton with source areas west and northwest (McCarron Brook Till) grey silty till with abundant coal frag ments, source area northeast (Joggins Till) yellowish sandy till with sand stone clasts (Shulie Lake Till)		W clendan 1941 Prest et al 1972 Stea 1983 1984 Stea et al 1985
45 Lower Cove	Base to top (3 m) sand, massive red dish brown diamicton peat fibrous, compacted greenish sand sea cliff exposure elevation 15 m above MSL	11,800 ± 100 (GSC 3945 top of the peat bed 11 100 ± 120 (GSC 3924) bottom 11 400 ± 100 (GSC 3950) bulk sample	Mott et al 1986b Stea et al 1985
46 S mms Settlement	Base to top (6 m) reddish brown sandy diamicton (Lawrencetown Till) bouldery sandy diamicton (Granite Till B) wedges of Granite Till B in trude into the Lawrencetown Till drumlin exposure		Graves and Finck 1988
47 Me ssers Point	Base to top calcareous, grey sh red silty diamicton reddish-brown sandy diamicton north south fabric (Lawrencetown Till) bouldery sandy diamicton with inclus ons of lower reddish diamicton and sand layers (Granite T II B) drumlin cut		Graves and Finck 1988
48 Porcupine Lake			Finck and Graves 1987a Graves and Finck 1988
49 L ttle Indian Lake			Finck and Graves 1987a
50 Bayside			Grant 1963
51 Whites Lake	Base to top (15 m) greyish red silty diamicton reddish brown sandy d amicton with sand layers bouldery sandy diamicton with wedge shaped intrusions into the lower unit dipping southeastward at 45 degrees drumlin til		Nielsen 1976
52 Harrietsfield	Base to top (15 m) reddish diamic ion laminated red silty sand and gravelly sand bouldery sandy di amicton with granite debris (Granite Till B)		Grant 1963
53 Sandwich Point	Base to top (10 m) granite residuum greyish silty diamicton with grey wacke clasts, eastward fabric (Hartlen Till) large quartzite boulders red dish fissile silty diamicton with southeastward fabric and abundant er ratic lithologies (Lawrencetown Till) waterlain sand bouldery sandy di amicton (Granite Till)		Grant 1963 Nielsen 1976 Stea and Fowler 1979 Finck and Graves 1987a Graves and Finck 1988
54 Halifax			Grant 1963

Number/Locality	Stratigraphy/Description	Dates (yr B.P)
55 Hartlen Po nt	Base to top (10 m) glacially... terraces are found in Squally Point to bedrock indicating eastward... the highest terrace greyish silt massive diam... an elevation of 37 southeast fabric (Hartlen T... the terraces consist der pavement reddish clay... platforms with var variable fabric many embe... each gravel on top em provenance (Lawrencetown... appear to decrease fluted till plant exposure... towards Cape	
56 West Lawrencetown		
57 Terminal Beach	Base to top (25 m) grey sh... reddish-brown diamicton with source areas west... source areas west indicating southeastward... Carron Brook Till) (Hartlen Till) diamicton... bundant coal frag gravelly sand and sand lowe... s northeast (Joggins pocket of waterlain sedimen... dy till with sand dish sandy diamicton with... Lake Till) erratics of Cobequid Hi... land, massive red provenance (Lawrencetown... an peat fibrous posure of two drumlins... n sand and sea cliff ... 15 m above MSL	11,800 ± 100 (GSC 3905) top of the peat bed 11 000 ± 120 (GSC 3924) bottom 11 400 ± 100 (GSC 3550) bulk sample
58 Musquodoboit	Mound of an iron-cemented... bedded diamicton cons sting... reddish-brown lar fragments of slate and... awrencetown Till) called the Bridgewater Cong... diamicton (Granite Interpreted to be either a pre... Granite Till B m sirean outwash depos t or a... awrencetown Till man name	
59 West Jeddon	Drumli e exposure of Law... eous greyish-red Till overlain by stony meta... dish brown sandy t ll with an erosional contact... h south fabric s till does not cone the ent... e bouldery sandy I n expos are, but produce... th wedge-shaped the top It bocket, or the... clusions of lower of the drumli n... and sand layers ... drumlin cut	
60 Spry Harbour	Base to top (4 m) carvi... h ton (Ha len Till sand pock... m sandy diamicton	
61 Mushaboom	Thick type exposure of the... plain (Beaver River T ll) al... the floss textured till sheet... r ch till beet quart e g... greyish red silty slate till e etc. This till... Brown sandy d characterized by rapid uptake... layers bouldery bedrock across contact ro... th wedge-shaped maximum d stanc. r irra... lower unit dipping cla t sted material down d... degrees drumlin order of 100×50 m	
62 Necum Teuch	Loose boulders diamicton... reddish diamic River Till overlie a reddish... silty sand and diamicton (Lawrencetown T... oldery sandy di an erosional contact expos... e debris (Granite flank of a drumlin	
63 Ecum Secum		granite residuum icton with grey d fabric (Hartlen
64 Wine Harbour	Base to top fo ded basin... e boulders red and silt greysh silt di... e diamicton with (Hartlen Fill) oxidized on... e and abundant er dish sandy diamicton (Law... wrencetown Till) Till) drumlin exposure... ldery sandy d	

DETROIT

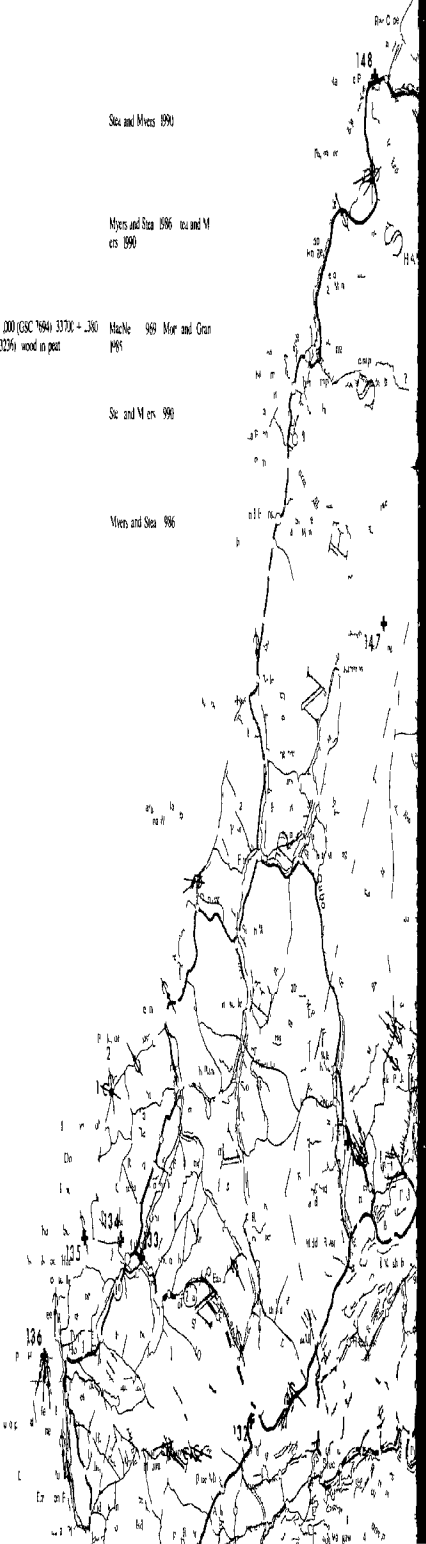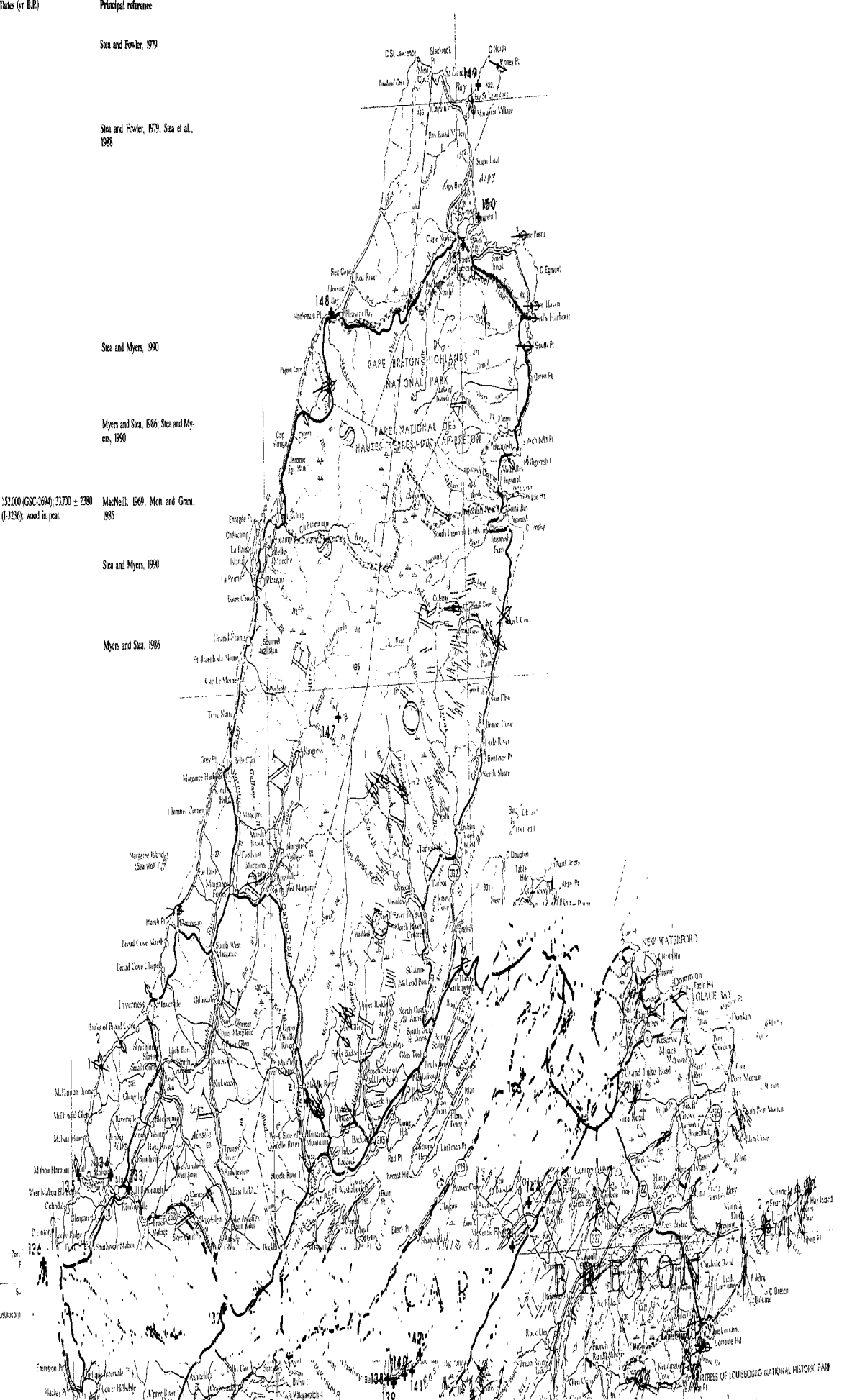| ription	Dates (yr B.P)	Principal reference	Number/Locality	Stratigraphy/Description	Dates (yr B.P)	Principal reference	Number/Locality	Stratigraphy/Description	Dates (yr B.P)	Principal reference		Number/Locality
rraces are found n Spally Point to e highest terrace an elevation of 37 terraces consist tforms with very ach gravel on top appear to decrease toward Cape		Stea 1983 Stea et al 1985	55 Hartlen Point	Base to top (60 m) glacially deformed bedrock indicating eastward ice flow greyish silty massive diamicton w th southeast fabric (Hartlen Till) boul der pavement reddish clay diamicton variable fabric many erratics of north ern provenance (Lawrencetown Till) fluted till plain exposure		Grant 1963 Nielsen 1976 Podolak and Shilts, 1978 Stea and Fowler 1979 Stea et al 1988	65 Holland Harbour	Base to top greyish silty compact di amicton brownish fissile sandy di amicton loose stony sandy diamic ton drumlin cut		Stea and Fowler 1979		65 Holland Harbour
			56 West Lawrencetown			Stea et al 1988	66 Sti wate	Ice contact delta complex Consists of planar and ripple laminated sand and silt (bottomset beds) overlain by steeply-dipping, sigmoidal foreset beds of coarse gravelly sand and top-set beds with bouldery diamicton High angle reverse faults, oversteep-ened beds and angular boulders sug gest the proximity of an ice front At th s point the St Mary s River takes a U-turn into a steep gorge its form-er path lay down the Indian Harbour Lakes system now dammed by glacial debris		Stea and Fowler 1979 Stea et al 1988		66 Stillwater
f reddish-brown source areas west amon Brook Till) bundant coal frag-Northeast (Jngeru dly till with sand-Lake Till)		W ckenden 1941 Prest et al 1972 S..a 1983,1984 Stea et al 1985	57 Terminal Beach	Base to top (25 m greyish red silty diamicton with boulder pavements indicating southeastward ice flow (Hartlen Till) diamicton with thin gravelly-sand and sand layers thick pocket of waterlain sediments red dish sandy diamicton with numerous erratics of Cobequ d Highland provenance (Lawrencetown Till) ex posure of two drumlins		Stea and Fowler 1979 Sorenchsen 1984 Stea and Brown 1989				Stea and Fowler 1979 Sorenchsen 1984		
nd, massive red n peat fibrous, n sand sea cliff m above MSL	11,800 180 (GSC 3985) top of the peat bed 1 100 ± 130 (GSC 3924) bottom 11 400 ± 100 (GSC 3550) bulk sample	Mott et al 1986b Stea et al 1985	58 Musquodoboi t	Mound of an iron-cemented crude y bedded diamicton consisting of angu lar fragments of slate and granite called the Bridgewater Conglomerate Interpreted to be either a pre Wiscon s nan outwash deposit or a W sconsi nan kame		Grant 1963 Stea 1978 Stea e al 1988	67 Glen A pine	Base to top (m) purpl sh silty di amicton wi h peat layers and stringers oxidized zone brown stony silty d amicton (Eastern Ile-Haute Till)		Stea and Myers 1990		67 Glen A pine
reddish-brown wrencetown Till) amucton (Granite ranite Till B m wrencetown Till		Graves and Finck 1988					68 Glen Alp ne	Base to top (3 m) brown f ssile silty diamicton (Eastern Ile Hants Til) grey stony diamicton (Three River Till)		Myers and Stea 1986 tea and M ers 1990		68 Glen Alpine
ous greyish-red, dish brown sandy h south fabric bouldery sandy lusions of lower and sand layers rumlin cut		Graves and Finck 1988	59 West Jeddore	Drumlin exposure of Lawrencetown Till overlain by stony ma tagreywacke till w th an erosional co tact The sta-ny till does not cover the entire drum-n exposure but punches out toward the top t is the kest on the NE side of the drumlin		Stea and Fowler 1979	69 Addington Forks	Base to top purplish silty diamicton organic sil peat clay reddish-brown diamicton (Eatonville Hants Till)	15 ,000 (GSC 7694) 33,700 ± ,380 7,3234) wood in peat	MacNe l 1969 Mott and Grant 1985		69 Addington Forks
			60 Spry Harbour	Base to top (4 m) grey s lty diami on (Hartlen Till) sand pockets to w sandy diamicton		Stea and Fowler 1979	70 J mtown	Base to top (12 m) compact silty clast poor diamicton north south fabric thin zone of gravel y-sand redd sh brown silty diamicton		Stea and M ers 1990		70 Jimtown
		Fink and Graves 1987a Graves and Finck 1988					1 Mac sac Point	Base to top (*1 m) rock bench at 4 m e evation with striae on surface trend-ing 10 degrees greyish-brown silty d am ton with fragments of Mer cetoria sp that sandy lay er reddish s lty sand d amicton with north ea tward striking fabric		Myers and Stea 1986		1 Macksac Point
		Finck and Graves 1987a	6 Mushaboom	Thick type exposure of the stony till plain (Beaver Rive Til) also termed the loose textured till sheet gravel-rich till sheet quartzite granite and slate tills etc This till sheet is characterized by rapid uptake of local bedrock across contact zones The maximum distance of transport of clast sized material down ce in the ord r of 100-900 m		Podolak and Shilts, 1978 Stea and Fowler 1979 Stea et al 1988						
reysish-red silty rown sandy di 3layers bouldery th wedge-shaped nner sand dipping degrees drumlin		Nie sen 1976										
reddish diamic silty sand and dery sandy di debris (Granite		Grant 1963	6 Necum Teuch	Loose, bouldery diamicton (Beaver Rive T.ll) overly ng a reddish silty d amic on (Lawrencetown Till) with an eros ona contact exposure of a flank of a drumlin		Stea and Fowler 1979						
ranite residum cton with grey rd fabric (Hartlen e boulders red-diamicton with and abundant er wrencetown Till) ider* sandy d-ill)		Grant 1963 Nielsen 1976 Stea and Fowler 1979 Finck and Graves 1987a Graves and Finck 1988	63 Ecum Secum			Stea and Fowler 1979						
			64 Wine Harbour	Base to top folded laminated sand and silt grey sh silty diamicton (Hartlen Till) oxidized on top red dish sandy diamicton (Lawrencetown Till) drumlin exposure		Stea and Fowler 1979 Stea and Brown 1989						
		Grant 1963										

D É T R O I T   D E

Number/Locality	Stratigraphy/Description	Dates (yr B.P.)	Principal reference
65 Holland Harbour	Base to top: greyish, silty, compact diamicton; brownish, fissile, sandy diamicton; loose, stony, sandy diamicton; drumlin cut.		Stea and Fowler, 1979
66 Stillwater	Ice contact delta complex. Consists of planar and ripple laminated sand and silt (bottomset beds) overlain by steeply-dipping, sigmoidal foreset beds of coarse gravelly sand and topset beds with bouldery diamictons. High angle reverse faults, oversteepened beds and angular boulders suggest the proximity of an ice front. At this point the St Mary's River takes a U-turn into a steep gorge. Its former path lay down the Indian Harbour Lakes system now dammed by glacial debris.		Stea and Fowler, 1979; Stea et al., 1988
67 Glen Alpine	Base to top (3m) purplish, silty diamicton with peat layers and stringers; oxidized zone; brown; stony, silty diamicton (Eatonville-Hants Till).		Stea and Myers, 1990
68 Glen Alpine	Base to top (3 m): brown, fissile, silty diamicton (Eatonville-Hants Till); grey, stony diamicton (Toney River Till).		Myers and Stea, 1986; Stea and Myers, 1990
69 Addington Forks	Base to top: purplish, silty diamicton; organic silt, peat, clay, reddish-brown diamicton (Eatonville-Hants Till).	>52,000 (GSC-2694); 33,700 ± 2380 (I-3236); wood in peat.	MacNeill, 1969; Mott and Grant, 1985
70 Jimtown	Base to top (12 m): compact, silty, clast-poor diamicton, north-south fabric; thin zone of gravelly-sand; reddish-brown, silty-sandy diamicton		Stea and Myers, 1990
71 MacIssacs Point	Base to top (21 m): rock bench at 4 m elevation with striae on surface trending 110 degrees; greyish-brown, silty diamicton with fragments of *Mercenaria* sp.; thin sandy layer; reddish, silty-sand diamicton with northeastward striking fabric.		Myers and Stea, 1986

de Vernal A, Richard P J H and Occhietti S 1983 Palynologie et paléoenvironnements du Wisconsinien de la région de la Baie Saint Laurent, Ile du Cap Breton. Géographie physique et Quaternaire, v 37 p 307-322

Dickie G B 1979 Report on geological, soil and radon geochemical surveys EM, magnetic, airborne and ground radiometric surveys, uranium Lambs Lake, Annapolis County Nova Scotia Shell Canada Resources Limited. Nova Scotia Department of Mines and Energy Assessment Report 21A/8C 54 A 34(07)

Finxus n S A 1983 Geological map of the Hantsport area, Nova Scotia. Nova Scotia Department of Mines and Energy Map 83-1 scale 1 : 50,000

Finck P W and Graves R M 1987a Glacial Geology of Halifax and Sambro (NTS sheets 11D/12 and 11D/05) Nova Scotia. Nova Scotia Department of Mines and Energy Map 87-2 scale 1 : 50,000.

Finck P W and Graves R M 1987b Glacial Geology of Mount Uniacke (NTS sheet 11D/13 west half) Nova Scotia. Nova Scotia Department of Mines and Energy Map 87-1 scale 1 : 50,000

Fowler J H 1978 Sand and gravel accumulations in Nova Scotia. Nova Scotia Department of Mines and Energy Open File Report 378 1 : 50,000 scale maps

Fowler J H and Duckie G B 1976 Sand and gravel resources of Pictou county. Nova Scotia. Nova Scotia Department of Mines Paper 77-6 49 p

Goldthwait J W 1924 Physiography of Nova Scotia. Geological Survey of Canada Memoir 140, 179 p

Goldthwait R P 1988 Classification of glacial morphologic features. in Genetic Classification of Glacigenic Deposits eds C Ghibaut R P and Matsch C L p 267-276 Balkema Rotterdam

Grant D R 1963 Pebble lithology of the tills of southeast Nova Scotia. M Sc thesis Dalhousie University Halifax Nova Scotia 235 p

Grant D R 1970 Recent coastal submergence of the Maritime Provinces. Canadian Journal of Earth Sciences v 7 no 2 p 676-689

Grant D R 1971a Surficial geology southwest Cape Breton Island Nova Scotia. in Report of Activities Part A Geological Survey of Canada Paper 71-1A p 161-164

Grant D R 1971b Glacial deposits, sea level changes and pre-Wisconsin deposits in southwest Nova Scotia. in Report of Activities Part B Geological Survey of Canada Paper 71-1B p 110-113

Grant D R 1971c Glaciation of Cape Breton Island, Nova Scotia. in Report of Activities Part B Geological Survey of Canada Paper 71-1B p 118-120.

Grant D R 1972 Surficial geology of northeastern Cape Breton Island, Nova Scotia. in Report of Activities Part A Geological Survey of Canada Paper 72-1A p 160-163

Grant D R 1975 Glacial style and the Quaternary stratigraphic record of the Atlantic Provinces Canada. in Report of Activities Part B Geological Survey of Canada Paper 75-1B p 109-110

Grant D R 1976 Reconnaissance of early and middle Wisconsinan deposits along the Yarmouth-Digby coast of Nova Scotia. in Report of Activities Part B Geological Survey of Canada Paper 76-1B p 363-369

Grant D R 1977 Glacial style and climate, the Quaternary stratigraphic record and changes of land and ocean level in the Atlantic Provinces Canada. Géographie Physique et Quaternaire, v 31 no 3-4 p 247-260.

Grant D R 1980 Quaternary stratigraphy of southwestern Nova Scotia glacial events and sea level changes. Geological Association of Canada and Mineralogical Association of Canada Field Trip Guidebook 63 p

Grant D R 1988 Surficial geology Cape Breton Island Nova Scotia. Geological Survey of Canada Map 1631A scale 1 : 125,000

Grant D R and King L H 1984 A stratigraphic framework for the Quaternary history of the Atlantic Provinces. in Quaternary Stratigraphy of Canada A Canadian Contribution to IGCP Project 24 ed R J Fulton Geological Survey of Canada Paper 84-10 p 173-191

Grossnor C P 1974 The Yarmouth drumlin field Nova Scotia. Journal of Glaciology, v 13 p 45-54

Graves R M and Finck P W 1988 The provenance of tills overlying the eastern part of the South Mountain Batholith Nova Scotia. Maritime Sediments and Atlantic Geology v 24 p 61-70

Green D G 1981 Time series and postglacial forest ecology. Quaternary Research v 15 no 3 p 265-277

Guilbault J P 1982 The pre-Late Wisconsinan foraminiferal assemblage of St Lawrence Bay, Cape Breton Island Nova Scotia. in Current Research Part C Geological Survey of Canada Paper 82-1C p 39-43

Hadden K A 1975 A pollen diagram from a postglacial peat bog in Hants County, Nova Scotia. Canadian Journal of Botany v 53 p 39-47

Hennigar T 1977 Hydrogeology of the Truro area Nova Scotia. Nova Scotia Department of Mines Report 72-1 127 p

Hennigar T 1979 A groundwater report to the Nova Scotia Department of Lands and Forests Complex at Shubenacadie Nova Scotia Department of the Environment, unpublished report 34 p

Hickox C F Jr 1962 Pleistocene geology of the central Annapolis Valley Nova Scotia. Nova Scotia Department of Mines Memoir 5 36 p

Hilchey J D, Cann D B and MacDougall J I 1960 Soil survey of Yarmouth County Nova Scotia. Nova Scotia Soil Survey Report no 9 47 p

Hockman A 1984 The application of remote sensing techniques for aggregate resource mapping and terrain analysis in southwestern Nova Scotia. Nova Scotia Department of Mines ...

... final geology of the western Part of Cumberland County, Nova Scotia. in Current Research Part A Geological Survey of Canada Paper 83-1A p 193-197 also in Mines and Minerals Branch Report of Activities 1982 Nova Scotia Department of Mines and Energy Report 83-1 p 357-368.

Stea R R 1984 The sequence of glacier movements in northern mainland Nova Scotia determined through mapping and till provenance studies. in Correlation of Quaternary Chronologies. ed W C Mahaney Geo Book Norwich England p 279-297

Stea R R and Brown Y 1989 Variations in drumlin orientation, form and stratigraphy relating to ice dynamics ice flows in southern and central Nova Scotia. Sedimentary Geology v 62 p 223-240

Stea R R and Finck P W 1984 Patterns of glacier movement in Cumberland, Colchester, Hants and Pictou Counties, northern Nova Scotia. in Current Research Part A Geological Survey of Canada Paper 84-1A p 477-484

Stea R R, Graves R M and Rogers P J 1988 Glacial geology and mineral deposits of mainland Nova Scotia 18th International symposium on Prospecting in Areas of Glaciated Terrain. Halifax Nova Scotia Field Trip Guide, 76 p

Stea R R and Hemsworth D 1979 Pleistocene stratigraphy of the Miller Creek Section, Hants County Nova Scotia. Nova Scotia Department of Mines and Energy Paper 79-5 16 p

Stea R R and Mott R J 1989 Deglaciation environments and evidence for glaciers of Younger Dryas age in Nova Scotia. Canada. Boreas v 18, p 169-187

Stea R R and Mott R J 1990 Quaternary Geology of Nova Scotia. 53rd Annual Reunion Friends of the Pleistocene Field Trip Guide book, 35 p

Stea R R, Scott D B, Kelley J T, Kelley A R, Wightman D M, Finck P W, Seaman A, Nickerson L, Bleakney S, Boss R, and Downie M 1987 Quaternary Glacial Sea Geomorphology and Sea Level Changes Bay of Fundy Region NATO Advanced Course on Sea Level Circulation and Applications Halifax Nova Scotia Field Trip Guidebook 79 p

Taylor F C 1967 Reconnaissance geology of Shelburne map area Queens, Shelburne, and Yarmouth Counties Nova Scotia. Geological Survey of Canada Memoir 349 83 p

Taylor F C 1969 Geology of the Annapolis St Marys Bay map area Nova Scotia. Geological Survey of Canada Memoir 358 58 p

Thomas J 1974 Deglaciation of Port Hood Island Nova Scotia. Canadian Journal of Earth Sciences v 11 no 10 p 1357-1366.

Vaughan J G and Somers G H 1980 Regional water resources Cumberland County Nova Scotia. Nova Scotia Department of the Environment Water Planning and Management Division Report 81 p

Wang C, Stea R R, Ross C J and Holmstrom P 1986 Age estimation of the Shale Lake, and Lanark tills in Nova Scotia by pedogenic development. Canadian Journal of Earth Sciences v 23 p 115-119

Wehmiller J F, Belknap D F, Boutin R R, Mirecki J E, Rahman S D and York L L 1988 A review of the amino stratigraphy of Quaternary mollusks from United States Atlantic Coastal Plain sites. in Dating Quaternary Sediments ed D J Easterbrook Geological Society of America Special Paper 277 p 79-102

Welsted J L 1971 Morphology and evolution of the Bay of Fundy with emphasis on changes of sea level during the Quaternary. unpublished Ph D dissertation Bristol University Bristol England 225 p

Wickenden R T D 1941 Glacial deposits of part of northern Nova Scotia. Transaction of the Royal Society of Canada Section 4 p 143-149

Wicklund R E and Smith G R 1948 Soil survey of Colchester County Nova Scotia. Dominion Department of Agriculture Report no 3 57 p

Wightman D M 1965 The sedimentology and paleontological significance of a late Pleistocene raised beach Advocate Harbour Nova Scotia. M Sc thesis Dalhousie University Halifax Nova Scotia 157 p

Wightman D M 1980 Late Pleistocene glaciofluvial and glaciomarine sediments on the north side of the Minas Basin Nova Scotia. Ph D thesis Dalhousie University Halifax Nova Scotia 426 p

Wightman D M and Cooke H B S 1978 Postglacial emergence in Atlantic Canada. Geoscience Canada v 3 p 81-82

Williams G L, Fyffe L R, Wardle R J, Colman-Sadd S P, Boehner R C and Watt J A 1985 Lexicon of Canadian Stratigraphy Volume VI Atlantic Region. Canadian Society of Petroleum Geologists 572 p

Stea F D J P and Borns H W 1967 A raised fluviomarine outwash terrace, north shore of the Minas Basin Nova Scotia. Journal of Geology v 75 no 6 p 17-73

Stea R R and Wightman D M 1987 Age of the Five Islands Formation and the deglaciation of the Bay of Fundy. Quaternary Research v 27 p 211-219

fore the Shulie Lake Till terrain north of the ice margin became ice free.

42 Spencers Island

At the mouth of Mahoney Brook a delta exposure reveals a tripartite structure, with rhythmically bedded sand and clay and diamictons at the base (bottomset beds), overlain by planar-bedded sand and gravel beds (foreset beds) and horizontally stratified gravelly sand (topset beds). The bottomset and foreset beds are the marine member (Advocate Harbour Member) of the Five Islands Formation. The topset part of the delta represents the subaerial outwash member (Saints Rest Member). These deltas formed when ice was cleared out of the Minas Basin but remained on the south slope of the Cobequid Highlands and the valleys therein. The elevation of the contact between topset and bottomset beds is a measure of former sea levels. The elevation at this delta is 32 m above MLS. The elevation of topset/bottomset surface is the Five Islands Formation decreases from 32 m to 0 m from Spencers Island to Saints Rest (see Fig. 5).

14,300 ± 320 (BETA-12858); 13,400 ± 300 (BETA-13728); 12,600 ± 273 (BETA-12859), shell periostracum fragments of *Portlandia arctica* from the delta bottomset beds.

Swift and Borns, 1967; Wightman, 1980; Stea et al., 1985; Stea and Wightman, 1987.

54 Halifax

Grant, 1963

Grant, 1980

Grant, 1980

Grant, 1980

Grant, 1980

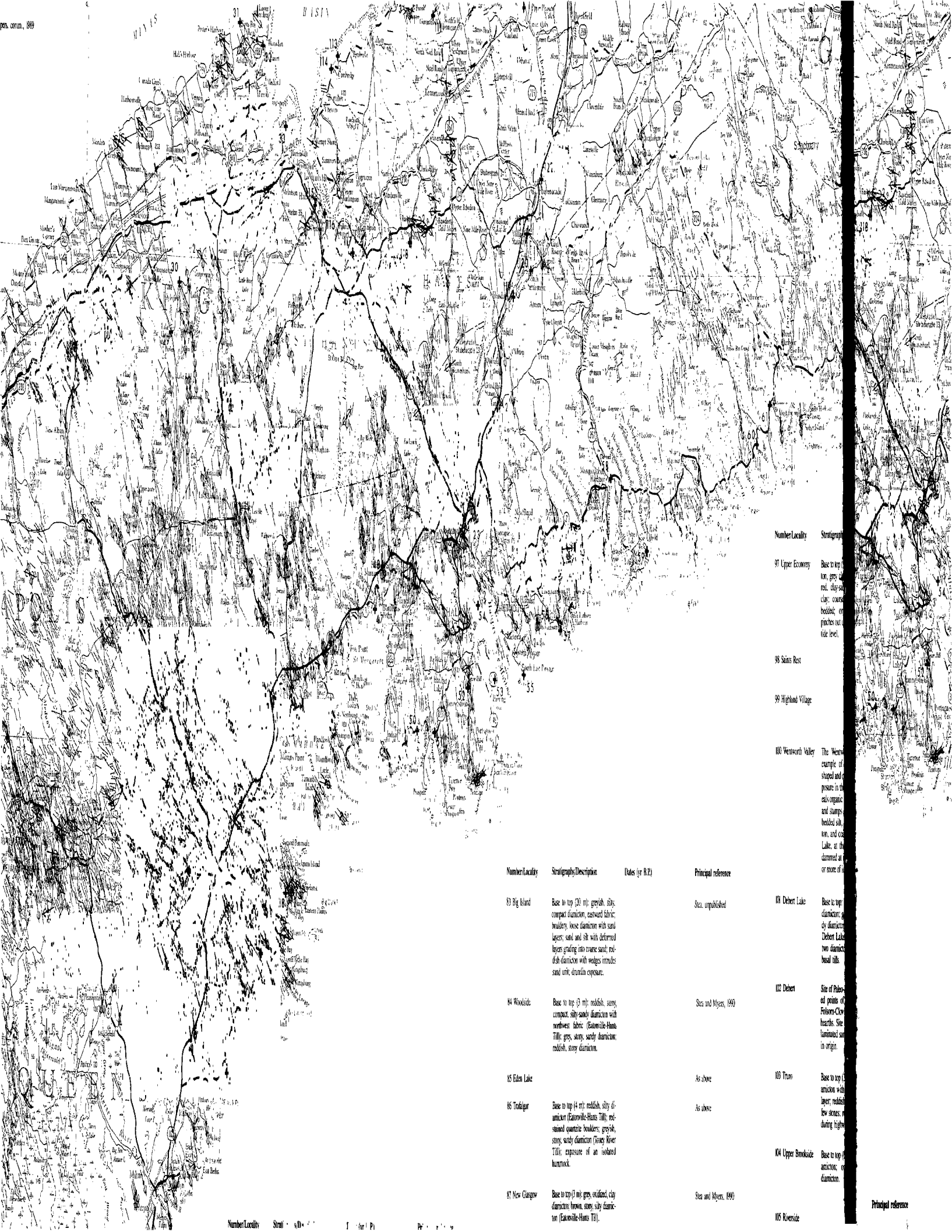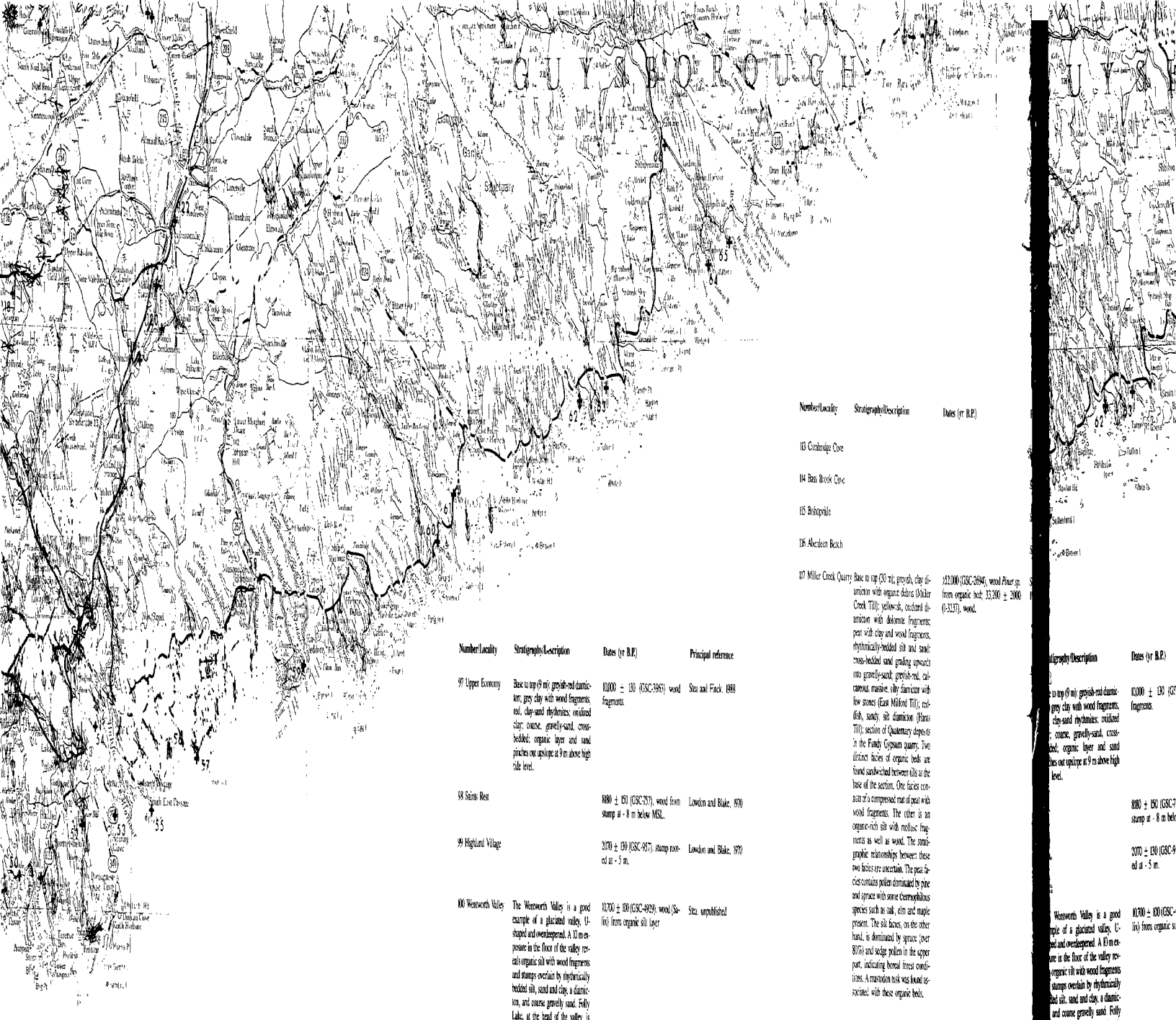| Description	Dating	Reference
Base to top: grey silt with shell fragments - including oyster (Barton Silt); reddish-brown sand; marine gravel.	Radiocarbon series: >39,000 (GSC-887), shell fragment Barton Silt; 14,000 ± 200 (GSC-1259), seaweed in marine gravel.	Grant, 1980 Wehmiller et al., 1988
Base to top (22 m): grey silt with shells (Barton Silt); gravel foreset beds; gravelly-sand topset beds delta exposure.	AAR series: (D/L Leu-32), age estimate, 200,000-300,000, shell fragments Barton Silt.	Grant, 1980
		As above
		As above
		As above
Base to top: (5 m); trees rooted in till; muds, marsh sediment; dryland. Low to high tide cross-section.	2080 ± 70 (GSC-298); trees in till; 720 ± 130 (GSC-907) salt marsh.	Grant, 1980
Base to top (46 m): flat-lying silt and clay beds, steeply-dipping, gravelly-sand foreset beds, flat lying, openwork, gravel topset beds, Gilbert-type delta exposure.	11,300 ± 150 (GSC-4460), basal lake date from the top of the delta	Grant, 1980, Mott, per. comm. 1988
Trees rooted in place below tide level; evidence of post-glacial sea level rise.	1230 ± 130 (GSC-889), wood.	Lowdon and Blake, 1970
Base to top: (4 m); stony, sandy diamicton of local bedrock's provenance (Beaver River Till); boulder ablation layer of transported Devono-Carboniferous granites.		
Base to top: (6 m); stony, gravelly diamicton, 2 m cemented with limonite, source area north; stony, sandy diamicton with source area south; ice contact stratified drift.		Dickie, 1973
Base to top: granite residuum; stony, sandy diamicton (Beaver River Till) with greywacke composition implying northwest flow.		P. W. Finck, pers. comm. 1989
Boulders of South Mountain granite transported northward across the Annapolis Valley and deposited on the North Mountain. These boulders rest on an older till deposited by ice crossing the Bay of Fundy.		Hickox, 1962
Base to top (3 m): red silty diamicton; oxidized pebbly gravel; wood and peat; reddish, stony diamicton; pebbly gravel.	11,200 ± 100 (GSC-3550), peat	Lowdon and Blake, 1975; Mott et al., 1986a.
Base to top (3 m): reddish-brown, sandy diamicton with northern provenance (Lawrencetown Till); stony, sandy diamicton (Beaver River Till) with inclusions of L.T.		P. W. Finck, pers. comm. 1989
Huge, intact mass of granitic bedrock (50 m by 5 m) overlying glaciofluvial sand and gravel, little disturbance of underlying beds.		
Base to top (13 m): residuum; red, muddy diamicton, northern provenance (East Milford Till); red, stony, sandy diamicton; loose, stony, sandy, basaltic diamicton (Bennett Bay Till), cross-bedded sand and red silt, pebbly-gravel, horizontally laminated. The uppermost unit is probably a beach deposit. It sits 13 m above MSL. Raised beach deposits are found along the North Mountain coast ranging in elevation from a maximum of 43 m near Delaps Cove to 13 m at this locality. There appears to be a discontinuity in beach levels at		Stea, 1982
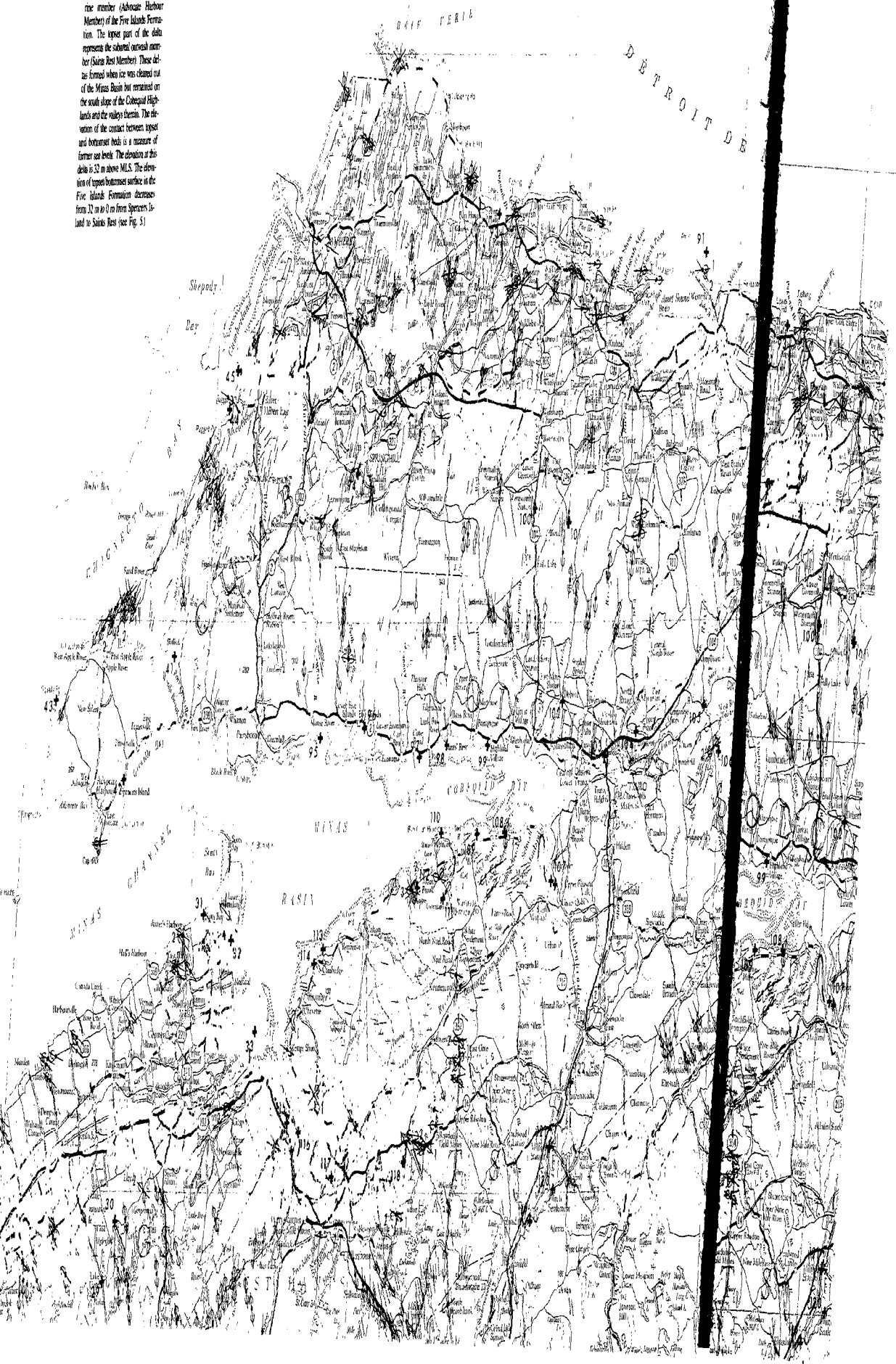
DÉTROIT DE NORTHUMBERLAND

ST GEORGES

BAY

BRAS D'OR

LAKE

CHEDABUCTO BAY

GUYSBOROUGH

Number/Locality	Stratigraphy/Description	Dates (yr B.P.)	Principal reference
113 Cambridge Cove			Stea, 1982; Stea, 1984

Number/Locality	Stratigraphy/Description	Dates (yr B.P.)	Principal reference
130 River Inhabitants	Base to top (25 m): compressed peat with wood fragments; fluvial gravel; red, silty diamicton with shell fragments; peat dominated by spruce and nonarboreal pollen indicating a boreal-subarctic environment.	>49,000 (GSC-1406), wood.	Blake, 1984; Grant and King, 1984
131 Big Brook	Base to top (composite section 30 m): yellowish, oxidized, silty diamicton; greyish, silty diamicton with wood fragments and disseminated organics; wood; greyish-red, silty diamicton; brown silty diamicton; organic mud; lacustrine sediments; drag line exposure in the Georgia Pacific Co. gypsum quarry.	>49,000 (GSC-3289), wood; 36,200 ± 1280 (GSC-3206), silt from organic bed at base of section; 11,000 ± 90 (GSC-3378) organic mud.	Blake, 1982; Blake, 1984
132 Whycocomagh	Base to top (15 m): diamicton; stratified clay-silt; organic silt with peat and wood; sand with organic silt; stony diamicton.	>44,000 (GSC-290), wood.	Mott and Prest, 1967
133 Hillsboro	Base to top (10 m): clayey gravel; orange sand with pebbles; mottled clay; grey silty clay with organics and wood; sand; red, clay diamicton.	>51,000 (GSC-370), wood.	Mott and Prest, 1967
134 Mabou	Wood and peat overlain by outwash and till.	>53,000 (GSC-3317), wood.	Blake, 1984; Grant and King, 1984
135 Green Point	Base to top (20 m): oxidized, bouldery gravel; peat, wood and clay; greyish-red, silty diamicton (Richmond Till)...	Radiocarbon series: >53,000 (GSC-3320), wood. U/Th disequilibrium series: 117,400 ±	Blake, 1984; de Vernal et al., 1986

Graves, R.M. and Finck, P.W. 1988. The provenance of tills overlying the eastern part of the South Mountain Batholith, Nova Scotia; Maritime Sediments and Atlantic Geology, v. 24, p. 61-70.

Green, D.C. 1981. Time series and postglacial forest ecology; Quaternary Research, v. 15, no. 3, p. 265-277.

Guilbault, J.P. 1982. The pre-Late Wisconsinian foraminiferal assemblage of St. Lawrence Bay, Cape Breton Island, Nova Scotia; in Current Research, Part C; Geological Survey of Canada, Paper 82-1C, p. 39-43.

Hadden, K.A. 1975. A pollen diagram from a postglacial peat bog in Hants County, Nova Scotia; Canadian Journal of Botany, v. 53, p. 39-47.

Hennigar, T. 1972. Hydrogeology of the Truro area, Nova Scotia; Nova Scotia Department of Mines, Report 72-1. 127 p.

Hennigar, T. 1970. A groundwater report on the Nova Scotia Department of Lands and Forests Complex at Shubenacadie; Nova Scotia Department of the Environment, unpublished report. 14 p.

Hickox, C.F., Jr. 1962. Pleistocene geology of the central Annapolis Valley, Nova Scotia; Nova Scotia Department of Mines, Memoir 5. 36 p.

Hilchey, J.D., Cann, D.B. and MacDougall, J.I. 1960. Soil survey of Yarmouth County, Nova Scotia; Nova Scotia Soil Survey, Report no. 9. 47 p.

Hocheim, K. 1984. The application of remote sensing techniques for aggregate resource mapping and terrain analysis in southwestern Nova Scotia; Nova Scotia Department of Mines and Energy, Open File Report 654.

Hugg, W.A. 1953. Pleistocene geology of Pictou County, Nova Scotia; M.Sc. thesis, Dalhousie University, Halifax, Nova Scotia; Nova Scotia Department of Mines and Energy, Thesis 159, 50 p.

Honeyman, D. 1882. Nova Scotia geology, superficial; Proceedings and Transactions of the Nova Scotian Institute of Natural Science, v. 5, p. 310-331.

Lin, C.L. 1970. Hydrogeology of the Musquodoboit River valley, Nova Scotia; Nova Scotia Department of Mines, Report 70-3. 60 p.

Livingstone, D.A. 1968. Some interstadial and postglacial pollen diagrams from Eastern Canada; Ecological Monographs, v. 38, p. 87-125.

Livingstone, D.A. and Estes, A.H. 1967. A carbon-dated pollen diagram from the Cape Breton plateau, Nova Scotia; Canadian Journal of Botany, v. 45, p. 339-359.

Livingstone, D.A. and Livingstone, B.G.R. 1958. Late-glacial and post-glacial vegetation from Gillis Lake in Richmond County, Cape Breton Island, Nova Scotia; American Journal of Science, v. 256, no. 5, p. 341-359.

Lowdon, J.A. and Blake, W., Jr. 1968. Geological Survey of Canada radiocarbon dates VII; Geological Survey of Canada, Paper 68-2, pt. B., p. 210-211.

——— 1970. Geological Survey of Canada radiocarbon dates IX; Radiocarbon, v. 12, no. 1, p. 46-86.

——— 1973. Geological Survey of Canada radiocarbon dates XIII; Geological Survey of Canada, Paper 73-7, p. 8.

——— 1975. Geological Survey of Canada radiocarbon dates XV; Geological Survey of Canada, Paper 75-7, p. 8.

——— 1976. Geological Survey of Canada radiocarbon dates XVI; Geological Survey of Canada, Paper 76-7, p. 4.

——— 1979. Geological Survey of Canada radiocarbon dates XIX; Geological Survey of Canada, Paper 79-7, p. 4.

——— 1980. Geological Survey of Canada radiocarbon dates XX; Geological Survey of Canada, Paper 80-7, p. 3-4.

——— 1981. Geological Survey of Canada radiocarbon dates XXI; Geological Survey of Canada, Paper 81-7, p. 5.

Lowdon, J.A., Robertson, I.M. and Blake, W., Jr. 1971. Geological Survey of Canada radiocarbon dates XI; Geological Survey of Canada, Paper 71-7, p. 263-267.

——— 1977. Geological Survey of Canada radiocarbon dates XVII; Geological Survey of Canada, Paper 77-7, p. 5.

MacDonald, G.F. 1968. Debert, a palaeo-Indian site in central Nova Scotia; Anthropology Papers, National Museum of Canada, no. 16. 207 p.

MacDougall, J.I., Cann, D.B. and Hilchey, J.D. 1963. Soil survey of Halifax County, Nova Scotia; Nova Scotia Soil Survey, Report no. 13. 53 p.

MacEachern, I.J. and Stea, R.R. 1985. The dispersal of gold and related elements in tills and soils at the Forest Hill Gold District, Guysborough County, Nova Scotia; Geological Survey of Canada, Paper 85-18.

MacNeill, R.H. 1951. Pleistocene geology of the Wolfville area, Nova Scotia; M.Sc. thesis, Acadia University, Wolfville, Nova Scotia; Nova Scotia Department of Mines and Energy, Thesis 241, 59 p.

——— 1956. Surficial geology maps of Nova Scotia, 1 : 50 000; Nova Scotia Research Foundation, Dartmouth, Nova Scotia.

——— 1969. Some dates relating to the dating of the last major ice sheets in Nova Scotia; Maritime Sediments, v. 5, no. 1, p. 3.

McKeague, J.A., Grant, D.R., Kodama, H., Beke, G.J. and Wang, C. 1983. Properties and genesis of soil and the underlying gibbsite-bearing saprolite, Cape Breton Island, Canada; Canadian Journal of Earth Sciences, v. 20, no. 1, p. 37-38.

Number/Locality	Stratigraphy/Description	Dates (yr B.P.)	Principal reference
83 Big Island	Base to top (20 m): greyish, silty, compact diamicton; eastward fabric; bouldery, loose diamicton with sand layers; sand and silt with deformed layers grading into coarse sand; reddish diamicton with wedges intrudes sand unit; drumlin exposure.		Stea, unpublished
84 Woodside	Base to top (3 m): reddish, stony, compact, silty-sandy diamicton with northwest fabric (Eatonville-Hants Till); grey, stony, sandy diamicton; reddish, stony diamicton.		Stea and Myers, 1990
85 Eden Lake			As above
86 Trafalgar	Base to top (4 m): reddish, silty diamicton (Eatonville-Hants Till); red-stained quartzite boulders; greyish, stony, sandy diamicton (Stoney River Till); exposure of an isolated hummock.		As above
87 New Glasgow	Base to top (3 m): grey, oxidized, clay diamicton; brown, stony, silty diamicton (Eatonville-Hants Till).		Stea and Myers, 1990

Number/Locality	Stratigraphy/Description
97 Upper Economy	Base to top [...] ton, grey [...] red, clay-silty [...] clay, coarse [...] bedded; or [...] pinches out [...] tide level.
98 Saints Rest	
99 Highland Village	
100 Wentworth Valley	The Wentworth [...] example of [...] shaped and [...] posure in the [...] als organic [...] and stumps [...] bedded silt, [...] ton, and co [...] Lake, at the [...] dammed at [...] or more of [...]
101 Debert Lake	Base to top [...] diamicton; g [...] dy diamicton [...] Debert Lake [...] two diamicton [...] basal tills.
102 Debert	Site of Paleo- [...] ed points of [...] Folsom-Clovis [...] hearths. Site [...] laminated sand [...] in origin.
103 Truro	Base to top [...] amicton with [...] layer; reddish [...] few stones; r [...] during highw [...]
104 Upper Brookside	Base to top [...] amicton; g [...] diamicton.
105 Riverside	

Number/Locality	Stratigraphy/Description	Dates (yr B.P.)	Principal reference
97 Upper Economy	Base to top (9 m); greyish-red diamicton; grey clay with wood fragments; red, clay-and rhythmites; oxidized clay; coarse, gravelly-sand, cross-bedded; organic layer and sand pinches out up-slope at 9 m above high tide level.	10,000 ± 130 (GSC-3963) wood fragments.	Stea and Finck, 1988
98 Saints Rest		8080 ± 150 (GSC-757), wood from stump at - 8 m below MSL.	Lowdon and Blake, 1970
99 Highland Village		2070 ± 130 (GSC-957), stump rooted at - 5 m.	Lowdon and Blake, 1970
100 Wentworth Valley	The Wentworth Valley is a good example of a glaciated valley, U-shaped and overdeepened. A 10 m exposure in the floor of the valley reveals organic silt with wood fragments and stumps overlain by rhythmically bedded silt, sand and clay, a diamicton, and coarse gravelly sand. Folly Lake, at the head of the valley, is dammed at its northern end by 40 m or more of ice contact stratified drift.	11,700 ± 100 (GSC-4929), wood (Salix) from organic silt layer.	Stea, unpublished

Number/Locality	Stratigraphy/Description	Dates (yr B.P.)	Principal reference
83 Big Island	Base to top (20 m); greyish, silty, compact diamicton, eastward fabric; bouldery, loose diamicton with sand layers; sand and silt with deformed layers grading into coarse sand; reddish diamicton with wedges intrudes sand unit; drumlin exposure.		Stea, unpublished
84 Woodside	Base to top (3 m); reddish, stony, compact, silty-sandy diamicton with northwest fabric (Eatonville-Hants Till); grey, stony, sandy diamicton; reddish, stony diamicton		Stea and Myers, 1990
85 Eden Lake			As above
86 Trafalgar	Base to top (4 m); reddish, silty diamicton (Eatonville-Hants Till); red-stained quartzite boulders; greyish, stony, sandy diamicton (Toney River Till); exposure of an isolated hummock.		As above
87 New Glasgow	Base to top (3 m) grey, oxidized, clay diamicton, brown, stony, silty diamicton (Eatonville-Hants Till).		Stea and Myers, 1990

Principal reference

Myers and Stea, 1986, Stea et al.,

Number/Locality	Stratigraphy/Description	Dates (yr B.P.)	Principal reference
88 Widow Point	Base to top (8 m), reddish, silty, clay diamicton (McCarron Brook Till);		Stea and Myers, 1990
101 Debert Lake	Base to top; reddish, stony, silty, sand diamicton; greyish-brown, stony, sandy diamicton; many drillholes in the Debert Lake area encountered these two diamictons, both interpreted as basal tills.		Alcock, 1984
102 Debert	Site of Paleo-Indian occupation. Fluted points of a tradition similar to Folsom-Clovis found along with hearths. Site buried by up to 1 m of laminated sand believed to be eolian in origin.	10,467 ± 118 (P-270A), charcoal hearth material, date represents the modal value of 18 dates obtained at the site.	MacDonald, 1968
103 Truro	Base to top (3 m); reddish, sandy diamicton with numerous stones; peat layer; reddish, sandy diamicton with few stones; roadside section exposed during highway construction.	12,000 ± 120 (GSC-4297), basal part of peat; 11,400 ± 150 (GSC-4265), peat inclusion in upper diamicton.	Stea and Mott, 1989
104 Upper Brookside	Base to top (3 m), reddish-brown diamicton; organic sand; reddish diamicton.	11,700 ± 100 (GSC-3774), base of buried organic layer, 11,800 ± 100 (GSC-3930) top of buried organic layer.	Mott et al., 1986a
105 Riverside			Stea and Finck, 1988
106 Riverside	Site showing superimposed striation sets. The oldest set trends 020 degrees		Stea and Finck, 1984

Number/Locality	Stratigraphy/Description	Dates (yr B.P.)
113 Cranberry Cove		
114 Bass Brook Cove		
115 Bishopville		
116 Aberdeen Beach		
117 Miller Creek Quarry	Base to top (50 m); greyish, clay diamicton with organic debris (Miller Creek Till); yellowish, oxidized diamicton with dolomite fragments; peat with clay and wood fragments, rhythmically-bedded silt and sand; cross-bedded sand grading upwards into gravelly-sand; greyish-red, calcareous, massive, silty diamicton with few stones (East Milford Till); reddish, sandy, silt diamicton (Hants Till); section of Quaternary deposits in the Fundy Gypsum quarry. Two distinct facies of organic beds are found sandwiched between tills at the base of the section. One facies consists of a compressed mat of peat with wood fragments. The other is an organic-rich silt with mollusc fragments as well as wood. The stratigraphic relationships between these two facies are uncertain. The peat facies contains pollen dominated by pine and spruce with some thermophilous species such as oak, elm and maple present. The silt facies, on the other hand, is dominated by spruce (over 80%) and sedge pollen in the upper part, indicating boreal forest conditions. A mastodon tusk was found associated with these organic beds.	>52,000 (GSC-2694), wood *Picea* sp. from organic bed; 33,200 ± 2000 (I-3237), wood.
118 Rawdon	Base to top (5 m); greyish-red, massive, silty diamicton (East Milford Till); silt and clay, grey, stony, clay diamicton (Rawdon Till).	
119 Lantz	Base to top (3 m); rhythmically-bedded clay and silt, massive clay; yellowish, gravelly-sand; peat with wood fragments; reddish, clay diamicton with few stones, intercalated, rhythmically-bedded clay-sand; cross-bedded, gravelly-sand grading into clay; exposure in the brick quarry of L. E. Shaw Ltd.	11,700 ± 100 (GSC-3774), base of peat; 10,900 ± 90 (GSC-3770), top of peat; 11,300 ± 125 (GSC-3411), calcareous concretion in lower clay unit; 9690 ± 110 (GSC-4042), wood in upper sand unit.
120 East Milford	Base to top (80 m) gypsum surface; grey, clay diamicton with gypsum clasts; brown, clay diamicton with few clasts and concretions; grey, coarse sand; yellowish, laminated sand and silt; banded silt with peaty layers and wood; reddish, gravelly sand; greyish red, silty diamicton (East Milford Till); yellowish, oxidized sand; reddish-brown, sandy diamicton (Hants Till); stripping wall exposure in the National Gypsum Co. Quarry; detailed pollen analyses of peat sections in Mott et al., 1982.	Radiocarbon series: >33,800 (GSC-13) coral; >50,000 (GSC-3642); wood; U/Th series: 84,900 ± 6,500 (UQT-23); 84,200 ± 11,300 (UQT-186); wood
121 Milford Station		
122 Shubenacadie	Base to top (30 m); massive clay; gravelly sand; peat; sand; exposure in	11,400 ± 180 (GSC-4337), bottom of peat layer; 10,800 ± 100 (GSC-3580),

tigraphy/Description	Dates (yr B.P.)	Principal reference
to top (9 m) greysh-red diamic grey clay with wood fragments clay sand rhythmites oxidized coarse gravelly sand cross ded organic layer and sand hes out upslope at 9 m above high level	10,000 ± 130 (GSC 3963) wood fragments	Stea and Finck 1988
	8180 ± 150 (GSC 757) wood from stump at 8 m below MSL	Lowdon and Blake 1970
	2070 ± 130 (GSC 957) stump root ed at 5 m	Lowdon and Blake 1970
Wentworth Valley is a good mple of a glaciated valley U ed and overdeepened A 10 m ex are in the floor of the valley rev organic silt with wood fragments stumps overlain by rhythmically ed silt, sand and clay a diamic and coarse gravelly sand Folly at the head of the valley, is mal at its northern end by 40 m ore of ice contact stratified drift	10,700 ± 100 (GSC-4929) wood (Sa lix) from organic silt layer	Stea unpublished
to top reddish stony silty sand acton greyish-brown, stony, san fiamicton many drillholes in the ert Lake area encountered these diamictons, both interpreted as l tills		Alcock 1984
of Paleo-Indian occupation Flut sonts of a tradition similar to ovis-Clovis found along with rths Site buried by up to 1 m of mated sand believed to be eolian ongin	10,467 ± 118 (P 270A) charcoal hearth material date represents the modal value of 98 dates obtained at the site	MacDonald 1968
to top (3 m) reddish, sandy di ction with numerous stones, peat r reddish sandy diamicton with stones roadside section exposed ng highway construction	12,000 ± 120 (GSC-4297) basal part of peat 11 400 ± 150 (GSC-4265) peat inclusion in upper diamicton	Stea and Mott 1989
to top (3 m) reddish-brown di ction, organic sand reddish ncton	11 700 ± 100 (GSC 3774) base of bu red organic layer, 11 100 ± 100 (GSC 2930) top of burned organic layer	Mott et al 1986a
		Stea and Finck 1988
		Stea and Finck 1984

Number/Locality	Stratigraphy/Description	Dates (yr B P)	Principal reference
113 Cambridge Cove			Stea 1982 Stea 1984
114 Pass Brook Cove			Stea 1982
115 Bishopville			Stea 1982
116 Aberdeen Beach			Stea 1982
117 Miller Creek Quarry	Base to top (30 m) greyish clay di amicton with organic debris (Miller Creek Till) yellowish oxidized di amicton with dolomite fragments peat with clay and wood fragments rhythmically bedded silt and sand cross bedded sand grading upwards into gravelly sand greyish-red cal careous massive silty diamicton with few stones (East Milford Till) red dish sandy silt diamicton (Hants Till) section of Quaternary deposits in the Fundy Gypsum quarry Two distinct facies of organic beds are found sandwiched between tills at the base of the section One facies con sists o a compressed mat of peat with wood fragments The other is an organic rich silt with mollusc frag ments as well as wood The strati graphic relationships between these two facies are uncertain The peat fa cies contains pollen dominated by pine and spruce with some thermophilous species such as oak elm and maple present The silt facies on the other hand is dominated by spruce (over 80%) and sedge pollen in the upper part indicating boreal forest condi tions A mastodon tusk was found as sociated with these organic beds	)52,000 (GSC 2694) wood Pinus sp from organic bed 33 200 ± 2000 (GSC 3237) wood	Stea and Hemsworth 1979 Stea 1982 1984 MacNeill 1969
118 Rawdon	Base to top (5 m) greyish red mas sive silty diamicton (East Milford Till) silt and clay grey stony clay di amicton (Rawdon Till)		Stea 1982
119 Lantz	Base to top (3 m) rhythmically bedded clay and silt massive clay yellowish gravelly sand peat with wood fragments reddish clay diamic ton with few stones intercalated rhythmically bedded clay sand cross bedded gravelly sand grading into clay exposure in the brick quarry of L E Shaw Ltd	11 700 ± 100 (GSC 3774) ba e of peat 10,900 ± 90 (GSC 3771) top of peat 11 310 ± 125 (GSC 1411) cal careous concentration in lower clay unit 9690 ± 110 (GSC-4042) wood in upper sand unit	Mott et al 1986b Stea and Mott 1989 Stea and Mott 1990
120 East Milford	Base to top (80 m) gypsum surface grey clay diamicton with gypsum clasts brown clay diamicton with few clasts and concretions grey coarse sand yellowish laminated sand and silt banded silt with peaty layers and wood reddish gravelly sand greyish red silty diamicton (East Milford Till) yellowish oxidized sand reddish brown sandy diamicton (Hants Till) stripping wall exposure in the National Gypsum Co Quarry detailed pollen analyses of peat sec tions in Mott et al 1982	Radiocarbon series)33,800 (GSC 33) wood >50,000 (GSC 1642) wood U/Th series 84 900 ± 6,500 (UQT 185) 84 200 ± 11 300 (UQT 186) wood	Mott et al 1982 Mott and Grant 1985
121 Milford Station			Hughes 1857
122 Shubenacadie	Base to top (20 m) massive clay gravelly sand and peat sand exposure in the Sh n W fo Park	11 400 ± 180 (GSC-4337) bottom of peat layer 10,800 ± 100 (GSC 3981) top of peat layer	Stea and Mott 1989

boreal su rette e ar

Number/Locality	Stratigraphy/Description	Dates (yr B P)	Principal reference
131 Big Brook	Base to top (composite section 30 m) yellowish oxidized silts di amicton greyish silty diamicton with wood fragments and disseminated or ganics wood greyish mud silty di amicton brown silty diamicton or ganic mud lacustrine sediments drag line exposure in the Georgia Pacific Co gypsum quarry	)49,000 (GSC 3289) wood 36 700 ± 1280 (GSC 3206) silt from organ ic bed at base of section 11,000 ± 90 (GSC 3378) organic mud	Blake 1982 Blake 1984
132 Whycocomagh	Base to top (15 m) diamicton strati fied clay silt organic silt with peat and wood sand with organic silt stony diamicton	)44 000 (GSC 290) wood	Mott and Prest 1967
133 Hillsboro	Base to top (30 m) clayey gravel orange sand with pebbles mottled clay grey silty clay with organics and wood sand red clay diamicton	)51 000 (GSC 370) wood	Mott and Prest 1967
134 Mabou	Wood and peat overlain by outwash and till	)53 000 (GSC 3517) wood	Blake 1984 Grant and King 1984
135 Green Point	Base to top (20 m) oxidized boul dery gravel peat wood and clay greyish red silty diamicton (Rich mond Till) SE fabric red clay di amicton coastal exposure of fluted till plain	Radiocarbon series >53,000 (GSC 3320) wood U/Th disequilibrium series 117 400 ± 10000 (UQT 189) wood	Blake 1984 de Vernal et al 1986
136 Port Hood	Base to top reddish stony silty-clas diamicton stratified sand with woo dy detritus reddish stony silty-clas diamicton sandy gravel peat sink h le infill	10 250 ± 240 (1 782) 1 000 ± 170 (GSC 540) wood	Hickox 1962 Rimstio 1974
137 Campbell	Base to top (3 m) sand peat sand	10,800 ± 100 (GSC 3897) op of the peat section 11 300 200 (GSC 3789) bottom peat 11 00 ± 200 (GSC 7212) bulk	Mott al 1986
138 Benacadie Point	Base to top (3 m) diamicton peat diamicton	10,900 ± 100 (GSC 3917) top of peat 12 100 ± 100 (GSC 3900) base 11 900 ± 90 (GSC 2418) bulk (11 670 ± 170 (13,234) bulk	MacNe ll 969 Mott et al 1986b
139 Benacadie 2	Base to top sand peat organic s lt diamicton	11 590 ± 390 (UQ 595) peat	Mott et al 1986
140 Benacadie 4	Base to top (2 4 m) diamicton or ganic silt diamicton sand with organ ic matter	12 310 ± 150 (UQ-394) peat from base	Mott et al 1986b
141 Amaguadees	Base to top 4 m) diamicton organ ic silt sand peat organic silt diamicton	11 400 ± 120 (GSC 4063) top of peat 11 600 ± 170 (GSC-40n2) bot tom of peat 11 750 ± 200 (UQ 970) bulk peat	Mott et al 1986b
142 Castle Bay	Base to top indurated gravel strati f ed deltaic sand and finely laminated organ silt colluvium diamicton wi n shells (till)	Radiocarbon series)47 000 (GSC 1577) organic silt)52,000 (GSC 1619) wood from organic s lt AAR series Occhietti and Rutter 1982) D/L ASP L5) shells from up per diamicton	Blake 1984 Grant and King 1984
143 East Bay	Complex cliff section with coarse to medium gravels at the base overlain by a diamicton Three distinct facies of organic sediments are enveloped by gravels Unit 1 compact woody peat Unit 2 silts clays interbedded with peat and wood Unit 3 organic silts The three organic facies also show distinct pollen sequences termed palynostratigraphic units The com pact peat (Unit 1) is distinguished by a pollen sequence dominated by oak white pine and hardwood genera The silty clays (Unit 2) are dominat ed by Balsam fir with some hardwood pollen The organic silts (Unit 3) are characterized by coniferous pollen es pecially spruce and pine with abun dant nonarboreal pollen Unit 1 represents a true interglacial with a pollen spectra indicating a warmer cli mate than today Units 2 and 3 are in terstadial assemblages with cooler cli mate affinities	Radiocarbon series (wood) Unit 1)50,000 (GSC 3861) Unit 2)49,000 (GSC 3871) Unit 3)50,000 (GSC 3978) U Th disequilibrium ser es (wood) Unit 1 126,400 + 15000 (UQT 175) 124 400 ± 30000 (UQT 176) 106,600 ± 9600 (UQT 108 60,800 ± 9100 (UQT 179) Unit 2 86,900 ± 6000 (UQT 109) Unit 3 62 100 ± 5000 (UQT 177) 98 700 ± 10 500 (UQT 227) 50 200 ± 5000 (UQT 188)	de Vernal et al 1986 Mott and Grant 1985
144 East Bay	Base to top diamicton peat diamicton	10,300 ± 150 (GSC 1578) peat	Grant 1971
145 Lenches Creek	Base to top (36 m) brown silty di amicton grey silty diamicton com pressed peat with wood greyish cob bly diamicton organic silty clay with wood fragments greyish sandy di	)52 000 (GSC 2678) peat for upper organics	Blake 1984 Mott 1971

1976, Geological Survey of Canada radiocarbon dates XVI; Geological Survey of Canada, Paper 76-7, p. 4.

1979, Geological Survey of Canada radiocarbon dates XIX; Geological Survey of Canada, Paper 79-7, p. 4.

1980, Geological Survey of Canada radiocarbon dates XX; Geological Survey of Canada, Paper 80-7, p. 3-4.

1981, Geological Survey of Canada radiocarbon dates XXI; Geological Survey of Canada, Paper 81-7, p. 5.

Lowdon, J.A., Robertson, I.M. and Blake, W., Jr. 1971. Geological Survey of Canada radiocarbon dates XI; Geological Survey of Canada, Paper 71-7, p. 263-267.

1972, Geological Survey of Canada radiocarbon dates XVII; Geological Survey of Canada, Paper 77-7, p. 5.

MacDonald, G.F. 1968. Debert, a palaeo-Indian site in central Nova Scotia; Anthropology Papers, National Museum of Canada, no. 16, 207 p.

MacDougall, J.I., Cann, D.B. and Hilchey, J.D. 1963. Soil survey of Halifax County, Nova Scotia; Nova Scotia Soil Survey, Report no. 13, 53 p.

MacEachern, I.J. and Stea, R.R. 1985. The dispersal of gold and related elements in tills and soils at the Forest Hill Gold District, Guysborough County, Nova Scotia; Geological Survey of Canada, Paper 85-18.

MacNeill, R.H. 1951. Pleistocene geology of the Wolfville area, Nova Scotia; M.Sc. thesis, Acadia University, Wolfville, Nova Scotia; Nova Scotia Department of Mines and Energy, Thesis 241, 59 p.

1956. Surficial geology maps of Nova Scotia, 1 : 50 000; Nova Scotia Research Foundation, Dartmouth, Nova Scotia.

1969. Some dates relating to the dating of the last major ice sheets in Nova Scotia; Maritime Sediments, v. 5, no. 1, p. 3.

McKeague, J.A., Grant, D.R., Kodama, H., Beke, G.J. and Wang, C. 1983. Properties and genesis of soil and the underlying gibbsite-bearing saprolite, Cape Breton Island, Canada; Canadian Journal of Earth Sciences, v. 20, no. 1, p. 37-38.

Mott, R.J. 1971. Palynology of a buried organic deposit, River Inhabitants, Cape Breton Island, Nova Scotia; in Report of Activities, Part B; Geological Survey of Canada, Paper 71-IB, p. 123-125.

Mott, R.J., Anderson, T.W. and Matthews, J.V., Jr. 1982. Pollen and macrofossil study of an interglacial deposit in Nova Scotia; in Special Edition Devoted to Papers from the Eleventh INQUA Congress, ed. P. Richard; Geographie physique et Quaternaire, v. 36, no. 1-2, p. 197-208.

Mott, R.J. and Grant, D.R.G. 1985. Pre-Late Wisconsinan paleoenvironments in Atlantic Canada; Geographie physique et Quaternaire, v. 39, p. 239-254.

Mott, R.J., Matthews, J.V., Jr., Grant, D.R. and Beke, G.J. 1986a. A late glacial b uried organic profile near Brookside, Nova Scotia; in Current Research, Part B; Geological Survey of Canada, Paper 86-IB, p. 289-294.

Mott, R.J. Grant, D.R.G., Stea, R.R. and Occhietti, S. 1986b. Late-glacial climatic oscillation in Atlantic Canada equivalent to the Allerod-Younger Dryas event; Nature, v. 323, no. 6085.

Mott, R.J. and Prest, V.K. 1967. Stratigraphy and palynology of buried organic deposits from Cape Breton Island, Nova Scotia; Canadian Journal of Earth Sciences, v. 4, p. 709-724.

Myers, R.A. and Stea, R.R. 1986. Surficial mapping results; Pictou, Guysborough and Antigonish Counties, Nova Scotia, in Mines and Minerals Branch, Report of Activities 1985, ed. J.L. Bates, p. 189-194.

Newman, W.A. 1971. Wisconsin glaciation of northern Cape Breton Island, Nova Scotia. Canada; Ph.D. thesis, Syracuse University, Syracuse, New York, 117 p.

Nielsen, E. 1976. The composition and origin of Wisconsinan tills in mainland Nova Scotia; Ph.D. thesis, Dalhousie University, Halifax, Nova Scotia, 256 p.

Occhietti, S. and Rutter, N. 1982. Amino acids and Wisconsinan interstades in the Saint Lawrence Valley and Cape Breton Island; in Current Research, Part B; Geological Survey of Canada, Paper 82-IB, p. 301-305.

Ogden, J.G., III. 1960. Recurrence surfaces and pollen stratigraphy of a post glacial raised bog, Kings County, Nova Scotia; American Journal of Science, v. 258, p. 341-353.

1987. Vegetational and climatic history of Nova Scotia. I. Radiocarbon-dated pollen profiles from Halifax, Nova Scotia; Canadian Journal of Botany, v. 65, no. 7, p. 1482-1490.

Ogden, K.F. 1960. An ice marginal lake in Annapolis Basin at the close of the Late Wisconsin; B.Sc. thesis, Acadia University, Wolfville, Nova Scotia, 39 p.

Podolak, W.E. and Shilts, W.W. 1977. Some physical and chemical properties of till derived from the Meguma Group, southeast Nova Scotia; in Report of Activities, Part A; Geological Survey of Canada, Paper 78-IA, p. 459-464.

Number/Locality	Stratigraphy/Description	Dates (yr B.P.)	Principal reference
72 Lakevale			Myers and Stea, 1986; Stea et al., 1987, 1988
73 Livingstone Brook			Myers and Stea, 1986; Stea et al., 1987, 1988
74 Cape George	Base to top (24 m); rock bench 3.5 m above highest tide level; buff, clean, well-sorted sand; gravelly-sand; reddish, sandy diamicton.		As above
75 Ballantynes Cove	Base to top (33 m); greyish-red, silty diamicton with shell fragments derived from ice flow across the Northumberland Strait; reddish, sandy diamicton with abundant Antigonish Highland erratics derived from ice flow across the highland regions to the southwest.		Myers and Stea, 1986; Stea et al., 1987, 1988
76 Cape George Point	Base to top (34 m); wave cut bench to 4 m above MSL, with potholes on its surface; fine, well-sorted sand; crudely-stratified, gravelly diamicton with angular clasts; reddish, silty diamicton with shell fragments (Mercenaria sp., Ostrea sp.)	Radiocarbon series (D.R. Grant, pers. comm., 1989), shell (Mercenaria sp.) >37000 (GSC-408); 35,600 ± 990 (GSC-4108); AAR series: D/L Leu 18-.19, age estimate 80,000-120,000; Mercenaria in lowest diamicton. ESR series: age estimate 90,000-190,000 Mercenaria sp. in lower diamicton	Myers and Stea, 1986; Stea et al., 1987, 1988, unpublished
77 Livingstone Point			Stea et al., 1987, 1988
78 Livingstone Cove			As above
79 Morar			As above
80 Malignant Cove			As above
81 Arisaig			As above
82 Lismore	Base to top (3 m), reddish sand; organic-rich peat; sandy peat; reddish sand with silt layers.	11,900 ± 100 (GSC-4453), bottom of organic rich peat; 10,600 ± 100 (GSC-4762), contact of sandy peat and peat; 10,500 ± 100 (GSC-4156), top of sandy peat.	Mott et al. 1986b; Stea and Mott, 1989

Number/Locality	Stratigraphy/Description	Dates (yr B.P.)	Principal reference
83 Big Island	Base to top (29 m); greyish, silty, compact diamicton, eastward fabric; bouldery, loose diamicton with sand layers; sand and silt with deformed layers grading into coarse sand; reddish diamicton with wedges intrudes sand unit; drumlin exposure.		Stea, unpublished
84 Woodside	Base to top (3 m); reddish, stony, compact, silty-sandy diamicton with northwest fabric (Eatonville-Hants Till); grey, stony, sandy diamicton; reddish, stony diamicton.		Stea and Myers, 1990
85 Eden Lake			As above
86 Trafalgar	Base to top (4 m); reddish, silty diamicton (Eatonville-Hants Till); red-stained quartzite boulders; greyish, stony, sandy diamicton (Toney River Till); exposure of an isolated hummock.		As above
87 New Glasgow	Base to top (3 m); grey, oxidized, clay diamicton; brown, stony, silty diamicton (Eatonville-Hants Till).		Stea and Myers, 1990
88 Widow Point	Base to top (11 m); reddish, silty, clay diamicton (McCarron Brook Till); gravelly-sand layer; greyish-red bouldery, sandy-silt diamicton with northward fabric (Eatonville-Hants Till); alteration zone with sand layers; reddish, stony diamicton (Toney River Till).		Stea and Myers, 1990
89 Sams Point	Base to top (10 m); greyish-red, massive, silty diamicton overlying bedrock with eastward striae (McCarron Brook Till); reddish, stony, silty diamicton (Eatonville Till).		Stea and Finck, 1988
90 Toney River	Base to top (4 m); reddish, stony, sandy diamicton (Eatonville Till); greyish, bouldery diamicton (Toney River Till); section overlies bedrock surface inscribed with two sets of striae: the older trending eastward and the younger, southwestward.		Stea and Finck, 1984, 1988
91 Cape John	Base to top (17 m); reddish-brown, clay diamicton overlying bedrock surface with eastward striae; greyish-red, silty diamicton (McCarron Brook Till); thin sand layer with alteration on the McCarron Brook Till; reddish, sandy diamicton with Cobequid Highland boulders.		Stea and Finck, 1984, 1988
92 South Shore			Stea and Finck, 1988
93 Bergman Point			Stea and Finck, 1988
94 Springhill			Stea and Finck, 1988
95 Moose River			Stea and Finck, 1988
96 Economy Mountain	Saprolite development on the tholeiitic basalt of Economy Mountain. The saprolite is believed to have formed during a lengthy warm period, perhaps the Tertiary. If this is true then little or no glacial erosion has occurred during the many ice ages that have characterized the Quaternary.		Rutherford and Thacker, 1988

Number/Locality	Stratigraphy/Description	Principal reference
100 Wentworth Valley	The Wentworth Valley... example of a glacial... shaped and overdeepen... posure in the floor of... eals organic silt with... and stumps overlain by... bedded silt, sand and... ion, and coarse grave... Lake, at the head... dammed at its norther... or more of ice contact...	
101 Debert Lake	Base to top; reddish, s... diamicton, greyish-bro... dy diamicton, many... Debert Lake area enc... two diamictons, both... basal tills.	
102 Debert	Site of Paleo-Indian occ... ed points of a traditio... Folsom-Clovis found... hearths. Site buried by... laminated sand believe... in origin.	
103 Truro	Base to top (3 m); reddi... amicton with numerous... layer, reddish, sandy s... few stones; roadside se... during highway constr...	
104 Upper Brookside	Base to top (3 m); reddi... amicton; organic s... diamicton.	
105 Riverside		
106 Riverside	Site showing superimp... sets. The oldest set trend... and is preserved in lar... the same trend on a res... crop. The grooves and... ations are stained... manganese-iron oxide... ply soil formation in a... non-glacial interval. Yo... cut across these groove... degrees.	Myers and Stea, 1986; Stea et al., 1987, 1988
107 Eagles Nest Point	Base to top (3-5 m); re... ton with Cobequid High... massive, sand, silt; grey... ton with gypsum clasts... silty diamicton with Co... land erratics (East Mil... and clay; reddish, silty... ton (Hants Till) with A... erratics; exposures alon... ley walls of the Shuben...	Myers and Stea, 1986; Stea et al., 1987, 1988
108 Lower Selmah		Myers and Stea, 1986; Stea et al., 1987, 1988, unpublished
109 King Creek		
110 Burncoat Head		
111 Noel Lake	Base to top (30 m); gre... amicton with limestone... bedded, compact clay... brownish peat, silt and... and shell fragments; red... amicton with abundant... Highland erratics (East... oxidized at top; clay; r... diamicton with abundant... River erratics (Hants Ti... of boreholes.	Stea et al., 1987, 1988 / As above / As above / As above / As above
112 Tennycape Quarry	Quarry surface reveals t... sets overlain by two dia... a lower greyish-red, sil... with few stones (East... and an upper reddish, s... (Hants Till). A bould... Mountain granite transp... south, was found embe... Hants Till.	Mott et al. 1986b, Stea and Mott, 1989

Number/Locality	Stratigraphy/Description	Dates (yr B.P.)	Principal reference
83 Big Island	Base to top (20 m) greyish silty compact diamicton, eastward fabric, bouldery, loose diamicton with sand layers, sand and silt with deformed layers grading into coarse sand, reddish diamicton with wedges, intrudes sand unit, drumlin exposure		Stea unpublished
84 Woodside	Base to top (1 m) reddish stony compact silty sandy diamicton with northwest fabric (Eatonville Hants Till), grey stony diamicton, reddish stony diamicton		Stea and Myers 1990
85 Eden Lake			As above
86 Trafalgar	Base to top (4 m) reddish silty diamicton (Eatonville Hants Till), red stained quartzite boulders, greyish stony sandy diamicton (Toney River Till), exposure of an isolated hummock		As above
87 New Glasgow	Base to top (1 m) grey oxidized clay diamicton, brown stony silty diamicton (Eatonville Hants Till)		Stea and Myers 1990
88 Wallace Point	Base to top (1 m) reddish silty clay diamicton (McCarron Brook Till), gravelly sand layer, greyish red blocky sandy silt diamicton with northwest fabric (Eatonville Hants Till), alteration zone with sand layers, reddish stony diamicton (Toney River Till)		Stea and Myers 1990
89 Sutns Point	Base to top (10 m) greyish red massive silty diamicton overlying bedrock with eastward strike (McCarron Brook Till), reddish stony silty diamicton (Eatonville Till)		Stea and Finck 1988
90 Toney River	Base to top (4 m) reddish stony sandy diamicton (Eatonville Till), greyish bouldery diamicton (Toney River Till), section overlies bedrock surface inscribed with two sets of striae the older trending eastward and the younger southwestward		Stea and Finck 1984, 1988
91 Cape John	Base to top (1 m) reddish brown clay diamicton overlying bedrock surface with eastward striae, greyish red silty diamicton (McCarron Brook Till), thin sand layer with alteration on the McCarron Brook Till, reddish sandy diamicton with Cobequid Highland boulders		Stea and Finck 1984, 1988
92 South Shore			Stea and Finck 1988
93 Bergeman Point			Stea and Finck 1988
94 Springhill			Stea and Finck 1988
95 Moose River			Stea and Finck 1988
96 Economy Mountain	Saprolite development on the tholeiitic basalt of Economy Mountain. The saprolite is believed to have formed during a lengthy warm period, perhaps the Tertiary. If this is true then little or no glacial erosion has occurred during the many ice ages that have characterized the Quaternary		Rutherford and Thacker 1988
100 Wentworth Valley	The Wentworth Valley is a good example of a glaciated valley, U-shaped and overdeepened. A 10 m exposure on the floor of the valley reveals organic silt with wood fragments and stumps overlain by rhythmically bedded silt, sand and clay, a diamicton and coarse gravelly sand. Folly Lake, at the head of the valley, is dammed at its northern end by 40 m or more of ice-contact stratified drift	10,700 ± 100 (GSC-4924) wood (Na-) lst from organic silt layer	Stea unpublished
101 Debert Lake	Base to top reddish stony silty sand diamicton, greyish brown stony sandy diamicton, many drumlins in the Debert Lake area encountered these two diamictons, both interpreted as basal tills		Alcock 1984
102 Debert	Site of Paleo-Indian occupation. Fluted points of a tradition similar to Folsom-Clovis found along with hearths. Site buried by up to 1 m of laminated sand believed to be eolian in origin	10,467 ± 118 (P-270A) charcoal hearth material, date represents the modal value of 18 dates obtained at the site	MacDonald 1968
103 Truro	Base to top (3 m) reddish sandy diamicton with numerous stones, peat layer, reddish sandy diamicton with few stones, roadside section exposed during highway construction	2,000 ± 120 (GSC-4297) basal part of peat, 11,400 ± 150 (GSC-4265) peat inclusion in upper diamicton	Stea and Mott 1989
104 Upper Brookside	Base to top (3 m) reddish brown diamicton, organic sand, reddish diamicton	11,700 ± 100 (GSC-3774) base of buried organic layer, 11,100 ± 100 (GSC-2930) top of buried organic layer	Mott et al 1986a
105 Riverside			Stea and Finck 1988
106 Riverside	Site showing superimposed striation sets. The oldest set trends 020 degrees and is preserved in large grooves of the same trend on a metasiltstone outcrop. The grooves and the older striations are stained with black manganese(?) oxide. This may imply soil formation in an intervening non-glacial interval. Younger striations cut across these grooves trending 250 degrees		Stea and Finck 1988
107 Eagles Nest Point	Base to top (3.5 m) reddish diamicton with Cobequid Highland erratics, massive sand and silt, grey silty diamicton with gypsum clasts, greyish red silty diamicton with Cobequid Highland erratics (East Milford Till), silt and clay, reddish silty sand diamicton (Hants Till) with Atlantic Upland erratics, exposures along the steep valley walls of the Shubenacadie River		Hughes 1957; Stea and Finck 1988
108 Lower Selmah			Stea and Finck 1988
109 Long Creek			Stea and Finck 1988
110 Burncoat Head			Stea and Finck 1988
111 Noel Lake	Base to top (30 m) greyish clay diamicton with limestone fragments, bedded compact clay with layers of brownish peat, silt and sand, wood and shell fragments, reddish silty diamicton with abundant Cobequid Highland erratics (East Milford Till) oxidized at top, clay reddish stony diamicton with abundant local clasts and erratics (Hants Till), composite of boreholes		Cornish 1980; Stea and Finck 1988
112 Tennycape Quarry	Quarry surface reveals three striation sets overlain by two diamicton units, a lower greyish-red silty diamicton with few stones (East Milford Till) and an upper reddish silty diamicton (Hants Till). A boulder of South Mountain granite transported from the south was found embedded in the Hants Till		Stea and Finck 1984; Stea et al 1987, 1988
118 Rawdon	Base to top (5 m) greyish red massive silty diamicton (East Milford Till), silt and clay, grey stony clay diamicton (Rawdon T)		
119 Luno	Base to top (3 m) rhythmically bedded clay and silt, massive clay, yellowish gravelly sand, peat with wood fragments, reddish clay diamicton with few stones, intercalated rhythmically bedded clay-sand, cross-bedded gravelly sand grading into clay, exposure in the brick quarry of L. E. Shaw Ltd	9,700 ± 100 (GSC-3774) base of peat, 10,900 ± 90 (GSC-3771) top of peat, 11,910 ± 125 (GSC-3411) calcareous concentration in lower clay unit, 9690 ± 100 (GSC-4042) wood in upper sand unit	
120 East Milford	Base to top (10 m) gypsum surface, grey clay diamicton with gypsum clasts, brown clay diamicton with few lavas and concretions, grey coarse sand, yellowish laminated sand and silt banded silt with peaty layers and wood, reddish gravelly sand, greyish red silt diamicton (East Milford Till), yellowish oxidized sand, reddish brown sandy diamicton (Hants Till), stripping wall exposure in the National Gypsum Co Quarry, detailed pollen analysis of peat sections in Mott et al 1982	Red ocarbon series 333,400 (GSC-) wood >50,000 (GSC-842), wood U/Th series 84,900 ± 6,500 (UQT-185), 84,700 ± 11,900 (UQT-186) wood	
121 Milford Station			Hughes
122 Shubenacadie	Base to top (20 m) massive clay, gravelly sand, peat, sand, exposure in the Shubenacadie Wildlife Park	11,400 ± 180 (GSC-433?) bottom of peat layer, 10,800 ± 100 (GSC-3980) top of peat layer	Stea
123 Frenci Hill	Base to top (4 m) yellowish brown compact stony diamicton, olive brown stony diamicton overlying bedrock with southeastward trending striation, yellowish-brown stony loose diamicton with strong southwestward fabric. Alteration (soil?) on the surface of the middle diamicton is very similar to the surface soil imply glacial free conditions intervening between the deposition of the two units		Mac
124 Gays River	Base to top (4 m) greyish sandy diamicton, iron cemented boulder diamicton above a sandy stony diamicton		Poole; Fowl
125 Mouse Point	Base to top (8 m) rock bench 4 m above MSL, sand, compressed peat with large wood fragments, silt, greyish red silty diamicton, sea cliff exposure in zone between drumlins		Stea
126 Colins Pond	Base to top (15 m) greyish red silty diamicton, peat with wood fragments, reddish brown stony silty diamicton, exposure on the flank of a drumlin-oid hill	12,700 ± 130 (GSC-4474) bottom of peat layer, 10,800 ± 100 (GSC-4367) top of peat layer, 10,900 ± 100 (GSC-4475) peat stringer in upper diamicton	Stea
127 Clams Cove	Base to top (31 m) greyish red silty diamicton with boulder pavements indicating eastward ice flow, reddish stony silty diamicton, drumlin exposure		Stea

CAPE BRETON SECTIONS

Note: Only major sections will be presented for Cape Breton Island. Other sections with coming memoir by D. R. Grant to accompany Cape Breton surficial map (Grant 198-)

Number/Locality	Stratigraphy/Description	Dates (yr B.P.)	Principal reference
128 Jarvin Island	Drumlin exposure red silty diamicton (Richmond Till) containing shells (Mercenaria sp.)	334,000 (GSC-1039) shell	Grant
129 Granville	Shells in esker	32,100 ± 900 (GSC-1408) shell	Grant

Principal reference

Myers and Stea 1986; Stea et al 1987, 1988

Myers and Stea 1986; Stea et al 1987, 1988

As above

Myers and Stea 1986; Stea et al 1987, 1988

Myers and Stea 1986; Stea et al 1987, 1988 unpublished

Stea et al 1987, 1988

As above

As above

As above

As above

Mott et al 1986b; Stea and Mott 1989

Westworth Valley is a good sample of a glaciated valley, U shaped and overdeepened. A 10 m exposure in the floor of the valley reveals organic silt with wood fragments. Stumps overlain by rhythmically bedded silt, sand and clay, a diamicton and coarse gravelly sand. Folly at the head of the valley is dammed at its northern end by 40 m or more of ice contact stratified drift — 10,700 ± 100 (GSC-4929) wood (Salix) from organic silt layer — Stea unpublished

to top reddish stony silty, sand diamicton greyish-brown, stony sandy diamicton. Many drillholes in the Ebert Lake area encountered these diamictons both interpreted as till — Alcock 1984

of Paleo-Indian occupation. Flat points of a tradition similar to Folsom-Clovis found along with hearths. Site buried by up to 1 m of laminated sand and believed to be eolian origin — 10,467 ± 118 (P-270A) charcoal hearth material date represents the modal value of 18 dates obtained at the site — MacDonald 1968

Base to top (3 m) reddish sandy diamicton with numerous stones, peat, reddish sandy diamicton with few stones, roadside section exposed during highway construction — 12,000 ± 120 (GSC-4287) basal part of peat 11,400 ± 150 (GSC-4265) peat inclusion in upper diamicton — Stea and Mott 1989

to top (3 m) reddish brown diamicton, organic sand, reddish diamicton — 11,700 ± 110 (GSC 3774) base of buried red organic layer 11,100 ± 100 (GSC 2930) top of buried organic layer — Mott et al 1986a

Stea and Finck 1988

showing superimposed striation. The oldest set trends 020 degrees is preserved in large grooves of same trend on a metasiltstone outcrop. The grooves and the older striae are stained with black manganese-iron? oxide. This may imply soil formation in an intervening non-glacial interval. Younger striations cut across these grooves trending 250 degrees — Stea and Finck 1984

to top (3-5 m) reddish diamicton with Cobequid Highland erratics massive sand, silt, grey, silty diamicton with gypsum clasts, greyish-red silty diamicton with Cobequid Highland erratics (East Milford Till), silt and clay reddish silty sand diamicton (Hants Till) with Atlantic Upland erratics, exposures along the steep valley walls of the Shubenacadie River — Hughes 1957 Stea and Finck 1988

Stea and Finck 1988
Stea and Finck 1989
Stea and Finck 1988

to top (30 m) greyish, clay diamicton with limestone fragments bedded compact clay with layers of brownish peat, silt and sand, wood shell fragments, reddish, silty diamicton with abundant Cobequid Highland erratics (East Milford Till) oxidized at top clay, reddish stony diamicton with abundant local clasts or erratics (Hants Till) composite boreholes — Cornish 1980 Stea and Finck 1988

surface reveals three striation overlain by two diamicton units, greyish-red silty diamicton, few stones (East Milford Till) and an upper reddish, silty diamicton Till) A boulder of South Mountain granite transported from the north was found embedded in the Till — Stea and Finck 1984 Stea 1984 Stea et al 1987 1988

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ties contains pollen dominated by pine and spruce with some thermophilous species such as oak, elm and maple present. The silt facies on the other hand is dominated by spruce (over 80%) and sedge pollen in the upper part indicating boreal forest conditions. A mastodon tusk was found associated with these organic beds

No.	Locality	Description	Dates	References
118	Rawdon	Base to top (5 m) greyish red massive silty diamicton (East Milford Till) salt and clay grey stony clay diamicton (Rawdon Till)		Stea 1982
119	Lantz	Base to top (3 m) rhythmically bedded clay and silt massive clay yellowish gravelly sand peat with wood fragments reddish clay diamicton with few stones intercalated rhythmically-bedded clay sand cross bedded gravelly sand grading into clay exposure in the brick quarry of L. E. Shaw Ltd	11,700 ± 100 (GSC 3774) base of peat 10,900 ± 90 (GSC 3771) top of peat 11,310 ± 125 (GSC 1411) calcareous concentration in lower clay unit 9690 ± 110 (GSC-4042) wood in upper sand unit	Mott et al 1986b Stea and Mott 1989 Stea and Mott 1990
120	East Milford	Base to top (10 m) gypsum surface grey clay diamicton with gypsum clasts brown clay diamicton with few clasts and concretions grey coarse sand yellowish laminated sand and silt banded silt with peaty layers and wood reddish gravelly sand greyish red silty diamicton (East Milford Till) yellowish oxidized sand reddish brown sandy diamicton (Hants Till) stripping wall exposure in the National Gypsum Co Quarry detailed pollen analyses of peat sections in Mott et al 1982	Radiocarbon series >33,800 (GSC 33) wood >50,000 (GSC 1642) wood U/Th series 84,900 ± 6,500 (UQT 185) 84,200 ± 11,300 (UQT 186) wood	Mott et al 1982 Mott and Grant 1985
121	Milford Station			Hughes 1957
122	Shubenacadie	Base to top (20 m) massive clay gravelly sand peat sand exposure in the Shubenacadie Wildlife Park	11,400 ± 180 (GSC-4337) bottom of peat layer 10,800 ± 100 (GSC 3398) top of peat layer	Stea and Mott, 1989
123	Forest Hill	Base to top (4 m) yellowish-brown compact stony diamicton olive brown stony diamicton overlying bedrock with southeastward trending striations yellowish-brown stony loose diamicton with strong southwestward fabric. Alteration (soil?) on the surface of the middle diamicton is very similar to the surface soil implying ice free conditions intervening between the deposition of the two units		MacEachern and Stea 1985
124	Queensport	Base to top (4 m) greyish sandy diamicton iron cemented bouldery diamicton loose sandy stony diamicton		Podolak and Shilts 1978 Stea and Fowler 1979
125	Moose Point	Base to top (8 m) rock bench 4 m above MSL sand compressed peat with large wood fragments silt greyish-red, silty diamicton, sea cliff exposure in zone between drumlins		Stea and Mott 1990
126	Collins Pond	Base to top (15 m) greyish red silty diamicton peat with wood fragments reddish brown stony silty diamicton exposure on the flank of a drumlinoid hill	12,700 ± 150 (GSC-4474) bottom of peat layer 11,800 ± 100 (GSC-4367) top of peat layer 10,900 ± 100 (GSC-4475) peat stringer in upper diamicton	Stea and Mott 1989
127	Clems Cove	Base to top (3 m) greyish red silty diamicton with boulder pavements indicating eastward ice flow reddish stony silty diamicton drumlin exposure		Stea and Mott 1990

CAPE BRETON SECTIONS

Note Only major sections will be presented for Cape Breton Island. Other sections will be described in detail in a forthcoming memoir by D R Grant to accompany Cape Breton surficial map (Grant 1988)

No.	Locality	Description	Dates	References
128	Janvrin Island	Drumlin exposure red silty diamicton (Richmond Till) containing shells (Mercenaria sp)	>34,000 (GSC 1639) shell	Grant 1971 Grant and King 1984
129	Grantville	Shells in esker	32,100 ± 900 (GSC 1408) shell	Grant, 1971 Grant and King 1984

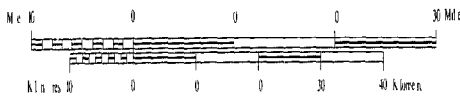| No.	Locality	Description	Dates	References
141	Antigonish	to top (4 m) diamicton organic silt sand peat organic silt diamicton	11,400 ± 120 (GSC-4466) top peat 11,600 ± 120 (GSC-4067) bottom of peat 11,790 ± 200 (UQ 970) bulk peat	
142	Castle Bay	Base to top indurated gravel stratified deltaic sand and finely laminated organic silt colluvium diamicton with shells (till)	Radiocarbon series >42,000 (GSC 157) organic silt >52,000 (GSC 169) wood from organic silt AAR series (Occhietti and Rutter 1982) D/L ASP (35) shell from upper diamicton	Blake 1984 Grant and King 1984
143	East Bay	Complex cliff section with coarse to medium gravels at the base overlain by a diamicton. Three distinct facies of organic sediments are enveloped by gravels Unit 1 compact woody peat Unit 2 silty clays interbedded with peat and wood Unit 3 organic silts. The three organic facies also show distinct pollen sequences termed palynostratigraphic units. The compact peat (Unit 1) is distinguished by a pollen sequence dominated by oak white pine and hardwood genera. The silty clays (Unit 2) are dominated by Balsam fir with some hardwood pollen. The organic silts (Unit 3) are characterized by coniferous pollen especially spruce and pine with abundant nonarboreal pollen. Unit 1 represents a true interglacial with a pollen spectra indicating a warmer climate than today. Units 2 and 3 are interstadial assemblages with cooler climate affinities	Radiocarbon series (wood) Unit 1 >50,000 (GSC 3860) Unit 1 2 >49,000 (GSC 3871) Unit 3 >50,000 (GSC 3878) U/Th disequilibrium series (wood) Unit 1 126,400 ± 15,000 (UQT 175) 123,400 ± 10,000 (UQT 176) 106,600 ± 9,600 (UQT 108) 60,800 ± 5100 (UQT 179) Unit 2 86,900 ± 6000 (UQT 109) Unit 3 62,100 ± 5000 (UQT 177) 98,700 ± 10,500 (UQT 227) 50,200 ± 5000 (UQT 188)	de Vernal et al 1986 Mott and Grant 1985
144	East Bay	Base to top diamicton peat diamicton	10,380 ± 150 (GSC 1578) peat	Grant 1971
145	Leitches Creek	Base to top (36 m) brown silty diamicton grey silty diamicton compressed peat with wood greyish cobbly diamicton organic silty clay with wood fragments greyish sandy diamicton. The upper organic layer is correlative with Palynostratigraphic Unit 3 The lower bed has high percentages of spruce pollen but with significant percentages of hardwood pollen. It is tentatively correlated with Unit 2 of the East Bay sequence	>52,000 (GSC 2678) peat for upper organics	Blake 1984 Mott 1971
146	Middle River	Mastodon teeth turned up by plow on the farm of Alexander MacRae	32,000 ± 630 (GSC 1770) bone	Blake 1984 Grant and King 1984
147	Saprolite locality	Base to top red and yellow saprolite (weathered residuum) developed from gneiss diamicton (till) and colluvium		McKeague et al 1983
148	Pleasant Bay	Base to top (3 m) diamicton sand peat organic silt sand diamicton	11,600 ± 100 (UQ 971) peat	Mott et al 1986b
149	St Lawrence	Base to top 25 m rock bench bouldery sandy diamicton and gravelly sand compressed peat with wood bouldery clast supported diamicton brown silty diamicton with shells grey and brown laminated silt and clay bouldery clast supported diamicton. The peat bed exhibits a conifer-dominated pollen assemblage correlative with Palynostratigraphic Unit 3 of East Bay The shell bearing diamicton has a foraminiferal assemblage indicating marine source beds of differing depths and paleoenvironments	Radiocarbon series 44,200 ± 820 (GSC 3636 wood) >46,000 (GSC 3864) wood >48,000 (GSC-4487 wood) U/Th disequilibrium series (wood) 47,000 ± 4700 (UQT 178) AAR series (Stea unpublished) shells from diamicton (D/L Leu 124–174) age estimate 90,000 120,000 AAA series (Occhietti and Rutter 1982 D L ASP 14-19) age estimate 75,000	Mott and Prest 1967 Newman 1971 Occhietti and Rutter 1982 Gnibault 1982 de Vernal 1983 de Vernal et al 1986 Mott and Grant 1986 Stea unpublished
150	Dingwall	Base to top organic silt or gyttja well rounded gravel reddish silty diamicton northern derivation sandy diamicton	32,000 ± 560 (GSC 3381) wood >39,000 (GSC 3417) wood 39,000 (GSC 3541) wood >48,000 (GSC 3541?) wood	Blake 1984 Grant and King 1984
151	South Aspy River	Base to top yellowish brown silty diamicton southwest fabric brown, cobbly diamicton southeast fabric with peaty silt blocks interbedded gravelly sand and silt bouldery diamicton	20,300 ± 400 (I 2438) peat 24,900 (I 3414) peat	Newman 1971

SURFICIAL GEOLOGY

OF

THE PROVINCE OF

NOVA SCOTIA

MAP 92-3

Compiled by R R Stea, H Conley and Y Brown

SCALE

1 500,000 or 789 miles to 1 inch

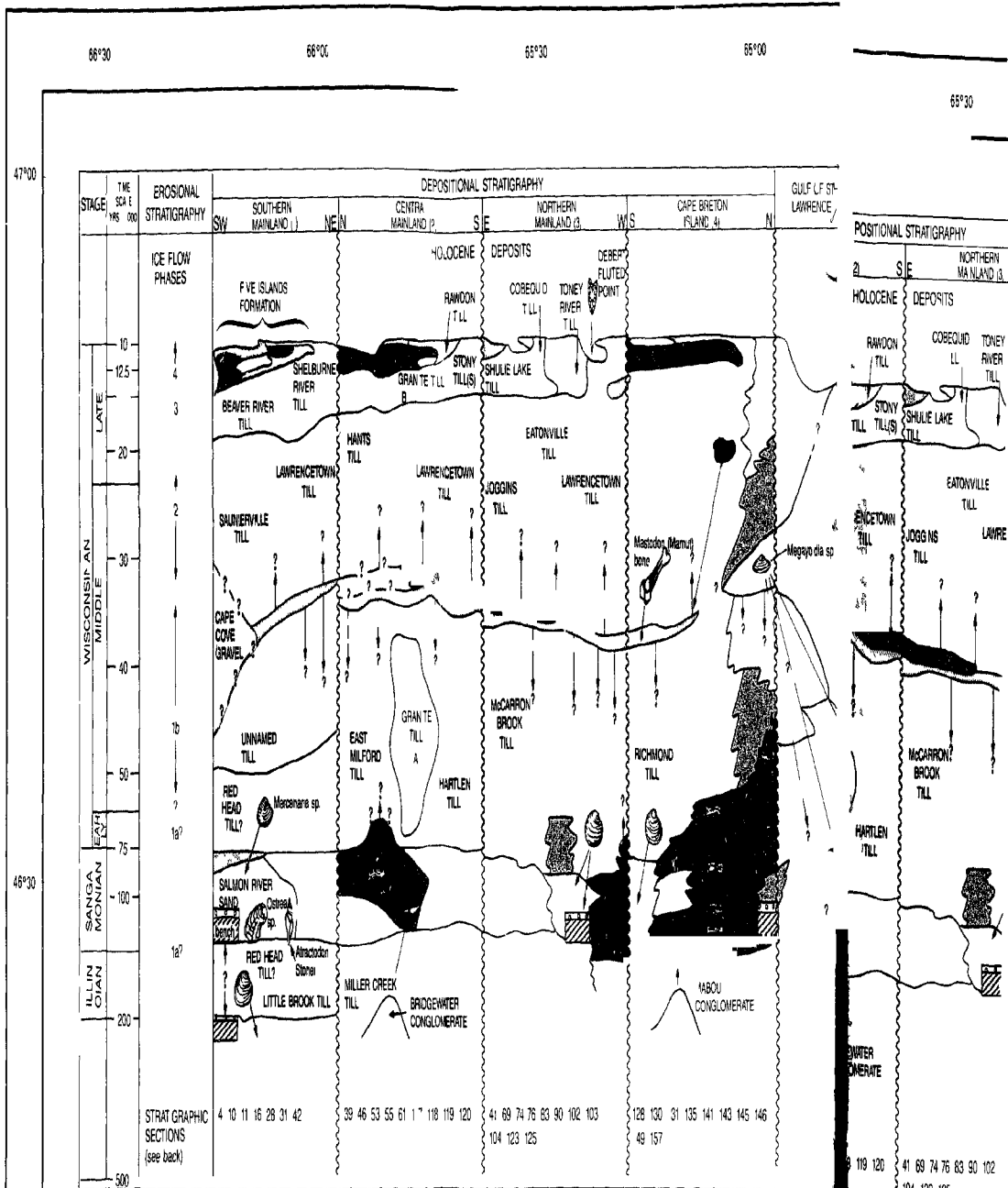### NOVA SCOTIA DEPARTMENT OF NATURAL RESOURCES

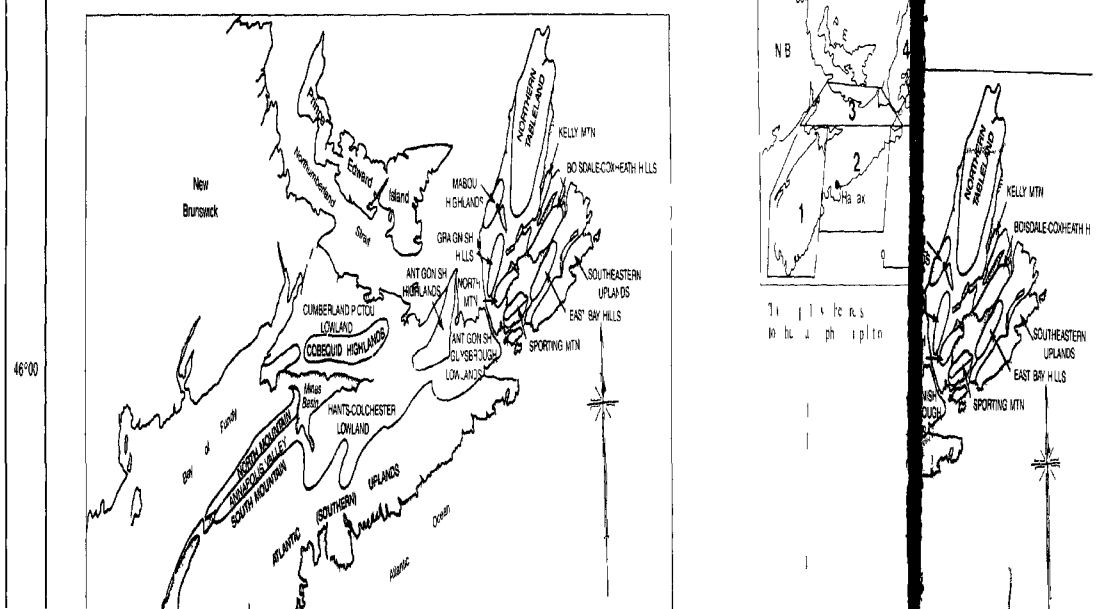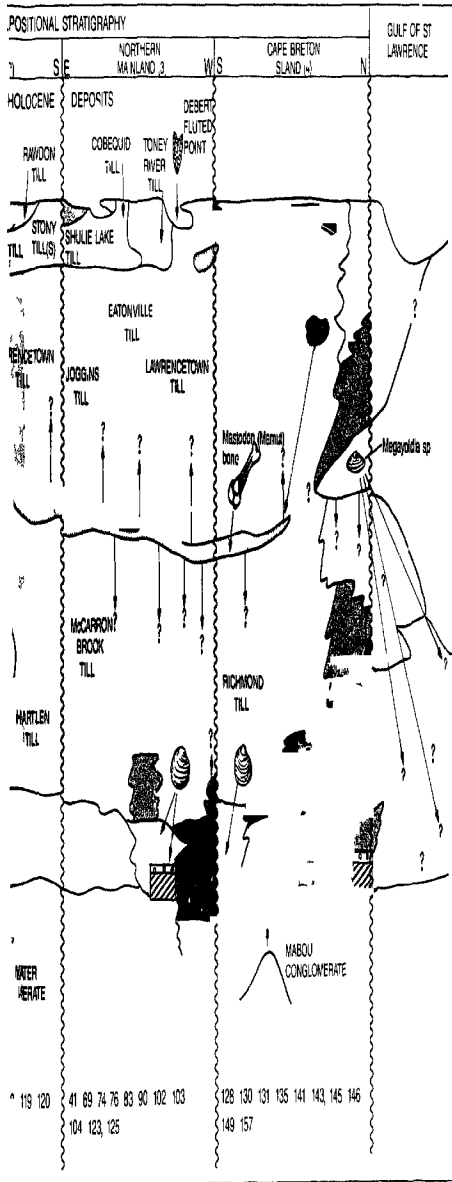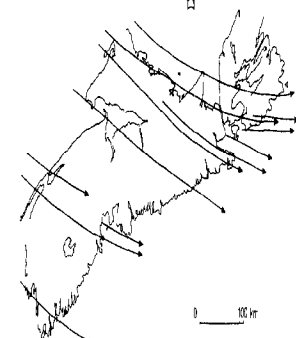### MINES AND ENERGY BRANCHES

Figure 1 Space time diagram illustrating the stratigraphic and temporal relationship between mapped surficial units and units found only in stratigraphic sections
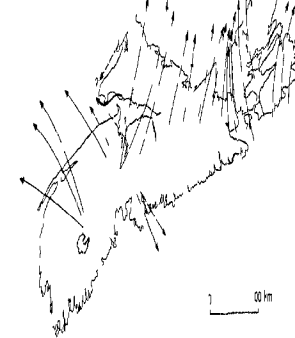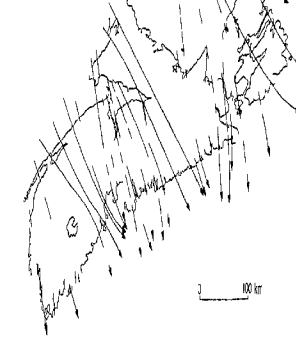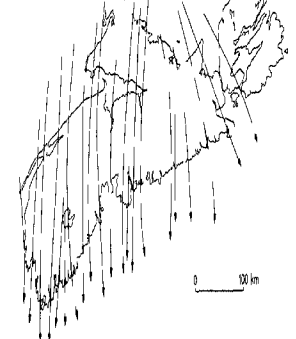
POSITIONAL STRATIGRAPHY

	NORTHERN MAINLAND ,3		CAPE BRETON ISLAND (4)	GULF OF ST LAWRENCE
S E		W S		N

HOLOCENE DEPOSITS

RAWDON TILL

COBEQUID TILL

DEBERT FLUTED POINT

TONEY RIVER TILL

STONY TILL(S)

SHULIE LAKE TILL

EATONVILLE TILL

RENCETOWN TILL

JOGGINS TILL

LAWRENCETOWN TILL

Mastodon (Mamut) bone

Megayoidia sp

McCARRON? BROOK TILL

RICHMOND TILL

HARTLEN TILL

WATER MERATE

MABOU CONGLOMERATE

119 120   41 69 74 76 83 90 102 103   128 130 131 135 141 143 145 146
           104 123, 125   149 157

NORTHERN HIGHLAND

KELLY MTN

BOISDALE-COXHEATH HILLS

SOUTHEASTERN UPLANDS

EAST BAY HILLS

SPORTING MTN

N B

Halifax

The map shows the areas used for the stratigraphic compilation

ICE FLOW PHASE 1A

ICE FLOW PHASE 1B

ICE FLOW PHASE 2

ICE FLOW PHASE 3

ICE FLOW PHASE 4

0   100 km

LEGEND

Ice center or divide early

Ice center or divide late

Flow paths   early   late

Ice margins   ?   ?
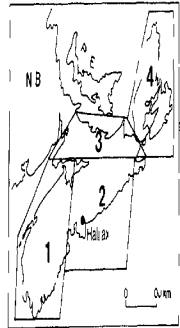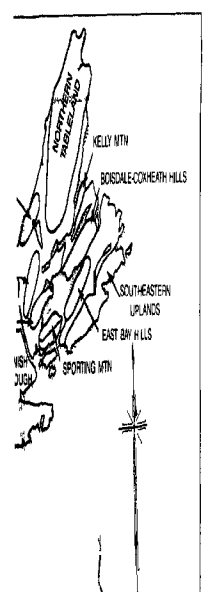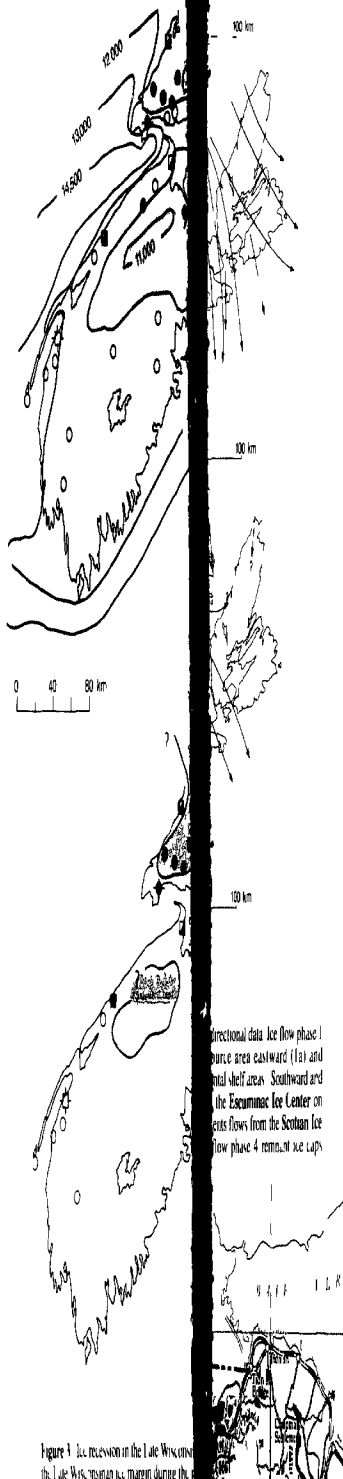
Figure 2 Ice flow pattern deduced from striation and drumlin directional data Ice flow phase 1 depicts ice flows from an Appalachian or Laurentian source area eastward (1a) and southeastward (1b) across the Bay of Fundy and onto the continental shelf areas. Southward and southeastward flow pattern during ice flow phase 2 stem from the Escuminac Ice Center on the shelf north of mainland Nova Scotia Ice flow phase 3 represent flows from the Scotian Ice Divide straddling the mainland of Nova Scotia During ice flow phase 4 remnant ice caps flowed into mainland areas adjacent to the Province

LATE GLACIAL SITES
(14,000-10,000 YR B.P)

- Peat buried by diamicton
- Peat buried by waterlain sediment
- Lakes bogs not recording oscillation
- Lakes bogs recording oscillation
- Ice marginal delta ca 14,000 12,600 y
- Raised beach ca 14,000 yr B P

0   40   80 km

directional data Ice flow phase 1 source area eastward (1a) and ntal shelf areas Southward and the Escuminac Ice Center on ents flows from the Scotian Ice flow phase 4 remnant ice caps

Figure 3 Ice recession in the Late Wisconsin the Late Wisconsinan ice margin during the

ICE FLOW PHASE 3

100 km

0 100 km

ICE FLOW PHASE 4

100 km

0 100 km

100 km

LEGEND

Ice center or divide early

Ice center or divide late

Flow paths early — late

Ice margins ?——?

Directional data ice flow phase 1
...urce area eastward (1a) and
...tal shelf areas Southward and
the **Escuminac Ice Center** on
...ents flows from the Scotian Ice
...low phase 4 remnant ice caps

H A L I F A X

LATE GLACIAL SITES
(14,000-10,000 YR B.P)

■ Peat buried by diamicton

▨ Peat buried by waterlain sediment

● Lakes, bogs not recording oscillation

○ Lakes, bogs recording oscillation

✦ Ice marginal delta ca 14,000-12,600 yr B.P

✧ Raised beach ca 14,000 yr B.P

ICE RECESSION IN THE
LATE WISCONSINAN

ICE ADVANCE
AT 10,500 YR B.P

0 40 80 km

LATE GLACIAL SITES
(14,000-10,000 YR B.P)

■ Peat buried by diamicton

▨ Peat buried by waterlain sediment

● Lakes, bogs not recording oscillation

○ Lakes, bogs recording oscillation

✦ Ice marginal delta ca 14,000-12,600 yr B.P

✧ Raised beach ca 14,000 yr B.P

0 40 80 km

Figure 3 Ice recession in the Late Wisconsinan. The first map shows the successive positions of
the Late Wisconsinan ice margin during the period from 14,500 yr B.P to 11,000 yr B.P. Darker
colours show progressively later areas of ice cover. The marginal positions are based on lake
and bog stratigraphy, landforms...

62°00' 61°30' 61°00' 60°30' 60°00'

47°00'

: IN THE
GINAN

14,000

12,000

12,000

46°30'

NCE
R. B.P.

LATE GLACIAL SITES
(14,000-10,000 YR. B.P.)

■ Peat buried by diamicton

▨ Peat buried by waterlain sediment

● Lakes, bogs not recording oscillation

○ Lakes, bogs recording oscillation

◆ Ice marginal delta ca.14,000-12,600 yr. B.P.

✧ Raised beach ca. 14,000 yr. B.P.

e positions of
: B.P. Darker

C St Lawrence   Blackrock Pt   C North
St Lawrence   Money Pt
Bay
Lowland Cove
Bay Road

Aspy
Bay

Pine Point
C Egmont
New Haven
Neil's Harbour
South Pt
Green Pt

CAPE BRETON HIGHLANDS
NATIONAL PARK
Archibald Pt
Ignatish I

Wreck Cove

Enrage Pt
Chéticamp
La Pointe
Island
La Pointe
Point Cross

Grand Étang
St Joseph du Moine
Cap Le Moine

Terre Noire

Grey Pt
Margaree Harbour

Chimney Corner

Naugee Island
(Sea Wolf I)

Marsh Pt
Broad Cove Marsh
Broad Cove Chapel

Inverness

Banks of Broad Cove

McKeigan Brook
McDonald Glen
Mabou Mines

Mabou Harbour Mouth

West Mabou Harbour
Colindale

C Linzee

Port Hood Island
Port Hood

Sea Man Pt

Little Judique Ponds

NEW WATERFORD
GLACE BAY
Table Hd
Flint I
C Percé

NORTH SYDNEY
SYDNEY
Port Morien
C Morien
South Port Morien
Hidden Cove
Mira

Scatarie Island
Eastern
Harbour
Mira
Gut
Louisbourg
C Breton

46°00'

Index map to compilation sources

46°00

45°30

45°00
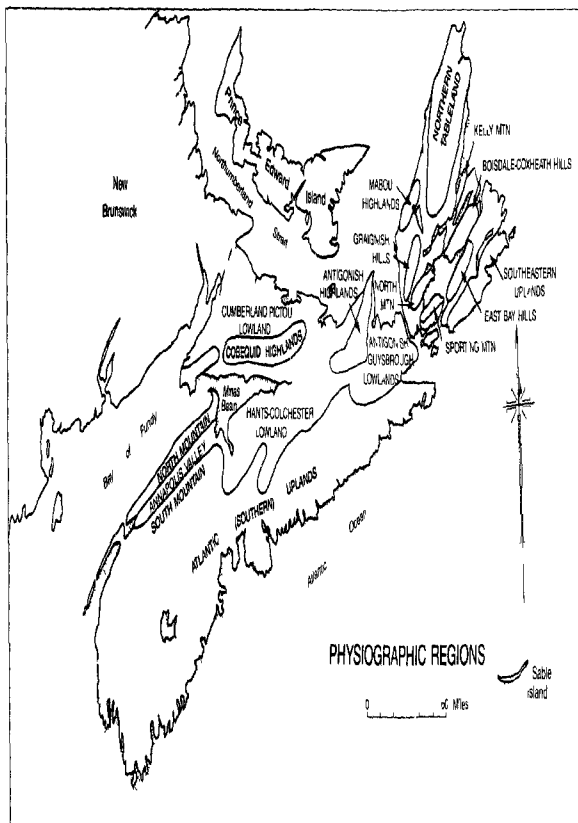
Figure 4 Physiographic regions of Nova Scotia

PHYSIOGRAPHIC REGIONS

Sable Island

MAJOR COMPILATION SOURCES

1 Cann D B and MacDougall J I 1960 Soil survey of Kings County Nova Scotia No 1 Scotia Soil Survey Report no 1 97 p

2 Finck P W Graves R M and Boner F J 1992 Glacial geology of the South Mountain Batholith Nova Scotia Nova Scotia Department of Natural Resources Map 92 2 scale 1 250 000

3 Grant D R 1988 Surficial geology Cape Breton Island Nova Scotia Geological Survey of Canada Map 1631 A scale 1 125 000

4 Hickox C F J 1962 Pleistocene geology of the central Annapolis Valley Nova Scotia Nova Scotia Department of Mines Memoir 5 36 p

5 Hughes O L 1957 Surficial geology of the Shubenacadie map area Nova Scotia Geological Survey of Canada Paper 56 7 30 p

6 MacNeil R H 1996 Surficial geology maps of Nova Scotia (NTS sheets 11A/6 7 11 21H/ 9) Nova Scotia Research Foundation Corporation Dartmouth Nova Scotia scale 1 50 000

7 Mott R F Stanley D J and James N 1967 The physical influences of spil over the morphology and preservation of Sable Island shelf process of Nova Scotia Quaternary Soil eds R B Morrison and H E Wright Proceedings of the VII INQUA Congress v 9 p 246-259

8 Stea R R 1982 Pleistocene geology and till geochemistry of south central Nova Scotia (sheet 0) Nova Scotia Department of Mines and Energy Map 82 1 scale 1 100 000

9 Stea R R (in progress) Surficial geology of part of Antigonish County (sheet 13) Nova Scotia Department of Mines and Energy scale 1 100 000

10 Stea R R and Finck P W 1988 Quaternary geology of Tatamagouche and Malagash Nova Scotia sheets 10 and 11 Nova Scotia Department of Mines and Energy Maps 88 13 and 88-14 scale 1 100 000

11 Stea R R Finck P W and Wightman D M 1986 Quaternary geology and till geochemistry of the western part of Cumberland County Nova Scotia (sheet 9) Geological Survey of Canada Paper 85 17

12 Stea R R and Fowler J H 1979 Minor and trace element variations in Wisconsin tills Eastern Shore region Nova Scotia Nova Scotia Department of Mines and Energy Paper 79 4 30 p

13 Stea R R and Fowler J H 1981 Pleistocene geology and till geochemistry of central Nova Scotia (sheet 4) Nova Scotia Department of Mines

EXPLANATION

This map depicts the distribution and nature of Quaternary glacial and other surficial deposits in Nova Scotia Outlined on the map is the glacial history of Nova Scotia Surficial deposits form the parent materials for most soils in Nova Scotia The data on this map are an aid to environmental studies mineral exploration agriculture forestry and construction

Figure 1 is a summary of the stratigraphic and temporal relationships of Nova Scotia Quaternary deposits Quaternary lithostratigraphic units in Nova Scotia are arranged by region and time from th

PHYSIOGRAPHIC RE

0   60

PHYSIOGRAPHIC REGIONS

NORTHERN TABLELAND

KELLY MTN

BO ISDALE-COXHEATH HILLS

MABOU HIGHLANDS

CRAIGNISH HILLS

ANTIGONISH HIGHLANDS

NORTH MTN

SOUTHEASTERN UPLANDS

ANTIGONISH GUYSBOROUGH LOWLANDS

SPORTING M TN

EAST BAY HILLS

0   60 Miles

Sable Island

Figure 2 The flow pattern deduced from ... dominated by ... ice flow phase 1 ... deposited ... ice flow from an **Appalachian–Laurentide** ice ... ... southeastward ... the Bay of Fundy and onto the continental shelf area. Southward and southeastward flow patterns during ... ice flow phase ... from the Escuminac Ice Center ... ... south mainland N ... S ... Ice flow phase 3 reflects flow from the Scotian Ice Divide straddling the mainland of No a S ... a. Du ng ... ice flow phase 4 remnant ... cap ... remnant ... at ... en o the Proven...

Figure 3 ... the La W ... contours show ... ... Scotian Ice Center remnant ice cap

AMHERST

SPRINGHILL

TRURO

KENTVILLE

LATE GLACIAL SITES
(14 000-10 000 YR B P)

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○ Lakes bogs recording oscillation

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0   40   80 km

Figure 3 Ice recession in the Late Wisconsinan The first map shows the successive position of the Late Wisconsinan ice margin during the period from 14 500 yr B P to 11 000 yr B P Darker colours show progressively older area of ice cover The marginal positions are based on lake and bog stratigraphy limiting radiocarbon dates ice marginal landforms and topography Lake core that show a transition from organic sediment to mineral sediment and back to organic sediment at the base are defined as lakes recording oscillation (see explanation) Such lakes are generally older than 13 000 yr B P and as old as 14 000 yr B P in southern Nova Scotia The second map depicts an ice advance ca 10 500 yr B P based on till and outwash cover, I late glacial peat site and lake site not showing the late wis018 n
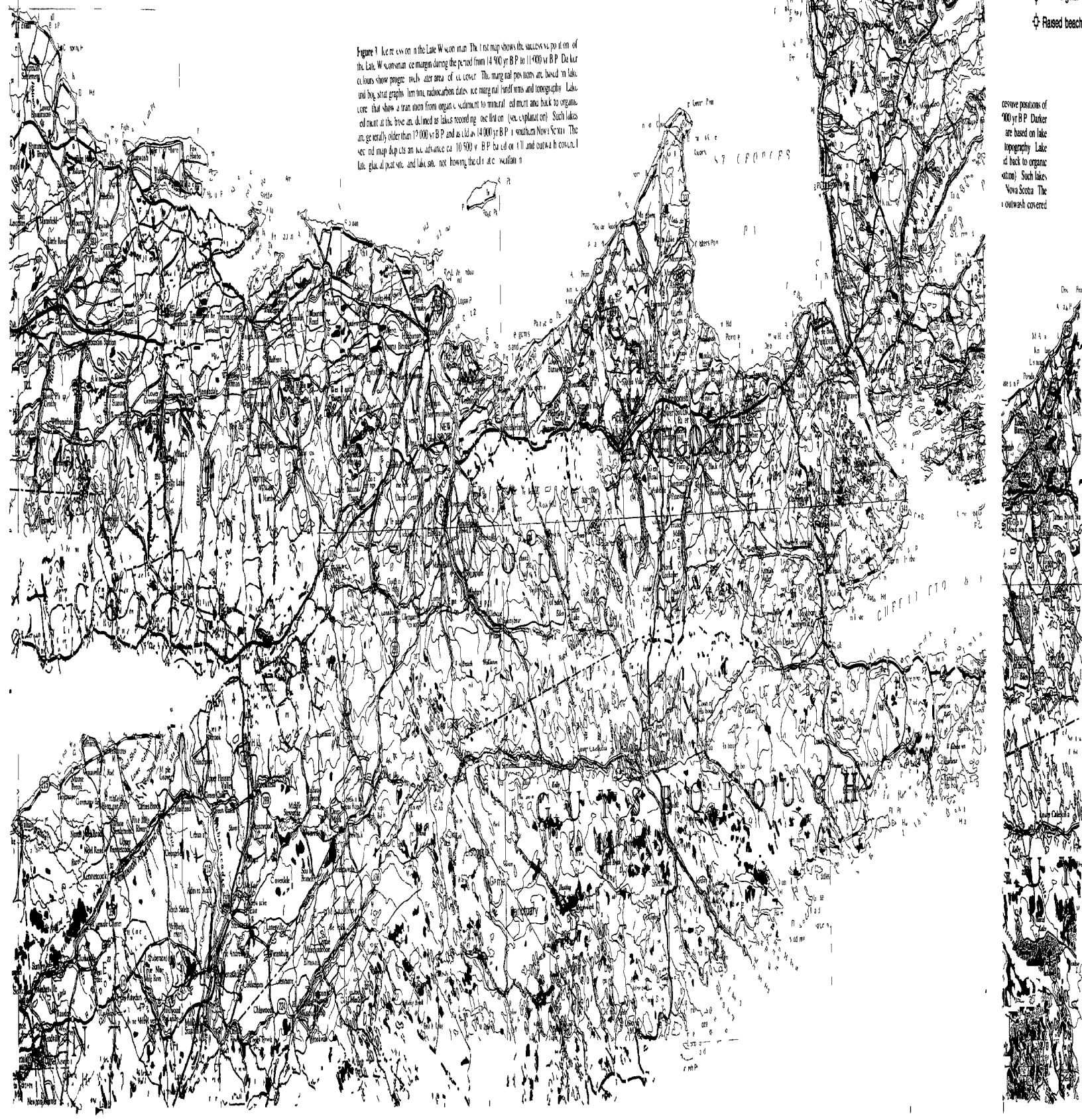
SYMBOLS

Geological boundary

Cirques a ge semic rcular rock basins)

Roche moutonnee (truncated ll pt cal outcrop steep lee de barb po nts down ice)

Glacial striae (large and small nea grooves on rock ice flow direct on known unknown l indicates older striae barb po nt n the direction of ce flow printed on reverse s de)

Drumlins fluted terra n (ridge and elliptical hill parallel to ice flow svn bx s prin ed on re erse side)

Moraine ridge (ridges perpendicular to ce flow major minor)

Hammocks (m unds of till and sand and gravel)

Esker (sinuou ridge of sand and gravel generally parallel to ice flow direct on of ac ce flow assumed or known unknown)

Delta (kame ou wash

Kettle (c rcular depressions or p ts large smal)

Meltwater sp llway channel (flat bottomed valleys w th misfit streams)

Terrace scarp

Location of stratigraphic section of special interest (numbers refer to sections refer nced in the

9 Stea R R. (in progress). Surficial geology of part of Antigonish County (sheet 13); Nova Scotia Department of Mines and Energy, scale 1:100,000

10 Stea R R. and Finck P. W. 1988. Quaternary geology of northern mainland Nova Scotia, sheets 10 and 11; Nova Scotia Department of Mines and Energy, Maps 88-13 and 88-14, scale 1:100,000

11 Stea R R. Finck P. W. and Wightman D. M. 1986; Quaternary geology and till geochemistry of the western part of Cumberland County, Nova Scotia (sheet 9); Geological Survey of Canada Paper 85-17.

12 Stea R. R. and Fowler J. H. 1979; Minor and trace element variations in Wisconsinan tills, Eastern Shore region Nova Scotia; Nova Scotia Department of Mines and Energy, Paper 79-4 30 p

13 Stea R. R. and Fowler J. H. 1981; Pleistocene geology and till geochemistry of central N Scotia (sheet 4); Nova Scotia Department of Mines and Energy, Map 81-1 scale 1:100,000

14 Stea R. R. and Grant D. R. 1982. Pleistocene geology and till geochemistry of southwest Nova Scotia (sheets 7 and 8); Nova Scotia Department of Mines and Energy, Map 82, scale 1:100,000

15 Stea R. R. and Myers R. A. 1991; Surficial geology of parts of Halifax, Pictou, Guysborough and Antigonish Counties (sheet 12); Nova Scotia Department of Mines and Energy, Map 90-6 Scale 1:100,000

16 Stea R. R. and Turner R. G. (in progress); Surficial geology of the Bridgetown map (NTS 21A/14); Nova Scotia Department of Mines and Energy, Open File Map, 1:50,000

17 Truscott P. C. 1968. Groundwater resources and hydrogeology of the Annapolis V Nova Scotia; Nova Scotia Department of Mines, Memoir 6, 154 p

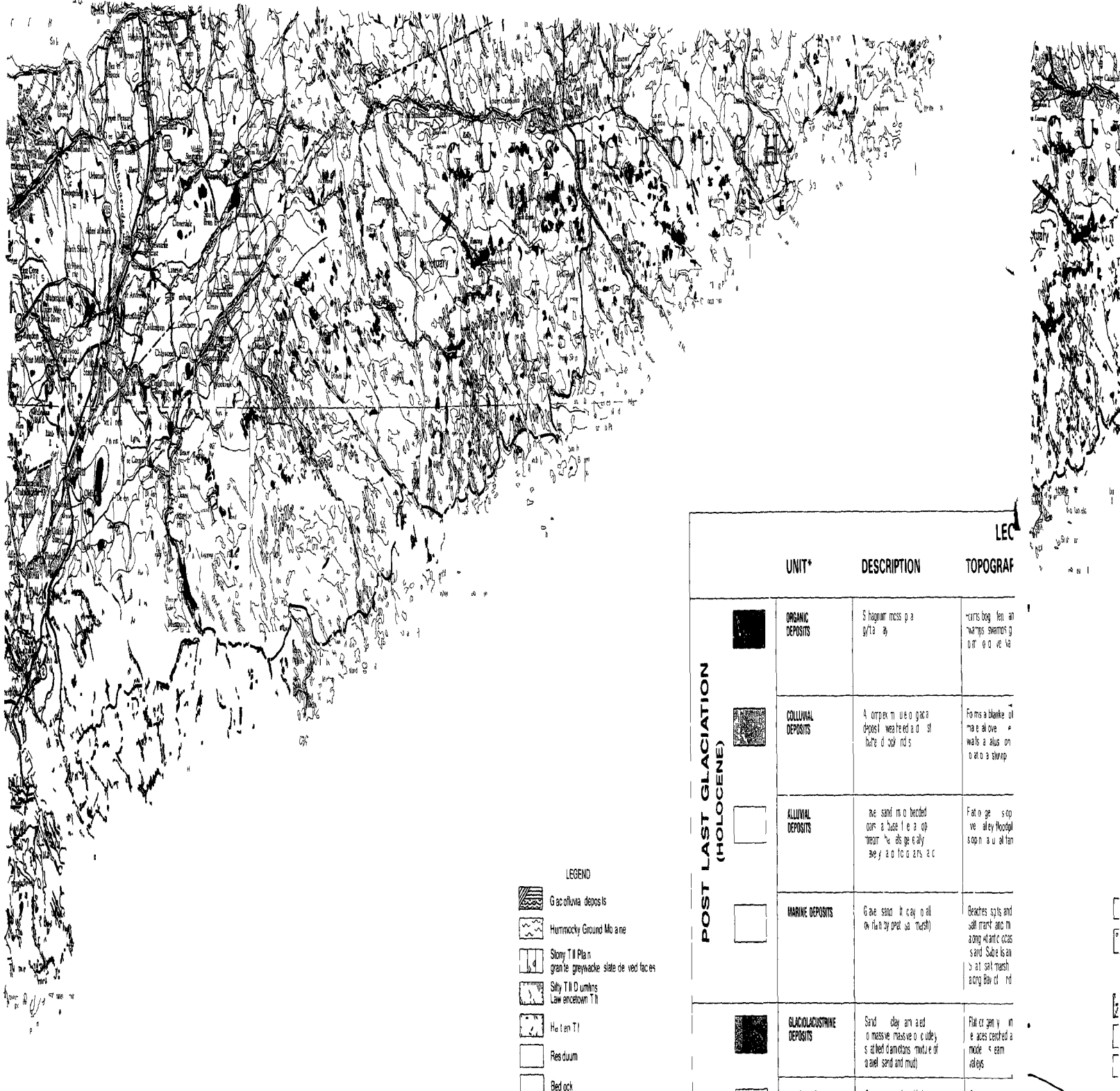## EXPLANATION

This map depicts the distribution and nature of Quaternary glacial and other surficial deposits in Nova Scotia. Outlined on the map is the glacial history of Nova Scotia. Surficial deposits form the parent materials for most soils in Nova Scotia. The data on this map are an aid to environmental studies, mineral exploration, agriculture, forestry and construction.

Figure 1 is a summary of the stratigraphic and temporal relationships of Nova Scotia Quaternary deposits. Quaternary lithostratigraphic units in Nova Scotia are arranged by region and time from the lowest or earliest units to the highest or latest units. The erosional stratigraphic record (striations) is also shown on this Figure (see also Fig. 2). Ice flow phases are correlated with till sheets by comparing regional ice flow directions with till provenance and fabric. Named Quaternary lithostratigraphic units are shown on this figure and described in more detail on back of the map. Reference sections used to construct this diagram are numbered on the bottom of the diagram. Refer to the map on the reverse side for section locations and descriptions.

Colours on Figure 1 refer to lithogenetic units described in the legend (i.e. green units are tills, orange = glaciofluvial, etc.). Screened regions on the diagram imply ice-free conditions prevailing, indicated by soil formation. Arrows indicate the uncertainty of age assignments in this compilation. Dated fossil materials (i.e. shells, wood and peat) are depicted on the diagram in their stratigraphic and temporal context. Reworked fossil materials (i.e. shells in till) have arrows pointing to their presumed source beds. Roman numerals correspond to pollen stratigraphic units (see list of sites on back for further description).

Intensely oxidized deposits (Bridgewater, Mabou Conglomerates) may predate the earliest glaciation. A pre-Illinoian interglacial interval (200,000–300,000 yr B P) is indicated by dates on shells in till in southwest Nova Scotia. The last interglacial period, the Sangamonian (75,000–128,000 yr B P), is represented by marine and terrestrial deposits underlying tills of the last glacial period, the Wisconsinan. The Salmon River Sand in southwest Nova Scotia has a warm water fauna indicating present-day conditions. During this time sea level was up to 5 m higher than at present. This higher sea level cut a shoreline whose remnants are flat, wave-cut rock benches underneath glacial deposits. At the same time forests grew on land. These forest communities changed from hardwood-dominated (Unit I) during the warm part of the interglacial to spruce and fir forests (Unit III) in the colder phases.

It is not certain when glaciers first developed in the Wisconsinan. In northern Cape Breton Island, ice-free conditions may have persisted until 50,000 yr B P, offshore in the Gulf of St. Lawrence perhaps later. Continuous ice cover throughout most of the Wisconsinan stage is indicated on the mainland except for indications (soils?, lacustrine deposition) of short-lived ice retreat at several sections.

The earliest Wisconsinan ice flows in Nova Scotia were eastward (Phase 1a, Fig. 2) then southeastward (Phase 1b, Fig 2). Several widely-spaced striation sites reveal a distinct eastward flow preserved in bedrock lee-side hollows and depressions later overrun by southeastward-trending striations. In fact the eastward ice flow may represent a separate, older phase of glaciation. The Hartlen, East Milford, Richmond and Red Head Tills (Fig 1) were formed during these ice flows. The East Milford Till contains boulders of igneous rocks from the Cobequid Highlands and basaltic rocks from the North Mountain which were transported southeastward and can be traced to the Atlantic Coast up to 120 km down-ice. This phase may represent glaciers with an Appalachian or Laurentide source.

The second major ice flow trend (Phase 2, Fig. 2) was southward and southwestward from the Escuminac Ice Center in the Prince Edward Island region. This event is recorded by southward-trending striae crossing earlier southeastward-trending striae at many localities on the upland regions of Nova Scotia and New Brunswick. The Lawrencetown and Eatonville Tills (Fig. 1) were formed during this flow event. Material from the vast area of redbeds in northern mainland Nova Scotia and Carboniferous basins in the Prince Edward Island region was transported southward onto the metamorphic and igneous terranes of mainland Nova Scotia. Southward dispersal of distinctive Cobequid Highland erratics occurred with the dispersal of the red material.

During the next ice flow event (Phase 3) granites from the Atlantic Uplands Physiographic Province were transported northward onto the North Mountain. The Hants and Beaver River Tills were formed during this ice flow phase. Erratics from the Cobequid Highlands can be found throughout the Cumberland–Pictou Lowlands to the north. Northward-trending striations can be traced across the northern mainland of Nova Scotia (Fig. 2). This well documented northward ice flow was clearly in response to the development of an ice divide in southern Nova Scotia (Fig. 2). Ice flow was northward and southward from this divide across the axis of the Nova Scotia peninsula. This divide may have formed as a result of marine incursion into the Bay of Fundy or a climatic event

45°00

44°30

44°00

Figure 6. Diagrammatic
on the Atlantic Uplands p

LEGEND

	UNIT*	DESCRIPTION	TOPOGRAF
POST LAST GLACIATION (HOLOCENE)	ORGANIC DEPOSITS	Shagnum moss p a g/ta ay	rms bog fen an wamps swamps g om g o ve Va
	COLLUVIAL DEPOSITS	A ompex m ue o gaca deposist weathe ed a d st hare d ock nd s	Fo ms a blanke ol ma e al ove wals a lus on o a o a sl mp
	ALLUVIAL DEPOSITS	a e sand m o bedded coa a base t e a op nteam h as ge ally ave y a d fo d ars a c	Fa o ge s op ve aley floodpl s op n a u al fan
	MARINE DEPOSITS	G ave sand lt cay o all ov n an by g at sa marsh)	Beaches spts and salt marsht anc m a ong Atant c ocas sand Sabe Is an 5 at salt marsh a ong Bav cl nd
—ACIATION —NSINAN) (GLACIAL)	GLACIOLACUSTRINE DEPOSITS	Sand clay am a ed o massive mass ve o c ude y s at ked d amctons m xtu e of a avel sand and mud)	Flat o gen y m e aces clerched a mode s eam valeys
	GLACIOMARINE DEPOSITS	G ave ano sand bedded d poor y seabe d 5 10 occa y s t and clay	Gent y s op ng sho above mode n t d with p ol udng né ra sed beaches) wave cu erra es
	GLACIOFLUVIAL DEPOSITS		
	OUTWASH FANS DELTAS AND VALLEY TRAIN DEPOSITS	G ave and sand mass ve to horzo taly st a ked coarse to fine g adation v thn sections and deposits	Fan-shaped obes mouths of valeys ol outwash conf n (VT) topset part Gilbert type delta. (see Fig 5)
	KAME FIELDS AND ESKER SYSTEMS	G ave sand and silt d amcton layers poo y to we bedded horizontal o angua beds faulting and col apse feat es common	Steep sided m (moul n kames) valey s des (kam sinuous steep s (eskers)

LEGEND

- Gacofluvia deposts
- Hummocky Ground Mo a ne
- Stony T ll Pla n gran te greywacke slate de ved fac es
- S lty T ll D umlins Law encetown T ll
- Ho ten T ll
- Res duum
- Bed ock

ATLANTIC UPLANDS PHYSIOGRAPHIC PROVINCE

Granitic rocks | Meta greywacke | Slate

NW / SE

Atlantic Ocean

Figure 6 D a mma r g a o o h a g p c a o h p e w n u fa l
n h Atlantic Upland ph e rug c g n

Drumlins fluted terrain (ridge and elliptical hills parallel to ice flow symbols printed on reverse side)

Moraine ridge (ridges perpendicular to ice flow major minor)

Hummocks (mounds of till and sand and gravel)

Esker (sinuous ridge of sand and gravel generally parallel to ice flow direction of meltwater flow assumed or known unknown)

Delta (kame outwash)

Kettle (circular depressions or pits large small)

Meltwater spillway channel flat bottomed valleys with misfit streams

Terrace scarp

Location of stratigraphic section of special interest (numbers refer to sections referenced in the time-space diagram (Figure 1) and in the sources of geological information on the back)

45°00

44°30

LEGEND

Glaciofluvial deposits

Hummocky Ground Moraine

Stony Till Plain granite greywacke slate derived facies

Silty Till Drumlins Lawrencetown Till

Hartlen Till

Residuum

Bedrock

Slate

SE

Atlantic Ocean

Relationships between surficial units

LEGEND / ECONOMIC AND ENVIRONMENTAL SIGNIFICANCE

UNIT*	DESCRIPTION	TOPOGRAPHY	THICKNESS	ORIGIN	ECONOMIC AND ENVIRONMENTAL SIGNIFICANCE
POST LAST GLACIATION (HOLOCENE)					
ORGANIC DEPOSITS	Sphagnum moss peat gyttja clay	Forms bogs fens and swamps swamps generally form along river valleys	Bogs 1 m at the edge 3 m in the centre swamps < 2 m	Develop by infilling of ponds or river courses by vegetation	Source of fuel fertilizer medicinal and industrial products wet lands provide nesting and feeding habitats for wildlife peat extracts contaminants from groundwater
COLLUVIAL DEPOSITS	A complex mixture of glacial deposits weathered and frost shattered rock and soils	Forms a blanket of material over steep valley walls a talus cone or rotational slump	increases from < 1 m at the top of the valley wall or slope 0 5 m a the base	Formed by periods of downslope creep and or mass movements along valley sides	Source of aggregate of poor quality valley sides can be subject to rapid destructive slides deforestation can cause severe erosion zone of springs and seeps
ALLUVIAL DEPOSITS	Gravel sand mud bedded coarse at base finer at top stream channels generally gravely sand floodplains sar	Flat or gently sloping river valley floodplains and sloping alluvial fans	Thin veneer < 1 m in small streams 20 m in large floodplains	Deposited by streams and rivers after retreat of the last glaciers	Major source of groundwater source of aggregate utilized for pasture land limitations for crop use and construction include flooding high water table poor drainage
MARINE DEPOSITS	Gravel sand silt clay locally overlain by peat (salt marsh)	Beaches spits and bars intertidal salt marsh and mud flats beaches along Atlantic coasts Cape Breton land Sable Island Northumberland Strait salt marsh and mud flat many along Bay of Fundy shoreline	Beaches 2 8 m salt marsh < 2 m	Formed by coastline sedimentation through wave action longshore currents and tides	Wildlife sanctuaries feeding grounds recreational areas
GLACIATION (ONSINAN)					
GLACIOLACUSTRINE DEPOSITS	Sand silt clay laminated to massive massive or crudely stratified diamictons (mixture of gravel sand and mud)	Flat or gently rolling terraces perched above modern stream or river valleys	Generally > 2 m can attain 30-40 m along major valley systems	Deposited in a ponded body of water either in direct contact with ice or fed by glacial meltwater	Clay utilized for brickmaking pottery land used for pasture limitations include poor drainage and surface runoff
GLACIOMARINE DEPOSITS	Gravel and sand bedded dipping seaward 5 10° locally silt and clay	Gently sloping shoreline above modern tide level with protruding ridges raised beaches) and scarps (wave cut terraces)	Shoreline deposits vary from 4 5 m gravelly raised beach ridges 3 10 m	Deposits formed as the sea flooded a lowered coastline depressed by the glaciers weight As the land rebounded after the glacier left the shoreline was raised above sea level	Gravel and sand utilized for aggregates cultivated for crops used as pasture land groundwater source
GLACIOFLUVIAL DEPOSITS					
OUTWASH FANS DELTAS AND VALLEY TRAIN DEPOSITS	Gravel and sand massive to horizontally stratified coarse to fine gradation within sections and deposits	Fan shaped lobes at the mouths of valleys (OF) belts of outwash confined to valleys (VT) topset part of Gilbert type deltas (OD) (see Fig 5)	Outwash fans 5 30 m valley trains 5 50 m outwash deltas 5 25 m	Deposition by freely wandering glacial streams in front of a glacier (OF) meltwater streams confined to valley walls (VT) meltwater streams depositing material in to the ocean (OD)	Source of quality aggregate for concrete roadbase especially in areas of hard rocks excellent aquifer sometimes confined by clay at the base (OD) rapid drainage and acidity impede cultivation aquifer easily contaminated
KAME FIELDS AND ESKER SYSTEMS	Gravel sand and silt diamicton layers poorly to well bedded horizontal to angular beds faulting and collapse features common	Steep sided mounds or hummocks (moulin kames) pitted terraces on valley sides (kame terrace) sinuous steep sided ridges (eskers)	Generally 4 6 m kames 4-20 m kame terraces 3-30 m eskers 5 10 m	Streams of glacier meltwater depositing material in holes in ice (MK) between glacier and valley slopes (KT) in water (kame delta) in tunnels	Source of aggregate of varied quality severe limitations to crop use include stoniness and drainage and irregular topography utilized for blue

perhaps the Continuous ice cover throughout the Wisconsinan was eliminated or the mild or perhaps indications soils? the warmest deposition the coldest reflects some ice so

The earliest Wisconsinan ice flow in Nova Scotia were to the ird (Phase 1) Phase 1 then southeastward. Phase 1b Parallel widely spaced striations were oriented... directed to ld flow preserved in bedrock keel... de hollows and depressions. later orient... by southeastward-trending striations. In fact the eastward ice flow may represent a separate older phase of glaciation. The Hartlin, East Milford, Richmond and Red Head Till... were formed during these ice flows. The East Milford Till contains boulders of igneous rocks from the Cobequid Highland... the rocks from the North Mountain which were transported to the eastward and... be traced to the Atlantic Coast up to 10 km to... ice. This phase may represent a later... with an Appalachian or local... source.

The second major ice flow trend (Phase 2) flow... was southward and southwestward from the Escuminac Ice Center in the Prince Edward Island region. This event is recorded by southward trending striae crossing earlier southeastward trending striae was localized on the upland regions of Nova Scotia and New Brunswick. The Lawrencetown and Fatonville Tills (Fig...) were formed during this flow event. Material from the vast area of redbed in northern mainland Nova Scotia and Carboniferous basins in the Prince Edward Island region was transported southward onto the metamorphic and igneous terrains of mainland Nova Scotia. Southward dispersal of till in the Cobequid Highland erratics occurred with the dispersal of the red material.

During the next ice flow event (Phase 3) granites from the Atlantic Uplands Physiographic Province were transported northward onto the North Mountain. The Hants and Beaver River Tills were formed during this ice flow phase. Erratics from the Cobequid Highlands can be found throughout the Cumberland Pictou Lowlands to the north. Northward trending striations can be traced across the northern mainland of Nova Scotia (Fig 2). This well documented northward ice flow was clearly in response to the development of an ice divide in southern Nova Scotia (Fig 2). The flow was northward and southward from this divide across the axis of the Nova Scotia peninsula. This divide may have formed as a result of marine incursion onto the Bay of Fundy or a climatic event.

The final phase of ice flow resulted from remnant ice caps developed from the Scotian Ice Divide (Fig 2). Eskers and striations cut across features formed by earlier ice flows. Ice caps or glaciers that formed over the Chignecto Peninsula and southern Nova Scotia had margins on land marked by moraines ablation till glaciofluvial deposits and the pinch-out of stony till sheets. The Shulie Lake and Toney River Tills were formed during this last ice flow phase. Ice flow during this last phase was tunnelled westward into the marine basins. Erosional features and deposits relating to this late glacial ice caps are restricted to low lying areas.

At the end of the Late Wisconsinan the sea encroached into the Bay of Fundy and ocean... retreat occurred rapidly through calving. Glaciomarine deltas formed along the coast dated from 14,900 to 12,600 yr B.P. Peat formed in depressions on land starting 12,700 yr B.P. The climate warmed and spruce trees migrated into the region along with ice age mammals including caribou. Indian first hunted in Nova Scotia at Debert 11,000 years ago. Then suddenly the climate became cooler and inhospitable. Glaciers advanced in some areas from highland remnant sometime after 11,000 yr B.P. Late glacial sites (Fig 3) record the change of climate. Lakes were inundated with sediment due to decreased vegetation cover. Glacial sediments buried some former peat bogs.

By 10,000 years ago all remaining ice melted and the climate warmed rapidly. Spruce forests were established in the early post-glacial period.
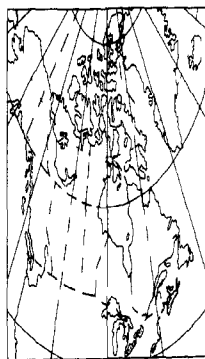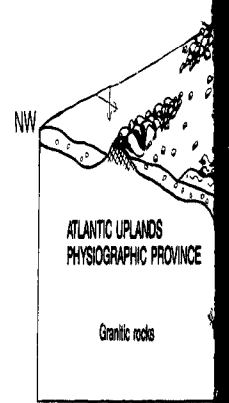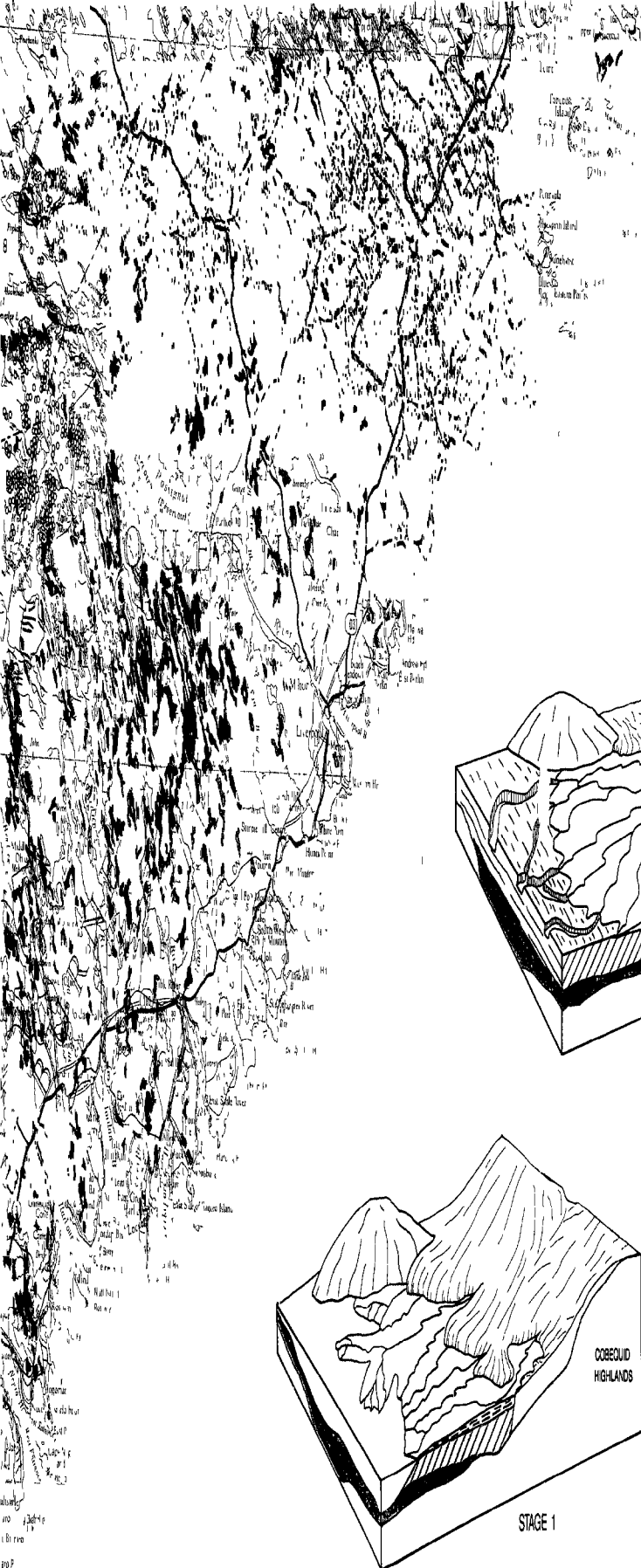

Index Map
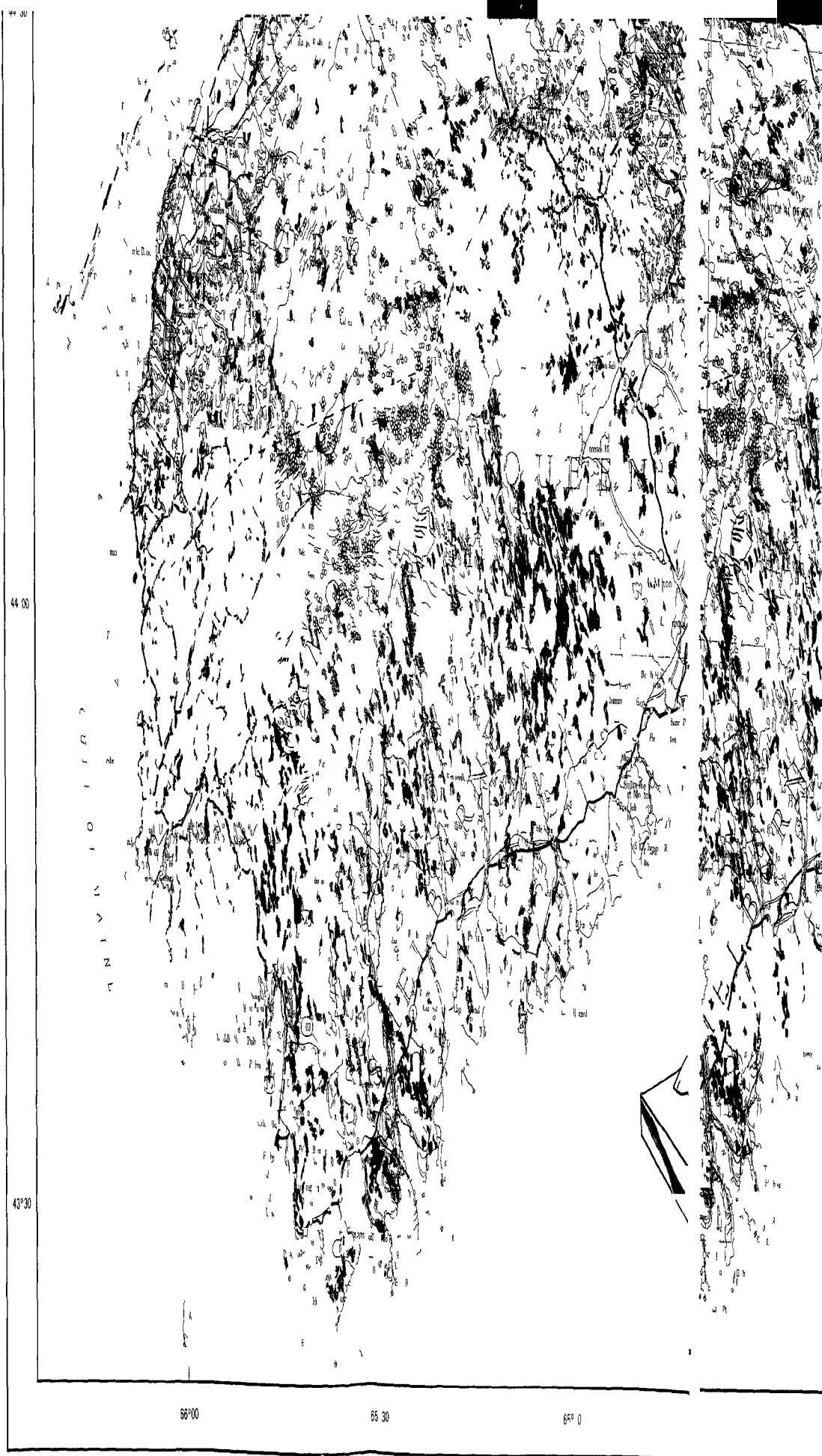
ATLANTIC UPLANDS
PHYSIOGRAPHIC PROVINCE

Granitic rocks

NW

Figure 6 Diagrammatic representation of the s...
on the Atlantic Uplands physiographic region

STAGE 2

COBEQUID
HIGHLANDS

STAGE 3

COBEQUID
HIGHLANDS

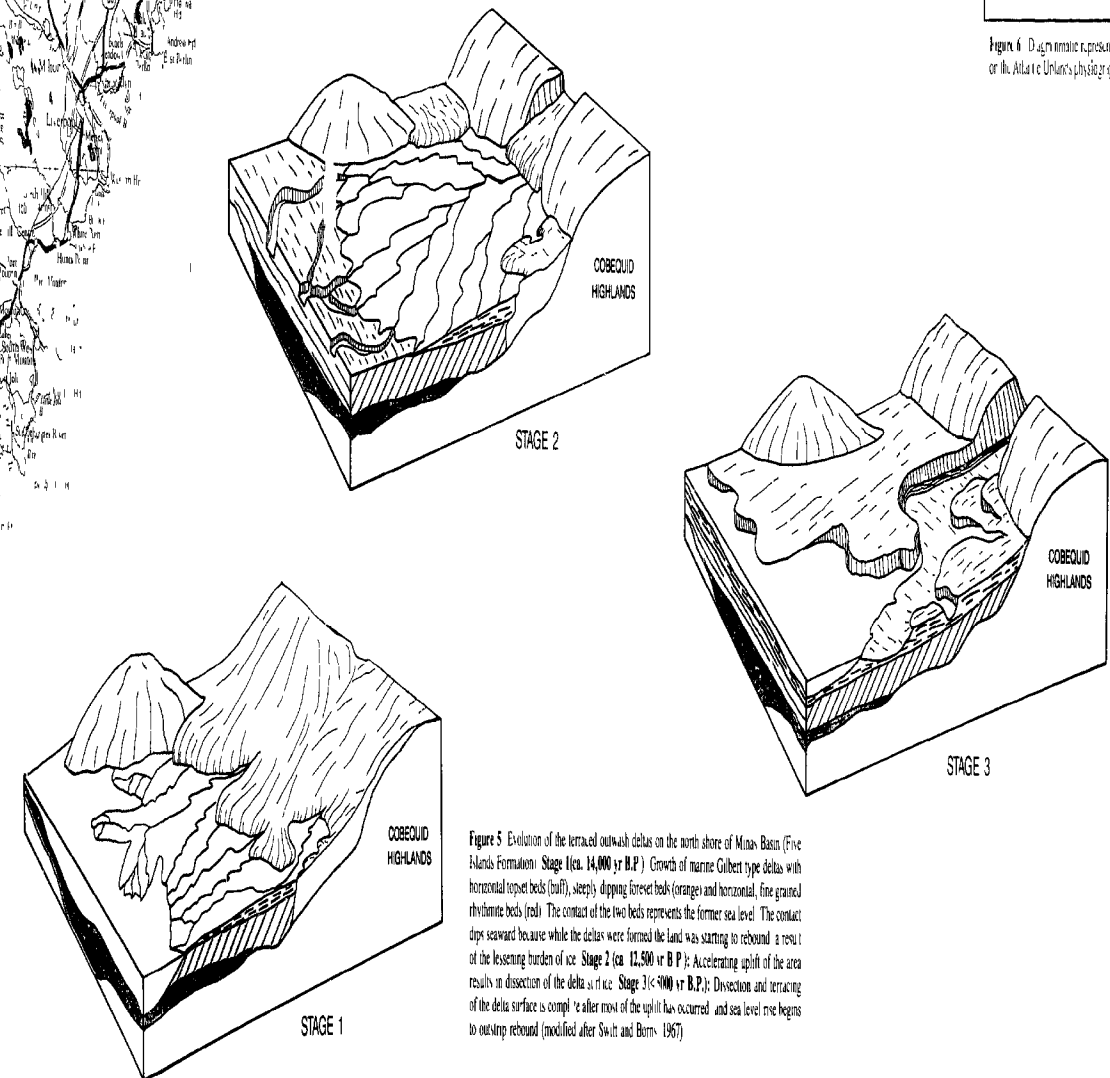STAGE 1

COBEQUID
HIGHLANDS

Figure 5 Evolution of the terraced outwash deltas on the north shore of Minas Basin (Five Islands Formation). **Stage 1 (ca. 14,000 yr B.P.)** Growth of marine Gilbert type deltas with horizontal topset beds (buff), steeply dipping foreset beds (orange) and horizontal, fine grained rhythmite beds (red). The contact of the two beds represents the former sea level. The contact dips seaward because while the deltas were formed the land was starting to rebound, a result of the lessening burden of ice. **Stage 2 (ca. 12,500 yr B.P.):** Accelerating uplift of the area results in dissection of the delta surface. **Stage 3 (< 5000 yr B.P.):** Dissection and terracing of the delta surface is complete after most of the uplift has occurred, and sea level rise begins to outstrip rebound (modified after Swift and Borns 1967)

eltas on the north shore of Minas Basin (Fi
): Growth of marine Gilbert-type deltas wi
eset beds (orange) and horizontal fine graine
s represents the former sea level. The conta
med the land was starting to rebound, a resu
,500 yr B.P.): Accelerating uplift of the are
3 (< 500 yr B.P.): Dissection and terracu
e uplift has occurred, and sea level rise begi
orns, 1967)

65 00   64 30'   64 00   63 30   63 00'   63 30

Glaciofluvial deposits

Hummocky Ground Moraine

Stony Till Plain
granite greywacke slate derived facies

Silty Till Drumlins
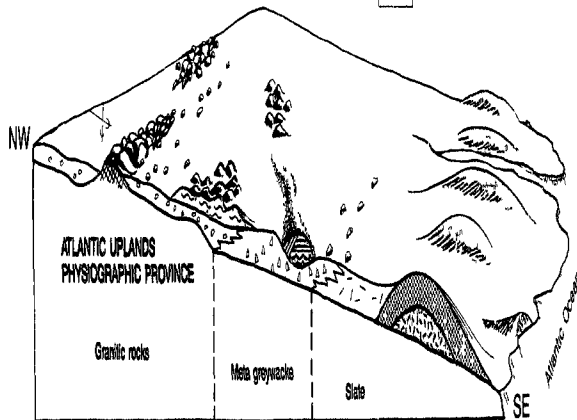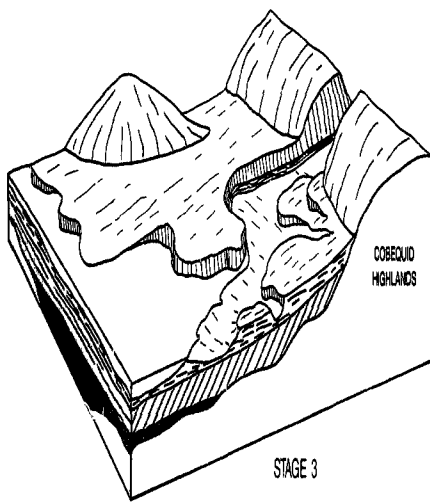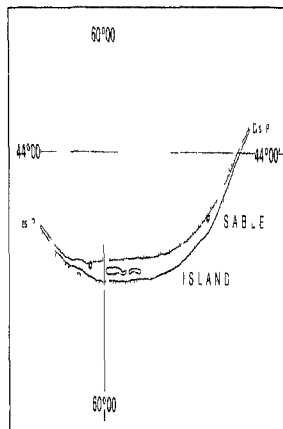Lawrencetown Till

Hartlen Till

Residuum

Bedrock

Figure 6 Diagrammatic representation of the stratigraphic relationships between surficial units on the Atlantic Uplands physiographic province.
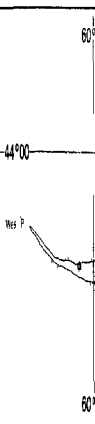

STAGE 3

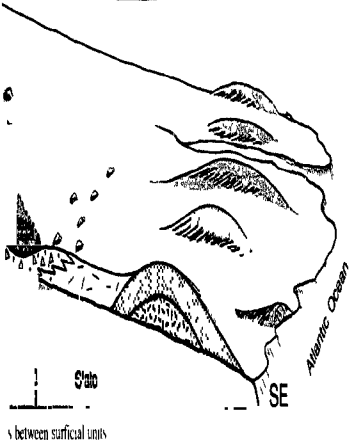...ltas on the north shore of Minas Basin (Five ...): Growth of marine Gilbert type deltas with ...eset beds (orange) and horizontal fine grained ...represents the former sea level. The contact ...ned the land was starting to rebound a result ...500 yr B P) Accelerating uplift of the area ...3 (< 5000 yr B P) Dissection and terracing ...uplift has occurred and sea level rise begins ...orns, 1967)

POST			
	MARINE DEPOSITS	Gravel sand silt clay locally overlain by peat salt marsh	Beaches spits and bars in mainland salt marsh and mud flats beaches along Atlantic coasts Cape Breton Island Sable Island Northumberland Strait salt marsh and mud flats along Bay of Fundy shoreline

LAST GLACIATION (WISCONSINAN)			
	GLACIOLACUSTRINE DEPOSITS	Sand silt clay laminated to massive massive or rudely stratified diamictons mixture of gravel sand and mud	Flat or gently rolling terraces perched above modern stream or river valleys
	GLACIOMARINE DEPOSITS	Gravel and sand bedded dipping seaward 5 10° locally silt and clay	Gently sloping shoreline above modern tide level with protruding ridges raised beaches and scarps wave cut terraces
	GLACIOFLUVIAL DEPOSITS OUTWASH FANS DELTAS AND VALLEY TRAIN DEPOSITS	Gravel and sand massive to horizontally stratified coarse to fine gradation within sections and deposits	Fan shaped lobes at the mouths of valleys (OF) belts of outwash confined to valleys (VT) topset part of Gilbert type deltas (GD) (see Fig 5)
	KAME FIELDS AND ESKER SYSTEMS	Gravel sand and silt diamicton layers poorly to well bedded horizontal to angular beds faulting and collapse features common	Steep sided mounds or hummocks moulin kames pitted terraces on valley sides (kame terrace sinuous steep sided ridges eskers)
	GROUND MORAINE AND STREAMLINED DRIFT HUMMOCKY GROUND MORAINE (NOT DIFFERENTIATED IN CAPE BRETON ISLAND)	Till mixture of gravel sand and mud of direct glacial origin often sandy and stony loose inclusions of waterlain sediment	Irregular rough topography local ridges (ribbed moraine) depressions o p s (kettles)
	STONY TILL PLAIN AND DRUMLINS	Till stony sandy matrix material derived from local bedrock sources drumlin facies silter till due to erosion and incorporation of older till units by glaciers	Flat to rolling with many surface boulders drumlins elongate or oval hills veneered by stony till with underlying multiple till layers (see Time Space diagram)
	SILTY TILL PLAIN AND DRUMLINS	Till silty compact material derived from both local and distant sources drumlin facies silter till higher percentage of distant source material including red clay	Flat to rolling few surface boulders till is thick enough to mask bedrock undulations drumlins often with multiple hills (see Time Space diagram)

PRE LAST GLACIATION			
	ROCK RESIDUUM	Fragmented rock consisting of angular blocks and finer interstitial debris overlain by thin discontinuous veneer of till	Flat to strongly rolling
	BEDROCK	Bedrock of various types and ages glacially scoured basins and knobs overlain by thin discontinuous veneer of till shaped by glacial erosion	Flat to strongly rolling ridges of hard rock exposed in thin till areas rock with stoss and lee form roche moutonnée

* Glacial units are classified by origin and associated landforms according to a system developed by Goldthwait (19...

Legend (surficial units)

- Glaciofluvial deposits
- Hummocky Ground Moraine
- Stony Till Plain — granite greywacke slate derived facies
- Silty Till Drumlins / Lawrencetown Till
- Hartlen Till
- Residuum
- Bedrock

Scale — between surficial units

Inset map coordinates: 60°00, 44°00, 44°00, SABLE ISLAND, Wes Pt, Fus P

44°30 ... 44°00 ... 43°30 (right margin)

	Unit	Composition	Topography / Landform	Thickness	Origin / Deposition	Land use / Limitations
POST GLACIATION	MARINE DEPOSITS	Gravel sand silt clay locally overlain by peat (salt marsh)	Beaches spits and bars intertidal salt marsh and mud flats beaches along Atlantic coasts Cape Breton Island Sable Island Northumberland Strait salt marsh and mud flat mainly along Bay of Fundy shoreline	Beaches 2 8 m salt marsh < 2 m	Formed by coastline sedimentation through wave action longshore currents and tides	Wildlife sanctuaries feeding grounds recreational areas
	GLACIOLACUSTRINE DEPOSITS	Sand silt clay laminated to massive massive or crudely stratified diamictons (mixture of gravel sand and mud)	Flat or gently rolling terraces perched above modern stream or river valleys	Generally > 2 m can attain 30-40 m along major valley systems	Deposited in a ponded body of water either in direct contact with ice or fed by glacial meltwater	Clay utilized for brickmaking pottery land used for pasture limitations include poor drainage and surface runoff
	GLACIOMARINE DEPOSITS	Gravel and sand bedded dipping seaward 5 10° locally silt and clay	Gently sloping shoreline above modern tide level with protruding ridges (raised beaches) and scarps (wave cut terraces)	Shoreline deposits vary from 4 5 m gravelly raised beach ridges 3 10 m	Deposits formed as the sea flooded a lowered coastline depressed by the glaciers weight As the land rebounded after the glacier left the shoreline was raised above sea level	Gravel and sand utilized for aggregates cultivated for crops used as pasture land groundwater source
LAST GLACIATION (WISCONSINAN)	GLACIOFLUVIAL DEPOSITS — OUTWASH FANS DELTAS AND VALLEY TRAIN DEPOSITS	Gravel and sand massive to horizontally stratified coarse to fine gradation within sections and deposits	Fan shaped lobes at the mouths of valleys (OF) belts of outwash confined to valleys (VT) topset part of Gilbert type deltas (OD) (see Fig 5)	Outwash fans 5-30 m valley trains 5 50 m outwash deltas 5 25 m	Deposition by freely wandering glacial streams in front of a glacier (OF) meltwater streams confined to valley walls (VT) meltwater streams depositing material in to the ocean (OD)	Source of quality aggregate for concrete roadbase especially in areas of hard rocks excellent aquifer sometimes confined by clay at the base (OD) rapid drainage and acidity impede cultivation aquifer easily contaminated
	KAME FIELDS AND ESKER SYSTEMS	Gravel sand and silt diamicton layers poorly to well bedded horizontal to angular beds faulting and collapse features common	Steep sided mounds or hummocks (moulin kames) pitted terraces on valley sides (kame terrace) sinuous steep sided ridges (eskers)	Generally 4 6 m kames 4 20 m kame terraces 3-30 m eskers 5 10 m	Streams of glacier meltwater depositing material in holes in ice (MK) between glacier and valley slopes (KT) in water (kame delta) in tunnels in the ice (E)	Source of aggregate of varied quality severe limitations to crop use include stoniness rapid drainage and irregular topography utilized for blue berries pastureland
	GROUND MORAINE AND STREAMLINED DRIFT — HUMMOCKY GROUND MORAINE (NOT DIFFERENTIATED IN CAPE BRETON ISLAND)	Till (mixture of gravel sand and mud of direct glacial origin) often sandy and stony loose inclusions of waterlain sediment	Irregular rough topography local ridges (ribbed moraine) depressions or pits (kettles)	Variable from 2 25 m	Material released from on top of or within stagnant ice masses by melting usually at or near the margins of these ice masses	Source of aggregate of poor quality severe limitations to crop use construction include stoniness drainage topography and acidity poor buffering capacity for acid rain
	STONY TILL PLAIN AND DRUMLINS	Till stony sandy matrix material derived from local bedrock sources drumlin facies silter till due to erosion and incorporation of older till units by glaciers	Flat to rolling with many surface boulders drumlins-elongate or oval hills veneered by stony till with underlying multiple till layers (see Time Space diagram)	Till plain 2 20 m drumlins 4 30 m	Material released from the base of an ice sheet by melting these tills deposited by ice sheets centered over Nova Scotia (see Time Space diagram)	Moderate limitations to crop use include stoniness rapid drainage erodibility factors affecting use for construction include shallowness stoniness and high water table poor buffering capacity for acid rain
	SILTY TILL PLAIN AND DRUMLINS	Till silty compact material derived from both local and distant sources drumlin facies silter till higher percentage of distant source material including red clay	Flat to rolling few surface boulders till is thick enough to mask bedrock undulations drumlins often with multiple tills (see Time Space diagram)	Till plain 3 30 m drumlins 4 30 m	Material released from the base of ice sheets by melting or lodgment these tills deposited by ice sheets centered outside of Nova Scotia (see Time Space diagram)	Generally provide the best agricultural land in the province moderate drainage and stoniness moderate to good buffering capacity for acid rain because of transported calcareous bedrock components
PRE LAST GLACIATION	ROCK RESIDUUM	Fragmented rock consisting of angular blocks and finer interstitial debris overlain by thin discontinuous veneer of till	Flat to strongly rolling	1 4 m	Mechanical and chemical disintegration of bedrock occurring before and during glaciations	Used for road base aggregate severe limitations for crop use generally forested acid rain buffering capacity depends on rock type but generally poor
	BEDROCK	Bedrock of various types and ages glacially scoured basins and knobs overlain by thin discontinuous veneer of till shaped by glacial erosion	Flat to strongly rolling ridges of hard rock exposed in thin till areas rock with stoss and lee form roche moutonnée		Areas of glacier erosion and/or non deposition	Forested regions little use as crop land acid rain buffer capacity depends on rock type but generally poor

Glacial units are classified by origin and associated landforms according to a system developed by Goldthwait (1988)